

The life and scientific work of William R. Evitt (1923–2009)

James B. Riding^{a*} and Joyce Lucas-Clark^b

^aBritish Geological Survey, Environmental Science Centre, Keyworth, Nottingham NG12 5GG, United Kingdom; ^bClark Geological Services, 1023 Old Canyon Road, Fremont, California 94536, USA

Occasionally (and fortunately), circumstances and timing combine to allow an individual, almost singlehandedly, to generate a paradigm shift in his or her chosen field of inquiry. William R. ('Bill') Evitt (1923–2009) was such a person. During his career as a palaeontologist, Bill Evitt made lasting and profound contributions to the study of both dinoflagellates and trilobites. He had a distinguished, long and varied career, researching first trilobites and techniques in palaeontology before moving on to marine palynomorphs. Bill is undoubtedly best known for his work on dinoflagellates, especially their resting cysts. He worked at three major US universities and spent a highly significant period in the oil industry. Bill's early profound interest in the natural sciences was actively encouraged both by his parents and at school. His *alma mater* was Johns Hopkins University where, commencing in 1940, he studied chemistry and geology as an undergraduate. He quickly developed a strong vocation in the earth sciences, and became fascinated by the fossiliferous Lower Palaeozoic strata of the northwestern United States. Bill commenced a PhD project on silicified Middle Ordovician trilobites from Virginia in 1943. His doctoral research was interrupted by military service during World War II; Bill served as an aerial photograph interpreter in China in 1944 and 1945, and received the Bronze Star for his excellent work. Upon demobilisation from the US Army Air Force, he resumed work on his PhD and was given significant teaching duties at Johns Hopkins, which he thoroughly enjoyed. He accepted his first professional position, as an instructor in sedimentary geology, at the University of Rochester in late 1948. Here Bill supervised his first two graduate students, and shared a great camaraderie with a highly motivated student body which largely comprised World War II veterans. At Rochester, Bill continued his trilobite research, and was the editor of the *Journal of Paleontology* between 1953 and 1956. Seeking a new challenge, he joined the Carter Oil Company in Tulsa, Oklahoma, during 1956. This brought about an irrevocable realignment of his research interests from trilobites to marine palynology. He undertook basic research on aquatic palynomorphs in a very well-resourced laboratory under the direction of one of his most influential mentors, William S. 'Bill' Hoffmeister. Bill Evitt visited the influential European palynologists Georges Deflandre and Alfred Eisenack during late 1959 and, while in Tulsa, first developed several groundbreaking hypotheses. He soon realised that the distinctive morphology of certain fossil dinoflagellates, notably the archaeopyle, meant that they represent the resting cyst stage of the life cycle. The archaeopyle clearly allows the excystment of the cell contents, and comprises one or more plate areas. Bill also concluded that spine-bearing palynomorphs, then called hystrichospheres, could be divided into two groups. The largely Palaeozoic spine-bearing palynomorphs are of uncertain biological affinity, and these were termed acritarchs. Moreover, he determined that unequivocal dinoflagellate cysts are all Mesozoic or younger, and that the fossil record of dinoflagellates is highly selective. Bill was always an academic at heart and he joined Stanford University in 1962, where he remained until retiring in 1988. Bill enjoyed getting back into teaching after his six years in industry. During his 26-year tenure at Stanford, Bill continued to revolutionise our understanding of dinoflagellate cysts. He produced many highly influential papers and two major textbooks. The highlights include defining the acritarchs and comprehensively documenting the archaeopyle, together with highly detailed work on the morphology of *Nannoceratopsis* and *Palaeoperidinium pyrophorum* using the scanning electron microscope. Bill supervised 11 graduate students while at Stanford University. He organised the Penrose Conference on Modern and Fossil Dinoflagellates in 1978, which was so successful that similar meetings have been held about every four years since that inaugural symposium. Bill also taught many short courses on dinoflagellate cysts aimed at the professional community. Unlike many eminent geologists, Bill actually retired from actively working in the earth sciences. His full retirement was in 1988; after this he worked on only a small number of dinoflagellate cyst projects, including an extensive paper on the genus *Palaeoperidinium*.

Keywords: acritarchs; biography; dinoflagellates and dinoflagellate cysts; history; palaeontological techniques; trilobites; United States; William R. Evitt

1. Introduction

William R. ('Bill') Evitt (1923–2009) was unequivocally the leading researcher on fossil dinoflagellates

during the modern era of palynology, i.e. since the late 1950s. He was the principal worker of his generation on the morphology of these complex, fascinating and

*Corresponding author. Email: jbri@bgs.ac.uk

highly useful palynomorphs over four decades from the early 1960s to the end of the twentieth century. Bill was the first to realise, and definitively demonstrate, that the vast majority of the dinoflagellate fossil record represents the resting cyst stage of the life cycle, using the excystment aperture as the key line of evidence. He also determined that the fossil record of the dinoflagellates is highly selective. Furthermore, the fact that most Mesozoic and Cenozoic hystrichospheres (spine-bearing palynomorphs) are, in fact, dinoflagellate cysts was discovered by Bill based on detailed and exhaustive morphological analyses of well-preserved material. He also termed the remainder of the hystrichospheres, i.e. those with no demonstrable dinoflagellate affinity, acritarchs. Bill's main scientific passion was the detailed morphology of dinoflagellate cysts. For example, he analysed the excystment aperture in considerable detail and coined the term 'archaeopyle' for this important feature. Bill also undertook groundbreaking fine-scale morphological studies of important genera such as *Ceratium*, *Dinogymnium*, *Nannoceratopsis*, *Palaeoperidinium* and *Peridinium*.

Bill had an active, long and productive life, and was not exclusively a palynologist. He also worked on Ordovician trilobites and palaeontological techniques, and undertook a successful spell of aerial photograph interpretation during World War II for which he received the Bronze Star (Appendix 1). Bill was also a consummate teacher of the earth sciences. He trained numerous undergraduates and graduate students (Appendix 2), ran a highly successful two-week course on fossil dinoflagellates and published 64 scientific contributions including some high-impact papers and two major textbooks (Appendix 3; Damassa & Leffingwell 2009).

He studied geology as an undergraduate and as a graduate student between 1940 and 1948 at Johns Hopkins University in Baltimore, Maryland; his studies there were interrupted by World War II. Bill's first professional position was on the faculty staff at the University of Rochester, New York State, where he stayed eight years, starting in the autumn of 1948. He then joined the oil industry in August 1956, spending six very happy years working for Bill Hoffmeister's famous palaeontological group at the Carter Oil Company (later rebranded as the Jersey Production Research Company) in Tulsa, Oklahoma. However, Bill's spiritual home was academia, and in the summer of 1962, he joined Stanford University in California where he remained until his full retirement in 1988. It was during his 26-year tenure at Stanford that Bill revolutionised the study of dinoflagellate cysts. This contribution seeks to comprehensively describe, and reevaluate where appropriate, Bill Evitt's remarkable life and his many scientific achievements; these are

summarised in Table 1. The author citations of the species mentioned in the text are given in Appendix 4.

2. Early Days (1923–1940)

2.1. Family background

William Robert Evitt II was born on 9 December 1923 in Baltimore, Maryland, United States (Figure 1), and was named after his paternal grandfather. He was the only child of Raymond Wilson ('Wils') Evitt and Elsa Schwarz Evitt, and was always known as Bill. Raymond Evitt had British heritage; by contrast, his mother's family, as the name Schwarz strongly suggests, was German and they were part of a large German community in Baltimore. Bill's maternal grandfather owned the Schwarz Toy Store in Baltimore; unfortunately, he died when Bill was only two years old. Bill also hardly knew his maternal grandmother, who died two years after her husband's passing.

Bill's father had studied civil engineering at Johns Hopkins University in Baltimore, but never practiced because he undertook military service in World War I immediately after graduating. Raymond served as a pilot for the final months of the war, joining Edward V. Rickenbacker's famous 94th Fighter Squadron ('Hat in the Ring') of the US Army Air Force (Woolley 2001) and was based in France. After the conflict ended, Raymond found it difficult to find a meaningful career, and took up jobs in insurance and real estate. Elsa Evitt was a talented artist, specialising in oil painting (Figures 2, 3), who trained at the Maryland Art Institute in Baltimore as did her mother before her.

Bill first lived in the house belonging to his maternal grandparents, the Schwarzes, until the age of four. The house was 3 Prospect Circle in Windsor Hills, one of the western suburbs of Baltimore. It was a large house built into a steep hillside which backs onto Gywnn's Falls, a small river which drains into Chesapeake Bay. The younger daughter of the original owners, and her husband, Henry Stanwood, became lifelong friends of Bill's parents.

2.2. An idyllic childhood at the Old Stone House

In 1927, Raymond Evitt finally obtained a relatively well-paid job with the Annapolis Dairy Products Company. Consequently, the Evitt family moved out to the open countryside on the relatively flat Atlantic Coastal Plain north of Annapolis and south of Baltimore to a region which has long since been subsumed into the Baltimore-Washington, DC Metropolitan Area (Figure 1). On 28 July 1928 they began a tenancy of an early eighteenth-century stone-built house on Old

Table 1. A tabulated synopsis of Bill Evitt's principal career milestones.

Year(s)	Career landmark
1940 to 1943	Undergraduate studies and graduate research at Johns Hopkins University, Maryland
1943	First scientific paper published (Secrist & Evitt 1943)
1944 to 1945	Worked as a military aerial photograph analyst in China with the US Army Air Force during World War II
1945	Awarded the Bronze Star Medal by the US Army Air Force
1946 to 1948	Completed PhD research on Ordovician trilobites at Johns Hopkins University, Maryland
1948 to 1956	Instructor/Associate Professor in sedimentary geology at the University of Rochester, New York
1950	Awarded PhD from Johns Hopkins University in January 1950
1953 to 1956	Editor of the <i>Journal of Paleontology</i>
1956 to 1962	Palynologist at the Carter Oil Company, Tulsa, Oklahoma
1959	Visit to Europe (England, France, Germany) to study fossil dinoflagellates for two months
1961	Visiting professor at Stanford University, California between January and June 1961
1961	First paper on dinoflagellates published (Evitt 1961b)
1961	The key paper 'Observations on the morphology of fossil dinoflagellates' published (Evitt 1961c)
1962	Became a full-time professor at Stanford University, California
1964	<i>Dinoflagellate Studies I. Dinoflagellate cysts and thecae</i> published (Evitt & Davidson 1964)
1967	<i>Dinoflagellate Studies II. The archeopyle</i> published (Evitt 1967c)
1971	Presented the first of 36 short (two-week) training courses on dinoflagellate cysts
1973	Organised a forum on dinoflagellates as part of the 6th Annual Meeting of AASP at Anaheim, California
1978	Co-organised the first International Conference on Living and Fossil Dinoflagellates ('Dino-1')
1978	The first major textbook on dinoflagellate cysts published (Stover & Evitt 1978)
1982	Awarded the inaugural AASP Medal for Scientific Excellence
1985	The second major textbook <i>Sporopollenin dinoflagellate cysts</i> published (Evitt 1985)
1985	Presented the last of 36 short (two-week) training courses on dinoflagellate cysts
1986	Formal retirement from Stanford University
1986 to 1988	Part-time teaching at Stanford University
1989	Awarded Honorary Membership in AASP
1998	Awarded Honorary Membership in the Palaeobotanical and Palynological Society of Utrecht, The Netherlands
1998	Major paper on the genus <i>Palaeoperidinium</i> published (Evitt et al. 1998)
2001	Final scientific paper published (Evitt 2001)
2006	Awarded the AASP Medal for Excellence in Education

Annapolis Road in what is now Severna Park in Anne Arundel County, very close to the main Baltimore-Annapolis Boulevard (now the Ritchie Highway). This imposing residence was always known to the Evitt family as the Old Stone House (Figure 4).

The land was apparently first owned by a Richard Beard in 1687, and known as Huckleberry Forest. This tract was purchased by a Mr Robinson in 1702, and the Old Stone House was built of the local field stone during that year. The grandson of Mr Robinson, Elijah 'Robison', sold the property to John Tydings in 1837. The son of the latter, John Lewis Tydings, married Laura C. Robinson, and their daughter, Laura Tydings Garcelon, was the last member of this dynasty to own the Old Stone House and the surrounding land. Mrs Garcelon did not wish the estate to be sold during her lifetime. Consequently, the Evitts paid her a nominal rent for the house and garden, and had the free use of the adjacent fields and pine forest. Bill's parents

eventually took up their option to buy the entire property in 1954 following the death of Laura Garcelon. The Old Stone House backs onto Cattail Creek to the south; this is a distributary of the Magothy River, one of the many tributaries of Chesapeake Bay (Figure 1D). In earlier times, the area had been extensively farmed, despite the very sandy soil. Bill's parents sold 140 acres of the land to the developer of Berrywood during 1964. Raymond Evitt eventually sold the house and the remainder of the plot in June 1978 for the development of Berrywood West, and moved to a retirement home. He had lived in the Old Stone House for 51 years. The present owners of the residence, which is now known as the Robinson House and is on Evitt Court (Figure 1D), have successfully applied for its placement in the National Historic Place Register (reference number 09000782).

Maryland is, of course, a mid-Atlantic state, but in the 1920s in cultural terms it was very 'southern', with

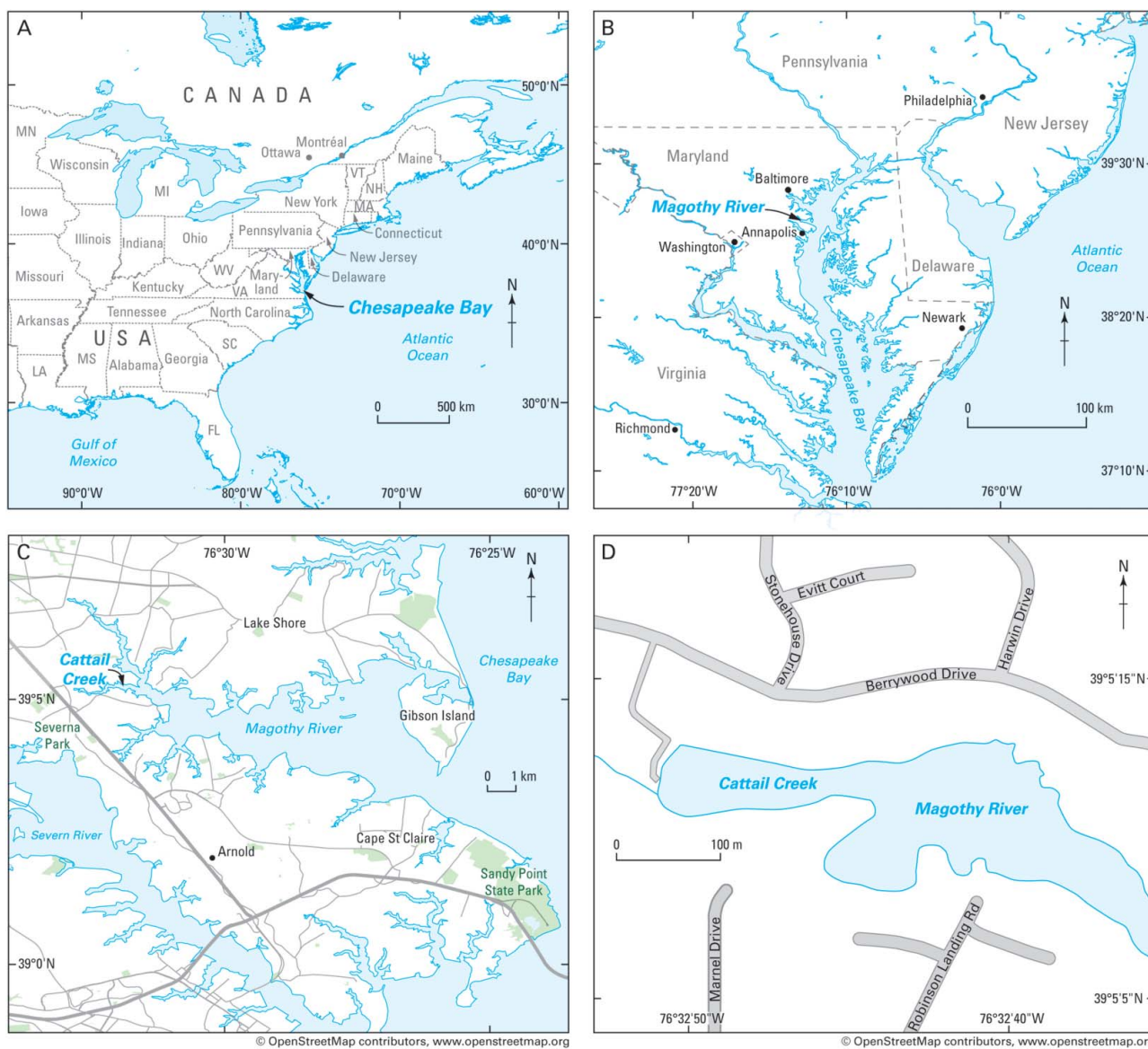


Figure 1. Four maps at various scales of the eastern United States to illustrate key localities pertaining to Bill Evitt’s early life (section 2). A, eastern North America; B, the central-eastern United States centred around Washington, DC, and Chesapeake Bay, Maryland; C, the mouth of the Magothy River in northern Chesapeake Bay; D, Cattail Creek close to the mouth of the Magothy River immediately south of the Old Stone House, which now is on Evitt Court.

a large, mostly poor and highly segregated black population. Indeed, during the summer of 1929 the Evitts hired Mandy, a black live-in servant. Life in rural Anne Arundel County at that time was ‘very country’, and hugely different to that of today. For example the only air conditioning was supplied by fans, and cooking was done on a paraffin (kerosene) stove. It was a 20-minute electric streetcar ride to Annapolis, and Baltimore was a 45-minute car journey away. The nearby two-lane roads were very winding. Petrol (gasoline) was 20 cents per gallon, and was supplied from a hand-pumped overhead tank. Bill enthusiastically helped his parents with the extensive renovations they made to

the Old Stone House. The Evitts kept several pets, including Nannette the German Shepherd dog, who they brought with them as a puppy when they moved to the country from Baltimore. Nannette probably saved the Old Stone House from a major fire by waking Elsa Evitt from a nap while the water heater in the basement was badly overheating. Other pets included Nannette’s puppies and their offspring, Billy-Bill the goat and Funny-Face the donkey (burro). The young Bill (Figure 2) was tasked with feeding and watering all the animals.

During this time, Bill had no friends from his peer group nearby, and consequently was a very independent



Figure 2. Bill Evitt at about nine years old, painted in oils by his mother, Elsa Evitt, around 1933. The image is reproduced with the approval of the Evitt family.

boy. He attributed his love of the natural sciences to his rural upbringing, where he would wander the disused farm buildings and woodland around the family home. Bill helped his parents with several practical hobbies such as copper plate etching, gem faceting, metalwork, pottery, silver casting, and wood carving and turning. Items made by the Evitt family were only sold during the worst years of the Great Depression in the mid 1930s. It seems likely that activities such as making silver jewellery allowed Bill to develop his dextrous skills in the fine-scale manipulation of fossils that he used to great effect during his career in palaeontology.

2.3. Early Education (1930–1940)

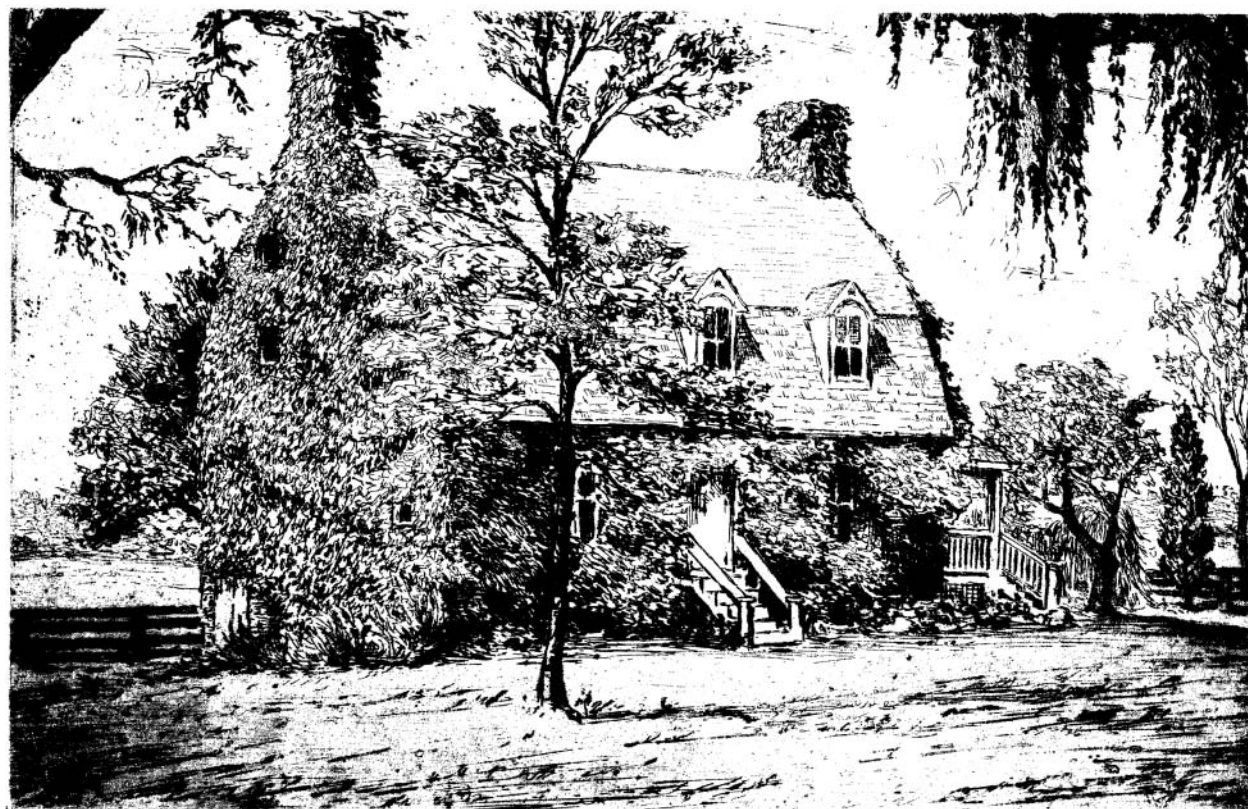
In 1930, Bill Evitt commenced his elementary education in a small, three-room schoolhouse in the then small community of Severna Park, 3 km from the Old Stone House (Figure 1C). The young Bill was extremely studious, and was quickly promoted from the second grade to the fourth. He was never an enthusiastic participant in team sports. Perhaps because of this, together with his academic nature, he was somewhat of a loner at school. Bill did feel that, as he was an only child living in a rural setting with little interaction with



Figure 3. Bill Evitt in profile at about fourteen years old, painted by his mother, Elsa Evitt, around 1938. The image is reproduced with the approval of the Evitt family.

a peer group, he became relatively ill equipped to relate easily to his peers in later life. He openly admitted to finding some social occasions stressful.

Bill commenced his four years of high school in 1936. He travelled 17 km each way to a high school in the western part of Annapolis. Bill studied biology, chemistry, English, French, history, Latin, maths, physics and social science. He found that his high school biology classes, allied with the microscope he received one Christmas, confirmed his profound interest in nature. Bill immediately took to microscopy and used the small (~20 cm high) transmitted light microscope, which magnified between 25 and 150 \times , to examine microscopic organisms from the ponds and streams near the Old Stone House and Cattail Creek. Occasionally he would project images onto a small screen to show his parents images of microorganisms. Bill also enjoyed studying chemistry. In particular, he loved to observe the growth of crystals from the evaporating solutions of various water-soluble substances in his much-loved chemistry set using his first microscope. He also loved to observe the changing shapes of iodine crystals in a glass vial that he had filled. Bill frequently indulged in more dangerous experiments in chemistry, such as boiling mercury in a test tube using a Bunsen burner! Furthermore, his Latin classes helped Bill with the use of Latinised terminology during his later career.



The Old Stone House ca. 1933

Figure 4. An etching of the Evitt family residence, the Old Stone House, in Severa Park, Anne Arundel County, Maryland, made by Bill's mother, Elsa Evitt, around 1933. The image is reproduced with the approval of the Evitt family.

He later said that his vocation to teach was awakened during his high school days. At this time he also learned how to type on his maternal grandmother's old upright Remington typewriter. Bill developed his great interest in music while at high school, and recalls this starting with listening to mostly operatic recordings. He clearly recalled the events leading to the outbreak of World War II in the summer of 1938, and how this awakened his interest in current affairs.

2.4. Nascent interest in geology

The Evitt family owned a 15-m, ketch-rigged, ex-World War I patrol boat named *Wanderer*. This boat was fitted with a small auxiliary engine, and was originally bought by Bill's paternal grandfather after the hostilities ceased. It was sailed around to Cattail Creek from Baltimore. *Wanderer* was moored at a small wharf on the Old Stone House property, and the Evitts used it for both day-trips and annual family holidays, where they sailed this rather clumsy vessel in Chesapeake Bay and its many tributaries (Figure 1B). Most of the extended trips were to the unspoiled countryside on the eastern shore of Maryland on Chesapeake Bay. Bill's

introduction to geology and fossils came with his father at the famous Calvert Cliffs on the eastern side of the Calvert Peninsula in west Chesapeake Bay (Figure 1B) during his high school years. These successions include the type section of the Lower to Middle Miocene Calvert Formation; this unit comprises highly fossiliferous sands with interbedded clays. The fauna is dominated by abundant echinoids, molluscs, shark teeth and vertebrate fossils (Vokes 1957). Bill collected many specimens from the Calvert Formation, and the fossils of Calvert Cliffs undoubtedly helped to inspire him to study geology at university. The father and son team also collected unconsolidated siliciclastic material from the pyrite beds in the Upper Cretaceous (Turonian–Santonian) Magothy Formation (Darton 1893; Owens et al. 1970; Jengo 1995) from the banks of the River Magothy in Maryland, close to the Old Stone House. Many years later, John P. Kokinos undertook a master's thesis at Stanford University on the palynology of these samples (Kokinos 1987). The fact that Bill kept and curated the Magothy Formation material for close to 50 years is a testament to his sustained commitment to his sound geological collecting practices.

Raymond and Elsa Evitt were always very supportive of their only son's great interest in the natural world. As mentioned previously, they bought him a microscope and Bill recalled observing for hours the fascinating spiralling and twisting motion of the freshwater/brackish dinoflagellate *Ceratium hirundinella* (Plate 1, figure 3; Plate 2, figure 1), which he had

caught on the boat dock at Cattail Creek. It is remarkable that Bill began his studies of dinoflagellates during the 1930s while still a young schoolboy! Apparently, his earliest publication was a one-paragraph note describing an unusual morphological phenomenon on a cactus plant in a monthly journal on cacti and succulents. Unfortunately, despite the best efforts of the



authors and the Evitt family, this contribution cannot be tracked down.

The Evitt family were clearly very close; Bill recalled that he was treated as an equal, and the three continued to explore eastern Canada, Maryland, New York State, Ohio and Virginia while Bill was an undergraduate student at Johns Hopkins University.

3. Student years at Johns Hopkins University (1940–1948)

3.1. Introduction

Bill Evitt was an undergraduate and graduate student at Johns Hopkins University, Baltimore, between 1940 and 1948. Johns Hopkins has an excellent reputation for both research and teaching. It was also conveniently close to the Evitt family home, and furthermore Bill's father had studied there. Bill commuted to college daily and lived with his parents in the Old Stone House during his sojourn at Johns Hopkins, with the exception of his wartime service between June 1943 and January 1946.

3.2. Chemistry to geology – the undergraduate years and the pre-war period (1940–1943)

Bill applied to become an undergraduate student, majoring in chemistry, at Johns Hopkins University to

formally commence studies in autumn 1940. In those days, undergraduate tuition fees were only US \$250 per semester. Bill's application was successful, and he joined the Alpha Delta Phi fraternity at Johns Hopkins. This group has a strong literary tradition and membership in it gave Bill a strong connection with his fellow students, which he badly needed because he lived off campus. Once Bill was accepted, he enrolled in a German course during mid 1940 because he did not have a summer job. This far-sighted strategy enabled Bill the freedom to take purely science courses during his freshman year. At this time he was considering becoming a chemist, having enjoyed studying chemistry at high school. However, probably based on the enjoyable geological fieldwork at the Calvert Cliffs as a schoolboy, and because his father regretted not studying earth sciences, he also enrolled in a subsidiary course in elementary geology. This decision was to prove pivotal. In his freshman year, Bill only scraped a pass in chemistry. By contrast, he loved geology immensely, especially palaeontology, and excelled in it. Bill also enjoyed studying crystallography and mineralogy. In particular, he found the classification of the various wooden models of crystals fascinating, and this probably contributed to his interest in biological classification, form and symmetry in his later career. Unsurprisingly, Bill was beginning to consider majoring in

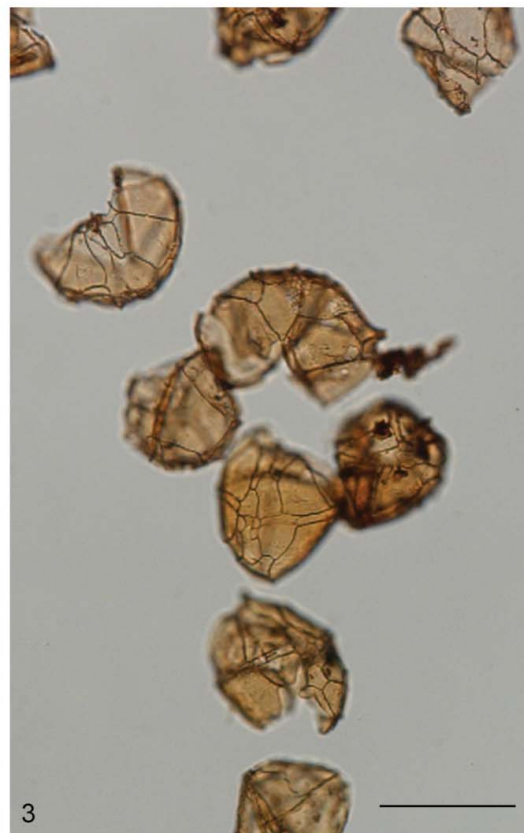
Plate 1. Four of the 35-mm transparency slides included in the ringbound file of course materials that Bill Evitt provided to participants of the two-week Teaching Conferences on Fossil Dinoflagellates (section 10). These slides accompanied the practical exercises and the specimens for study. Figures 1 to 3 are modern thecate forms and figure 4 is a Paleocene dinoflagellate cyst. All of the images are reproduced with the approval of the Evitt family.

Figure 1. A theca of *Protoperidinium leonis*; modern, marine, California. This specimen, which is in ventral view, was captured using a plankton net and was slide 1. Note the hyaline (somewhat glassy) appearance, the prominent hexagonal 1' plate which is positioned midventrally, the laevorotatory (descending) cingulum, and the slightly sloping and highly indented sulcus which is largely on the hypotheca. The overall length is 90 μm , and the specimen is 85 μm in maximum width.

Figure 2. A resting cyst within a theca of *Protoperidinium leonis*; modern, marine, California. This theca and cyst combination, which is in dorsal view, was captured using a plankton net and was slide 2. Note the contrast in appearance between the hyaline theca and the brown, somewhat granular resting cyst. The outer wall of the resting cyst is in close proximity to the inner surface of the theca; despite this, the rounded antapical horns of the cyst contrast markedly with the very sharply pointed horns of the theca. The uninterrupted dorsal part of the reflected cingulum is readily discernible on the resting cyst. The overall length of this specimen is 85 μm , and it is 80 μm in maximum width.

Figure 3. A theca of *Ceratium hirundinella*; modern, freshwater, California. The specimen, which is in ventral view and high focus, was captured using a plankton net and was slide 3. Note the hyaline appearance, the reticulate wall texture, the well-developed cingulum and the four horns. The largest horn is apical in position and the others are all hypothecal (i.e. one antapical and two postcingular). The smaller of the postcingular horns is the left one (Evitt & Wall 1975, fig. 1). This is a corniform dinoflagellate organisation principally due to the prominent horns. The corniform grouping of Evitt (1985) exhibits an extremely distinctive tabulation style with an extensive concave ventral area formed of the 6'', 6c and 6''' plates which are relatively thin (Evitt & Wall 1975). The overall length of this specimen is 145 μm , and it is 80 μm in maximum width (including horns).

Figure 4. *Dracodinium samlandicum*; ventral view, median focus; Eocene, unnamed borehole, Maryland. This specimen was illustrated as *Wetzeliiella* sp. in the course manual as slide 20. Note the proximochorate and circumcavate/cornucavate cyst organisation. The wall of the microgranulate ovoidal endocyst is markedly thicker than that of the spinose subpentagonal pericyst. It has a characteristic anterior intercalary (type A) latiepeliform archaeopyle formed by the loss of the distinctly four-sided (quadra) plate 2a in both cyst walls. The endopericulum and periopericulum are both displaced and are present. The endopericulum is within the hypocyst, and appears to have fallen back into the endocyst. By contrast, the periopericulum lies largely in the epicyst; it is offset to the left-hand side of the cyst; it may have become lodged between the periphragm and endophragm. The archaeopyle is the principal indicator of tabulation; however, the cingulum is also vaguely discernible in this specimen. This species is typical of the Palaeogene peridiniacean subfamily Wetzeliielloideae, which was recently comprehensively reviewed by Williams et al. (2015). The overall length of this specimen is 125 μm , and its maximum width is 127 μm .



geology after his freshman year. In 1941, he undertook another summer school in order to be more flexible in his remaining time as an undergraduate.

Bill worked as a field assistant for his geology professor, Mark H. Secrist, during the late summer of 1941. The two of them undertook fieldwork in the central Appalachians and immediately formed an excellent personal and working relationship. These field trips helped Bill to finally decide to major in geology, with a special interest in palaeontology, before the start of his second (sophomore) year in the autumn of 1941. Mark Secrist became Bill's geological mentor and they undertook much joint fieldwork during which they would measure sections, mostly in roadcuts, and collect fossils and rock specimens. Bill's first paper was co-authored with Mark Secrist on the palaeontology of the upper Martinsburg Formation (Ordovician) of Massanutten Mountain in the Shenandoah Valley, Virginia (Secrist & Evitt 1943). In this work, the authors described the Martinsburg Formation and its abundant and diverse macrofauna from two sections, Cub Run and Passage Creek. They described nine new species of molluscs and one new brachiopod variety (Appendix 3; Table 2).

At this time, Bill became especially interested in a study which clearly had great potential for a master's or PhD project. He had read about a succession of highly fossiliferous Middle Ordovician limestones at Tumbling Run, a small tributary of the North Fork of the Shenandoah River, southwest of Strasburg in Shenandoah County, Virginia. The source of this was a field guide produced for the International Geological Congress in Washington, DC, during 1933, specifically a comment by the bryozoan researcher Ray Bassler that silicified fossils were present at this locality. Unusually, all of the abundant calcareous and organic fossils had been entirely replaced by silica. Tumbling Run was relatively close to home, a three-hour drive

away, and Bill visited the locality during the summer of 1941 where he collected many cobble-sized blocks of fossiliferous limestone.

The three-dimensionally preserved trilobites and other fossils could easily and most optimally be extracted by dissolving away the calcareous matrix using hydrochloric acid. However, Bill first etched the limestone blocks with sulphuric acid from old car batteries with their partitions knocked out, in some of the outbuildings at the Old Stone House. The post-acid residues included abundant and superbly preserved silicified bryozoans, ostracods and trilobites. Bill became especially interested in the ostracods and the trilobites. The latter had been previously studied by Reuben J. Ross (Palmer & Dutro 2005) and Harry B. Whittington (Whittington 1941). Bill briefly considered undertaking a master's project at Johns Hopkins on the ostracods from Tumbling Run during the academic year 1942–1943. This did not happen, but by the time he left Johns Hopkins for his wartime service, Bill had decided to pursue a PhD project on the rich collection of silicified trilobites he had already amassed. He had become fascinated by the small size and the glasslike fragility of these exquisitely preserved trilobites, and successfully developed techniques for picking them up and gently releasing them under a binocular stereoscopic microscope. To do this he modified tweezers for extracting the small, delicate trilobite specimens from the washed and dried post-hydrochloric acid residues. Bill extended the tips of the tweezers by attaching a short and very thin strip of aluminium foil to each one with glue. The foil he first used was from the decorative reflective strip within the walls of cellophane drinking straws. The modified tweezers were described in Evitt (1951a) and worked superbly well, due to the flexibility and robustness of the aluminium foil. However, it was clear that he also needed to work on an effective

Plate 2. Three low-magnification photomicrographs of microscope slides distributed by Bill Evitt at his Teaching Conferences on Fossil Dinoflagellates (section 10).

Figure 1. A group of several dissected plates of *Ceratium hirundinella* from a lake in California. The thecae were treated with sodium hypochlorite solution to dissociate the plates; hence, individual elements can be studied in detail. This is Stanford University palynology sample PL 5134. The England Finder coordinate is L35/3 and the image was taken using differential interference contrast (DIC). This slide was distributed at the 20th course held at Sunbury-on-Thames, England, between 10 and 21 August 1981. *Ceratium hirundinella* is discussed in more detail in the caption to Plate 1. The elongate oblong object in the top right is a diatom referable to the genus *Aulacoseira*; it is probably *Aulacoseira granulata*. The scale bar represents 25 µm.

Figure 2. A group of several specimens of *Gonyaulacysta dualis* from the Upper Jurassic Naknek Formation of Amber Bay, southwest Alaska. This is Stanford University palynology sample PL 5002; the England Finder coordinate is G38/1. The slide was distributed at the 20th course held at Sunbury-on-Thames, England, between 10 and 21 August 1981. This sample clearly yielded a virtually monospecific assemblage of *Gonyaulacysta dualis*, which is discussed in more detail in the caption to Plate 15. The scale bar represents 100 µm.

Figure 3. A group of several specimens of *Leptodinium mirabile* from the Upper Jurassic Naknek Formation of Amber Bay, southwest Alaska. This is Stanford University palynology sample PL 5004; the England Finder coordinate is M40. The slide was distributed at the 29th course held at Glasgow, Scotland, between 19 and 30 August 1985. Sample PL 5004 produced a palynoflora overwhelmingly dominated by *Leptodinium mirabile*; rare specimens of *Gonyaulacysta dualis* are also present. *Leptodinium mirabile* is discussed in more detail in the caption to Plate 14. The scale bar represents 100 µm.

Table 2. A tabulated synopsis of the 11 research papers on macropalaeontology authored by Bill Evitt and his co-workers. Secrist & Evitt (1943) is on the Ordovician shelly faunas of Virginia. The remaining 10 papers are all on silicified trilobites from the Ordovician of the northeast of the United States. Note that all the material studied was from Virginia; however, Evitt (1953) and Evitt & Whittington (1953) included material from New York State and Ohio. All these contributions on trilobites were on material from the Middle Ordovician except Evitt & Whittington (1953), which included specimens from the Upper Ordovician. The numbers of the papers are the ones used in Appendix 3. The three most important papers are indicated with an asterisk. An ellipsis (...) in any of the four columns indicating new taxa means that none of that respective rank were erected.

No.	Author(s)	Year	Trilobite families/family documented	New taxa			
				Subfamilies	Genera	Species	Subspecies/varieties
1	Secrist & Evitt	1943	N/A	...	...	9	1 variety
*4	Evitt	1951b	Cheiruridae, Harpidae, Lichidae	1	1	3	...
5	Evitt	1953	Cheiruridae	...	...	1	1 variety
6	Evitt & Whittington	1953	Calymenidae	...	...	...	...
*7	Whittington & Evitt	1954	Cheirurinae, Dimeropygidae, Odontopleuridae	1	3	15	...
9	Evitt	1961a	Asaphidae	...	...	...	...
*44	Evitt & Tripp	1977	Encrinuridae, Staurocephalidae	...	1	5	1 subspecies
53	Tripp & Evitt	1981	Lichidae	...	...	...	1 subspecies
55	Tripp & Evitt	1983	Dimeropygidae	...	...	1	...
59	Tripp & Evitt	1986	Asaphidae	...	...	1	...
62	Tripp et al.	1997	Cheiruridae	...	...	2	...

photographic technique. Because the specimens were uncrushed, their three-dimensional nature and irregular shapes ensured that they were not easily oriented for photography and study. Bill did not possess the artistic skills of his mother, so drawing each specimen was not feasible. He needed a photographic technique suited to the great fragility and small size of the trilobites he was studying. Strangely enough, it was the intervention of World War II and Bill's service therein that provided the necessary technique.

By early to mid 1941, it was clear that the United States would eventually become embroiled in World War II. Consequently, the demands of national service began to deplete the teaching staff, and courses were quickly modified to include topics suited to wartime, such as meteorology and photogrammetry. After the United States formally entered World War II in early December 1941, Johns Hopkins University, like all American colleges, immediately moved to an accelerated academic schedule. This meant that all courses were concentrated and intensified, and the summer break was eliminated. These accelerated courses did not compromise teaching loads; work was undertaken during the summer, and teaching hours were increased during the terms. Because Bill began his bachelor's course in autumn 1940, he was originally due to graduate in the summer of 1944. The accelerated wartime courses would potentially have Bill graduating in June 1943. However, because of his two summer schools and the more regular courses, he received his bachelor's degree, majoring in geology, during the summer of 1942.

This somewhat unusual transition to graduate-student status was further complicated because Bill had enrolled in the Infantry Reserve Officers Training Corps (ROTC) during his bachelor's programme. By the time of his graduation in the summer of 1942, he still needed to complete two semesters of the full ROTC course. He therefore spent the academic year 1942–1943 as a first-year graduate student taking both graduate and ROTC courses, and beginning research towards his PhD on his silicified Ordovician trilobites.

3.3. *Military service during World War II (1943–1946)*

By June 1943, the United States had been at war with the Axis for 18 months. Because Bill had completed his ROTC programme in 1942–1943, he had to interrupt his sojourn at Johns Hopkins and join the armed forces in the conflict during June 1943. He joined the Officer Candidate School of the Infantry at Fort Benning in Georgia. Bill became a Second Lieutenant (Infantry) in the US Army during late September 1943, following three months of training comprising class work and strenuous field exercises (Figure 5). The next stage was assignment to a unit which would soon join the European theatre of operations via Fort McClennan, Alabama, in just two weeks time.

During a brief spell of leave following graduation from Fort Benning, Mark Secrist suggested that Bill request a transfer to the US Army Air Force Air Intelligence School (AFAIS) at Harrisburg, Pennsylvania.



Figure 5. Bill Evitt proudly wearing his US Army uniform in 1943. The image is reproduced with the approval of the Evitt family.

This was based on the belief that his geological training would be a far better background for a military career in aerial photograph interpretation, as opposed to a posting as a generic infantry officer. A request for a transfer was made to the AFAIS by a close family friend, Colonel Henry Stanwood, who was then the Director of the Maryland Selective Service. Stanwood happened to be married to the youngest daughter of the couple who used to own Bill's first home, on Prospect Circle, Baltimore (subsection 2.1). The AFAIS agreed that Bill's background in geology was appropriate for work in photogrammetry, but a transfer request from his present unit to join the AFAIS was required. Colonel Henry Stanwood then interceded again and obtained an audience with a General Record, who personally oversaw all military operations in Maryland and adjacent states, in order for Raymond Evitt to present the case for the transfer on behalf of his son. As a result of this meeting, General Record endorsed the application and, following an anxious few days, Bill was assigned to the AFAIS in Harrisburg with a full transfer from the US Army Infantry into the US Army Air Force. Bill always felt profoundly grateful to Colonel Henry Stanwood for facilitating the transfer which probably saved his life. His two contemporaries from the Johns Hopkins ROTC who also became Second Lieutenants (Infantry) in 1943 were both killed in action in Italy within 12 months, aged just 24.

Bill graduated from the AFAIS in Harrisburg in early December 1943 and, following a brief early Christmas leave, was sent to Seymour Johnson Army Air Force Base in Goldsboro, North Carolina. After Christmas, Bill travelled to another way station, Camp Patrick Henry in Virginia. He eventually boarded a refitted troop ship, *The Empress of Scotland*, at Newport News, Virginia en route for the Burma-China-India Theatre via Cape Town, South Africa. *The Empress of Scotland* arrived at Bombay (now Mumbai) after 30 days at sea, and Bill was billeted for one week in barracks at a British military base in the suburb of Worli. The military party then travelled to Calcutta (now Kolkata) by train, and Bill was able to see the famous Deccan Traps large igneous province from his carriage. He was temporarily assigned to the photo intelligence detachment linked to the British headquarters in Calcutta. Bill and his colleagues were now aware that they were ultimately headed for China, and consequently they had no regular duties in Calcutta. In late March 1944, the 'China Group' was flown northeast to the United States air base at Chabua in the State of Assam so that they could then fly across the eastern Himalayas ('The Hump') to Kunming in Yunnan Province, southern China. By this time, Japanese expansion through Burma towards China and India had been halted, so the flight to Kunming on 30 March 1944 was relatively safe. At Kunming, Bill was posted to the 18th Photo Intelligence Detachment (PID), a part of the 14th US Army Air Force, a little under three months after leaving the United States (Figure 6).

The duties of a photo interpreter at Kunming were to examine photographs taken throughout Japanese-occupied southeastern Asia by the 21st Photo Reconnaissance Squadron. The principal emphasis was to identify anti-aircraft installations. Several phases of study were performed, depending upon the strategic nature of the materials. In his first few months at Kunming, Bill prepared some simple reports and assisted the report editor. He proofread manuscripts and hence quickly became aware of where the important photographic targets were. Bill returned to photograph interpretation but eventually became responsible for all the reports written by the group (Figure 7).

Bill found the photograph interpretation work fascinating, and discovered that it significantly honed his interpretational and observational skills. Some techniques he learned at Kunming, especially the use of stereoscopy, proved useful in his later work in palaeontology. He used a folding pocket stereoscope to view the aerial photographs in three dimensions. Bill would then prepare a report on any strategically important features. This type of work was clearly relatively similar to examining fossils and describing them. Bill thus could not have obtained more suitable



Figure 6. A photograph of Bill Evitt standing immediately outside a village near Kunming in Yunnan Province, southern China, during his posting there in World War II. The image is reproduced with the approval of the Evitt family.

military duties in preparation for a career in micropalaeontology. While Bill was stationed in China, his father and he had corresponded about the trilobite research, particularly photographic aspects. Raymond Evitt sent Bill papers which used stereophotography. This technique was already being used for the study of conodonts (e.g. Branson et al. 1933), and Bill suggested to his father that this technique would be important in his own trilobite research. Bill also undertook some occasional geological exploration of the local area, and located an outcrop of Cambrian strata south of Kunming which yielded abundant trilobites.

During Bill's early service at Kunming, the principal military focus was repelling the Japanese out of northern Burma and southwestern China in order to reopen the Burma Road. This was achieved, and road transport into China was possible from India. Then the targets became the Japanese presence in eastern and southeastern China (i.e. modern Cambodia, Laos and Vietnam), and Japanese rail and shipping activities. Bill was involved in detailed reports on major cities in this theatre of operations such as Hong Kong, Peking (now Beijing), Saigon (now Ho Chi Minh City) and Shanghai. Life on the base was generally free from direct Japanese military activities; however, there were occasional air raids. During early 1945, Bill and a colleague were sent to Kharagpur, India, to investigate whether radar photography

could be applicable to the reconnaissance work of the 18th PID at Kunming. Their conclusion was that this new technology was not relevant. On the way back, Bill and his partner undertook somewhat impromptu visits to Calcutta and New Delhi in India, and Kandy in Ceylon (now Sri Lanka).

The 18th PID moved its operational base northwards to new facilities at Peishiyi, west of Chongqing in southwest China, on 7 August 1945. Ironically, while the unit was setting up its equipment, the Second World War came to an abrupt end. So, during mid September 1945, the 18th PID was disbanded, and received their orders to return home. Bill and his comrades were flown east towards the Chinese coast where they were stationed at Hangchow, southwest of Shanghai, at a former Japanese air base. While waiting to return home, Bill visited tourist venues in and around Shanghai and Peking. The group sailed east from Shanghai aboard an American troop ship on a very stormy passage across the Pacific Ocean. They reached Puget Sound, Washington State, on 29 December 1945. From there the party travelled to nearby Fort Lawton at Tacoma, and then were dispersed homewards. Bill travelled via troop train to Fort Meade, Maryland, where he was met by his parents and rejoined civilian life on 13 January 1946 after nearly 3 years of military service. In recognition of his wartime record,



Figure 7. A photograph of Bill Evitt deep in thought while typing up a military report on aerial photograph interpretation as part of his duties with the 18th Photo Intelligence Department (PID) in Kunming, southern China, during World War II. The image is reproduced with the approval of the Evitt family.

Bill was awarded the Bronze Star medal by the US Army Air Force (Appendix 1).

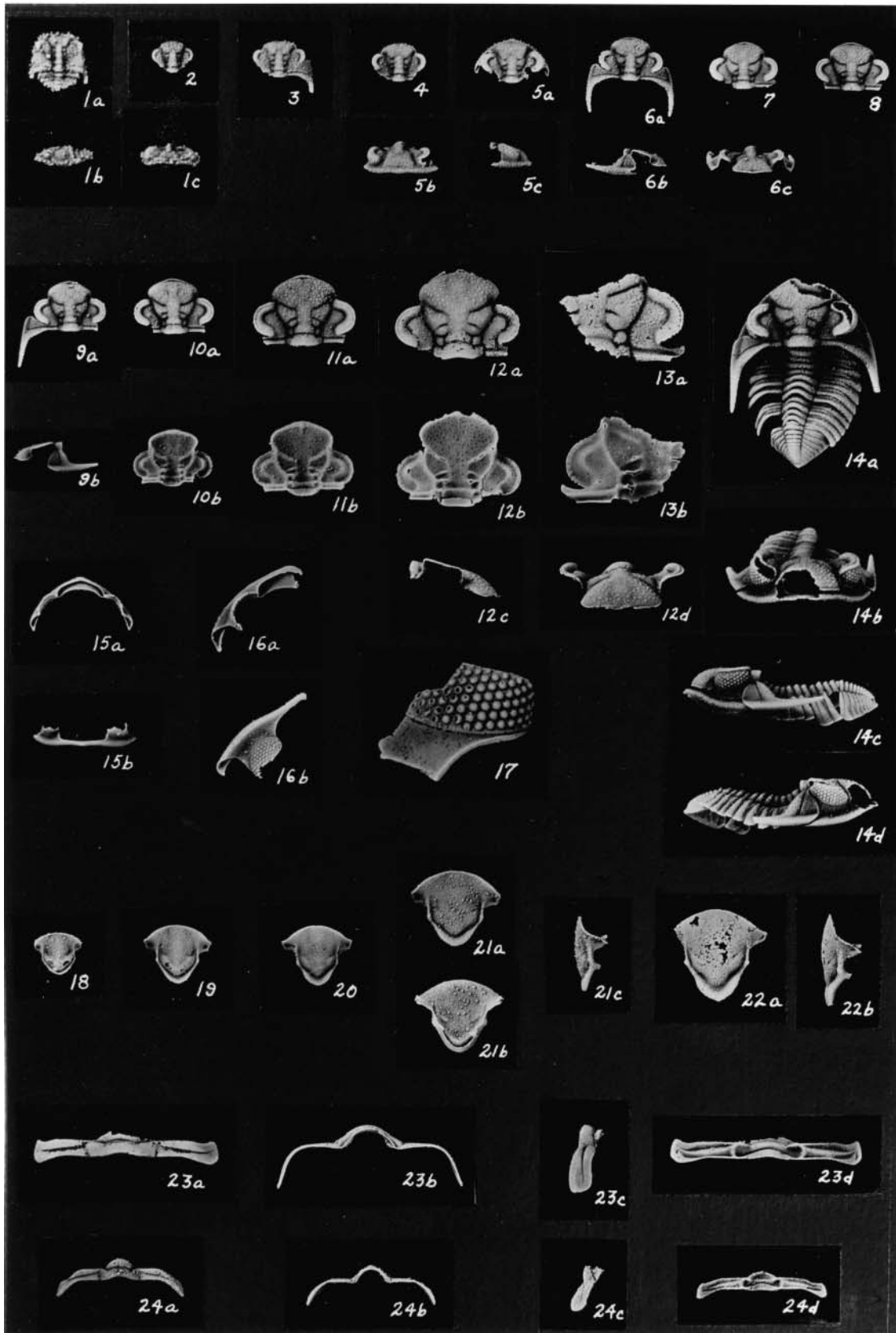
3.4. *PhD research on silicified Ordovician trilobites (1946–1948)*

During early 1946, Bill could relax and reconnect with his interrupted PhD research after his wartime service. His formal return to Johns Hopkins University was due in the autumn of 1946. By his sophomore undergraduate year, Bill had collected sufficient fossil material containing silicified trilobites from the Middle Ordovician of Virginia for his PhD research and well beyond (subsection 3.2). He continued his etching of limestone samples and picked and studied the best trilobite specimens. Bill carefully sorted and stored the specimens in glass-covered cardboard slides with wells of sufficient depth. At this time he focussed the scope of his PhD on especially well-preserved material from part of the Tumbling Run section. Entire trilobite fossils proved relatively rare; the faunas are dominated by moult stages which comprise disaggregated cephalons, thoraxes and pygidia (Plates 3, 4). Bill physically reconstructed dissociated trilobite sections, which were almost certainly not from the same individual, by

carefully gluing them together. This was achieved by uniting the specimens mounted on springy pieces of hair under the stereomicroscope. Typically, a rich sample would yield between 10 and 30 species which meant that working out the affinities of the separate parts, which varied in size due to moulting, was extremely difficult. However, because this material was so rich, it was possible, with much effort, to describe species which were reconstructed at different stages of their life cycles. Juvenile forms could be as small as ~ 100 μm in diameter, and the adults could attain lengths of up to 5 cm.

During Bill's wartime service, his father had constructed a suitable camera apparatus and a three-axis stage for orienting the trilobite specimens. The camera was fitted with a long bellows made of interlocking wooden sections between the lens and the film holder. The adjustable bellows allowed different magnifications (up to $\sim 40\times$) with good focus and depth of field. The camera apparatus was also designed to allow taking stereopairs of photographs. The use of stereophotography as a tool for the palaeontologist was the topic of Bill's first independently authored paper (Evitt, 1949); he was the first to use stereophotographic techniques in the study of trilobites. Subsequently, Bill

PLATE XIV



described the three-axis stage in Evitt (1951a). The three-axis stage was positioned below the camera lens and held the specimen firmly in its gripping device in any position so that all the trilobite features could be photographed. He used the camera for all of his subsequent work on silicified trilobites. Bill and his students subsequently used stereoscopy (e.g. Helenes 1984, pl. 5), and Bill also used stereo scanning electron photomicrographs in his palynological research (Plate 5; Evitt et al. 1998, pls 7–9).

Firstly, a trilobite specimen manipulated with tweezers or an eyelash manipulator was mounted onto the point of an insect pin using water-soluble glue, then whitened with magnesium oxide for photography, before the pin was positioned in the three-axis stage. After photography, the specimen was removed from the pin by dissolving the glue, the coating removed using hydrochloric acid, before being recurated. The extreme dexterity and care needed to manipulate individual dinoflagellate cyst specimens was clearly developed during this stage of Bill's trilobite research. This practical work for the PhD at this time was all done using the extensive outbuildings of the Old Stone House. For example, the cellars made an ideal darkroom.

During the spring of 1946, Bill was invited by Gustav Arthur ('Gus') Cooper, the curator in palaeontology at the museum of the Smithsonian Institution in Washington, DC, on a field trip to other localities in the Shenandoah Valley which yield Ordovician silicified trilobites. These fossil localities were discovered during exploration for cement resources in the Second World War. The excursion was principally for Harry B. Whittington (1916–2010), the newly appointed Curator of Palaeontology at Harvard University, Massachusetts. Harry Whittington and Bill became firm friends as a result of their mutual interest in trilobites on this excursion. They did more fieldwork together in the summer of 1946, and this collaboration led to two joint publications (Evitt & Whittington 1953; Whittington & Evitt 1954).

Bill and his father also undertook fieldwork in the Cincinnati area of southwest Ohio to collect fossils from the Upper Ordovician limestone-dominated successions of this region. Unlike the Shenandoah Valley material, this material was not silicified. Later, the

father and son team would collect fossils from New York State and eastern Canada. The close participation in their son's professional interests by Raymond and Elsa Evitt showed the strong unity of the Evitt family.

By the autumn of 1946, Bill was ready to return to Johns Hopkins University to formally resume his graduate student career, aiming to obtain his PhD in 1949. He had few remaining course requirements, and was looking forward to spending the next three years largely on research and dissertation writing. A new hire in 1947, Franco Dino Rasetti (1901–2001), was appointed as Bill's research advisor and mentor. Rasetti was an eminent Italian nuclear physicist, and worked in the Department of Physics at Johns Hopkins. He and Enrico Fermi, a Nobel laureate, discovered key processes leading to nuclear fission (Fermi et al. 1934). Interestingly, Rasetti had refused to work on the production of atomic bombs, specifically the Manhattan Project, on moral grounds. Rasetti was a polymath with a photographic memory and had researched other topics, in effect as hobbies, including Cambrian trilobites from the Canadian Rockies (Rasetti 1951), and Alpine wildflowers. Franco Rasetti therefore had the requisite experience to be Bill's mentor, and he was extremely supportive of Bill's work. The two only did a single field trip together, to the southern Appalachians, and Franco allowed Bill to conduct research at his own pace without significant interventions. Eventually Rasetti was the chair at Bill's PhD oral examination in January 1950, and gave a glowing report (Figure 8).

Bill found that life at Johns Hopkins had changed considerably since he had left for his military service. Following World War II, the number of staff in the Department of Geology was reduced due to retirements and the inevitable tragic wartime losses. For example, Mark Secrist and the two previous lecturers in palaeontology had departed. Ernst Cloos, a structural geologist, took over the physical geology course from Mark Secrist. Two new hires in palaeontology were also appointed, neither of whom were trilobite specialists. Furthermore, the chair, Joseph T. Singewald Jr., was rather parsimonious with departmental funds and general resources (Pettijohn 1988). This relative low point in the department's history was reversed

Plate 3. Plate 14 of Bill Evitt's PhD thesis on silicified Middle Ordovician trilobites from Virginia, illustrating the (informal) species *Calyptaulax micta*. This form has never been formalised with this species name. Bill did not use scale bars, and the magnifications quoted below should be considered approximate. The complete specimen in dorsal view illustrated in figure 14a is 16.5 cm long, and its maximum width is 13.0 cm.

Figure 1a–c are of a meraspid at 12× magnification. Figures 2–11 are of cranidia in several orientations and at various magnifications. Figure 12a–d is the cranium of the (informal) holotype at 4.1×. Figures 13a–b are dorsal and ventral views respectively of a fragmentary cranium at 4.1×. Figures 14a–d are of various views of an entire individual specimen at 5×. Figures 15–17 are free cheeks at various magnifications. Figures 18–22 are hypostomes and figures 23 and 24 are thoracic segments, all at various magnifications. The image is reproduced with the approval of the Evitt family.



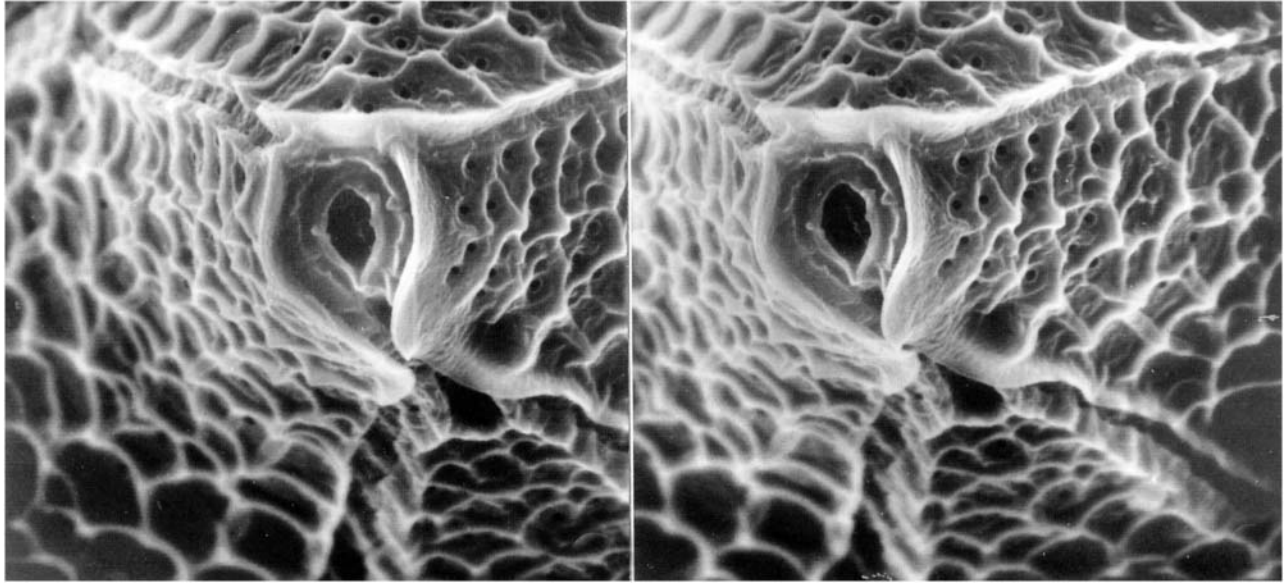


Plate 5. A stereopair of two scanning electron microscope (SEM) photographs of the apical region of *Protoperidinium* sp., a modern thecate dinoflagellate captured with a plankton net from off the California coast. The subovoidal apical pore is prominent, and lies in the centre right of each image. The canal plate lies below the apical pore, but is largely overlapped by the 2' plate. Each image is 17 μm in width. This plate is Evitt et al. (1998, pl. 9, fig. 7) and is reproduced with the permission of AASP – The Palynological Society.

by Ernst Cloos following Singewald's retirement, and the former recruited eminent academic geologists such as Francis J. Pettijohn, David M. Raup, Steven M. Stanley and Aaron C. Waters to Johns Hopkins (Pettijohn 1988).

In addition to his graduate courses and research, Bill was given the post of graduate teaching assistant for the 1946–1947 academic year. These duties entailed being the teaching assistant in the practical classes (laboratories) for the first-year course in physical geology headed by Ernst Cloos. Bill thoroughly enjoyed this work, and it convinced him that his vocation was in earth science research and teaching at a university. However, shortly before the 1947–1948 session began, Bill was asked to visit Ernst Cloos at his home. Cloos was on his sickbed; he had suffered his second heart attack during the week before the autumn semester began. This illness prevented Ernst Cloos from giving the one-semester physical geology course; this

represented half of the first-year geology course. Cloos asked Bill to assume full responsibility for all the lectures, practical classes and field trips for this course. Naturally, Bill accepted, but this major task took up most of his time; he had to prepare lectures and, during the course, he was never more than one step ahead of the undergraduates. These relatively onerous duties naturally adversely affected his graduate courses and, especially, his trilobite research. He was only able to seriously continue research work on his PhD during the spring of 1948.

3.5. Farewell to Johns Hopkins University (1948)

In early 1948, J. Edward ('Ed') Hoffmeister, a palaeontologist and Johns Hopkins graduate, who was the chairman of the Department of Geology at the University of Rochester, New York, relinquished all teaching duties in order to become dean and concentrate on

Plate 4. Plate 15 of Bill Evitt's PhD thesis on silicified Middle Ordovician trilobites from Virginia, illustrating the (informal) species *Calyptaulax micta* (figures 1–8) and *Dolichoharpes reticulata* (figures 9–24). *Calyptaulax micta* has never been formalised. Bill did not use scale bars, and the magnifications quoted below should be considered approximate. However, the dorsoventral width of the single thoracic segment of *Dolichoharpes reticulata* illustrated in figures 22a–d is 12.5 cm. Figures 1–4 are transitory pygidia, and figures 5–8 are holaspid pygidia of *Calyptaulax micta*, all at various magnifications. The remaining figures are all of *Dolichoharpes reticulata*. Figures 9–16 are cephalons in several orientations and at varying magnifications. Figures 17 and 18 are lower lamella of the cephalon at 6 \times . Figures 19–21 are hypostomes at several magnifications. Figures 22a–d are of a single thoracic segment at 5 \times . Figures 23a–b are dorsal and ventral views respectively of a transitory pygidium at 12 \times . Figures 24a–f are all of a single holaspid pygidium in various views, and are all at 5 \times . The image is reproduced with the approval of the Evitt family.

THE JOHNS HOPKINS UNIVERSITY

DEPARTMENT OF PHYSICS
HOMEWOOD CAMPUS
BALTIMORE-18, MARYLAND

Remarks and suggestions by F. Rasetti on the dissertation
presented by Mr. William R. Evitt.

The referee finds the dissertation presented by Mr. Evitt a work of exceptionally high quality, showing knowledge of the subject and maturity of judgment far above the standards expected from candidates for the degree of Doctor of Philosophy. The use of the techniques involved in the preparation and photography of the delicate fossils studied by Mr. Evitt, shows very unusual ability. The discussion of the trilobite structure, ontogeny and taxonomy indicates that the candidate has thoroughly mastered these subjects through a very complete study of the relevant literature.

The referee considers Mr. Evitt's work as one of the most significant contributions to the knowledge of this group of fossil arthropods that have appeared in recent years.

A few suggestions for minor modifications to be considered before the dissertation is typed in definitive form are listed on the enclosed sheet.


F. Rasetti

Figure 8. The very positive report on Bill Evitt's PhD thesis (*Trilobites from the Lower Lincolnshire Limestone near Strasburg, Shenandoah County, Virginia*) by his principal supervisor, Franco Rasetti of Johns Hopkins University, Maryland. The oral examination upon which the report is based took place in mid-January 1950, with Rasetti as chair. The image is reproduced with the approval of the Evitt family.

administration. Ed Hoffmeister contacted Joseph Singewald at Johns Hopkins to ask for suggestions for someone to take over his teaching commitments in palaeontology, sedimentary geology and stratigraphy. Singewald suggested Bill on the basis of his excellence in teaching, and Bill was offered the position at Rochester in the spring of 1948. Bill felt somewhat in a quandary because he had been looking forward to a relatively relaxed final year finishing his trilobite dissertation. His colleagues on the faculty at Johns Hopkins, who greatly admired the Rochester Department, very strongly encouraged Bill to take the job. Perhaps due to a combination of the state of Johns Hopkins immediately post-war, and the lure of a new challenge, Bill

accepted this faculty position to start in the autumn of 1948 sight unseen, on the single condition that he was allowed to complete his PhD as soon as possible.

Bill had a preliminary visit to the University of Rochester shortly after the end of the spring semester in 1948; he was shown around the campus by Gisela Cloos, a first-year undergraduate. He was much impressed by the Department of Geology, and looked forward to starting work there later that year. Coincidentally Gisela was the daughter of Bill's colleague at Johns Hopkins University, Ernst Cloos. She was also the granddaughter of Hans Spemann, the 1935 Nobel Laureate in Physiology/Medicine and Professor of Biology at the University of Freiburg, Germany

(Hamburger 1985). She and Bill clearly got along very well; the couple later married. So it was that Bill left Johns Hopkins University in the summer of 1948 before finishing his PhD dissertation. The PhD was completed at Rochester, and Bill graduated from Johns Hopkins in January 1950 (subsection 4.3).

4. The first professional appointment: the University of Rochester (1948–1956)

4.1. Introduction

Bill Evitt embarked on the second leg of his professional journey in the autumn of 1948 when he joined the University of Rochester, on the southern shore of Lake Ontario in western New York State, as an instructor earning a salary of US \$3700 per year. At that time the University of Rochester enjoyed a very good reputation, especially in science and medicine; optics and physics were especially strong there. The university was an excellent working environment; the main campus, known as the River Campus, is located 3 km to the south of downtown Rochester on a large bend of the Genesee River. The Rochester years were extremely eventful for Bill in both his personal and professional life. He completed his dissertation, acquired his PhD, established himself as an academic, got married, bought a house and had two sons while there.

4.2. Personal life in Rochester

In Bill's first academic year at Rochester, 1948–1949, he rented rooms in a private home close to the campus. Outside of work, which largely comprised teaching, he explored the Rochester area and beyond. Bill visited many excellent fossiliferous Silurian and Devonian localities in the immediate area, and subsequently took student classes to some of these. He also spent much time with his girlfriend, Gisela Cloos. At the start of the academic session 1949–1950, Bill moved onto the Rochester campus, in the Alpha Delta Phi house as 'house father' to the fraternity.

