The palaeoecology of two Scottish encrinites: Jurassic crinoid assemblages from the Trotternish Peninsula, Isle of Skye, Scotland

Synopsis
Despite a long history of investigation, articulate crinoids from the Jurassic of Scotland have not received great attention compared to their counterparts in Southern England or continental Europe; this is thought to be largely due to poor preservation. Two examples of 'local' encrinites (rocks almost entirely composed of crinoids debris), one from the Pliensbachian and the other from the Aalenian/Bajocian from the Isle of Skye, are shown to consist of columnals of *Hispidocrinus* cf. *schlumbergeri* and *Balanocrinus donovani* respectively. They represent local encrinites that have been deposited parautochthonously; one in a proximal, and the other in a more offshore low energy environment. This demonstrates that even limited encrinite material can not only be assigned systematically, but can also be used to reconstruct the original palaeoenvironments that the crinoids inhabited.

Records of crinoids in the Jurassic rocks of Scotland go back nearly 150 years, Wright (1858) described crinoids as early as 1858 from a collection owned by Mr. Geikie in what was then termed the 'Scottish Lias'. Despite such observations, taxonomic work has been thin on the ground with the notable exceptions of Oak & Donovan (1984), and Simms (1989). Due to the restricted amount of the Jurassic outcrop in Scotland, occurrences in this study tend to be restricted to the area around the Inner Hebrides and West Highlands, although there are large outcrops of Middle Jurassic from NE Scotland along the Moray Firth close to Brora and Dunrobin Castle (Sutherland) and these contain well preserved crinoid columnals provisionally identified as *Isocrinus sp*. (Hunter & Clark in press). The specimens described by Oak & Donovan (1984) occur in the Sinemurian–Pliensbachian Lady's Walk Shale Member, the overlying Middle Jurassic horizons further north are devoid of echinoderm material (Hunter 2006). Oak & Donovan (1984) were the first to fully describe an articulate crinoid from Scotland systematically, allowing them to successfully reassign an outcrop originally thought to belong to the Cambro–Ordovician Durness limestone, to the Jurassic. Oak & Donovan (1984) used three associated blocks, which have been cut and polished. The present paper uses a similar treatment although we go one step further and use thin sections for one of the samples. Simms (1989) noted the occurrence of several specimens of *Isocrinina* from Western Scotland (which were presumably personally collected by the author) and include members of the genus *Isocrinus*, *Balanocrinus* and *Hispidocrinus*. In his monograph of British Lower Jurassic crinoids, Simms notes several areas of the highlands and islands that are rich in material including Loch Aline, Morvern, Argyllshire and Applecross, Invernesshire, which contain *Isocrinus psilonoti* of Sinemurian age (*Coroniceras rotiiforme* Subbiozone). On the Isle of Mull *Balanocrinus subteroides* & *Isocrinus robustus* have been collected from the Carixian (Pliensbachian) of Carsaig Bay, along with Sinemurian (raricostatum Sub-biozone) *Hispidocrinus scalaris*. From the Isle of Pabba/Pabay in Southern Skye, *Isocrinus robustus* & *Balanocrinus gracilis* can also be collected, and finally on the Isle of Raasay, Hispidocrinus scalaris is found in the Sinemurian (*raricostatoides* and *Leptechioceras macdonnelli* sub-biozones) Pabba Shales, and further up the sequence in the Raasay Ironstone bed (Toarcian, *Grammoceras striatulum* Sub-zone), *Chariocrinus wuerttembergicus* can be collected (Simms 1989).

Although, Simms (1989) is used as the basis of this study, the accounts given in this monograph tend to be integrated with the detailed descriptions of articulated specimens primarily from England and thus no detailed information is given of their depositional environments or preservation. This study reviews the occurrences of two samples packed with articulate crinoid remains from northern part of the Isle of Skye, Scotland, and follows the tradition of Wright (1858) in documenting fossils collected by local fossil collectors. In this paper the columnals are assigned to species systematically, using an open nomenclature as disarticulated columnals that are generally considered problematic to identify. The key aim is to analyse the specific content of the crinoids and there associated matrix in order to determine the palaeoecological and palaeoenvironmental information for these crinoids (See Hunter 2006; Hunter & Zonnaveld 2008).