Directly after his dissertation examination in January 1950 (subsection 4.3), Bill plucked up courage to ask Ernst Cloos, who was one member of the panel, for approval to marry his daughter Gisela. Naturally, Cloos did not demur. Their engagement was relatively brief and, on a very hot 29 July 1950, Bill Evitt and Gisela Cloos were married at the Friends Meeting House in Baltimore. They spent their honeymoon in the Appalachians, before moving into 750 University Park, a small apartment in a faculty housing project.

Bill and Gisela had never previously ventured west of the Appalachians, and so they decided to undertake a road trip from Rochester to California and back

during the summer of 1951. They converted their Chevrolet two-door sedan into a customised camping vehicle and embarked on a 10,000 km round trip, collecting rock samples on the way. This long and eventful trip took in many states such as Arkansas, California, Idaho, Michigan, Oklahoma, Oregon, South Dakota, Tennessee, Utah and Wyoming. They visited iconic tourist venues such as Crater Lake, Death Valley, Devils Tower, Glacier Lake National Park, the Grand Canyon and Yellowstone National Park. The trip to Yosemite in California had special significance for Gisela. This was because in the early 1930s her father, Ernst Cloos, had spent two summers undertaking geological fieldwork there. This work, along with the rise of Adolf Hitler, persuaded Cloos, who was German, to move permanently to the United States. Bill and Gisela also crossed the Canadian border and visited Ontario on the way back to Rochester.

In November 1952, Bill and Gisela bought their first house in the south of the city of Rochester. This was 36 Midland Avenue, which is a 10-minute drive from the Rochester campus. It was somewhat isolated, being located at the end of a cul-de-sac in a low-lying, swampy area. Bill and Gisela lived in this house for the next four years, and their first two sons, Eric and Steven, were born while they lived there. Eric was born on 17 June 1953, and Steven arrived on 2 December 1955. The Evitts lived in this house very much as a nuclear family, with relatively little contact with the outside world. The two small children and the non-existent public transport made for a strictly limited social life for Bill and Gisela.

4.3. Academic life in Rochester

In 1948, the Department of Geology and Geography at the University of Rochester was very small, with a faculty staff of three geologists and one geographer. Personal relationships within the group were good, and there was a very congenial atmosphere. Bill was the only sedimentary geologist, and taught courses in invertebrate palaeontology, micropalaeontology and stratigraphy to both undergraduates and graduates. Teaching took up most of his time during the student terms. Bill was given excellent laboratory and office facilities at Rochester. He was promoted to assistant professor in 1951 and, during 1955–1956, Bill became associate professor and acting chairman of the department.

At this time, the undergraduate and graduate student body at Rochester largely comprised World War II veterans who were returning to their studies which had been interrupted by the hostilities. These students received significant help with the cost of their studies via the Servicemen's Readjustment Act of 1944 (also

known as the ‘GI Bill’). Many of these veterans were near contemporaries of Bill’s, and mostly married. Their war-punctuated educations made them ambitious, determined and very mature. This, and the fact that they were the same age as junior instructor Bill Evitt, made for an unparalleled staff-student rapport.

At Rochester the department initially offered only bachelor’s and master’s degrees, and had only recently been authorised to grant PhDs when Bill joined. The first two graduate students, Donald W. Fisher and Lewis E. Stover, both worked under Bill. Donald Fisher researched the Lower Ordovician palaeontology and stratigraphy of the Mohawk Valley, New York, and graduated in 1952 (Appendix 2; Fisher 1953). Bill advised Donald Fisher, but was not his principal supervisor. Fisher went on to have a distinguished career with the New York Geological Survey (Landing 1994).

In the summer of 1949, Bill resumed his work on trilobites, and spent these months back home at the Old Stone House on his dissertation research. He worked effectively and, by the time he returned to Rochester at the end of the summer, the dissertation was completed and ready for typing. The title was *Trilobites from the Lower Lincolnshire Limestone near Strasburg, Shenandoah County, Virginia*. After Bill had prepared the dissertation, Johns Hopkins University gave Bill a date in mid-January 1950 for his oral examination. This was during the midwinter break in undergraduate teaching. The examination went very well, the report stating that the dissertation is of ‘exceptionally high quality’ and ‘far above the standards expected from candidates for the degree of Doctor of Philosophy’ (Figure 8). Bill was awarded the PhD on the condition that a version of it would be accepted for publication in a peer-reviewed journal. He prepared part of his PhD dissertation for publication during the early summer of 1950; the manuscript he wrote was later published as Evitt (1951b).

During the autumn of 1953, Lewis Eugene (‘Lew’) Stover (1925–1993) arrived in Rochester. Lew Stover was Bill’s first *bona fide* graduate student, and worked on the diverse and well-preserved Devonian ostracod microfaunas from the highly fossiliferous Windom shale near Rochester, and graduated in 1956 (Appendix 2; Stover 1956). Like Bill, Lew was a married World War II veteran, and the Evitt and Stover families soon became firm friends. Lew Stover later relinquished ostracods to become a leading palynologist and a collaborator of Bill’s (Figure 9; Williams & Partridge 1993).

Bill’s principal research during his eight years at Rochester was on the silicified trilobite faunas he collected from the Middle Ordovician limestones of Virginia during his undergraduate years at Johns Hopkins University in 1941–1942 (section 3). The main focus of

Bill’s research on these trilobites was their functional morphology and early ontogeny, and Bill and Gisela worked as a team on this endeavour.

4.4. *A husband-and-wife trilobite research team at Rochester*

Gisela Evitt (*née* Cloos) majored in biology as an undergraduate, gaining her bachelor’s degree from the University of Rochester in 1950. Following graduation she took a position as a laboratory assistant to Johannes Holtfreter (1901–1992), a noted experimental embryologist (Gerhart 1998). Coincidentally Holtfreter was a former student of Hans Spemann, Gisela’s grandfather (subsection 3.5). Not long after they were married, Bill and Gisela attended the annual Geological Society of America (GSA) meeting in Washington, DC, in the autumn of 1950, and visited the Palaeozoic brachiopod expert and museum curator ‘Gus’ Cooper at the Smithsonian National Museum of Natural History there. Gisela in particular was fascinated by the etched silicified brachiopods from the Permian limestones of Glass Mountains in west Texas that Cooper was researching (Cooper & Grant 1972).

Bill had collected samples of these limestones on a field trip associated with the 1949 annual GSA meeting at El Paso, west Texas, and Gisela began to extract these exquisitely preserved brachiopods from the calcareous matrix. Armed with this experience, Gisela started to develop and sort more of Bill’s Middle Ordovician silicified trilobites from Virginia. Because Bill was busy teaching students, this work advanced his trilobite research significantly. During 1950–1951, Gisela combined the trilobite work with her day job. However, she became fascinated by the trilobite research, and resigned her paid work with Johannes Holtfreter during 1951 to become Bill’s unpaid research assistant. Gisela etched out the trilobite concentrates with hydrochloric acid, sieve-washed them to neutrality and sorted through the post-acid residues. Bill instructed Gisela on how to use a stack of sieves and extract the trilobite fossils from all the fractions that were collected, except the finest fraction. She extracted many superb specimens using Bill’s modified tweezers (subsection 3.2; section 8), and one of her many coups was to discover small early ontogenetic stages in the fine fraction which Bill had previously overlooked. Bill thought that the fines would be devoid of fossils of interest, and used to discard this fraction. Therefore it was Gisela’s innate curiosity that led to her discovering these previously unknown juvenile stages. These proved crucial to Bill’s interpretations of segmentation changes and the many moults undergone by these fascinating organisms. Initially Bill did not think that



Figure 9. Bill Evitt (left) and Lew Stover (1925–1993; right) at the Second International Congress on Palynology at Utrecht, The Netherlands, in August 1966. This image was used in Sarjeant (1998, pl. 5), and is reproduced here with permission.

these small objects were noteworthy. However, when he realised how common they are, he understood that these ‘baby trilobites’ are extremely significant. Bill acknowledged the massive contribution by Gisela made to his understanding of trilobite ontogeny in Evitt (1961a, p. 987). Also, the species *Isotelus giselae* was named in recognition of the input by Gisela to this research by Tripp & Evitt (1986).

The silicified trilobites from Virginia are preserved completely undistorted with granular quartz, which gives exquisitely detailed preservation of even the minutest morphological features, both external and internal. The mineralised nature of these fossils makes them easily extractable from the calcareous matrix using hydrochloric acid. The siliceous exoskeletons are all disarticulated, and generally range in size between 1 mm and 3 cm. The assemblages are a mixture of the disarticulated cephalons, pygidia and thoraxes of the protaspid, meraspid and holaspid stages. Therefore, these associations require

much careful study to determine precisely which species are present, and the developmental history of each taxon (Plates 3, 4). Bill and his co-authors used stereophotographs of selected specimens to illustrate the complex morphologies.

This work taught Bill the value of concentrating on very-well-preserved fossil material, a paradigm that he religiously adhered to for all his life. He reasoned, eminently logically, that what is readily observable in well-preserved biotas is of far greater value than the many conjectures necessary with material in an inferior preservational state. Furthermore, Bill believed firmly that if undergraduates are taught with good material, and graduate students research similar assemblages, they will have a good grounding in their subsequent careers when they may be required to work with more poorly preserved associations of fossils. Bill’s work on well-preserved silicified trilobites was a new departure in this field, and his *modus operandi* for both extraction and study was subsequently used by many other researchers.

4.5. *The overworked editor (1953–1956)*

During his time at Johns Hopkins and Rochester, Bill was an active member of the Paleontological Society. Bill became significantly more involved in 1953, when he was elected to the position of editor of the *Journal of Paleontology*. He served in this position, and sat on the Paleontological Society council, until he left Rochester in 1956. Bill was elected to take over the editorship from Aldred Scott Warthin, Jr., of the University of Chicago. This well-established journal of the Paleontological Society was first published in 1927 and has always been a highly regarded periodical. The *Journal of Paleontology* is published bimonthly, and consequently has a significant annual page budget. Naturally, these editorial duties were extremely onerous because Bill was the sole editor. However, this work also kept Bill up to date with modern developments in palaeontology, and provided him with a wide network of valuable contacts throughout the subject. Bill largely edited contributions on what can be termed traditional palaeontology, as befitted this specialist title. However, he handled several papers on relatively new areas at the time such as palaeoecology and statistical methods in taxonomy. Despite this, the tenure of Bill's editorship was well before the advent of paradigm shifts such as molecular methods in palaeontology and the discovery of plate tectonics. Bill edited Hoffmeister et al. (1955a), which was an early classic in palynology. This article demonstrated that Palaeozoic spores extracted by mineral acid digestion could be used for stratigraphical correlation, and Bill surely would not have guessed at this time that his future career would be in palynology. Bill was the last sole editor of the *Journal of Paleontology*; he relinquished the position in 1956 when he left the University of Rochester. He then became a vice president of the society for 1957. The *Journal of Paleontology* was then edited by a team of two; in 1956, Bob Kessler and Erwin Stumm jointly took on this important job. This editorial position was the only term of service with portfolio on the board of a learned scientific society that Bill ever undertook. This is perhaps an indication of the all-consuming nature of the duties of a Managing/Technical Editor who also has a full-time day job and a young family. Bill and Gisela's first two sons, Eric and Steven, were both born during Bill's time at Rochester. Indeed, Bill acknowledged that the editorship of the *Journal of Paleontology* impacted negatively on his research, and probably his teaching too. Despite this, Bill served on the editorial board of *Marine Micropaleontology* between 1976 and 1982. The only other voluntary committee work that Bill took on, outside his main employment, was membership of the Committee on Fossil Plants between 1970 and 1986, and as a councillor on the board of directors of the

American Association of Stratigraphic Palynologists (AASP) in 1971–1972 (Demchuk & Riding 2008, p. 99). Bill was on the scene when the AASP was instigated in 1967, but declined an invitation to be a founding member (Leffingwell 1990).

4.6. *Goodbye to Rochester (1956)*

In 1955 Bill was promoted to associate professor, and was made acting chairman of the Department of Geology and Geography at Rochester due to the promotion of Ed Hoffmeister to dean. Paradoxically, Hoffmeister's promotion had a negative effect on the department. Hoffmeister had retained the substantive chairmanship; however, he was anxious that he should not be seen to overtly favour his home department within the university as a whole. There was significant overcompensation by Ed Hoffmeister and, as a consequence, the Department of Geology and Geography did not receive its fair share of resources under his tenure as dean. This, together with domestic financial pressures, ultimately triggered Bill's departure from Rochester to the oil industry in 1956 (section 5).

In 1956 Bill had been at the University of Rochester for over seven years, and he was ready for a fresh challenge. General working conditions in the department had deteriorated somewhat, and he was not relishing the role of acting departmental chair. Specifically, departmental budgets were tighter and future prospects were less bright since the halcyon years of the late 1940s and early 1950s. Furthermore, Bill was finding married life with two small children very tough on the salary of a relatively junior academic. The winters in Rochester were cold and long, and Gisela found their house somewhat isolated in that it lacked public transport.

At this time Bill's graduate student, Lew Stover, was nearing the completion of his doctoral research at Rochester and was applying for jobs. One of the positions that Lew was in contention for was an industrial palaeontologist position with the Carter Oil Company in Tulsa, Oklahoma. This was in the palaeontology laboratory headed by William S. ('Bill') Hoffmeister (1901–1980), a Johns Hopkins University graduate, who was developing a vibrant research programme in palynology (Figure 10). He was also the brother of Ed Hoffmeister. After World War II, the number of micropalaeontologists working in the oil industry increased significantly (Hopping 1967). Lew Stover returned to Rochester from his successful job interview at the Carter Oil Company in January 1956 palpably enthused. The Evitts and the Stovers dined together upon Lew's return from Oklahoma, and Bill Evitt was struck by Lew's massive enthusiasm about the laboratory in Tulsa. Lew quickly accepted the position after discussing it with Bill Evitt, his mentor. Furthermore,



Figure 10. A photograph of William S. ('Bill') Hoffmeister (1901–1980), who became Bill Evitt's mentor in palynology during his time with the Carter Oil Company/the Jersey Production Research Company between 1956 and 1962. This photograph was used in the dedication to Bill Hoffmeister by Bill Evitt in the collection of papers presented at the first Annual Meeting of the AASP held in Baton Rouge, Louisiana, in October 1968, and published as volume 1 of *Geoscience and Man* in 1970. Reproduced with the permission of AASP – The Palynological Society.

Bill Hoffmeister regularly visited the University of Rochester to present seminars on palynology and its use in geological exploration. These annual seminars were extremely popular with both staff and students because of their acutely topical and applied nature. Lew's enthusiasm and Bill Hoffmeister's charismatic seminars significantly excited Bill Evitt's interest in a job in industry. During a visit by Bill Hoffmeister to Rochester during February 1956, Bill Evitt tentatively inquired as to the possibility of a position with Carter; he and Gisela had previously discussed this scenario. Bill Hoffmeister answered Bill Evitt's question with an impish grin (remember that Bill Evitt then worked for his brother, Ed Hoffmeister), and immediately produced an application form from his pocket. It is clear that Bill Hoffmeister was intending to ask Bill Evitt to apply to Carter on this visit. He later admitted that he had carried the forms with him for a long time waiting for a chance to pass them on to Bill Evitt. Needless to say, Bill Evitt applied, and was soon interviewed. Like Lew Stover, Bill Evitt was very impressed by Bill Hoffmeister's laboratory, the personnel and the work undertaken in Tulsa. Bill Evitt was offered a position

as a senior research geologist in Tulsa despite warning his interviewers that he did not care if he ever found a drop of oil! He had no hesitation in accepting the post and immediately tendered his resignation to the University of Rochester.

Unfortunately, due to being out of town at the time, Ed Hoffmeister discovered Bill Evitt had resigned from Rochester via the president of the university. Ed Hoffmeister was understandably unhappy to hear this news indirectly, and to lose one of the best members of staff. It is also entirely probable that some of Ed Hoffmeister's dismay at Bill Evitt's imminent departure was exacerbated because he was going to work for his brother, Bill Hoffmeister. The hitherto excellent relationship between Bill Evitt and Ed Hoffmeister was very strained during the months before the former's departure. Ed Hoffmeister tried very hard, but ultimately unsuccessfully, to persuade Bill Evitt to stay at Rochester. Happily, after he ceased to be Dean at Rochester several years later, Ed Hoffmeister rekindled his good relationship with Bill Evitt.

5. Get Carter – joining the oil industry (1956–1962)

5.1. Introduction

The Evitt family drove west from a comparatively cool Rochester to a sweltering ($\sim 45^\circ\text{C}$) Tulsa, Oklahoma, in August 1956. They all found the very high Oklahoman temperatures difficult to deal with at first, but gradually acclimatised to the far hotter weather, despite initially living in an apartment with no air conditioning. The family quickly settled in to life in Tulsa, and moved into an air-conditioned home in late 1956. This was 5341 East 26th Place, which was in a newly built estate (tract) development with a community swimming pool. Bill and Gisela enjoyed landscaping their new garden from what was originally virgin pasture. They also enjoyed the vibrant social life in Tulsa; in the hot Oklahoman summers the swimming pool was a focal point, and good friendships developed quickly. Several of Bill's colleagues at the Carter Oil Company lived in the same development, and he was able to carpool to and from work which was a 20-minute drive away at 1133 North Lewis Avenue in north Tulsa. This left Gisela free to use the family car, which she had been unable to do in Rochester. Bill found the transition from academia to industry both abrupt and gentle in equal measure. As a senior research geologist, his job description was entirely technical with negligible administrative duties. Furthermore, he earned a much more comfortable salary in the private sector, and the whole family received corporate health care benefits. Bill and Gisela's third son, Glenn M. Evitt, was born in Tulsa on 13 September 1958.

5.2. *Bill Hoffmeister and the palaeontology laboratory at Carter Oil*

The Carter Oil Company was an affiliate of Standard Oil of New Jersey, and undertook all geological research for the parent company. Carter Oil was rebranded as the Jersey Production Research Company in 1959, and Bill Hoffmeister's palaeontology laboratory was separated off within Esso Production Research (now Exxon-Mobil). Hoffmeister had worked for many years on foraminifera and petroleum geology for Standard Oil of New Jersey affiliates in the Caribbean and Venezuela (Hoffmeister 1938). He was moved to Tulsa in the early 1950s in order to head a group of micropalaeontologists at the Carter Oil Company, and to develop a corporate capability in stratigraphical palynology.

Hoffmeister was highly ambitious for his team of micropalaeontologists, and provided an extremely amenable and well-resourced working environment for all his staff. Consequently, Bill found the research atmosphere at the Carter/Jersey laboratory exceptionally congenial. Most of the scientific staff had PhDs, and the technicians were also very well trained. It was essentially a scientific (virtually academic) research job with minimal administration and, of course, no teaching or supervision. The mission of the laboratory was to undertake strategic research in micropalaeontology, with the ultimate aim of making the company more effective at finding and producing oil. Only a minor part of the scientists' time was given over to routine service tasks. These, in turn, could be turned into research projects because of the relative youth of the science of micropalaeontology at this time. Within broad limits, the staff at Carter Oil could choose their own research topics. Hoffmeister's palaeontological laboratory at Carter/Jersey was a somewhat similar scenario to the research group headed by Peter Vail at Exxon in Houston, Texas. Vail and his colleagues developed sequence stratigraphy during the 1970s under similar conditions allowing 'blue-sky research' (Vail et al. 1977; Haq et al. 1987; Sloss 1988).

Moreover, Hoffmeister enthusiastically encouraged his staff to attend scientific conferences and to publish their findings, provided company approval was forthcoming. He believed firmly that the free flow of information in the rapidly expanding field of micropalaeontology and palynology would benefit all stakeholders, whether they be academics or in industry. Hoffmeister would assuredly have had to use his considerable charisma and significant persistence to persuade the Carter/Jersey management to agree to the virtually pure-research focus of his staff, and their freedom to publish in the mainstream scientific literature and to attend conferences.

There can be no doubt that Hoffmeister was an extremely engaging individual. Bill often recounted numerous anecdotes about Hoffmeister's ability as

(what Bill termed) a 'promoter'. For example, when describing new methods of palynomorph extraction developed by his laboratory to a group of company executives, Hoffmeister outlined a method that involved producing gunpowder from coal as part of the process. He noted that there was an attendant danger of explosion. As he finished, he said, 'Of course you lose a few technicians along the way, but the spore and pollen recovery is excellent!' Apparently he said this with such a totally impassive face that it took some of his audience a significant time to be sure that he was joking (personal communication, Bill Evitt to JL-C).

5.3. *The history and role of palynology in the Carter Oil Company*

Bill Hoffmeister was very impressed by the consulting work on palynology undertaken in South America for Standard Oil of New Jersey by Robert S. Tschudy, and research by Shell and their affiliates in the Orinoco Delta in eastern Venezuela (Muller 1959). On this basis, Hoffmeister suggested to the Carter Oil Company management that the company should instigate a programme in palynology themselves. Hoffmeister was a very persuasive man, and this was agreed. The eminent pollen/spore expert Leonard R. Wilson, then of the University of Massachusetts, Amherst, Massachusetts, was employed as an external consultant to assist Hoffmeister.

The first team of palynologists at Carter Oil in the early 1950s were Bill Hoffmeister, Raymond E. Malloy, Frank L. Staplin and Leonard R. Wilson. In the summer of 1956, when Bill Evitt arrived in Tulsa, Ray Malloy had already left Oklahoma to work in Peru, and Frank Staplin was about to join Imperial Oil in Calgary, Canada. So the Tulsa team of palynologists from mid-1956 comprised Bill Evitt, John W. Funkhouser, Bill Hoffmeister, Lew Stover and Leonard R. Wilson. Then, in the late 1950s, Harry A. Leffingwell joined the team.

John Funkhouser's research background was in biology, specifically South American frogs. Funkhouser undertook graduate research at Stanford University in California, and was mentored in palynology by Hans Thalmann, an expert on foraminifera. Thalmann had perceptively realised how significantly industrial palynology was going to expand in the future, and had established a small palynology processing laboratory at Stanford University. After John Funkhouser graduated, it was Hans Thalmann who suggested that he should apply for a job with the Carter Oil Company. The fact that a researcher on modern frogs was accepted into an industrial micropalaeontology unit is an indication of how few appropriately trained palynologists were around in the mid 1950s. Lew Stover, of course, was an expert in Devonian ostracods; his only

experience of palynology at that time was the occasional seminars given by Bill Hoffmeister at the University of Rochester. Also present in the group was Lili Ronai, a specialist on foraminifera who trained at the American Museum of Natural History in New York under Brooks Ellis.

The Carter Oil Company palynology group investigated the palynomorph content of samples from prospects and fields owned and operated by Standard Oil of New Jersey. Prior to Bill Evitt and Lew Stover's arrival in Tulsa in 1956, Bill Hoffmeister worked mainly with Ray Malloy and Frank Staplin. This three-man team confirmed that palynomorphs were indeed excellent stratigraphical index fossils. This conclusion was simultaneously being drawn elsewhere in the United States (Woods 1955a, 1955b; Wilson 1956, 1961; Grayson 1960). Additionally, Isabel C. Cookson and her collaborators were investigating stratigraphical palynology in Australia at this time (e.g. Cookson 1953, 1954; Baker & Cookson 1955) and several practitioners were active in Europe (e.g. Balme & Butterworth 1952; Butterworth & Millot 1955; Downie 1957; Gocht 1952, 1955, 1957, 1959; Eisenack 1958; Hughes 1958; Sarjeant 1959).

The first publications on palynology from the Carter Oil laboratory included Wilson & Hoffmeister (1953, 1955, 1956), Hoffmeister & Staplin (1955) and Hoffmeister et al. (1955a, 1955b). Hoffmeister et al. (1955a) is a classic, and documented Upper Palaeozoic spores from the subsurface of Oklahoma. This was one of the first contributions on stratigraphical palynology directly applicable to industrial operations. Bill Evitt suspected that Hoffmeister et al. (1955a) was issued relatively quickly due to a perceived rivalry with stratigraphical palynologists at Shell such as Jan Muller (Kuyf et al. 1955). The data presented in Hoffmeister et al. (1955a) were relatively old, and not considered to be commercially sensitive by the management of the Carter Oil Company. Despite this, Bill Hoffmeister would have had to argue hard for permission to publish. Other relevant publications include Hoffmeister (1959, 1960).

5.4. *A new era: the industrial use of marine palynomorphs*

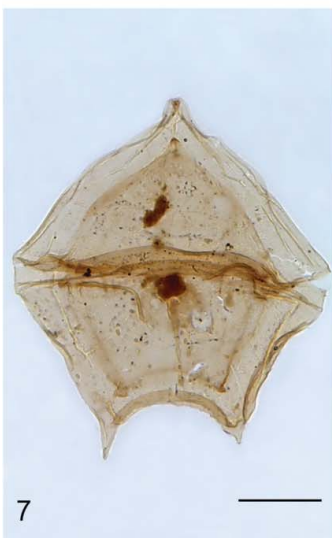
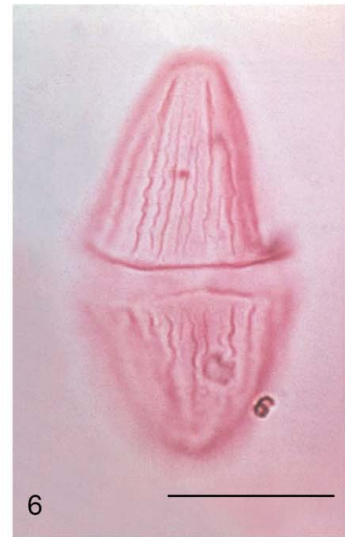
During the 1950s, pollen and spores were beginning to be used in oilfield operations, but knowledge on, and the use of, the various marine palynomorph groups was minimal. One of the aims of Bill Hoffmeister's team was to undertake both routine service requests from affiliates in the Esso group of companies, and applied research into both marine and terrestrial palynology. The research into the biostratigraphical utility of aquatic palynomorphs undertaken by Hoffmeister's group in Tulsa was truly groundbreaking. Very little

was known about organic-walled marine microplankton at this time. It is clear that Hoffmeister was aware of the stratigraphical potential of fossil dinoflagellates and other aquatic palynomorphs prior to Bill Evitt's recruitment (Wilson & Hoffmeister 1953, 1955). The latter was especially significant in terms of the development of aquatic palynology. Wilson & Hoffmeister (1955) briefly described their study of the hystrichospheres from around 1000 Palaeozoic to Cenozoic samples. They recorded 16 or 17 genera, and noted that certain forms have restricted stratigraphical ranges and that hystrichospheres are proxies for marine conditions.

Others were also realising the value of aquatic palynomorphs. For example, Raymond D. Woods of the Humble Oil and Refining Company in Houston, Texas, briefly mentioned dinoflagellates and hystrichosphaerids, and illustrated three specimens (Woods 1955a, p. 371, pl. 1, figs 3, 6). The same author also wrote: 'In addition, current research on spores and pollen has revealed the distribution of heretofore little known microfossils, particularly the "hystrichs" which are proving to be as useful as plant remains in stratigraphic work' (Woods 1955b, p. 135).

The expertise of Bill Hoffmeister and Leonard Wilson was principally in pollen and spores, and Hoffmeister plainly needed someone else to undertake research into marine palynomorphs at this time. Thus, when Bill Evitt joined the Carter Oil Company in 1956, the research portfolio on marine palynology begun so competently and far-sightedly by Hoffmeister and Leonard Wilson in the early 1950s was passed to him in its entirety under the project title of 'little known microfossils'. Bill Evitt therefore already had an excellent sample base, together with Hoffmeister and Wilson's initial observations.

After the first few weeks of corporate familiarisation at Carter, Bill Evitt quickly realised that his new job offered the exciting opportunity to be at the forefront of an entirely new field in the modern era of palynology, i.e. the study of fossil dinoflagellates, hystrichospheres and related marine microplankton. Prior to starting his new job, he had no practical experience in palynology. Despite this, the procedures of extraction using mineral acids, and the concentration, examination and identification of palynomorphs were similar in principle to his previous work with trilobites at Johns Hopkins and Rochester universities. The main new aspects of palynology, apart from the unfamiliar fossil groups, were the use of hydrofluoric acid and becoming familiar with the prolonged use of a biological microscope. In addition to routine service work, Bill Evitt was specifically instructed by Bill Hoffmeister to investigate marine palynomorphs of strategically important successions with a view to using them as index fossils, and was given a great deal of freedom and independence in this endeavour. This degree of



latitude in a research role was (and still is) extremely unusual in the oil industry.

Bill Evitt's first project was to prepare and study palynomorphs from the highly macrofossiliferous Silurian and Devonian strata of western New York State. Bill Hoffmeister had asked Bill Evitt to sample this succession before his arrival in Tulsa. Bill Evitt firstly learned how to prepare this material and produce strew-mounted slides, before studying and photographing the palynomorphs. When Bill Evitt arrived in Tulsa, palynomorph processing procedures were, at best, rudimentary. Consequently, Bill Evitt, John Funkhouser and their laboratory technicians worked on improving techniques for the extraction, concentration and presentation of palynomorphs from sediments and sedimentary rocks. This work was written up as Funkhouser & Evitt (1959). This paper includes sections on gravity separation using zinc chloride solution, the use of water-soluble mountants and 'swirling' using a large watchglass to separate palynomorphs from organic particles of slightly higher density (Appendix 3). Bill and John Funkhouser were among

the first to document techniques such as heavy liquid separation and 'swirling' for the concentration of palynomorphs. Unfortunately, Bill Evitt found that the majority of his Silurian and Devonian samples from New York State produced only sparse and poorly preserved palynofloras. However, part of the Middle Silurian Maplewood Shale yielded abundant and well-preserved acritarchs, or hystrichospheres, as these palynomorphs were then known.

The next investigation was to prove much more rewarding for Bill Evitt. An Esso affiliate in Pakistan, the Socony Vacuum Oil Company, requested the biostratigraphical analysis of some subsurface samples of 'Mid' to Late Cretaceous age, from which he recovered some abundant palynofloras which included many unequivocal fossil dinoflagellates. Bill soon realised that the latter were largely taxonomically undescribed, but they offered significantly greater stratigraphical potential than did the much more thoroughly researched pollen and spores. This was Bill's first research success in palynology, but it has never been published. It was studying this material that convinced

Plate 6. A montage of dinoflagellate cysts which were of special interest to Bill Evitt.

Figures 1–3. *Nannoceratopsis gracilis*. All specimens from the lowermost Middle Jurassic Brent Group (probably the Broom Formation) from quadrant 211 in the northern North Sea (precise well/depth details unknown). Note that the specimens are all in left lateral view, with the prominent dorsal antapical horn to the right-hand side. The autophragm is microreticulate, and the small cingular archaeopyle can be discerned close to the apex on all three specimens (Piel & Evitt 1980a). 1. British Geological Survey (BGS) specimen number MPK 14583, slide 0004, England Finder coordinate T38/3 (length 60 μm ; width 47 μm). 2. BGS specimen number MPK 14584, slide 0004, England Finder coordinate W51 (length 58 μm ; width 47 μm). 3. BGS specimen number MPK 14585, slide 0004, England Finder coordinate P41 (length 67 μm ; width 44 μm). The scale bars all represent 25 μm .

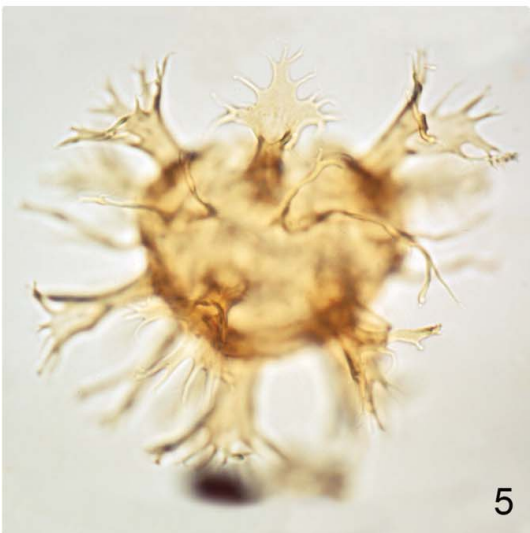
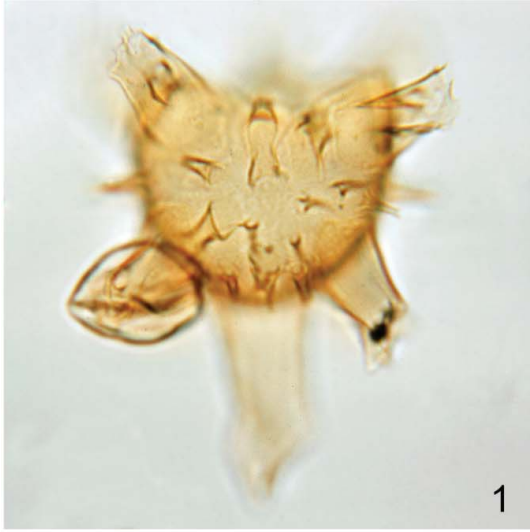
Figure 4. *Gillinia hymenophora*. The holotype from the Rough Range South No. 1 bore, Western Australia, from between 729.39 and 728.47 m (Cookson & Eisenack 1960, pl. 3, fig. 4). *Gillinia* is a Late Cretaceous genus with a global distribution and *Gillinia hymenophora* is marker for the Santonian to Campanian–Maastrichtian interval in Australia (Helby et al. 1987, fig. 40). It is paritiform and a representative of the *Phanerodinium* complex of Evitt (1985). Note the cingulum which is located high on the cyst, and with pericoel locally developed in the lateral cingular areas. The length of the specimen is 38 μm , and its width is 33 μm ; the scale bar represents 25 μm .

Figures 5, 6. *Dinogymnium undulosum*. The holotype from the Upper Cretaceous Madura Shale from 295.05 to 293.52 m in the Madura No. 1 Bore (Cookson & Eisenack 1970, pl. 10, fig. 3). This water borehole was drilled in the Eucla Basin, Western Australia (Lowry 1968). Note the broad, rounded apices, the prominent cingulum and sulcus, the subequal epittract and hypottract, and the undulating longitudinal ridges. Hengreen (1975, p. 63) suggested that *Dinogymnium denticulatum* may possibly be synonymous with this species. The length of the specimen is c. 64 μm , and its width is 34 μm ; the scale bar represents 25 μm .

Figure 7. *Palaeoperidinium pyrophorum* from the earliest Paleocene (Danian) Sobral Formation of central Seymour Island, Antarctica. British Antarctic Survey slide number D9.129.1A, England Finder coordinate K65/1. Photomicrograph taken by Dr Vanessa C. Bowman (British Antarctic Survey) and is used with permission. The specimen is in dorsal view. Note the subpentagonal outline, the three relatively short, distally pointed polar horns, the prominent cingulum and the two cyst layers; the innermost one is the apparently closely appressed endophragm and periphragm. The outer layer is the smooth exophragm (Evitt et al. 1998). The scale bar represents 25 μm . This specimen was originally illustrated in Bowman et al. (2016, fig. 3.4).

Figure 8. *Dinogymnium nelsonense*. The holotype from the Upper Cretaceous at 1899.82 m in the Nelson Bore (Cookson 1956, pl. 1, fig. 10). This borehole was drilled by the Victoria Department of Mines close to a bridge over the Glenelg River at Nelson, Glenelg Parish, southwest Victoria, Australia (Deflandre & Cookson 1955, fig. 1). Note the elongate ambitus, the truncated apical region, the prominent cingulum, the large epittract and the relatively thin, smooth wall which exhibits longitudinal folds. The length of the specimen is 70 μm , and its width is 38 μm ; the scale bar represents 25 μm .

Figure 9. *Dinogymnium westralium*. The holotype from the Upper Cretaceous (Campanian–Lower Maastrichtian) Korojon Calcarenite between 423.06 m and 420.62 m in Wapet's Rough Range Well No. 4 (Cookson & Eisenack 1958, pl. 1, fig. 9). This well is located in the Exmouth Gulf area of the Carnarvon Basin, Western Australia. Note the elongate biconical ambitus, the relatively narrow cingulum and the dense longitudinal ridges which have irregular distal margins. The hypottract is slightly larger than the epittract, and has a broadly rounded antapex. The length is 47 μm , and the width is 28 μm ; the scale bar represents 25 μm .



Bill that much of the dinoflagellate record was represented by the cyst phase of the life cycle. At this time it was simply assumed that the dinoflagellate fossil record represented preserved motile dinoflagellate thecae. Except for the fact that the delicate cellulosic nature of the dinoflagellate theca is extremely unlikely to be

preserved, this was entirely understandable because some fossil taxa are extremely similar in morphology, shape and size to living dinoflagellates. For example, the Late Cretaceous to Paleocene species *Palaeoperidinium pyrophorum* (Plate 6, figure 7) is similar in morphology to modern *Protooperidinium* thecae except that

Plate 7. Six of the 35-mm transparency slides included in the ringbound file of course materials that Bill Evitt provided to participants of the two-week Teaching Conferences on Fossil Dinoflagellates (section 10). These slides accompanied the practical exercises and the specimens for study. These four specimens are all skolochorate forms with apical archaeopyles. All of the images are reproduced with the approval of the Evitt family.

Figures 1, 2. *Hystrichokolpoma* sp. cf. *H. cinctum*; ventral view, high and low focus respectively; Calvert Formation, Miocene, Maryland. Note these photographs have been image-reversed or inverted. This was illustrated as *Hystrichokolpoma* sp. in the course manual as slides 16 and 17. Note the funnel-shaped intratabular processes which narrow distally. Proximally, these distinctive processes approximate to the area of their respective plate and are open distally. The antapical (1''') process is by far the longest. By contrast, the cingular and sulcal processes are the most slender. A standard, presumably sexiform, gonyaulaccean tabulation is clearly indicated by the processes, and the ventral organisation is L-type. It is not considered to be *Hystrichokolpoma cinctum* sensu stricto due to the relatively entire distal margins of the processes. In the type material, these are significantly scalloped (Williams & Downie 1966, fig. 46; Damassa 1979a, fig. 5). This morphotype is also similar to *Hystrichokolpoma rigaudiae*; however, *Hystrichokolpoma* sp. cf. *H. cinctum* is significantly larger and the processes are larger and taper distally. The processes in *Hystrichokolpoma rigaudiae* are expanded and slightly furcate distally (Deflandre & Cookson 1955, fig. 42). The cyst body is 50 µm in length, and is 60 µm wide; the overall dimensions of this specimen (including processes) are 110 µm long by 80 µm wide. Figures 3, 4. *Hystrichosphaeridium tubiferum*; ventral view, high and low focus respectively; Fox Hills Formation, Maastrichtian, Montana. These were slides 10 and 11. This is a classic chorate gonyaulaccean dinoflagellate cyst with plate-centred processes, and it was among the species which first convinced Bill Evitt that most of the Mesozoic and Cenozoic hystrichospheres were dinoflagellate cysts (sections 5, 6, 9; Figure 11). Specifically, it is clear that the processes have a one-to-one relationship to the thecal plates. Furthermore, in some cases, the polygonal outlines of the process tips indicate the shape of the respective thecal plate. For example, see the distinctly quadrangular middorsal postcingular plate (4''') in figure 4, which mimics the overall outline of this plate in the parent theca. Other obvious examples of this are the elongate outlines of the distal tips of the cingular processes in figure 4. Like in *Hystrichokolpoma* sp. cf. *H. cinctum* above, the intratabular processes reflect a standard, gonyaulaccean tabulation pattern and exhibit L-type ventral organisation. The sulcal processes, the L-type ventral configuration and the intersection of the sulcus and cingulum are clearly evident in figure 3. The apical archaeopyle has operated, and the precingular, cingular, postcingular and antapical plates are shown beautifully in figure 4. Note also the relatively smooth cyst wall and the prominent hollow, trumpet-shaped processes which are open distally but do not communicate with the cyst body proximally. This is because the processes in the centre of each plate are formed of periphragm, which only separates from the endophragm at the base. In the areas between the processes, both cyst layers are closely appressed. The cyst body is 44 µm in length, and is 40 µm wide; the overall dimensions of this specimen (including the processes) are 64 µm long by 88 µm wide.

Figure 5. *Perisseiasphaeridium pannosum*; oblique ventral view, low focus; Lower Cretaceous (Barremian), The Netherlands. This was slide 18, and Bill termed it *Perisseiasphaeridium* sp. This genus is low in diversity and ranges from the Late Jurassic to the Early Cretaceous (Fensome & Williams 2004, p. 515–516). It is especially characteristic of the latest Jurassic–earliest Cretaceous interval (Davey 1982; Nøhr-Hansen 1986; Stevens & Helby 1987; Riding & Thomas 1988). The holotype is Eocene, but this material was reworked from the Late Jurassic (Kimmeridgian) (Fensome 1979; Riding 1987). *Perisseiasphaeridium* is a chorate genus with prominent plate-centred processes in the large plate areas such as the precingulars and postcingulars which are distally expanded, hollow, multifurcate and open. By contrast, the cingulum and sulcus bear slender, solid processes. Note the apical archaeopyle, the smooth autophragm and the complex distal branching exhibited by the large processes. This focal level is on the dorsal side and the 2'', 3'', 4'', 3c, 4c, 3''', 4''', 5''' and 1''' processes can all be clearly discerned. The cyst body is 70 µm long, and 80 µm in width; the overall dimensions of the specimen (including the processes) are 125 µm long by 140 µm wide.

Figure 6. *Oligosphaeridium* sp. cf. *O. pulcherrimum*; ventral view, high focus; Mowry Shale, Lower Cretaceous (Albian), South Dakota. This was slide 14, and Bill termed it *Oligosphaeridium* sp. *Oligosphaeridium* is a very diverse chorate dinoflagellate cyst genus which is most characteristic of the Cretaceous, but ranges from the Late Jurassic to the Palaeocene (Wilson & Clowes 1980, p. 74; Fensome & Williams 2004, p. 470–475). It was most abundant during the Early Cretaceous, where the most common representative was the type, *Oligosphaeridium complex* (see Morgan 1980; Heilmann-Clausen 1987). The prominent process-free equatorial area is the most diagnostic feature of *Oligosphaeridium*. Indeed, the genus is identical to *Perisseiasphaeridium* except for the complete lack of cingular and sulcal processes. Note the apical archaeopyle, the smooth cyst wall and the intricate branching at the distal part of the plate-centred processes. Branching occurs in the distal 35 to 25% of the processes. The extreme distal parts of the branches tend to be connected by thin, smooth trabeculae. The processes are distally flared, hollow and open distally. The anterior sulcal (as) plate is clearly seen at the top of the sulcus; this is termed the sulcal tab. The separation of periphragm (the processes) from the underlying endophragm can be seen at the proximal part of the processes. The latter phenomenon is best observed on the large antapical (1''') process. The intricate branching in the distal part of the processes suggests a strong affinity with *Oligosphaeridium pulcherrimum*. This species is similar in size to the South Dakotan material, and both are Albian in age. The distal branching is significantly greater than in *Oligosphaeridium complex*. However, the type material of *Oligosphaeridium pulcherrimum* lacks the trabeculae which connect the distal process branches of the form illustrated here (Deflandre & Cookson 1955, figs 21, 22). The cyst body is 63 µm long, and 60 µm in width; the overall diameter, i.e. including the processes, is 125 µm.

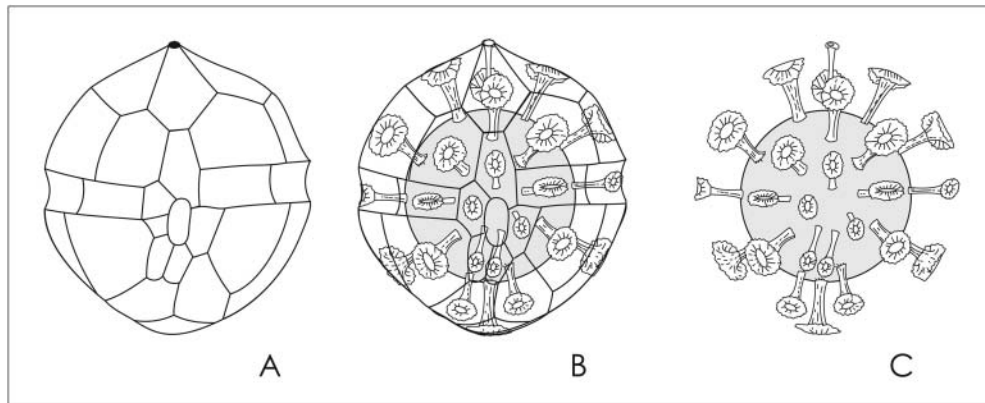


Figure 11. A line drawing to illustrate the derivation of a typical chorate dinoflagellate cyst. This is the Late Cretaceous to Eocene (Turonian–Ypresian) chorate species *Hystrichosphaeridium tubiferum* based on material from the Upper Cretaceous (Maastrichtian) Redbank Formation of New Jersey. The figure seeks to illustrate its relationship with the parent dinoflagellate thecate cell. A, the thecate cell which exhibits a standard L-type sexiform gonyaulaccean tabulation pattern in ventral view. B, the *Hystrichosphaeridium tubiferum* cyst within this thecate cell; note how the expanded distal extremity of every cylindrical plate-centred process is adherent to the inside of the central part of each thecal plate. C, the isolated *Hystrichosphaeridium tubiferum* cyst when the thecate cell has fully disintegrated and dispersed. The cyst body is shaded. The overall diameter of *Hystrichosphaeridium tubiferum* including processes varies between ca. 60 and 80 μm , and is typically around 75 μm . Parts B and C of this iconic diagram were originally published in Evitt (1963a, fig. 3); this figure is adapted from Evitt (1963a, fig. 3), Evitt (1985, fig. 3.3) and Fensome et al. (1996, fig. 26).

the wall relief in the former is interior and not exterior (see A3.63 below).

At the same time, Bill also hypothesised that many Mesozoic and Cenozoic hystrichospheres were in fact dinoflagellate cysts. This theory had been pondered earlier by the European researchers Wetzel (1933a, 1933b), Deflandre (1936a, 1937) and Lejeune (1937). Genera such as *Hystrichosphaera* (now *Spiniferites*) and *Hystrichosphaeridium* shaped Bill's theory. He noticed that (i) the processes on genera such as *Hystrichosphaeridium* apparently emerged from the centre of plates in the standard gonyaulaccean tabulation pattern, and (ii) the distal part of these processes in all of these process-bearing forms must have been originally in contact with the inside of the dinoflagellate thecal wall (Figure 11; Plates 7–11). The key evidence for the former phenomenon was the fact that some process-bearing (chorate) dinoflagellate cysts exhibit expanded process tips which are polygonal in outline, and that these features are precisely the shape of the thecal plates in their respective positions. These observations gave rise to the now-famous diagram of a specimen of *Hystrichosphaeridium tubiferum* (Plate 7, figures 3, 4) inside a hypothetical motile theca (Figure 11). This line drawing illustrating the relationship between the dinoflagellates and the hystrichospheres has become an icon of dinoflagellate cyst literature, and was first published in Evitt (1963a, fig. 3). Bill, of course, was an accomplished microscopist by this time and this, together with his highly tuned observational skills of small-scale features, allowed him to undertake the three-dimensional

reconstruction of the spiny cyst inside a theca. This was based on studying well-preserved fossil chorate dinoflagellates at several focal levels. Naturally, the fact that Bill could convincingly demonstrate that chorate dinoflagellate cysts formed inside another body (presumably the theca) also helped to demonstrate that the vast majority of proximate and proximochorate fossil dinoflagellates represent the cyst stage. From this point on, as Bill examined more and more material, he realised that there is a complete gradation between proximate, proximochorate and chorate dinoflagellate cysts (Figure 12).

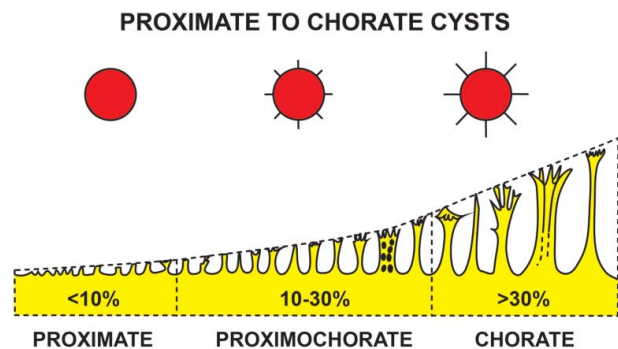


Figure 12. A diagram to illustrate the range of ornamentation exhibited by dinoflagellate cysts in terms of relative height. The continuum between low relief features on the left and the relatively long processes on the right is subdivided into three types of dinoflagellate cysts (i.e. proximate, proximochorate and chorate) depending on the ornamentation length as a percentage of the shortest diameter of the central body. The image is adapted from Fensome et al. (1996c, fig. 22), which was in turn modified from Sarjeant (1982a, fig. 2).

Bill first presented his new ideas outside the Carter Oil Company group in a lecture to members of the Paleobotanical Section of the Botanical Society of America, who visited Tulsa on a field trip during their annual national meeting in Oklahoma City in 1958. Clearly, the project on the Cretaceous of Pakistan first excited Bill's great interest in the dinoflagellates, especially their complex morphologies. His skills in analysing morphology had already been honed by his trilobite research and his aerial photography in the US Army Air Force.

Bill Evitt authored or co-authored six papers while employed by Carter/Jersey (Appendix 3), all of which were issued with the enthusiastic encouragement of Bill Hoffmeister. In addition to these contributions, Bill Evitt and his colleagues prepared an alphabetically arranged card index file with each fossil dinoflagellate genus and species having a card with illustrations and its published description (Riding et al. 2012). This card index would help the Carter/Jersey palynologists familiarise themselves with the known taxa, and identify them. When Bill Evitt left Jersey for Stanford in 1962, the index had grown to around 1000 cards, and he was allowed to take the original index with him to Stanford, leaving a copy in Tulsa.

5.5. *Doing Europe – 1959*

5.5.1. *Background*

Bill Evitt was very well regarded at Jersey Production Research, and he was promoted to research associate in 1959. Furthermore, during spring 1959, Bill Hoffmeister and his line manager told Bill Evitt that the laboratory had some unspent travel funds in the budget, and they asked him if he would like to utilise this to further develop his expertise in the use of fossil dinoflagellates in petroleum exploration. This, of course, was a fantastic opportunity and Bill Evitt immediately suggested an extended visit to Europe in order to work with the two pioneers of marine palynology, namely Georges Deflandre of Paris, France, and Alfred Eisenack from Tübingen, Germany (Figures 13, 14). This was readily agreed, and Bill embarked on a two-month working visit in August 1959 to be mentored by Deflandre and Eisenack, to work on their extensive collections, and discuss his new ideas on dinoflagellate life cycles and the affinity of the hystrichospheres. These hypotheses were both somewhat preliminary in 1959, entirely unpublished and significantly at variance with the interpretations of both Deflandre and Eisenack. However, Bill's primary mission was to learn all he could from these giants of the subject, who had produced the vast majority of the literature on fossil

dinoflagellates at that time (e.g. Deflandre 1935, 1936a, 1936b, 1937, 1938, 1941; Eisenack 1935, 1936a, 1936b, 1938a, 1954, 1958; Deflandre & Cookson 1955).

Both Georges Deflandre and Alfred Eisenack were very happy to host Bill, and they duly received him into their respective workplaces with great courtesy; the trip to Europe was a resounding success. It led to lifelong friendships between Bill and these eminent early researchers, who were profoundly different in many respects. Bill corresponded extensively with both Deflandre and Eisenack over many years, and he developed a massive respect for their major contributions to our science. The dedication in Evitt (1985, p. iii) is to both Deflandre and Eisenack.

During August 1959, Bill and Gisela sailed from New York to Southampton on the USS *United States*. Both sets of parents had agreed to care for the three boys for the duration of the European tour. Gisela's mother looked after the infant Glenn; she was especially keen that her daughter had a chance to reconnect with her German relatives. Raymond and Elsa Evitt cared for Eric and Steven, who were six and four respectively at the time. This was the first time Bill had visited Europe, and it was Gisela's first trip there since World War II.

After a few days in London, the couple took a train north to Sheffield so that Bill could briefly visit Charles Downie and his then-postgraduate student William A. S. ('Bill') Sarjeant at the University of Sheffield. Bill presented his new ideas on the nature of the dinoflagellate fossil record, the affinity of some of the younger hystrichospheres and the archaeopyle to Downie and Sarjeant. Initially, the two Sheffield palynologists were somewhat negative and sceptical (Sarjeant 1976, p. 1–2). The visit to the University of Sheffield was unexpected, and Sarjeant (1984a, p. 4) somewhat amusingly recalled that, at the time, Charles Downie and he thought that Bill was a crank! It was only when his first papers on fossil dinoflagellates were published, two years later (Evitt 1961b, 1961c, 1961d), that Downie and Sarjeant realised just how perceptive Bill's ideas were. Despite this uncertain start, Bill clearly struck up a good working relationship with the two Sheffield palynologists because they subsequently published together on the classification of the acritarchs and the nature of fossil dinoflagellates (Downie et al. 1963). Following Downie et al. (1963), Bill never worked closely with Downie again. By contrast, he maintained a close relationship with Bill Sarjeant, largely via correspondence. However, Evitt and Sarjeant never published together after Downie et al. (1963). Incidentally, Bill and Gisela did not especially warm to the city of Sheffield during their short visit there, and opted for Chinese meals as opposed to the local fare. What they undoubtedly noticed was the long and painful recovery



Figure 13. A photograph of the French algalogist and micropalaeontologist Georges Deflandre (1897–1973) at his desk in the Laboratoire de Micropaléontologie at the École Pratique des Hautes Études, Paris, France. The image is reproduced with the permission of AASP – The Palynological Society.

from World War II, which was especially protracted in the northern cities of England. Because it was (and still is) an industrial centre, specialising in steelmaking, Sheffield had suffered terrible bombing during the conflict (License 2000).

From Sheffield, Bill and Gisela returned to London before travelling to Hamburg in northern Germany by train and ferry. In Hamburg they met Gisela's sister, Veronica, who was then a student. The three of them hired a car and took a two-week vacation before Bill was due in Tübingen to begin working with Alfred Eisenack. The intention was to drive southwest to

Freiburg and visit Gisela's family there. At that time, Gisela's grandmother still lived in the house built by her husband, Nobel Laureate Hans Spemann, and in which Gisela had been born. Gisela had not seen her grandmother for 21 years. Unfortunately the Evitts' arrival in Freiburg coincided with the death of Gisela's aunt, and they went to Lake Constance in Switzerland for the funeral. Gisela and Bill's longstanding interest in textiles began in Switzerland, where they visited the annual exhibition of a weaving school. Bill and Gisela fell in love with Freiburg and the Black Forest, and undertook many visits to the extended family. These



Figure 14. A photograph of the eminent German marine palynologist Alfred Eisenack (1891–1982). Alfred worked at the University of Tübingen, and lived in nearby Reutlingen in southwest Germany. Eisenack is pictured here in Tübingen during 1963. This image was used in Sarjeant (1998, pl. 5), and is reproduced here with permission.

included Gisela's godmother, Rose ten Bruggencate, and Neisa, her 18-year-old daughter. Neisa was about to finish her final secondary-school exams (*Abitur*). Because Neisa wished to travel, it was agreed that she would travel to Tulsa the next year, 1960, where she would study English and help out with the three Evitt boys.

5.5.2. *Visiting Alfred Eisenack in Tübingen*

Bill and Gisela travelled northeast to Tübingen during late September 1959. Tübingen is an old university town in Baden-Württemberg, southwest Germany, and the couple stayed in a small hotel near this famous seat of learning. Gisela explored the ancient city, and

the surrounding area, while Bill worked with Alfred Eisenack in his laboratory at the University of Tübingen. Alfred Eisenack (1891–1982) had trained in geology, but his career was tragically interrupted by both world wars. He became a schoolteacher in Königsberg (now Kaliningrad) and eventually fulfilled his lifetime ambition of becoming a university researcher in 1951, when he was 60 years old (Gocht & Sarjeant 1983; Sarjeant 1985; Evitt 2001). He retired in 1957, so when Bill visited in September 1959, Eisenack had no teaching duties.

Alfred Eisenack's first studies in palynology were on blocks of allochthonous Ordovician, Silurian and Jurassic limestones derived from the Baltic Sea in glacial erratics found on the North German Plain (e.g. Eisenack 1931). He moved on, for example, to studies of indigenous Cretaceous and Palaeogene material, including many collaborative studies with Isabel Cookson on material from Australasia (Gocht 1982; Riding & Dettmann 2013). The first of these southern-hemisphere studies was the classic Cookson & Eisenack (1958).

Eisenack was a courteous, generous and welcoming individual, and he made Bill very comfortable throughout his extended stay in Tübingen. Bill was able to examine any slides in his extensive collections that he wished. For example, Eisenack had much well-preserved Cretaceous and Palaeogene material from Germany. Alfred Eisenack had discovered superbly preserved fossil dinoflagellates from Eocene phosphatic nodules from Samland in Kaliningrad Oblast (Eisenack 1938a), and it seems likely that he advised Bill at this time about how early diagenetic concretions/nodules can frequently yield superbly preserved palynomorphs. Bill also studied the type material of the important chorate dinoflagellate cyst species *Areosphaeridium diktyoplokum* during this visit (Evitt 1972).

Bill found that the specimens he studied in Germany confirmed his ideas about excystment in fossil dinoflagellates, and the dinoflagellate affinity of genera such as *Hystrichosphaeridium*. Alfred Eisenack did not speak English well, and Bill had only perfunctory German at that time. Despite these communication difficulties, they discussed Bill's emerging hypotheses on fossil dinoflagellates extensively. However Evitt's ideas did not convince Eisenack; moreover, he thought that Bill was entirely wrong. Bill attributed Eisenack's profound unreceptiveness to 'German stubbornness', and was frequently significantly frustrated by Eisenack's stock reply of 'time will tell', when Bill explained his new ideas. In particular, Eisenack did not agree with Bill's hypothesis that many Mesozoic and Cenozoic hystrichospheres, such as *Hystrichosphaeridium tubiferum*, were process-bearing dinoflagellate cysts based on the number and the positions of plate-centred

processes (Figure 11; Plate 7, figures 3, 4). This was principally because Eisenack had long been convinced that the hystrichospheres were a coherent group of extinct unicellular algae with a constant basic morphology, and completely unrelated to the dinoflagellates (Eisenack 1954). Despite these professional differences, the two men developed a warm friendship. Perhaps unsurprisingly, they never published together. Although Bill undoubtedly learned much from Eisenack in 1959, and he was impressed at Alfred's very extensive publication record, he clearly felt that some of his scientific contributions were somewhat limited in scope.

Hystrichospheres (literally meaning 'spiny spheres') replaced the old term 'xanthidia' (Sarjeant 1965; 1967a), and was an informal term used from the description of *Hystrichosphaera* (now *Spiniferites*) by Wetzel (1933b) until the 1960s (Sarjeant 1960, 1961). The informal term 'hystrichospheres' developed chiefly due to erection of the Family Hystrichosphaeridae and the Order Hystrichosphaeridea by Wetzel (1933b) and Eisenack (1938b), respectively. Alfred Eisenack emphatically did not agree with some of his contemporaries that the hystrichospheres might have dinoflagellate affinity. In one of his early papers, he cited the fact that the reflected fields/plates in hystrichospheres do not break up as in dinoflagellate thecae (Eisenack 1938a). Alfred Eisenack stubbornly clung to the concept of 'The unity of the hystrichospheres' (*die Einheitlichkeit der Hystrichosphären*) for several years after Bill published his then-revolutionary hypotheses regarding fossil dinoflagellates being cysts (Evitt 1961c; Eisenack 1963a, 1963b). In Eisenack (1963a), he strenuously defended his hypothesis that spinose acritarchs and skolochorate dinoflagellate cysts should continue to be termed hystrichospheres. One of his main lines of evidence was the apparent similarities in the walls of acritarchs and hystrichospheres. Eisenack completely rejected the contention that the hystrichospheres were extant (Eisenack 1964), and it was several years later that he (albeit tacitly) accepted the new Evittian paradigm (Eisenack 1969a, 1969b; Eisenack et al. 1973).

Many years later, Bill very much welcomed the description of the Early Cretaceous process-bearing dinoflagellate cyst species *Oligosphaeridium abaculum* (Plates 9, 10). This magnificent skolochorate species has an unequivocal gonyaulacacean tabulation based on low sutural ridges and plate-centred processes (Davey 1979a). Had *Oligosphaeridium abaculum* been described in 1959, there would surely have been no dinoflagellate cyst versus hystrichosphere debate. How Bill would have loved to have shown *Oligosphaeridium abaculum* to Alfred Eisenack in late 1959.

After Bill and Gisela had been in Germany for six weeks, word came in late October 1959 that Elsa Evitt

was finding caring for Eric and Steven somewhat difficult, and so Gisela decided to return to the United States immediately. Bill drove her to Bremen to catch a liner to New York. On the way to Bremen they stopped in nearby Barnstorf in Lower Saxony, northwest Germany, to meet Hans Gocht (1930–2014), an extremely promising young palynologist (Figure 15). Hans Gocht originally worked for a German oil company, preparing foraminifera (Riding et al. 2015). Remarkably, he taught himself palynology, and published several papers while working as a technician (e.g. Gocht 1952, 1955, 1957, 1959). Alfred Eisenack quickly recognised Gocht's considerable talents, and encouraged him to return to education to sit his secondary school examinations (*Abitur*). After doing this, Hans Gocht obtained a PhD and worked under Eisenack at the University of Tübingen. Bill and Hans Gocht were both fascinated by the morphology and fine structure of dinoflagellate cysts, and were extremely analytical and meticulous in their

approach. They inevitably became respected colleagues and close friends. In many respects, Hans Gocht was Bill's European contemporary counterpart, and Bill always had the highest respect for Gocht's work. Somewhat surprisingly, they only published together once, in a *Festschrift* for Alfred Eisenack (Evitt et al. 1985). Bill's final paper is a contribution to Hans Gocht's *Festschrift* to celebrate the latter's 70th birthday (Evitt 2001).

5.5.3. Visiting Georges Deflandre in Paris

The day after meeting Hans Gocht during late October 1959, Gisela sailed on the USS *United States* from Bremen *en route* to New York. She picked Eric and Steven up in Maryland, and returned to Tulsa by train. At the same time in Europe, Bill travelled from Tübingen to Paris to work with Georges Deflandre at the Laboratoire de Micropaléontologie at the École Pratique des Hautes Études.



Figure 15. A photograph of the German marine palynologist Hans Gocht (1930–2014) of Tübingen, southwest Germany. The image is taken from Riding et al. (2015), and is used here with the permission of AASP – The Palynological Society.

Georges Victor Deflandre (1897–1973) was a former railway worker and schoolteacher with no formal academic qualifications. After the end of World War I he became fascinated by microscopy and protistology, and was awarded a PhD in 1926. He undertook a post-doctoral position, and became head of the aforementioned *Laboratoire de Micropaléontologie* in 1943. Like Alfred Eisenack, he was an avid taxonomist and polymathic in his interests (Caulet 2013). Deflandre became interested in fossil dinoflagellates in the 1930s, and worked mainly on Upper Jurassic, Upper Cretaceous and Palaeogene material (Sarjeant 1973; Evitt 1975a; Noel 1975; Verdier 1975). His first paper on dinoflagellates was Deflandre (1933) on Eocene siliceous forms from New Zealand. Georges Deflandre also researched the Upper Jurassic successions of northern France (Deflandre 1938, 1941) and the Upper Cretaceous flints of the Paris area (e.g. Deflandre 1936a, 1937). He worked with Isabel Cookson to produce the first monograph on fossil dinoflagellates from the southern hemisphere (Deflandre & Cookson 1955). During the 1930s, Deflandre observed that *Hystrichosphaera* (now *Spiniferites*) has an equatorial girdle and lineations which are consistent with a dinoflagellate affinity. He also perceptively noted that some of the hystrichospheres exhibit dinoflagellate-like characteristics (Deflandre 1947). It seems likely that Bill was significantly influenced by these remarks.

Bill's month in Paris during November 1959 was similar to his experience in Tübingen, in that he spent the time studying slides at the microscope or in discussion. Georges Deflandre was extremely kind and cooperative throughout; he allowed Bill to freely peruse his files and his extensive collection of slides and specimens, as well as spending much time exchanging ideas on fossil dinoflagellates. He gave Bill a portion of an aqueous residue full of superbly preserved dinoflagellates from an Oligocene limestone from northern Germany, originally given to Deflandre by Walter Wetzel of Kiel, Germany. Walter Wetzel was one of the earliest palynologists, and served in the German Army during World War II (Dietz et al. 1999). He visited Deflandre in occupied Paris, and presumably passed on the residue during the war years. Bill said that this assemblage was the most instructive that he had ever studied.

Georges Deflandre was reluctant to speak English, and Bill did not speak French well. So, on Bill's first day, they decided to communicate in German which apparently worked well. However, on the following day, Deflandre made it clear that they would use French for the rest of the visit, which made things rather difficult for Bill (personal communication, Bill Evitt to JL-C). Despite these difficulties, the two communicated effectively and learned much from each other.

Bill commented that Georges Deflandre had a truly photographic memory. Apparently he could recall with ease individual specimens that he had studied years earlier. Deflandre kept a highly organised file system which documented the essential details of all his collection of thousands of microorganisms and microfossil samples and specimens. Bill recalled in particular the vastness of Deflandre's collections of carefully filed unpublished notes. It is clear that Deflandre was a very systematic individual; he published his card indexes on marine palynomorphs as several catalogues ('fiches') between 1943 and 1966 (e.g. Deflandre 1945).

Bill found Georges Deflandre to be rather outspoken in his criticism of his peers who did not, in Deflandre's view, measure up to his extremely high standards. This candour did not win Deflandre friends among the French micropalaeontological community, some of whom were generally somewhat distrustful of him (personal communication, Bill Evitt to JBR). As a consequence, Georges Deflandre was somewhat of an aloof and isolated figure amongst French micropalaeontologists at this time. Perhaps because of Deflandre's relative isolation, and his apparent collaboration with the German palynologist Walter Wetzel during World War II, he was never elected to full membership of the Académie des Sciences (Dietz et al. 1999, p. 8, 9). During the conflict Otto Wetzel, Walter Wetzel and Deflandre wrote a short article on the formation of Upper Cretaceous flint (Wetzel et al. 1941).

Georges Deflandre was, however, in marked contrast to Alfred Eisenack, very receptive to Bill's new hypotheses concerning fossil dinoflagellates. Deflandre clearly understood Bill's new ideas, and was immediately converted. His enthusiasm was so great that he offered to help amass new evidence that would be helpful. However, Bill was somewhat perturbed by Deflandre's tendency to publish (albeit with full acknowledgements) concepts and ideas discussed between the two of them in private correspondence. There is no doubt that Bill was far less open with Deflandre in correspondence after this facet of the latter's character was revealed. Probably as a consequence of this issue, Deflandre and Evitt never published together as joint authors, although Evitt (1968) was written in collaboration with Deflandre. Despite Deflandre's persistent tendency to publish informal discussions, it is clear that Bill had the highest regard for him, and patently felt that he was the pioneer in marine palynology who had made by far the highest impact.

After the month in Paris, Bill flew from Paris to New York in early December 1960 (his first time in a jet plane) on his way back to Tulsa. Immediately upon returning, Evitt began working on what he learned in Europe and wrote his first papers on dinoflagellates

(Evitt 1961b, 1961c, 1961d). Coincidentally, his final single-author paper on trilobites was published that year (Evitt 1961a), thereby marking a significant milestone in his career.

5.6. *A return to the Indian subcontinent*

In 1960, Bill was instructed to visit a palaeontological laboratory affiliated with Standard Oil of New Jersey in Calcutta (now Kolkata), India. This was a trans-global trip as he was asked to visit other affiliated laboratories *en route*. He had some previous experience of Kolkata, having visited twice during his wartime service (subsection 3.3). Two of the local palynologists had studied the sediments of the Ganges Delta in northeastern India. This study was aimed at correlating environments at the surface with their equivalents at depth based on the pollen and spore content of the samples, and Bill's task was to review this work. Bill departed from Tulsa in September 1960; his circumnavigation of the planet included visits to Spain (Barcelona), Libya (Tripoli), Italy (Rome), Greece (Athens), India (Kolkata and New Delhi), Hong Kong and the Philippines (Manila).

The principal task was the visit to the laboratory in Kolkata. After reviewing reports and samples in the office, Bill visited the Ganges Delta itself. The party took a hired boat and sailed south into the more distal areas in the delta right out to the delta front. They returned to the coast and visited Orissa State, southwest of Kolkata, in an area where the meandering distributaries of the Ganges periodically flooded the surrounding land to create an intricate interfingering of dry land, lakes and swamps. The local palynologists had sampled these different modern environments and found distinctive associations of pollen and spores in each. The different depositional settings could then be identified in the subsurface using this 'palynological fingerprinting'. This work is similar to the study of Muller (1959) in the Orinoco Delta of eastern Venezuela. Bill Evitt was suitably impressed by this work, and reported his findings to Bill Hoffmeister upon his return to Tulsa in November 1960.

5.7. *Tulsa turnaround (1960–1962)*

Upon Bill Evitt's return to Tulsa from India in late 1960, he turned his attention to a letter received earlier that year from the chairman of the Department of Geology at Stanford University in California. This communication had come completely out of the blue and, in purely professional terms, it was his career watershed moment. The letter was an invitation to work as a visiting professor for six months at Stanford during the academic year 1960–1961. Stanford

University is located in Palo Alto, south of San Francisco, California. Specifically, Bill was asked to teach an undergraduate course in palaeontology of his choice and a graduate student seminar during the first half of 1961. Bill had imagined that Jersey Production Research would not allow him to leave for such an extended period, but made enquiries with the company nevertheless. To his considerable surprise (and possibly some mildly hubristic chagrin), he was told that a six-month leave of absence could be arranged. Consequently, Bill undertook this temporary teaching position at Stanford University while still permanently employed by Jersey Production Research. So, just before Christmas 1960, the Evitt family drove west to California. A significant domestic change in the Evitt household was that Neisa ten Bruggencate had arrived from Germany to spend a year in the US (subsection 5.5.1). They spent Christmas Day in Gallup, New Mexico, *en route* before arriving in Palo Alto just before the end of 1960, where they rented a house in Menlo Park.

Bill enjoyed tremendously being back in an academic environment teaching palaeontology and palynology to both undergraduates and graduate students. He also very much liked the Department of Geology at Stanford University, which included good facilities for sample processing. Bill actively explored the geology of the west coast, and undertook several field trips to the Coast Ranges in order to sample the local Mesozoic and Cenozoic strata for palynomorphs. He found several localities which yielded excellent assemblages that were used for PhD studies by his students later in his career. Inevitably, the Evitt family had a wonderful time in California. The spring of 1961 was unusually dry, and they spent virtually every weekend exploring the Bay Area and environs. It was naturally assumed that they would never return to the west coast, and the Evitts were therefore determined to make the most of their six months in San Francisco.

However, on the last day before the long drive back to Oklahoma in June 1961, the department chairman sought out Bill for a chat. He told Bill that they were so impressed with him throughout the visiting professorship that they wanted to offer him a permanent position at Stanford to teach palaeontology, starting in the autumn of 1962. Bill was somewhat taken aback, and did not agree immediately because the family were all happy with life in Tulsa. He requested several weeks in order to seriously consider the offer. Consequently, the Evitt family returned to Tulsa in somewhat thoughtful mood. Neisa helped with settling back into life in Tulsa, before returning to Germany in the autumn of 1961.

The offer from Stanford University in 1961 was truly a bombshell. The initial post in 1960 was strictly for a visiting professor. Furthermore, the Evitts were

all contented with life in Tulsa, where professional life for Bill was great and they had all made many good friends. Initially, Bill and Gisela tended to the view that they should stay in Oklahoma. However, on further consideration, they acknowledged that Tulsa had its limitations and their three boys would have better academic, cultural and sporting opportunities in the Bay Area of San Francisco. Moreover, working life at the Jersey Production Research Company was also changing. During Bill's sabbatical in California, Bill Hoffmeister had retired from the Jersey Production Research Company and there were management changes upwards in the hierarchy. These events caused abrupt changes to the atmosphere and focus in the palaeontology group. Without the massively protective and stabilising influence of Bill Hoffmeister, the future of the pure micropalaeontological research programme at Jersey appeared to be under threat. The charismatic Hoffmeister had single-handedly created the unique research-focussed ethos referred to in subsections 5.2 to 5.5. It was inevitable that the Jersey laboratory would henceforth concentrate on routine company projects, and that the highly prized research dimension would be largely lost.

So the lure of the Golden State, together with the changes at Jersey Production Research, led Bill and Gisela to accept the offer from Stanford University subject to the stipulation that he was not to be made departmental chairman. Bill still yearned to teach; he missed the daily interactions with students he had enjoyed so much at Johns Hopkins and Rochester universities. The six years in Tulsa had helped to financially stabilise the Evitt family, and had irrevocably set Bill's career path in palynology. Despite the overwhelmingly positive experience in Oklahoma, Bill was clearly still an academic at heart.

Bill Evitt's final few months at Jersey Production Research were unfortunately somewhat awkward. Although Bill Hoffmeister (who was not present on a daily basis) was supportive, others in the management were not. They made it clear, in these last months, that Bill Evitt was not part of the functioning organisation. It seems likely that, in hindsight, the Jersey management regretted allowing Bill Evitt to have six months' leave of absence to go to Stanford University in late 1960. It should be stressed here that Bill's scientific and technical colleagues in other parts of the company did not consider him *persona non grata*. So Bill uncomfortably sat out his notice period and travelled to the Bay Area of San Francisco to house-hunt in the spring of 1962 before the whole family moved to California during the summer of that year.

Lew Stover took over from Bill as senior palynologist at Jersey. Subsequently, the Jersey Production Research Company merged with Humble Oil, and

moved from Tulsa to Houston, Texas, to form a new company, Esso (subsequently Exxon and ExxonMobil) Production Research. Lew Stover remained a very good friend of the Evitt family, and he collaborated with Bill on Evitt et al. (1977) and Stover & Evitt (1978). Lew worked at Esso/Exxon in Houston for the remainder of his long and illustrious career (Williams & Partridge 1993).

6. The return to academe: Stanford University (1962–1988)

6.1. Introduction

During Bill's tough final months in Tulsa, there was considerable correspondence with Stanford University regarding his requirements in order to initiate a vibrant research programme in palynology. Bill designed a palynology laboratory based on the one in Tulsa, with preparation facilities at one end and microscopes at the other (Figures 16, 17). This logistical work at Stanford University was financed by a National Science Foundation grant over three years that Bill had successfully applied for to cover fieldwork, a graduate student (John S. Warren), the laboratory and a technician. The latter was Susan E. Davidson (later Thomas), who had taken the palynology course given at Stanford by Bill in 1961. Upon arriving at Stanford in the summer of 1962, Bill oversaw the installation of the palynology laboratory and prepared his undergraduate courses in palynology and invertebrate palaeontology, which were commenced that autumn.

6.2. Family life at Stanford

In 1962, the Evitt family bought a house, 2074 Sandalwood Court, about 5 km from the Stanford University campus. This was close to the boys' grade school, and also very near to the freeway in eastern Palo Alto. Life in California was good, and provided many unique opportunities. Holidays were spent on excursions to the spectacular Sierra Nevada mountains to the east, including the high country of Yosemite National Park. When the boys were young the family used their camp trailer, and they went backpacking in 1968 and 1969. The latter trip was a six-day hiking trip in the central Sierra, and was their last vacation as a family of five before Eric started college. In the summers of 1964 and 1968, the Evitts took long camping roadtrips to the east to visit family and friends.

In 1975 the residence rules pertaining to local schools were somewhat relaxed, making it possible for the Evitt family to move from Sandalwood Court, which was rather too close to the freeway, while allowing Glenn Evitt to remain in his high school in Palo

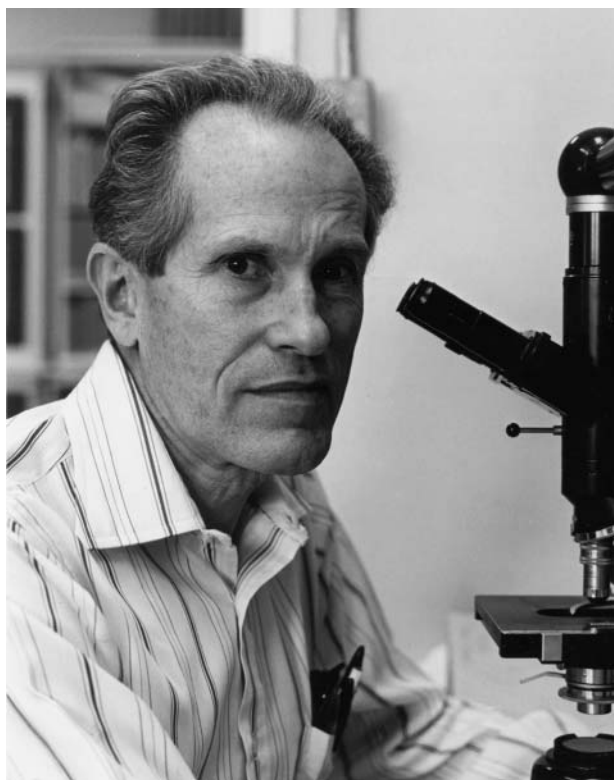


Figure 16. Bill Evitt at his microscope in the palynology laboratory that he established at Stanford University. The image is reproduced with the approval of the Evitt family.

Alto. The new home was in the faculty housing area on the Stanford University campus at 882 Cedro Way. This was a much more pleasant environment, and gave Bill a five-minute bicycle ride to his office. The Evitts worked hard on this house; they had it extended to accommodate Gisela's spinning and weaving equipment, fenced off the plot, drained the damp foundations and restocked the garden. This residence served the Evitts well for 29 years, although it was somewhat shaken by the 1989 Loma Prieta earthquake, in which some domestic items were damaged or destroyed (section 13). Bill and Gisela moved to a retirement home at 14500 Fruitvale Avenue in Saratoga, California, in 2004.

All his life Bill loved using microscopes, and he would often use them informally. One example of this was during his early years at Stanford University. One day while at work, Bill found the vial of iodine crystals he had made as a schoolboy (subsection 2.3) in his office desk. Bill clearly remembered watching the rapidly changing crystals as the iodine melted and recrystallised all those years ago. Intrigued, Bill placed a small amount of iodine from the vial onto a microscope slide, gently placed a coverslip over it, then placed the slide on the hotplate he used for making

palynomorph slides. The iodine quickly melted and flowed to the edges of the coverslip, making a superthin layer. The melting point of iodine is 113.7 °C. When the slide was removed from the coverslip, the iodine quickly cooled and recrystallised. Under the microscope, the intensely coloured iodine crystals were spectacular. The playful Bill was now on a roll, and he realised that sulphur has a similar melting point (115.2 °C). Next, he placed small amounts of iodine and sulphur on a slide under a coverslip and heated it as before. The two substances melted and flowed together but, when the slide was allowed to cool, the iodine and sulphur separated and crystals of both elements formed fantastic intergrown shapes. The mixture of crystals was especially aesthetically pleasing due to the light yellow sulphur contrasting sharply with the deep red iodine. Bill reheated the slide several times, and scanned it under the microscope to look for especially photogenic fields of view. He photographed some of these at various magnifications using several levels of cross-polarised light to vary the colour combinations.

Some time later, Gisela audited a course in the Department of Art at Stanford University which was taught by Professor Matt Khan. She thought that Khan and his art class might be interested in Bill's images of the iodine-sulphur slides. The art class was indeed fascinated by the photomicrographs, and Matt Khan asked for copies. He went on to use the images in his art class for the remainder of his career.

6.3. Professional life at Stanford

The Department of Geology at Stanford University (Figure 18) was very strong in several subdisciplines, including palaeontology and stratigraphy, during the early 1960s. Bill obviously was involved in the undergraduate and postgraduate sedimentary geology/soft rock programmes, and was recruited in anticipation of the retirement of some senior faculty members. He taught invertebrate palaeontology, vertebrate palaeontology and palynology. When Bill accepted the position, he insisted that he did not wish to be made chairman of the department (subsection 5.7). In 1962 this duty had an open-ended tenure, but later the chairmanship changed to three-year rotating terms. Bill absolutely preferred research and teaching to administration. The position of departmental chairman for him would have been extremely tedious, verging on anathema. Furthermore, Bill felt that he would not be a good figurehead and that he had little aptitude in fundraising, which was a key role of the chairman. The department willingly accepted this stipulation in 1961, and honoured their commitment thereafter. However, Bill did undertake certain departmental administration



Figure 17. The palynology laboratory at Stanford University. This facility was based on the combined microscope suite and preparation laboratory that Bill Evitt worked in while at Carter/Jersey in Tulsa ([section 5](#)). The Stanford University laboratory had chemical preparation facilities to one side and microscopes at the other. These two photographs illustrate Joyce Lucas-Clark working in the laboratory during 1981. The upper photograph (A) shows her at the microscope using several of Bill's dinoflagellate models ([section 10](#)). The lower photograph (B) is of Joyce working in the adjacent preparation facility. Note the rubber gloves stored on upright poles to prevent any drops of acid from entering the interior of the gloves, and the centrifuges on both the left and the right. Both photographs are from the personal collection of Joyce Lucas-Clark.

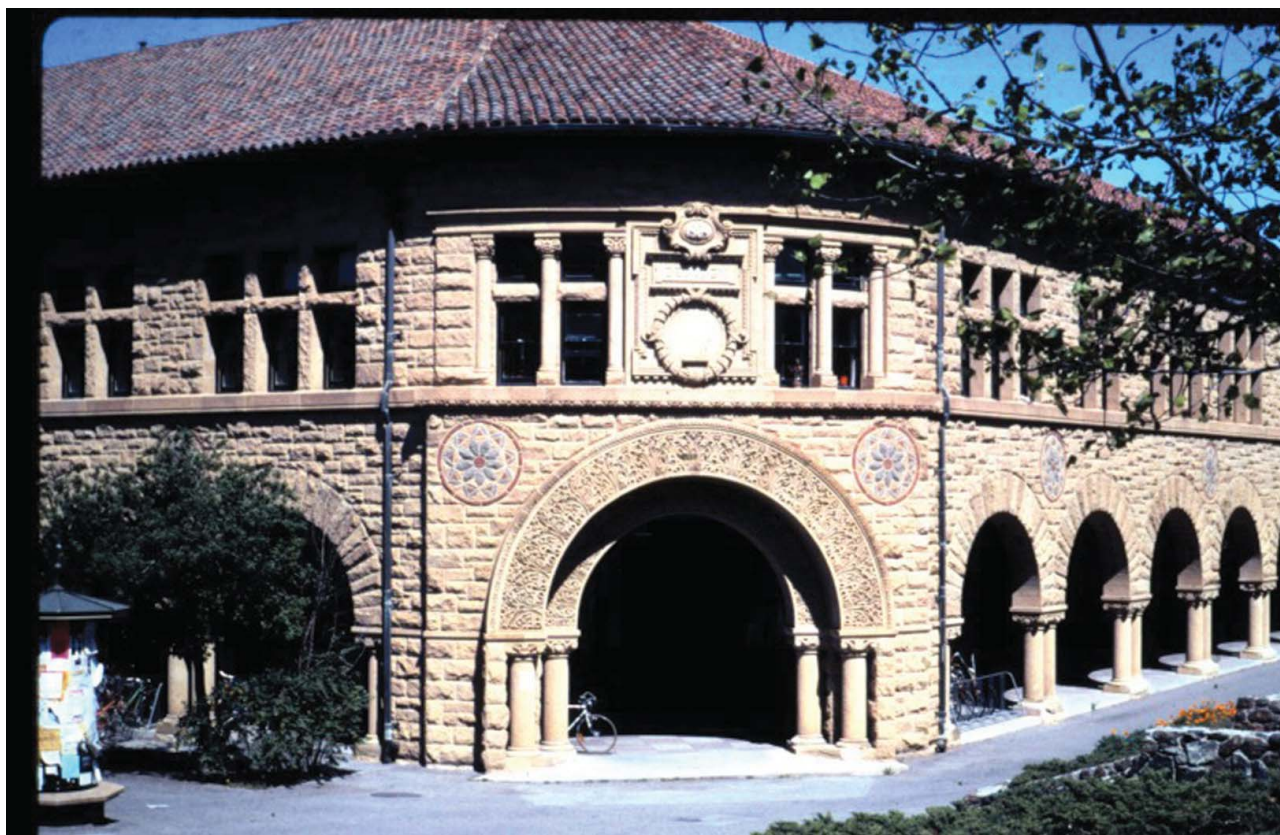


Figure 18. The Geology Department building at Stanford University, the home of Bill Evitt's palynology laboratory between 1962 and 1988. The specific area illustrated was known as 'geology corner'. This is part of the overall Stanford University quadrangle, which is a large double quadrangular building with different departments on each of the corners. Photograph by Joyce Lucas-Clark.

duties. For example, he was chairman of the graduate admissions committee for most of his time at Stanford. Bill also served as assistant departmental chair for some of his Stanford tenure and undertook several *ad hoc* administrative tasks over the years.

At Stanford University, Bill was largely involved in teaching and supervisory duties during term time. He undertook his own research as time permitted, but he found that it was only during the summers that he could really concentrate on this work. His fieldwork, undertaken in the Coast Ranges during his visiting professorship in 1961, provided much valuable sample material and successions for master's and PhD projects, and also for his personal research in palynology. Obtaining good palynomorph assemblages from the western United States is problematical due to the deep weathering profile typical of arid climates. Due to the warm climates during the Cenozoic, most Californian outcrops have been subjected to prolonged and intense weathering, and this has degraded or destroyed much of the palynomorph content by oxidation. This problem can be overcome by carefully selecting fresh material, sampling very hard lithotypes such as early

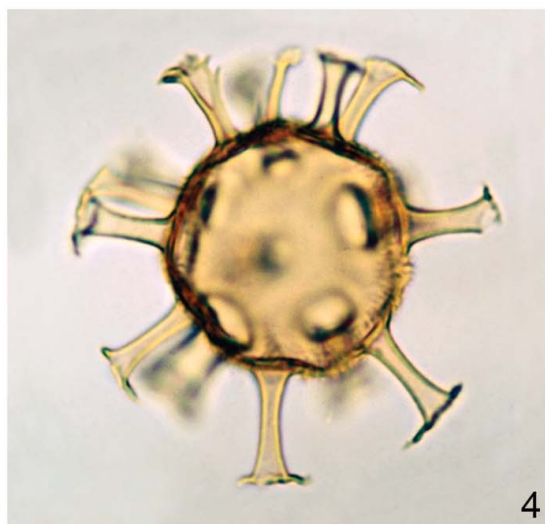
diagenetic limestones and nodules, or exclusively using borehole material. If lithification is intense as in some nodules, and this occurs early in diagenesis, the fossils will have been protected from post-depositional compaction and weathering. Bill found that the Lower Cretaceous limestones and calcareous concretions of northern California, and the phosphatic concretions from the Upper Cretaceous of central California produced especially abundant and well-preserved dinoflagellate cysts. These distinctive lithotypes were therefore targeted in sampling campaigns. John S. Warren based his PhD on Jurassic and Lower Cretaceous limestones and calcareous concretions from the west side of the Sacramento Valley (Warren 1967, 1973; Warren & Habib 1971; Habib & Warren 1973). The Upper Cretaceous phosphatic nodules provided material for the PhDs of Carol A. Chmura and Jeffery A. Stein (Appendix 2; Chmura 1973).

Communication between all the geologists working in the Palo Alto area was good. Bill asked Bob McLaughlin and his colleagues at the United States Geological Survey (USGS) office at Menlo Park, close to the Stanford University campus, to send for

processing any material for which they needed biostratigraphical analyses. This led to a steady flow of samples submitted to Stanford by USGS geologists working in the Californian coastal ranges and northwards into Oregon. The biostratigraphical conclusions provided by Bill were included in publications such as Berkland (1973), Blake & Jones (1974, table 1), Maxwell (1974), Gucwa (1975, table 2) and McLaughlin et al. (1984). Bill used the scanning electron microscope (SEM) at the USGS Menlo Park office, operated by Bob Oscarson. As such, he was one of the first palynologists to use this instrument.

The most important of the USGS material were limestone samples from Mendocino County in the Coastal Belt of the Franciscan Complex, west of the Sacramento Valley in northern California. This terrane, which comprises many accreted blocks of

disparate provenance (Wakabayashi 1992), was originally thought to be extremely sparsely fossiliferous. The Coastal Belt had yielded some tentative indications of Late Cretaceous ages (Bailey et al. 1964). However, Bill and his master's student Sarah Pierce (later Damassa) recovered abundant assemblages of Cretaceous and Eocene dinoflagellate cysts (Evitt & Pierce 1975; Damassa 1979a, 1979b). By contrast, the Franciscan rocks to the east yielded Cretaceous palynomorphs (Evitt & Pierce 1975). The discovery of Eocene rocks in the Franciscan Complex was very surprising at the time, and caused a revision of the standard interpretation of the Northern Coast Ranges of California (Berkland et al. 1972; Blake & Jones 1974). Bill also processed several samples of the Monterey Formation, of Miocene age, from California. This organic-rich unit is rich in calcareous nannofossils, diatoms and



foraminifera, but yielded sparse, poorly preserved marine palynomorphs.

The departmental collections at Stanford University, in particular samples collected for foraminifera by Hubert G. Schenck from Europe and the United States, also produced good samples for Bill's research. Schenck was an eminent micropalaeontologist and stratigrapher (Schenck & Muller 1941), who died shortly after World War II. This collection was curated in shoe boxes, and stored in the attic of the geology building at Stanford. Bill found much excellent material from this collection, including samples from the Lower Eocene London Clay Formation of southern England and material from some early Californian oil wells.

Bill ordered a small plankton net for use in local lakes and ponds, and the nearby coastline. It arrived while he was away from the department, and Susan Davidson took the net to rockpools on the Pacific shore in nearby San Mateo County where she found a very rich assemblage of living marine dinoflagellates. The net was attached to a long pole, and a fishing weight was used to submerge the net. The net was

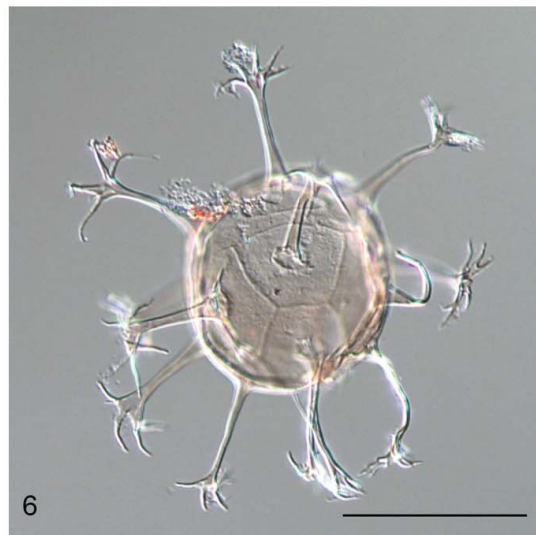
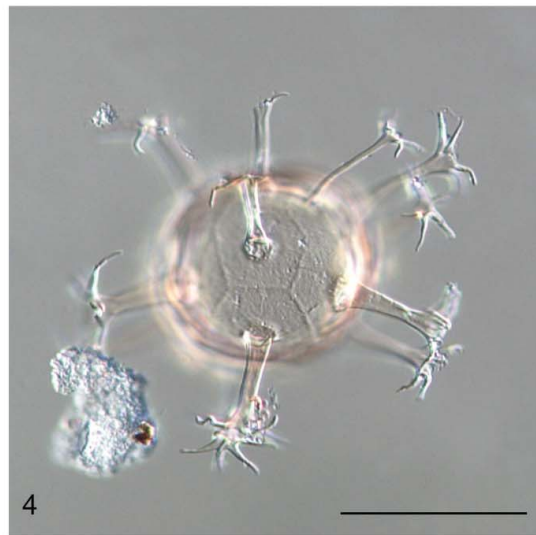
towed through the surface water, and the catch was occasionally washed into a collecting bottle. Most of the catch remained alive for up to a few days, and was eventually preserved by adding a small amount of ethanol. Susan Davidson made microscope slides of the Pacific dinoflagellate material, both raw and some processed using hydrofluoric acid. These were the first living marine dinoflagellate cysts that Bill had ever seen. The material largely included empty cysts with open archaeopyles and isolated cysts with granular protoplasm. Other plankton net material from Drøbak Sound, Oslo Fjord, Norway, provided by Trygve Braarud, yielded an extremely important specimen. This was an organic-walled cyst referred to *Hystrichosphaera* (now *Spiniferites*) inside a partly broken theca of *Gonyaulax digitale* (Plate 11). Of course this specimen unequivocally proved Bill's earlier contention that organic dinoflagellates represent the cyst stage. It exhibited exactly the relationship of cyst and theca hypothesised in Evitt (1961c). This specimen was published in Evitt & Davidson (1964, pl. 1, figs 10, 11). Unfortunately, Bill never found another specimen of a

Plate 8. Four of the 35-mm transparency slides included in the ringbound file of course materials that Bill Evitt provided to participants of the two-week Teaching Conferences on Fossil Dinoflagellates (section 10). These slides accompanied the practical exercises and the specimens for study. These three specimens are all skolochorate forms. All the images are reproduced with the approval of the Evitt family.

Figures 1, 2. *Spiniferites pseudofurcatus*; two specimens in ventral and antapical view, respectively, both at high focus; Calvert Formation, Miocene, Maryland. These were slides 8 and 9. This is a relatively long-ranging species; it has been recorded from the Late Cretaceous (Late Turonian) to the Late Miocene (Tortonian) (Foucher 1976; 1979; Powell 1992). It is most prominent in the Palaeocene to Miocene interval, and the type is from the Late Eocene of Germany (Klumpp 1953). *Spiniferites pseudofurcatus* was emended by Sarjeant (1981, p. 108–109). It has a characteristically ovoidal/subpentagonal cyst body, typically smooth autophragm and low, distally smooth sutural crests which are markedly suppressed in the midventral area. Note the prominent gonol processes which are distally open, hollow, trifurcate and triangular in cross section. The hollow and distally open nature of the processes is unusual for this genus. Some of the processes merge proximally. The first-order distal branches of the processes are variable in morphology; they may be distally blunt, concave, pointed or furcate. In Figure 1, note the wide, sulcal region and the prominent 6'' plate. Figure 2 illustrates the 1'''' plate which is surrounded by the ps, 1p, 3''', 4''', 5'' and 6''' plates (from the top, clockwise). The 1'''' plate exhibits a suturocavate organisation (Riding 1983; Evitt 1985, figs 4.1P–R). In Figure 1 the cyst body is 90 µm in diameter, and the overall dimensions including the processes are 150 µm long by 140 µm wide. The cyst body and the overall specimen (including processes) of Figure 2 are 90 µm and 130 µm in diameter, respectively.

Figure 3. *Homotryblium tenuispinosum*, ventral view, high focus; London Clay Formation, Lower Eocene (Ypresian), southern England. This was slide 12 and Bill termed it *Homotryblium* sp. The specimen was first published in Evitt (1967c, pl. 9, fig. 7) as *Forma AC*. *Homotryblium* is a skolochorate gonyaulacacean genus with distally expanded and open, hollow, plate-centred processes. The archaeopyle is of combination type [A(3A)6P]. This excystment aperture is unique amongst sixiform gonyaulacaceans in that all the apical and precingular plates are involved in a compound archaeopyle. Moreover, plates 2', 3' and 4' are lost as a single piece, and all seven others are dehiscence individually (Evitt 1985, figs 6.4L, 6.10R; Fensome et al. 1993, fig. 113D). The most similar archaeopyle type is in *Mancodinium*, but this genus has a significantly different epicystal tabulation (Morgenroth 1979; Fensome et al. 1993, fig. 70C). This means that, when the archaeopyle is fully operated, there are eight separate opercular pieces. *Homotryblium tenuispinosum* is characterised by its ovoidal cyst body, granulate autophragm and relatively slender, tubiform, distally open plate-centred processes with aculeate to serrate terminations (Davey & Williams 1966, p. 101–102). The combination archaeopyle is forming in this very well-preserved specimen; note the major dehiscence immediately anterior of the cingulum. The ventral tabulation is clearly discernible. The most obvious plates are 1', 4', 1'', 6'', 1c, 6c, 2''', 6''', 1p, 1'''' and as. The latter plate forms the prominent sulcal tab. The cyst body is 63 µm long, and 65 µm wide; the overall diameter, i.e. including the processes, is 105 µm.

Figure 4. *Homotryblium* sp. cf. *H. tenuispinosum*, antapical view, high focus; London Clay Formation, Lower Eocene (Ypresian), southern England. This was slide 13 and Bill termed it *Homotryblium* sp. It is attributed here to *Homotryblium* sp. cf. *H. tenuispinosum* because it has a smooth, and not granulate, autophragm. The 1'''' process is in the centre and is not in sharp focus, the slender sulcal processes are visible at the top of the specimen, and the large equatorial processes are largely from the postcingular series. The diameters of the cyst body and the entire cyst including processes are 50 µm and 90 µm, respectively.



cyst within a theca in this material. However, he later observed cyst-theca relationships in *Protoperidinium* from other Pacific coastal samples, but these were never published. This means, therefore, that Evitt & Davidson (1964) was among the first convincing indications of the true nature of fossil dinoflagellates in terms of the life cycle, i.e. that they represent benthic resting cysts.

David Wall and Barrie Dale were also working on modern dinoflagellate cysts on the east coast of the United States at Woods Hole Oceanographic Institution in Massachusetts at that time. Wall (1965, figs 24–29) illustrated the excystment of a cyst of *Spiniferites bentorii* that had been incubated. The relevance of Evitt & Davidson (1964) was only discussed by David Wall in an addendum (Wall 1965, p. 312–313). It is now clear that David Wall and Barrie Dale made the discovery regarding the cyst-theca relationship at virtually the same time as Bill and Susan Davidson did. The Wall and Dale team established the detailed life cycle of cyst-producing dinoflagellates experimentally by observing the production of cysts inside dinoflagellate thecae, and the incubation and excystment of modern dinoflagellate cysts. David Wall, Barrie Dale and their colleagues continued to extensively research dinoflagellate encystment and excystment using incubation experiments (e.g. Wall & Dale 1966, 1968a, 1969, 1970; Wall et al. 1967; Wall 1971; Dale 1977, 1983; Anderson & Wall 1978). The work of Wall and Dale was briefly reviewed by Head & Harland (2004a, 2004b).

Bill worked with modern plankton in a collaboration with David Wall (Evitt & Wall 1968). This study was chiefly on the thecate species *Peridinium limbatum* from Round Pond, Falmouth, Massachusetts. The locality is close to Woods Hole Oceanographic Institution, where David Wall worked. This contribution was a detailed study of cyst development in *Peridinium limbatum*, and includes the first ever SEM images of dinoflagellates (Plate 12; Evitt & Wall 1968, pl. 1, figs 1–4). Bill also used the plankton net in the freshwater ponds and lakes around Stanford University, including Felt Lake, and discovered several species of *Ceratium* in assemblages containing abundant active thecate individuals and fewer numbers of cysts. The cysts were both isolated and inside the motile stage. He found that the thecae in some of these samples would largely encyst if left unattended for several days. These associations of *Ceratium* were the basis for another major collaboration with David Wall on modern and fossil ceratioid forms (Wall & Evitt 1975).

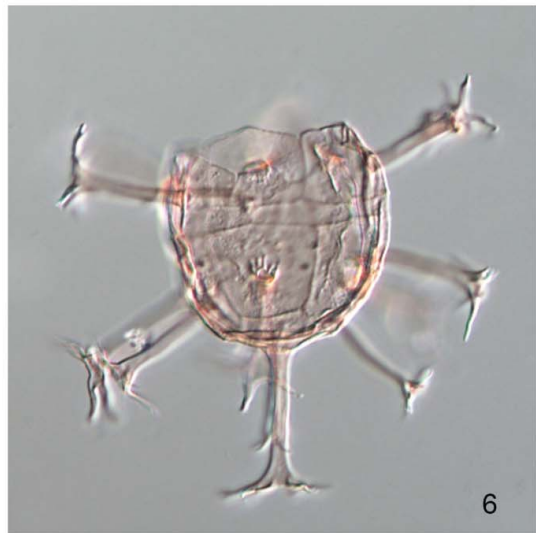
At the same time as he was making great breakthroughs in dinoflagellate research, Bill also added to his teaching repertoire. He developed a survey (i.e. textbook-based) course on vertebrate palaeontology. This was instigated due to the high-profile discovery of a specimen of the large aquatic herbiferous mammal *Palaeoparadoxia* in a trench in Miocene strata which was being dug for the Stanford Linear Accelerator Center (SLAC) about 1.5 km from the main university campus during 1964 (Inuzuka 2005; Domning &

Plate 9. Topotype material of the distinctive Early Cretaceous skolochorate dinoflagellate cyst species *Oligosphaeridium abaculum*. The photomicrographs were all taken using differential interference contrast (DIC). All the specimens are from British Geological Survey (BGS) offshore United Kingdom borehole 77/80B at 78.95 m. Borehole 77/80B was drilled during June 1977, 30 km northeast of Unst, Shetland Islands in the East Shetland Basin, northern North Sea (Davey 1979a). The sample is at the terminal depth in this well and is of a Lower Barremian mudstone within the Cromer Knoll Group (undivided). The palynomorph preparation is BGS registration number CSC 1824. Note the subcircular dorsoventral outline of the cyst body, the prominent hollow, distally open, expanded and furcate plate-centred processes, and the apical archaeopyle. This species is unique in that it exhibits low sutural ridges which define a standard gonyaulacacean tabulation pattern. The formula is 1pr, 4', 6'', 6c, 6''', 1p, 1''', 5s. *Oligosphaeridium abaculum* is a reliable marker for the Late Hauterivian to the earliest Barremian interval (Costa & Davey 1992). In the North Sea, it is common throughout its relatively short range, which spans the latest Hauterivian to earliest Barremian (*Simbirskites marginatus* ammonite biozone to within the *Simbirskites variabilis* ammonite biozone) in the central North Sea according to Duxbury (2001, fig 17). Its biogeographical distribution in the North Sea indicates that *Oligosphaeridium abaculum* was a high-latitude, Boreal species.

Figures 1, 2. British Geological Survey (BGS) specimen number MPK 14563, slide CSC 1824/6, England Finder coordinate J62/4. A loisthocyst in ventral view, high and low focus, respectively. Note the prominent sulcal notch, and the faintly indicated cingulum and sulcus in 1. The cyst body is 49 µm long and 60 µm wide, the overall length and width are both 95 µm, and a typical processes is 27 µm in length. The scale bar in 2 represents 50 µm.

Figures 3, 4. BGS specimen number MPK 14564, slide CSC 1824/3, England Finder coordinate H67. A loisthocyst in antapical view, low and high focus, respectively. The sulcus is uppermost in both photomicrographs. Note the principal archaeopyle suture in figure 3, and the antapical (1''') and surrounding postcingular plates in figure 4. The diameter of the cyst body is 53 µm, the overall diameter is 102 µm and a typical processes is 31 µm long. The scale bar in figure 4 represents 50 µm.

Figures 5, 6. BGS specimen number MPK 14565, slide CSC 1824/6, England Finder coordinate F57/4. A loisthocyst in oblique dorsal view, low and high focus, respectively. Note the prominent sulcal notch in figure 5; the 4' and 6'' plates are especially prominent. The central plate in figure 6 is the middorsal postcingular (4'''); note also the narrow cingulum. The cyst body is 60 µm long and 56 µm wide, the overall length and width are 129 µm and 111 µm, respectively, and a typical processes is 40 µm in length. The scale bar in 6 represents 50 µm.



Barnes 2007; Barnes 2013). This virtually complete skeleton was excavated and reassembled by Adele I. Panofsky. She assembled the *Palaeoparadoxia* bones, and constructed displays for the University of California Berkeley Museum of Paleontology and SLAC. Adele Panofsky taught herself by consulting with experienced vertebrate palaeontologists, having no previous experience in this subject (Panofsky 1998). Bill's graduate seminar classes visited Adele Panofsky and the *Palaeoparadoxia* bones until they were complete and on display at SLAC. The course on vertebrate palaeontology was planned as a one-off delivery by Bill, but it proved so popular that the module was presented another 15 times during the next 20 years. One of us (JL-C) remembers the exquisite chalk drawings Bill spontaneously produced while teaching the class. Incidentally, Bill was asked by the then chair of the department, Ben Page, to investigate the palynology of some samples from this trench. This material produced some poorly preserved Palaeogene dinoflagellate cysts.

Bill, his graduate students and some paid assistants including Susan Davidson and Martha Helenes at Stanford University continued with the fossil

dinoflagellate genus and species card index file he had begun while at the Jersey Production Research Company in Tulsa during the 1950s (Figure 19; subsection 5.4). When Bill ceased active research in 1989, it had around 10,000 entries. Publishing this index, much in the style of Georges Deflandre, had been considered but advances in electronic copying information, especially using CDs, rendered this superfluous. When Bill retired, the dinoflagellate cyst card index and his entire reprint collection were donated to the Center for Excellence in Palynology (CENEX) at Louisiana State University in Baton Rouge, Louisiana. His microscope slide collection was transferred to the University of California Berkeley Museum of Paleontology under the curatorship of Ken Finger, while the rock samples are now housed at Clark Geological Services, under the care of Joyce Lucas-Clark.

Bill's career at Stanford saw many breakthroughs in the earth sciences, including plate tectonics and sequence stratigraphy. Furthermore, Bill witnessed many changes locally and further afield. Federal funding for faculty and student research, largely via grants from the National Science Foundation, diminished significantly during Bill's tenure. His graduate students

Plate 10. A direct comparison of the tabulate chorate dinoflagellate cysts *Oligosphaeridium abaculum* and *Oligosphaeridium complex*; the latter lacks sutural ornamentation. All specimens were photographed using DIC, except figure 5 which was taken using plain transmitted light. *Oligosphaeridium abaculum* was fully described in the caption to Plate 9 (above). *Oligosphaeridium complex* has a subcircular cyst body in outline, and a smooth to occasionally microgranulate cyst wall, and bears cylindrical, distally expanded, branched and open plate-centred processes in all plate series except the cingulars. The processes typically bear four to six simple or occasionally bifurcate branches at the distal end, which is normally aculeate or secate. This distinctive species is most common in the Early Cretaceous; its total range is Early Cretaceous (early Valanginian) to Eocene (early Lutetian) (Costa & Davey 1992; Stover et al. 1996, figs 24A, 32).

Figures 1, 3, 5. *Oligosphaeridium complex*. All of the specimens are from drill cuttings between 4047.74 m and 4044.70 m in central North Sea well 22/1-2A; this interval is within the Lower Cretaceous Cromer Knoll Group.

Figure 1. BGS specimen number MPK 14586, slide MPZ 7780/1, England Finder coordinate O36/4. An isolated operculum; note the 1' plate in the top right. At the base of the four processes, a distinct ring indicates where the periphragm (which forms the processes) has separated from the endophragm. The length (the dorsoventral dimension, excluding the processes) is 38 μm , and the width (the lateral dimension, excluding the processes) is 31 μm . The length of the 1' process at the top right is 31 μm . The scale bar represents 20 μm .

Figure 3. BGS specimen number MPK 14587, slide MPZ 7780/1, England Finder coordinate L33/3. A loisthocyst in dorsal view, high focus. Note the apical archaeopyle, the clear lack of cingular (equatorial) processes and the prominent, straight plate-centred processes. The cyst body is 49 μm long and is 51 μm wide, the overall length and width are 91 μm and 100 μm , respectively, and a typical process is c. 29 μm in length. The scale bar represents 25 μm .

Figure 5. BGS specimen number MPK 14588, slide MPZ 7780/1, England Finder coordinate T46/3. A loisthocyst with (its presumed) operculum, oblique right lateral view, high-median focus. Note the similar height of the processes; it is easy to visualise the distal ends of them adjacent to the inner thecal wall of the parent cell. The cyst body is 62 μm in both length and width, and the overall length and width are both 118 μm ; a typical processes is c. 38 μm in length. The scale bar represents 20 μm .

Figures 2, 4, 6. *Oligosphaeridium abaculum*. All specimens are topotypes from the East Shetland Basin (see the caption to Plate 9).

Figure 2. BGS specimen number MPK 14589, slide CSC 1824/5, England Finder coordinate P54/4. An isolated operculum; note the clear sutural ridges, the single preapical plate and the relatively small 1' plate in the top right. The four circular features at the base of the processes clearly indicate the separation of periphragm and endophragm. The length (the dorsoventral dimension, excluding the processes) is 42 μm , and the width (the lateral dimension, excluding the processes) is 36 μm . The length of the 3' process at the bottom left is 31 μm . The scale bar represents 20 μm .

Figures 4, 6. BGS specimen number MPK 14590, slide CSC 1824/5, England Finder coordinate R65/2. Specimen in ventral view, high and low focus, respectively; note the apical archaeopyle. This superbly preserved specimen clearly demonstrates the gonyaulacacean tabulation and the plate-centred processes. The sulcus is visible in figure 4, as is the middorsal postcingular plate (4'') immediately below the cingulum in 6. The cyst body is 56 μm long and 53 μm wide, the overall length and width are 98 μm and 109 μm , respectively, and a typical processes is 31 μm in length. The scale bar represents 25 μm .

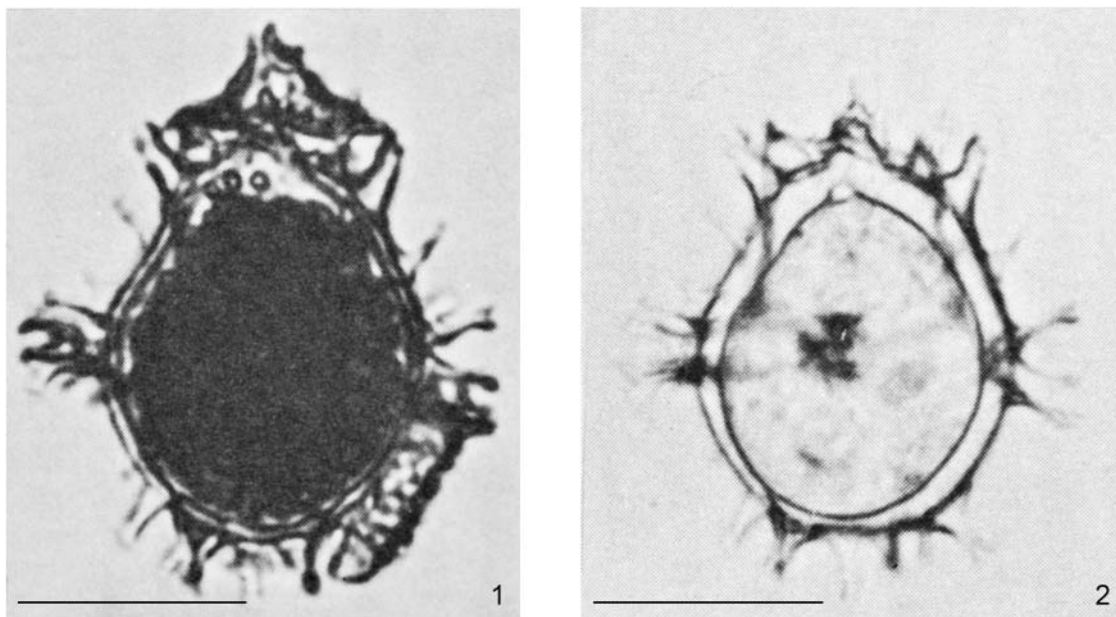


Plate 11. A dinoflagellate cyst produced by a theca of *Gonyaulax digitale*; this cyst is clearly referable to the genus *Spiniferites*. The specimen is from a plankton net sample taken from Drøbak Sound, Oslo Fjord, Norway on 9 September 1950 (Evitt & Davidson 1964, p. 5). Both images are from Evitt & Davidson (1964, pl. 1, figs 10, 11 respectively) and are reproduced with the approval of the Evitt family. These images, originally published by Evitt & Davidson (1964), are among the first illustrations of the relationship of a cyst-producing dinoflagellate theca and its cyst. They confirmed that dinoflagellate cysts are benthic resting bodies, and this is entirely consistent with the cyst-theca relationship first hypothesised by Evitt (1964, pl. 1, figs 15–17).

Figure 1. The spinose cyst of *Gonyaulax digitale* is filled by dark cytoplasm, and some of the disaggregated thecal plates are adherent; note those in the apical region and on the bottom right. The scale bar represents 25 μm .

Figure 2. The same specimen following treatment with sodium hypochlorite solution. This reagent has destroyed the thecal plates and bleached out the protoplasm, making the specimen of *Spiniferites* much easier to study. The scale bar represents 25 μm .

were funded from diverse sources, such as their home governments for the non-United States citizens, the GSA, oil companies, the USGS or directly from Stanford University. In the department, mineralogy/petrology and structural geology increased in strength, and basin analysis and environmental geology were instigated and thrived. The corollary of these trends was a decline in palaeontology and stratigraphy. The Stanford University department remains very strong today, especially in modern technologically driven disciplines. It is larger and significantly more diverse than in Bill's time there. Palaeontology is still taught, but it is not as prominent today as it was in the early 1960s.

Bill was not replaced by a palynologist when he retired in 1988, and his dynasty was, unfortunately, not continued. The principal connection with dinoflagellates at Stanford University in the post-Evitt era was the appointment of J. Michael Moldowan who worked on the chemical fossil record, specifically molecular fossils (biomarkers). Moldowan's work has helped to elucidate the early history of the dinoflagellates (e.g. Moldowan et al. 1996, 2001; Moldowan and Talyzina 1998; Talyzina et al. 2000; Zhang et al. 2000). Significantly, this biogeochemical research has supported Bill's long-held hypothesis that dinoflagellates

can switch on and off the ability to produce preservable fossil remains (subsection 9.4).

Because Bill worked at Stanford University during most of the 1960s, he witnessed many socio-political changes. He commented that the profound student unrest of the late 1960s came to rather conservative Stanford relatively late. However, the tensions that had gripped most campuses in the United States arrived in Palo Alto at the turn of that febrile and precipitous decade. There were building closures, fires, protests and strikes on the campus which undoubtedly affected both research and teaching. Bill recalled that the university authorities had the ornamental cobbles which surrounded the campus gardens replaced with far less dangerous pea gravel.

6.4. Graduate students at Stanford University

Bill supervised 11 PhD students and five master's students at Stanford University (Appendix 2). The PhDs graduated in two principal phases. The first cohort comprised John S. Warren, who graduated in 1967, followed by Neely H. Bostick in 1967, Carol A. Chmura McLeroy in 1970 and Dewey M. McLean in 1971. There then followed a 12-year hiatus until both David

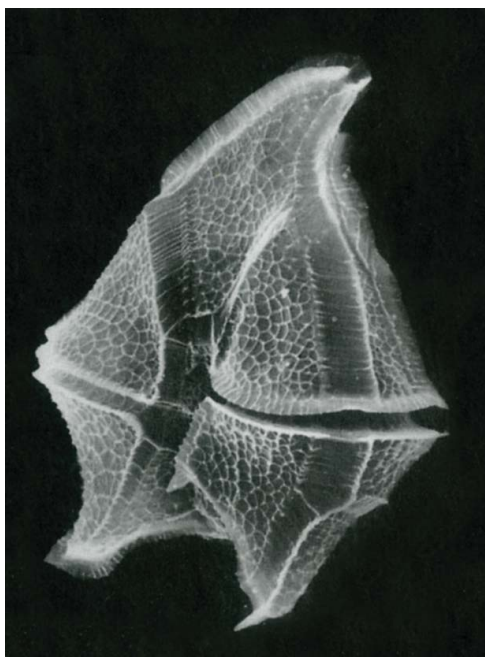


Plate 12. A scanning electron microscope (SEM) image of an entire theca of the modern freshwater dinoflagellate *Peridinium limbatum* in oblique ventral view. Note the subtriangular dorsoventral outline, the three polar horns, the prominent, highly indented cingulum and sulcus, the regularly reticulate thecal wall, and the striate growth bands which separate the original plate areas. The theca is 94 μm long, and has an equatorial width of 68 μm . This specimen of *Peridinium limbatum* from Round Pond, Falmouth, Massachusetts, together with others in Evitt & Wall (1968) are believed to be the first ever SEM images of dinoflagellates to be published. They were taken at the Cambridge Instrument Company, Chicago, at a promotional demonstration of the Stereoscan SEM shortly after this model became available. This image was originally published in Evitt & Wall (1968, pl. 1, figs 2, 3), and by Evitt et al. (1998, pl. 1, fig. 5). It is reproduced with the permission of AASP – The Palynological Society.

K. Goodman and Jeffrey A. Stein graduated in 1983. The other PhD graduates in this second wave were Anthony N. Bint in 1984, Javier Helenes-Escamilla in 1984, Joyce E. Lucas-Clark in 1986, Nairn R. Albert in 1988 and David I. Wharton in 1988. Several of the dissertations produced by these students are in the public domain (e.g. Albert 1988; Wharton 1988a). Fred E. May was not a graduate student of Bill. Although he frequently communicated with Bill about his research, Fred May was never a student at Stanford University. He was a student of Dewey M. McLean at Virginia Polytechnic Institute and State University, Blacksburg, Virginia, and hence was a 'graduate student once removed' of Bill's.

Only two of these PhD projects, those of Neely H. Bostick and Carol A. Chmura McLeroy, were not on dinoflagellate cysts. The former was on the thermal

alteration of phytoclasts as a proxy for metamorphism (Bostick 1971, 1974), and the latter concerned Late Cretaceous angiosperm pollen from the western San Joaquin Valley of California (Chmura 1973). The nine other Stanford PhD dissertations were all on dinoflagellate cysts. They comprise three on the Late Jurassic and Cretaceous of California, two on the Middle Jurassic to Early Cretaceous of Alaska, one on the Mesozoic and Cenozoic of Mexico, one on the Cretaceous of the Western Interior of the United States and two on the Late Cretaceous to Eocene of Maryland and Virginia (Appendix 2). Most of these studies have had at least some of their findings published (McLean 1971, 1972, 1973a, 1973b, 1974, 1976; Warren & Habib 1971; Habib & Warren 1973; Warren 1973; Goodman 1979, 1984; Bint 1983, 1986; Goodman & Ford 1983; Helenes 1983, 1984, 1986, 2000; Lucas-Clark 1984, 1986, 1987, 2007; Goodman & Witmer 1985; Albert et al. 1986; Jan du Chêne et al. 1986a; Ford & Goodman 1987; Wharton 1988b; Albert 1990; Helenes & Lucas-Clark 1997; Lucas-Clark & Helenes 2000). Even a casual glance at the previous list of publications will make clear that Bill allowed his graduate students sole authorship of their work, despite having himself made an enormous material contribution to these. If Bill was a co-author, he had assuredly made a major contribution to both the research and the writing effort.

Master's students at Stanford included Sarah T. Pierce and John P. Kokinos. Both of them clearly enjoyed the research environment, because they went on to undertake PhDs at the University of California, Los Angeles, and Woods Hole Oceanographic Institution, Massachusetts, respectively (Damassa 1979c; Kokinos 1994). In addition to these graduate students, the South Korean palynologist Hyesu Yun visited Stanford University to undertake a postdoctoral research project during the summer of 1980.

Bill took his supervisory duties very seriously and gave each graduate student an individual two-week induction course during which they learned his methods of processing, individual dinoflagellate picking and manipulation, and microscopy (Appendix 5). In particular, he really enjoyed supervising his relatively large and diverse cohort of research students during the 1980s. This was when he supervised Nairn Albert, Tony Bint, Javier Helenes, John Kokinos, Joyce Lucas-Clark and David Wharton. This large number of Stanford palynologists formed a very congenial and sociable group. They all shared a single large, open-plan office, and got along famously. All of them enjoyed the regular weekly afternoon seminar at Bill and Gisela's house on the campus, where dissertation progress was reviewed and wider palynological topics were discussed.



Figure 19. Martha Helenes working on updates to the alphabetical card index of dinoflagellate cyst genera and species in the palynology laboratory at Stanford University in 1981. The index was begun in the 1950s, while Bill Evitt was at Carter/Jersey in Tulsa, and continued at Stanford. Photograph by Joyce Lucas-Clark.

7. The scientific legacy of Bill Evitt: trilobites

Bill Evitt published 64 scientific contributions (Appendix 3). This and the following two sections are syntheses of Bill's scientific legacy on his three principal research interests, i.e. trilobites, palaeontological techniques and marine palynomorphs.

Bill undertook research on the siliceous trilobite faunas from the Middle Ordovician limestone successions of Virginia for his PhD at Johns Hopkins University between 1942 and 1950 (sections 3, 4). He was not the first to work on these faunas. G. Arthur Cooper discovered silicified trilobites from the Middle Ordovician limestones near Strasburg around 1935, and these were mentioned in a major paper on the Ordovician geology and stratigraphy of the Shenandoah Valley of Virginia (Cooper & Cooper 1946). Furthermore, Harry Whittington had undertaken research on these silicified trilobites, beginning at around the time Bill began his PhD (Whittington 1941).

The principal succession that Bill studied was at Tumbling Run near the Shenandoah River, in

Shenandoah County, Virginia. He developed methodologies for the extraction and study of this extremely well-preserved material (subsections 3.2, 3.4). Bill's small trilobite specimens are typically extremely fragile. Initially, they were picked from the post-hydrochloric acid residue to mount in cavity slides, or to mount for photography using a waxed needle or a moistened paintbrush. Unfortunately, these methods, which are used in calcareous micropalaeontology, resulted in significant breakage of specimens. In particular, the moistened paintbrush was ineffective because the silicified trilobite specimens are porous and absorb the water on the tip of the paintbrush. Additionally, if there was too much moisture on the brush, the surface tension could physically break the trilobite specimens. Bill achieved a significantly improved performance by using an eyelash manipulator; this is a small wooden dowel with an eyelash glued to the tip. Working with a dissecting microscope, the micron-scale distal part of the eyelash could, with practice, be used to touch and move the small trilobite specimens. Bill went on to use

the eyelash manipulator to pick and manipulate dinoflagellate cyst specimens which, of course, are an order of magnitude smaller than trilobites (Appendix 5).

Another breakthrough was the discovery by Gisela Evitt of the significance of juvenile trilobites in the ontogeny of the assemblages (subsection 4.4). The moulting histories of trilobites are also key to their taxonomy. Bill and Gisela's work also provided detailed descriptions of trilobite exoskeleton morphology. This was critical to our understanding of how the hard trilobite shell behaved during their physically active lives. The silicified trilobite faunas from the Middle Ordovician of Virginia are both abundant and superbly preserved. This made possible the accurate determinations of different body parts from the various growth stages of individual species. Hence, this work helped to identify these entities which were not as abundant and well preserved in the far more widespread non-silicified material.

Bill continued work on this topic until he left the University of Rochester for the Carter Oil Company in 1956. He authored or co-authored 10 papers on trilobites, which are summarised in Table 2 and briefly synthesised in Appendix 3. This work was almost exclusively focussed on Middle Ordovician silicified material from Virginia. However, Evitt & Whittington (1953) included some calcareous trilobite specimens from near Cincinnati, Ohio. His

work extended over nine trilobite families (Table 2). The 10 papers on trilobites were published during two phases of Bill's career. The first interval, between 1951 and 1961, was based on the original research done at Johns Hopkins and Rochester universities (sections 3, 4). The second phase, between 1977 and 1997, was work begun by Bill prior to 1956 and finished off by Ronald P. Tripp (Table 2). A paper on techniques for the study of trilobites (Evitt 1951a) is included in section 8 below.

The 10 trilobite papers are each restricted to one, two or three trilobite families each (Table 2), and discussed detailed functional morphology and ontogeny, with some taxonomy. Bill and his co-authors established two new subfamilies, five new genera, 28 new species, two new subspecies and one new variety of trilobites (Table 2). These papers include some of the most painstakingly detailed morphological research ever undertaken on well-preserved invertebrate fossils (Figure 20). It is clear that if these papers were all that Bill had ever done in his career, he would still have been considered to have been a truly great palaeontologist. Bill's trilobite research was intensely focused on morphology; he did not particularly consider aspects such as biostratigraphy or diversity. It is little wonder that Bill went on to become the leading expert on the morphology of dinoflagellate cysts, with such a strong

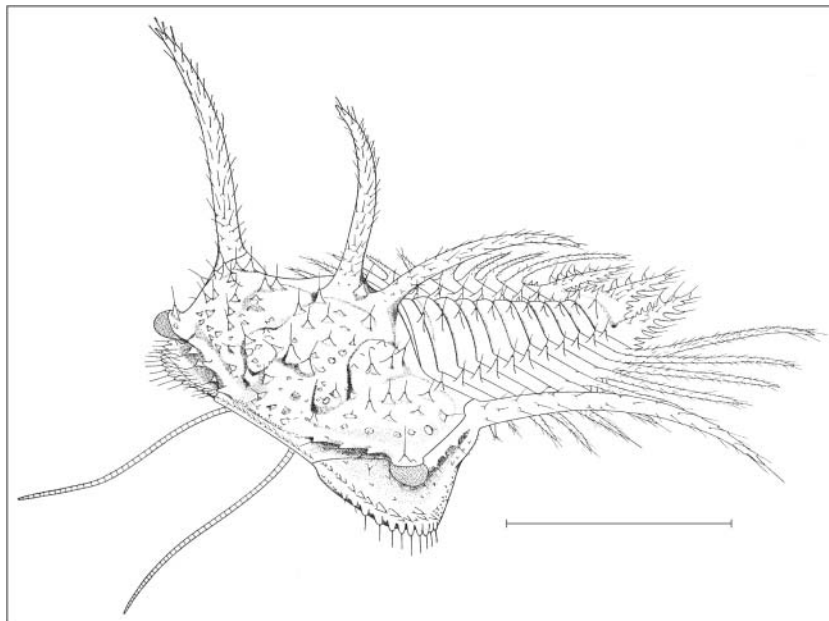


Figure 20. A line drawing of the silicified Middle Ordovician trilobite *Ceratocephala laciniata* from the Middle Ordovician Bote-tourt Member (Edinburg Formation) of Strasburg Junction, Shenandoah County, Virginia. This is a reconstruction in oblique exterior view of this fast-moving, low-level epifaunal carnivorous trilobite species. The reconstruction assumes that the thorax comprises 10 segments, that the openings in the spines and tubercles on the outer surface of the exoskeleton were occupied by sensory hairs and that typical trilobite antennules were present. The image has been modified from the frontispiece of Whittington & Evitt (1954, fig. 1). The scale bar represents 5 mm.

background in trilobite form and ontogeny.

Bill collaborated with Harry B. Whittington from 1946 to 1956. Whittington, who had a long career at the University of Cambridge, was at Harvard University at that time (Bruton 2011; Fortey 2012). Evitt and Whittington first met on a field trip in 1946 with G. Arthur Cooper to the Shenandoah Valley in Virginia, when Bill was a graduate student at Johns Hopkins University. Bill and Harry Whittington met frequently, particularly during Bill's time at Rochester University, and they published together twice. The first joint paper was on the common Middle Ordovician trilobite genus *Flexicalymene*, and the second was a major monograph on overlapping aspects of their work in Virginia (Evitt & Whittington 1953 and Whittington & Evitt 1954, respectively). Despite Bill's move away from trilobite research in 1956, he stayed in close contact with Whittington until Harry moved back to the United Kingdom in 1966. Because of this collaboration, the Evitt and Whittington families became firm friends for life.

When Bill left the University of Rochester in 1956 (subsection 4.6), his trilobite research came to an abrupt halt. Despite this, he had a collection of prepared, but as yet unstudied, siliceous material and a preliminary manuscript on the Family Encrinuridae. He also had several other manuscripts on trilobites in the planning and/or preliminary stages. His final trilobite paper of this era was Evitt (1961a). This was a study of early ontogeny in the Family Asaphidae, and was completed in his spare time when he joined the Carter Oil Company. Coincidentally, this paper and one of Bill's first papers on dinoflagellates (Evitt 1961d) were published next to each other in the journal!

Upon leaving Rochester University, Bill concentrated fully on palynology at the Carter Oil Company from 1956 onwards. Consequently, he did not have the time or resources to complete his trilobite research. In order for work on the trilobites to continue after 1956, Bill turned over all of his trilobite materials to Ronald Pearson Tripp (1914–2001). Tripp was an eminent, yet amateur, palaeontologist introduced to Bill by Harry Whittington in the early 1970s (Gass 2002). Tripp had worked in industry and had, over many years, become an expert on Silurian and Ordovician trilobites, especially the Family Encrinuridae (e.g. Tripp 1965, 1967; Tripp et al. 1977). Despite the fact that he was never a professional geologist, Tripp became immersed in the subject. For example, he was an associate researcher at the Natural History Museum in London (which he used as his professional address) and a Fellow of the Royal Society of Edinburgh, and served as Treasurer of the Palaeontological Association. When Ronald retired, he was able to devote much of his time to his research. Tripp travelled to Stanford University in the

early 1970s to collect all of Bill's trilobite materials, i.e. notes, photographs, preliminary manuscripts and specimens. It was mutually agreed that Ronald had full freedom to develop Bill's trilobite research as he saw fit and to no specified deadlines. Ronald and Bill produced five papers (Evitt & Tripp 1977; Tripp & Evitt 1981, 1983, 1986; Tripp et al. 1997). All of these contributions were principally produced by Tripp, but the latter modestly insisted that Bill should be the senior author on the first paper they completed. Bill, equally unassumingly, was willing to allow Tripp to be sole author of all of these works and take full credit for the work (personal communication, Bill Evitt to JL-C), but Tripp steadfastly refused to leave Bill out. The first of these collaborations was Bill's partially completed manuscript of a monograph on the Family Encrinuridae (Evitt & Tripp 1977). This was the project that was closest to completion, and included some of Gisela Evitt's most important contributions. Tripp & Evitt (1981, 1983, 1986) and Tripp et al. (1997) included the vast majority of Bill's remaining trilobite research. Hence Tripp salvaged much important trilobite work of Bill's which would otherwise never have been completed and published.

8. The scientific legacy of Bill Evitt: palaeontological techniques

Throughout Bill Evitt's career he was extremely interested in techniques used in palaeontology, and published six articles on this topic (Table 3). These papers are summarised in Appendix 3, and a comprehensive description of the techniques used in the palynology laboratory at Stanford University is given as Appendix 5.

Bill always believed, entirely correctly, that the techniques used to extract, prepare, manipulate and image fossils are fundamental to all research in palaeontology irrespective of the age, biological affinity, composition and size of the materials concerned. He always felt that palaeontologists should constantly strive to find better ways to study fossils and freely share these ideas with the community. The first two of these contributions were on macropalaeontology (Table 3). Evitt (1949) described the use of stereophotography in palaeontology. This technique was first used in terrain analysis using aerial photographs, but stereophotography works most effectively on small objects such as uncrushed fossils. Bill found it ideal for illustrating his silicified Middle Ordovician trilobites (sections 3, 4, 7). Evitt (1951a) also described techniques used in trilobite research. A triaxial stage was used for specimen orientation in any direction. Bill also developed tweezers modified with thin strips of aluminium foil attached to each tip for manipulating his small and delicate trilobites, and found that a

Table 3. A tabulated synopsis of the six research papers on procedures and techniques in palaeontology authored by Bill Evitt and his co-workers. Funkhouser & Evitt (1959) and Evitt (1965, 1984) are on palynological techniques. The numbers of the papers are the ones used in Appendix 3. The two most important papers are indicated with an asterisk. Note that Evitt (1984) is also listed in Table 4.

No.	Author(s)	Year	Subject	Fossil group(s)	Comments
2	Evitt	1949	Stereophotography	Various	A brief review of stereophotography in palaeontology
3	Evitt	1951a	Various	Trilobites	Cleaning, manipulation, picking and photography of trilobites
*8	Funkhouser & Evitt	1959	Preparation	Palynomorphs	Oxidation, density separation and palynomorph slide production
13	Schaetti et al.	1961	Industrial palaeontology	Various	Geological procedures used in exploration for hydrocarbons
21	Evitt	1965	Sectioning	Palynomorphs	Description of a sectioning technique for fossil palynomorphs
*56	Evitt	1984	Various	Dinoflagellates	Comprehensive descriptions of various techniques for dinoflagellates

solution of potassium dichromate in concentrated nitric or sulphuric acid would remove tenacious fibrous organic material from his post-hydrochloric acid residues.

The next four articles all pertained to micropalaeontology and palynology (Table 3). The first of these, Funkhouser & Evitt (1959), described three elements of palynomorph preparation procedures used at the Jersey Production Research Company in Tulsa. In order to remove extraneous organic matter, the palynomorph residues were treated with either Schulze's Solution or a saturated solution of chromium trioxide and concentrated nitric acid. Four procedures were outlined to separate palynomorphs from the resistant mineral grains. These are ultrasonic treatment, centrifuging in water, density separation using zinc chloride solution and 'swirling' in a watch glass. Palynomorph slides were made using glycerin jelly or polyvinyl alcohol solution as mounting media on the coverslips, and fixed to glass slides with Canada Balsam. This paper was extremely influential; it was one of the first detailed accounts of pre-Quaternary palynomorph extraction and concentration (Riding & Kyffin-Hughes 2004).

Bill Evitt and his mentor at Jersey Production Research, Bill Hoffmeister, contributed text on industrial palaeontology to a review article on geological procedures used in exploration for hydrocarbons (Schaetti et al. 1961). Evitt (1965) described a straightforward method for producing serial sections of fossil palynomorphs. The specimens are embedded in a ball of wax which is placed in a wax block. The sections can then be made using a microtome and mounted on slides. The last of Bill's articles on palaeontological techniques was Evitt (1984), which described techniques for both fossil and modern

dinoflagellates. The preparation procedures for pre-Quaternary and modern dinoflagellate cysts were summarised (Evitt 1984, p. 11–12). Several specialised techniques were then described (Evitt 1984, p. 12–18). These included the production and use of the rubber-stoppered plastic tubing centrifuged in a water-filled centrifuge tube (called a Bostick tube), the glass micropipette and the eyelash manipulator. The latter two are used to pick up, clean and manipulate individual specimens. This was the first comprehensive description of Bill's unique methods of picking and orienting single dinoflagellates. However, he went on to document other specialist techniques in Evitt et al. (1998).

Because of his insistence on working only on superbly preserved material, Bill was forever experimenting with new methods or improving his existing techniques. He loved this process, and would discuss procedures extremely enthusiastically. Bill had an enormous fund of anecdotes on this topic. An example of this was an experiment he once did on flakes of flint. Bill had long admired the work of Georges Deflandre, who described fossil dinoflagellates from thin, translucent flakes of Upper Cretaceous flint from France (e.g. Deflandre 1935, 1936a, 1937). He thought it would be a good idea to macerate some French flints to extract these dinoflagellate cyst assemblages. To his enormous surprise, he found the residues to be entirely barren of palynomorphs. To test this, Bill then placed a small chip of flint with a clearly observable dinoflagellate cyst embedded in it into a shallow vessel under a stereomicroscope. Bill then carefully added some very dilute hydrofluoric acid, and watched as the acid slowly dissolved the flint. As the acid etched the rock, to Bill's absolute astonishment, the dinoflagellate cyst disappeared! Therefore these specimens were simply very

well preserved moulds with a thin brown/black coating of organic residue which simply disintegrated upon etching.

9. The scientific legacy of Bill Evitt: acritarchs and dinoflagellate cysts

9.1. Introduction

Of all his many and varied scientific endeavours, it is for his groundbreaking and unique research into Mesozoic and Cenozoic marine palynomorphs that Bill Evitt will always be remembered. He published 48 papers on aquatic palynomorphs, dominantly dinoflagellate cysts (Table 4). Bill described, or jointly described, 23 new genera and 10 new species of acritarchs and dinoflagellate cysts (Table 4). In this section, Bill's work on acritarchs and dinoflagellate cysts is reviewed. There are also subsections on the selectivity of the fossil dinoflagellate cyst record, and on his two major textbooks, Stover & Evitt (1978) and Evitt (1985).