Geological setting of the encrinites

Jurassic crinoids are typically preserved as isolated columnals, encrinites (crinoid-rich beds) or obrution Lagerstätten (Lagerstätten that are preserved as an intact and complete record following a catastrophic event) (Hunter & Zonnerveld 2008). Encrinites are an extinct lithofacies (Ausich 1997) comprising crinoidal grainstones and packstones that are composed of more than 50% pelmatozoan debris by volume (Ausich 1997). Regional encrinites worldwide range from the Ordovician to the Jurassic, have an average thickness of more than 5–10 m and may extend over more than 500 km (Ausich 1997). The encrinites in this paper do not meet these criteria, and thus they are termed 'local encrinites', similar to those described by Hunter (2006) or Hunter & Zonnerveld (2008). They comprise individual lenses or beds 2–5m in thickness. In some environments crinoidal limestones developed in relatively restricted microfacies (Tang et al. 2000). Similar accumulations of echinoderm biogenic sediment are not being deposited at the present day (Carozzi & Gerber 1985). Under normal circumstances crinoids rapidly disarticulate into component ossicles (Hunter & Zonnerveld 2008). These isolated ossicles are easily transported, and most of the fragmentary material present in regional encrinites has undergone transportation. However, transportation in both regional and local encrinites is interpreted to be minor or parautochthonous.

Wilson (1975) considered encrinites to be a special microfacies formed within shoal environments in agitated water. In contrast, Ausich (1997) regarded regional encrinites in the Palaeozoic to be from deeper-water settings, typically formed below normal wave base although within storm wave base. It is clear that their formation may differ substantially from case to case, however the occurrence of encrinites in this Scottish example has a 'local' limited outcrop, and it is apparent that the only true Jurassic regional encrinite is that of the Polish Smolegowa Limestone (Birkenmajer 1977).

Both of the samples come from the Hebridean Basin (Hesselbo & Coe 2000). Although the Mesozoic sedimentary rocks are less well-studied than the Tertiary volcanic centres, this region is famous for its geology. The Jurassic of Skye is very well exposed and several excellent field guides exist e.g. Morton & Hudson (1995), Bell & Harris (1986). The two studied encrinite samples were collected from the Trotternish Peninsula. The older of the two is from the Pliensbachian Scalpay Sandstone Formation (See Fig. 4) from near the Scarf Caves (NG510427), east of Portree (collected by Neil Roberts) and it is referred to herein as Skye Encrinite 1 or

SE1. The second sample (sampled by Dugald Ross) is from the Aalenian/Bajocian Bearreraig Sandstone Formation (See Fig. 4) near Staffin and is termed Skye Encrinite 2 or SE2. The locality from which SE1 was collected is well documented in the literature, Anderson et al. (1966) stated that 'At Scorr Skerry, west of the Scarf Caves, the Middle Lias sandstones are faulted down to the west and are not seen again until they appear from below sea-level about half a mile north of Beal Point (Rubha na h-Airde Glaise), north of Portree. Northwards for three miles these beds form a sea-cliff often covered by scree and slip but here, as at Prince Charlie's Cave, the highest beds, which are criniodal and contain nests of rhynchonellids, can be examined.' More recently Morton (2002) described 'Discrete patches of crinoid debris indicate local disarticulation of crinoids without significant lateral transport, and bioturbation is interpreted as the main cause of disturbance of shell material before fossilization.' More precisely the Scalpay Sandstone Formation is exposed at Holm in the northern part of the Isle of Skye (Figs 1 & 3). This formation was deposited on top, and partly diachronously with the Pabay Shale (ammonite-bearing silty mudstones of the Pleuroceras spinatum zone) with rather low organic content (Hesselbo & Coe 2000; Simms et al. 2004). The age of this regionally extensive shallow-marine unit is Late Pliensbachian (Howarth 1956). Both the major deepening phase at the beginning of the Pliensbachian and subsequent shallowing in the Late Pliensbachian are effectively synchronous over a remarkably wide region within the Laurasian seaway (Howarth 1956; Sellwood 1972), although it is thought that the significant tectonic–eustatic sequence of events are not obviously linked to movements on individual fault systems (Hesselbo & Jenkyns 1998).