9.2. Acritarchs

One of Bill Evitt's finest achievements was the resolution of the question of the hystrichospheres (Evitt 1961c, 1963a, p. 159–160). As explained in subsection 5.5.2, prior to the early 1960s, all spinose marine palynomorphs were assigned to this informal group, which was championed by Eisenack (1938b, 1963a, 1963b, 1964). Bill elegantly demonstrated that the Mesozoic to Cenozoic hystrichospheres with a distinct archaeopyle and plate-centred processes were of dinoflagellate affinity (e.g. Evitt 1961c). Hystrichospheres that could not be confidently assigned to the dinoflagellates, and are hence of unknown affinity, were termed acritarchs. The classification of these palynomorphs as hystrichospheres could not be maintained because genera such as *Hystrichosphaera* (now *Spiniferites*) and *Hystrichosphaeridium* clearly are dinoflagellate cysts (Plates 7, 8). Consequently, if the *status quo* had prevailed, there would inevitably have been endless confusion over the affinity of the pre-Mesozoic hystrichospheres. Hence, a new name was urgently needed. Despite this, at the outset, the introduction of the acritarchs as a concept was somewhat controversial, largely due to strenuous opposition by Alfred Eisenack (subsection 5.5.2; Sarjeant 1998, p. 4).

Acritarchs were defined thus: 'Small microfossils of unknown and probably varied biological affinities consisting of a central cavity enclosed by a wall of single or multiple layers and of chiefly organic composition; symmetry, shape, structure and ornamentation varied; central cavity closed or communicating with the

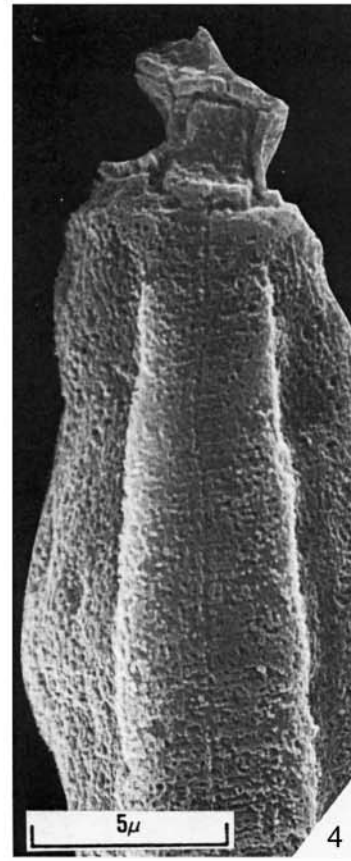
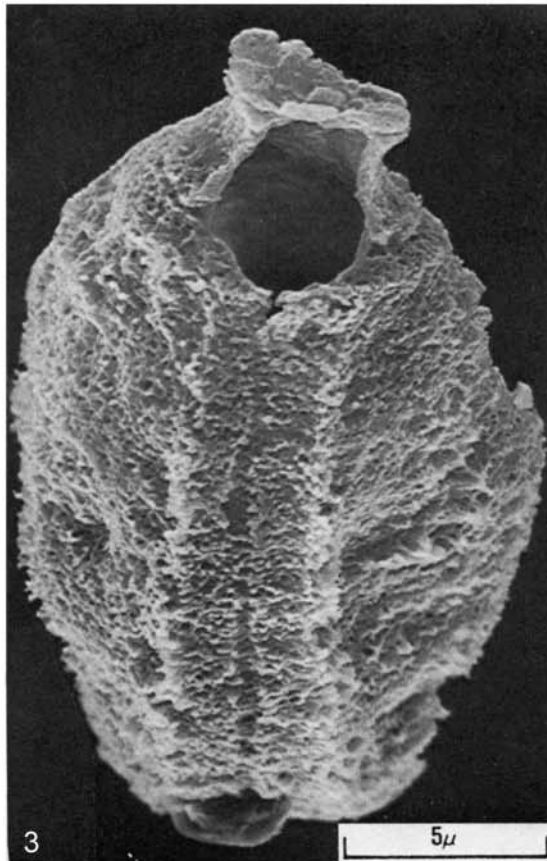
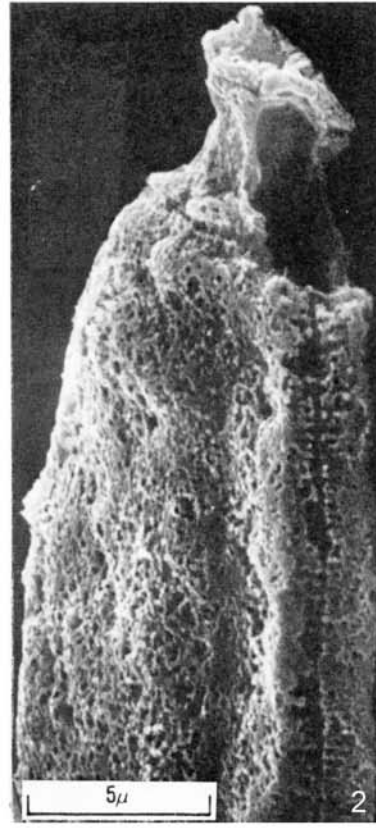
exterior by varied means, for example: pores, a slit-like or irregular rupture, a circular opening (the pylome)' (Evitt 1963b, p. 300). A more succinct definition would be 'A single-celled, organic-walled microfossil of unknown affinity' (Fensome et al. 1993, p. 249). All 10 published definitions of the acritarchs were compiled by Williams et al. (2000, p. 3–4).

The acritarchs were therefore formally established in Evitt (1963b, p. 300–302; see Appendix 3). As outlined above they represent a highly variable group of dominantly marine forms of unknown affinities, and are probably polyphyletic. They originated during the late Precambrian, but are largely Palaeozoic. During the Early and Middle Palaeozoic, marine phytoplankton largely comprised acritarchs (Fensome et al. 1990; Falkowski et al. 2004). There is now a significant literature on the acritarchs, which are important stratigraphical markers in the Early Palaeozoic (e.g. Downie 1984; Martin 1993; Colbath & Grenfell 1995; Strother 1996). The majority of Late Precambrian and Palaeozoic acritarchs are considered to represent the cysts of unicellular planktonic organisms, analogous to the cysts of modern dinoflagellates, but probably having affinities with the green algae (Tappan 1980; Servais et al. 1997; Martin et al. 2008; Traverse 2008; Moczyłowska et al. 2011). It is also possible that some Early Palaeozoic acritarchs represent microalgal motile stages (Moczyłowska 2010). The group is still widely acknowledged to be polyphyletic (e.g. Fensome et al. 1990, p. 3).

The account of the acritarchs in Evitt (1963b, p. 300–302) was rather brief. Downie et al. (1963, p. 7) expanded the definition to specify that acritarchs were 'unicellular or apparently unicellular', and added several descriptors of the shapes and ornamentation of typical acritarchs. These authors also presented a formal taxonomy, defined 13 subgroups and stated which existing genera should be attributed to the Acritarcha (Appendix 3). Following Downie et al. (1963), Bill did not work extensively on the acritarchs; his palynological interests were always firmly rooted in the Mesozoic and Cenozoic. One of Bill's few forays into pre-Mesozoic palynology was his work on the Early Silurian Maplewood Shale Formation of western New York State, which he began while working at the Carter Oil Company (subsection 5.4). Much later, this led to his only paper solely on acritarchs. This was Deunff & Evitt (1968), in which three species of the acritarch genus *Tunisphaeridium* were erected (Appendix 3; Table 4). The only other contribution Bill made on acritarchs was an extensive synthesis of the group in a review paper which was largely on dinoflagellate cysts (Evitt 1969, p. 463–468; see Appendix 3).

Table 4. A tabulated synopsis of the 48 research papers and books on aquatic palynomorphs authored by Bill Evitt and his co-workers. The numbers of the publications are the ones used in Appendix 3. The 16 most important contributions are indicated with an asterisk. An ellipsis (...) in the three columns indicating new taxa means that none of that respective rank were erected. Note that Evitt (1984) is also listed in Table 3.

No.	Author(s)	Year	Geography	Age	No. of new genera	No. of new species	Comments
10	Evitt	1961b	Denmark and USA	Jurassic	...	1	A review of the genus <i>Nannoceratopsis</i>
*11	Evitt	1961c	Various	Silurian to Palaeogene	...	...	The interpretation of dinoflagellate cysts
12	Evitt	1961d	Denmark	Early Jurassic	1	1	Description of the species <i>Dapcodinium priscum</i>
14	Evitt	1962a	Denmark and Germany	Early and Middle Jurassic	...	...	The taxonomy of the genus <i>Nannoceratopsis</i>
*15	Evitt	1963a	N/A	N/A	1	...	Affinities, morphology and taxonomy
*16	Evitt	1963b	N/A	N/A	...	...	Acritarchs and taxonomy
17	Evitt	1963c	California and Pakistan	Cretaceous	...	...	The algal genus <i>Pediastrum</i>
*18	Downie et al.	1963	N/A	N/A	...	...	The classification of the acritarchs
19	Evitt	1964	N/A	N/A	...	...	A review of the utility of dinoflagellate cysts
*20	Evitt & Davidson	1964	California and Norway	Modern	...	...	Cyst-theca relationships in dinoflagellates
22	Evitt	1967a	N/A	N/A	...	...	A review of five dinoflagellate cyst catalogues
23	Evitt	1967b	USA	Late Cretaceous	...	...	Fossil <i>Gymnodinium</i> (<i>Dinogymnium</i>)
*24	Evitt	1967c	N/A	N/A	...	...	The archaeopyle
25	Evitt et al.	1967	Various	N/A	...	...	The dinoflagellate cyst genus <i>Dinogymnium</i>
26	Evitt	1968	France and USA	Cretaceous	1	1	The acritarch species <i>Scuticobolus lapidaris</i>
27	Deunff & Evitt	1968	Tunisia and USA	Silurian and Devonian	...	3 (ac.)	The acritarch genus <i>Tunisphaeridium</i>
*28	Evitt & Wall	1968	USA	Modern	1 (ac.)	...	The dinoflagellate species <i>Peridinium limbatum</i>
29	Evitt	1969	N/A	N/A	...	...	A general review of aquatic palynomorphs
*30	Evitt	1970a	N/A	N/A	...	...	A review of research on dinoflagellates
31	Evitt	1970b	Alaska	Eocene	...	...	The biostratigraphy of the Andrew Lake Formation
32	Evitt	1973a	Bering Sea	Eocene	...	...	The biostratigraphy of DSDP Leg 19, Site 183
33	Evitt	1973b	Texas	Cretaceous to Palaeogene	...	...	Cretaceous/Palaeogene transition palynofloras
34	Evitt	1974a	Vermont	Miocene	...	...	The dino. cyst species <i>Saeptodinium hansonianum</i>
35	Evitt	1974b	N/A	Jurassic	...	...	The genus <i>Nannoceratopsis</i> and foraminiferal affinities
36	Evitt	1974a	N/A	N/A	...	...	Memorial to Georges Deflandre
37	Evitt	1975b	Arctic Canada and USA	Cretaceous to Modern	...	...	The dino. cyst species <i>Palaeoperidinium? eurypylum</i>
38	Evitt	1975c	N/A	N/A	...	...	Book review of Sarjeant (1974)
*39	Evitt (editor)	1975d	N/A	N/A	...	...	Proceedings of a forum on dinoflagellates
40	Evitt	1975e	N/A	N/A	...	...	Introduction to the forum on dinoflagellates
41	Evitt & Pierce	1975	California	Palaeogene	...	...	The biostratigraphy of the Franciscan complex
*42	Wall & Evitt	1975	Europe, Pakistan and USA	Cretaceous and Modern	...	...	The dinoflagellate genus <i>Ceratium</i> and its relatives
43	Evitt	1977	N/A	N/A	...	...	Award nomination for Bill Hoffmeister
45	Evitt et al.	1977	N/A	N/A	...	...	Dinoflagellate cyst terminology
46	Evitt	1978	N/A	N/A	...	...	Descriptive terminology in peritimid dino. cysts
*47	Stover & Evitt	1978	N/A	N/A	17	3	A synthesis of dinoflagellate cyst genera
48	Evitt et al.	1979	N/A	N/A	...	...	The Penrose meeting of 1978
49	Evitt	1980	N/A	N/A	...	...	Memorial to Bill Hoffmeister
*50	Piel & Evitt	1980a	England	Middle Jurassic	...	...	The dinoflagellate cyst genus <i>Nannoceratopsis</i>
*51	Evitt	1981a	N/A	N/A	...	...	The dinoflagellate fossil record
52	Goodman & Evitt	1981	California	Cretaceous	1	...	The dinoflagellate cyst species <i>Angustidinium acribes</i>
54	Frederiksen et al.	1982	N/A	N/A	...	...	Panel discussion on palynology
*56	Evitt	1984	N/A	N/A	...	...	Techniques for studying dinoflagellates
*57	Evitt	1985	N/A	N/A	...	...	The morphology of dinoflagellate cysts
58	Evitt et al.	1985	Switzerland	Modern	...	...	The cysts of the species <i>Gonyaulax apiculata</i>
60	Albert et al.	1986	Alaska and California	Jurassic and Early Cretaceous	1	1	Description of the species <i>Lacrymodinium warrenii</i>
61	Sliter et al.	1986	California	Eocene	...	...	The biostratigraphy of the Franciscan complex
*63	Evitt et al.	1998	Various	Cretaceous to Modern	...	...	The dinoflagellate cyst genus <i>Palaeoperidinium</i>
64	Evitt	2001	Kaliningrad Oblast	Eocene	...	...	Translation of Eisenack (1938a)



9.3. *Dinoflagellate cysts*

The majority of Bill Evitt's scientific efforts during his long and distinguished career were spent undertaking research on the dinoflagellates, and especially their cysts. This and the following three subsections seek to document the massive impact Bill had (and continues to have) on the world of dinoflagellate research.

Bill Evitt made his biggest career move in the late summer of 1956 when he moved from the University of Rochester, where he researched trilobites, to the Carter Oil Company in Tulsa where he was to study marine palynomorphs (sections 4, 5). His line manager at Carter Oil, Bill Hoffmeister, presented Bill Evitt with a magnificent collection of prepared material from throughout the Phanerozoic which was rich in fossil dinoflagellates and hystrichospheres. At this time, there were very few publications on these palynomorph groups, so Bill Evitt had virtually a blank canvas to work on (section 5). He took full advantage of this excellent position to use his acute observational skills on a wide variety of fossil dinoflagellates and hystrichospheres. The first breakthrough by Bill Evitt at Tulsa was in the late 1950s with the realisation that certain well-preserved hystrichospheres have definite dinoflagellate affinity, based on an archaeopyle which corresponds to one or more plates and plate-centred processes (Figure 11; Plates 7–11; Evitt 1963a, fig. 3). Bill Evitt's research on dinoflagellate cysts is well documented elsewhere (sections 5, 6, 10, 11; Appendix 3; Table 4), so a detailed analysis of this is not repeated here. This short section, by contrast, aims to summarise Bill Evitt's massive contribution to our knowledge of Mesozoic–Cenozoic sporopollenin dinoflagellate cysts. Bill Evitt himself felt that his four most impactful publications were (Evitt 1961c), Evitt & Davidson (1964), Evitt (1967c) and Evitt et al. (1998) (see Leffingwell & Damassa 2004).

Bill Hoffmeister encouraged his staff to publish, and Bill Evitt issued three publications on dinoflagellate cysts during his six-year industrial sojourn in Tulsa

(Evitt 1961b, 1961c, 1961d). By far the most significant of these was Evitt (1961c), entitled *Observations on the morphology of fossil dinoflagellates*. This paper was the first indication that the dinoflagellate fossil record is mostly represented by the resting cyst stage, and that dinoflagellate cysts reflect the tabulation of the parent theca. However, Evitt (1961c) stated that some (largely proximate) fossil dinoflagellates were thecae due to their strong resemblance to the motile stages of certain modern forms. These are now known to be dinoflagellate cysts. The other key elements of this work were (i) many hystrichospheres were recognised as being dinoflagellates, based largely on analysis of *Hystrichosphaeridium* and *Spiniferites* (as *Hystrichosphaera*), and (ii) the archaeopyle was first defined. Evitt (1961c) recognised that the excystment aperture of dinoflagellate cysts is widespread, and that the operculum is comprised of one or more reflected plates. These extremely perceptive observations were superbly illustrated (Evitt 1961c, plates 1–9), and were made at a time when the life cycle of dinoflagellate cysts was not well understood. Given the profound nature of these discoveries, it could be argued that this, only the second of Bill's 48 publications on marine palynology, was his finest hour. Bill himself considered that his key breakthrough was Evitt (1961c), and that his subsequent career was simply 'filling in the details' (Leffingwell & Damassa 2004). It certainly was a major watershed in the history of study of the dinoflagellate fossil record.

Two years later, just after Bill had left Carter Oil/Jersey Production Research for Stanford University, he published two short works of very high significance. The main achievements of Evitt (1963a, 1963b) were the beginning of Bill's mastery of dinoflagellate cyst morphology and certain taxonomic actions, the most significant of which was the formal establishment of the acritarchs. This group was erected to accommodate the hystrichospheres which are not dinoflagellate cysts, and other forms with obscure affinities. The acritarchs were subsequently subdivided into 13 subgroups by

Plate 13. Four scanning electron microscope (SEM) images of *Nannoceratopsis deflandrei* subsp. *senex* from the early Aalenian *Tmetoceras scissum* ammonite biozone (Middle Jurassic) of southern England. The photomicrographs are all taken from Piel & Evitt (1980a), and clearly demonstrate the overall cyst organisation and the unique cingular (type C) archaeopyle. The images are reproduced with the permission of AASP – The Palynological Society.

Figure 1. Slightly oblique apical view. Note the small epicyst with clearly subdivided plates, above the markedly concave cingulum and the strongly perforate autophragm; the middorsal plate 3c forms the archaeopyle. The highly indented sulcus is on the ventral side (facing downwards here), directly opposite the archaeopyle. This image was pl. 1, fig. 7 of Piel & Evitt (1980a).

Figure 2. A specimen in slightly oblique dorsal view. The image demonstrates the profound disparity in the size of the epicyst and hypocyst. Note the clear sagittal suture between the two large hypocystical plates H₂ and H₃ within the prominent sagittal band (median groove), which is somewhat striated. These transverse lineations are interpreted as reflected growth features (megacytic zones) from the parent theca. This image was pl. 2, fig. 4 of Piel & Evitt (1980a).

Figure 3. A well-preserved specimen in dorsal view. The cingular archaeopyle and the sagittal suture are especially prominent. This image was pl. 2, fig. 3 of Piel & Evitt (1980a).

Figure 4. A specimen in dorsal view; note that the operculum (plate 3c) is in place. This image was pl. 2, fig. 5 of Piel & Evitt (1980a).

Downie et al. (1963). Evitt & Davidson (1964) was akin to Evitt (1961c) in impact. These authors helped establish the cyst-producing dinoflagellate life cycle by illustrating a sporopollenin chorate resting cyst inside a motile cellulosic theca (Plate 11; Evitt & Davidson 1964, pl. 1, figs 10, 11). This observation from modern plankton samples confirmed the cyst-theca relationship hypothesised earlier in Evitt (1963a, 1963b).

Bill's virtuosity with dinoflagellate cysts was further demonstrated throughout the rest of the 1960s and early–mid 1970s. Evitt (1967c) is a major work on the archaeopyle which was sumptuously illustrated. Bill collaborated with David Wall who, together with Barrie Dale, also did early pioneering work on the dinoflagellate life cycle. The Evitt and Wall team produced two landmark papers, on *Peridinium limbatum* and the family Ceratiaceae (Evitt & Wall 1968; Wall & Evitt 1975). Evitt (1970a) was an important review paper, which in effect was an update and expansion of Evitt (1961c). Bill was the guiding force of a forum on dinoflagellates held in 1973, and published as Evitt (1975d). At this time, Bill and Lew Stover undertook a major review of all dinoflagellate cyst genera and their constituent species. Such a massive compilatory task had never been attempted previously, and culminated in Stover & Evitt (1978), which is reviewed in detail in subsection 9.5.

In the 1980s and 1990s, Bill continued his research on the morphology of dinoflagellate cysts. The principal outputs were a textbook (Evitt 1985) and definitive works on the genera *Nannoceratopsis* and *Palaeoperidinium* (Piel & Evitt 1980a; Evitt et al. 1998 respectively). Evitt (1985) is documented in detail in subsection 9.6. Piel & Evitt (1980a) demonstrated the intricate epicystal tabulation and the unique circular archaeopyle of the intriguing Jurassic genus *Nannoceratopsis* (Plate 13). Evitt et al. (1998) was the long-awaited culmination of his long-held fascination with the genus *Palaeoperidinium*, especially *Palaeoperidinium pyrophorum*. This work was truly groundbreaking in that the authors used new techniques in order to prove that the outer cyst wall in this genus was formed outside the theca (Appendix 3). Bill persistently mentioned the fact that not all motile dinoflagellates produce resistant resting cysts, and that this fact constrained some interpretations of the fossil record. This was encapsulated concisely in a short article (Evitt 1981a), and is discussed in subsection 9.4 below.

As befits a major researcher, there have been several dinoflagellate cyst and acritarch taxa named in honour of Bill. These are the dinoflagellate cyst genera *Evittodinium* (type: *Evittodinium giselae*), *Evittosphaerula* (type: *Evittosphaerula paratabulata*) and *Wrevittia* (type: *Wrevittia helicoidea*), and the acritarch genus *Evittia* (type: *Evittia sommeri*). Seven dinoflagellate

cyst species have been named after Bill. These are *Alisogymnium evittii*, *Evansia evittii*, *Gingnodinium evittii*, *Komewuia evittii*, *Polygonifera evittii*, *Tehamadinium evittii* and *Trithyrodinium evittii* (see Lentin & Williams 1989, p. 17). In addition, the Silurian acritarch *Tunisphaeridium evittii* was named after Bill by Cramer (1968). The latter taxon was, however, deemed to be a junior synonym of *Tunisphaeridium parvum* by Eisenack et al. (1973, p. 1055).

Bill felt that his principal contributions on dinoflagellates were the discovery that fossil forms represented the cyst stage, and his research on dinoflagellate cyst morphology. He thought that future studies would be on the elucidation of dinoflagellate phylogenies using DNA, ecology and palaeobiology (Leffingwell & Damassa 2004); this perceptive forward look has absolutely proved to be the case.

9.4. *The selectivity of the dinoflagellate cyst fossil record*

Some major groups of dinoflagellates apparently switch on and off the ability to produce preservable resting cysts as part of their life cycle. This phenomenon means that the dinoflagellate fossil record is potentially significantly biased, over and above any preservation and taphonomic factors which can affect even the most resilient fossils. Bill went to great pains to stress the selectivity of the dinoflagellate cyst fossil record (e.g. Evitt 1981a, 1981b, 1985, p. 37–42).

Evidence from cytological and molecular sequencing studies (Knoll 1993; Fensome et al. 1996a; Medlin & Fensome 2013) indicates that dinoflagellates are relatively primitive, and thus may have originated as early as the Neoproterozoic (~700 Ma) or Early Palaeozoic (~500 Ma). This is consistent with data from dinoflagellate biomarkers (Moldowan et al. 1996, 2001; Moldowan & Talyzina 1998). However, the first unequivocal fossil dinoflagellates are Middle Triassic (Helby et al. 1987; Riding et al. 2010). This means that pre-Triassic dinoflagellates either did not make preservable cysts, and/or were represented by certain acritarchs (Dale 1967, 1978; Lister, 1970; Rasul 1974; Miller 1987; Colbath and Grenfell 1995; Playford 2003). The enigmatic Early Palaeozoic (Late Silurian) palynomorph genus *Arpylorus* was, for a long time, considered to be a dinoflagellate cyst (Sarjeant 1978). However, this genus was recently demonstrated to have possible relationships with the arthropods or the eurypterids, and hence has no dinoflagellate affinity (Le Hérisse et al. 2012).

It is estimated that only around 15–20% of the approximately 2400 known living dinoflagellate species produce fossilisable resting cysts (Head 1996; Gómez 2012). This ratio is an average and is not ecologically

consistent. For example, there are relatively few cyst species produced by the diverse dinoflagellate floras in modern tropical environments. By contrast, contemporary shallow-water settings at higher latitudes are characterised by low thecate dinoflagellate diversities, but many of these are cyst-producers (Dale 1976; Wall et al. 1977). There is no known reliable method of determining whether the present low ratio of non cyst-producers to cyst-producers is typical of the geological past. The consequence of all this is that the selectivity of the dinoflagellate fossil record means that dinoflagellate cysts are probably a significant under-representation of the entire dinoflagellate record. This should always be borne in mind when interpreting fossil dinoflagellate data. Because of the relative incompleteness of the fossil record, dinoflagellate cysts should not be used as direct proxies for biodiversity and bioproductivity in the same way that, for example, calcareous nannofossils and planktonic foraminifera are. Similarly, they should be used with appropriate caution when analysing, for example, atmospheric and oceanic perturbations, rates of evolution and fluctuations in levels of photosynthesis. However, it should be pointed out that all calcareous fossils are relatively susceptible to pre-, syn- and post-diagenetic dissolution, unlike organic-walled dinoflagellate cysts.

Furthermore, the materials used to construct the dinoflagellate cyst wall are somewhat varied; not all dinoflagellate cysts are organic-walled. Some taxa have mineralised outer layers; there is a relatively diverse group of extant calcareous dinoflagellate cysts and sparse siliceous fossil forms (Figure 21). The calcareous dinoflagellate cysts are extant, emerged during the Late Triassic, and diversified in the Early Cretaceous (Streng et al. 2004). These are all in the peridinioid family Calciodinelliodeae (e.g. Keupp 1984, 1987, 1991; Willems 1988; Keupp & Versteegh 1989). There are only two unequivocal genera of non-endoskeletal siliceous dinoflagellates, both of which are confined to the Palaeogene (Deflandre 1933; Lefèvre 1933a, 1933b; Vozzhenikova 1963). One siliceous genus, *Lithoperidinium*, is a dinoflagellate cyst; by contrast, the other one, *Peridinites*, represents the remains of motile thecate cells (Harding & Lewis 1994).

However, perhaps the most significant factor here is the disjunct temporal distribution of certain dinoflagellate taxa. The apparently selective stratigraphical ranges of certain organic dinoflagellate cyst groups are discussed below. Bill mentioned the selectivity of the dinoflagellate fossil record in his first paper on palynology. In Evitt (1961b), he commented that the Jurassic (Pliensbachian–Kimmeridgian) dinoflagellate cyst genus *Nannoceratopsis* is similar in overall morphology to the modern genus *Dinophysis*, and hence appears to be closely related. The living representatives of the

subclass Dinophysiphycidae do not produce preservable resting cysts, and *Nannoceratopsis* is confined to the Jurassic (Figure 21). Much later, Piel & Evitt (1980a) determined that the tabulation of *Nannoceratopsis* is reminiscent of the orders Dinophysiales and Gonyaulacales because the epicystal tabulation is peridiniophysidalean, and appears to have gonyaulacacean affinities (Plate 12). Because of this, *Nannoceratopsis* was placed in the monogeneric Order Nannoceratopsiales of the subclass Dinophysiphycidae by Piel & Evitt (1980a). Therefore, *Dinophysis* and *Nannoceratopsis* are in the same subclass, but their relationship is somewhat more distant than originally envisaged by Evitt (1961b). Hence it is possible that *Nannoceratopsis* is an extinct offshoot of the early representatives of the Dinophysiphycidae, and therefore does not necessarily represent a selective phase of cyst production of dinophysialean forms.

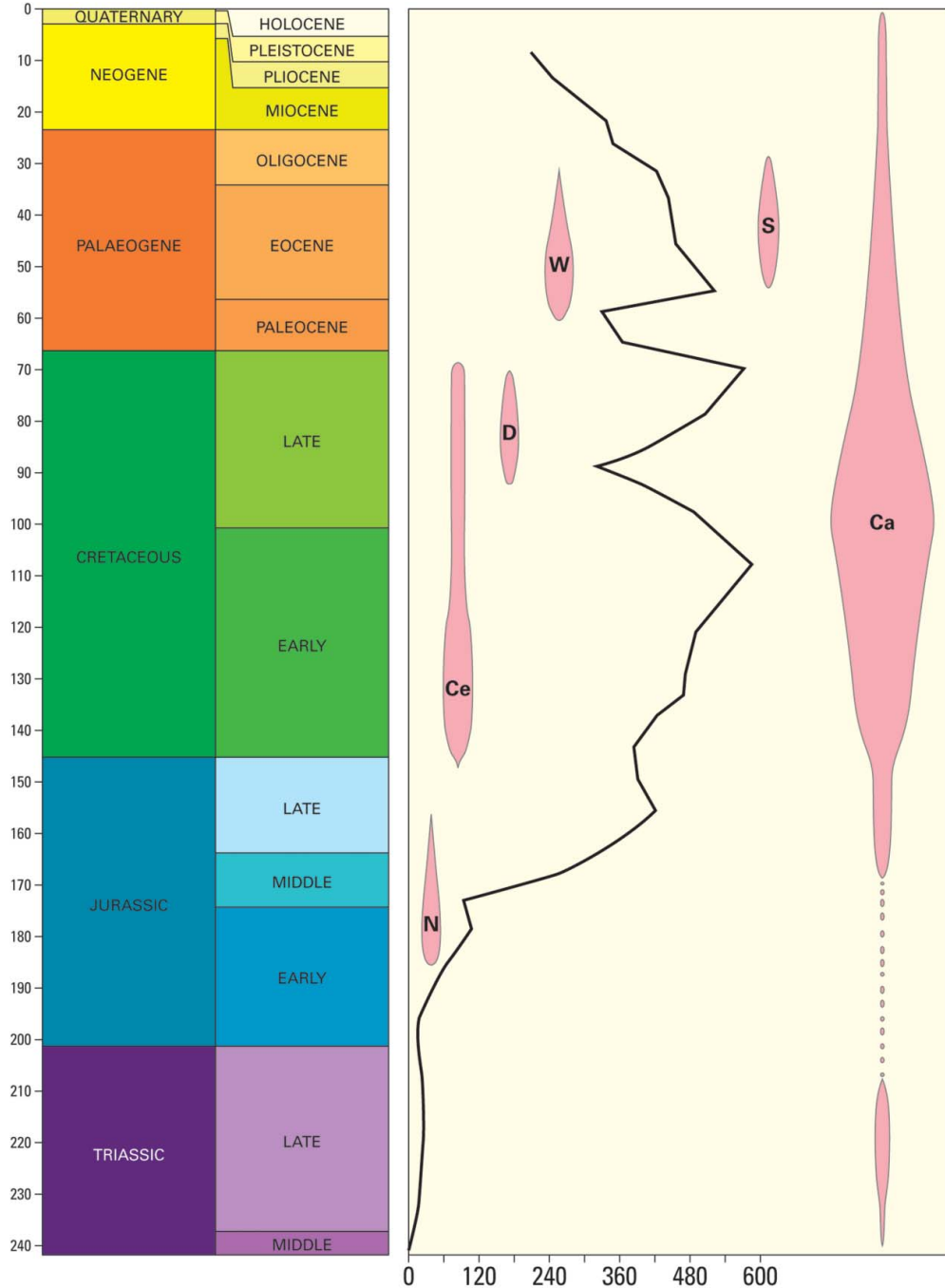
One of the best examples of the disjunct and selective nature of the dinoflagellate fossil record is the family Ceratiaceae. These distinctive forms with three, four or five horns were present in the Mesozoic, from the latest Jurassic to the latest Cretaceous, and were relatively diverse throughout much of the Early Cretaceous (Figure 21; Wall & Evitt 1975; Bint 1986; Helby 1987; Monteil 1991; Riding et al. 2000). By contrast, they were entirely absent throughout the Palaeogene and Neogene, but numerous (> 100 species) non-cyst producing representatives are present today both in freshwater and marine settings (Wall & Evitt 1975). This apparent gap of ~66 My between the end of the fossil record and the modern thecate representatives strongly implies that these forms ceased producing resting cysts during the latest Cretaceous. However, it seems likely that at least some of the range tops of species in genera such as *Muderongia*, *Odontochitina*, *Phoberocysta*, *Pseudoceratium* and *Xenascus* represent genuine extinction events. The diversity of the Family Ceratiaceae declined significantly during the Campanian and Maastrichtian. The youngest representatives (e.g. *Odontochitina operculata*) have Campanian–Maastrichtian range tops (Helby et al. 1987, fig. 40; Crame et al. 1991; Pirrie et al. 1991, 1997; Costa & Davey 1992, fig. 3.9; Roncaglia et al. 1999). Their apparent extinctions may have been related to late Maastrichtian cooling (Bowman et al. 2013), but were apparently entirely unrelated to the Cretaceous/Palaeogene boundary event.

Dinogymnium is a Cretaceous genus, being especially characteristic of the Late Cretaceous interval (Evitt et al. 1967). It is acavate and biconical, and typically has longitudinal folds, an apical archaeopyle and wall canals (Plate 6, figures 5, 6, 8, 9). The latter feature appears to indicate that it is a thecate fossil genus (May 1976, 1977). *Dinogymnium* is extremely similar in

morphology to the modern unarmoured thecate genus *Gymnodinium*. Although some living species of *Gymnodinium*, such as *Gymnodinium catenatum*, apparently produce resistant cysts (Anderson et al. 1988), the Palaeogene to Pleistocene fossil record is devoid of gymnodinioid forms. Therefore, there is a significant stratigraphical gap in the gymnodinioid lineage between the Late Cretaceous and Holocene (Figure 21).

Another example of selectivity is the Palaeogene (Thanetian–Rupelian) cavate peridiniacean subfamily

Wetzelielloideae (Figure 21). Representatives of this group are characterised by a four-sided (quadra), rather than a six-sided (hexa), 2a plate (Williams et al. 2015, fig. 1). The quadra 2a plate, and the para ventral arrangement, helps define the subfamily Wetzelielloideae, whereas most fossil and modern taxa in the family Peridiniaceae have hexa 2a plates (Bujak & Davies 1983; Fensome et al. 1993). However, living species of the genus *Protoperidinium*, which are comparable to *Wetzeliella* and its relatives, also have quadra 2a plates.



The question remains, is the Thanetian to Rupelian range of cavate dinoflagellate cysts referable to the subfamily Wetzelielloideae the true temporal extent of this group, or does this interval simply represent a phase when they produced resting cysts? Evitt (1985, p. 38–39) gave a more wide-ranging review of the selectivity of the fossil record of dinoflagellate cysts related to modern *Protoperidinium*.

Bill mentioned the selectivity of the dinoflagellate fossil record repeatedly (Appendix 3), and Evitt (1981a) was entirely devoted to this topic. Bill privately commented (personal communication to JBR) that his zeal in emphasising this aspect of the fossil record was largely as a result of compiled dinoflagellate cyst data being used as a proxy for primary productivity in the geological past (e.g. Tappan & Loeblich 1973). It is

indeed intriguing that dinoflagellate cysts were produced by certain taxa during specific intervals. The fact that the fossil dinoflagellate cyst record represents a relatively small proportion of the entirety of the Triassic to Pleistocene dinoflagellate spectrum significantly constrains our use of the fossil record. For example, the overall dinoflagellate population density cannot be determined from an association of fossil dinoflagellate cysts, dinoflagellate bioproductivity cannot be meaningfully assessed from the fossil record and the range of a particular pre-Holocene lineage cannot be unequivocally derived from its stratigraphical range.

This Evittian paradigm is a somewhat cautious approach, but nonetheless is extremely insightful. However, despite Bill's misgivings about the completeness of the dinoflagellate fossil record, Fensome et al.

Figure 21. The species diversity of the organic dinoflagellate cyst fossil record with the ranges of certain genera and groups plotted in order to attempt to illustrate examples of selectivity. The overall numbers of organic-walled species are plotted on the horizontal axis; these data were taken from MacRae et al. (1996, table 1). Six different dinoflagellate cyst groups are illustrated. These comprise four groups of sporopollenin forms, together with calcareous and siliceous dinoflagellates. The geochronological ages were taken from Gradstein et al. (2012).

N – The unusual Jurassic genus *Nannoceratopsis*; the range of this, which is most diverse in the Toarcian and Aalenian, is Late Pliensbachian to earliest Kimmeridgian in Europe (Riding & Thomas 1992). There are presently 17 validly described species of *Nannoceratopsis* (see Fensome & Williams 2004, p. 449–451). *Nannoceratopsis* is somewhat reminiscent of the modern dinoflagellate genus *Dinophysis* (order Dinophysiales) which does not produce preservable resting cysts (Piel & Evitt 1980a). Ce – Dinoflagellate cysts referable to the family Ceratiaceae. There are 11 unequivocal ceratioid genera which range from the latest Jurassic (Tithonian) to the latest Cretaceous (Maastrichtian). There are 114 species of fossil ceratioid dinoflagellate cysts according to Fensome & Williams (2004). These are as follows: *Aptea* (two); *Balmula* (four); *Endoceratium* (five); *Muderongia* (18); *Nyktericysta* (13); *Odontochitina* (18); *Odontochitinopsis* (two); *Phoberocysta* (three); *Pseudoceratium* (22); *Vesperopsis* (13); and *Xenascus* (14). None of these three- to five-horned genera are present in the Palaeogene and Neogene; however, abundant and diverse non-preserved resting cyst-producing representatives are present today in freshwater and marine environments (Wall & Evitt 1975). D – The genus *Dinogymnium* (and the closely related genus *Alisogymnium*). These distinctive forms, which appear to represent dinoflagellate motile forms due to the presence of wall canals (May 1976, 1977; Evitt 1985), are confined to the Late Cretaceous (Turonian to Maastrichtian) interval (Evitt et al. 1967; Wilson & Clowes, 1980, p. 36; Costa & Davey 1992). However, there are isolated reports of *Dinogymnium* from the Early Cretaceous (Londeix et al. 1996). There are currently eight and 29 valid species of *Alisogymnium* and *Dinogymnium*, respectively (Fensome & Williams 2004, p. 37–38, 209–213). These two fossil genera are morphologically similar to the modern unarmoured genus *Gymnodinium*. The Palaeogene to Pleistocene interval entirely lacks gymnodinioid forms, although some living *Gymnodinium* species produce preservable cysts as part of their life cycle. W – Dinoflagellate cysts referable to the subfamily Wetzelielloideae. The *Wetzeliella* group is entirely cavate and comprises 21 genera and 126 species which are confined to the latest Paleocene (late Thanetian) to Oligocene (Rupelian) interval. This plexus is most diverse in the Eocene. The members of this complex all have a four-sided (quadra) 2a plate and have para ventral arrangements (Bujak & Davies 1983, fig. 13; Williams et al. 2015, fig. 1). Most other taxa in the extant family Peridiniaceae have hexa 2a plates (Bujak & Davies 1983). Modern forms of the similar, but acavate, genus *Protoperidinium* exhibit quadra 2a plates, but only < 5% of the species in this important genus produce geologically preservable resting cysts (Bujak & Davies 1983, p. 43). Most *Protoperidinium* cysts exhibit ortho-style ventral tabulation. It is therefore not clear whether or not the Thanetian to Rupelian range of the subfamily Wetzelielloideae is the authentic range of this group. Ca – Calcareous dinoflagellate cysts (subfamily Calciodinelliodeae). Modern representatives of this important extant peridiniacean subfamily are entirely autotrophic and marine, and their fossil counterparts are assumed to have had the same life strategy. The cyst wall of the Calciodinelliodeae includes a robust calcareous layer which is prone to fossilisation (Wall & Dale 1968b). This subfamily originated during the Late Triassic (Early Carnian), where it is largely represented by cryptotabulate forms (Janofske 1992; Streng et al. 2004; Gottschling et al. 2005). The Late Triassic floras are relatively sparse, and there are no records whatsoever from the Hettangian to the Bathonian. This represents the entire Early Jurassic and most of the Middle Jurassic, an interval of c. 35 My. It is not certain whether this hiatus is genuine, or whether it reflects a lack of investigation and/or unsuitable facies. Calcareous dinoflagellate cysts reappeared in the Callovian, before diversifying markedly in the Early Cretaceous (Keupp & Ilg 1989; Streng et al. 2004, fig. 14.1). They were most diverse during the Cretaceous to Early Palaeogene interval (e.g. Keupp 1991; Kohring 1993; Willems 1994), and the major diversification was during the Hauterivian (Streng et al. 2004, fig. 14.1). This means that the diversity record of calcareous dinoflagellate cysts closely mirrors that of their organic-walled counterparts. S – Non-endoskeletal siliceous dinoflagellate cysts and thecae. These forms represent the fossil peridiniacean subfamily Lithoperidiniodeae. This comprises two genera, i.e. *Lithoperidinium* (a cyst genus comprising seven species) and *Peridinites* (a fossil thecal genus with three species), which are confined to the Palaeogene (Eocene to Early Oligocene) (Vozzhennikova 1963; Fensome et al. 1993, p. 137–138; Harding & Lewis 1994).

(1996b) commented that the Mesozoic and Cenozoic fossil record exhibits significant phylogenetic continuity, and that the Early Mesozoic radiation is a true evolutionary event as opposed to being a preservational artefact. For example, major groups such as the family Gonyaulacaceae appear to have emerged globally due to a genuine evolutionary radiation during the Middle Jurassic, and are extant (Feist-Burkhardt & Monteil 1997; Mantle & Riding 2012). Similarly, the decline in diversity during the Neogene appears to be a direct reaction to declining global temperatures and sea levels (Bujak & Williams 1979; Fensome et al. 1996b). Similarly, while cautioning against what he termed 'megathinking' using the dinoflagellate cyst record, Bill admitted that certain evolutionary studies based on fossil dinoflagellate cysts are valid. These are studies at the genus/species level that document changes in local stratigraphical successions over relatively small time slices (e.g. Eaton 1971; Habib 1973; Bujak 1976, 1979; Fensome 1981; Riding & Helby 2001; Riding & Fensome 2002).

9.5. *The first 'Blue Book': Analyses of pre-Pleistocene organic-walled dinoflagellates – Stover & Evitt (1978)*

During the mid 1970s, Lew Stover and Bill Evitt embarked on their only major collaborative project, which was published as Stover & Evitt (1978). This was the first of two 'Blue Books' that Bill was involved with (subsection 9.6). The only other collaborations which included Bill and Lew were two relatively short papers (Evitt et al. 1977, 1979). Stover & Evitt (1978) was published by Stanford University and aimed to stabilise the nomenclature and taxonomy of pre-Quaternary organic dinoflagellate cysts. The number of research papers on fossil dinoflagellates had increased exponentially during the 1960s and 1970s. Consequently, numerous taxonomic problems had arisen, and a major overview was well overdue.

Stover & Evitt (1978) gave comprehensive summaries of 279 dinoflagellate cyst genera, including a synopsis, description and comparison (but unfortunately no illustrations), in the main part of this softcover book. It is one of the most important reference works on dinoflagellate cysts ever published and is still used today despite its relatively venerable age, similar to the earlier major works by Davey et al. (1966, 1969). The overall impact of Stover & Evitt (1978) is similar to that of the 'Lentin and Williams' indexes of dinoflagellate cyst genera and species (e.g. Fensome & Williams 2004). Stover & Evitt (1978) is a comprehensive (300 pages) systematic analysis of pre-Pleistocene organic dinoflagellate cysts; it was prompted by the belief of both authors that many generic descriptions in the

literature were somewhat incomplete and vague. This lack of quality was perceived to be at least partially due to the extremely rapid expansion of research on this topic between the mid 1960s and the mid 1970s. Hence, the principal aims of Stover & Evitt (1978) were to recast generic concepts in a uniform format, and to clearly define new criteria and limits so that any overlapping taxonomic concepts were eliminated. The review that was undertaken by Stover & Evitt (1978) led to many emended genera, and the reattribution of large numbers of species. Wherever possible, existing taxa were maintained irrespective of the level of clarification required. Issues pertaining to taxonomic levels above the genus level were not undertaken. Of the 279 genera considered, 17 were new. It was found that several genera could be suppressed, largely due to them being junior synonyms of older taxa. For each genus, all of the constituent species were treated. Furthermore, the book established three new dinoflagellate cyst species. Bill and Lew had much control over the format and appearance of the book because it was issued by Stanford University Publications. An update of Stover & Evitt (1978) was issued nine years later by Stover & Williams (1987), which included all 84 valid genera published between 1977 and 1985. Stover & Williams (1987) also included a line drawing for the majority of these genera.

The *modus operandi* of Stover & Evitt (1978) was discussed in the first main chapter ('Procedures and considerations', p. 3–9). This described the format for the generic analyses, and defined several key descriptors. For example small, intermediate and large dinoflagellate cysts were defined as having maximum dimensions of < 50 µm, 50–100 µm and > 100 µm, respectively. The descriptive terminology used was clarified here, and concentrated on archaeopyles and opercula, cyst organisation (cavation), and shape.

The main section of the book (p. 11–241) was entitled 'Analyses of dinoflagellate genera'. It was subdivided into five sections based entirely upon archaeopyle type where known, rather than using a suprageneric classification. These five subchapters are on apical, combination, intercalary and precingular archaeopyles, with the final subdivision ('other genera') being on 33 genera where either the forms apparently lack an archaeopyle or the mode of excystment was unknown. This section includes the genus *Tuberculodinium*, which was considered to have an antapical archaeopyle by Stover & Evitt (1978, p. 240). However, this archaeopyle has more recently been interpreted as being of compound epicystal type by Matsuoka et al. (1998). The majority (61%) of dinoflagellate cyst genera known at that time have apical or precingular archaeopyles. In each of the five sections, the genera were arranged alphabetically. The original description

was given (translated into English where appropriate), prior to a one-paragraph synopsis which aimed to concisely summarise the essential characters of the genus. Next, a 'modified description' was presented; this provides descriptions of the eight key features of each genus, namely shape, wall relationships, wall features, tabulation, archaeopyle, cingulum, sulcus and size. Each genus was briefly compared to similar genera, then the type was given followed by the other constituent species. The constituent species were subdivided, as appropriate, into accepted species, provisionally accepted species, problematical species and reattributed species. This breakdown is a very useful guide as to the status of a species. Provisionally accepted species have a question mark following the generic name; they do not unequivocally belong to the respective genus and the relevant issues were briefly noted. Problematic species have quotation marks around the generic name, and are even less securely assigned to the genus. They probably do not belong to the respective genus, and it was normally recommended that these taxa should be confined to the type specimens only. Reattributed species are, of course, taxa which were recombined into other genera.

Following the references (p. 243–257), 10 appendices were included in Stover & Evitt (1978, p. 259–287). The subject matter of these appendices is extremely diverse. The first of these, Appendix A (p. 259–264), listed all of the taxonomic departures from Lentin & Williams (1977). The latter work was the second edition of an index of dinoflagellate cyst genera and species. Clearly, this was a major compilation on this palynomorph group and also made taxonomic changes, so it was appropriate that Stover & Evitt (1978) listed any differences from Lentin & Williams (1977) such as species reallocations.

Appendices B (p. 265) and C (p. 266) pertain to Tasch (1963) and Tasch et al. (1964), respectively. Bill concluded in Appendix B that the Permian material from Kansas of Tasch (1963) represents mineral grains (probably gypsum) and specimens of the trilete spore genus *Raistrickia*. He also contributed Appendix C, which was a brief restudy of the aquatic palynomorphs described from the Lower Cretaceous (Albian) of Kansas by Tasch et al. (1964). Bill found that the majority of the new species described by Tasch in Tasch et al. (1964) have significant problems. Many of the types are poorly preserved, and most of the new species are based solely on single specimens. Fifteen of these new taxa are conspecific, and were consolidated as *Kiokansium unituberculatum*, which was formally described in Appendix D (Stover & Evitt 1978, p. 267–268). Bill was very intrigued by the assemblages that Tasch et al. (1964) reported from the Albian of Kansas. He later suggested to one of his graduate students, Anthony M.

Bint, that this material should be recollected and used for a PhD thesis (Bint 1984).

Appendix E (p. 269–270) was a brief review of archaeopyle variability. Certain genera such as *Diphyes* and *Lingulodinium* appear to exhibit different archaeopyle styles, which clearly has implications for the integrity of this feature as a generic criterion.

A perceptive and highly influential review of the *Gonyaulacysta* complex was presented as Appendix F (p. 271–297). This is a wide-ranging synthesis of this major group, and the style of detailed morphological analysis was followed in Evitt (1985). The key characteristics of 18 gonyaulacacean genera were summarised (Stover & Evitt 1978, table 5). Two pairs of genera (*Gonyaulacysta* and *Rhynchodiniopsis*, and *Impagidinium* and *Leptodinium*) were compared and discussed in detail. The use of details of tabulation to distinguish genera was somewhat controversial at first, but eventually became a standard criterion for distinguishing genera and the higher levels of classification, especially in the gonyaulacaceans (Fensome et al. 1993).

Appendix G (p. 280–281) is a brief assessment of the genera *Herendeenia* and *Omatia*, and the seven genera in the *Lanternosphaeridium* complex were summarised in Appendix H (p. 282). The principal morphological features of the several genera in the very important and closely related *Spiniferites* complex were outlined in Appendix I (p. 283–284). This topic was further explored in Evitt (1978a).

The final section, Appendix J (p. 285–287), is a concise and highly influential review of the peridiniacean genera. It included a summary of the principal morphological features of 24 genera, which were subdivided into three categories (Stover & Evitt 1978, table 6). The final section of the entire book (Stover & Evitt 1978, p. 289–298) is an alphabetical listing and index of the dinoflagellate cyst genera with archaeopyle group assignments. This section is very helpful in navigating the main section of the book.

It is clear that Lew Stover and Bill put a massive amount of work into this hugely ambitious project. Amassing all the literature and critically evaluating each genus and species, in addition to all the associated microscope work, was a colossal task. Lucy E. Edwards, now of the USGS, worked under Lew Stover as an Exxon Production Research student summer intern while the book was being researched and written in 1974. She recalls that Bill also sporadically worked at Exxon as a consultant, and that he had maintained the index card file of dinoflagellate cysts that was used for Stover & Evitt (1978) since his days at the Jersey Production Research Company (section 5). The principal task undertaken by Lucy Edwards was to work on the card index, and to ensure that each genus had a

unique set of the requisite descriptors. This system made synonymous genera easy to identify. Furthermore, Lucy recalls that Lew Stover had already amassed the entire literature on pre-Quaternary dinoflagellate cysts, including copies and translations of many publications not originally written in English. Despite this, Bill and Lew did not need to refer to the literature as, according to Lucy, they had all the genera and species in their heads. However, notwithstanding this encyclopaedic knowledge, they meticulously rechecked all the details when compiling Stover & Evitt (1978).

Bill and Lew's sterling efforts were rewarded by the final product which was a very well-received and extensively used book among all workers on aquatic palynology. It is still an enduring reference text, (at the time of writing) 37 years since it was first published. Stover & Evitt (1978) was, deservedly, one of the best sellers of Stanford University Publications (Geological Sciences), but unfortunately it is currently out of print. It is clear that other researchers were working on similar projects during the late 1970s. Artzner et al. (1979) is a guide to organic dinoflagellate cyst genera organised into 33 families plus *incertae sedis*. A total of 276 genera were reviewed by Artzner et al. (1979); the main part comprises line drawings of the types of these genera within the 33 families considered. Wilson & Clowes (1980) is another guide to dinoflagellate cyst genera. This includes an alphabetical listing of 330 genera, each with a line drawing and brief details. Wilson & Clowes (1980) was designed so that the pages can be cut up into index cards. The stratigraphical extents of the genera were given in six range charts. Perhaps the most useful features are the line drawings of the types of each genus arranged by five archaeopyle types (Wilson & Clowes, 1980, figs 1–412). The illustrated generic guides of Artzner et al. (1979), Wilson & Clowes (1980) and Stover & Williams (1987) can all be used to help assign dinoflagellate cyst specimens to the most appropriate genus.

9.6. *The second 'Blue Book': Sporopollenin dinoflagellate cysts – their morphology and interpretation – Evitt (1985)*

9.6.1. Introduction

Bill Evitt's *magnum opus* was undoubtedly his seminal textbook on dinoflagellate cyst morphology, which he had been working on for many years. Evitt (1985) draws on Bill's morphological research over his entire career in palynology, which started in the mid 1950s. The project came to fruition in the summer of 1985 when *Sporopollenin dinoflagellate cysts – their morphology and interpretation* was published by the AASP

Foundation. It was an immediate classic, and its striking blue cover (Figure 22) gave it the colloquial name of the 'Blue Bible' or the 'Blue Book'. This volume was effectively launched at the Third International Conference on Modern and Fossil Dinoflagellates (Dino 3) at Royal Holloway and Bedford New College, Egham, Surrey, United Kingdom, in August 1985 (Head & Harland 2013). The book had been published several weeks prior to Dino 3, and Bill gave a keynote address on the first day of this symposium. Probably, most of the 140 participants of Dino 3 bought a copy. The principal subject matter of this textbook was presaged by a talk given during 1983 (Helenes et al. 1984).

The writing of Evitt (1985) brought Bill into contact with computers for the first time. The book was written in its entirety on a Wang word processor, and Bill really appreciated the ease of writing and editing that came with digital media. The final manuscript was sent to Bob Clarke, the AASP Foundation production editor, on a disc. This was the first time that Bill had delivered a manuscript which was not on paper. Soon after he finished writing the manuscript in 1984, Bill bought one of the early Apple/Macintosh personal computers for the Stanford University palynology laboratory. Bob Clarke recalls that he met with Bill twice to discuss the book (personal communication to JBR). These were short meetings to finalise various aspects pertaining to production of this book. Bill chose the cover style, the fonts, the two-column format and the type of binding. It was decided to go for the best quality possible due to the importance of this publication.

Evitt (1985) is the only textbook on dinoflagellate cysts in existence, the main subject matter being morphology and tabulation, which were Bill's major research interests. Aspects such as classification and evolution were treated relatively briefly, and there is virtually nothing on biostratigraphy, palaeoecology or geographical distributions. It is a beautifully produced hardcover book of 333 pages, and all of the topics explored were treated authoritatively and comprehensively. Bill began planning the book during the early 1970s. He could see a time in the future when he would retire, and he wanted to expand and formally publish material which he had initially produced for his dinoflagellate cyst short courses. The starting point for Evitt (1985) was the second edition of the course manual for his Teaching Conferences on Fossil Dinoflagellates (section 10). The book is an updated and very much expanded version of these unpublished course notes.

However, the principal impetus which spurred Bill to complete this major project were the new ideas on dinoflagellate tabulation of F.J.R. 'Max' Taylor of the University of British Columbia, Vancouver, Canada. Bill first learned about these new concepts in Norway

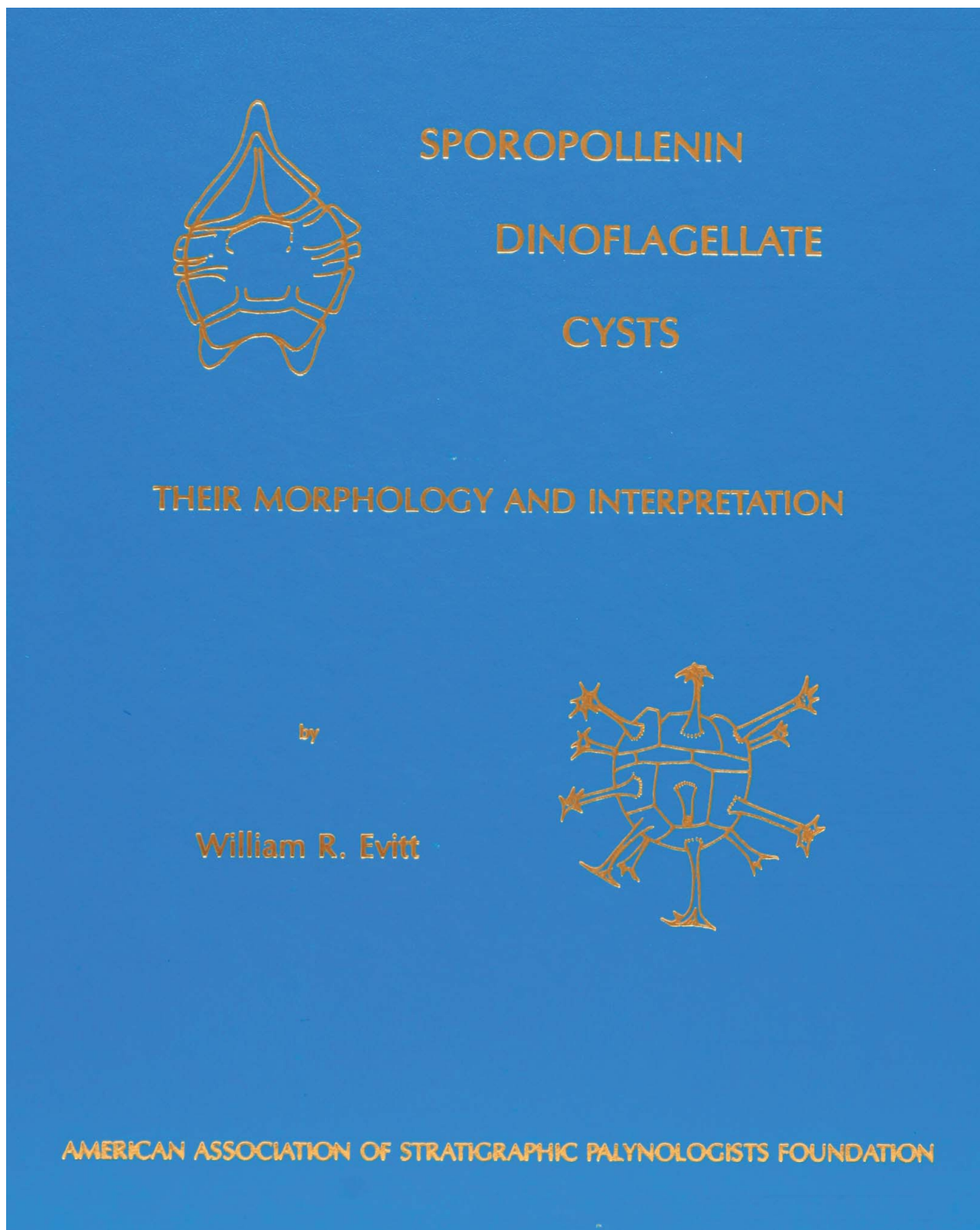


Figure 22. The front cover of Bill Evitt's major textbook *Sporopollenin dinoflagellate cysts - their morphology and interpretation*, published during the summer of 1985 by the AASP Foundation (Evitt 1985) (subsection 9.6). Its vibrant blue colour quickly gave it the nicknames the 'Blue Bible' and the 'Blue Book'. Note the line drawings of *Areoligera?* sp. (top left) and *Oligosphaeridium abaculum* (bottom right), both in dorsal view. The two images are based on Wall & Evitt (1975, pl. 3, fig. 14) and Evitt (1985, fig. 10.2A), and Davey (1979a, fig. 1B; pl. 49, fig. 3) and Evitt (1985, fig. 1.7F) respectively. This image is reproduced with the permission of AASP – The Palynological Society.

during the summer of 1976, and discussed them with colleagues at Stanford University afterwards (section 10). Thus the majority of the text of Evitt (1985) was written between 1978 and 1983, and this huge effort took up most of Bill's research and personal time during this period. The most protracted phase of work on the book was undertaken during the 1978–1979 academic year, when Bill was given sabbatical leave from Stanford University. Bill commented that the writing proceeded slowly, and that he had badly underestimated the time needed to complete such a large project. He found that he had to recast sections when important new papers were published. For example, Bill rewrote the section on tabulation patterns because he was so strongly influenced by Taylor's ideas on this topic. These were published in biological journals (e.g. Taylor 1978, 1980), and Bill adapted these theories to fossil dinoflagellates over several iterations.

Evitt (1985) included exhaustive descriptions of the large diversity of morphological features exhibited by dinoflagellate cysts, and new ideas on tabulation patterns and their interpretations. Bill was similar in many ways to pioneers such as Georges Deflandre and Alfred Eisenack (to whom the volume is dedicated) in that he was not especially interested in biostratigraphy. He preferred instead to concentrate on morphology, while working on exceptionally well-preserved material. A principal strand of this text is a description of a new tabulation scheme, now known as the 'Taylor-Evitt System' which was first proposed by Taylor (1978, 1980). Evitt (1985) was initially subdivided into three parts, namely a general section on dinoflagellates and a section on cyst morphology followed by one on cyst interpretation. These major sections were then further arranged into 13 chapters.

9.6.2. Part I – On dinoflagellates in general (Chapters 1 and 2)

Part I of Evitt (1985, p. 5–45) followed a brief introduction, and Chapters 1 and 2 described the biology of the dinoflagellates and gave an overview of their geological record respectively. These chapters thus provide a background for the rest of the book. Because of the review nature of this part, selected references were given at the end of each of the two chapters. In the introduction to Part I, Bill emphasised the cyst as an integral aspect of the life cycle of dinoflagellates, with a specific character and function. Not all modern dinoflagellates produce preservable cysts, and this situation is presumed to have been the case in the past. This means that there are significant limitations that the selective nature of the dinoflagellate cyst record places on inferences that can be made using these fossils

(subsection 9.4). This key message was expanded in Chapter 2 (see below).

In Chapter 1, 'Aspects of living dinoflagellates', Evitt (1985, p. 7–29) discussed living dinoflagellates insofar as they are pertinent to the fossil record. The differences between cysts and thecae were outlined, and the life cycle of a cyst-producing dinoflagellate was illustrated (Evitt 1985, fig. 1.3). The latter diagram has become a classic, and has been modified by many others (Figure 23). Most dinoflagellate cysts are deemed to be hypnozygotes, but cysts may be produced in other parts of the life cycle (Dale 1983). This chapter included consideration of the morphology and variability of dinoflagellate thecae, and particularly the modern genera which are especially important in the fossil record, i.e. *Ceratium*, *Gonyaulax*, *Peridinium* and *Protoperidinium*.

Chapter 2 (Evitt 1985 p. 31–45) covered 'Aspects of the dinoflagellate fossil record' beginning with an historical review, which Evitt (1985) admitted was not comprehensive, referring the reader to Sarjeant (1974). Bill focused on the work of certain individuals in the early phases prior to the major burst of activity due to the interest of the oil industry beginning in the mid to late 1950s. The progression of ideas regarding fossil dinoflagellates was described, and Bill modestly noted his own huge contribution only by citing his publications where appropriate. He went on to review the confirmation of his ideas by his work, and the research of others such as David Wall and Barrie Dale. This section was concluded with mention of the 1978 Penrose conference (Evitt et al. 1979; section 11). There followed an exhaustive discussion of the qualitatively and quantitatively biased nature of the dinoflagellate fossil record. It was noted that dinoflagellate cysts, in addition to the usual taphonomic biasing applied to other fossils, have an additional selectivity 'as a consequence of the fact that the sporopollenin structure on which the fossil record of dinoflagellates largely depends is an adaptive feature peculiar to a certain stage in the life cycle of only certain species' (Evitt 1985, p. 37). This selectivity means that conclusions on aspects such as the evolutionary succession of characters or taxa, population size and assemblage composition, and rates of extinction or speciation based on dinoflagellate cyst data are subject to significant caveats (Evitt 1981a; subsection 9.4). The remainder of Chapter 2 discussed aspects such as freshwater dinoflagellate cysts, and the distinction between acritarchs and dinoflagellate cysts.

9.6.2. Part II – Morphology of the cyst (Chapters 3 to 6)

Part II of Evitt (1985, p. 47–145) was entitled 'Morphology of the cyst'. The introduction set out the

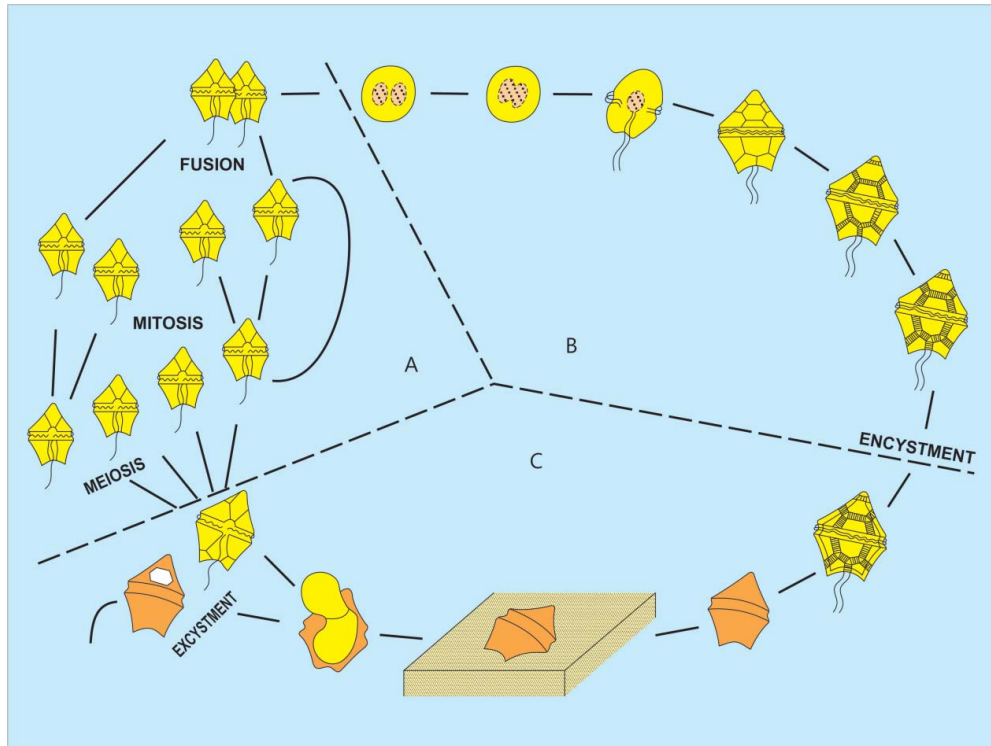


Figure 23. A diagrammatic depiction of the idealised life cycle of a cyst-producing dinoflagellate. It involves both sexual reproduction and cyst formation. In phase A, the dinoflagellate cells are haploid and mobile schizonts. Phase B illustrates diploid, motile dinoflagellate cells which are planozygotes; the nucleus is indicated by large dots. In phase C, the dinoflagellate cells are diploid and nonmotile hypnozygotes apart from the cell which has excysted on the left. Note the open archaeopyle in the empty cyst on the extreme left in phase C, which represents a potential fossil. This image is modified from Fensome et al. (1996c, fig. 4), and was originally published as Evitt (1985, fig. 1.3).

criteria for the identification of dinoflagellate cysts. These are: (i) general features such as shape, size and orientation; (ii) wall structure and surface features; (iii) tabulation; and (iv) the archaeopyle. This section is concerned virtually exclusively with the order Peridiniales, especially the relationships between modern thecae and fossil cysts. The four chapters of Part II provide a thorough review of the morphology of dinoflagellate cysts. These are on the organisation of cysts and thecae, the cyst wall, tabulation and the archaeopyle, respectively.

Chapter 3 (Evitt 1985, p. 49–60) discussed the morphology and organisation of dinoflagellate cysts and thecae. Basic descriptive terms were introduced, and the system of Kofoid (1909) for analysing and labelling thecal tabulation was briefly described. It was Bill's intent to minimise the number of descriptive morphological terms. The shortcomings of the Kofoidian tabulation system with respect to plate homologies were outlined. The term 'paratabulation' for the reflected tabulation of dinoflagellate cysts was used throughout. However, this term is not commonly used at present because it should always be obvious whether a dinoflagellate cyst or a theca is being discussed (Norris 1978b,

p. 303). The Kofoidian system can be used for the tabulation of dinoflagellate cysts with certain limitations. These are: (i) cyst tabulation is often incompletely expressed; (ii) a variety of cyst features indicate the position and shape of plates; (iii) small thecal plates are unlikely to be expressed on the cyst; (iv) shapes of plates on cysts may differ from their thecal counterparts because cyst and thecal shapes differ; (v) post-mortem degradation may affect cysts. Therefore, the cyst tabulation may differ from the precise configuration of plates on the theca. The shape of cysts may also affect the possibility of viewing all areas in a fixed mount, necessitating the manipulation of individual specimens. Dinoflagellate cysts may exhibit significant intraspecific variability; hence, descriptions of species based on small numbers of poorly preserved specimens are of limited value.

Chapter 4 (Evitt 1985, p. 61–79) described the structure of the dinoflagellate cyst wall. Dinoflagellate cysts, particularly proximate forms, may exhibit theca-morphic features. These are items that resemble and correspond to thecal elements, but which are functionless or have a different purpose on the cyst. Other features, particularly the processes of chorate cysts, are

cystomorphic in that, although they may be homologs of thecal characters, they are the defining features of the cyst. Cyst walls may be multi-layered, with cavities separating or partly separating the layers. The external relief of a dinoflagellate cyst may comprise a great variety of projections; these include some with distal interconnections that form an additional layer. The morphology, number and orientation of the distal process tips may indicate tabulation. Features may be sutural and/or gonal, intergonal or intratabular. Zones of incremental plate growth in the theca may be represented by pandasutural bands in the cyst. Other features such as claustra and the porichnion may occur. The development and functional morphology of the cyst wall are not well known; however, fossil evidence can limit the possibilities. The theca appears to have at least some role as a template for cyst development. Large processes and other ornament suggest a centripetal sense of development. However, further centrifugal growth of processes and other elements cannot be ruled out, and major restructuring of the cyst wall during its ontogeny may occur.

Chapter 5 described tabulation, which is the principal criterion used to classify and identify thecate dinoflagellates (Evitt 1985, p. 81–119). The complete tabulation of a theca can be obtained by dissection of the plates using sodium hypochlorite solution. By contrast, cyst tabulation is frequently expressed partially and variably, if at all. Separation of the plates in cysts is impossible because there are no true sutures between them except for the archaeopyle sutures. A variety of wall features and ornamentation of the cyst reflect thecal tabulation, which can be interpreted by the careful observation of well preserved material.

This account primarily described gonyaulacoid and peridinioid tabulation patterns, which are the two most commonly encountered in fossil cysts. Peridinioid cysts are relatively less diverse in their tabulation patterns than the gonyaulacoids are. Also, the Kofoidian system of plate labelling only rarely leads to non-homologous plates being given the same label in peridiniacean forms. This Kofoidian system of labelling is therefore adequate, and no new system was proposed for peridinioid patterns. However, for the more complicated and variable tabulation patterns of the gonyaulacoid group, Evitt (1985) modified the plate nomenclatural system first suggested by Taylor (1978, 1980). This is now referred to as the Taylor-Evitt system. The new system more clearly preserves homologies by giving equivalent plates the same label. The traditional Kofoidian tabulation nomenclatural scheme was not being used effectively, so Evitt (1985) developed a new scheme which concentrated on geographical plate homologs, rather than a more rigid and mechanistic plate numbering system.

Four groups of gonyaulacoid tabulation patterns, corniform, partiform, quinqueform and sexiform, were distinguished. These are all theoretically derived from a hypothetical precursor proposed by Taylor (1978, 1980), and modified by Evitt (1985). The four tabulation patterns were described in detail, with both Kofoidian and Taylor-Evitt labelling systems included, and including subdivisions and variations (Evitt 1985, p. 91–119). Evitt (1985, p. 117) concluded that cyst tabulation, including that of the sulcus, merits diligent investigation and thorough description, despite the frequent difficulty of study. Immediately following the publication of Evitt (1985), many authors began to provide both Kofoidian and Taylor-Evitt plate labelling systems on line drawings of dinoflagellate cysts (e.g. Dürr 1987, figs 2, 3; Riding 1987, figs 12–14). However, since the mid to late 1980s, the tendency has developed for researchers to use the Kofoidian plate labelling scheme in a strictly disciplined, interpretive and objective way, fully taking into account plate homologs.

Chapter 6 (Evitt 1985, p. 121–145) is on the archaeopyle and, as such, is an update of Evitt (1967c). The archaeopyle is the opening in the cyst wall through which the protoplast emerges during excystment. Typically, the archaeopyle is an operculate opening that corresponds to one or more plates, even when no other indication of tabulation is present. It is outlined by the principal archaeopyle suture, a cystomorphic feature that may be reduced or enlarged. Often, some of the tabulation pattern can be interpreted from the archaeopyle and/or the operculum. For example, peridinioid cysts can often be recognised because the archaeopyle consists of the distinctive anterior intercalary plates. Accessory archaeopyle sutures, if present, can yield more information on tabulation. Opercula or opercular pieces can be free, adherent or adnate. In peridinioid cavate cysts, there are usually two identical archaeopyles in each wall. By contrast, in cavate gonyaulacoid cysts there are two openings, but there is only one operculum made from endophragm (Eaton 1984). The archaeopyle type can be abbreviated; for example, type P is a monoplacoid archaeopyle formed by the complete release of the area corresponding to a precingular plate. A comprehensive survey of archaeopyle types, and ways of describing them, was given (Evitt 1985, p. 130–144). The taxonomic significance of the archaeopyle was debated. Although many genera and species are currently separated on the basis of archaeopyle type, the number of taxa that include more than one style of archaeopyle is growing. Evitt (1985, p. 145) commented that the use of archaeopyle type at the generic level to separate otherwise similar taxa is inappropriate.

9.6.3. Part III – Interpretation of the cyst (Chapters 7 to 13)

Part III (Evitt 1985, p. 147–297) is on the interpretation of dinoflagellate cysts and is, by some margin, the largest section of the book. It comprises seven chapters which are on guides to interpretation, analytical procedures, the seven major cyst/test morphological categories recognised, and thoughts on classification and evolution. In the introduction, Evitt (1985, p. 147–148) described the usual procedure that a palynologist might undertake in approaching a putative dinoflagellate cyst specimen. This is: (i) a survey of basic morphology, eventually leading to identification as a dinoflagellate cyst; (ii) comparison of the morphology observed with some models, or comparison to the literature; (iii) hypothesis; (iv) testing; and (v) conclusions. The chapters in this section were intended to convey the procedure and models with which to form these hypotheses, test them and draw conclusions, i.e. to interpret the morphology of dinoflagellate cysts.

Chapter 7 of Evitt (1985 p. 149–170) explored principles of interpretation and reasoning, or 15 things to bear in mind when studying dinoflagellate cysts. While most of these principles seem relatively intuitive once stated, the fact that Bill could synthesise and eloquently state what probably amounted to a lifetime of experience is remarkable. Most experienced microscopists will be familiar with most of these principles, but Bill remains the only person to have enunciated them in his usual clear, erudite style. One example is Bill's principle 3: Coordinated Displacement ('If a specimen is rotated, all its visible features will appear to be displaced in a coordinated way', Evitt 1985, p. 151). This helps with the interpretation of specimens in a permanent mount which may not be in a favourable orientation for comparison with other material. Another important principle is 4: Triple Junctions ('The great majority of plates meet at triple junctions', Evitt 1985, p. 152). This enables the full tabulation to be interpreted, even if plate sutures are incompletely expressed (Evitt 1985, fig. 7.2). These are among the first principles he taught his graduate students, and to those who took his short course. Other aspects of the study of dinoflagellate cysts discussed in this section include 2: Spherical Concealment; 6: Uncommon Concavity; 7: Minority Suppression; 8: Centripetal Projection; and 13: Variable Variables. The final section was on interpreting the literature (Evitt 1985, p. 194–170). This was a very sensitively worded piece about how one can interpret legacy papers on dinoflagellate cysts in the light of the modern understanding of tabulation patterns. It constructively encouraged an analytical and critical, rather than a passive, approach to previous research on the descriptive taxonomy of dinoflagellate cysts.

Chapter 8 (Evitt 1985, p. 171–188) followed on logically from the comprehensive descriptions of morphological features in Part II, together with the interpretational principles in Chapter 7. An analytical procedure for a given specimen, including a checklist of features to be observed if possible, was provided (Evitt 1985, p. 173). Next, a strictly morphologically based set of 17 suprageneric morphological dinoflagellate cyst categories were defined. These are all within seven major categories, namely D-tests, G-cysts, M-cysts, N-cysts, P-cysts, R-cysts and S-cysts. The first two major categories to be defined were both monogeneric and have unique characteristics; these are D-tests for *Dinogymnium*, and N-cysts for *Nannoceratopsis*. Other major categories were subdivided; for example, the G-cysts (gonyaulacoids) were placed into one of eight subcategories. These include Gc-cysts, which are corniform genera which belong in the family Ceratiaceae. At the time Evitt (1985) was written, there was no suprageneric classification encompassing both dinoflagellate cysts and thecae. Subsequently, the 17 morphological cyst categories guided the suprageneric classification of Fensome et al. (1993). A key to the 17 morphological categories was given in Evitt (1985, fig. 8.1), and the remainder of Chapter 8 is a detailed discussion of the key and its application.

Chapters 9 to 12 inclusive (Evitt 1985 p. 189–272) described in more detail the characteristics of the 17 morphologically based cyst categories introduced in Chapter 8 (see above). The morphology of P-cysts was documented in Chapter 9, G-cysts were described in chapters 10 and 11, and all of the other categories (D-tests, M-cysts, N-cysts, R-cysts and S-cysts) were chronicled in Chapter 12. Some morphological categories were further subdivided into 'complexes' named after prominent genera. For example, the category of Pp-cysts was divided into the *Ascodinium*, *Deflandrea*, *Palaeoperidinium*, *Phthanoperidinium*, *Selenopemphix* and *Spinidinium* complexes (Evitt 1985, p. 190–195). Dichotomous botanical keys were included for the morphological categories to help distinguish these complexes. Each chapter also included several additional selected topics regarding the respective cyst types discussed. The horns of *Muderongia*, and the extremely important *Spiniferites* complex, were treated at the close of Chapter 10. The wealth of information contained in these four chapters is too overwhelming to adequately summarise in detail. They represent an authoritative and comprehensive, yet succinct, synthesis on the morphology of every significant dinoflagellate cyst genus known at the time. The chapters were illustrated with many high-quality line drawings which clearly set out interpretations of tabulation including many subtle details.

Chapter 13 (Evitt 1985, p. 273–297) tackled the classification and formal taxonomy of dinoflagellate cysts and thecae. The account aimed at the future, and stated early on what an ideal classification that included both fossil and modern dinoflagellates would look like at the supergeneric, generic and species levels. It is certain that the authors of Fensome et al. (1993) were significantly influenced by this synthesis. Dinoflagellate classifications and phylogenies from Eisenack (1961) onwards were reviewed. This section (Evitt 1985, p. 277–285) comprises some personal comments on the schemes of, for example, Norris (1978a, 1978b), Dörhöfer & Davies (1980), Eaton (1980) and Bujak & Davies (1983), including both perceived shortcomings and virtues. Throughout, Bill emphasised the limitation of the dinoflagellate fossil record which severely limits phylogenetic interpretations. Through a discussion of the ideas of Taylor (1978, 1980), Evitt (1985, p. 285–297) synthesised the intriguing and speculative hypothetical derivations of tabulation in the Peridinales. The expressed purpose of this was to evoke future discoveries of evidence to disprove or support this putative evolutionary process. This textbook was concluded with an endpiece which amplified the conclusions of Taylor (1980) to ‘place sporopollenin-producing dinoflagellates in perspective with the dinoflagellates as a whole’ (Evitt 1985, p. 299).

9.6.4. Reviews

Evitt (1985) was reviewed by, for example, Masure (1986) and Sarjeant (1986). The first of these was a short, rather descriptive account in French. Sarjeant (1986), however, was an extended review by one of Bill’s contemporaries (subsection 5.5.1). Sarjeant (1986) discussed several areas of disagreement. For example, he had an issue with the title in that dinoflagellate cysts frequently react differently to biological stains than pollen and spores. Therefore Sarjeant (1986) did not believe that organic-walled dinoflagellate cysts were made from sporopollenin *sensu stricto*. He further commented that the book had been a long time in production, such that this long-awaited tome would render all pre-existing ideas on dinoflagellates out of date.

Several more explicit criticisms were made. Sarjeant (1986) did not like aspects of Bill’s morphological terminology, the two-column format, the use of complex archaeopyle formulae in the running text and the lack of cross-referencing. The latter point could have been overcome with a glossary. The comments on morphological terminology were based on Sarjeant’s belief that Bill had not delivered on his promise to simplify this important aspect (Evitt 1985, p. xiv). Other objections included the use of ‘monoplacoid’, ‘biplacoid’

and ‘polyplacoid’ for one-plate, two-plate and multi-plate archaeopyles, respectively. Sarjeant (1986) also did not agree with the use of ‘descending’ and ‘ascending’ for laevorotatory and dextrorotatory cingulums (Evitt 1985, fig. 3.1C). A lengthy critique on the use of the term ‘autophragm’ was also given. The continued use of the ‘para-’ terminology in Evitt (1985), despite the work of Norris (1978b), was also criticised by Sarjeant (1986).

It is clear that Sarjeant would have preferred a more concise book. He felt that the wealth of new information was overwhelming. In particular he felt that special themes, such as the treatment of *Oligosphaeridium abaculum* (see Evitt 1985, p. 254–257), should have been made the topic of individual research papers. In the opinion of Sarjeant (1986, p. 283), Bill should have applied the new Taylorian plate labelling system to peridinioid dinoflagellates. However, Sarjeant clearly misunderstood that the hypothetical precursor tabulation used to derive the Taylor-Evitt scheme was uniquely developed for gonyaulacoids, and as such cannot be applied to peridiniacean forms. This is because the hypothetical precursor hypothesised by Taylor (1980) is part of an evolutionary progression from *Triadinium* to *Gonyaulax* (Evitt 1986, fig. 5.5). The Taylorian approach to tabulation which sought to replace Kofoidian nomenclature hence can only be applied to the gonyaulacacean lineage. Sarjeant (1986) clearly felt that Bill was somewhat overcritical when discussing the work of others. Examples given were the dismissal of some terms pertaining to dinoflagellate cyst cavation erected by Sarjeant (1982a), and the criticisms levelled at the interpretations of phylogeny and tabulation by Dörhöfer & Davies (1980) in Evitt (1985, p. 66, 282). Sarjeant (1986) termed these commentaries ‘cavalier’ and ‘unduly harsh’, respectively. All this being said, however, Sarjeant (1986) was largely a positive review of a major work by a respected colleague.

9.6.5. The ‘Blue Bible’ in retrospective

The ‘Blue Bible’ naturally was an instant classic and it has assuredly stood the test of time. Evitt (1985) has been widely cited, and is still being read by researchers on dinoflagellate cysts. The first edition has recently sold out, but the volume is still available digitally (<http://palynology.org/publications/>). Evitt (1985) is, as previously stated, essential reading for all students of fossil dinoflagellate cysts. However, both present authors are still somewhat surprised at the lack of photographic illustrations. The only photomicrographs included were 10 figures in the frontispiece (Evitt 1985, p. v). Four of these were SEM images, and six were transmitted-light photographs of Jurassic to

Palaeogene dinoflagellate cysts and modern dinoflagellate thecae. It seems somewhat odd that more photographs of dinoflagellate cysts and thecae were not included. This is despite the wealth of potential illustrative materials Bill had at his disposal at Stanford University. Bill and his students had built up an extensive collection of well preserved material from all over the world that he could have drawn upon to illustrate key aspects of morphology and tabulation in this book. By contrast, two of his major papers in the 1960s (Evitt 1961c, 1967c) were lavishly illustrated with nine and 11 plates respectively. The relative lack of photomicrographs in Evitt (1985) may have been related to the cost of reproduction. The present authors also agree with Sarjeant (1986) that some of the comments on some previous research were perhaps a little intemperate, and would have been better suited to confidential peer reviews.

10. The Teaching Conferences on Fossil Dinoflagellates (1971–1988)

In the spring of 1969, the palynologist John E. Bennett of the Atlantic Richfield oil company (ARCO) in Dallas, Texas visited Bill Evitt at Stanford University for two weeks. This was for informal, one-to-one, tutoring on dinoflagellate cyst morphology, and for John to study well-preserved material in Bill's collection on a consulting basis. Bill prepared teaching material, hand-outs and laboratory exercises covering the full extent of his knowledge on fossil dinoflagellates. After the two weeks, John Bennett felt that the experience had been extremely positive and worthwhile. He enthusiastically encouraged Bill to formalise the course into a structured training module specifically aimed at the significantly increasing numbers of industrial palynologists at this time. Bill was persuaded by John, and a course manual was produced. Subsequently, the first formal Teaching Conference on Fossil Dinoflagellates was presented to six industrial palynologists in the summer of 1971 at Stanford University. This course emphasised the morphology of dinoflagellate cysts, and their detailed study using the transmitted light microscope.

At the time, Bill expected this to be the first and the last course. Unsurprisingly, the inaugural event in 1971 was extremely successful, and he decided to present the course regularly during summers or sabbaticals in the future to between five and eight participants. Throughout the next 16 years the course was presented, on average, twice annually; the final one was held in Midhurst, West Sussex, United Kingdom, in 1988.

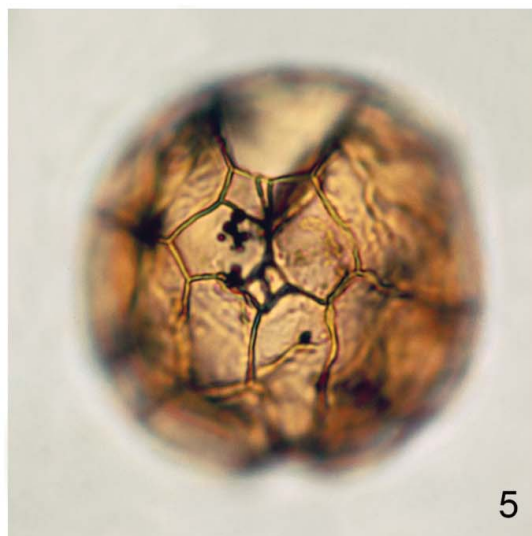
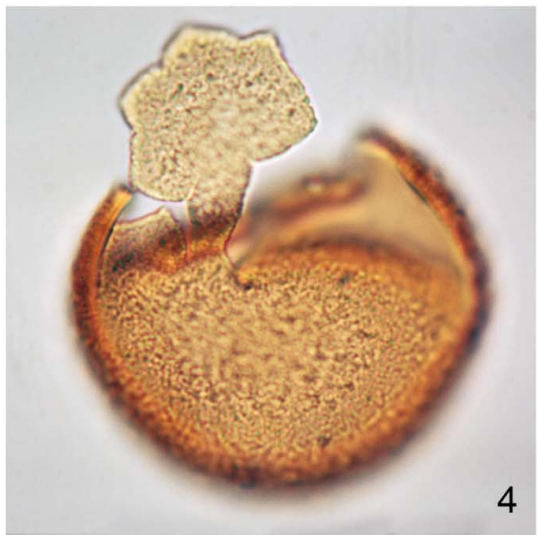
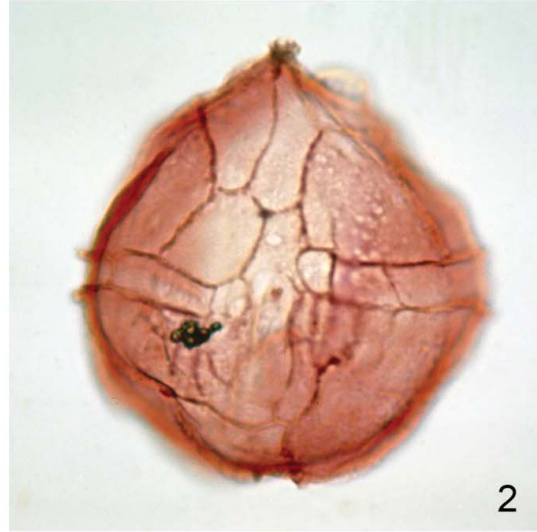
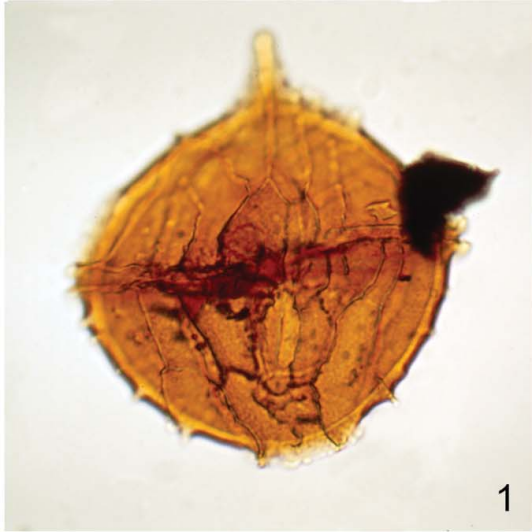
Like the first informal course, the structured presentations consisted of 10 days of study, with a field

trip during the middle weekend to collect living dinoflagellates using plankton nets. For the courses held at Stanford, Bill took the delegates to two local lakes or rocky promontories along the nearby Pacific coastline. Typically, they would catch abundant live and active dinoflagellates, largely *Ceratium*, with plankton nets. Generally this would be the first time these palynologists would have observed a living dinoflagellate, and the delegates were all enthralled by the spiral motion of the motile stages through the water (Fenchel 2001). For his courses held outside Stanford, Bill would research potential sources of living dinoflagellates. The first author recalls successfully fishing for dinoflagellates with Bill in the River Clyde in Glasgow, United Kingdom, during the 29th course in 1985.

The attendees spent extended periods at the microscope undertaking practical exercises supervised by Bill, and these sessions were regularly punctuated by lectures on a wide variety of topics centred around dinoflagellate cyst morphology. The courses were always very informal, and Bill immensely enjoyed the *ad hoc* input from the participants. In this sense, the courses were indeed 'Teaching Conferences' as they were badged. Bill very much enjoyed meeting and teaching other palynologists, and the courses were learning experiences for him as well as the participants. An example of this was in Oslo, Norway, in 1976. Bill stayed on after the course to work with Barrie Dale at the University of Oslo. At this time he became aware of the ideas of 'Max' Taylor on dinoflagellate tabulation (Taylor 1978, 1980), which profoundly affected Bill's understanding of this topic. Taylor was in Norway at this time, undertaking a sabbatical at the University of Oslo. Bill attended a talk given by Taylor, who he had never met before, on this visit and he immediately reported that it was the single most stimulating lecture he had ever heard! Bill could clearly see the potential of applying Taylor's hypotheses to fossil dinoflagellate cysts. Furthermore, it was evident that Taylor's understanding of the group would benefit from more insight into their fossil record. Bill spent the following day excitedly discussing Taylor's ideas with Barrie Dale.

Bill ran a seminar on tabulation at Stanford University immediately upon his return from Norway with Svein B. Manum of the University of Oslo, who was visiting Stanford on a sabbatical at that time, together with David K. Goodman and Jeffrey A. Stein, two of his graduate students. The results of this meeting directly led to Bill's ideas on the derivation, nomenclature and stability of dinoflagellate tabulation patterns that eventually were published in Evitt (1985; see subsection 9.6).

The first edition of the dinoflagellate cyst course manual was used for the first 15 presentations during



the 1970s. Our knowledge of fossil dinoflagellates significantly expanded during that decade, including 'Max' Taylor's theories on tabulation. Bill produced a second edition in May 1980, which was a complete revision of the original. Bill, by now, had commenced writing the text of his textbook *Sporopollenin dinoflagellate cysts – their morphology and interpretation* (Evitt 1985; see subsection 9.6), and the second edition of the course manual comprised excerpts from this working document. A third and final edition was produced in May 1983; this comprised only relatively minor changes from the second edition (Figure 24). The course manuals included text, exercises on tabulation and line drawings of specific dinoflagellate cyst specimens that Bill would bring along, and a set of 35-

mm transparency slides of exquisitely preserved material (Plates 1, 7, 8, 14). Many of these transparency slides referred to the practical exercises. Each delegate was given a wooden polo ball (~8 cm in diameter) painted white and with the standard gonyaulacacean tabulation pattern marked on it for use as a teaching aid (Plate 15). One of the first practical exercises in the course was to mark the plate numbers on this model. Bill also encouraged delegates to use glass chemistry flasks as study aids. If the tabulation pattern is drawn onto a glass sphere, this particularly helps with the interpretation of the tabulation of the lower surface of a dinoflagellate cyst (Figure 17). The lower surface of the specimen appears reversed because it is viewed through the upper surface, and hence the plates are

Plate 14. Six of the 35-mm transparency slides included in the ringbound file of course materials that Bill Evitt provided to participants of the two-week Teaching Conferences on Fossil Dinoflagellates (section 10). These slides accompanied the practical exercises and the specimens for study. These four specimens are all acavate, gonyaulacacean and proximate. All of the images are reproduced with the approval of the Evitt family.

Figure 1. *Cribroperidinium orthoceras*; ventral view, high focus; Lower Cretaceous (Barremian), The Netherlands. This was slide 19. Note the solid apical horn, the relatively thick, smooth autophragm with scattered tubercles and the prominent intratabular ridges/sutures. *Cribroperidinium orthoceras* was first described from the Lower Cretaceous (Upper Aptian) of northern Germany by Eisenack (1958). It is similar in morphology to *Cribroperidinium? edwardsii*, and Davey & Verdier (1971, p. 17), Stover & Evitt (1978, p. 150) and Lentin & Williams (1981, p. 60) deemed these species to be synonyms. However, Below (1981, p. 39), Helenes (1984) and Lentin & Williams (1985, p. 79) maintained both taxa as separate entities. The justification for the latter action is the presence of intratabular spines or tubercles in *Cribroperidinium orthoceras* which are visible on this specimen. The specimen figured here exhibits relatively sparse intratabular tubercles and small sutural spines. These are both slightly more prominent on the hypocyst than the epicyst. This species has a range of latest Jurassic (Tithonian) to Late Cretaceous (Santonian), according to Helenes (1984, fig. 3). The overall length of this specimen is 115 µm, and it is 105 µm in maximum width.

Figure 2. *Cribroperidinium* sp.; ventral view, high focus; Muddy Formation, Lower Cretaceous (Albian), Wyoming. This was slide 7. *Cribroperidinium* is a highly diverse and morphologically variable genus with many unpublished morphotypes (Davey 1982; Helenes 1984). This is a form which is subspherical in dorsoventral view and lacks prominent intratabular ridges/sutures; it is most similar to species such as *Cribroperidinium giuseppei*. Note also the short apical protuberance, the smooth, sporadically perforate autophragm and the well-defined tabulation indicated by the low, distally smooth sutural crests. The tabulation clearly indicates that this is a sexiform gonyaulacacean morphotype with L-type ventral organisation. The overall length of this specimen is 66 µm, and it is 64 µm in maximum width.

Figures 3, 5, 6. *Leptodinium mirabile*; Naknek Formation, Upper Jurassic, Amber Bay, southwest Alaska (Albert 1988; 1990). Ventral view (figure 3), apical view (figure 5) and antapical view (figure 6), all in high focus. These were slides 4 to 6. Note the acavate, proximate cyst organisation, the smooth autophragm, the subpentagonal dorsoventral outline, the low, smooth sutural crests and the single-plate precingular archaeopyle. *Leptodinium mirabile* is an excellent example of a sexiform gonyaulacacean species with L-type ventral organisation (Evitt 1985). It is one of the rare examples of a species which exhibits a complete ventral tabulation pattern. Sutures clearly demarcate the five plates in the sulcus (i.e. as, ras, rs, ls and ps), the flagellar scar and the first postcingular plate (1''). It has two preapical plates and two anterior intercalary plates; hence, the tabulation formula is 2pr, 4', 2a, 6'', 6c, 6''', 1p, 1''''', 5s. The sample from the Naknek Formation of Alaska is especially rich in *Leptodinium mirabile*, and *Gonyaulacysta dualis* is also present in lower proportions. *Leptodinium mirabile* was originally described from the Middle Oxfordian of southwest Germany by Klement (1960), and restudied by Sarjeant (1984b). It is a reliable marker for the Late Jurassic (Middle Oxfordian to Kimmeridgian) of Germany (Brenner 1988; Feist-Burkhardt & Wille 1992), but is rarely encountered in significant numbers in Europe. The superabundant material from the Naknek Formation of Alaska is, by comparison with lower latitudes, highly unusual, and indicates that *Leptodinium mirabile* was an Arctic/Boreal form, which was suggested independently by Riding & Hubbard (1999, p. 26). Its association here with the definite Arctic species *Gonyaulacysta dualis* is additional evidence of this (Brideaux & Fisher 1976). Figure 3 is 105 µm long and 90 µm wide. Figure 5 is 95 µm in overall diameter. Figure 6 is 80 µm in dorsoventral width, and 70 µm in lateral width. The Alaskan material appears to be somewhat larger than the type material. For example, the holotype from Germany is 81 µm long, and 70 µm wide (Klement 1960, p. 50; Sarjeant 1984b, p. 165). Figure 4. *Kallosphaeridium* sp. cf. *K. capulatum*; ventral view, high focus; Aquia Formation, Paleocene, Virginia. This was illustrated as *Kallosphaeridium* sp. in the course manual, and was slide 15. Note the acavate cyst organisation, the relatively thick, scabrate autophragm, the subcircular outline and the apical archaeopyle with an attached operculum. The prominent angulation at the dorsal side of the attached operculum clearly indicates the presence of a relatively large anterior intercalary (1a) plate (Jan du Chêne et al. 1985, figs 1–7). This 1a plate is diagnostic of this genus. The operculum is attached ventrally at the as/1' plate boundary, and comprises all four apical plates plus the 1a plate. The only indications of tabulation are the archaeopyle sutures. The equatorial width of this specimen is 72 µm.

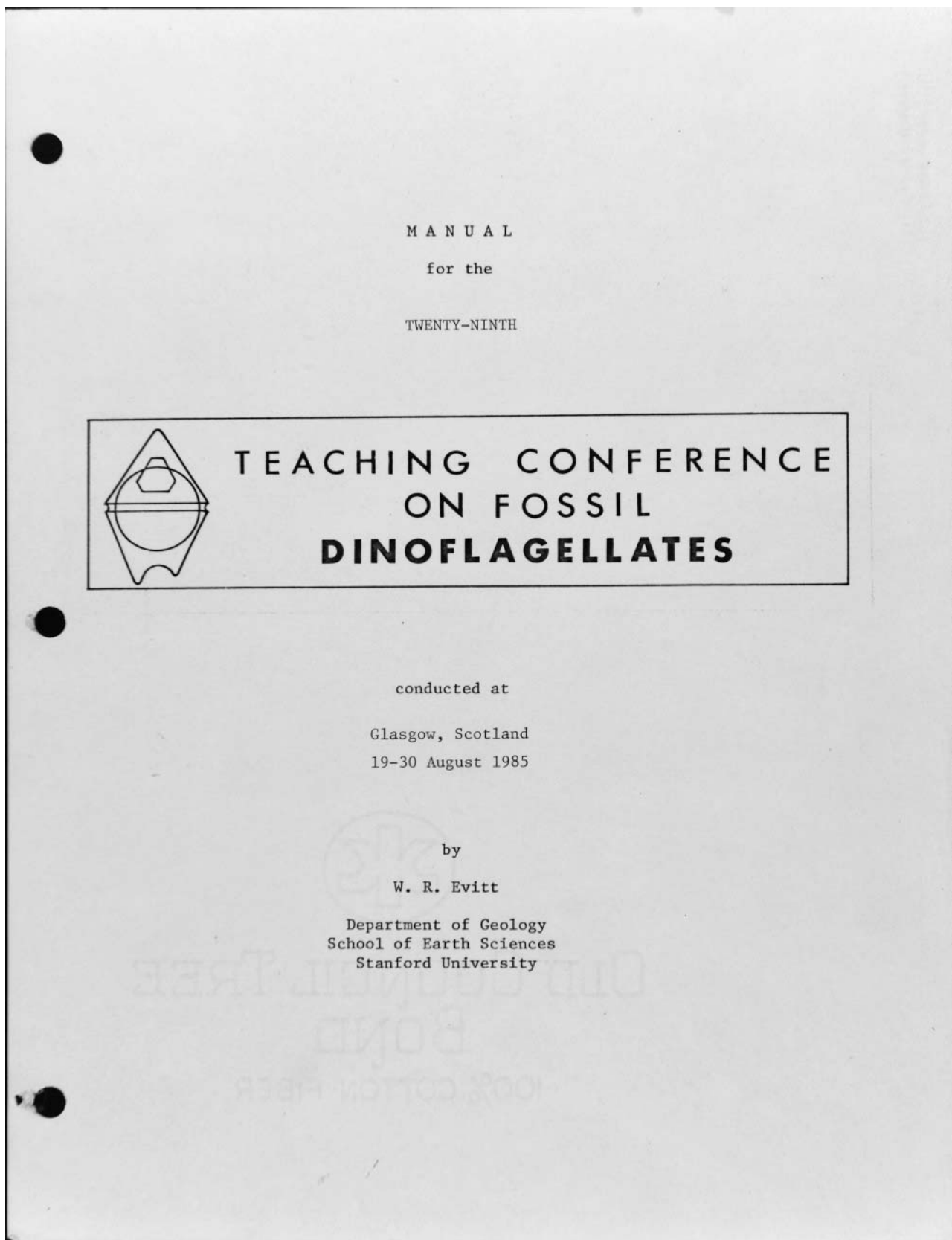


Figure 24. The front cover of the manual for Bill Evitt's 29th Teaching Conference on Fossil Dinoflagellates (section 10). It represents the third and final edition of this document. This short course on dinoflagellate cysts was held in Glasgow, Scotland, between 19 and 30 August 1985. The image is reproduced with the approval of the Evitt family.

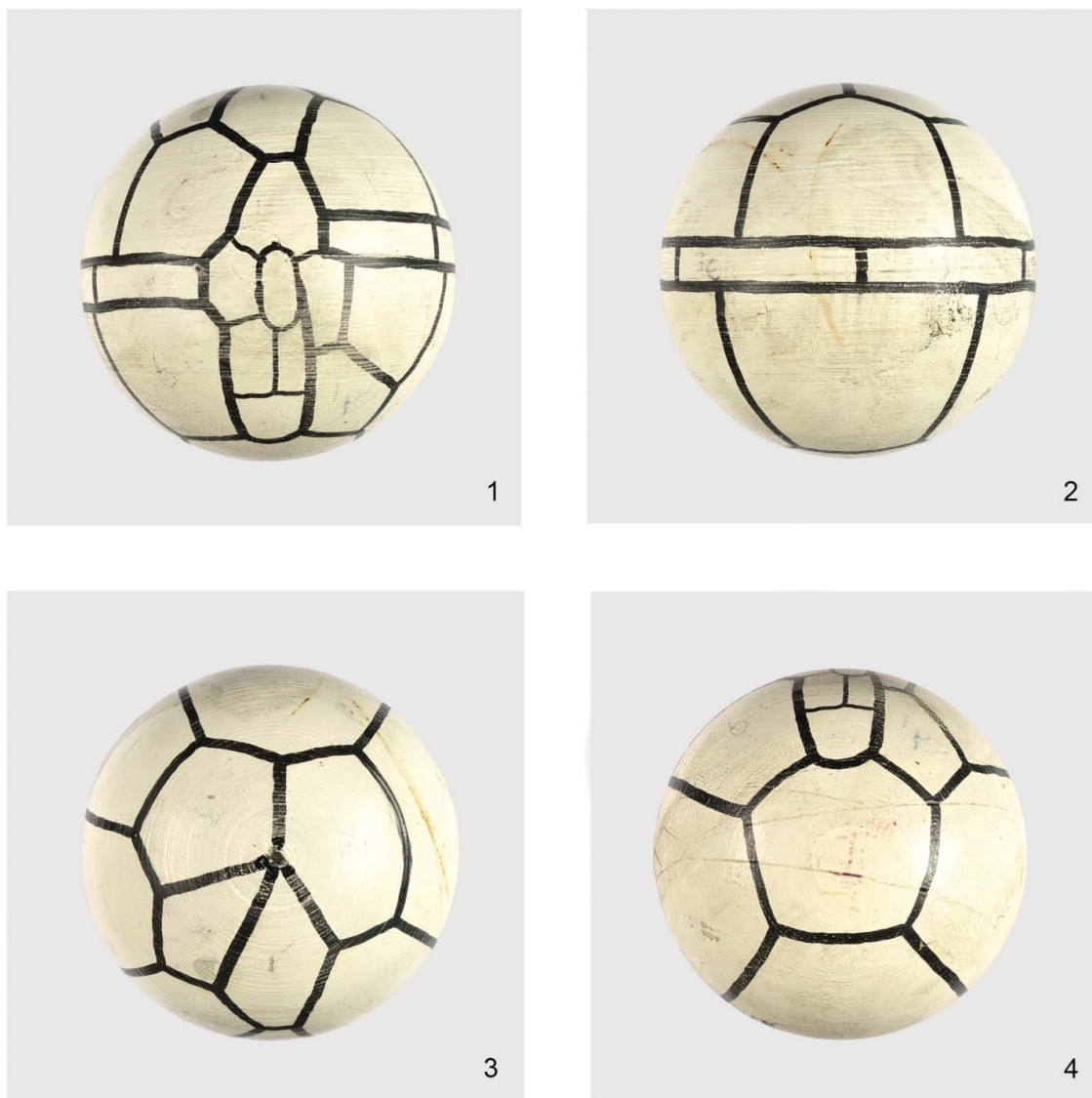


Plate 15. The model of the tabulation in gonyaulacacean dinoflagellates used by Bill Evitt for his Teaching Conferences on Fossil Dinoflagellates (section 10). It is based on a sexiform gonyaulacoid form which exhibits neutral torsion, and has a longitudinal (L-type) sulcus which is subdivided into platelets (Evitt 1985). A candidate genus would be *Leptodinium*. The tabulation formula is: 4', 6'', 6c, 6''', 1p, 1''''', 6s. No preapical plates were represented, in the interests of simplicity and because of the great variability of these small plates (Evitt 1985, figs 5.8, 5.12, 5.16). This model is simply a wooden polo ball which has been painted white and annotated. The polo ball is 8.5 cm in diameter. Note the faint traces of plate numbering made by one of us (JBR). Figure 1. mid-ventral view; figure 2. mid-dorsal view; figure 3. apical view, sulcus facing downwards; figure 4. antapical view, sulcus facing upwards.

seen in mirror image. Thus the lower surface of the glass sphere, viewed through the upper surface, provides an interpreted plate pattern when viewed from any angle. These annotated glass spheres can therefore quickly enable a reversed plate pattern to be recognised.

The participants also received two glass microscope slides. One of these was a strew mount of theca of the modern freshwater dinoflagellate species *Ceratium hirundinella*; the other was a slide containing abundant and well-preserved dinoflagellate cysts.

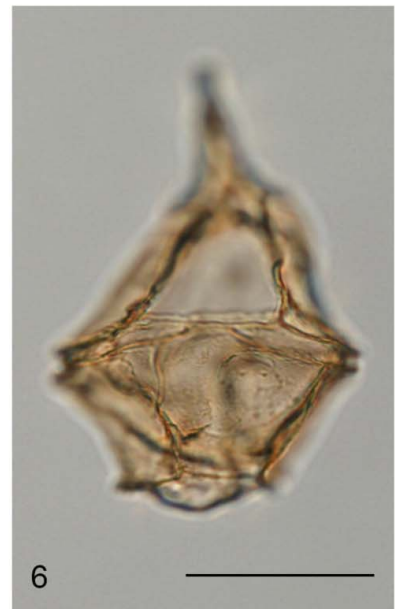
The latter were either *Gonyaulacysta dualis* or *Leptodinium mirabile* from the Upper Jurassic of Alaska (Plates 2, 16).

The Teaching Conference on Fossil Dinoflagellates was presented 36 times during a 17-year period to over 230 delegates, who all benefited significantly from Bill's experience and knowledge without the need to do a PhD at Stanford University. The courses also helped to put Bill's three sons through college, and enabled him to spend his summers doing research. The participants, the majority of whom were industrial

palynologists, inevitably shared their course manuals with their immediate colleagues; hence, Bill's ideas on dinoflagellate cysts were very widely disseminated well before the publication of Evitt (1985). This meant that Bill helped to train, often indirectly, most oil company palynologists in the western world. This inevitably would have enhanced exploration and production outcomes, contrary to the shouts of 'Ok – but where's the oil?!' mentioned in the Preface. Just under half (15) of the 36 courses were presented at Stanford, but Bill also gave the course in Houston, Texas, and outside the United States. The overseas venues included France

(Bordeaux), the Netherlands (Utrecht), Norway (Bergen, Oslo and Stavanger) and the United Kingdom (Glasgow, Midhurst and Sunbury-on-Thames). Bill often gave the course twice in succession when he went overseas. The courses proved extremely popular, and typically they were booked up for three or four sessions in advance. When the three Evitt boys had left home to go to college, Gisela accompanied Bill on the overseas trips, and they frequently took holidays either before or after the courses.

The first author attended the 29th Teaching Conference on Fossil Dinoflagellates, held in Glasgow



between 19 and 30 August 1985. This was run directly after Dino 3 at Egham, Surrey, England (11–17 August 1985). Bill gave the 28th course immediately prior to Dino 3, so he had an extended visit to Europe during the year that Evitt (1985) was published. The courses were of course very well planned and executed. Bill tailored his delivery of the course appropriately, taking into consideration the palynological experience of the attendees. The pace was such that one could assimilate the course materials effectively and steadily. A general introduction to the dinoflagellates was presented, then Bill equally split the remainder of the course on gonyaulacacean and peridiniacean dinoflagellate cysts. The lectures were varied, and included entire sessions on his favourite dinoflagellate cysts such as *Gillinia hymenophora*, *Palaeoperidinium pyrophorum* and *Spiniferites*. The first practical sessions initially comprised paper exercises where delegates would fill in the plate numbers on some drawings of idealised specimens (e.g. Evitt 1985, figs 5.2, 5.10, 5.11 and 5.13). After these theoretical exercises, selected specimens were studied, the aim of this being to interpret morphology and tabulation, making sketches and/or filling in drawings which were provided. Bill provided a set of microscope slides with marked specimens that the students would study by rotation. The courses included lunches and refreshment breaks, and Bill took all these with the attendees. The first author vividly recalls Bill recounting anecdotes from his European tour of 1959 (subsections 5.5.2 and 5.5.3), and giving personal reminiscences about his many acquaintances including Isabel Cookson, Georges Deflandre and Alfred Eisenack. He would describe his interactions with various

colleagues, and what their laboratories were like. These recollections included a preparation facility in Europe which vented acid fumes directly into the loft space of an old building, thereby causing great damage! Bill also loved telling interesting stories involving preparation techniques. He would sometimes become very animated on this topic. One of us (JBR) recalls Bill recounting the development of palynomorph extraction procedures at Carter/Jersey in Tulsa, and at Stanford University. This included how he would try to observe palynomorphs being extracted from sedimentary rocks under a stereomicroscope using dilute hydrochloric and hydrofluoric acids. An example of this was the etching of dinoflagellate cyst-bearing chips of flint with very dilute hydrofluoric acid, referred to in section 8.

11. The International Conferences on Modern and Fossil Dinoflagellates

11.1. Introduction

Bill Evitt organised the first ever scientific gathering specifically on dinoflagellates and their cysts. This was a forum on this topic held at Anaheim, California, on 16 October 1973 as part of the Sixth Annual Meeting of the AASP (Figure 25). The symposium comprised six keynote presentations followed by panel discussions on biostratigraphy and other aspects; it was subsequently published as (Evitt 1975d).

Perhaps due to Bill's great success with the 1973 meeting at Anaheim, during the mid 1970s, Graham L. Williams urged Bill and Lew Stover to organise a

Plate 16. *Leptodinium mirabile* and *Gonyaulacysta dualis* from microscope slides distributed by Bill Evitt at his Teaching Conferences on Fossil Dinoflagellates (section 10).

Figures 1–3. *Leptodinium mirabile*. Specimen from the Upper Jurassic Naknek Formation of Amber Bay, southwest Alaska. Stanford University palynology sample PL 5004. This slide was distributed on the 29th course held at Glasgow, Scotland, between 19 and 30 August 1985. BGS specimen number MPK 14561, England Finder coordinate N39/1. Ventral view; high- to low-focus sequence. *Leptodinium mirabile* was comprehensively described in the caption to Plate 14. In figure 1, note the five extremely clearly defined sulcal plates (i.e. from the top, the as, ras, rs, ls and ps) plus the flagellar scar and l^{'''}. The relatively low, distally smooth sutural crests are clearly visible in figure 2, and the orientation of the specimen is such that the large, quadrangular mid-dorsal postcingular plate is very prominent in figure 3. This extremely well-preserved specimen is 89 µm long, and 87 µm wide. The scale bar in figure 3 represents 50 µm.

Figures 4–6. *Gonyaulacysta dualis*. Specimen from the Upper Jurassic Naknek Formation of Amber Bay, southwest Alaska. Stanford University palynology sample PL 5002. This slide was distributed at the 20th course held at Sunbury-on-Thames, England, between 10 and 21 August 1981. BGS specimen number MPK 14562, England Finder coordinate K37. Ventral view; high- to low-focus sequence. Note the elongate outline, the prominent apical horn, the bicavate cyst organisation, the distally smooth sutural crests, the precingular archaeopyle and the displaced endopericulum. The endocyst is subovoid with a prominent apical protuberance, and an antapical claustrum (opening) is present in the posterior sulcal (ps) plate (Evitt 1985, fig. 4.6P). *Gonyaulacysta dualis* differs from *Gonyaulacysta jurassica* subsp. *jurassica* by having dominantly distally smooth sutural crests (Brideaux & Fisher 1976, pl. 1, figs 4, 5; Jan du Chêne et al. 1986b, pl. 37, figs 11, 12). By contrast, the former is characterised by densely denticulate sutural crests. Sarjeant (1982b, p. 18, 29) deemed *Gonyaulacysta dualis* to be a junior synonym of *Gonyaulacysta jurassica*; however, Jan du Chêne et al. (1986b, p. 131) retained the former name. The *Gonyaulacysta jurassica* group are characterised, amongst other features, by a long epicyst and a relatively short hypocyst (Stover & Evitt 1978, p. 275–278). This species was first described by Brideaux & Fisher (1976, p. 18–20) as *Psaligonyaulax dualis* from the Late Jurassic (Upper Oxfordian to Upper Kimmeridgian) of Arctic Canada; it is a distinctly Boreal taxon. This very-well-preserved specimen is 118 µm long, and 73 µm wide. The scale bar in figure 6 represents 50 µm.



Figure 25. A photograph of the team of 10 panellists and speakers at the ‘Forum on Dinoflagellates’ organised by Bill Evitt and held on the first day of the 6th Annual Meeting of the AASP at Anaheim, California. This forum took place on 16 October 1973, and the panel held a discussion on dinoflagellate cyst biostratigraphy and related topics during the afternoon. The members of the panel are, from left to right: Lewis E. Stover, Warren S. Drugg, Marcel E. Millioud, Graham L. Williams, Geoffrey Norris, David Wall, William A.S. Sarjeant, Bill Evitt, David J. McIntyre and Wayne W. Brideaux. This image is from Evitt (1975d, p. v), and is reproduced with the permission of AASP – The Palynological Society.

major conference on both fossil and modern dinoflagellates. Graham Williams was the instigator of the famous ‘Lentin and Williams’ indexes of dinoflagellate cysts (e.g. Fensome & Williams 2004). The ultimate vision of Graham Williams was a gathering designed to unify researchers who shared an interest in this remarkable group of protists. At that time, it was clear that fossil specialists knew little about the biology of modern dinoflagellates. Similarly, the biologists did not fully comprehend the scope of the dinoflagellate fossil record. As a consequence of these promptings, Bill, Lew and Karen Steidinger successfully organised such a meeting in 1978. This symposium was such a great success that similar conferences, informally termed the ‘Dino meetings’, have been held approximately every four years (Head & Harland 2013).

11.2. *The Penrose Conference on Modern and Fossil Dinoflagellates (1978)*

As a direct result of the entreaties of Graham Williams, Bill Evitt, Lew Stover and the biologist Karen A. Steidinger sought financial support from the GSA for a

Penrose conference on dinoflagellates. Richard A.F. Penrose, Jr. (1863–1931), a mining geologist and entrepreneur, was very active in and a major benefactor of the GSA, and the Penrose conferences are named after him (Stanley-Brown 1932). The GSA instigated the Penrose conference series in 1969 in order to bring together multidisciplinary groups of earth scientists, to facilitate open discussions of ideas in an informal atmosphere and to stimulate individual and collaborative research with no commitment to publication (<http://www.geosociety.org/penrose>).

The GSA agreed to fund this meeting, and the Penrose Conference on Modern and Fossil Dinoflagellates was held at Colorado Springs, Colorado, between 16 and 21 April 1978. The conference was originally due to be held in the Rocky Mountain ski resort of Vail, Colorado, but a highly contagious outbreak of a viral gastric sickness necessitated a change of venue with only a few days’ notice. It was not a fully open meeting; the 68 delegates (including eight students) were a mix of palaeontologists (~60%) and biologists (~40%), and were all invited (Figure 26). However, it was apparently possible to request an invitation (personal



Figure 26. The group photograph taken at the Penrose Conference on Modern and Fossil Dinoflagellates held at Colorado Springs, Colorado, in April 1978. Bill Evitt is seated in the second row from the front, and is the fourth person from the left. He is sporting a 'Stanford Palynology' t-shirt with the famous SEM image of *Peridinium limbatum*, and is flanked by co-organiser Karen Steidinger on his right and Lois Elms on his left. Lew Stover, the other main proponent of the meeting, is sixth from the left on the same row and is clearly enjoying a joke with Lucy Edwards to his left. The names of all participants were given in Head & Harland (2013, p. 4). The image was supplied by Martin Head, and is reproduced with permission.

communication, Lucy E. Edwards to JBR). Most attendees were from North America (56), but 12 delegates from Argentina, Australia and Europe also participated.

At this Penrose conference, the two groups, i.e. biologists and geologists, spent a considerable time explaining and defining concepts and terminology in order to ensure mutual understanding before the more formal scientific presentations. Discussions then followed on a very broad range of topics including blooms, classification, ecology, evolution, the fossil record, geographical distributions, life cycles, morphology, the origins of dinoflagellates, plate homologies, plate imbrication patterns, plate labelling, selective preservation, tabulation and taxonomy. There were several keynote presentations by invited speakers, who were given the specific task of communicating to both disciplines. Particularly lengthy discussions took place on the evolution of dinoflagellates, and whether a decrease or an increase in plate numbers with time represented an evolutionary progression (Bujak & Williams 1981). Bill stressed that the dinoflagellate fossil record is profoundly incomplete, and how the disjunct lineages may engender spurious conclusions on aspects such as bioproductivity and evolution (subsection 9.4). Furthermore, Bill noted how the classic Kofoidian

plate notation can frequently obscure morphological homologues, and hence evolutionary relationships. Some of the talks at Colorado Springs on plate imbrication patterns represented the first ever discussion of this phenomenon. Also prominent were debates on the role of dinoflagellate cysts in seeding red tides, and the fact that some modern dinoflagellate cysts are, in purely morphological terms, acritarchs.

Sarjeant (1998, p. 8) recalled Geoff Eaton's presentation on the development of dinoflagellate plate patterns, and a talk by Geoff Norris on dinoflagellate evolution. These were later published as Eaton (1980) and Norris (1978a), respectively. It quickly became clear that, in the late 1970s, workers on modern dinoflagellates were largely unaware of the extensive, rich and diverse fossil record of dinoflagellate cysts. Likewise, the geological community was not cognisant of the expansion in knowledge of the morphology of living dinoflagellates, for example the eyespot (Sarjeant 1998, p. 8). This conference was universally deemed to have been a resounding success, and valuable cross-discipline liaisons were made which eventually led to significant collaborations across the two communities. A short report on the meeting was published as Evitt et al. (1979).

11.3. *The International Conferences on Modern and Fossil Dinoflagellates (1981 onwards)*

The Penrose meeting in 1978 was so successful that the now-united community of dinoflagellate researchers organised similar international unified fossil/modern dinoflagellate conferences approximately every three to five years following the Colorado Springs meeting. The subsequent symposia were open to all interested parties, and the next one was organised by Hans Gocht and Harald Netzel; it was held in Tübingen, Germany, in early September 1981 (Head & Harland 2013, fig. 2). This was playfully entitled the ‘Hexrose meeting’. The tradition was continued further, and these meetings are now colloquially termed the ‘Dino meetings’. At the time of writing, the last one was Dino 10, a joint meeting led and organised by AASP – The Palynological Society, and held in San Francisco, California, during late October 2013 (Clark et al. 2013). The history of the first nine ‘Dino meetings’ was comprehensively documented by Head & Harland (2013). Each one seems to have had an especially memorable aspect. Examples include the wider realisation of the abundance and diversity of calcareous dinoflagellates at the ‘Hexrose meeting’ in 1981, the concept of ‘round brown’ dinoflagellate cysts at Dino 3 (or ‘Heptrose’) in 1985 and the toxic dinoflagellate *Pfiesteria piscicida* or ‘phantom dinoflagellate’ (Burkholder et al. 1992; Burkholder & Marshall 2012) at Dino 5 in 1993.

Bill attended most of the post-Penrose ‘Dino meetings’. His *magnum opus* (Evitt 1985) was published only weeks prior to Dino 3 at Egham, Surrey, United Kingdom, in August 1985. Bill gave a keynote talk at this meeting, summarising the new Taylor-Evitt tabulation scheme. The last one he attended was Dino 6 held in Trondheim, Norway, in June 1998, where he was awarded an honorary membership to the Palaeobotanical and Palynological Society of Utrecht (Appendix 1). Bill was wholeheartedly of the view that the ‘Dino meetings’ have, over the years, significantly aided communication between biologists and geologists. Specifically, he felt that the collaboration between the geologist Rob Fensome and the biologist ‘Max’ Taylor, which led to the publication of the unified suprageneric classification of fossil and living dinoflagellates (Fensome et al. 1993), would never have materialised without the galvanising effect of the ‘Dino meetings’. The principal importance of Fensome et al. (1993) is that the community of dinoflagellate researchers are now fully aware of the need for a totally integrated classification scheme.

12. Life in retirement

Bill Evitt officially retired from Stanford University after 26 years of service, on 1 January 1986. However,

he taught part-time at Stanford, and continued to present the Teaching Conferences on Fossil Dinoflagellates, for two more years. Hence, his full retirement came during 1988 at the age of 65. He chose to retain an office at Stanford University and moved within the Department of Geology in 1988, where he was given all the usual facilities except a preparation laboratory. However, Bill’s situation was severely disrupted on 17 October 1989 when the Loma Prieta earthquake hit the San Francisco Bay Area. This major earthquake was a 6.9 on the Richter scale, and was caused by a significant movement of the nearby San Andreas Fault (Berroza 1991). It damaged the Department of Geology building significantly, and all personnel were moved to temporary accommodation at another location on the campus. This major perturbation caused Bill to radically rethink his retirement plans. Over the years he had developed several non-geological interests and pastimes, and he felt that the time was now right for a clean break from his research. The only scientific projects he completed after the earthquake were the major paper on *Palaeoperidinium* (see Evitt et al. 1998), and a restudy of some of Alfred Eisenack’s Eocene and Quaternary material from the Baltic Sea area (Evitt 2001). When Bill finally ceased his research in 1989, he gave the dinoflagellate cyst card index and his reprints to CENEX at Louisiana State University.

Bill loved to work with wood, and made many utilitarian household objects during his retirement. He also took up handweaving and handspinning so that he could share Gisela’s interest in textiles, which she began in 1965. Bill and Gisela even raised their own silkworms. During his working life, Bill was only able to dabble in these activities. At the time of the sale of the Old Stone House in 1979 (subsection 2.1), Bill brought over an old spinning wheel to California which had been in the attic of the old family home when the Evitt family moved there in 1928. The landlady of the property, Mrs Laura Garcelon, vividly recalled her mother spinning wool on it. Bill’s parents brought it down from the attic, cleaned it up, and used ‘the great wool wheel’ as an *objet d’art* or a piece of furniture; it was never used for spinning. However, when Bill brought it over to Palo Alto in 1979, he restored it and Gisela used it for spinning, as did Bill when he retired. In 2004, when Bill and Gisela moved to the retirement home on Fruitvale Avenue, Saratoga, California, and had far less space, the spinning wheel was returned to the Old Stone House in Maryland.

At this time Bill acquired many skills in information technology, especially in graphic design. He acquired software to help Gisela design and test weaving patterns, in addition to producing other abstract geometric designs. Bill also researched genealogical data online, and transferred paper household records to digital

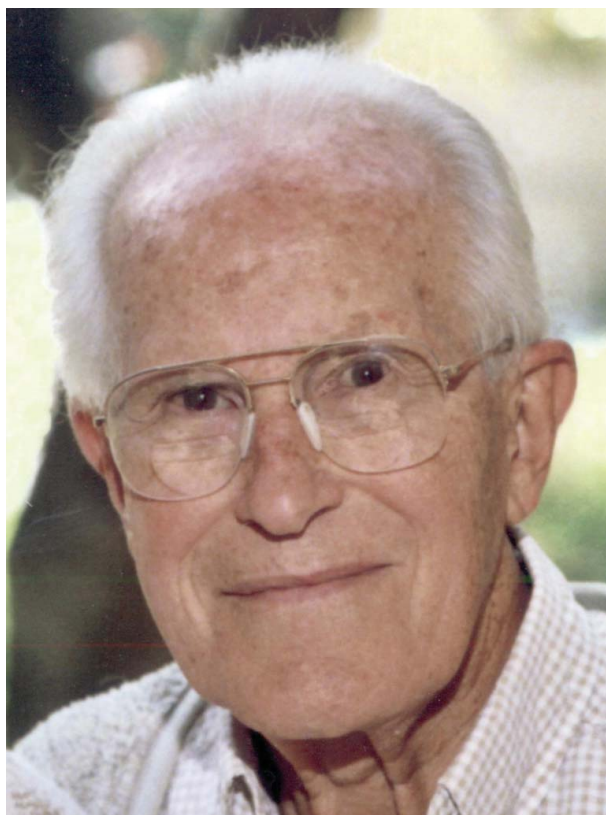


Figure 27. A photograph of Bill Evitt aged 83, during his retirement, taken in October 2007. The image is reproduced with the approval of the Evitt family.

media. Gisela and Bill also enjoyed books and music together, so the couple undertook many shared pursuits during their retirement years (Figure 27). Sadly, Bill passed away, at the age of 85, following a long battle with prostate cancer on 22 March 2009, at home. He is survived by his wife Gisela of nearly 59 years, and his three sons and their families, which include five grandsons and one great-granddaughter.

13. Overview

Bill Evitt had an extremely accomplished, active, fulfilling and productive life, both professionally and personally. When he looked back on his working life during retirement, Bill believed that he had consistently made very good career choices. At several critical points when a choice had to be made, he absolutely never regretted the decision he came to. These watersheds were: deciding to major in geology as an undergraduate; becoming interested in trilobites at Johns Hopkins University; undertaking teaching duties at Johns Hopkins; taking the faculty job at Rochester University; switching to palynology in industry during 1956; and taking the job at Stanford University in 1962. His active scientific life in trilobites lasted for 15 years between 1941 and 1956, and Bill had

established himself as one of the world's most eminent researchers in this field. Despite this, he made a profound shift in his palaeontological focus when he moved to the Carter Oil Company in 1956, where he switched to industrial palynology.

The applied study of pre-Quaternary palynomorphs was burgeoning in the mid 1950s, and Bill undoubtedly caught the crest of this wave. Bill had clearly done his homework because he quickly learned how to use a high-power microscope and found that he loved working on palynomorphs, especially marine microplankton. He greatly relished the challenge of researching the new field of hystrichospheres and fossil dinoflagellates, especially on their affinities, detailed morphology and stratigraphical distributions. In the mid 1950s, very little was known about this topic and Bill enjoyed undertaking this pioneering work. This sudden surge of interest in pre-Quaternary palynology by the oil and gas industry greatly stimulated the interest in palynology by universities. Bill again was there to catch this wave when he made his final career move by joining Stanford University in 1962.

The debt owed to Bill Evitt by all acritarch and dinoflagellate workers is a huge one. In 1956, Bill Hoffmeister gave Bill Evitt a fabulous opportunity to work on pre-Quaternary marine palynomorphs, and

provided a sound base of both initial ideas and superb material (subsection 5.4). Bill Evitt picked up the baton and metaphorically sprinted with it. His palaeontological expertise, perceptiveness and work ethic led to massive advances in a relatively short time. The big questions of the dinoflagellate life cycle and the hystri-chospheres were resolved by Bill. Integral to these issues were the fact that only cysts are represented in the fossil record, and the cyst-theca resemblance being dependent upon the extent to which the cyst fills the interior cavity of the theca. The selectivity of the dinoflagellate record was noted, and Bill was also the master of fine-scale observational work so notably demonstrated in Piel & Evitt (1980a) and Evitt et al. (1998). The latter skill helped demonstrate, for example, that Mesozoic–Cenozoic dinoflagellates and many of the hystri-chospheres display an archaeopyle and recognisable, repeatable plate patterns.

As with all pioneering researchers, it is interesting to speculate on what would have happened if Bill had decided not to become a palynologist and stayed at Rochester University to research trilobites in 1956. The advances that Bill made would have undoubtedly happened because of the massive increase in the numbers of pre-Quaternary palynologists between the late 1950s and the early 1980s. There was a real momentum to the subject at that time due to pressure from the oil and gas industry. Workers at European centres such as Sheffield, Tübingen and Utrecht would probably have worked out issues such as the nature of the dinoflagellate cyst archaeopyle and plate-centred processes in chorate forms. However, the pace of these strides would, in all likelihood, have been iterative, slower and more erratic. What seems probable is that many of the subtleties and variations of dinoflagellate cyst morphology and tabulation so cogently expounded in Evitt (1985) would never have been comprehensively documented. Bill's research was very well timed because, in the current funding climate, leveraging monies from funding bodies for (perceived) arcane pursuits such as fossil morphology would be virtually impossible.

Bill's principal scientific interests were the observation and interpretation of the morphology of dinoflagellate cysts and trilobites and, as such, he considered himself to be essentially an 'old-school' palaeontologist. He consistently attempted to understand fossils as three-dimensional objects, analysed functional morphology and explored the relationships of fossils to their living representatives. Bill preferred pure morphological work, and did not do vast amounts of taxonomy. However, over his career he established, or jointly described, 28 new genera and 47 new species (Tables 2, 4). Bill was also interested in the development of palaeontological techniques, but undertook only relatively brief excursions into fields such as biostratigraphy, classification, palaeoecology and taxonomy. He was fully aware of

how others viewed fossil morphological studies as arcane, and was cognisant of his good fortune to have had the freedom to pursue his passion for morphology throughout his career. Bill only ever worked on well-preserved materials, and perceptively asserted that a clear understanding of morphology is fundamental to the capturing of palaeontological data, and their subsequent analysis and interpretation.

The number of Bill's publications was not prodigiously high, at 64. This figure is fewer than the numbers of articles and books by several of his contemporary colleagues. However, a significant proportion of Bill's contributions were truly groundbreaking; he clearly preferred impact to what might be termed incremental articles. Moreover, two of these works were major textbooks with a combined page count of 633 (Stover & Evitt, 1978; Evitt 1985). The present authors have deemed 20 of Bill's works to be of especially high significance (Appendix 3). In his opinion, Bill himself felt that Evitt (1961c, 1967c), Evitt & Davidson (1964) and Evitt et al. (1998) were his most influential publications (Leffingwell & Damassa 2004).

Bill combined his incredibly acute observational skills with a grasp of how to communicate his ideas to both students at all levels and his peer group. His master's student John Kokinos, whose observational skills were also remarkably sharp, remembers showing specimens to Bill, and being astonished at what Bill saw that John had overlooked, time after time (personal communication, John Kokinos to JL-C). Bill was both an expert communicator and a superb educator. He consistently worked hard on his teaching, and delivered lectures and presentations in a very clear and logical fashion in his trademark measured and soft-spoken intonation. He was also an extremely diligent and hardworking supervisor of his graduate students, and mentored many palynologists who have gone on to have long careers in the discipline themselves (Appendix 2). Despite his rather quiet and reserved nature, he was a passionate advocate for research on dinoflagellates. This was manifested in his organisation of the forum on dinoflagellates at the 1973 Annual Meeting of the AASP (Evitt 1975d), the Penrose Conference on Modern and Fossil Dinoflagellates in 1978 and his 36 presentations of the Teaching Conferences on Fossil Dinoflagellates (sections 10, 11).

It should be emphasised that Bill Evitt was a very balanced individual. He was not as absolutely single-minded regarding his science as, for example, Isabel Cookson (Riding & Dettmann 2013). Bill was a consummate family man and clearly was a very hands-on father. He was also very cultured and was particularly interested in literature and music, as well as being extremely practical around the house.

The term genius is somewhat overused today, but to state that William Robert Evitt II was a genius is

emphatically not hyperbole. He entered the world of marine palynology in industry as an extremely well-established trilobite researcher and university teacher during his early 30s. This was during the mid 1950s, when only a handful of relevant publications were available. Remarkably, he completely revolutionised the scientific understanding of the fossil record of dinoflagellates and the acritarchs. The major breakthroughs in our understanding of the fossil record of dinoflagellate cysts were largely made by Bill Evitt. He demonstrated acute levels of observational detail and also had a clear understanding of big-picture phenomena such as classification and phylogeny. Evitt (1963a, 1963b), for instance, made crucial changes in familial and generic assignments that resolved the question of the hystrichospheres, chorate cysts, tabulate cysts, forms with minimal but distinctive dinoflagellate affinities and the acritarchs. In Evitt (1967c), he set out the basis of our knowledge of the dinoflagellate cyst excystment aperture, the archaeopyle. Stover & Evitt (1978) established new and more consistent criteria for genera of all pre-Pleistocene dinoflagellates known at the time, and much of Bill's research was summarised in Evitt (1985). Much of the informal classification in Evitt (1985) was adopted by Fensome et al. (1993) as the criteria for the suprageneric divisions they established. The work of Bill Evitt has had immense impact and, as long as palynologists continue to study dinoflagellate cysts and acritarchs, his name will live on.

Acknowledgements

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Author biographies



JAMES B. RIDING is a palynologist with the British Geological Survey (BGS), based in Nottingham, England, UK, and specialising on the Mesozoic and Cenozoic. After studying geology at the University of Leicester, he pursued an interest in palynology which developed as an undergraduate. This started with the famous MSc course in

palynology at the University of Sheffield directed by Roger Neves and the late Charles Downie. Jim left Sheffield for BGS, which was then known as the Institute of Geological Sciences, joining the Palaeontological Department run by the legendary Palaeozoic palaeontologist and stratigrapher W.H. C. ('Bill') Ramsbottom in the Northern England office, based in Leeds, West Yorkshire. Here, he worked closely with Ron Woollam on the Mesozoic palynology of onshore and offshore UK; much of the work in those days was on the North Sea. The Leeds office was closed, and Jim and colleagues relocated to the relatively new BGS headquarters at Keyworth, immediately south of Nottingham in the East Midlands of England. He was awarded a PhD by the University of Sheffield for a thesis on the Jurassic dinoflagellate cyst floras of northern and eastern England. His current palynological interests are wide-ranging and include the Mesozoic–Cenozoic palynology of the world (especially Africa, the Americas, Antarctica, Australasia, Europe, India, the Middle East and Russia), palaeoenvironmental palynology, palynomorph floral provinces, forensic palynology, preparation techniques, the history of palynology and the morphology, systematics and taxonomy of dinoflagellate cysts. The British Antarctic Survey, a sister organisation to BGS, have used Jim as a consultant palynologist for many years, and he visited the Antarctic Peninsula for fieldwork during the austral summers of 1989 and 2006. The most recent field season was spent on Seymour Island. The European Union has funded two collaborative projects involving Jim on research into the Jurassic palynology of Russia and southern Europe. Jim undertook a one-year secondment in 1999–2000 to the Australian Geological Survey Organisation (now Geoscience Australia), Canberra, Australia, where he worked on the taxonomy of Australian Jurassic dinoflagellate cysts with Robin Helby and Clinton Foster. The work emanating from this was published in 2001 as Memoir 24 of the Association of Australasian Palaeontologists. Jim was awarded a DSc by the University of Leicester in 2003. He served as a Director-at-Large of AASP between 1999 and 2001, was President in 2003, and became Managing Editor in 2004. Jim has previously served as Secretary and Treasurer of The Micropalaeontological Society (TMS), and is currently the Secretary-Treasurer of the International Federation of Palynological Societies (IFPS).



JOYCE LUCAS-CLARK is an independent researcher on dinoflagellate cysts. She recently retired from teaching geology and palaeontology at the City College of San Francisco and California State University East Bay. Joyce began her career in palynology as a summer hire at the Mobil Stratigraphic Laboratory in Dallas, and then at Chevron

Overseas Petroleum Inc. in San Francisco. She began to consult in palynostratigraphy while still a graduate student under Bill Evitt at Stanford University. Joyce received her PhD from Stanford in 1986, and continued to consult under the name of Clark Geological Services. However, in 1999 she began teaching, while continuing to undertake some consulting. Although the consulting work meant taking on various types of palynology, and even organic petrography, dinoflagellate cysts have always been the primary focus of her research. Her interest and expertise have primarily been in Late Cretaceous and Palaeogene dinoflagellate cysts. However, Joyce has more recently become involved in working on Late Jurassic and Early Cretaceous dinoflagellate cysts from California. Joyce's goal is to finish and publish research begun or inspired by the many projects from her consulting career, and her work at Stanford with Bill Evitt.