The Middle Jurassic deposits of the Skye–Raasay area where sample SE2 is found, fall mostly into two distinctive lithostratigraphic groups: the Bearreraig Sandstone of late Aalenian to late Bajocian age, and the Great Estuarine Group (GEG) of late Bajocian to Bathonian age. Whilst the Bearreraig Sandstone is largely of marine origin and easily dated using ammonite index taxa, the Great Estuarine Group represents a complex of lagoonal, deltaic and fluvial environments of varied salinity and lithology (Morton & Hudson 1995). The GEG is largely devoid of echinoderms apart from two notable exceptions including a cidaroid in the Valtos Sandstone (Hunter 2006) and undescribed crinoids from the Cullaidh Shale Formation (Harris & Hudson 1980; Oak & Donovan 1984). SE2 was found within the Bearrereaig Sandstone Formation and are thought to have been collected from the Ollach Sandstone Member (*Murchisonae* and *Bradfordensis* biozones), the occurrence of crinoids in this Member has been recorded by Morton (2002) where the following interpretation was given 'Discrete patches of crinoid debris indicate local disarticulation of crinoids without significant lateral transport, and bioturbation is interpreted as the main cause of disturbance of shell material before fossilization'. Crinoids have also been recorded from the Bearreraig Sandstone near Elgol, however, these are undescribed (Oak & Donovan 1984). Sedimentary facies making up the Bearreraig Sandstone are variable (Hesselbo & Coe 2000), although it is generally thought that at the type section in Trotternish the facies is relatively distal in origin.