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Appendix 1. A list of military and academic awards bestowed upon Bill Evitt

Bill Evitt received one military and four academic awards, and these are listed below with citations where appropriate. Three of Bill's four academic awards were made to him by the American Association of Stratigraphic Palynologists. In addition to these, Bill became a fellow of the Geological Society of America in 1952 and a fellow of the California Academy of Sciences in 1964.

AI.1. 1945 - The Bronze Star Medal, US Army Air Force

Citation: 'Captain WILLIAM R. EVITT, II, 0-528881, Air Corps, distinguished himself by meritorious service in direct support of combat operations against the enemy from 30 March 1944 to 30 August 1945 as Photo Interpreter, Assistant Chief of Interpretation Section and Chief of Industrial Studies section of the [18th] Photo Intelligence Detachment. He labored indefatigably under handicaps of poor working conditions, inadequate supplies and insufficient relaxation to ensure the unbroken flow of photo intelligence to the tactical units of the Fourteenth Air Force. In direct consequence of the excellence of his works, his enduring initiative, and his devotion to duty, however onerous, many attacks of singular success were carried out against enemy rail lines, bridges, airfields, shipping facilities, bivouacs and industrial areas. The accomplishments of Captain Evitt reflect conspicuous [sic.] on his personal record and on the fine traditions of the Army Air Forces'.

AI.2. 1982 - The inaugural American Association of Stratigraphic Palynologists (AASP) Medal for Scientific Excellence

Citation: 'The first AASP Medal for Scientific Excellence is presented to William R. Evitt for 25 years of outstanding scholarship in the study of fossil dinoflagellate cysts. His early morphologic insights permitted an orderly development of dinocyst taxonomy and encouraged the detailed description of species which greatly enhanced their use in geologic studies' (Leffingwell & Whitney 1982, p. 3).

Note: Bill did not attend the 15th Annual Meeting of the AASP held in Dublin, Ireland, between 13 and 15 September 1982 to accept this award, which is the association's highest honour (Demchuk & Riding 2008).

AI.3. 1989 - The American Association of Stratigraphic Palynologists Honorary Membership Award

Citation: 'AASP Honorary Membership is awarded to William R. Evitt in recognition of the outstanding achievements of a research scientist who has sustained high standards of scholarship and scientific leadership in his dedicated study of fossil and living dinoflagellates' (Leffingwell 1990, p. 1).

Note: Bill did not attend the 22nd Annual Meeting of the AASP held in Tulsa, Oklahoma, between 18 and 21 October 1989; hence, this award was presented *in absentia*.

AI.4. 1998 - Honorary Membership of the Palaeobotanical and Palynological Society of Utrecht (PPGU), University of Utrecht, The Netherlands

This honour was presented to Bill at the Dino 6 meeting between 7 and 12 June 1998 at Trondheim, Norway. He was

the first non-Dutchman to receive this award. The citation is unavailable.

AI.5. 2006 - The American Association of Stratigraphic Palynologists Medal for Excellence in Education

Citation: 'The American Association of Stratigraphic Palynologists bestows upon Dr. William R. Evitt the AASP Medal for Excellence in Education in recognition of a man whose devotion to his students and to the art of teaching have brought him the unparalleled admiration of both academia and industry' (Strother 2007, p. 1).

Note: Bill did not attend the 39th Annual Meeting of the AASP held in Philadelphia, Pennsylvania, between 22 and 25 October 2006 to accept this award, which was collected on his behalf by Joyce Lucas-Clark.

Appendix 2. Graduate students supervised by Bill Evitt

Bill Evitt oversaw 13 PhD projects during his career (see the list below). The first two dissertations, by Donald W. Fisher and Lewis E. Stover, are on the Palaeozoic palaeontology of New York State, and were completed at the University of Rochester. Bill advised Donald W. Fisher, but was not his principal supervisor. The subsequent 11 research programmes were all on the Mesozoic–Cenozoic palynology of North and Central America, and were undertaken at Stanford University with Bill as the sole supervisor. Most of the material in the dissertation by David K. Goodman was from the Upper Cretaceous to Lower Eocene strata from the Atlantic Coastal Plain of Maryland and Virginia, and included a global synthesis of the Paleocene to Oligocene *Wetzeliella* complex.

1. Donald W. Fisher (1952) *Lower Ordovician stratigraphy and paleontology of the Mohawk Valley*, 254 p.
2. Lewis E. Stover (1956) *Part I, Stratigraphy and paleontology of the Moscow Formation (Hamilton) in central and western New York; Part II, Ostracoda from the Windom shale in western New York*, 552 p.
3. John S. Warren (1967) *Dinoflagellates and acritarchs from the Upper Jurassic and Lower Cretaceous rocks on the west side of the Sacramento Valley, California*, 408 p.
4. Neely H. Bostick (1970) *Thermal alteration of clastic organic particles (phytoclads) as an indicator of contact and burial metamorphism in sedimentary rocks*, 220 p.
5. Carol A. Chmura McLeroy (1970) *Upper Cretaceous (Campanian–Maastrichtian) angiosperm pollen from the western San Joaquin Valley, California*, 382 p.
6. Dewey M. McLean (1971) *Organic-walled phytoplankton from the Lower Tertiary Pamunkey Group of Virginia and Maryland*, 330 p.
7. David K. Goodman (1983) *Morphology, taxonomy and paleoecology of Cretaceous and Tertiary organic-walled dinoflagellate cysts*, 478 p.

8. Jeffrey A. Stein (1983) *Upper Cretaceous (Campanian–Maestrichtian) dinoflagellate cysts from the Great Valley Group, central California*, 410 p.
9. Anthony N. Bint (1984) *Mid-Cretaceous dinoflagellates from the Western Interior, USA*, 373 p.
10. Javier Helenes-Escamilla (1984) *Studies on the morphology of fossil dinoflagellates, mainly from Baja California, Mexico*, 326 p.
11. Joyce E. Lucas-Clark (1986) *Studies of Late Albian dinoflagellates from the Franciscan Central Belt, northern California*, 209 p.
12. Nairn R. Albert (1988) *Dinoflagellate cysts from the Early Cretaceous of the Yukon-Koyukuk Basin and from the Upper Jurassic Naknek Formation, Alaska*, 481 p.
13. David I. Wharton (1988) *Dinoflagellates from Middle Jurassic sediments of southern Alaska*, 443 p.

Bill supervised six master's projects during his time at the University of Rochester, all on non-palynological topics. The six students were Donald W. Hoskins, Edward A. Kennedy, K. Norman Sachs, Daniel B. Sass, Marvin A. Smith and Robert G. Sutton. He also supervised five master's students at Stanford University. These were Ignacio A. Brito, Claire Carter, Sarah T. Pierce, Donald W. Ester and John P. Kokinos. Only Sarah Pierce and John Kokinos undertook research on palynology. Sarah Pierce did not write a dissertation; instead, her master's degree was awarded on the basis of a publication (Pierce 1976). John Kokinos submitted his master's dissertation in 1987; it was entitled *Late Cretaceous dinoflagellate cysts from the Type Magothy Formation, Maryland*.

Appendix 3. Bill Evitt's scientific publications

This major section is a numbered listing of all of the 64 scientific publications, excluding abstracts, by Bill Evitt and his co-authors between 1943 and 2001, arranged in chronological order. Each of these publications is thoroughly described. These syntheses are designed to give the reader a sense of the breadth, depth and significance of Bill's research. The 20 most important contributions are asterisked.

Only one paper, Secrist & Evitt (1943), was published during Bill's student years at Johns Hopkins University. Six publications were authored/co-authored from Bill's spell at the University of Rochester. When Bill joined the Carter Oil Company (later the Jersey Production Research Company) in 1956, he published six papers while in Tulsa, Oklahoma. Most of Bill's career was spent at Stanford University (1962 to 1988), and 49 of his 64 scientific contributions were written at Stanford. Following retirement in 1988, Bill gave his personal address at 882 Cedro Way, Stanford, on his final two publications, Evitt et al. (1998) and Evitt (2001).

It is interesting to note trends in Bill's palynological publications. In the early 1960s, the specialist journals for palynology were *Grana* and *Pollen et Spores* which were principally aimed at terrestrial palynomorphs. Consequently, Bill used several more generic journals such as the *Journal of Paleontology* and *Micropaleontology*. He then started to

submit to one of the Stanford University in-house journals, *Stanford University Publications, Geological Sciences*, between 1963 and 1978. As the 1960s wore on, Bill increasingly used more appropriate specialist journals such as *Geoscience and Man*, *Palynology* and *Review of Palaeobotany and Palynology*.

A3.1. Secrist, M.H. & Evitt, W.R. 1943. The paleontology and stratigraphy of the upper Martinsburg formation of Massanutten Mountain, Virginia. *Journal of the Washington Academy of Sciences*, 33(12): 358–368.

Bill's first scientific publication, and also the first of his 11 contributions on macropalaeontology (Table 2), is a co-authored account of the Ordovician upper Martinsburg Formation from two successions, Cub Run and Passage Creek, from Massanutten Mountain, Shenandoah Valley, Virginia. The Palaeozoic geology of the area was discussed, followed by a detailed description of the Martinsburg Formation and its macrofauna. Measured sections were given for both Cub Run and Passage Creek. The authors then formally described five new species of bivalves, four new gastropod species and one new variety of brachiopod from the upper Martinsburg Formation (Table 2). Secrist & Evitt (1943) was the only contribution published while Bill was a student at Johns Hopkins University.

A3.2. Evitt, W.R. II. 1949. Stereophotography as a tool of the paleontologist. *Journal of Paleontology*, 23 (5): 566–570.

This short article described the use of stereophotography in palaeontology. Evitt (1949) is the first of six papers that Bill produced on palaeontological techniques (Table 3). Stereophotography is used extensively in the analysis of terrain using aerial photographs, and was practiced by Bill during his military service in World War II (subsection 3.3). In palaeontology, fossils are photographed at slightly different angles such that the resultant stereopairs produce three-dimensional images when viewed using a pocket-sized stereoscope. The relatively few contributions which include stereophotographs of fossils between 1913 and 1948 were briefly reviewed. The logistics and practicalities of stereophotography in palaeontology, such as the need for two suitably spaced photographs of each image, were outlined. Stereophotography works best on relatively small specimens which have three-dimensional preservation. For example, it effectively illustrates morphological details which are hidden in concavities where profile views are impossible. Fossils well suited to stereophotography include uncrushed specimens of brachiopods, conodonts, corals, crinoids, foraminifera, ostracods and trilobites. Evitt (1949) is the first of the six publications issued during Bill's sojourn at the University of Rochester.

A3.3. Evitt, W.R. 1951a. Paleontologic techniques. *Journal of Paleontology*, 25(5): 693–695.

Evitt (1951a) described three techniques developed during his PhD research on silicified Ordovician trilobites. The first of these was a simple three-axis stage for the orientation of specimens for microscopical observation and photography. This was inspired by similar devices used by entomologists for insect specimens. A drawing-compass tip embedded into a radio tuning knob was fitted with an insect pin and attached to a vertical support on a base plate, which was in turn

supported by a second metal base plate (Evitt 1951a, fig. 1). This three-axis stage allows a fossil specimen to be precisely rotated so that it can be observed and photographed in any direction without lateral movement.

Bill's trilobite specimens are typically small, thin and fragile, and many have delicate, long spines. After the etching of the limestone matrix, the post-hydrochloric acid residue was examined under a stereomicroscope and the best specimens picked out for study. This can be done using a needle coated with beeswax or a moistened paintbrush, but these can result in significant breakage of specimens. A former colleague at Johns Hopkins University noted that small items can be manipulated using a small pair of tweezers with short pieces of watch hair-spring cemented to the tips. These modified tweezers enabled Bill to extract trilobite specimens effectively and safely, but watch hair-spring is extremely fragile and very susceptible to rusting. So, in the second technique described, Bill used short (5–8 mm) lengths of the thin thread of aluminium foil then used to strengthen cellophane drinking straws instead. These modified tweezers proved highly effective and extremely robust.

The trilobite-bearing limestones are rich in small inorganic fragments encased in organic material. These tenacious stringy masses obscured the trilobites, and proved difficult to remove manually. In the third technique described, this extraneous material was removed by treatment with a solution of potassium dichromate in concentrated nitric or sulphuric acids. This cleaning fluid, which is also used to clean chemical apparatus in palynology laboratories, is extremely effective in completely removing the fibrous material.

*A3.4. Evitt, W.R. 1951b. Some Middle Ordovician trilobites of the families Cheiruridae, Harpidae and Lichidae. *Journal of Paleontology*, 25(5): 587–616.

This major systematic study was the first of 10 papers on trilobites published by Bill (Table 2). Evitt (1951b) was based on his PhD dissertation submitted to Johns Hopkins University in January 1950. The paper is on silicified trilobites from the families Cheiruridae, Harpidae and Lichidae. All the material was collected from the lower part of the Lincolnshire Formation of Middle Ordovician age at Tumbling Run, Virginia. The new subfamily Heliomerinae was erected within the family Cheiruridae. Within the Heliomerinae, the new genus *Heliomeroides*, and the species *Heliomeroides teres* and *Heliomeroides treta* were established. Of the Family Harpidae, only *Dolichoharpes reticulata* was treated. A comprehensive redescription of the genus *Dolichoharpes* was provided. One new species, *Amphilichas (Probolichas) pandus*, was described within the Family Lichidae.

A3.5. Evitt, W.R. 1953. Observations on the trilobite *Ceraurus*. *Journal of Paleontology*, 27(1): 33–48.

This paper documented a comprehensive investigation of silicified specimens of the trilobite genus *Ceraurus* from the Middle Ordovician of New York and Virginia. Evitt (1953) further elucidated the morphology of the type species, *Ceraurus pleurexanthemus*. A new variety, *Ceraurus pleurexanthemus* var. *montyensis* was established from Clinton County, New York. The new species *Ceraurus whittingtoni* was described from Augusta County, Virginia. The latter was based on a morphotype which was previously attributed to *Ceraurus pleurexanthemus*. The morphology of the species *Ceraurus pleurexanthemus* and *Ceraurus whittingtoni* was compared in detail. Some transitory pygidia of *Ceraurus* have helped to determine the detailed ontogeny of this genus.

A3.6. Evitt, W.R. & Whittington, H.B. 1953. The exoskeleton of *Flexicalymene* (Trilobita). *Journal of Paleontology*, 27(1): 49–55.

Evitt & Whittington (1953) is an extremely detailed account of the exoskeleton morphology of well-preserved specimens of the trilobite genus *Flexicalymene* from the Ordovician of the northeastern United States. The material studied comprised silicified specimens of *Flexicalymene senaria* from the Middle Ordovician of New York and Virginia, and calcareous individuals of *Flexicalymene meeki* from the Upper Ordovician of Ohio. The study is focussed on the hypostome, perforations and rostrum. The perforations are variable in size, and are best observed in well-preserved material. These features were interpreted as the loci of sensory hairs because they are concentrated in areas most likely to contact external objects in the environment (Figure 20). The results of this morphological study are relevant to most of the representatives of the Family Calymenidae.

*A3.7. Whittington, H.B. & Evitt, W.R. II. 1954 (cover date 1953). *Silicified Middle Ordovician trilobites*. Geological Society of America Memoir, 59, 137 p.

This is the most comprehensive of Bill's five publications on trilobites during the pre-Ronald Tripp era. Whittington & Evitt (1954) is a major monograph on the silicified faunas from the Middle Ordovician limestones of Virginia. Specifically, material from the families Cheirurinae, Dimeropygidae and Odontopleuridae was studied from six localities spanning the Lincolnshire and Edinburg formations. It is subdivided into three parts. The first of these (Whittington & Evitt 1954, p. 5–14) is an introduction comprising descriptions of the six localities, the mode of trilobite occurrence and preservation, the techniques used, reconstruction of the holaspis stages and terminology. Part II (Whittington & Evitt 1954, p. 15–33) is a comprehensive synthesis of the morphology and exoskeleton development, including a brief discussion of the mode of life. The final and most important section comprises the systematics (Whittington & Evitt 1954, p. 35–95). This includes the descriptions of one new subfamily (the Acanthoparyphinae of the family Cheirurinae), three new genera (*Acanthoparypha*, *Chomatopyge* and *Mesotaphraspis*) and 15 new species. This material was extremely well illustrated with 27 beautiful line drawings and 33 plates. The frontispiece, a superb drawing of *Ceratocephala laciniata*, is especially stunning (Figure 20; Whittington & Evitt 1954, fig. 1). Whittington & Evitt (1954) is the last of the six publications issued during Bill's tenure at the University of Rochester.

*A3.8. Funkhouser, J.W. & Evitt, W.R. 1959. Preparation techniques for acid-insoluble microfossils. *Micropaleontology*, 5(3): 369–375.

Funkhouser & Evitt (1959) described three aspects of palynomorph preparation, all of which were developed at the Jersey Production Research Company, Tulsa, Oklahoma. It is the first of the six articles that Bill authored or co-authored while working at Carter Oil/Jersey Production Research. This paper described the oxidation of organic matter, the separation of palynomorphs from mineral grains and slide production.

If oxidation is performed correctly, any extraneous organic matter is destroyed before the palynomorphs are damaged by the reagents. Oxidising agents either directly dissolve the organic matter, or convert it to humic acids that are

soluble with weak bases. Schulze's Solution and a saturated solution of chromium trioxide and concentrated nitric acid were used as oxidants. Four methods were described for separating the light organics from the heavier mineral grains. The first is agitation with an ultrasonic generator which fragments clumps of insoluble debris so that it can be sieved away. Centrifuging in water can also separate the two fractions; the palynomorphs settle, and the fine mineral grains remain in suspension. Heavy liquid separation uses saturated zinc chloride solution. A mixture of residue and heavy liquid is placed in a plastic tube, which is folded and put inside a test tube. This apparatus is then centrifuged at 1500 rpm for five to 30 minutes. The organics rise to the top of the plastic tube, and hence can be separated. Swirling uses density differences to separate the palynomorphs from mineral grains. The residue is placed in a watch glass which is gently swirled to concentrate the heavy fraction at the base of the receptacle. The lighter palynomorphs are present directly above the significantly denser mineral grains, and can be extracted using a pipette. Permanent slides are made using glycerin jelly or polyvinyl alcohol solution as coverslip mountants. These are fixed to the microscope slides with a clear adhesive such as Canada Balsam diluted with xylene.

A3.9. Evitt, W.R. 1961a. Early ontogeny in the trilobite Family Asaphidae. *Journal of Paleontology*, 35 (5): 986–995.

Evitt (1961a) is an extremely detailed study on the young ontogenetic stages (protaspids) in the trilobite Family Asaphidae. It was based on Middle Ordovician silicified material from northern Virginia. This comprised limestones collected from the Lincolnshire, Edinburg, Oranda and Martinsburg formations. The article was the first to comprehensively describe and illustrate asaphid protaspids. It was noted that it is extremely difficult to match protaspids with their respective meraspids due to a significant ontogenetic gap during the late protaspid period. Bill wrote this paper during his first year at the Carter Oil Company. Because he had effectively changed disciplines to palynology when he moved to Tulsa, this was Bill's final paper on trilobites before the collaboration with Ronald P. Tripp which began in the mid 1970s.

A3.10. Evitt, W.R. 1961b. The dinoflagellate *Nannoceratopsis* Deflandre; morphology, affinities and infraspecific variability. *Micropaleontology*, 7(3): 305–316.

This largely taxonomic paper on the reinterpretation of the important Jurassic dinoflagellate cyst genus *Nannoceratopsis* is the first of Bill's 48 contributions on palynology (Table 4). Evitt (1961b) was written during Bill's tenure at the Jersey Production Research Company in Tulsa. He was already familiar with the genus, having studied the type material of *Nannoceratopsis pellucida* while at Georges Deflandre's laboratory in Paris during 1959 (subsection 5.5.3). Evitt (1961b) noted the possible relationship between *Nannoceratopsis* and the dinophysialean dinoflagellates based on gross morphology. *Nannoceratopsis* is highly unusual because of its profound lateral flattening, and the subapical cingulum. The comparison to the living genus *Dinophysis* was perhaps more apposite at the time because Evitt (1961b) considered *Nannoceratopsis* to be a fossil thecate genus, possibly due to the thin wall and the apparent lack of an archaeopyle. This was the first time that Bill commented on the selectivity of the dinoflagellate fossil record in that *Nannoceratopsis* is confined to the Jurassic, and the living representatives of the Subclass

Dinophysiphycidae do not produce preservable resting cysts (subsection 9.4; Figure 21).

The genus *Nannoceratopsis* was emended in the light of Bill's detailed morphological observations. Additionally, the new species *Nannoceratopsis deflandrei* was described from a rich, apparently monospecific assemblage. This was from a mudstone horizon at 1209.1 m from the Lower Jurassic (Upper Pliensbachian) of the Danish American Prospecting Company's Gassum No. 1 well drilled north of Randers, Jutland, in central Denmark. One can clearly see the influence of Bill's considerable experience in complex morphological descriptions from his previous work on trilobites. Evitt (1961b) did not mention any other dinoflagellate cysts from this material, although he may have overlooked some of the taxa later described by Morgenroth (1970) from coeval strata in northern Germany. *Nannoceratopsis deflandrei* was, at the time of publication, one of the oldest known dinoflagellate cysts and is a highly variable taxon. The intraspecific variation includes differences in the shape and size, the colour and texture of the cyst wall, and the morphology of the apical region (Evitt 1961b, figs 9–17, pl. 1, figs 1–14, pl. 2, figs 1–29). The teardrop-shaped morphotypes of *Nannoceratopsis deflandrei* such as Evitt (1961b, pl. 1, figs 1–2, pl. 2, figs 1–11) would currently be identified as *Nannoceratopsis deflandrei* subsp. *senex*.

Evitt (1961b) also recorded and emended the cosmopolitan species *Nannoceratopsis pellucida* from the Upper Jurassic (Oxfordian) Curtis Formation of Uintah County, Utah. This was the first report of this genus from North America, and *Nannoceratopsis pellucida* co-occurs with *Gonyaulacysta jurassica* and *Scriniodinium crystallinum*. This is a typical Oxfordian association (Woollam & Riding 1983; Riding & Thomas 1992). *Nannoceratopsis pellucida* lacks the significant intraspecific variability of *Nannoceratopsis deflandrei*. It is also the youngest representative of the genus, and differs from *Nannoceratopsis deflandrei* due to its pair of elongate antapical horns.

***A3.11.** Evitt, W.R. 1961c. Observations on the morphology of fossil dinoflagellates. *Micropaleontology*, 7(4): 385–420.

This was the second of Bill's papers on fossil dinoflagellates; it was also his 'breakthrough paper' on this topic, and one of his finest contributions. Evitt (1961c) broke new ground in that it hypothesised, for the first time, that the fossil record of dinoflagellates is significantly based on resting cysts. Moreover, it demonstrated that many post-Palaeozoic hystrichospheres are, in fact, dinoflagellate cysts, and the archaeopyle was first described and defined. Evitt (1961c) also revealed that dinoflagellate cyst plate patterns reflect the tabulation of the parent theca. In summary, several phenomena which contemporary biologists and palynologists absolutely take for granted were first documented.

Evitt (1961c) was largely written at the Jersey Production Research Company in Tulsa after Bill returned from his visits to Georges Deflandre and Alfred Eisenack in late 1959 (subsections 5.5.2, 5.5.3). Georges Deflandre was acknowledged (Evitt 1961c, p. 386) for providing a written summary of the discussions which took place between the two of them in late 1959. Reading between the lines it seems possible, even probable, that Deflandre aspired to joint authorship of this work. It is clear that Bill must have realised that he was on the brink of making huge strides in the understanding of fossil dinoflagellates because he clearly stated that his conclusions here were preliminary.

It was noted that Deflandre and Eisenack thought that the hystrichospheres were polyphyletic and monophyletic, respectively, and Bill strongly supported the former hypothesis. Evitt (1961c) noted that the resistant resting cyst may form as part of dinoflagellate reproduction, or simply as a response to unfavourable environmental conditions. It should be remembered that, at this time, the dinoflagellate life cycle was not well understood. In particular, the excystment process was largely obscure. In terms of tabulation patterns, the conservative nature of the plate configuration of the gonyaulacacean forms was noted. The endocyst of cavate peridiniaceans such as *Deflandrea* was interpreted as the resting cyst, and the periplasm as the theca. At this time, Bill clearly thought that significant numbers of fossil dinoflagellates were thecae. The clear implication of Evitt (1961c, captions to figs 5–8) was that both cysts and thecae have archaeopyles.

Evitt (1961c) was the first paper to note the systematic and widespread nature of the excystment aperture in fossil forms, its significance and its plate equivalence. He named it the archeopyle (archaeopyle in English, see Feist-Burkhardt 2007). Georges Deflandre suggested this term, which derives from the Greek *archo* (ancient) and *pyle* (door, gate or orifice). Evitt (1961c) recognised apical, intercalary and precingular archaeopyles, and noted forms in which the individual splits in half immediately anterior to the cingulum which were later to be termed epicystal.

In this paper, Evitt (1961c) interpreted the genus *Hystrichosphaeridium*, the most typical of the hystrichospheres, as being a fossil dinoflagellate having an apical archaeopyle and plate-centred processes. He noted that ‘the processes braced the cyst against a now-missing outer wall’ in *Hystrichosphaeridium* and *Spiniferites* (as *Hystrichosphaera*) (Evitt 1961c, p. 393). A major part of this contribution is the discussion of 112 dinoflagellate and hystrichosphere genera (Evitt 1961c, p. 394–401). Many important forms were discussed and illustrated in the superbly executed nine plates, but no new taxa were formally established in this paper.

A3.12. Evitt, W.R. 1961d. *Dapcodinium priscum* n. gen., n. sp., a dinoflagellate from the Lower Lias of Denmark. *Journal of Paleontology*, 35(5): 996–1002.

Evitt (1961d) is a relatively short taxonomic paper, which set the standard for taxonomic descriptions of dinoflagellate cysts. It documented an extremely important genus and species with a unique and unusual tabulation style. This is the cosmopolitan taxon *Dapcodinium priscum*, which is an important marker for the Late Triassic to Early Jurassic (Rhaetian–Early Sinemurian) of Alaska, Australia and Europe (Riding & Thomas, 1992; Riding et al., 2010). The type material is from a single core sample of grey shale at 1439.27–1433.17 m in the Gassum No. 1 Well, drilled north of Randers, Jutland, in Denmark. *Dapcodinium priscum* was the only dinoflagellate cyst found at this horizon; it proved extremely abundant, and was often found in clusters (Evitt, 1961d, pl. 119, fig. 3; Morbey & Dunay, 1978, pl. 2, fig. 10). This is the same succession from which Bill described *Nannoceratopsis deflandrei* (see Evitt 1961b). The material is earliest Jurassic (Late Hettangian) in age, and is referred to the *Schlotheimia angulata* ammonite Biozone.

At the time *Dapcodinium* was monotypic, and *Dapcodinium priscum* was the oldest fossil dinoflagellate known. *Dapcodinium* was named for the operator of the Gassum No. 1 Well, the Danish American Prospecting Company. The tabulation formula was interpreted as being 4', 4a, 7'', 6c, 6''', 2p,

1''', and this was the first comprehensive tabulation pattern determined for a dinoflagellate cyst. The genus was later emended by Below (1987, p. 141), and the tabulation reinterpreted as 1pr, 5', 4a–6a, 7'', 8c, 6–8''', 3''', 4–5 s. *Dapcodinium priscum* is a small, thin-walled form, ovoidal in outline, having a prominent cingulum and sulcus, and a combination (type AI) archaeopyle. Due largely to the prominent anterior intercalary plates, Evitt (1961d) speculated that *Dapcodinium priscum* was a primitive peridiniacean form. Evitt (1961d) realised that *Dapcodinium priscum* was both very significant and highly unusual, and compared *Dapcodinium* to the modern freshwater genus *Sphaerodinium*. A tabulate dinoflagellate cyst of earliest Jurassic age strongly implied a pre-Jurassic origin which, of course, was later confirmed.

A3.13. Schaetti, H.J., Campbell, C.V., Claypool, C.G., Evitt, W.R. & Hoffmeister, W.S. 1961. Chapter 22. Laboratory procedures in exploration. In: Moody, G.B. (editor). *Petroleum exploration handbook*. McGraw-Hill Book Company Inc., New York, 25 p.

This contribution on geological procedures during oil and gas exploration was authored by five members of the staff at the Jersey Production Research Company in Tulsa, Oklahoma. Schaetti et al. (1961) is in a major textbook on petroleum exploration, and was subdivided into three main sections, i.e. the physical properties, compositional properties and fossil content of rocks. The latter section is relevant here and presumably was written jointly by Bill Evitt and Bill Hoffmeister. It is a concise review of palaeontology. The first section ('fossil content of rocks') stresses how important microfossils are in oil exploration due to their small size which enables them to escape the destructive action of the drilling bit. The authors commented that palynology had become widely used in industrial micropalaeontology during the previous decade, and discussed the complex interactions between evolution and ecology in controlling fossil assemblages. Schaetti et al. (1961, p. 18–19) discussed the attributes of biostratigraphically significant fossils, and gave examples such as ammonites, foraminifera, and pollen and spores. Palaeoecology was also briefly described in the context of petroleum exploration, and the authors observed that an assemblage of pollen and spores, coupled with a complete absence of marine microfossils, indicates a continental depositional setting. The final subsection was on zonation and correlation using palaeontology. Schaetti et al. (1961, p. 20) documented both potential and constraints. The authors observed that not every succession yields abundant and reliable marker fossils. For example, a thick succession of Palaeogene/Neogene strata yielding only long-ranging pollen and spores would need a statistical study to develop a detailed biozonation. Schaetti et al. (1961) is the final scientific contribution of Bill's issued while he worked for the Jersey Production Research Company.

A3.14. Evitt, W.R. 1962a. Dinoflagellate synonyms: *Nannoceratopsis deflandrei* Evitt junior to N.? *gracilis* Alberti. *Journal of Paleontology*, 36(5): 1129–1130.

This short note dealt with a dinoflagellate cyst synonymy issue. During 1961, Gerhard Alberti and Bill published the species *Nannoceratopsis? gracilis* from the Aalenian of Germany and *Nannoceratopsis deflandrei* from the Upper Pliensbachian of Denmark, respectively (Alberti 1961; Evitt 1961b). Evitt (1962a) asserted that the species *Nannoceratopsis gracilis* should be assigned to *Nannoceratopsis* without question, and that his species *Nannoceratopsis deflandrei* is a junior synonym of *Nannoceratopsis gracilis* because Alberti

(1961) was published during June 1961. This was several weeks prior to Evitt (1961b), which was issued during July of that year. Evitt (1962a) also included an emendation of *Nannoceratopsis gracilis*, and extended its range into the Early Jurassic. This paper is the first of Bill's 49 scientific articles and books published while he worked at Stanford University.

*A3.15. Evitt, W.R. 1963a. A discussion and proposals concerning fossil dinoflagellates, hystrichospheres, and acritarchs, I. *Proceedings of the National Academy of Sciences*, 49(2/3): 158–164.

Two short papers (Evitt 1963a, 1963b) were published in volume 49(2/3) of *Proceedings of the National Academy of Sciences*. They are clearly a single article subdivided once, possibly due to a strict page or word limit imposed by this journal at the time. The entire work was communicated by Bill's father-in-law, Ernst Cloos, on 27 November 1962. These very important papers on the nomenclature and taxonomy of marine palynomorphs drew heavily on research carried out when Bill worked at the Jersey Production Research Company in Tulsa.

In Evitt (1963a), Bill commented that recent research since Evitt (1961c) had absolutely confirmed that most post-Palaeozoic hystrichospheres were dinoflagellate cysts. He accepted the proposal by Downie et al. (1961) that fossil dinoflagellates and hystrichospheres be classified using the International Code of Botanical Nomenclature (ICBN). This was an early stage in the development of marine palynology, and Evitt (1963a) was still not totally sure that all fossil dinoflagellates were resting cysts, preferring the less committal term 'dinoflagellate tests'. It is fascinating to record the evolution of Bill's ideas. He clearly grasped, and communicated, the morphological continuum between what we now know as proximate, proximochorate and chorate cysts (Figure 12), and the fact that most cysts are primarily two-layered (Evitt 1963a, p. 159).

Evitt (1963a, p. 159–160) briefly reviewed the history and the perceived affinities of the hystrichospheres (Sarjeant 1961). The genera *Hystrichosphaera* (now *Spiniferites*) and *Hystrichosphaeridium* were deemed to be fossil dinoflagellates. Because of this assignment of *Hystrichosphaera*, the family Hystrichosphaeraceae had to be emended and transferred to the dinoflagellates. Furthermore, the family Hystrichosphaeraceae had to be emended to exclude forms which have no dinoflagellate affinity, and to allow the separation of forms placed into a new family of dinoflagellates, the Areoligeraceae, in Evitt (1963b). The order Hystrichosphaerida was deemed to be superfluous by Evitt (1963a, p. 160). This work significantly altered the concept and use of the informal term 'hystrichosphere'. This now has the status of a dinoflagellate family, the Hystrichosphaeraceae, and the Palaeozoic hystrichospheres were removed by their transferral to the acritarchs by Evitt (1963b).

Evitt (1963a, p. 160–161, figs 1–4) outlined some descriptive terminology pertaining to dinoflagellate tests including 'capsule', 'central body', 'intratabular', 'nontabular', 'process-groups' and 'sutural'. The iconic line drawing of the chorate dinoflagellate cyst species *Hystrichosphaeridium tubiferum*, and its relationship to the parent theca, was published here for the first time (Evitt 1963a, fig. 3). The left-hand diagram is the cyst with its characteristic trumpet-shaped intratabular, plate-centred processes; by contrast, the right-hand figure illustrates the cyst/theca combination with the distal ends of the processes in contact with the inner surface of the theca in the centre of each plate (Evitt 1963a, figs

3a and b, respectively). This diagram has been reproduced numerous times since, and is included here also (Figure 11). Interestingly, when this iconic diagram was first published, it was entirely hypothetical. The relationship of chorate dinoflagellate cysts to the parent thecae had been previously briefly described in published abstracts (Evitt 1962b, 1962c).

The term 'sulcal notch' was introduced, referring to the equatorialward extension of the first apical plate in line with the sulcus. It can be midventral, or is offset to the left in the family Areoligeraceae (Evitt 1963a, fig. 4A). In the systematic section (Evitt 1963a, p. 162–164), the family Hystrichosphaeraceae was emended to comprise axially and radially symmetrical process-bearing dinoflagellate cysts with precingular archaeopyles and normally having sutural features. A new genus, *Achomosphaera*, was erected to accommodate representatives of the Hystrichosphaeraceae which lack sutural ridges or septa connecting the processes. Finally the family Hystrichosphaeridiaceae was established to accommodate genera such as *Hystrichosphaeridium*. These are process-bearing, axially and radially symmetrical forms normally with apical or precingular archaeopyles.

*A3.16. Evitt, W.R. 1963b. A discussion and proposals concerning fossil dinoflagellates, hystrichospheres, and acritarchs, II. *Proceedings of the National Academy of Sciences*, 49(2/3): 298–302.

This paper is a direct continuation of the systematic section of Evitt (1963a), and consequently lacks an introduction. It comprises two sections, the first of which is the erection of the dinoflagellate family Areoligeraceae (Evitt 1963b, p. 298–300). These are dorsoventrally flattened fossil dinoflagellates with apical archaeopyles, highly varied typically marginate ornamentation and significantly offset sulcal notches. Two groups were distinguished. One of these has low-relief ornamentation, and the other exhibits longer processes. Some representatives of the latter group may be bilaterally symmetrical, defined by prominent antapical processes. Evitt (1963b, p. 300) perceptively noted that, in members of the Areoligeraceae, the midventral and middorsal areas were close to (or in direct contact with) the parent theca, whereas the lateral margins were separated from it by the ornamentation. This situation contrasts markedly with the families Hystrichosphaeraceae and Hystrichosphaeridiaceae, where the cyst is virtually perfectly concentric within the theca (Figure 11).

The second part of this paper is the formal establishment of the acritarchs (Evitt 1963b, p. 300–302). This new group comprises marine palynomorphs of unknown, and probably diverse, biological affinities and is morphologically highly varied. The acritarchs are largely Palaeozoic in age and represent the residue of the hystrichospheres, now that the majority of the post-Palaeozoic process-bearing dinoflagellate cysts have been recognised as such. Because the dinoflagellate affinity of the genus *Hystrichosphaera* was recognised, the term 'hystrichosphere' and the Order Hystrichosphaerida are inappropriate. The term acritarch itself literally means of uncertain origin, and was derived from Greek (*akritos* = uncertain, and *arche* = origin). It is entirely possible that some acritarchs are dinoflagellates, but this cannot be demonstrated on purely morphological grounds. This contention has been supported by subsequent research, e.g. Dale (1978). The obscure biological affinity of the acritarchs precludes classifying them as a class, an order or any other formal suprageneric unit. Should the affinities of any acritarch genera be subsequently established, they should be removed and

classified more formally. For example, Evitt (1963b, p. 301) immediately recommended the removal of *Tasmanites* to the Chlorophyceae (see Wall 1962). Evitt (1963b, p. 301–302) gave a list of 59 genera that, in his view, should be classified as acritarchs. Of these acritarch genera, several have since been reclassified as dinoflagellates (e.g. *Dioxya*, *Gillinia*, *Komewuia*, *Omatia* and *Samlandia*) and prasinophytes (e.g. *Crassosphaera*, *Cymatiosphaera*, *Pterospermopsis* and *Tythodiscus*).

A3.17. Evitt, W.R. 1963c. Occurrence of freshwater alga *Pediastrum* in Cretaceous marine sediments. *American Journal of Science*, 262: 890–893.

This short note recorded two occurrences of the freshwater green alga *Pediastrum* from marine strata; these were the Lower Cretaceous of Pakistan and the Upper Cretaceous of California. The work was done while Bill was at the Jersey Production Research Company in Tulsa. At the time of publication, Evitt (1963c) was the first report of *Pediastrum* from strata older than Palaeogene. The Pakistan material is from cores drilled east of Hyderabad, Sindh, by the Standard-Vacuum Oil Company. These samples also contain abundant dinoflagellate cysts, pollen and spores which are indicative of an Early Cretaceous (Albian) age. By contrast, the Californian material is from the San Joaquin valley near Patterson in Stanislaus County, and is Late Cretaceous in age. The Californian *Pediastrum* specimens are associated with dinoflagellate cysts, foraminifera, pollen and radiolaria characteristic of the Campanian–Maastrichtian interval. It is clear that, in both these cases, the specimens of *Pediastrum* had been transported into marine depositional settings. Furthermore, this algal genus appears to have had a remarkably conservative evolutionary history.

***A3.18.** Downie, C., Evitt, W.R. & Sarjeant, W.A.S. 1963. *Dinoflagellates, hystrichospheres, and the classification of the acritarchs*. Stanford University Publications, Geological Sciences, 7(3), 16 p.

Downie et al. (1963) was the one and only collaboration born out of Bill Evitt's association with the two marine palynologists from Sheffield, Charles Downie and Bill Sarjeant (subsection 5.5.1.). It was also the first of eight papers written or co-written by Bill Evitt in Stanford University Publications, Geological Sciences. At this time Downie and Sarjeant were working on a classification of the hystrichospheres, so it made perfect sense for them to collaborate with Bill Evitt in the light of the latter's recent research (e.g. Evitt 1961c; 1963a,b). The principal purpose of Downie et al. (1963) was to outline a morphologically based classification of the acritarchs.

This highly significant paper discussed the classification of the acritarchs, dinoflagellates and hystrichospheres, and followed on from Evitt (1963a, 1963b). It was hoped that the scheme proposed would provide a stable classification for future research. Downie et al. (1963) began by outlining the somewhat confused nature of the history of classification of these aquatic palynomorph groups, and reiterated that they should all be classified under the ICBN. The authors rejected the option of using form-genera, as had been adopted for fossil pollen and spores (Potonié 1956). They preferred instead to allocate genera to systematic groups according to their biological affinity, with the option of an *incertae sedis* category. For example, genera with unequivocal dinoflagellate affinity should be attributed to the Class Dinophyceae. The terms 'hystrichosphere' and 'hystrichosphaerid' were deemed

useful for spine-bearing fossil dinoflagellates, despite having no formal taxonomic status. This meant that undoubted fossil dinoflagellates with processes such as *Areoligera*, *Hystrichosphaeridium* and *Spiniferites* were hystrichospheres. By contrast, genera such as *Baltisphaeridium* and *Micrhystridium*, which lack any evidence of dinoflagellate affinity, are acritarchs *sensu* Evitt (1963b).

The acritarchs were considered to be a group by Evitt (1963b). This term means an association of similar forms with no implied biological affinity. Downie et al. (1963, p. 7) gave a detailed formal diagnosis for the Group Acritarcha. These authors also defined 13 subgroups based on their overall morphology. For example, the subgroup Acanthomorphitae comprises spine-bearing acritarchs; the name was derived from the Greek *akantha*, meaning thorn (Downie et al. 1963, p. 6). Each subgroup was given a brief morphological description, and the constituent genera were listed alphabetically (Downie et al. 1963, p. 7–12). There was also a Subgroup Uncertain for 13 genera which could not be allocated elsewhere. Listings of 108 definite fossil dinoflagellate genera and five genera referable to the Chlorophyceae were also given (Downie et al. 1963, p. 12–15).

A3.19. Evitt, W.R. 1964. Dinoflagellates and their use in petroleum geology. In: Cross, A.T. (editor). *Palynology in oil exploration. A symposium*. Society of Economic Paleontologists and Mineralogists Special Publication, No. 11: 65–72.

This is a short review article on dinoflagellate cysts and their use in petroleum geology. It was started while Bill was working for the Jersey Production Research Company in Tulsa in the early 1960s (section 5). Evitt (1964, p. 65) briefly reviewed the group and their history of study. He noted that, at the time of writing, fossil dinoflagellates had only very recently become useful as Mesozoic and Cenozoic stratigraphical markers.

The nature of modern dinoflagellates was briefly outlined (Evitt, 1964, p. 66–67). This included the cell covering (or lack of it), life cycle, locomotion, morphology, nutritional strategies and tabulation. The principal section is on the fossil record of the dinoflagellates (Evitt, 1964, p. 67–70). Aspects of morphology such as the archaeopyle and cavate fossil dinoflagellates were described, and the dinoflagellate cyst affinity of many hystrichospheres was discussed (Evitt, 1964, pl. 1, figs 15–17). It is clear that, at this time (the manuscript was finalised in 1962), Bill was quickly realising that the vast majority of fossil dinoflagellates represent the resting cyst stage (Evitt 1964, p. 69, footnote 2). Evitt (1964, p. 69) recommended the use of the term 'test' to distinguish suspected cysts from fossilised thecae.

The theme of the volume in which this paper appeared was petroleum geology, and dinoflagellate cyst biostratigraphy was discussed. In the early 1960s, this topic was in its infancy and very few data on the stratigraphical distributions of dinoflagellate cysts were in the public domain. The principal papers on this subject that were published at the time of writing were Cookson & Eisenack (1958), Gocht (1959), Klement (1960) and Alberti (1961). Evitt (1964, p. 70) gave the example of some morphologically characteristic species such as *Gonyaulacysta jurassica* and *Scriniodinium crystallinum* from an early Late Jurassic (Oxfordian) assemblage originally described from northern France by Deflandre (1938) being present in coeval strata from Australia, elsewhere in Europe and Utah. Another example given was the widespread presence of the genus *Dinogymnium* (as *Gymnodinium*) during the Late Cretaceous.

Palaeoecology was also briefly reviewed by Evitt (1964, p. 71). Very little was known about this topic in the early 1960s. However, Evitt (1964) noted the occasional floods of dinoflagellate cysts, where prodigiously large numbers of one species occur in a single horizon. Evitt (1964, p. 71) speculated whether these superabundances may represent fossil blooms or red tides, and stated that it would be interesting to examine samples for fossil dinoflagellates from beds with death assemblages of macrofossils such as abundant fish remains. This was a remarkably far-sighted observation because, 23 years later, Noe-Nygaard et al. (1987) reported repeated acmes (> 99%) of the dinoflagellate cyst *Sentusidinium pelionense* associated with mass mortalities of molluscs from the earliest Cretaceous of Denmark. Noe-Nygaard et al. (1987) concluded that seasonal toxic blooms caused by the motile dinoflagellate which produced *Sentusidinium pelionense* killed the abundant assemblages of the opportunistic bivalve *Neomiodon*. Evitt (1964, p. 71) also noted that living freshwater dinoflagellates are relatively abundant but that, by contrast, their fossil counterparts are extremely sparse.

*A3.20. Evitt, W.R. & Davidson, S.E. 1964. *Dinoflagellate studies. I. Dinoflagellate cysts and thecae*. Stanford University Publications, Geological Sciences, 10(1), 12 p.

Evitt & Davidson (1964) is a landmark publication. These authors clearly demonstrated that non-acritarch hystrichospheres are dinoflagellate cysts and that fossil dinoflagellates represent benthic resting cysts, as well as clearly establishing the cyst-producing dinoflagellate life cycle. Most significantly, it was proved that a typical *Hystrichosphaera* (= *Spiniferites*) cyst (i.e. an organic cyst which was not then recognised by researchers on modern dinoflagellates) forms inside a typical cellulose motile theca of *Gonyaulax digitale* (see Evitt & Davidson 1964, fig. 2; pl. 1, figs 10, 11). This unequivocally confirmed the cyst-theca relationship previously hypothesised in Evitt (1963a, 1963b) on the basis of fossil morphology and a comparison with thecal patterns in modern species. Prior to Evitt & Davidson (1964), the cyst-theca relationship in dinoflagellates was largely theoretical. This study strongly suggested that fossil dinoflagellates represent the cyst stage, and that thecal remains are not normally fossilised. The fact that fossil dinoflagellates were previously simply assumed to be thecae contributed to the relatively late discovery of the cyst-producing dinoflagellate life cycle, and the cyst-theca relationship.

Evitt & Davidson (1964) was based on modern plankton samples from Drøbak Sound, Oslo Fjord, Norway, and the Pacific Ocean along the coast of San Mateo County, California. It is based on a study of the thecae and resting cysts of four modern dinoflagellates, namely *Gonyaulax digitale*, *Lingulodinium polyedrum* (as *Gonyaulax polyedra*), *Protoceratium reticulatum* and *Protoperidinium leonis* (as *Peridinium leonis*). It was found that the cysts of *Gonyaulax digitale*, *Lingulodinium polyedrum* and *Protoceratium reticulatum* are typical hystrichospheres with precingular archaeopyles. By contrast, the cyst of *Protoperidinium leonis* is proximate, but also has an anterior intercalary archaeopyle. The dinoflagellate cysts recovered are all organic-walled and hence resistant to hydrofluoric acid; the only natural rupture is the archaeopyle and they all lack ventral flagellar pores. By contrast, the thecae are made of cellulose, exhibit one or two ventral flagellar pores and intratabular pores, and entirely lack archaeopyles.

Gonyaulax digitale and *Lingulodinium polyedrum* produce resting cysts which differ significantly in morphology, and

would certainly not be placed in *Gonyaulax*, *Gonyaulacysta*, or indeed the same (cyst-based) genus. This phenomenon indicates that there is the potential for serious nomenclatural problems at the cyst-theca interface. For example, the fact that *Gonyaulax digitale* produces a cyst referable to *Hystrichosphaera* (= *Spiniferites*) strongly implies that these two genera are synonyms. The fact that modern *Gonyaulax* produces other cysts which are markedly different to *Hystrichosphaera* (= *Spiniferites*) (see Dale 1983, fig. 45) suggests even more profound nomenclatural difficulties. Evitt & Davidson (1964) advised against precipitate taxonomic proposals until much more was discovered about both modern and fossil dinoflagellates. These authors also mentioned that the record of cysts of peridiniacean forms is more significant than was realised at the time. They also commented on the fossil record of probable ceratioid dinoflagellates.

A3.21. Evitt, W.R. 1965. A method for making serial sections of pollen and other organic microfossils. In: Kummel, B. & Raup, D. (editors). *Handbook of paleontological techniques*. W.H. Freeman and Company, San Francisco, 696–699.

Fossil palynomorphs are sectioned infrequently compared to modern pollen and spores. Material from fresh plants is homogenous, and the sections unequivocally represent the same taxon. By contrast, fossil palynomorph assemblages normally comprise many taxa. Hence, a method of selecting individual grains and a technique to cut them was required. The procedure described by Evitt (1965) is quick and simple, and can give serial sections of many specimens. However, the polarity of the individual grains is entirely random.

The method described by Evitt (1965) can be summarised thus. The palynomorphs are placed into a mixture of 30% ethanol, 20% n-butyl alcohol and 50% water, and allowed to dry. Paraffin wax is added and melted. The specimens are mechanically gathered onto the tip of a dissecting needle until they become embedded in a small ball of solid wax. The wax ball is then dipped into stained molten wax to help in locating the specimens during sectioning. A small cavity is made in a block of unstained wax, the palynomorph-bearing stained wax block is inserted and it is mounted in a microtome. The sections are then cut and mounted on slides.

A3.22. Evitt, W.R. 1967a. Five compilations of the literature on organic-walled microplankton. *Micropaleontology*, 13(1): 111–114.

This short paper is a description and comparison of five major catalogues/indexes of acritarchs, dinoflagellate cysts and prasinophytes which were available in the mid 1960s; these were summarised in Evitt (1967a, table 1). Access to some items from this rapidly burgeoning literature on marine palynomorphs could be (and still is) problematical, so all of these contributions were extremely important resources.

The first to be considered was Loeblich Jr. & Loeblich III (1966), which is an index of fossil and modern dinoflagellates. The introduction comprises a summary of the cytology, fossil record, mode of life and morphology of the dinoflagellates, and is followed by an alphabetical list of genera with references. Loeblich Jr. & Loeblich III (1966) did not distinguish between fossil and modern dinoflagellate taxa, and included some acritarch and prasinophyte genera.

Downie & Sarjeant (1965) is a bibliography and index of fossil dinoflagellates and acritarchs, and is divided into three sections. These are a bibliography, an index of lithostratigraphical units which have yielded organic microplankton,

and two alphabetical indexes of genera and species. The indexes are of 'valid' and 'invalid and rejected' taxa. The latter were determined somewhat subjectively. Downie & Sarjeant (1965) did not distinguish between acritarchs and dinoflagellate cysts. In the same year, Norris & Sarjeant (1965) issued a somewhat similar contribution. This was a descriptive index of acritarchs and dinoflagellate cysts. The main text comprises an annotated, alphabetical listing of genera with all the essential details including the description and any emendations. As in Downie & Sarjeant (1965), genera considered to be invalid for various reasons were indicated.

Eisenack & Klement (1964) was the first of a series of 11 catalogues of acritarchs and dinoflagellate cysts produced in Germany by Alfred Eisenack and his colleagues. This book is a loose-leaved publication with separate entries for each of the 83 genera and 420 species considered. A comprehensive introduction is followed by alphabetical taxonomic entries. The species pages include stratigraphical data and at least one line drawing. The comprehensive and professional nature of the 'Eisenack Katalogs' meant that they became the standard laboratory index for marine palynomorphs. The series was revived during the 1990s (e.g. Fensome et al. 1991).

The final publication reviewed was the *Fichier Micropaléontologique Général*, which was produced in several volumes issued between 1943 and 1966 by Georges Deflandre and his wife, Marthe Deflandre-Rigaud. Nine of these parts were on dinoflagellate cysts and hystrichospheres (e.g. Deflandre 1945; Deflandre & Deflandre-Rigaud 1958). The *Fichier Micropaléontologique Général* was based on an index card file compiled by the authors, and covered a more varied range of microfossil types than the 'Eisenack Katalogs'. The groups documented included acritarchs, archaeomonads, chitinozoans, dinoflagellate cysts, hystrichospheres, radiolarians and tintinnids. Its aim was to provide a comprehensive card index for illustrations of microfossils. The pages of the *Fichier Micropaléontologique Général* are facsimiles of hand-written index cards. The user can simply store the volumes in the normal way, or separate each card for filing in card index drawers. The concept of the *Fichier Micropaléontologique Général* was outlined by Deflandre & Deflandre-Rigaud (1943).

Evitt (1967a, p. 114) commented on the clear overlap between the five publications reviewed, and stated that the various authors had performed a great service to the user community by compiling large amounts of information from a widely scattered and frequently obscure literature. The five publications were quickly rendered out of date even during their respective publication processes because of the extremely rapid expansion of the literature on marine palynology during the 1960s.

A3.23. Evitt, W.R. 1967b. Progress in the study of fossil *Gymnodinium* (Dinophyceae). *Review of Palaeobotany and Palynology*, 2: 355–363.

This short paper is the second of two papers by Bill on fossil gymnodiniophycidean dinoflagellates. Modern representatives of this group are aquatic, free-living, unarmoured forms lacking a cellulosic theca. Evitt (1967b) is a preliminary paper, and was written before the much more comprehensive Evitt et al. (1967). Hence, the generic name *Gymnodinium*, and not *Dinogymnium*, was used in Evitt (1967b). Somewhat surprisingly, Evitt et al. (1967) was published several months before Evitt (1967b) was issued, and a footnote explaining this scenario was included in the latter.

The material in Evitt (1967b) is from the Upper Cretaceous (Coniacian to Maastrichtian) of Alabama, California, Kansas and New Jersey. A characteristic apical opening, referred to as the archeopyle, and small pore canals were noted. Evitt (1967b) did not describe any new species, but observed that this genus could be subdivided using the position of the cingulum, the ornamentation, the distribution and orientation of the wall-canals and the size of the archeopyle. The size and outline of individual specimens exhibit significant variability within species. Evitt (1967b) noted that the previous reports of fossil *Gymnodinium* were relatively sparse, and are largely of Late Cretaceous age. The material from the United States revealed previously unknown morphological complexity and variability. Some of the forms have biostratigraphical significance in the Late Cretaceous, and the wall canals are reminiscent of the trichocyst canals of motile cells as opposed to resting cysts. Fossil *Gymnodinium* specimens exhibit clear cingulums and sulci. Evitt (1967b) defined the cingulum index (CI), which is the number derived by dividing the distance from the apex to the centre of the cingulum by the total length and multiplying by 100. Deflandre (1966) believed that fossil *Gymnodinium* specimens represent resting cysts; they are much more robust than modern thecal forms, and appear to have an archeopyle. However the wall canals, indicating communication through the wall, are inconsistent with them being cysts. Subsequently, May (1976, 1977) proposed that *Dinogymnium* possibly represent fossilised motile cells, and this contention has been accepted (e.g. Evitt 1985).

***A3.24.** Evitt, W.R. 1967c. *Dinoflagellate studies. II. The archeopyle*. Stanford University Publications, Geological Sciences, 10(3), 83 p.

This is one of Bill's most important contributions, and Evitt (1967c) was the definitive paper on the excystment aperture or archeopyle of dinoflagellate cysts prior to Evitt (1985, chapter 6). Being American, Bill termed this feature the archeopyle; in Europe the spelling of this is archaeopyle (Feist-Burkhardt 2007). In the first sentence of the introduction Bill wryly admitted that 'In the sense that a hole is the absence of material, this paper, which might be subtitled "—a study of holes", is about nothing, for it deals with holes in the walls of dinoflagellate cysts' (emphasis added). Bill had begun to study this important morphological feature at the Jersey Production Research Company in 1958, and this was continued at Stanford University. When John Warren began his PhD at Stanford on Lower Cretaceous material in 1965, he and Bill began to list the different types of apertures in dinoflagellate cysts. They noted that the vast majority of these occurred within the epicyst; only extremely rarely is the archeopyle within the hypocyst.

Evitt (1967c) is extremely comprehensive and, unlike Evitt (1985), was illustrated with many exquisite photomicrographs. The paper was divided into three, with the first section being a relatively brief introduction (Evitt 1967c, p. 3–9). The term 'archeopyle' was first introduced by Evitt (1961c, p. 389), and was redefined in Evitt (1967c, p. 6) as 'an excystment aperture in the wall of a dinoflagellate cyst'. Naturally, this opening has a wholly or partially detached area of cyst wall which is termed the operculum (plural: opercula). The term archeopyle contrasts with pylome, which is a sub-circular opening in some acritarchs (e.g. Eisenack 1962; 1968; Lister 1970).

Part two of Evitt (1967c, p. 9–31) was on the morphology, classification and taxonomic significance of archeopyle types. Archaeopyles have been observed in modern

dinoflagellate cysts, and these confirm that the plate equivalence of the archaeopyle is a reflection of thecal tabulation. It was noted that peridinian forms typically exhibit anterior intercalary archaeopyles. Gonyaulacacean cysts differ from peridinoids; for example, *Spiniferites* has a single plate precingular archaeopyle and the cyst of *Lingulodinium polyedrum* (as *Gonyaulax polyedra*) has a three-plate precingular excystment aperture (Evitt 1967c, figs 13, 14). It was demonstrated that the archaeopyle can be expressed in one, all or none of the cyst wall layers (Evitt 1967c, fig. 15). Some taxa, such as *Palaeohystrichophora infusorioides* and *Subtilisphaera*, do not appear to exhibit an archaeopyle. It is possible that excystment in these forms occurred by a general deterioration of the cyst walls. Evitt (1967c, p. 14–16, figs 16–21) described the necessary terminology for the archaeopyle, such as accessory and principal archaeopyle sutures, operculum and sulcal notch.

The archaeopyle is a highly variable feature, with the nature of the operculum, position, shape and size differing markedly. The overwhelming majority occur on the epicyst, and hence comprise anterior intercalary, apical and/or precingular plates. There are five major archaeopyle types, namely apical, combination, intercalary, miscellaneous and precingular. These types are largely named after the respective plate series involved. A combination archaeopyle comprises plates from more than one series, and this includes the epicystal archaeopyle. Intercalary and precingular archaeopyles tend to be bilaterally symmetrical and middorsal; by contrast, apical archaeopyles are markedly asymmetrical. The operculum clearly is the same shape and size as its associated archaeopyle, and can vary markedly in size. The opercula also vary in that they can be adherent after formation (attached), or may be entirely detached (free). Additionally, up to eight individual plates may be lost separately (compound), or the operculum retains its integrity (simple). Simple, free opercula close most archaeopyles, and are isolated or can fall back into the empty cyst following excystment (e.g. Riding 1984, pl. 4, fig. 4). The operculum detaches by the formation of the principal archaeopyle suture. Accessory archaeopyle sutures are partial splits along plate boundaries in the operculum and/or the residual cyst (the loisthocyst of Sarjeant et al. 1987).

Evitt (1967c) detailed several important generalisations. For example, apical archaeopyles dominantly have simple opercula; if they are attached, they are hinged ventrally. All precingular archaeopyles have free opercula, and most combination archaeopyles involve the apical and precingular plate series. Multiplate intercalary and precingular archaeopyles all have compound opercula, and combination archaeopyles may have either simple or compound opercula. Finally, attached opercula, for example in epicystal archaeopyles, also exhibit a consistent trend in that they are attached ventrally at the sulcus. Not all opercula or opercular pieces correspond precisely to the size of the parent thecal plate(s). If an operculum is smaller or larger than the corresponding thecal plate(s), it is termed a reduced or enlarged archaeopyle (Evitt 1967c, figs 22–25).

Evitt (1967c, p. 21–26) devised a shorthand notation system for abbreviating the archaeopyle type. The capital letters A, I and P denote apical, intercalary and precingular archaeopyles, respectively. A superscript bar directly above the letter indicates that the operculum is simple. When Bill liaised with the Stanford University publishing department, he was advised that this diacritical mark could not be typeset normally and that the superscript bars had to be inserted

manually with a fine pen! Even in the contemporary digital world, there is no symbol in most word-processing packages which could be used for this purpose. Because of these serious typesetting problems, the notation for simple archaeopyles was changed to parentheses or square brackets in positions corresponding to each end of the superscript bar by Norris (1978b, p. 303); see also Evitt (1985, p. 129). An example of this is (4A), for a four-plate apical archaeopyle with a simple operculum. Other abbreviations were devised by Evitt (1967c); for example, a lower-case 'a' following the main capital letter means that the operculum is adnate (attached; e.g. Ia). Twelve different archaeopyle types, with abbreviations, were illustrated by Evitt (1967c, fig. 32).

In the 1960s, there were classifications for both dinoflagellate cysts and motile cells. Evitt (1967c) believed that the archaeopyle is a prime taxonomic criterion, not least due to the fact that it is dominantly genus- and species specific. It was suggested that the archaeopyle type and the division of the operculum into separate pieces are taxonomically important at the genus level. By contrast, the size and the shape of the archaeopyle and the presence and length of any accessory archaeopyle sutures can also be applied at the species level. Whether or not the operculum is attached was deemed to be of relatively minor taxonomic importance. Apical and epicystal archaeopyles are attached by the short as/1' plate suture. This delicate attachment is clearly prone to mechanical damage during taphonomy, diagenesis or preparation which mitigates against attachment being a prime taxonomic discriminator for these archaeopyle types. However, attachment is a much more robust taxonomic criterion in intercalary archaeopyles (Williams et al. 2015).

The stratigraphical distributions of 12 different archaeopyle types were illustrated in Evitt (1967c, p.29). Because the archaeopyle had received little attention in the mid-1960s, this range chart was very preliminary and many of the bioevents depicted can now be revised. For example, the inception of precingular archaeopyles was placed in the Late Jurassic in the chart. However, *Scrinocassis* has a 2P archaeopyle (Gocht 1964; 1979) and the range base of this genus is in the Early Jurassic (Late Pliensbachian) (Riding & Thomas 1992).

Evitt (1967c) was an extremely foresighted study, and one which posed some important questions. These include: Why are archaeopyles dominantly located on the epicyst, and why are so many excystment apertures positioned symmetrically about the dorsal midline? What is the functional morphological significance of compound versus simple opercula? Another important question is: What external and internal influences resulted in the opening of the archaeopyle? The latter is especially pertinent in cavate cysts where the periplasm is physically separated from the cytoplasm by the endoplasm. Eaton (1984), Riding (2012) and Riding & Michoux (2013) partially addressed this with the discovery that some cavate gonyaulacacean forms lack a periooperculum. Despite this, the precise answers to these four questions still have not been satisfactorily answered.

It is surprising that, given that the archaeopyle has to facilitate the hatching of the naked protoplast from the cyst, it differs so profoundly in size. For example, the archaeopyle in *Nannoceratopsis* is minute (Plate 13; Piel & Evitt 1980a), whereas it represents the full width of the cyst in *Ctenidodinium*, *Korystocysta* and *Wanaea* (see Woollam 1982; 1983). The high frequency of displaced opercula in the empty cyst is also interesting. This phenomenon does not seem compatible with the operculum as an excystment structure. Perhaps these

cases represent dinoflagellate cysts which have failed to successfully excyst? There are certain archaeopyle styles observed in the fossil record which are rarely, if ever, manifested in modern forms, for example apical and epicystal archaeopyles.

The third and final section of Evitt (1967c, p. 31–51) is devoted to descriptions of different archaeopyle types and styles. This comprehensive section is very well illustrated with detailed line drawings, photomicrographs of superbly preserved specimens and synoptic diagrams (Evitt 1967c, figs 32–50, pls 1–11). Bill continued to be fascinated by archaeopyle styles throughout his career (e.g. Piel & Evitt 1980a; Evitt & Witmer 1988).

A3.25. Evitt, W.R., Clarke, R.F.A. & Verdier, J.-P. 1967. *Dinoflagellate studies. III. Dinogymnium acuminatum n. gen., n. sp. (Maastrichtian) and other fossils formerly referable to Gymnodinium Stein.* Stanford University Publications, Geological Sciences, 10(4), 27 p.

This contribution was meant to be a follow-up paper to Evitt (1967b), but was actually published first. Bill gave a presentation on Late Cretaceous dinoflagellate cysts apparently related to the modern genus *Gymnodinium* at the Second International Conference on Palynology in Utrecht, The Netherlands, in 1966. Evitt et al. (1967) was written on the basis of this talk and subsequent discussions with two Europeans, Robin F.A. Clarke and Jean-Pierre Verdier, at this major symposium. All three authors had been working on this topic independently and they decided to pool their considerable knowledge of these forms, which can be sporadically common, to describe a new genus. The two European authors published their detailed results on the Upper Cretaceous marine palynology of the Isle of Wight, southern England, separately (Clarke & Verdier 1967).

Evitt (1967c, p. 17–18) mentioned the archaeopyle in Late Cretaceous dinoflagellate cysts referred to *Gymnodinium*, and Evitt (1976b) was a preliminary study on the morphology of this group. These fossil dinoflagellates exhibit unique morphological features which are absent in modern *Gymnodinium* thecae, so Evitt et al. (1967) decided to erect the new genus, *Dinogymnium*. The type was designated as the new species *Dinogymnium acuminatum* because its type material is very well preserved, and its intraspecific variability is much better understood than that of any of the other species.

Dinogymnium is a distinctive acavate, biconical to ellipsoidal genus which normally exhibits characteristic longitudinal folds or ribs and a prominent cingulum. It also has a small apical archaeopyle or opening, and an autophragm 'that may be partially or completely penetrated by wall canals' (Stover & Evitt 1978, p. 37). The latter feature is unique amongst dinoflagellate cysts, and specimens of *Dinogymnium* may be the remains of motile dinoflagellate cells (May 1976; 1977). The longitudinal folds give this genus a uniquely accordion-like appearance. These folds, together with the cingulum, allow some distortion of the outline (Evitt et al. 1967, figs 2–10). *Dinogymnium* is relatively conservative in its surface ornament, although the wall canals differ considerably in their density, depth of penetration, diameter and inclination. It is a cosmopolitan genus and is largely confined to the Late Cretaceous, although Londeix et al. (1996) reported material from the Early Cretaceous of Europe and the Gulf of Mexico. Its peak of abundance and diversity was during the Campanian and Maastrichtian interval.

Thirteen species originally described as *Gymnodinium* were transferred to *Dinogymnium* by Evitt et al. (1967, p. 5); some of these taxa exhibit significant intraspecific variability. Seven dinoflagellate cyst species were originally assigned to *Gymnodinium*, but were subsequently removed, largely transferred into other genera (Evitt et al. 1967, p. 6). Finally, four fossil species, originally attributed to *Gymnodinium*, were listed by Evitt et al. (1967, p. 6) as not having the appropriate morphologies to be accommodated in *Dinogymnium*; however, these taxa were not formally transferred out. These four species were subsequently reattributed, and are *Apteodinium australiense*, *Diconodinium ventriosum*, *Luxadinium? dabendorfense* and *Muiradinium dorsispirale*.

For this paper, Bill and Jean-Pierre Verdier restudied the type material of eight species of *Dinogymnium* originally described from the Upper Cretaceous flints of the Paris Basin by Georges Deflandre. Most of these were difficult to study in detail due to the opacity of the rock matrix. It was found that the somewhat obscure morphologies of species such as *Dinogymnium digitus*, *Dinogymnium heterocostatum* and *Dinogymnium laticinctum* mean that it is problematical to assign matrix-free specimens to them.

Dinogymnium acuminatum is the type of the genus and is from a phosphate nodule collected from the Maastrichtian Uhalde Formation from Del Puerto Canyon, Stanislaus County, California. The type material is matrix-free, and is exquisitely preserved (Evitt et al. 1967, figs 11–18). This species was documented in considerable detail (Evitt et al. 1967, p. 8–16, figs 19–22, pl. 1–3). Of all the previously described species, only *Dinogymnium heterocostatum* resembles *Dinogymnium acuminatum*, and it is possible that these taxa are conspecific. However, because the type of *Dinogymnium heterocostatum* is embedded in a flint which is of uncertain age and provenance (Deflandre 1936a), detailed comparisons and analysis of intraspecific variability are not possible. Following the description of *Dinogymnium acuminatum*, the 13 species transferred into the genus together with specimens identified only to generic level were treated systematically (Evitt et al. 1967, p. 16–25).

A3.26. Evitt, W.R. (with the collaboration of G. Deflandre). 1968. *The Cretaceous microfossil Ophiobolus lapidaris O. Wetzel and its flagellum-like filaments.* Stanford University Publications, Geological Sciences, 12(3), 11 p.

Evitt (1968) is a remarkable paper because, in 1962, Georges Deflandre was about to finalise a manuscript on the Cretaceous acritarch genus *Ophiobolus*. However, upon learning of Bill's interest in this genus, he refrained from submitting his paper and sent Bill a copy. Therefore the resulting Evitt (1968) was published 'in collaboration with Georges Deflandre'. It is therefore somewhat surprising that this was not formally a joint paper.

Ophiobolus was treated under the International Code for Zoological Nomenclature (ICZN), largely for historical reasons, which were outlined in an extensive systematic section (Evitt 1968, p. 2–8). *Ophiobolus lapidaris* was documented and formally described by Otto Wetzel (1932, 1933a, respectively) from the Upper Cretaceous of Germany. However, the generic name was illegitimate as it is preoccupied by the extant fungus *Ophiobolus* Riess 1854. The species is now assigned to the monotypic acritarch genus *Scuticabolus* as *Scuticabolus lapidaris* (see Fensome et al. 1990, p. 372, 452). This distinctive species is hollow, ovoid, smooth to weakly ornamented and thin walled. Furthermore, it bears one to up

to around seven extremely long, sinuous and slender polar to sub-polar (presumably posterior) filamentous projections, and has no consistently preformed excystment aperture. Duxbury (1983, p. 44) later speculated that *Scuticobolus lapidaris* has an apical or precingular archaeopyle. The processes of *Scuticobolus lapidaris* are normally around five times the body length, and may be intricately tangled; some may be lost due to mechanical damage. Deflandre (1936b) hypothesised that the processes were too numerous to represent longitudinal flagellae. Alberti (1961) demonstrated that they were not flagellae, and suggested that they may have been holdfasts.

Evitt (1968) reported well-preserved *Scuticobolus lapidaris* from the Upper Cretaceous (Campanian and Maastrichtian) of Alabama, Kansas, New Jersey and Texas. Like Alberti (1961), he interpreted the prominent filaments as structures adapted for attaching to other planktonic objects. *Scuticobolus lapidaris* exhibits significant intraspecific variability, ranges throughout the Late Cretaceous and is typically associated with abundant dinoflagellate cysts. It was postulated that *Scuticobolus lapidaris* represents the egg case of an extinct planktonic organism, and that the long processes helped their buoyancy and dispersal (Evitt 1968, p. 8).

An apparently related form, *Ophiobolus* sp. A., was documented from the Early Cretaceous (Late Hauterivian) of northern England and the North Sea by Davey (1979b). This morphotype has a clear precingular, type 2P, archaeopyle and, because of this feature, was assigned to the dinoflagellate cyst genus *Desmocysta* as *Desmocysta simplex*.

A3.27. Deunff, J. & Evitt, W.R. 1968. *Tunisphaeridium: A new acritarch genus from the Silurian and Devonian*. Stanford University Publications, Geological Sciences, 12(1), 13 p.

This is Bill Evitt's only contribution solely on specific acritarch taxa, and Deunff & Evitt (1968) comprises a detailed morphological and taxonomic treatment of the new genus *Tunisphaeridium* and the three new species *Tunisphaeridium caudatum*, *Tunisphaeridium concentricum* and *Tunisphaeridium parvum*. Bill wrote this paper with the French palynologist Jean Deunff of the University of Reims in northeast France entirely by correspondence; the two co-authors never met in person. Jean Deunff discovered *Tunisphaeridium* in small numbers from relatively diverse Early and Middle Devonian marine palynomorph associations from Tunisia. Bill encountered abundant material of this genus from a single sample of the Early Silurian (Llandovery) Maplewood Shale Formation of western New York State associated with species of *Baltisphaeridium*, *Micrhystridium* and *Veryhachium*. The genus is present in the Silurian and Devonian globally (e.g. Hill 1974; Wood & Clendening 1985; Rubinstein 1990).

Tunisphaeridium is subspherical, with a central body which bears processes that are connected distally by a membrane or filaments; the type is *Tunisphaeridium concentricum*. It is therefore somewhat similar in gross morphology to the Eocene dinoflagellate cyst genus *Eatonicysta*. *Tunisphaeridium* exhibits significant morphological variability, and this was demonstrated using scatter diagrams (Deunff & Evitt 1968, figs 1–6). The morphological overlap of the three species of *Tunisphaeridium* as demonstrated in the scatter plots was discussed in considerable detail by Deunff & Evitt (1968, p. 4–8). These scatter plots generally confirm the coherence of the three form species described, but some significant anomalies were discerned. For example, it is also clear that

there is a morphological continuum which connects all the specimens of *Tunisphaeridium* studied by Deunff & Evitt (1968). This phenomenon means that not all specimens of *Tunisphaeridium* can be confidently assigned to species level.

The simplest taxonomic strategy therefore would have been the establishment of *Tunisphaeridium* as a monospecific genus, with the type exhibiting significant intraspecific variability. However, this would have dismissed the extremely distinctive nature of the three holotypes. Alternatively, the distinctly bimodal distributions shown in Deunff & Evitt (1968, fig. 8) would indicate that the formalisation of two, or four, species would have been credible alternatives. In the four-species scenario, *Tunisphaeridium caudatum* would have been subdivided into two species based on size. The preferred scenario of Deunff & Evitt (1968) was that morphotypes with some extremely long processes are *Tunisphaeridium caudatum*, whereas *Tunisphaeridium concentricum* and *Tunisphaeridium parvum* have processes which are similar in length.

*A3.28. Evitt, W.R. & Wall, D. 1968. *Dinoflagellate studies IV. Theca and cyst of Recent freshwater Peridinium limbatum (Stokes) Lemmermann*. Stanford University Publications, Geological Sciences, 12(2), 15 p.

Evitt & Wall (1968) is an important and very-well-illustrated paper. It is principally on the cysts, thecae and life cycle of the extant freshwater dinoflagellate *Peridinium limbatum* from Grews Pond and Round Pond, Falmouth, Massachusetts. The theca of this species is distinguished by the left lateral inclination of the apical horn. This material was compared with the modern cavate dinoflagellate cyst *Peridinium limbatum* subsp. *minnesotense*. This cavate modern dinoflagellate cyst was first described by Eisenack & Fries (1965) from Weber Lake, northeast Minnesota. Eisenack & Fries (1965) hypothesised that *Peridinium limbatum* spp. *minnesotense* is a theca, and is homologous to cavate fossil dinoflagellates such as *Deflandrea phosphorica*. However *Peridinium limbatum* spp. *minnesotense* was reinterpreted as a dinoflagellate cyst, and synonymised with *Peridinium limbatum*, by Evitt & Wall (1968).

The overwhelming majority of this contribution is the systematics section (Evitt & Wall 1968, p. 2–12). Material from Grews Pond and Weber Lake only yielded empty cysts; however, Round Pond produced a mixture of cysts, cysts within thecae and living motile individuals. Evitt & Wall (1968) hatched a motile stage from a cyst in the laboratory, thereby confirming the life cycle of *Peridinium limbatum*. In this study, cysts were acetolysed and some thecae were dissected using sodium hypochlorite solution. The morphology of cysts and thecae of *Peridinium limbatum* was described in considerable detail (Evitt & Wall 1968, p. 3–9). Thecae have a typically peridinacean rounded subpentagonal shape, a tabulation formula of 4', 3a, 7'', 5c, 5''', 2'''' (Evitt & Wall 1968, figs 1–8), and the surface is perforate and reticulate (Plate 12). The cyst is released from the theca via a longitudinal, lateral schism which subdivides the theca into separate dorsal and ventral parts. Cysts of *Peridinium limbatum* are cornucavate and proximate; hence, they reflect the characteristic peridinioid shape of the parent theca. The surface ornamentation is somewhat variable; it may comprise granules or short spines which are tabular and nontabular (Evitt & Wall 1968, pl. 2, fig. 4; pl. 3, figs 1–9). In most specimens, the inner surface of the endocyst bears numerous narrow, shallow grooves with deeper furrows defining the tabulation (e.g. Evitt & Wall 1968, pl. 2, fig. 20). The archaeopyle is formed by a lateral

longitudinal (transapical) fissure on the epicyst which affects both the periphragm and endophragm. The principal archaeopyle suture ends at the cingulum. This feature of bipesoid cysts was later termed a 'transapical suture' by Norris & Hedlund (1972).

In Round Pond, *Peridinium limbatum* encysted during early November 1966 when the surface water temperature reached 10 °C. It was observed that, in most specimens, the endocyst developed early in cyst formation. A few cysts remained acavate, and these forms would not have been viable. The early-formed cysts proved resistant to mild acetolysis. Remains of the eye-spot were noted; it is possible that these small granular bodies in *Peridinium limbatum* cysts, and other dinoflagellate cysts, are the remains of this organelle. These features may be equivalent to the accumulation bodies or omphali observed in many pre-Quaternary dinoflagellate cysts.

Cysts of *Peridinium limbatum* were compared to other similar forms. Similar morphotypes were observed in Grews Pond. These are slightly larger than the material from Round Pond, and have stronger ornamentation. Round Pond also yielded abundant cysts of *Peridinium wisconsinense*. Despite differences in morphology, chiefly that of the single median antapical horn, the cyst of *Peridinium wisconsinense* has the same basic organisation as *Peridinium limbatum* cysts. However, cysts of *Peridinium wisconsinense* exhibit an attached apical archaeopyle (type tAa), which is highly unusual for peridinioid cysts. Furthermore, the cysts of *Peridinium willei* from Felt Lake, California were considered. The thecae and cysts of *Peridinium willei* are less typically peridinioid than *Peridinium limbatum*, but these taxa are similar in morphology and cyst organisation. Marine species of *Peridinium* typically produce acavate, proximate, smooth, resting cysts with anterior intercalary (type I) archaeopyles.

Peridinium limbatum cysts are very similar in basic organisation to many Mesozoic and Cenozoic cavate peridiniacean cysts such as *Deflandrea phosphoritica*. The pericyst and endocyst of *Peridinium limbatum* cysts and *Deflandrea phosphoritica* are homologous, and this evidence unequivocally proves that *Deflandrea phosphoritica* and its fossil relatives are cysts. The discovery of definite modern cavate dinoflagellate cysts by Evitt & Wall (1968) banished all doubts which remained in the 1960s that the fossil record of these forms is entirely represented by resting cysts. Acapsulate dinoflagellate cysts such as *Deflandrea* sp. of Evitt (1961c, pl. 1, fig. 1) appear to be similar to the acavate forms of *Peridinium limbatum*. However, the latter appear to be primarily acapsulate and apparently unviable. By contrast, pre-Quaternary capsulate peridinioids such as *Deflandrea* sp. of Evitt (1961c, pl. 1, fig. 1) are prone to the endophragm separating from the periphragm. The adhesion between the two wall layers in peridiniacean dinoflagellate cysts is low; hence, endocysts can relatively easily be mechanically dislodged from the pericyst (Eaton 1984).

The archaeopyles of *Peridinium limbatum* cysts and most other peridiniacean forms are different. The cyst of *Peridinium limbatum* has a transapical archaeopyle suture, whereas most pre-Quaternary peridinioids have anterior intercalary (type I) archaeopyles. Cysts of *Peridinium limbatum* confirm that the reflection of tabulation and other morphological features on the resting cyst is a result of genotypic control from the dinoflagellate cell. This is as opposed to some kind of mechanical mechanism such as moulding by the inner surface of the parent theca. The principal reason for this contention is that a tabulation pattern is present on the inner surface of the endocyst; by contrast, the outer surface is

smooth. Similarly, archaeopyle formation is also genotypically controlled.

A3.29. Evitt, W.R. 1969. Chapter 18. Dinoflagellates and other organisms in palynological preparations. In: Tschudy, R.H. & Scott, R.A. (editors). *Aspects of palynology*. Wiley, New York: 439–479.

Tschudy & Scott (1969) was, for many years, the only textbook available on pre-Quaternary palynology, comprising 18 chapters written by specialists. The first 17 chapters were largely on terrestrially derived palynomorphs. Very few palynologists worked on aqueous/marine forms during the 1960s, and this is probably why Evitt (1969) was the final chapter in this volume. Evitt (1969) is a thorough account of aquatic palynomorphs in five main sections. After a brief introduction, the distinction between the archaeopyle in dinoflagellate cysts and the pylome in acritarchs, and the chemical composition of marine and freshwater palynomorphs, was discussed.

The first main section is a brief account of living dinoflagellates. Evitt (1969, p. 441–445) discussed aspects such as classification, mode of life and morphology. Some dinoflagellates include an encysted stage in their life cycle. However, at the time of writing, the cysts of modern dinoflagellates, and the purpose of encystment, were poorly known. The work of Entz (1925) on cyst formation in *Ceratium* was summarised. It is remarkable that a living dinoflagellate species can produce cysts which have significantly different morphologies.

The second section on fossil dinoflagellates is by far the most extensive, and reflects the author's principal research interests (Evitt 1969, p. 446–463). It was emphasised that, at the time of writing, research in this area was expanding almost exponentially. Some dinoflagellate cysts approach the shape and size of the parent theca, whereas others are process bearing and the cyst body in these hystrichosphaerid types is far smaller than the cell of the motile form (Figure 11). Evitt (1969, p. 447–449) discussed the history of the concepts of the acritarchs and the hystrichospheres. During the encystment of a dinoflagellate, an organic resting cyst forms inside the theca, which eventually excysts via an operculate opening. The variety of the fidelity with which a cyst reflects the morphology of the parent theca was discussed. This section includes the classic figure of the development of a chorate dinoflagellate cyst first published by Evitt (1963a, fig. 3) and reproduced here as Figure 11.

The utility of the flagellar furrows (i.e. the cingulum and sulcus), tabulation and shape as recognitional criteria for fossil dinoflagellates was discussed (Evitt 1969, p. 450–451). All are significant, except that shape is unreliable in spherical/subspherical forms. There followed an extensive description of morphology (Evitt 1969, p. 451–459). This was subdivided into shape and projection structure, symmetry and wall structure. The first of these aspects is especially detailed. It was noted that both primary dorso-ventral compression and longitudinal extension are dominant; by contrast, lateral and longitudinal compression are rare. The prevalence of dorso-ventral compression means that the preferred orientation of most dinoflagellate cysts on microscope slides is either dorsal or ventral. It also means that this flattening is exaggerated in clay-rich sedimentary lithotypes which are susceptible to post-depositional compaction such as mudstones and shales. Most dinoflagellates and their cysts tend toward bilateral symmetry.

The cyst wall may be smooth, may bear various types of ornamentation (from low-relief features to major processes or septa), and may be extended into up to five major

projections or horns at 'cardinal' positions (Evitt 1969, fig. 18-6). Furthermore, the ornamentation may reflect tabulation (Evitt 1969, fig. 18-7). The archaeopyle is the excystment structure, and the description of this important feature was distilled from Evitt (1967c). The operculum normally comprises one or more epicystal plates. In some cases, the archaeopyle can be the only indication of tabulation. Frequently, detached opercula can be found isolated or are displaced back into the empty cyst. Most dinoflagellate cysts have two wall layers, the internal endophragm and the exterior periphragm. If these layers are separated, the cyst is termed cavate.

The use of the botanical and zoological codes of nomenclature was briefly discussed. Fossil dinoflagellates were originally described using the ICZN, but the living forms were considered to be algal. The ICBN is thus most appropriate for dinoflagellate cysts, and has the significant advantage of allowing the use of form genera. At the generic level, fossil dinoflagellates are classified and identified using archaeopyle style, cavation, shape and tabulation. This contrasts with living dinoflagellates, in which the thecal tabulation is the sole criterion. Species of fossil dinoflagellates are typically differentiated using relatively minor details such as ornamentation. Evitt (1969, p. 460) reiterated his plea for the rigorous description of significant populations and high-quality illustrations. Evitt (1969, p. 461–462) gave a synopsis of the suprageneric classification of dinoflagellates with a perspective on both fossil and modern forms; most are in the Class Dinophyceae.

Dinoflagellate cyst biostratigraphy and palaeoecology were briefly discussed (Evitt 1969, p. 462–463). Pre-Middle Jurassic forms are scarce, but diversity increased from the Middle Jurassic onwards, and some forms appear to have restricted stratigraphical ranges. However, in the 1960s, little was known about the detailed geographical and temporal extents of most taxa.

The third major section was on acritarchs, which are apparently unicellular organic-walled bodies with a central cavity, and which exhibit a wide variety of morphologies and ornamentation (Evitt 1969, p. 463–468). Eight subgroups were established by Downie et al. (1963). They are largely marine, probably polyphyletic and are of unknown affinity. Many acritarch taxa bear processes, septa and spines which are largely concordant; this strongly implies that they formed in a similar way to chorate dinoflagellate cysts (e.g. Lister 1970, fig. 21). Furthermore, some acritarchs have an operculate pylome.

The penultimate section was on the chitinozoa (Evitt 1969, p. 468–471). These are relatively large, vase-shaped marine palynomorphs of uncertain affinity found from the Ordovician to the Devonian (Jenkins 1970; Miller 1996). Their morphology is highly variable, some occur in chains, and many species are good biostratigraphical markers (Evitt 1969, figs 18–12). Finally, miscellaneous aquatic palynomorphs (i.e. *Ophiobolus*, *Pediastrum* and prasinophytes) were documented (Evitt 1969, p. 471–473). Due to the rapidly expanding literature on aqueous palynomorphs, an addendum was included to mention key publications which were issued while this textbook was in press (Evitt 1969, p. 473–474).

*A3.30. Evitt, W.R. 1970a. Dinoflagellates – a selective review. *Geoscience and Man*, 1: 29–45.

This paper is one of Bill's most influential contributions, being a major synthesis of dinoflagellate research during the 1960s. Bill presented this contribution as an invited keynote

presentation at the first Annual Meeting of the newly formed AASP at Louisiana State University, Baton Rouge, Louisiana, on 17 October 1968. Evitt (1970a) comprised an introduction and conclusions followed by 10 other sections. Research into fossil dinoflagellates was only being undertaken by six active workers during the mid 1950s, but expanded significantly in the subsequent 15 years. Also, during this time, some crossover had occurred between specialists on living and fossil forms. Following a brief introduction, Evitt (1970a, p. 30–31, fig. 1) detailed the history of the study of fossil dinoflagellates subdivided into three periods. The first of these was between the publication of Ehrenberg (1838) and 1932. Only two genera were published at this time, and interest in the topic was minimal to say the least. Period II (1933–1959) was an era of much taxonomy and cataloguing; 79 genera were established by 1959. The first phase, before World War II, was dominated by the European workers Georges Deflandre, Alfred Eisenack, Maria Lejeune-Carpentier and Otto Wetzel. Following World War II, dinoflagellates and hystrichospheres were first reported from Australasia by Isabel Cookson and her collaborators (Riding & Dettmann 2013), and palynology was extensively taken up by the oil industry. The final period comprised the 1960s, when this discipline became truly international. During this interval, dinoflagellate cysts were first used in biostratigraphy, and intraspecific variability and the nature of the fossil record were researched. Perhaps most importantly, major breakthroughs in understanding were made. These were the realisation that the fossil record was overwhelmingly represented by dinoflagellate resting cysts and included many hystrichospheres, that dinoflagellate cysts are distinguishable from other aquatic palynomorphs of unknown affinity termed acritarchs, and that the study of the life cycle of modern dinoflagellates can help us better understand the fossil record. By 1967, 224 genera of dinoflagellate cysts had been described. The principal thrust of Evitt (1970a) was the fossil record; however, a brief review of living forms was given. A comparison grid illustrating the six principal differences between dinoflagellate thecae and cysts (Evitt 1970a, table 1) was presented. These include areal patterns, composition and layering/continuity.

A checklist of features which should be used in the description of dinoflagellate cysts was given by Evitt (1970a, table 2). This listing is just as applicable today. Bill believed that, of these seven main headings, tabulation and variability were paramount. As in living dinoflagellates, the number and configuration of the reflected plates on dinoflagellate cysts, where these are manifested, are crucial for identification at all taxonomic levels. Intraspecific variability in dinoflagellate cysts can be significant. To fully assess this, adequate numbers of specimens (i.e. 20–30) should be studied prior to formalisation. During the 1960s, the variation within species was frequently not fully appreciated, and many taxa which were established on the basis of only one or two specimens are synonyms. Bill felt strongly that it is preferable to formalise a new species based on an adequate number of well-preserved specimens, rather than to assign the material to a poorly described taxon or one where the type material is unavailable for restudy.

Evitt (1970a) also commented that it was geologists such as Barrie Dale, David Wall and himself, rather than biologists, who had first discerned dinoflagellate cyst-theca relationships. Bill referred to the groundbreaking work of Barrie Dale and David Wall as 'experimental palaeontology'. This comprised the laboratory incubation of viable modern

dinoflagellate cysts collected in the field in order to correlate cyst species to the motile form which emerges from them (e.g. Wall 1965; Wall & Dale 1966; 1968a; Wall et al. 1967). This research presented taxonomic problems, for example the fact that some thecate species produce more than one taxon of cysts (Dale 1983, fig. 45). Evitt (1970a) believed that the morphological contrasts between different cyst species are more marked than the differences between thecae.

Fossil dinoflagellate cysts either exhibit a tabulation unknown in modern floras, or plate patterns akin to those in the modern genera *Ceratium*, *Gonyaulax* or *Peridinium*. Others have little or no demonstrable tabulation. It is remarkable that the species within the ~230 dinoflagellate cyst genera described at this time would be assigned to less than 12 thecate genera if the generic distinctions of cysts were made on the basis of tabulation alone, as in modern motile forms. Furthermore, it was becoming clear in the 1960s that not all motile dinoflagellate taxa produced fossilisable resting cysts. This begs the question as to why a resting cyst stage gives a selective advantage in some groups, but not others. The nature of the fossil record of calcareous and siliceous dinoflagellate cysts was not fully appreciated during the 1960s, and these forms were only mentioned briefly by Evitt (1970a, p. 36). He made the point that, when these forms were first discovered in the 1930s and 1940s, they were naturally assumed to be thecae.

Nomenclatural and taxonomic problems were discussed in detail by Evitt (1970a, p. 36–39). These phenomena are more profound in the dinoflagellates because of the two different stages of the life cycle. The complex and somewhat emotive question of the seniority of the cyst genera *Hystri-chosphaera* and *Spiniferites*, and their relationship to modern thecate species of *Gonyaulax*, was discussed as a prime example of this issue. Evitt (1970a) speculated whether a comprehensive and unified classification, which includes both fossil cysts and living forms, was desirable and/or possible. This eventually proved to be both, but took another 23 years to achieve its fruition (Fensome et al. 1993). Evitt (1970a) reiterated his opposition to a classification scheme for dinoflagellates which is similar to that used for pollen and spores (Potonié 1956). It was noted that the suprageneric classifications of fossil dinoflagellates in the 1960s were purely based on morphology, and took no account of affinities with modern dinoflagellates. Evitt (1970a) believed that, at this early stage in research into dinoflagellate cysts, a suprageneric classification was inappropriate.

Evitt (1970a, p. 39–41) contrasted the relatively sparse record of pre-Quaternary freshwater dinoflagellates with the abundant and widespread representatives of modern motile freshwater forms, especially species of *Ceratium* and *Peridinium*. Only the resting cysts of *Ceratium hirundinella* had been studied in detail at that time. Evitt (1970a, p. 39) reviewed the early work of Huber & Nipkow (1922; 1923) on material from Lake Zürich, Switzerland, who successfully incubated the three- or four-horned proximate cysts of *Ceratium hirundinella* (see Wall & Evitt 1975, fig. 7). Evitt & Wall (1968) undertook detailed research on the freshwater dinoflagellate *Peridinium limbatum*, the resting cyst of which is cavate and deflandreoid in morphology. Evitt (1970a) speculated that *Ceratium hirundinella* and *Peridinium limbatum* may be the freshwater survivors of the Late Mesozoic/Palaeogene *Deflandrea* lineage. One major difference is the archaeopyle which, in *Peridinium limbatum*, is formed by a transapical suture. Resting cysts of *Peridinium limbatum* exhibit pandasutural ornamentation i.e. reflecting the thecal tabulation. It

was hypothesised by Evitt (1970a) that this fidelity of reflection was due to the ‘proximity effect’, where the geographical closeness of the inner surface of the thecal wall to the cyst is conducive to the reflection of tabulation. However morphology is clearly genetically driven, as opposed to being purely the result of any physical effects.

Some progress was being made in the late 1960s on the ecology and evolutionary patterns of the dinoflagellates, but understanding of these topics at this time was somewhat limited. Some ecological studies, for example the use of dinoflagellates as shoreline indicators and the temperature controls on Quaternary dinoflagellate cysts, were reviewed. It is possible that floods of dinoflagellate cysts in the fossil record may record ancient instances of blooms. Evitt (1970a, p. 41) speculated that fish kill beds may be related to red tides of extinct cyst-producing toxic dinoflagellates. This was later confirmed by Noe-Nygaard et al. (1987). It was commented that an assessment of which dinoflagellate cyst species were cosmopolitan, and which were endemic, must await much more detailed research. Despite the limitations of the dinoflagellate fossil record, some morphological lineages of genera and species which may represent evolutionary change were identified. These include *Deflandrea*, *Odontochitina*, *Sirmiodinium grossii* (see Warren 1967; 1973) and *Wetzeliella*. Some major dinoflagellate cyst bioevents were also noted. One of these is the virtual extinction of the hystri-chosphaerid dinoflagellate cysts such as *Homotryblium*, *Hystri-chokolpoma* and *Hystri-chosphaeridium* in the Neogene. Evitt (1970a, p. 42) concluded with a listing of five future research trends including biostratigraphy, cataloguing and ecology.

A3.31. Evitt, W.R. 1970b. Microflora. In: Appendix: paleontology and age of Andrew Lake Formation. In: Scholl, D.W., Greene, H.G. & Marlow, M.S. *Eocene age of the Adak ‘Paleozoic(?)’ rocks, Aleutian Islands, Alaska*. Geological Society of America Bulletin, 81: 3589.

Scholl et al. (1970) described the geology of the northern part of Adak Island, Alaska. Adak Island is located at the western end of the Aleutian Archipelago. On the northern side of Adak Island, the lowermost part of the Andrew Lake Formation has yielded plant fossils which were originally attributed to the Upper Palaeozoic (Late Carboniferous to Permian) genus *Annularia*. The latter age assessment is clearly in error because Evitt (1970b) recovered an unequivocal Eocene marine microplankton assemblage from the matrix of these plant fossils, and this contribution represents one of his relatively rare forays into biostratigraphy. The association comprises the dinoflagellate cysts *Areosphaeridium diktyoplokum*, *Diphyes colligerum*, *Enneadocysta* sp. cf. *E. pectiniformis*, *Impagidinium maculatum*, *Leptodinium* sp. cf. *L. membranigerum* and *Stichodium? lineidentatum*, and the acritarch *Paucilobimorpha incurvata* (see Scholl et al. 1970, table 1). The palynological evidence of an Eocene age is entirely consistent with the presence of Eocene bivalves, fish scales and foraminifera in the beds overlying the plant fossils.

Specifically, Bill contributed part of the palaeontological appendix in Scholl et al. (1970, p. 3589). Evitt (1970b) stated that 14 marine microplankton species were found, eight of which indicate a Middle–Late Eocene age by comparison to occurrences in Australia, northern California and southern England. For example, *Areosphaeridium diktyoplokum* is typically Middle–Late Eocene in age (Powell 1992; Stover et al. 1996), and *Stichodium? lineidentatum* is a Middle Eocene marker in New Zealand (Wilson 1984, fig. 4). The single

sample studied by Bill is dominated by marine microplankton; pollen and spores are relatively sparse. This may reflect remoteness of land, or the sparsely vegetated nature of the hinterland. These results were previewed by Scholl et al. (1969).

A3.32. Evitt, W.R. 1973a. 24. Dinoflagellates from Leg 19, Sites 183 and 192 Deep Sea Drilling Project. *Initial Reports of the Deep Sea Drilling Project*, 19: 737–738.

Evitt (1973a) is a brief contribution on the palynology of 12 samples of latest Cretaceous (Maastrichtian) to Palaeogene/Neogene (Oligocene or Early Miocene) age from Sites 183 and 192, Leg 19 of the Deep Sea Drilling Project. This leg was drilled in the Bering Sea in the North Pacific Ocean. Site 183 was drilled south of the Aleutian Islands, and Site 192 is off the east coast of Kamchatka (Creager et al., 1973, fig. 1). Only the nine samples from Site 183 were productive; the three samples from Site 192 proved barren (Evitt, 1973a, table 1). The samples from Site 183 were generally sparse in dinoflagellate cysts, except at 390 m (Core 35); this horizon produced the single species *Areosphaeridium diktyoplakum* (see Evitt, 1973a, figs 1, 2). This distinctive and widespread skolochorate taxon is indicative of the Eocene (Powell, 1992; Stover et al., 1996, fig. 32). The associated pollen and spores, which include *Alnus* and *Tsuga*, are indicative of a nearshore Boreal/temperate environment.

A3.33. Evitt, W.R. 1973b. Maastrichtian *Aquilapollenites* in Texas, Maryland, and New Jersey. *Geoscience and Man*, 7: 31–38.

This short paper is on latest Cretaceous and earliest Palaeogene palynofloras from a locality in east Texas, with the principal emphasis on the triprojectate pollen genus *Aquilapollenites*. The units investigated were the Kemp Clay (Maastrichtian) and the Kincaid Formation (Danian) of a succession on the bank of the Brazos River in Falls County, Texas (Evitt 1973b, fig. 1). Abundant and relatively diverse palynofloras were recorded; these include the dinoflagellate cysts *Cannosphaeropsis* sp. aff. *C. utinensis*, *Carpatella cornuta* (as *Danea mutabilis*), *Dinogymnium acuminatum*, *Eisenackia circumtabulata*, *Manumiella druggii* (identified as *Deflandrea cretacea* – now *Manumiella? cretacea*) and *Spiniferites* spp. Pollen belonging to the Triprojectacites group was not prominent, but a relatively diverse association which includes 12 species of *Aquilapollenites sensu lato* were recognised (Evitt 1973b, table 1). Other pollen recovered includes *Cranwellia striata*, *Ephedra voluta*, *Proteacidites thalmani* and *Wodehouseia spinata*. *Aquilapollenites* pollen is confined to northern Asia and northwest North America (Herngreen et al. 1996, fig. 2). Therefore this record is close to the southwestern limit of this extremely distinctive phytogeoprovince. Consequently, the diversity is not as great as it is farther north, for example in the Rocky Mountains. Reworking of Upper Cretaceous palynomorphs into the Danian is extensive in the Brazos River section, and this often dominates the indigenous palynofloras. The presence of three specimens of triprojectate pollen from the Upper Cretaceous of Maryland and New Jersey were also mentioned. These occurrences from the Atlantic Coastal Plain are outside the main *Aquilapollenites* phytogeoprovince, and may have been transported by wind. Evitt (1973b) is one of the few papers Bill wrote which mention pollen; moreover, he only very rarely described the entire palynoflora from a single stratigraphical succession.

A3.34. Evitt, W.R. 1974a. Restudy of an Oligocene freshwater dinoflagellate from Vermont. *Geoscience and Man*, 9: 1–6.

The first freshwater dinoflagellate cyst to be reported was from the Upper Oligocene Brandon Formation of near Brandon, central Vermont, and was originally named *Peridinium hansonianum* by Traverse (1955). This species was subsequently recombined, and is now *Saepodinium hansonianum*. The type material is now considered to be Early Miocene in age (Traverse 1994). In this short paper, Evitt (1974a) extensively redescribed this distinctive species, which has a combination type (A313P)a archaeopyle. Its cavate nature means that *Saepodinium hansonianum* resembles species in several marine peridiniacean genera such as *Cerodinium*, *Chatangiella*, *Deflandrea* and *Senegalinium*. However, it is morphologically most similar to the cyst of the modern freshwater dinoflagellate *Peridinium limbatum* (see Evitt 1974a, table 1). *Saepodinium hansonianum* was found abundantly from a freshwater silt immediately above a lignite which is rich in plant fossils, by Traverse (1955). It co-occurs with the freshwater algae *Botryococcus* and *Pediastrum*, and pollen. This monospecific occurrence is typical of freshwater dinoflagellate cysts. Evitt (1974a) hypothesised that certain marine dinoflagellates colonised freshwater habitats during the Cenozoic, possibly as a survival strategy. However, unequivocal freshwater and brackish dinoflagellate cysts are now known from the Cretaceous (e.g. Hughes & Harding 1985; Batten & Lister 1988a, 1988b; Harding 1990; Sha et al. 2009); hence, this phenomenon appears to have taken place throughout the dinoflagellate cyst record. A modern review of freshwater dinoflagellate cysts was given by Mertens et al. (2012).

A3.35. Evitt, W.R. 1974b. Foraminiferal affinities... comment. *Geology*, 2(12): 582–583.

Haskell (1974) noted that the morphology of the chambers in some organic foraminiferal test linings appears to be somewhat similar to that of the Jurassic dinoflagellate cyst species *Nannoceratopsis gracilis*. This author hypothesised that if specimens of *Nannoceratopsis gracilis* were arranged in a spiral, the resultant structure would resemble a planispiral foraminifer (Haskell, 1974, fig. 4). An incisive and measured rebuttal of this paper by Evitt (1974b) was published immediately following Haskell (1974) in the journal. Evitt (1974b) pointed out that the detailed morphology of *Nannoceratopsis*, including a cingulum and a sulcus, is entirely consistent with it representing a dinophysidalean dinoflagellate and it is therefore definitely not a part of a foraminiferal test lining. Furthermore, Haskell (1974) erroneously stated that *Nannoceratopsis* lacks an archaeopyle. Evitt (1974b) argued that the rupture of the autophragm in the cingulum of this genus appears to be an excystment aperture. This was subsequently unequivocally confirmed by Piel & Evitt (1980a); see Plate 13. The theory advanced by Haskell (1974) is also untenable because other species of *Nannoceratopsis*, i.e. *Nannoceratopsis pellucida* and *Nannoceratopsis spiculata*, do not exhibit the variability in shape which would be required for the foraminiferal hypothesis. The fact that *Nannoceratopsis* is confined to the Jurassic (Figure 21), and the closely similar motile genus *Dinophysis* is modern, was used by Haskell (1974) to support his foraminiferal theory. However, the temporally disjunct nature of *Nannoceratopsis* and *Dinophysis* does not preclude a relationship between these dinoflagellate genera. Selectivity of cyst formation is well known in other unequivocal dinoflagellates (e.g. Wall & Evitt 1975). Evitt (1974b) also

noted that foraminiferal test linings normally do not resemble *Nannoceratopsis* in morphology, and also are significantly darker in body colour.

The journal allowed a reply to Evitt (1974b), and Haskell (1975) sought to defend his original contention that *Nannoceratopsis gracilis* represents the chambers in an organic foraminiferal test lining. Haskell (1975) attempted to rebut the contention of Evitt (1974b) that the shape of *Nannoceratopsis* is inconsistent with a foraminiferal affinity, and gave examples of suitable genera of foraminifera. Haskell (1975) also posited that the rupture in the apical region of *Nannoceratopsis* is a result of mechanical damage, and is hence unlikely to be an archaeopyle. This contention was subsequently comprehensively disproved by Piel & Evitt (1980a). Furthermore, Haskell (1975) sought to rebut Evitt's (1974b) view that *Nannoceratopsis pellucida* cannot be a foraminiferal chamber on morphological grounds, and that there is a marked colour difference between *Nannoceratopsis* and foraminiferal test linings. In conclusion, it is now quite clear that *Nannoceratopsis* is of unequivocal dinoflagellate affinity, and that the comment of Evitt (1974b) was entirely correct.

A3.36. Evitt, W.R. 1975a. Memorial to Georges Deflandre 1897–1973. *Geological Society of America Memorials*, 5, 11 p.

It is abundantly clear that the French scientist Georges Victor Deflandre (1897–1973) was Bill's principal mentor and source of inspiration in palynology. Evitt (1975a) was effusive in his praise of him, stating that (*inter alia*) Deflandre had great energy and perseverance, penetratingly critical judgement, a brilliant, creative and highly ordered mind, a generous and warm spirit, and the highest of scientific standards. An example of his single-mindedness about the pursuit of scientific truth is that Deflandre would often quote personal communications from colleagues without permission in order to be as thorough as possible. Following Deflandre's passing on 17 June 1973, Bill liaised with his widow, Marthe Deflandre-Rigaud, to produce Evitt (1975a), which was a comprehensive obituary article.

Georges Deflandre was born in 1897 in northeast France. He was forced to abandon his secondary education in 1913 in order to obtain work on the railways due to the poor health of his father. In 1915 Deflandre became a schoolteacher, a career he pursued until 1932. Georges had always been interested in the natural world. He studied various microscopic organisms while he was a teacher, and Deflandre (1923) was his first paper. This work on freshwater algology was continued, and he was granted permission to submit a doctoral thesis on the flagellate *Trachelemonas* in 1926. Georges Deflandre's long-held ambition of becoming a full-time professional research scientist was achieved in 1932 with a position at the Laboratoire d'Evolution des Êtres Organisés in Paris. There, he began to undertake research on marine calcareous, organic and siliceous microfossils. Deflandre rose through the ranks and, in 1943, he was made head of the Laboratoire de Micropaléontologie of the École Pratique des Hautes Études in Paris.

Deflandre was hugely influential during the first phase of research into aquatic palynomorphs. He largely worked on documentation, taxonomy and techniques, but did not concern himself with biostratigraphy. He was massively scientifically productive, publishing 314 scientific contributions and describing over 1000 taxa spanning several microfossil groups (Evitt 1975a, p. 5–11). These numerous publications are beautifully illustrated with intricate line drawings; Georges clearly inherited his father's artistic skills. His range of

interests is impressive; Deflandre worked on acritarchs, archaeomonads, chitinozoans, ciliates, coccolithophorids, desmids, diatoms, dinoflagellates, ebridians, foraminifera, phytoflagellates, radiolarians, scolecodonts, silicoflagellates and thecamoebians. Another facet of Georges Deflandre's nature was his assiduous record keeping. He amassed ~50,000 illustrated description index cards, ~15,000 microscope slides and copious amounts of notes, photographs etc., all of which were organised meticulously. All of these materials can still be accessed at the Muséum National d'Histoire Naturelle in Paris.

His work on silicofossils was largely on radiolarians; Deflandre found that their evolution was much more complex than previously thought. He also researched calcareous nannofossils, co-authoring a seminal paper (Deflandre & Fert 1952). Georges Deflandre first encountered fossil dinoflagellates in flakes of Upper Cretaceous flint collected from the kerbstones of central Paris. During the 1930s, Deflandre put the majority of his research effort into marine palynology, publishing around 70 papers on this topic between 1934 and 1970. The most influential of these are Deflandre (1936a, 1936b, 1937, 1938, 1941, 1946) and Deflandre & Cookson (1955). Most of these contributions are largely taxonomic. Georges Deflandre also contributed on the nature of fossil dinoflagellates and hystrichospheres (e.g. Deflandre 1947). In 1959 Deflandre was highly receptive to Bill's hypothesis that the dinoflagellate fossil record was largely comprised of the cyst stage, and that most Mesozoic and Cenozoic hystrichospheres are fossil dinoflagellates (subsection 5.5.3.). From 1941, he worked with Marthe, his wife, to produce the seminal *Fichier de Micropaléontologie* (Deflandre & Deflandre-Rigaud 1943).

A3.37. Evitt, W.R. 1975b. The archaeopyle in Cretaceous *Palaeoperidinium eurypyllum* (Manum and Cookson) comb. nov., and similar dinoflagellates. *Geoscience and Man*, 11: 77–86.

Manum & Cookson (1964) described *Scriniodinium eurypyllum* from the Upper Cretaceous Kanguk Formation of Ellef Ringes Island, Northwest Territories, Arctic Canada. The principal purpose of Evitt (1975b) was to remove *eurypyllum* from the gonyaulacacean genus *Scriniodinium*, and transfer this species to the peridiniacean genus *Palaeoperidinium*. Evitt (1975b) restudied *Scriniodinium eurypyllum*, recognised its peridiniacean morphology and noted that it has a combination (type AIP) archaeopyle as opposed to the precingular excystment aperture interpreted by Manum & Cookson (1964). The operculum is effectively the dorsal side of the epicyst. The archaeopyle style of *Palaeoperidinium? eurypyllum* was discussed in considerable detail by Evitt (1975b, p. 77–79). This species has a similar excystment aperture to *Saepodinium hansonianum*.

In the systematic section (Evitt 1975b, p. 79–81), the genus *Palaeoperidinium* was discussed at some length. Sarjeant (1967b) deemed that, despite some taxonomic problems, *Palaeoperidinium* should be credited to Deflandre (1934), and that *Palaeoperidinium pyrophorum* is the valid type. Furthermore, he argued that *Peridinium pyrophorum* was validly transferred to *Palaeoperidinium* by Deflandre (1935). After considering some of the finer points of the ICBN, Evitt (1975b, p. 80) concluded that Sarjeant (1967b) was basically correct, but that the 'full citation of this species should read: *Palaeoperidinium pyrophorum* (Ehrenberg 1838) Deflandre 1935, emend. Sarjeant 1967'.

Evitt (1975b) demonstrated that *Palaeoperidinium pyrophorum* has an archaeopyle formed by a transapical suture with a dorsal connection along the cingulum, and moreover

that *Palaeoperidinium? eurypyllum* and *Saeptodinium hansonianum* have similar archaeopyles. A very comprehensive morphological redescription of *Palaeoperidinium? eurypyllum* was given by Evitt (1975b, p. 81–82). The combination (type AIP) archaeopyle has a simple operculum which is formed by seven plates, i.e. 3', 1a–3a and 3''–5''. Other characteristic features are the striate reflected thecal growth bands on the periphragm (Evitt 1975b, pl. 1, figs 10–12). *Palaeoperidinium basilium*, *Palaeoperidinium* sp., *Peridinium limbatum* and *Saeptodinium hansonianum* (as *Palaeoperidinium? hansonianum*) are comparable forms to *Palaeoperidinium? eurypyllum*, and were also treated briefly in the systematic section (Evitt 1975b, p. 83–85). *Palaeoperidinium basilium* is a junior synonym of *Palaeoperidinium pyrphorum* according to Stover & Evitt (1978, p. 218).

Following the publication of Evitt (1975b), the species *eurypyllum* was transferred from *Palaeoperidinium* to *Saeptodinium* by Stover & Evitt (1978, p. 220). However, Evitt et al. (1998, p. 52) subsequently rejected this transfer, but only provisionally retained *eurypyllum* in *Palaeoperidinium* (see Fensome & Williams 2004, p. 494). Bill's interest in *Palaeoperidinium* and its close relatives persisted throughout his career, culminating with the detailed analysis of the morphology of *Palaeoperidinium* in Evitt et al. (1998), his last paper on dinoflagellate morphology.

A3.38. Evitt, W.R. 1975c. Book review of: *Fossil and living dinoflagellates* by W.A.S. Sarjeant, Academic Press, New York, 1974, viii + 182 p. *Science*, 189 (4208): 1081–1082.

This is the only book review that Bill Evitt published; it is of an early volume on dinoflagellates, and was published in a very high-profile journal. Sarjeant (1974) is a comprehensive textbook on fossil and living dinoflagellates. Evitt (1975c) commented that it would be useful for geologists needing to learn about living dinoflagellates, and that it would inform biologists about the long and diverse fossil record of this group. The fact that Sarjeant (1974) covered both fossil and living dinoflagellates was indeed far-sighted in that it was published four years prior to the Penrose conference in 1978 (section 11). It is entirely possible that this textbook provided the initial stimulus for this important meeting. Bill clearly liked the book, terming it 'readable and informative' (p. 1081) and further commenting that it is 'unique and successful' (p. 1082). The clear writing style was praised, and Evitt (1975c) stated that Chapter 5 on the history of study of fossil dinoflagellates was Bill Sarjeant at his eloquent best. In this section, Sarjeant (1974, p. 49–62) lucidly wove an eminently readable narrative of how Christian Gottfried Ehrenberg's xanthidia became Otto Wetzel's hystrichospheres, and then ultimately acanthomorph acritarchs and chorate dinoflagellate cysts as appropriate. Bill's criticisms were relatively few. He noted some of the original display materials are of relatively poor quality, a few typographical errors, some internal inconsistencies and a somewhat disparaging comment about a colleague.

*A3.39. Evitt, W.R. (editor). 1975d. *Proceedings of a forum on dinoflagellates held at Anaheim, California, October 16, 1973 as part of the Sixth Annual Meeting, AASP*. American Association of Stratigraphic Palynologists Contributions Series No. 4, 76 p.

This major publication was co-ordinated and edited by Bill, and represents the proceedings of a 'Forum on Dinoflagellates' held on the first day (Tuesday 16 October 1973) of the 6th Annual Meeting of the AASP held at the

Grand Hotel, Anaheim, California. The forum was organised by Bill, and was dedicated to the memory of Georges Deflandre (1897–1973). The morning session comprised six keynote presentations by prominent experts, which were included as abstracts or papers in the volume (Evitt 1975d, p. 1–48). During the afternoon, there were panel discussions on dinoflagellate cyst biostratigraphy and selected topics moderated by Bill. The 10 members of the panel (Evitt 1975d, p. v) were the principal discussants, but the audience also actively participated. The second part of the volume comprised range charts and plates arranged in four age-related chapters (Evitt 1975d, p. 49–76).

A3.40. Evitt, W.R. 1975e. Introduction to the forum and remarks on classification and morphology. In: Evitt, W.R. (editor). *Proceedings of a forum on dinoflagellates held at Anaheim, California, October 16, 1973 as part of the Sixth Annual Meeting, AASP*. American Association of Stratigraphic Palynologists Contributions Series, No. 4: 7–13.

This relatively short piece prefaced Evitt (1975d), and fulfilled two functions. Firstly, Evitt (1975e) noted the recent death of his mentor Georges Deflandre on 17 June 1973. He paid fulsome tributes to the great Frenchman, noting that Deflandre was, for example, 'intellectually brilliant' and 'of strong character' (p. 7). The fact that the Deflandre collections in the Laboratoire de Micropaléontologie of the École Pratique des Hautes Études in Paris would be well curated and available to researchers in perpetuity was mentioned. Evitt (1975e) also briefly reviewed the state of the art of dinoflagellate cyst research in the early 1970s. This included mention of the culturing of living dinoflagellates from cysts by Barrie Dale and David Wall. He also drew attention to the burgeoning literature mass on this topic as a result of the significant expansion of frontier petroleum exploration, and the urgent need for a family-level classification scheme of dinoflagellate cysts.

The second part of the article was a plea for the meticulous observation and recording of fine morphological details. The archaeopyle variability in peridinalean dinoflagellate cysts was used as an example of this. The plate equivalence of the archaeopyle, and the nature of the operculum, in these forms involves several combinations of the apical, anterior intercalary and precingular plates (Evitt 1975e, figs 1–5). Taxa such as *Chatangiella granulifera* (as *Australiella granulifera*), *Deflandrea phosphoritica*, *Palaeoperidinium? eurypyllum* (as *Scrinioidinium eurypyllum*) and *Trithyrodinium* spp. were discussed. At the close of this article, Bill stressed the importance of dealing explicitly with morphological detail in descriptions of taxa so that identifications would be accurate and the stratigraphical interpretations from them would be reliable.

A3.41. Evitt, W.R. & Pierce, S.T. 1975. Early Tertiary ages from the coastal belt of the Franciscan complex, northern California. *Geology*, 3(8): 433–436.

Evitt & Pierce (1975) is a short paper on the stratigraphical palynology of material from the Coastal belt of the Franciscan complex and the Yager Formation in northern California. It was one of the five largely biostratigraphical papers that Bill wrote or co-wrote. Evitt & Pierce (1975) established a Palaeogene, no older than Eocene, age for many widely scattered localities over approximately 3000 km² between Cape Mendocino and Fort Bragg (Evitt & Pierce, 1975, fig. 1). The Palaeogene age for most of the Coastal belt contrasts starkly with Franciscan strata to the east, which are dominantly Cretaceous in age.

A total of 58 productive samples were studied. Of these, 26 proved to be of Eocene age, 26 were assigned to the Palaeogene (undifferentiated) and six were demonstrated to be Cretaceous on dinoflagellate cyst and pollen evidence. The Eocene samples yielded abundant and well-preserved species of the characteristic dinoflagellate cyst genus *Wetzelia* (see Evitt & Pierce, 1975, fig. 2); these strata were previously thought to be Cretaceous. Other key Palaeogene dinoflagellate cyst taxa recognised were *Achilleodinium biformoides* (as *Hystrichokolpoma biformoides*), *Areosphaeridium diktyoplokum*, *Cordosphaeridium funiculatum*, *Deflandrea phosphoritica*, *Glaphyrocysta pastielsii* (as *Cyclonephelium pastielsii*) and *Samlandia chlamydothora*. The few Cretaceous samples yielded dinoflagellate cysts such as *Dinogymnium* spp., *Litosphaeridium siphoniphorum*, *Palaeohystrichophora infusorioides* and *Muderongia* sp. Significant reworking from the Upper Jurassic and Cretaceous was also noted.

The discovery of the young age of the Coastal Belt part of the Franciscan complex was startling at the time because all other mapped areas of the Franciscan Complex in California had yielded only Jurassic to Cretaceous ages. The subduction history of the west coast of North America had to be revised to accommodate the Palaeogene age of the Coastal Belt (Berkland et al. 1972; Blake & Jones 1974; 1978; Bachman 1982).

*A3.42. Wall, D. & Evitt, W.R. 1975. A comparison of the modern genus *Ceratium* Schrank, 1793, with certain Cretaceous marine dinoflagellates. *Micropaleontology*, 21(1): 14–44.

Wall & Evitt (1975) is a detailed account comparing the modern dinoflagellate genus *Ceratium* with its fossil relatives from the Mesozoic. It is without doubt one of Bill's most enduring and insightful contributions. Certain latest Jurassic and Cretaceous marine dinoflagellate cyst genera with three, four or five horns such as *Muderongia*, *Odontochitina*, *Phoberocysta* and *Pseudoceratium* closely resemble the diverse and geographically extensive modern dinoflagellate genus *Ceratium* (see Wall & Evitt 1975, table 1). This closely related group of dinoflagellate cysts were described as being corniform (i.e. horn-bearing) by Evitt (1985). *Ceratium* is a gonyaulacacean genus with a tabulation formula of 4^{''}, 0a, 6^{''}, 5-6c, 6^{'''}, 1p, 1^{''''}, > 2s. It has an asymmetrical hypotheca, the left side being appreciably longer than the right side. No dinoflagellate cysts of ceratioid aspect are present in the Palaeogene or the Neogene; hence, there is a gap of ~66 My between the end of the fossil record and the modern representatives, which do not produce robust (i.e. fossilisable) resting cysts. This strongly suggests that ceratioid dinoflagellates existed during the Palaeogene and the Neogene, but that these forms were not cyst-producers (Evitt 1981a). The fossil forms and the modern species appear to be very closely phylogenetically related. An alternative interpretation is that the ceratioid morphology and tabulation evolved iteratively, and that the two time-related groups are entirely unrelated. This scenario appears to be highly unlikely. Some modern species of *Ceratium*, for example *Ceratium hirundinella*, live in freshwater. Bill frequently discussed the timing of when certain dinoflagellate groups migrated from the marine realm into freshwater habitats, and generally believed that this phenomenon occurred during the Palaeogene/Neogene. In the case of *Ceratium* and its relatives, however, freshwater/brackish dinoflagellate cysts have since been found to have existed in the Early Cretaceous (e.g. Batten & Lister 1988a, 1988b).

The first part of this paper is on the theca and cyst morphology of modern *Ceratium* (see Wall & Evitt 1975,

p. 16–28). The extensive early research on marine forms of *Ceratium* placed much more emphasis on the morphology of the horns than the tabulation. Two of the horns are subangular and lateral in position, and are entirely postcingular in origin. The first worker to recognise the characteristic three large hyaline plates in the ventral area was Steidinger (1970). The development of understanding of the tabulation of freshwater representatives of *Ceratium*, largely *Ceratium hirundinella*, was described in some detail by Wall & Evitt (1975, p. 16–25). Unlike any modern marine species, three freshwater species, *Ceratium carolinianum*, *Ceratium cornutum* and *Ceratium hirundinella*, produce proximate cysts with shorter horns than those of the theca. Cysts of *Ceratium hirundinella* vary considerably in morphology, and Huber & Nipkow (1922) observed excystment in laboratory cultures through a slit-like aperture, and found that these cysts are viable for six to seven years.

Wall & Evitt (1975) studied six marine thecate morphotypes, *Ceratium bucephalum*, *Ceratium furca*, *Ceratium* sp. cf. *C. lineatum*, *Ceratium longipes*, *Ceratium tripos* and *Ceratium* sp. cf. *C. tripos*. All of these forms have 23 plates. The ventral area is concave, and the plates and platelets here are delicate and thin (Wall & Evitt 1975, fig. 4). The freshwater thecate species *Ceratium hirundinella* and *Ceratium carolinianum* each have 26 plates. The tabulation was described in detail; both species possessed the characteristic three large ventral plates, but these are significantly denser than in the marine species (Wall & Evitt 1975, p. 16–28).

Cysts of *Ceratium hirundinella* from Felt Lake, California, and Lake Zürich, Switzerland, were studied by Wall & Evitt (1975). The cysts from Felt Lake exhibit marked morphological diversity; for example, the shape varies between subtriangular to subrhombic in dorsoventral view (Wall & Evitt 1975, fig. 7). The corresponding thecate forms are also somewhat variable (Wall & Evitt 1975, fig. 8). Unsurprisingly, the cysts are slightly smaller than their parent thecae, and the horns are considerably shorter. Furthermore, cyst size is much less variable than the dimensions of the theca. The autophragm is colourless, smooth, thin and transparent, and lacks a distinct archaeopyle or indications of tabulation. Excystment apparently takes place through random splits. *Ceratium hirundinella* cysts are formed of cellulose; hence, they differ from dinosporin/sporopollenin fossil dinoflagellate resting cysts, and therefore do not survive long in sediments.

The literature review and original research of Wall & Evitt (1975) on modern *Ceratium* provided several important conclusions. Firstly, there are one apical, one antapical and one or two lateral subangular horns, which are all coplanar. The horns are all formed from specific plates, and *Ceratium* is the only modern dinoflagellate genus to exhibit postcingular horns. Secondly, the two horns on the hypotheca impart a marked asymmetry, with the left side being markedly longer than the right. The right postcingular horn is formed from postcingular plates 4^{''} and 5^{''}. By contrast the antapical horn, which is close to the offset sulcus, is located left of the midline, and is formed from plates 1p and 1^{''''} (Wall & Evitt 1975, fig. 3). The epitheca is subconical, and hence the entire theca is elongate subtriangular in shape. Characteristically, the hypotheca slopes downwards from right to left. Thirdly, cysts of modern *Ceratium* are only found in freshwater species and are cellulosic. Wall & Evitt (1975) considered that the large, thin midventral plates x, y and z of Entz (1927) are plates 6^{''}, 6c and 6^{'''}, respectively, and are therefore not part of the sulcus. Furthermore there is only one antapical plate,

so the tabulation formula is 4', 0a, 6'', 5-6c, 6''', 1p, 1''''', > 2s. If the fossil record were to be entirely ignored, modern *Ceratium* would be classified in a monogeneric dinoflagellate family.

The second part of this contribution is on ceratioid morphologies in fossil dinoflagellate cysts from the Mesozoic (Wall & Evitt 1975, p. 28–37). These authors used the three or four coplanar horns, the asymmetrical hypocyst, and the gonyaulacoid tabulation with a large mid-ventral 6'' plate and an offset sulcus to recognise fossil ceratiacean cyst taxa for the first time. At the time, there were seven ceratioid fossil genera (i.e. *Aptea*, *Endoceratium*, *Muderongia*, *Odontochitina*, *Odontochitinoopsis*, *Phoberocysta* and *Pseudoceratium*), and these were listed and documented by Wall & Evitt (1975, p. 29–34). There are now 11 genera according to Fensome et al. (1993, p. 102); Wall & Evitt (1975) did not recognise *Xenascus* as being a valid ceratioid genus. Furthermore, since the publication of Wall & Evitt (1975), three other unequivocal fossil genera in the Family Ceratiaceae (*Balmula*, *Nyktericysta* and *Vesperopsis*) were described by Bint (1986). Of these 11 genera, all except *Odontochitinoopsis* include very well-known and stratigraphically useful species, which are frequently documented and illustrated. The type of *Odontochitinoopsis* is *Odontochitinoopsis molesta*, which is based on a single specimen embedded in a flake of chert.

It was noted that the cyst shape in *Pseudoceratium pelliferum* is virtually identical to the cysts of modern *Ceratium hirundinella* (see Wall & Evitt 1975, fig. 7). Furthermore, well-preserved specimens of *Pseudoceratium pelliferum* clearly exhibit a ceratioid tabulation (Wall & Evitt 1975, fig. 9A, pl. 1, fig. 13). The type of *Endoceratium* is *Endoceratium ludbrookiae*. This genus is clearly ceratioid in overall morphology and tabulation, and has a circumcavate cyst organisation (Wall & Evitt 1975, figs 9B, C). *Aptea polymorpha* exhibits significant morphological variability, especially on the hypocyst. Forms with recognisable horns are demonstrably ceratioid; however, other apparently similar forms have more affinity with *Areoligera/Cyclonephelium*. The genus *Odontochitina* is unequivocally ceratioid; the three horns are analogous with these features in modern *Ceratium*. *Odontochitina operculata* ranges from the Early to the Late Cretaceous (Early Barremian–Early Maastrichtian) (Heilman-Clausen 1987; Helby et al. 1987; Costa & Davey 1992). *Xenascus* is substantially similar to *Odontochitina*, but differs in that the periphragm bears spines. *Muderongia* is a diverse and characteristic latest Jurassic to Early Cretaceous genus (Morgan 1980; Heilman-Clausen 1987; Helby 1987; Monteil 1991; Costa & Davey 1992; Riding et al. 2000). The tabulate representatives of *Muderongia* exhibit a plate pattern which is virtually identical to that of modern *Ceratium*. *Muderongia* is cavate, and has four strong (but variable) ceratioid horns (Monteil 1991). The two postcingular horns are frequently deflected antapically. Some forms also exhibit a much-reduced fifth horn in a right antapical position adjacent to the base of the principal antapical horn; this feature is never observed in the cysts or thecae of *Ceratium*. *Phoberocysta* has the basic cyst architecture of *Muderongia*, but is spinose. The type, *Phoberocysta neocomica*, is markedly more bilaterally symmetrical than most representatives of this group.

Wall & Evitt (1975, p. 34–36) discussed several other dinoflagellate cyst taxa which are possibly closely related to modern *Ceratium*. These are mainly in the *Areoligera-Cyclonephelium* complex, and have large 6'' plates and sulcal notches which are displaced to the left. This distinctive group is extinct, and includes *Canningia* and *Canninginopsis*.

However, these forms lack ceratioid tabulation, postcingular horns and hypocystal asymmetry. It was concluded from this that representatives of the *Areoligera-Cyclonephelium* complex have no immediate living relatives, and are not directly related to *Ceratium* but have significant morphological overlap (Wall & Evitt 1975, table 2). This major paper was summarised with seven key conclusions (Wall & Evitt 1975, p. 36–37).

A3.43. Evitt, W.R. 1977. William S. Hoffmeister (AASP Honorary Membership Awards, 1975). *Palynology*, 1: 186.

Bill Evitt successfully nominated Bill Hoffmeister as an Honorary Member of the AASP, and this award was deservedly endorsed at the eighth Annual Meeting of the AASP held in Houston, Texas, during October 1975. Evitt (1977) is the formal citation of this award. Bill Hoffmeister was one of the first pre-Quaternary palynologists, and the pioneer of the use of stratigraphical palynology in oil exploration (section 5). Working at the Carter Oil Company in Tulsa with Leonard R. Wilson during the mid 1950s, Bill Hoffmeister researched the use of Palaeozoic spores as index fossils in North Africa and North America (Hoffmeister & Staplin 1955; Hoffmeister et al. 1955a, 1955b; Hoffmeister 1959). In the 1950s, the principal microfossils used in geological exploration were foraminifera. Bill Hoffmeister enthusiastically promoted stratigraphical palynology in the Carter Oil Company/Jersey Production Research Company (Evitt 1980). However, it was some years before palynology was successfully used routinely by the hydrocarbon industry. It is somewhat surprising to learn that, initially, palynostratigraphy was regarded as an expensive and unresponsive luxury. Bill Hoffmeister was clearly a far-sighted individual and saw, at an early stage, that both marine and terrestrial palynomorphs were numerous and robust, and could be used to solve problems in petroleum geology.

Previously, Evitt (1970c) had dedicated the first volume of *Geoscience and Man*, the journal of the AASP between 1970 and 1976, to Bill Hoffmeister. The first AASP Annual Meeting was held in Baton Rouge, Louisiana, in October 1968, and was attended by Bill Hoffmeister. Bill Evitt was effusive in his praise of his old mentor. He wrote, *inter alia*, 'To those few privileged to have known you well or even to have worked closely with you, your presence [at this meeting] brought a special personal pleasure' and 'your influence, direct or indirect, on palynology and palynologists in America has been profound'.

**A3.44.* Evitt, W.R. & Tripp, R.P. 1977. Silicified Middle Ordovician trilobites from the Families Encrinuridae and Staurocephalidae. *Palaeontographica Abteilung A*, 157(4–6): 109–174.

Evitt & Tripp (1977) is a major monograph on Middle Ordovician silicified trilobites belonging to the families Encrinuridae and Staurocephalidae. It represents the first, and the most important, contribution of the Evitt-Tripp era of trilobite research. The material is from the Lincolnshire, Boteourt, Edinburg, Oranda and Martinsburg formations from nine localities in the Shenandoah Valley of northern Virginia. It is based on research undertaken by Bill between 1950 and 1955 when he was at the University of Rochester (section 4). The morphological terminology of the cephalon was discussed in considerable detail (Evitt & Tripp 1977, p. 112–119). Meraspidids of all species considered were documented, and protaspidids for four of these were identified. The

majority of the taxa are within the Family Encrinuridae, and one new genus (*Celtencrinurus*), five new species and one new subspecies of this family were described. The new species *Physemataspis coopi* was named for G. Arthur Cooper, who helped Bill find many new localities and donated additional specimens. The single non-encrinurioid species considered was *Libertella corona*; this taxon was extensively redescribed and referred to the Family Staurocephalidae. Many features of the staurocephaloid genus *Libertella* clearly demonstrate the close relationship between the Encrinuridae and the Staurocephalidae. This material was lavishly illustrated with 17 highly detailed line drawings and 24 plates.

A3.45. Evitt, W.R., Lentin, J.K., Millioud, M.E., Stover, L.E. & Williams, G.L. 1977. Dinoflagellate cyst terminology. *Geological Survey of Canada Paper*, 76-24: 1–11.

This contribution is on the morphology and associated terminology of dinoflagellate cysts. Principally, Evitt et al. (1977) sought to make clear how terminology differs between dinoflagellate cysts and thecae via the use of key terms, prefixes and suffixes. Evitt et al. (1977) recommended that the more etymologically correct terms 'epicyst' and 'hypocyst' replace 'epittract' and 'hypottract' for the anterior and posterior hemispheres of dinoflagellate cysts, respectively. Epicyst and hypocyst were first introduced for acritarchs by Lister (1970). This change means that the term 'epicystal archaeopyle' replaces 'epittractal archaeopyle' in genera such as *Ctenidodinium* and *Wanaea*, where the principal archaeopyle suture lies immediately anterior of the cingulum.

Evitt et al. (1977) recommended the use of the prefix 'para' for morphological features which correspond to equivalents on the theca. 'Para' means beside or near, and this prefix was endorsed for use associated with the terms cingulum, plate, sulcus, suture and tabulation (Evitt et al. 1977, fig. 1). However, it is clearly superfluous for cyst-specific features such as archaeopyle and operculum. The 'para' terminology was used by many authors during the 1980s and 1990s, but is much less common in contemporary publications. The reason for this is that, in virtually all cases, it should be clearly obvious, either from the age of the material or the context, whether a dinoflagellate cyst or a theca is been discussed. Norris (1978b, p. 303) strenuously repudiated 'para' terminology, stating that it 'is considered confusing, redundant at inception, and needlessly complicating with technical verbiage a basically simple relationship'.

A thorough account of the tabulation formula for dinoflagellate cysts was given. This is a shorthand notation for the numbers of plates, and is virtually identical to that used for thecae (Kofoid 1909). The tabulation formula for a dinoflagellate cyst is purely interpretational, and hence cannot be used as an unequivocal guide to the tabulation of the parent theca. There may be some parts of the cyst, for example the apical and midventral areas, where especially small plates may lack features which delineate them. In these cases, the plates are said to be suppressed. By contrast, the tabulation of the theca is inherently complete, in that it is subdivided by sutures into plates which can be individually dissected. In chorate dinoflagellate cysts with intratabular processes or process groups, a similar process formula can be delineated (Evitt et al. 1977, table 1).

A system of prefixes and suffixes is used to denote specific features in dinoflagellate cysts. For example, the five prefixes auto-, ecto-, endo-, meso- and peri-, in conjunction with the

three suffixes -coel, -cyst and -phragm, allow the naming of cavities and walls. For example, an endocoel is the inner cavity of a cavate dinoflagellate cyst which is defined by the endophragm (Evitt et al. 1977, fig. 2; tables 2, 3). The five wall layers, i.e. autophragm, ectophragm, endophragm, mesophragm and periphragm, were then described in detail (Evitt et al. 1977, p. 6–7). Specific features can be referred to in the context of the different wall layers using compound terms, e.g. endoperculum and periarchaeopyle (Evitt et al. 1977, fig. 4). Furthermore, the prefixes epi- and hypo- can specify the location of a specific feature, e.g. epipericoel and hypendo-phragm on both hemispheres (Evitt et al. 1977, fig. 5).

The final section refers to the terms 'penitabular' and 'pandasutural'. Penitabular refers to linear, subparallel ornamentation immediately interior to the margins of the plates, for example in *Eisenackia circumtabulata* (see Evitt et al. 1977, fig. 6a). Pandasutural bands are the narrow, peripheral, areas of plates which have contrasting, frequently low-relief ornamentation to the central plate area. Examples of species with pandasutural bands are *Deflandrea phosphoritica* and *Palaeoperidinium pyrophorum* (see Evitt et al. 1977, fig. 6b, c).

A3.46. Evitt, W.R. 1978b. Special connotations of 'quadra,' 'penta,' and 'hexa' in descriptive terminology of dinoflagellates. *Palynology*, 2: 199–204.

This short contribution discussed the plate configuration on the dorsal part of the epicyst in peridinioid dinoflagellates. Evitt (1978b) asserted that the terms 'quadra', 'penta' and 'hexa', for the number of sides of the second anterior intercalary plate (2a) (and hence the number of plates surrounding this plate), should be used with caution in describing fossil dinoflagellate cysts. In peridinioid dinoflagellate cysts which lack sutural features, it can be impossible to determine the precise tabulation pattern, except for the fact that an archaeopyle is normally developed. Furthermore, the archaeopyle does not always clearly correspond to a specific plate or plates. Archaeopyles can be markedly larger or smaller than the thecal plate/plates to which it/they largely correspond, and thus the outline may therefore be significantly rounded (Evitt 1967c, figs 22–25). When an archaeopyle is not unequivocally polygonal, the style (e.g. anterior intercalary) should be clear, but the 'quadra', 'penta' and 'hexa' plate configuration cannot be determined with absolute certainty. Evitt (1978b) pointed out that the phrase 'hexa 2a archaeopyle' used for a peridinioid dinoflagellate cyst is, hence, potentially ambiguous because of the rounded nature of some archaeopyles. Therefore, a more accurate alternative to 'hexa 2a archaeopyle' would be 'archaeopyle formed by plate 2a in a hexa style tabulation'. Among peridinioid dinoflagellate cysts, the hexa style of dorsal epicystal tabulation is dominant; the quadra style is restricted to the *Wetzelia* complex (Williams et al. 2015).

*A3.47. Stover, L.E. & Evitt, W.R. 1978. *Analyses of pre-Pleistocene organic-walled dinoflagellates*. Stanford University Publications, Geological Sciences, 15, 300 p. This major publication is fully described in subsection 9.4.

A3.48. Evitt, W.R., Steidinger, K.A. & Stover, L.E. (convenors). 1979. Modern and fossil dinoflagellates. *Geology*, 7(2): 112–113.

The subject of this short conference report is fully discussed in section 11.

A3.49. Evitt, W.R. 1980. William S. Hoffmeister 26 February 1901–20 March 1980. *Palynology*, 4: 232.

Evitt (1980) was a brief memorial article dedicated to Bill Hoffmeister (1901–1980), who recruited Bill Evitt to the Carter Oil Company in 1956 (sections 4, 5) and was his first mentor in palynology. Bill Evitt rightly considered that Bill Hoffmeister was the leading light in the development of the use of palynology by the petroleum industry, and successfully sponsored him as an Honorary Member of the AASP (Evitt 1977). Bill Evitt worked with Bill Hoffmeister for the final five years of the latter's career, and was absolutely glowing in his praise of him. Bill Hoffmeister was characterised as being determined, genuine, loyal, perceptive, sincere and unassuming; furthermore, his sense of competition, loving heart and wry wit were also highlighted. Bill Hoffmeister enthusiastically and robustly championed the use of stratigraphical palynology in hydrocarbon exploration in the Carter Oil Company/Jersey Production Research Company (section 5). He passionately persuaded management over a long period to allow him to develop and use this new discipline. Evitt (1980) noted that the company administrators were not as far-sighted, and this tested Hoffmeister's considerable diplomacy, eloquence, patience, persuasiveness and tenacity almost to the limit. It is obvious from Evitt (1980) that Bill Hoffmeister had to frequently change his tactics when dealing with the body corporate during the building up of his micropalaeontology laboratory. Clearly, Hoffmeister's vision was eminently justified; other oil companies quickly and enthusiastically followed the lead provided by the Carter Oil Company in the practical application of palynology. Bill Hoffmeister put together a small team of highly skilled scientists, including Bill Evitt and Lew Stover, which allowed his vision to be effectively realised. The team at the Carter Oil Company/Jersey Production Research Company clearly shared Hoffmeister's vision, and gave him their unswerving loyalty and support.

*A3.50. Piel, K.M. & Evitt, W.R. 1980a. Paratabulation in the Jurassic dinoflagellate genus *Nannoceratopsis* and a comparison with modern taxa. *Palynology*, 4: 79–104.

The Jurassic dinoflagellate cyst genus *Nannoceratopsis* has a unique morphology in that it is profoundly laterally compressed, and has a minute epicyst and a large hypocyst. It was the subject of two of Bill's earliest papers on fossil dinoflagellates (Evitt 1961b, 1962a). Piel & Evitt (1980a) is based on the SEM study of superbly preserved material of *Nannoceratopsis deflandrei* subsp. *senex* (as *Nannoceratopsis senex*) and *Nannoceratopsis gracilis* collected from the earliest Middle Jurassic (early Aalenian, *Tmetoceras scissum* ammonite biozone) of southern England by Kenneth M. Piel. The purpose of the paper was to further elucidate the detailed morphology of these two Early to Middle Jurassic (Late Pliensbachian–Early Bajocian) taxa, and to compare the tabulation of *Nannoceratopsis* with some extant dinoflagellate orders. The material examined allowed the tabulation formula of ?pr, 5', 5'', 4c, 4s, 4H to be determined for *Nannoceratopsis*. An apical pore, a circular (type C) archaeopyle and a flagellar pore were also observed. The type C archaeopyle, involving the middorsal cingular plate (3c), is unique among dinoflagellate cysts (Plate 13). The tabulation of *Nannoceratopsis* is highly unusual because it combines features of both the orders Dinophysiales and Gonyaulacales, thereby implying a relationship between them.

The tabulation of *Nannoceratopsis deflandrei* subsp. *senex* was outlined in detail; this species has a single dorsal

antapical horn, and a granulate, perforate, spongy and uneven autophragm (Piel & Evitt 1980a, p. 83–86, pl. 3, fig. 1). By contrast, *Nannoceratopsis gracilis* may have two hypocystal horns and a perforate, smooth autophragm (Piel & Evitt 1980a, pl. 3, fig. 2). The sagittal area on the hypocyst can exhibit transverse striations which reflect growth bands on the parent theca, together with bordering ridges (Piel & Evitt 1980a, pl. 2, fig. 3 and pl. 5, fig. 3 respectively).

Nannoceratopsis is comparable to three orders of living dinoflagellates, i.e. the Dinophysiales, Gonyaulacales and Prorocentrales. The only resemblance between *Nannoceratopsis* and the Prorocentrales is the laterally compressed cyst/theca with a sagittal suture separating the two large hypocystal/hypothecal plates. However, the Prorocentrales lack the distinct cingulum and sulcus, and the multiple epicystal/epithecal plates of *Nannoceratopsis*. In marked contrast, *Nannoceratopsis* and the Dinophysiales apparently have a much closer relationship (Piel & Evitt 1980a, p. 94–99). Both *Nannoceratopsis* and the dinophysialeans have an anteriorly positioned sulcus, are laterally compressed, have a major sagittal suture and possess two large hypocystal/hypothecal plates. However, there are some significant differences. Firstly, the mid-ventral regions of *Nannoceratopsis* and living dinophysialeans, while being broadly similar, exhibit some differences in tabulation (Piel & Evitt, 1980a, fig. 5). Secondly, the tabulation of the cingulum and the epicyst/epitheca, and the nature of the sagittal suture, are markedly disparate. With regard to the latter, the cingulum and epicyst of *Nannoceratopsis* are not subdivided by the equivalent of the sagittal fission suture in *Dinophysis*. The SEM observations in this paper clearly demonstrated that the epicystal tabulation of *Nannoceratopsis* is distinctly peridiniphycidean, and is most comparable to the gonyaulacacean pattern (Piel & Evitt 1980a, pl. 1, fig. 7).

The final part of this paper is a brief systematic section (Piel & Evitt, 1980a, p. 101–103). Because of the apparently gonyaulacacean epicyst, *Nannoceratopsis* cannot be accommodated in the Order Dinophysiales. Therefore, the monogeneric Order Nannoceratopsiales was established by Piel & Evitt (1980a, p. 101–102). This order is now accommodated in the subclass Dinophysiphycidae (Fensome et al. 1993, p. 151–152). The mixed dinophysialean and peridiniphycidean characters in *Nannoceratopsis* strongly suggest a direct relationship between the Order Dinophysiales and the Subclass Peridiniphycidae. However, which of these two groups/orders was ancestral is difficult to determine due to the selectivity of the fossil dinoflagellate record (Evitt 1981a). It is entirely possible that *Nannoceratopsis* is an extinct offshoot. *Nannoceratopsis* was also emended in the light of the observations in this paper (Piel & Evitt 1980a, p. 102). *Nannoceratopsis deflandrei* subsp. *senex* and *Nannoceratopsis gracilis* have one and two antapical horns, respectively, according to van Helden (1977). However, Piel & Evitt (1980a, p. 103) stated that overall shape and the number of antapical horns are not reliable criteria for distinguishing these taxa, and that the texture of the autophragm appears to be a better way of identifying these forms. An abstract based on this study was published in the same volume (Piel & Evitt 1980b).

*A3.51. Evitt, W.R. 1981a. The difference it makes that dinoflagellates did it differently. *International Commission for Palynology Newsletter*, 4(1): 6–7.

Evitt (1981a) is a short contribution in a newsletter, and is based around a talk that Bill gave at the 13th Annual Meeting of the AASP in Keystone, Colorado (Evitt 1981b). It addresses a hugely important concept, that of the selectivity

of the dinoflagellate fossil record. Because this is such an important topic, it is also reviewed in subsection 9.4.

Organic-walled dinoflagellate cysts, unlike calcareous microfossils such as coccoliths and foraminifera, are entirely unaffected by syn- and postdepositional dissolution. However, the dinoflagellate cyst record is apparently highly selective in that they were produced by certain taxa during specific intervals (Figure 21). This unusual phenomenon was explored in this short, incisive piece and provided the intriguing title, i.e. that some dinoflagellates did it differently to other dinoflagellates.

In the life cycle of a typical cyst-producing dinoflagellate, the resistant resting cyst produced by the parent zygotic theca is a potential fossil (Figure 23). Only a significant minority (15–20%) of the 2400 known modern dinoflagellate species produce geologically preservable resting cysts (Gómez, 2012). The cyst-producers live together with many other species of the same or different genera that do not. It is therefore assumed that the fossil dinoflagellate cyst record represents a similarly small proportion of the entire Middle Triassic to Pleistocene dinoflagellate spectrum.

Perhaps the best example of this selectivity is the genus *Ceratium*; none of the numerous extant species of this distinctive genus produce preservable cysts. However, fossil cysts clearly related to *Ceratium* are present, frequently in large numbers, throughout the latest Jurassic to latest Cretaceous interval (Figure 21). No ceratioid forms have been recorded from the Palaeogene and Neogene (Wall & Evitt 1975). Another example is *Protoperidinium*, living species of which have a characteristic orthoquadra tabulation, and do not produce cysts. The *Wetzeliella* group are comparable fossil forms, but only occur from the Paleocene to the Oligocene (Figure 21; Williams et al. 2015). The enigmatic Late Silurian palynomorph *Arpylorus* was once believed to be a dinoflagellate cyst. The ~185 My gap between the Late Silurian and the Middle Triassic, where the continuous dinoflagellate cyst record begins, would have been another example of the selectivity of the dinoflagellate cyst record. However, *Arpylorus* was recently demonstrated to lack any dinoflagellate affinity (Le Hérisse et al. 2012).

The selective nature of the fossil dinoflagellate cyst has several serious implications. It means that the number of motile dinoflagellate cells, or the number of non-cyst-producing species, cannot be estimated from counts of fossil cysts. Likewise, the species composition, or the population density, of an association of living dinoflagellates cannot be determined from the cysts which it produced. Furthermore, the biased record of dinoflagellate cysts precludes their use in assessing biomass, or the levels of oxygen produced during photosynthesis. It also has implications for phylogeny, for example in that the inception of a distinctive lineage or morphological feature may not be its earliest manifestation. Likewise, dinoflagellate cyst survivorship plots and similar data sets should be viewed with caution. Evitt (1981a) also warned against using the fossil record even in a very broad sense, for example casting doubt on both the Mesozoic diversification and the Neogene decline. Subsequently, Fensome et al. (1996b) demonstrated that at least part of the diversification in the Mesozoic was a real evolutionary explosion. In summing up, Evitt (1981a) stressed that this contribution encourages the cautious use of the positive, and does not emphasise the negative, aspects of the fossil record of dinoflagellate cysts.

A3.52. Goodman, D.K. & Evitt, W.R. 1981. The dinoflagellate *Angustidinium acribes* (Davey & Verdier) gen. et comb. nov. from the mid-Cretaceous of the northern California Coast Ranges. *Grana*, 20(1): 43–54.

This relatively brief contribution is a restudy of the Cretaceous bicavate peridiniacean dinoflagellate cyst first described as *Deflandrea ascribes* by Davey & Verdier (1971) from the Early Albian of northeast France. Goodman & Evitt (1981) obtained abundant and well-preserved specimens of *Angustidinium acribes* from the Albian to Cenomanian of the Coast Ranges of northern California. This taxon has several unique features, notably having a seven-sided 2a plate, five apical plates, a long and narrow essentially four-sided 1' plate, and a small hole in each of the two antapical plates. The species was comprehensively redescribed and assigned to the new genus *Angustidinium*; in particular, the unique paratabulation was discussed in great detail. The plate configuration is similar to the living dinoflagellate genus *Heterocapsa*, and especially resembles *Heterocapsa niei*.

A3.53. Tripp, R.P. & Evitt, W.R. 1981. Silicified Lichidae (Trilobita) from the Middle Ordovician of Virginia. *Geological Magazine*, 118(6): 665–677.

Silicified representatives of the trilobite Family Lichidae from four localities of the Lincolnshire, Edinburg and Oranda formations within the Middle Ordovician of Virginia were described and illustrated by Tripp & Evitt (1981). This family is represented by the genera *Amphilichas* and *Hemiarges*, and this contribution documented the developmental stages and the detailed morphology of both. The new subspecies *Hemiarges turneri* subsp. *rasettii* was formalised.

A3.54. Frederiksen, N.O., Evitt, W.R., Hedlund, R. W., Nichols, D.J., Gensel, P.G., Markgraf, V. & Staplin, F.L. 1982. The future of palynology. *Palynology*, 6: 1–7.

Frederiksen et al. (1982) is an abbreviated and edited transcript of a panel discussion on the future of palynology held at the 12th Annual Meeting of the AASP in Dallas, Texas, in honour of the centenary of the USGS. Bill was one of six panellists, and the chair was Norman O. Frederiksen. Bill, the only dinoflagellate specialist on the panel, made eight responses. First he was asked about the future of dinoflagellate studies. Bill made his now familiar plea for improved and more detailed descriptions of new taxa in order to enhance the quality of palynological data sets. Bill was sometimes critical of contemporary taxonomic studies. He felt strongly that either authors were too hasty and cut corners in descriptions, or journal editors were too parsimonious with space in articles for both illustrations and text. Bill also made the point that stratigraphical ranges of dinoflagellate cysts based on literature compilations are of strictly limited value because of the consequent inconsistent and uncertain species identifications. He also encouraged collaborations between researchers on fossil and living dinoflagellates, and hoped for a unified classification. It was 11 years before the latter was published (Fensome et al. 1993). Bill called for the release of the vast amounts of non-competitive and uncontentious palynological data in oil company files to avoid duplications of effort in research. This was a time of much needless confidentiality amongst corporations. He also touched upon his long-held conviction that the dinoflagellate fossil record is highly selective (Figure 21). The importance of using Pliocene

and Quaternary dinoflagellate cysts in order to make the link between fossil and modern floras was stressed. Since the early 1980s, research on the Pliocene and Quaternary fossil record had expanded significantly. The fact that industrial palynologists do not routinely (or ever) use the SEM was mentioned. Bill pointed out the obvious problems inherent in the identifications of certain taxa being entirely reliant on SEM observations. In Bill's final response he perceptively stated that, in his view, multidisciplinary studies involving palynology were achieved more effectively in industrial settings, as opposed to the university sector, because of the overriding operational needs of the former.

A3.55. Tripp, R.P. & Evitt, W.R. 1983. Silicified trilobites of the genus *Dimeropyge* from the Middle Ordovician of Virginia. *Special Papers in Palaeontology*, 30: 229–240.

This contribution largely concerned the detailed ontogeny of the trilobite species *Dimeropyge virginiensis*. The material studied comprised silicified forms from the Edinburg Formation of Virginia. When this taxon was first described, the protaspis was unknown. Tripp & Evitt (1983) found three main ontogenetic stages in the protaspis, described the tubercles on the protaspis and documented the development of the meraspis. The new species *Dimeropyge dorotheae* was described from the Oranda Formation of Virginia. This was named for Dorothy Whittington, the wife of Bill's close collaborator on trilobites, Harry Whittington.

*A3.56. Evitt, W.R. 1984. Some techniques for preparing, manipulating and mounting dinoflagellates. *Journal of Micropalaeontology*, 3(2): 11–18.

This paper described techniques pertaining to fossil and modern dinoflagellates. The standard preparation procedure for pre-Quaternary palynomorphs was summarised. This comprises mineral acid treatment, oxidation, heavy liquid centrifugation, acetolysis, sieving and mounting. By contrast, modern dinoflagellate cysts can be prepared simply by acid treatment followed by acetolysis.

Evitt (1984) went on to describe specialised procedures. The first of these is a variant of the U-shaped plastic centrifugation tube of Funkhouser & Evitt (1959). A glass micropipette can be used to pick specimens up from a mixture of residue and glycerol, clean them, and manipulate them. This technique was also described by Damassa (1979a). Similarly, an eyelash manipulator can be used to move and orient specimens in glycerine jelly, and to clear away extraneous material. This is a small piece of doweling with a single eyelash affixed to one end, used for manipulating small objects (Appendix 5). Evitt (1984) also described graded sieves made from nylon bolting cloth of 20–100 µm mesh. Bill preferred glycerine jelly as a slide mounting medium, and this contribution described his method for making these mounts. Evitt (1984) also described how to cut a section of a specimen using a broken or cut glass rod.

This paper also outlined techniques for modern dinoflagellates. For example, specimens of these can be acetolysed to destroy the theca and protoplasm, and/or stained using double-cavity slides. The individual plates of dinoflagellate thecae can be dissected using dilute sodium hypochlorite solution. The plates dissociate rapidly, and the plates can be eyelash manipulated.

*A3.57. Evitt, W.R. 1985. *Sporopollenin dinoflagellate cysts – their morphology and interpretation*. American Association of Stratigraphic Palynologists Foundation, Dallas, 333 p.

This textbook is comprehensively documented in subsection 9.6.

A3.58. Evitt, W.R., Gocht, H. & Netzel, H. 1985. *Gonyaulax* cysts from Lake Zürich sediments. *Review of Palaeobotany and Palynology*, 45(1–2): 35–46.

Evitt et al. (1985) is in a memorial volume dedicated to Alfred Eisenack. It is a relatively short contribution which describes some gonyaulacacean dinoflagellate cysts from a sediment core taken in Lake Zürich, Switzerland. The sample studied represents the period between 1905 and 1925 using evidence from varves, and yielded a rich assemblage of somewhat morphologically variable gonyaulacacean dinoflagellate cysts. They were all identified as *Gonyaulax apiculata*, the only known freshwater species of this genus. The cysts are rounded to ovoid, with a short apical horn and a distinctive pustulate ornamentation. Many of the pustules are sutural. Its tabulation was comprehensively described and illustrated; three apical and five precingular plates are present (Evitt et al. 1985, fig. 1). Interestingly the five precingular plates are reminiscent of the Early to Middle Jurassic genus *Eyachial Scrinioicassis* (see Gocht 1979).

A3.59. Tripp, R.P. & Evitt, W.R. 1986. Silicified trilobites of the family Asaphidae from the Middle Ordovician of Virginia. *Palaeontology*, 29(4): 705–724.

The principal thrust of Tripp & Evitt (1986) was the formalisation of the Middle Ordovician silicified asaphid trilobite *Isotelus giselae*, and the description of its ontogenetic development. The species was named for Gisela Cloos Evitt in recognition of her perceptive observations on the protaspis stages within the Family Asaphidae. Protaspis, meraspis and holaspis stages were described from material from the Edinburg Formation of Virginia. Four moults were observed during the protaspis stage. Five broadly coeval morphotypes, *Isotelus* A–E, from the Lincolnshire, Oranda and Martinsburg formations of Virginia were placed in open nomenclature due to the relatively less complete populations compared to *Isotelus giselae*. Furthermore, *Nahannia* sp. was documented from the Lincolnshire Formation.

A3.60. Albert, N.R., Evitt, W.R. & Stein, J.A. 1986. *Lacrymodinium*, n. gen., a gonyaulacoid dinoflagellate with intercalary archeopyle from the Jurassic and Early Cretaceous of California and Alaska. *Micropaleontology*, 32(4): 303–315.

This paper was first given as an oral presentation in 1983 (Albert et al. 1984). In an unpublished dissertation, Warren (1967, p. 264–269) informally described *?Pareodinia albertii* from the uppermost Jurassic to Lower Cretaceous (Tithonian–Valanginian) of northern California. Similar material was discovered by Albert et al. (1986) from the Middle and Upper Jurassic strata of Alaska, and these authors formalised *?Pareodinia albertii* as *Lacrymodinium warrenii* in recognition of John S. Warren. *Lacrymodinium* appears to be very closely related to other genera in the subfamily Pareodinioideae. The new genus *Lacrymodinium* and its type, *Lacrymodinium warrenii*, were comprehensively described by Albert et al. (1986, p. 306–310). These authors used the Taylor-Evitt tabulation

nomenclature (Evitt 1985), and discussed the plate pattern in considerable detail (Albert et al. 1986, p. 312–314).

Lacrymodinium is an acavate, proximate genus with an apical horn and a single-plate anterior intercalary (type I) archaeopyle; it exhibits a non-standard partiform gonyaulacacean tabulation pattern via sutural ridges. The hypocyst is somewhat reminiscent of that of partiform species, but the epicyst was compared to that of *Triadinium*, a modern gonyaulacacean genus. The presence of a single anterior intercalary plate (4v = 1a), seven cingular plates and two posterior sulcal plates (Zi and Zu) was noted. Another morphotype from the Upper Jurassic of Alaska, which has a small apical horn and is more elongate than *Lacrymodinium warrenii*, was named informally as *Lacrymodinium* sp. (see Albert et al. 1986, p. 310–312).

The tabulation of *Lacrymodinium* was interpreted by Albert et al. (1986, p. 312) by assuming that the plates have not deviated from well-established topological configurations. Certain plates were considered to have increased in size (e.g. plate 4v [= 1a] of Albert et al. 1986, fig. 3). Perhaps more significantly, there was some increase in the number of plates due to division, e.g. plates Zi and Zu of Albert et al. (1986, fig. 3) which are the equivalents of the posterior sulcal (ps) plate in *Paragonyaulacysta*.

Albert et al. (1986) distinguished *Lacrymodinium* from similar genera such as *Paragonyaulacysta* and *Pareodinia* by its type I archaeopyle. *Paragonyaulacysta* has either a type I or 2I archaeopyle, and *Pareodinia* has a 2I archaeopyle (Below 1990). At the species level, *Lacrymodinium warrenii* was compared with *Paragonyaulacysta? borealis* and *Paragonyaulacysta capillosa*. Warren (1967, p. 264) indicated that the line-drawn specimen figured as *Pareodinia ceratophora* by Alberti (1961, pl. 12, fig. 14) is *Lacrymodinium warrenii* (as *?Pareodinia albertii*). However, this contention is rejected here because the specimen figured by Alberti (1961, pl. 12, fig. 14) appears to entirely lack sutures, and hence is most likely to be referable to *Pareodinia*.

The genera *Lacrymodinium* and *Paragonyaulacysta* are substantially similar in gross morphology and stratigraphical extent. Both are pareodinioid, and are acavate, ellipsoidal/pyriform, proximate, gonyaulacacean genera with apical horns and anterior intercalary archaeopyles. The autophragm of both is smooth or bears low-relief ornamentation, and the tabulation is indicated by low sutural ridges. Furthermore, *Lacrymodinium* and *Paragonyaulacysta* have similar stratigraphical ranges and biogeographical extents. Both genera range from the Middle Jurassic to the Early Cretaceous (Valanginian), according to Warren (1967), Davies (1983) and Albert et al. (1986). Much of the *Lacrymodinium*-bearing material of Albert et al. (1986) is from Alaska, and *Paragonyaulacysta* is highly characteristic of dinoflagellate cysts from the high northerly latitudes (Johnson & Hills 1973; Brideaux & Fisher 1976; Dörhöfer & Davies 1980; Davies 1983; Smelror 1988; Riding & Ioannides 1996; Riding & Thomas 1997; Riding 2005). The type material of the existing species of *Paragonyaulacysta* is all from arctic Canada, except *Paragonyaulacysta spinisutura* which was first described from the Upper Jurassic (Kimmeridgian) of northern France (Below 1990, p. 62–64).

The genera *Lacrymodinium* and *Paragonyaulacysta* hence have marked similarities, but are not synonymous; they differ in archaeopyle style and tabulation. *Lacrymodinium* has a type I archaeopyle; hence, it is consistent with the parameters of *Paragonyaulacysta* as described by Below (1990, p. 60). In

Lacrymodinium the five-sided 1a plate is lost, but by contrast the operculum comprises the hexagonal 2a plate in *Paragonyaulacysta* (Fensome et al. 1993, fig. 79). Furthermore, Albert et al. (1986), Wharton (1988a), Below (1990) and Fensome et al. (1993) demonstrated some differences in epicystal tabulation between the two genera. These are largely centred on the dorsal plates of the epicyst. Specifically, the apical boundary of plate 4'' is linear/linteloid in *Paragonyaulacysta*, and is angular/geniculate in *Lacrymodinium*. Similarly, the apical margin of the 3'' plate in *Paragonyaulacysta* is angular/geniculate, whereas in *Lacrymodinium* it is linear/linteloid (Albert et al. 1986, fig. 3; Wharton 1988a, fig. 4.12; Below 1990, figs 17, 18; Fensome et al. 1993, figs 78, 79). These differences in the topology of the dorsal plates on the epicyst are deemed sufficient to separate these genera. That said, at the practical level and using the transmitted light microscope, it may prove difficult to consistently resolve the detailed tabulation of the dorsal epicyst of many specimens of *Lacrymodinium* and *Paragonyaulacysta*.

A3.61. Sliter, W.V., McLaughlin, R.J., Keller, G. & Evitt, W.R. 1986. Paleogene accretion of Upper Cretaceous oceanic limestone in northern California. *Geology*, 14(4): 350–353.

Sliter et al. (1986) is a short account of the tectonic history and biostratigraphy of heterolithic strata from a coastal terrane mélangé from Cape Mendocino in the Franciscan Complex of northern California. This is a highly tectonised region comprising several accreted terranes. Planktonic foraminifera from allochthonous pelagic limestone blocks within the mélangé indicate a Late Cretaceous (Early Campanian–'Mid' Maastrichtian) age. By contrast, carbonate concretions within the highly sheared, fine-grained, turbiditic matrix of this mélangé yielded Middle to Late Eocene dinoflagellate cysts and planktonic foraminifera. Bill recorded the dinoflagellate cysts *Areosphaeridium diktyoplokum*, *Cordosphaeridium* sp., *Deflandrea phosphoritica*, *Rhombodinium* sp., *Turbiosphaera* sp. and *Wetzelia* sp. This assemblage is similar to those recorded from coeval strata to the south and east of Cape Mendocino by Evitt & Pierce (1975). The presence of *Areosphaeridium diktyoplokum* and *Rhombodinium* sp. is indicative of the Middle to Late Eocene (Powell 1992; Stover et al. 1996). The data on foraminifera indicate that the Upper Cretaceous deep-sea limestone blocks were derived from an oceanic plate, and were deposited in a low-latitude setting. However, the Eocene foraminifera from the matrix indicate a temperate, middle-latitude depositional environment. The latest Cretaceous limestones migrated north on the Farallon Plate, and eventually tectonically mixed with the Eocene terrigenous deepwater sediments which were derived from the margin of the North American craton after the Middle/Late Eocene. These biostratigraphical conclusions enabled the reconstruction of continental collision during the latest Eocene, with final accretion of the coastal terrane during the Late Oligocene.

A3.62. Tripp, R.P., Rudkin, D.M. & Evitt, W.R. 1997. Silicified trilobites of the genus *Sphaerocoryphe* from the Middle Ordovician of Virginia. *Canadian Journal of Earth Sciences*, 34(6): 770–788.

Tripp et al. (1997) is the final of Bill's 10 papers on trilobites (Table 2). It is on silicified material referable to the genus *Sphaerocoryphe* from the Middle Ordovician of northwest Virginia. *Sphaerocoryphe* is a cosmopolitan Middle and Late

Ordovician trilobite genus. Two new species, *Sphaerocoryphe gemina* and *Sphaerocoryphe longispina*, were described from the Edinburgh Formation. These taxa are morphologically similar, the most significant differences being in the pygidia. Furthermore, the developmental histories of the two species were analysed in great detail. It is clear that *Sphaerocoryphe gemina* and *Sphaerocoryphe longispina* are separate taxa because they have two distinct ontogenetic series. This fact rules out the possibility of two dimorphic species. These authors also compiled detailed morphometric data for all 29 species of *Sphaerocoryphe* (Tripp et al. 1997, table 2). This paper was published nine years following Bill's retirement, but he still gave his address as Stanford University. As such, Tripp et al. (1997) is the final of Bill's 49 scientific contributions with the Stanford imprimatur.

*A3.63. Evitt, W.R., Damassa, S.P. & Albert, N.R. 1998. A tiger by the tail: the exophragm of the Cretaceous–Paleocene dinoflagellate *Palaeoperidinium* and its implications. *Palynology*, 22: 1–55.

Evitt et al. (1998) is one of Bill's most impactful papers, and is arguably the finest contribution on dinoflagellate cyst morphology ever published. Bill gave his domestic address at 882 Cedro Way, Stanford, on this paper and the following one (Evitt 2001). The central finding of Evitt et al. (1998) was that the outer cyst wall in *Palaeoperidinium pyrophorum* and *Palaeoperidinium cretaceum*, which was termed the exophragm, formed exterior to the parent theca and was formed in the manner of a fine moulding. The ornamentation of the exophragm of *Palaeoperidinium pyrophorum* was demonstrated to be internal; therefore, it is a direct 'negative' reflection of the 'positive' relief of the external surface of the original dinoflagellate theca. Evitt et al. (1998) believed that *Palaeoperidinium pyrophorum* is the most obvious dinoflagellate cyst to have formed outside the theca, and that there are more forms which have this apparently unusual morphology.

Bill had, for a long time, been intrigued by the unique morphology of the distinctive, geographically widespread Late Cretaceous to Paleocene (Cenomanian–Thanetian) peridiniacean dinoflagellate cyst *Palaeoperidinium pyrophorum*. It is the fossil dinoflagellate cyst species with the most obvious dinoflagellate features, and most closely resembles a living peridiniacean thecate form. Evitt et al. (1998) is lavishly illustrated (there are 18 plates), and this paper had a long gestation period. Bill previously referred to the main conclusions in Evitt (1985, p. 205–207, fig. 9.6F, G, I, J) and Evitt et al. (1988).

The material studied is Early Cretaceous to modern (Evitt et al. 1998, table 1) and two highly inventive new techniques were utilised. Firstly, inverted SEM images of the interior of the exophragm were created which apparently reverse the relief. Also, an optical adhesive (a monomer) was used to produce moulds or peels of the interior of the exophragm. Both of these procedures allow the exterior surface of the absent theca to be imaged and reproduced, respectively. Bill used an eyelash manipulator for manoeuvring specimens and fragments of *Palaeoperidinium pyrophorum*. This was a very delicate operation due to the thin and fragile walls of this species. He used a sharpened needle or a glass knife, together with an eyelash manipulator, to cut a section of the cyst wall in a drop of water. The dissected fragment was then moved for drying off using the eyelash manipulator so that the interior surface was upwards. A small amount of optical adhesive was placed onto the cyst fragment, polymerised and peeled away. The film of the adhesive therefore was a regeneration

of the original thecal surface, and could be coated, and photographed using the SEM.

Evitt et al. (1998, p. 4–5) reviewed the morphology of the living species *Peridinium limbatum* in order to contrast the morphology of modern peridiniacean dinoflagellates with that of *Palaeoperidinium pyrophorum*. The morphology of *Palaeoperidinium pyrophorum* had been studied previously, and it was the work of Gocht & Netzel (1976) which drew the attention of Bill to this unusual species. Gocht & Netzel (1976) were the first to discover that the relief of the outer wall of *Palaeoperidinium pyrophorum* was on the interior surface. These authors interpreted this configuration to be genetically controlled, like the interior grooved ornamentation of the endocyst of *Peridinium limbatum* cysts.

The principal section of Evitt et al. (1998, p. 10–29) is on the exophragm and general morphology of *Palaeoperidinium pyrophorum*. These authors preferred the interpretation that the inner layer of the exophragm of this species formed immediately exterior to the theca. This is in the manner of a fine moulding, solidified from a once-liquid substance, in direct contact with the theca as the appearance suggests. This means that the interior of the exophragm represents a mould of the exterior of the theca. This is in contrast to the conclusions of Gocht & Netzel (1976). The exophragm of *Palaeoperidinium pyrophorum* normally bears prominent corrugate growth bands which are characteristic of zygotic peridiniacean thecae. This contrasts markedly with, for example, the simple grooves on the interior of the endocyst of the cyst of *Peridinium limbatum*. The body which comprises the exophragm of *Palaeoperidinium pyrophorum* was defined as the exocyst (Evitt et al. 1998, p. 12). The exophragm also bears prominent trichocyst pores (e.g. Evitt et al. 1998, pl. 5, figs 4, 6); small features such as these are only discernible using the SEM. These authors noted considerable intraspecific variability.

The exocyst of *Palaeoperidinium pyrophorum* may or may not contain a bicavate to cornucavate intrathecal cyst. The archaeopyle is of combination type (type A3I3P), involving the 3', 1a–3a and 3''–5'' plates, and members of this species bear five cingular plates. Both *Palaeoperidinium pyrophorum* and *Palaeoperidinium cretaceum* exhibit significant variation in size (Evitt et al. 1998, table 2). These authors undertook a detailed study of the sulcus and surrounding plates in the mid-ventral area. Evitt et al. (1998, pl. 6–8) identified two prominent sulcal lists, and two flagellar scars as paired short conical projections immediately posterior of the left side of the cingulum. The apical extremity of the exocyst of *Palaeoperidinium pyrophorum* was examined, and an apical boss (indicating an apical pore) and an adjacent elongate canal plate were observed (Evitt et al. 1998, pl. 9, figs 1–6).

The exophragm and morphology of *Palaeoperidinium cretaceum* was also discussed by Evitt et al. (1998, p. 30–36). This species appears to exhibit significant intraspecific variation. Harding (1990) concluded that this species was not an exophragm, as in *Palaeoperidinium pyrophorum*, probably because the interior surface is obscured by the intrathecal cyst. However, based on material from Alaska, Evitt et al. (1998, p. 32) found that the outer wall of *Palaeoperidinium cretaceum* is indeed an exophragm with thecamorphic features such as corrugate growth bands on the interior surface. In contrast to *Palaeoperidinium pyrophorum*, the Alaskan specimens of *Palaeoperidinium cretaceum* have a thin exophragm which partially reflects the interior morphology on the exterior. This thin exophragm gives *Palaeoperidinium cretaceum* a deceptively theca-like appearance. Corrugate

growth bands are not confined to *Palaeoperidinium cretaceum* and *Palaeoperidinium pyrophorum*. They have also been observed in, for example, *Deflandrea phosphoritica*, *Deflandrea webbii*, *Deflandrea* sp. and *Sirmiodinium grossii* (see Warren 1973, Weiler 1988, Wrenn & Hart 1988).

One of the most fascinating phenomena on the interior of the exophragm of *Palaeoperidinium* is the papillae, which were interpreted as the partial distal infillings of trichocyst pores by Evitt et al. (1998, figs 1, 2, 4A, pl. 17, figs 1–5). This led these authors to speculate that extrathecal layers were more widespread in dinoflagellate cysts than previously thought. The papillae may be complete, where they connect the exophragm to the autophragm or periphragm, an area originally filled by the theca, or incomplete (Evitt et al. 1998, fig. 4). Other examples of this phenomenon include species of *Deflandrea*, *Muderongia*, *Pseudoceratium*, *Subtilisphaera* and *Wetzeliiella* which have short projections on the autophragm or periphragm. These elements are interpreted as the partial (proximal) infillings of trichocyst pores in the absence of an exophragm (Evitt et al. 1998, fig. 4C, pl. 18, figs 1–5). These short, cylindrical pillars are positioned outside the sutural areas (growth bands), and are concentrated along the adcingular plate margins. This configuration is typical of the distribution of trichocyst pores in living thecate dinoflagellates, i.e. within the central areas of the plates and densest along plate boundaries. In some taxa such as *Dingodinium cerviculum*, there are proximal trichocyst pore infillings on a periphragm below an entirely smooth exophragm (Evitt et al. 1998, fig. 4D).

The dinoflagellate cyst wall configuration termed 'holocavate' was illustrated by Evitt et al. (1998, fig. 4E); this cyst organisation was defined by Stover & Evitt (1978, p. 7). This is where short cylinders or rods connect the autophragm or periphragm with the ectophragm (Downie & Sarjeant 1966, p. 15). There are several holocavate genera including *Charlesdownia*, *Chlamydomphorella*, *Gardodinium*, *Nelchinopsis* and *Stephanelytron*. Evitt et al. (1998) interpreted the outer layer or ectophragm of these genera as being precisely homologous to the exophragm of *Palaeoperidinium pyrophorum*, with the short connecting elements representing infilled trichocyst pores. This means that the ectocoel of holocavate genera (now the exocoel) would have been the area occupied by the parent theca. This contention is mitigated against by the fact that certain holocavate species such as *Stephanelytron redcliffense* exhibit exclusively sutural elements (Stover et al. 1977, fig. 1, pl. 1). If these were infilled trichocyst pores, they would not be present in the sutural areas, and there would be elements concentrated in the centre of the plates (Evitt et al. 1998, pl. 18, fig. 4). However, because the short processes between the autophragm and the ectophragm in *Stephanelytron redcliffense* are wholly sutural, it seems most likely that this species was formed intrathecally. Despite this, a specimen of *Gardodinium* sp. figured by Evitt et al. (1998, pl. 18, fig. 11) does appear to have adcingular infilled trichocyst pores which indicate that the ectophragm/exophragm is possibly extrathecal. It is feasible that holocavate gonyaulacacean cysts are largely intrathecal, and only some peridiniacean taxa such as *Palaeoperidinium pyrophorum* have genuine exophragm. This is consistent with the specimen of *Deflandrea* sp. with a lineation of infilled trichocyst pores within the cingulum illustrated by Evitt et al. (1998, pl. 18, fig. 5).

It was noted that the exophragm is very delicate, and hence is easily damaged or degraded. Other dinoflagellate cyst genera which may exhibit complex thecamorphic wall morphologies including trichocyst pore fillings include

Dinopterygium, *Glossodinium*, *Heteraulacacysta*, *Hystrichodinium*, *Phanerodinium* and *Xiphophoridium*. These genera have relatively thick, complex cyst walls which may represent closely appressed autophragm and exophragm. The scenarios illustrated in Evitt et al. (1998, figs 4F, G), with proximal and distal trichocyst pore fillings and no trichocyst pore fillings, respectively, have no known examples.

The demonstration by Evitt et al. (1998) that not all dinoflagellate cyst walls are intrathecal necessitated four new morphological terms. These are 'conjunct' (e.g. *Chlamydomphorella*, *Dinopterygium*), 'disjunct' (e.g. *Dingodinium*, *Palaeoperidinium pyrophorum*), 'exoproximate' (e.g. *Gardodinium*; *Palaeoperidinium pyrophorum*) and 'periproximate' (e.g. *Deflandrea*) (see Evitt et al. 1998, table 3). 'Ectophragm' should be only used for walls that are unequivocally intrathecal such as the complete or incomplete distal expansions of the processes in chorate genera such as *Areosphaeridium*, *Eatonicysta*, *Hystrichosphaeridium* and *Nematosphaeropsis* according to Evitt et al. 1998, p. 44). This means that the term 'ectophragm' may be at least partially homologous to 'trabeculum' (Downie & Sarjeant 1966, p. 15) in this sense.

In the systematic section (Evitt et al. 1998, p. 46–52), the genus *Palaeoperidinium* and the species *Palaeoperidinium cretaceum* and *Palaeoperidinium pyrophorum* were emended. Only the latter two species were accepted in *Palaeoperidinium*, and these were compared in Evitt et al. (1998, table 4). The remaining 18 species which were placed in *Palaeoperidinium* prior to 1998, and *Palaeoperidinium? eurypylum*, were deemed only to be provisionally accepted by Evitt et al. (1998, p. 48), pending SEM studies to identify an exophragm.

In conclusion, Evitt et al. (1998) stated that the detailed examination of *Palaeoperidinium pyrophorum* led to the discovery of a definite exophragmal layer in dinoflagellate cysts. This is remarkable in many senses, including the fact that this unusual species was the first fossil form to be recognised as a dinoflagellate [by Ehrenberg (1838), who understandably referred it to the genus *Peridinium*].

A3.64. Evitt, W.R. 2001. Eisenack's dinoflagellates from the amber-bearing beds of East Prussia. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, 219(1/2): 3–14.

Bill's 64th and final paper was a contribution to a *Festschrift* to celebrate Hans Gocht's 70th birthday. Evitt (2001) largely comprised an English translation of Eisenack (1938a), preceded by a brief review of Alfred Eisenack's research on aquatic palynomorphs. From 1920 to 1945, Alfred Eisenack worked in Königsberg (now Kaliningrad) in East Prussia (now Kaliningrad Oblast) and became fascinated by the Samland (or Sambia) Peninsula on the southeastern shore of the Baltic Sea, particularly the Upper Eocene Blue Earth and the overlying Quaternary tills. The Blue Earth contains the world-famous Baltic amber, and is rich in phosphatic nodules. Eisenack launched his prodigious research efforts in marine microplankton on these two units. His early studies on palynomorphs from limestone erratics in the Samland tills were among the very first which used mineral acid maceration (e.g. Eisenack 1930; 1931). He then dissolved some phosphatic nodules, some of which appear to be coprolitic, from the Blue Earth with hydrochloric acid and discovered extremely abundant and exquisitely preserved fossil dinoflagellates.

Eisenack (1938a) was a preliminary communication; the Second World War delayed his detailed study of this

assemblage, and it was 16 years later before this was published (Eisenack 1954). He had the foresight to store the precious slides from this material in neutral Switzerland during the conflict. Furthermore, Eisenack (1938a) is in a somewhat obscure journal which ceased publication in 1941. This contribution included the original description of two extremely important dinoflagellate cyst genera. They are *Deflandrea* and *Wetzeliella*, named for Georges Deflandre and Otto Wetzel, respectively. The species *Deflandrea phosphoritica* and *Wetzeliella clathrata* (now *Talladinium? clathratum*) were also described in Eisenack (1938a). The main body of Evitt (2001, p. 6–13) is an English translation of Eisenack (1938a) with extensive footnotes. It is a clear testament of how Bill's grasp of the German language had improved since his first visit to Germany in 1959 (subsection 5.5.2).

Appendix 4. List of species

The valid species mentioned in the running text of this contribution are listed alphabetically here in six sections with full author citations. Most of the references pertaining to the dinoflagellate cysts can be found in Fensome & Williams (2004).

A4.1. Acritarchs

Evittia sommeri Brito 1967
Paucilobimorpha incurvata (Cookson & Eisenack 1962) Prössl 1994
Scuticabulus lapidaris (O. Wetzel 1933) Loeblich III 1967
Tunisphaeridium caudatum Deunff & Evitt 1968
Tunisphaeridium concentricum Deunff & Evitt 1968
Tunisphaeridium parvum Deunff & Evitt 1968

A4.2. Dinoflagellate cysts

Achilleodinium biformoides (Eisenack 1954) Eaton 1976
Alisogymnium evittii (Boltenhagen 1977) Lentin & Vozzhennikova 1990
Angustidinium acribes (Davey & Verdier 1971) Goodman & Evitt 1981
Aptea polymorpha Eisenack 1958
Apteodinium australiense (Deflandre & Cookson 1955) Williams 1978
Areosphaeridium diktyoplokum (Klumpp 1953) Eaton 1971
Cannosphaeropsis utinensis O. Wetzel 1933
Carpatella cornuta Grigorovich 1969
Chatangiella granulifera (Manum 1963) Vozzhennikova 1967
Cordosphaeridium funiculatum Morgenroth 1966
Cribroperidinium? edwardsii (Cookson & Eisenack 1958) Davey 1969
Cribroperidinium giuseppei (Morgenroth 1966) Helenes 1984
Cribroperidinium orthoceras (Eisenack 1958) Davey 1969
Dapcodinium priscum Evitt 1961
Deflandrea phosphoritica Eisenack 1938
Deflandrea webbii Wrenn & Hart 1988
Desmocysta simplex Duxbury 2001
Diconodinium ventriosum (Alberti 1961) Lentin & Williams 1973
Dingodinium cerviculum Cookson & Eisenack 1958
Dinogymnium acuminatum Evitt et al. 1967
Dinogymnium denticulatum (Alberti 1961) Evitt et al. 1967
Dinogymnium digitus (Deflandre 1936) Evitt et al. 1967
Dinogymnium heterocostatum (Deflandre 1936) Evitt et al. 1967
Dinogymnium laticinctum (Deflandre 1943) Evitt et al. 1967
Dinogymnium nelsonense (Cookson 1956) Evitt et al. 1967

Dinogymnium undulosum Cookson & Eisenack 1970
Dinogymnium westralium (Cookson & Eisenack 1958) Evitt et al. 1967
Diphyes colligerum (Deflandre & Cookson 1955) Cookson 1965
Dracodinium samlandicum (Eisenack 1954) Costa & Downie 1979
Eisenackia circumtabulata Drugg 1967
Endoceratium ludbrookiae (Cookson & Eisenack 1958) Loeblich Jr. & Loeblich III 1966
Enneadocysta pectiniformis (Gerlach 1961) Stover & Williams 1995
Evansia evittii (Pocock 1972) Jansonius 1986
Evittodinium giselae Deflandre 1964
Evittosphaerula paratabulata Manum 1979
Gillinia hymenophora Cookson & Eisenack 1960
Gingodinium evittii Singh 1983
Glaphyrocysta pastielsii (Deflandre & Cookson 1955 ex de Coninck 1965) Stover & Evitt 1978
Gonyaulacysta dualis (Brideaux & Fisher 1976) Stover & Evitt 1978
Gonyaulacysta jurassica (Deflandre 1938) Norris & Sarjeant 1965
Gonyaulacysta jurassica (Deflandre 1938) Norris & Sarjeant 1965 subsp. *jurassica* (autonym)
Homotryblium tenuispinosum Davey & Williams 1966
Hystrichokolpoma cinctum Klumpp 1953
Hystrichokolpoma rigaudiae Deflandre & Cookson 1955
Hystrichosphaeridium tubiferum (Ehrenberg 1838) Deflandre 1937
Impagidinium maculatum (Cookson & Eisenack 1961) Stover & Evitt 1978
Kallosphaeridium capulatum Stover 1977
Kiokansium unituberculatum (Tasch in Tasch et al. 1964) Stover & Evitt 1978
Komewuia evittii Chen 1982
Lacrymodinium warrenii Albert et al. 1986
Leptodinium membranigerum Gerlach 1961
Leptodinium mirabile Klement 1960
Litosphaeridium siphoniphorum (Cookson & Eisenack 1958) Davey & Williams 1966
Luxadinium? dabendorfense (Alberti 1961) Bujak & Davies 1983
Manumiella? cretacea (Cookson 1956) Bujak & Davies 1983
Manumiella druggii (Stover 1974) Bujak & Davies 1983
Muiradinium dorsispirale (Churchill & Sarjeant 1963) Harland & Sarjeant 1970
Nannoceratopsis deflandrei Evitt 1961
Nannoceratopsis deflandrei Evitt 1961 subsp. *senex* van Helten 1977
Nannoceratopsis gracilis Alberti 1961
Nannoceratopsis pellucida Deflandre 1938
Nannoceratopsis spiculata Stover 1966
Odontochitina operculata (Wetzel 1933) Deflandre & Cookson 1955
Odontochitinosopsis molesta (Deflandre 1937) Eisenack 1961
Oligosphaeridium abaculum Davey 1979
Oligosphaeridium complex (White 1842) Davey & Williams 1966
Oligosphaeridium pulcherrimum (Deflandre & Cookson 1955) Davey & Williams 1966
Palaeohystrichophora infusorioides Deflandre 1935
Palaeoperidinium cretaceum Pocock 1962
Palaeoperidinium? eurypylum (Manum & Cookson 1964) Evitt 1975

Palaeoperidinium pyrophorum (Ehrenberg 1938 ex O. Wetzel 1933) Sarjeant 1967
Paragonyaulacysta? borealis (Brideaux & Fisher 1976) Stover & Evitt 1978
Paragonyaulacysta capillosa (Brideaux & Fisher 1976) Stover & Evitt 1978
Paragonyaulacysta spinisutura Below 1990
Pareodinia ceratophora Deflandre 1947
Perisseiasphaeridium pannosum Davey & Williams 1966
Phoberocysta neocomica (Gocht 1957) Millioud 1969
Polygonifera evittii Habib 1972
Pseudoceratium pelliferum Gocht 1957
Saeptodinium hansonianum (Traverse 1955) Stover & Evitt 1978
Samlandia chlamydophora Eisenack 1954
Sentusidinium pelionense Fensome 1979
Scrinioidinium crystallinum (Deflandre 1938) Klement 1960
Sirmiodinium grossii Alberti 1961
Spiniferites bentorii (Rossignol 1964) Wall & Dale 1970
Spiniferites pseudofurcatus (Klumpp 1953) Sarjeant 1970
Stephanelytron redcliffense Sarjeant 1961
Stichodium? lineidentataum (Deflandre & Cookson 1955) Williams et al. 2015
Talladinium? clathratum (Eisenack 1938) Williams et al. in Fensome et al. 2009
Tehamadinium evittii (Dodekova 1969) Jan du Chêne et al. 1986
Trithyrodinium evittii Drugg 1967
Wrevittia helicoidea (Eisenack & Cookson 1960) Helenes & Lucas-Clark 1997

A4.3. Modern (motile) dinoflagellates

Ceratium bucephalum (Cleve 1897) Cleve 1900
Ceratium carolinianum (Bailey 1850) Jörgensen 1911
Ceratium cornutum (Ehrenberg 1832) Claparède & Lachmann 1895
Ceratium furca (Ehrenberg 1834) Claparède & Lachmann 1859
Ceratium hirundinella (Müller 1773) Dujardin 1841
Ceratium lineatum (Ehrenberg 1854) Cleve 1899
Ceratium longipes (Bailey 1855) Gran 1902
Ceratium tripos (Müller 1786) Nitzsch 1817
Gonyaulax apiculata (Pénard 1891) Entz 1904
Gonyaulax digitale (Pouchet 1883) Kofoid 1911
Gymnodinium catenatum Graham 1943
Heterocapsa niei (Loeblich 1968) Morill & Loeblich 1981
Lingulodinium polyedrum (Stein 1883) Dodge 1989
Peridinium limbatum (Stokes 1888) Lemmermann 1900
Peridinium willei Huitfeldt-Kaas 1900
Peridinium wisconsinense Eddy 1930
Pfiesteria piscicida Steidinger & Burkholder 1996
Protoceratium reticulatum (Claparède & Lachmann 1859) Bütschli 1885
Protoperidinium leonis (Pavillard 1916) Balech 1974

A4.4. Pollen

Cranwellia striata (Couper 1953) Srivastava 1966
Ephedra voluta Stanley 1965
Proteacidites thalmani Anderson 1960
Wodehouseia spinata Stanley 1961

A4.5. Trilobites

Amphilichas (Probolichas) pandus Evitt 1951
Ceratocephala laciniata Whittington & Evitt 1954

Ceraurus pleurexanthemus Green 1832
Ceraurus pleurexanthemus Green 1832 var. *montyensis* Evitt 1953
Ceraurus whittingtoni Evitt 1953
Dimeropyge dorotheae Tripp & Evitt 1983
Dimeropyge virginensis Whittington & Evitt 1954
Dolichoharpes reticulata Whittington 1949
Flexicalymene meeki Foerste 1910
Flexicalymene senaria Conrad 1841
Heliomeroides teres Evitt 1951
Heliomeroides treta Evitt 1951
Hemiarges turneri Chatterton & Ludvigsen 1976 subsp. *rasettii* Tripp & Evitt 1981
Isotelus giselae Tripp & Evitt 1986
Libertella corona Hu 1971
Physemataspis coopi Evitt & Tripp 1977
Sphaerocoryphe gemina Tripp et al. 1997
Sphaerocoryphe longispina Tripp et al. 1997

A4.6. Diatom

Aulacoseira granulata (Ehrenberg 1843) Simonsen 1979

Appendix 5. Palynological techniques used at Stanford University during the Bill Evitt era

A5.1. Introduction

This appendix documents the procedures used in the palynology laboratory at Stanford University and is largely based on the recollections of one of us (JL-C), who worked there between 1979 and 1988. It is therefore complementary to section 8 and Evitt (1984), and is divided into two parts. Firstly, palynomorph extraction, slide production and curation are documented, followed by techniques applicable to individual dinoflagellate specimens.

Bill Evitt began to develop techniques for extracting, concentrating, manipulating and observing dinoflagellate cysts and other palynomorphs from 1956 onwards at the Carter Oil Company/Jersey Production Research Company in Tulsa (section 5). This was continued at Stanford University from 1962, and was a highly iterative process whereby improvements were continually being made via experimentation. Every step of the processing technique was subjected to very careful testing, and no procedure was exempt from being revised and improved if a competing or new idea emerged. Some of the techniques described herein were first documented in Evitt (1984). Several of them are complex and time-consuming, but they are all extremely effective.

Visitors to the Stanford University laboratory were consistently amazed by these complex preparation techniques, which were generally significantly more sophisticated than those they were used to. In terms of sample material, Bill preferred calcareous concretions and phosphatic nodules because these lithotypes frequently yielded superbly preserved, undeformed dinoflagellate cysts.

Bill always taught laboratory procedures at the beginning of a graduate student's tenure, so that they acquired this skill set before they started their research. This instruction in techniques typically comprised several three-hour sessions during the first few weeks of the semester. He explained and demonstrated everything clearly and without notes, and gave the students a written manual. Bill was continually experimenting with and updating his techniques, and would always

demonstrate new discoveries or inventions to all of the students as soon as he had fully developed them.

A5.2. Palynomorph extraction and slide production

A5.2.1. Introduction

For any work in the processing laboratory, especially when using mineral acids in the fume cupboard, Bill insisted on full personal protective equipment. This comprised a plastic apron, thick boots or shoes, a full face shield, high-quality plastic or rubber gloves and a robust laboratory coat. Bill was extremely meticulous about health and safety issues. For example, he insisted that everyone used finger coverings when using heavy liquids in the centrifuge, to protect their fingertips from damage by continual exposure to zinc bromide solution which is acidic and corrosive. Bill always had demonstration samples at various different stages so that he could easily move from one step to the next during the training sessions. The different procedures are described sequentially in the following 13 subsections (Evitt 1984, p. 11–12). Other accounts of generic palynomorph extraction and preparation techniques include Barss & Williams (1973), Doherty (1980), Phipps & Playford (1984), Wood et al. (1996), Riding & Kyffin-Hughes (2004) and Riding & Warny (2008).

A5.2.2. Rock sample curation

The curation system in the Stanford University laboratory was designed to allow the quick and easy relocation of unused rock sample material, microscope slides and aqueous palynomorph residues. Every rock sample submitted to the laboratory was given a unique, sequential sample number which was prefixed 'PL' (meaning 'palynology laboratory'). A sample record index card was completed with all relevant data comprising everything known about the sample, including the number of the processing record card(s), which were kept separately. The sample record cards were coloured salmon pink for Palaeozoic, green for Mesozoic, yellow for Paleogene/Neogene and white for Quaternary. A rubber ink-stamp template was used to mark each index card with spaces for age, formation, locality, etc. This information was also recorded on the sample processing record sheets, which recorded all of the laboratory treatments all the way to slide production. For example, notes were made on any reactions and/or anything unusual. All of the slides produced from a sample were recorded on the appropriate sample card and processing record sheet.

A5.2.3. Crushing

The rock sample material was placed between two (clean and new) disposable aluminum food containers and crushed into small (pea-sized) fragments using a hammer on a steel plate mounted on the top of a stout wooden post mounted in concrete.

A5.2.4. Hydrochloric acid treatment

The crushed sample was placed in a beaker, wetted then treated with 50% hydrochloric acid. Water or acetone delivered from a squirt bottle was used to control any foaming. More hydrochloric acid was gradually added until the reaction ceased, which could take as little as 20 minutes. Next, the residue was decant-washed then centrifuge-washed, or simply centrifuge-washed. Alternatively, the sample was centrifuged in 50-mL plastic tubes. Following centrifugation, the

supernatant liquor was carefully poured off. All work involving concentrated hydrochloric acid was done inside the fume cupboard. Once the acid was diluted, centrifugation could be done outside the fume cupboard.

A5.2.5. Hydrofluoric acid treatment

Using a plastic squirt bottle, a small amount of cold 50% hydrofluoric acid was added to the plastic tube containing the post-hydrochloric acid residue, and stirred with a plastic stirring rod. The mixture was then poured into a large, new and clean polystyrene (styrofoam) cup. These receptacles are acid-resistant, disposable and inexpensive. More hydrofluoric acid was added to the cup until the sample material was covered. The samples were normally only in hydrofluoric acid for approximately 20 minutes; Bill found that several hours in hydrofluoric acid did not produce better palynomorph recovery. By stark contrast, most laboratories leave the sample in hydrofluoric acid for at least 24 hours (e.g. Barss & Williams 1973, p. 5, Traverse 2008, fig. A.3). The hydrofluoric acid was then diluted, the sample decant-washed and then centrifuged. The polystyrene cups, together with any residual rock material, were discarded after one use.

A5.2.6. Hot hydrochloric acid treatment

Following the hydrofluoric acid stage, the residue was transferred into a glass tube, hydrochloric acid was then added and the mixture boiled to remove fluorosilicates that might have accumulated during the hydrofluoric acid treatment. Then the tube was filled with water and centrifuged.

A5.2.7. Oxidation

Crystals of pyrite, which is a relatively dense mineral, can cause palynomorphs to sink during heavy liquid separation. If the sample contained pyrite, nitric acid was added to the glass tube and briefly heated to close to boiling point before being centrifuge-washed. This step should be performed only if absolutely necessary because excessive exposure to hot nitric acid can damage and/or destroy palynomorphs, especially some of the more delicate dinoflagellate cysts. Because of this, the use of hot nitric acid was extensively tested, and many samples were processed with and without it to test its suitability. Coals were oxidised using nitric acid, followed by rinsing in a dilute alkaline solution.

Most oxidation procedures to remove extraneous organic material at Stanford University were performed using 5% sodium hypochlorite solution. This is simply household bleach. In the same glass tube used in step A5.2.6, sodium hypochlorite solution was added and the mixture stirred. Next, small amounts of bleach and concentrated hydrochloric acid were added alternately. There is often a delayed reaction, the colour of the residue perceptibly lightens and heat is generated. The reaction could be terminated by adding excess bleach; then the mixture was centrifuge-washed. This use of bleach is an ideal substitute for more aggressive oxidants such as Schultze's Solution. Unlike nitric acid-based oxidising agents, bleach will not damage delicate dinoflagellate cysts.

A5.2.8. Detergent treatment

Undigested clay in the residue, which makes heavy liquid significantly less effective, can be removed using a normal laboratory-grade detergent. The remaining residue in a glass tube was treated with a small amount of detergent solution (e.g.

600 mL of warm water and 16 mL of detergent). The mixture was homogenised, more detergent solution added and the tube filled with water. The tube was centrifuged, then centrifuge-washed until the supernatant liquid became clear.

A5.2.9. Heavy liquid separation

Heavy liquid separation of the organic and inorganic (mineral) residues at Stanford University was described by Evitt (1984, p. 12, 14, fig. 1A). It was unusual due to the use of the Bostick tube. This was invented by Neely H. Bostick, who was one of Bill's early graduate students at Stanford (Appendix 2). An aqueous solution of zinc bromide with a specific gravity of 2.0 was used rather than the more commonly used zinc chloride solution. The latter is cheaper, but is more viscous (and hence is more difficult to rinse away), and is a respiratory and skin irritant.

A5.2.10. Acetolysis

Acetolysis is used to remove extraneous material such as lipid pollenkit and protoplasm from modern pollen so that the detailed morphology of the exine can be studied (Erdtman 1960). The procedure also increases the body colour of palynomorphs, and was described in detail by Traverse (2008, p. 621–623). Bill used it on dinoflagellate cyst residues to clean organic debris from the specimens, and to impart a yellow-brown colour that enhances morphological features.

The residue from the Bostick tube was transferred to a 15-mL glass tube, the zinc bromide washed from it and glacial acetic acid added. The organic concentrate was centrifuge-washed, then acetic anhydride mixed in and the tube gently stirred. The next step was to carefully add around 10 drops of concentrated sulphuric acid and homogenise, before placing the tube in a warm water bath. The sample was gently stirred and boiled in the water bath for between 10 and 15 minutes, or until the mixture turned brown. After the mixture cooled, the tube was centrifuged, rinsed with glacial acetic acid then thoroughly centrifuge-washed. The aqueous palynomorph concentrate could, at this point, be mounted on microscope slides. If the dinoflagellate cysts are free of superfluous organic material, they can be further darkened by simply using a biological stain such as bismark brown, fuchsin or safranin.

A5.2.11. Sieve separation

Sieving the residue into separate size fractions was used at Stanford University to concentrate specific taxa for picking (see below). This procedure, however, compromises the residue for any future statistical/quantitative analysis. The sieves were made from 15-mm plastic tubes, nylon monofilament bolting cloth ('Nitex') and a hose washer (Evitt 1984, p. 15, fig. 1E). When the sieving was completed, the coarse (> 100 μm), intermediate (50–100 μm) and fine (< 50 μm) fractions were examined. Dinoflagellate cysts are normally most abundant in the intermediate and fine fractions.

A5.2.12. Swirling

Swirling is a technique that was used to separate the different size fractions before the sieving techniques mentioned above were developed. It could also be used for concentrating small volumes of residue for slide production. The aqueous residue was placed into a large watch glass on a flat, smooth surface, and the suspension allowed to settle. Then the watch glass was gripped firmly between the thumb and forefinger,

with the heel of the hand resting on the table. Keeping the watch glass in contact with the table, the watch glass was moved gently and smoothly in small circles (~2–4 mm diameter) using the arm and not the fingers. The residue gradually concentrated in the centre of the watch glass in different density/size fractions. At this point, the individual fractions could be extracted using a pipette.

A5.2.13. Slide production

This procedure is done on a slide-warming table or hot plate heated to around 50 °C. A small amount of the aqueous palynomorph residue was drawn up into a pipette, and a few drops gently placed on a clean coverslip. Two or three drops of melted glycerine jelly (a mixture of gelatin, glycerine and water) were added to the coverslip from a dropper bottle, and the mixture stirred and spread close to the edge of the coverslip. The coverslip was then allowed to dry and cool. Several drops of warm glycerine jelly were added to a clean microscope slide, placed in a slide holder, with the coverslip position clearly marked. Then the dry and cool coverslip was gently inverted onto the glycerine jelly on the slide, slowly lowering it at one end first to prevent air bubbles forming. The coverslip was gently pressed down so that the glycerine jelly flowed just beyond the edges of the coverslip. Any air bubbles that formed could be gently pressed out. The microscope slide was clearly marked with the sample number (and the size fraction if appropriate) using a diamond or carbon steel glass-marking scribe.

The slide was then allowed to cool. The excess glycerine jelly around the coverslip was cut away using a scalpel and the edges cleaned of smears with a wipe. The edges of the coverslip were sealed with clear nail polish using a fine brush. It is very important to completely seal the coverslip to avoid dessication of the glycerine jelly. The slide was then further individualised more clearly using an adhesive label.

Bill preferred using glycerine jelly as a mountant rather than other media because of its low refractive index, which provides good optical contrast, and because it can easily be melted on a hot plate to reorient individual dinoflagellate cyst specimens (Evitt 1984, p. 12). He also had an iron nail wired to a transformer so that it would heat up when a current was passed through the nail. The hot tip of the nail could be used to melt the glycerine surrounding a specimen by gently touching the relevant part of the coverslip to the tip of the nail. Then, applying gentle pressure with a dissecting needle (or a similar implement) on the coverslip close to the specimen will cause the specimen to roll over. This procedure therefore allows a specimen to be observed and photographed in different orientations.

Late in Bill's career, during the mid to late 1980s, graduate student Tony Bint suggested to Bill that clear optical adhesive could be used to attach palynomorph coverslips to microscope slides instead of glycerine jelly. Optical adhesives are monomers which are used to stick pieces of glass (such as lenses) together. The glue is hardened (polymerised) by brief exposure to ultraviolet light. The refractive index of most optical adhesives is eminently suitable for microscopy, and the coverslips do not need sealing. However, slides produced in this way are permanent, and the adhesive cannot be remelted to move a specimen. Bill enthusiastically experimented with several optical adhesives and constructed a light box with ultraviolet light tubes for curing trays of slides made in this way.

A5.2.14. Palynomorph slide and residue curation

Microscope slides were housed in 100-slide boxes. These were stored on a strong shelf with a bar across it, which was separately bolted to the wall. The purpose of the bar was to prevent the boxes falling off during an earthquake. Each slide box was given a unique two-letter code (AA, AB, AC, etc.). Within a box, each slide was numbered in sequence from 1 to 100 preceded by the two-letter box code. For example, the twentieth slide in box AD would be labelled AD 20. When the Stanford University laboratory was dismantled in the late 1980s, the microscope slides were transferred to the University of California Paleontology Museum at Berkeley and are permanently curated there.

The aqueous palynomorph residues were also carefully curated so that more slides could be made whenever necessary. These were stored in 5-mL glass vials. The residue was placed in the vial, and topped up with distilled water. Several drops of phenol and two or three drops of glycerine were then added. The phenol prevents fungal damage, and the glycerine is in case the liquid dries up. The top of the vial was covered with a small piece of plastic film, and the cap screwed on firmly. The vial vessel and cap were carefully labelled. The vials were stored in numbered boxes, each box having a unique number and being divided into numbered rows and lettered columns. The box number, row and column (e.g. 6D8) were recorded on the vial label, the sample record card and the laboratory processing sheet.

A5.3. Procedures for individual dinoflagellate specimens

A5.3.1. Introduction

In this section, techniques developed by Bill for picking, manipulating and sectioning individual dinoflagellate specimens are outlined in three paragraphs. During their first semester, Bill taught his graduate students all of the other procedures for individual dinoflagellate specimens described in Evitt (1984, p. 14–18), including the acetolysis of a single specimen, staining an individual cyst, drying a specimen for SEM analysis and dissecting a theca.

A5.3.2. Picking individual specimens

Individual dinoflagellate specimens can be picked out of a residue or a strew mount. This is achieved by using the micropipetting technique developed by Bill. Micropipettes were made from glass blood capillary tubes. The tube was heat-softened, and the ends pulled apart to produce two very fine tubes. When cooled and hardened, the tube was scratched with a diamond scribe at a point which is $\sim 200\ \mu\text{m}$ in diameter and flexed in order to break the tube. The broken ends were examined to ensure they are not oblique or irregular. If the break was clean, the tube was used for picking (Evitt 1984, p. 14, 15, fig. 1B). The modified glass tube was then affixed to a length of flexible chemical tubing with a medical

syringe at the other end. The plastic tubing was squeezed to execute delicate actions such as cleaning, discharging, moving and sucking up individual specimens (Evitt 1984, fig. 1C).

One or two drops of aqueous residue were pipetted onto a slide, and a drop of glycerine added. This was mixed well, spread out and allowed to dry on a hot plate. The residue was then examined to locate good specimens. The high viscosity of the glycerine then allows these specimens to be picked up using the micropipette. Bill was very practiced in these techniques, and would perform them with great aplomb. New graduate students would watch in awe (and utter disbelief that they would ever be as adept) as he would pick up and place dinoflagellate specimens into extremely small drops of glycerine. These would often be arranged in a row of glycerine drops, sometimes one by one, and occasionally with several dinoflagellates in the pipette. Bill never seemed to hesitate, slip up or fail to achieve his goal.

A5.3.3. Manipulating and orienting individual specimens

When a dinoflagellate specimen has been isolated, it can be manipulated and oriented under a microscope using an eyelash manipulator. Bill learned that eyelashes taper gently to a fine point. When a single eyelash is affixed to a small piece of wooden doweling, it makes a perfect probe or tool for manipulating extremely small objects in media such as glycerine jelly, glycerol or water (Evitt 1984, p. 15, fig. 1D). Bill first used the eyelash manipulator to move his small, silicified trilobite specimens (sections 3, 7). The first description of the use of the eyelash manipulator in palynology was in Pierce (1976, p. 26). These eyelash probes can be used to clean dinoflagellate specimens of extraneous debris, even inside the cyst or theca. A dry probe can transfer dry specimens to an SEM stub. For example, one of us (JL-C) used one of these to study specimens of the chorate dinoflagellate cyst genus *Litosphaeridium*. Using a mixture of glycerine and glycerine jelly, the mounted specimen was heated slightly, then carefully rotated using the eyelash manipulator to obtain a direct view of a process including the morphology of the tip and the base (Lucas-Clarke 1984, pl. 2, figs 5, 6, 9, 10, 13, 14). In this way, the configuration of all of the processes could be observed in order to record the tabulation pattern.

A5.3.4. Sectioning dinoflagellate cysts

Perhaps the most remarkable procedure that Bill taught his graduate students was how to cut a dinoflagellate specimen. The cutting tool or knife was made by heating a small glass rod and drawing it out. After it cooled, the thinnest portion was scribed and broken off. The resultant knife could cut a specimen in glycerine with a rolling action. A serrated knife can be made by breaking the thin glass thread without scribing. The resultant jagged edge should be used with a sawing motion (Evitt 1984, p. 17, figs 1F, G).