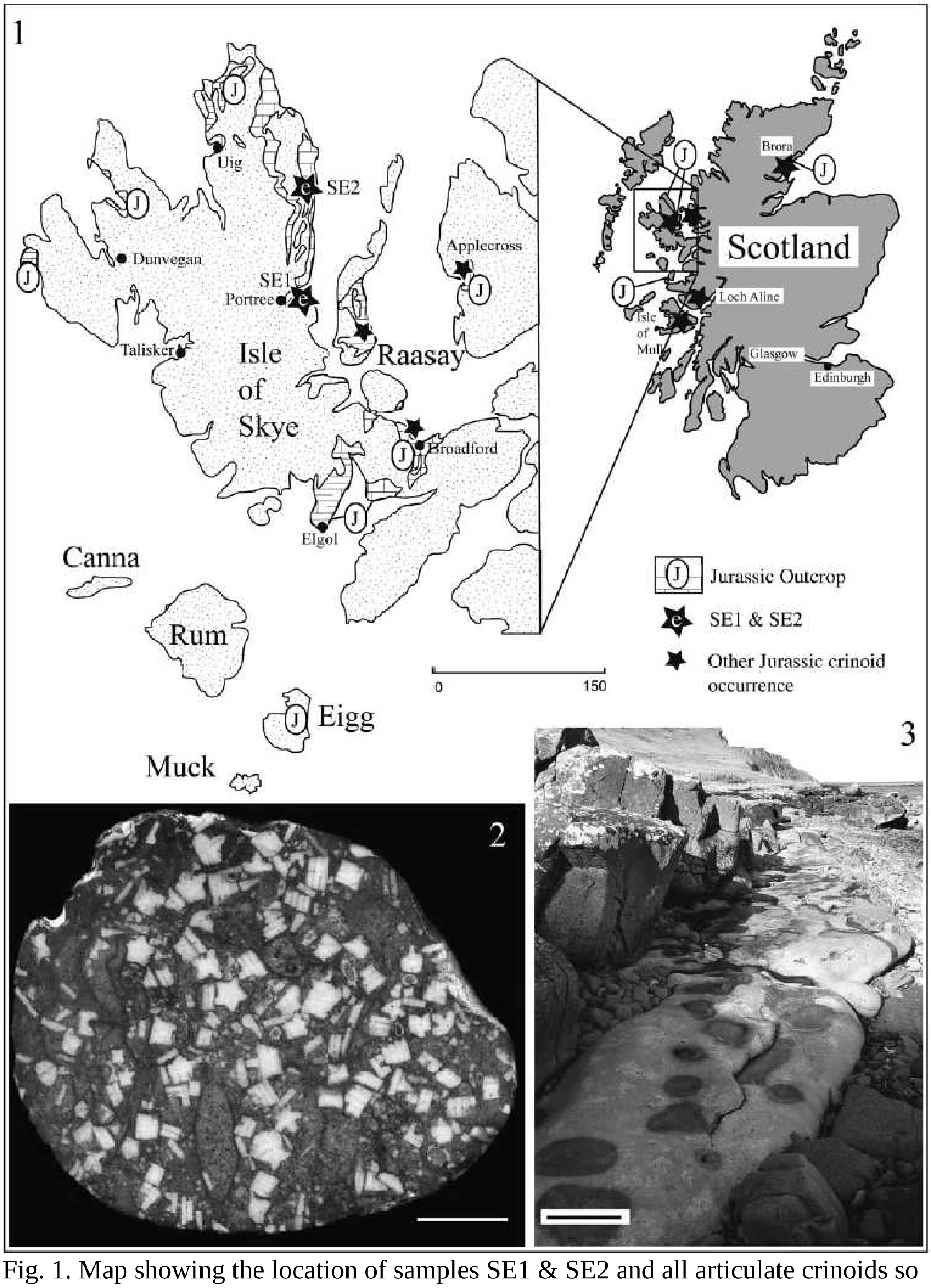

Fig. 1. Map showing the location of samples SE1 & SE2 and all articulate crinoids so far recorded from Western Scotland.
Fig. 2. Scanned polished surface of SE1 (Scale 1cm)
Fig. 3. Photograph of the Scalpay Sandstone Formation encrinite at Holm (looking north), North of Portree, Isle of Skye (Scale 30cm) courtesy of Mr Paul Booth, (Pitlochry)

Systematic palaeontology

Crinoid terminology used in this paper follows Simms

(1989).

Class CRINOIDEA Miller, 1821
Subclass ARTICULATA von Zittel, 1879
Order ISOCRINIDA Sieverts-Doreck, 1952
Family ISOCRINIDAE Gislén, 1924,
Genus HISPIDOCRINUS Simms, 1988

Diagnosis. After Simms 1989: Moderately robust Isocrinidae. Stem pentastellate to pentalobate. Noditaxes short. Cirral scars small, directed outwards and slightly upwards. Symplectial areolae elongate elliptical. Adradial crenulae of adjacent areolae separated by a furrow or smooth band. Cryptosymplectial articula with first and second order crenulae.

Discussion. The arrangement of the areola into five, petal-like areas, each surrounded by a crenularium in which the outer crenulae extend to the margin of the articular facet, is diagnostic of crinoids of the Family Isocrinidae Gislen, 1924, of the Order Isocrinida Sieverts-Doreck, 1952. The shape of the interradi are suggestive of the genus *Hispidocrinus* Simms 1988. The original diagnosis made by Simms (1988, 1989) proposed this genus of Isocrinidae bearing prominent spines on the brachials. This genus differs from other Jurassic Isocrinidae by having brachial spines although this is not preserved in those examples. Instead the character in the columnals is used. The stem *Hispidocrinus* is markedly more stellate than that of either *Isocrinus* or *Balanocrinus* and the areolae are more elongate and narrow (Fig. 4) and tend to border the edge of the columnal than either of these two genera (Simms 1989), although still much broader than pentacrinites with the latter having smaller crenulae. The columnal height is low relative to diameter compared to other members of the family cirral scars are also significantly smaller. Some species of *Chariocrinus* have pentastellate to pentalobate columnals with symplectial articula that appear diagnostic of *Hispidocrinus* (Eagle & Hikuroa 2003). However, Eagle & Hikuroa (2003) assigned these specimens to the *Chariocrinus latadiensis* (Middle Jurassic of Antarctica) based on their spineless axillaries and fused adjacent crenulae. In-fact Simms (1989) assigned *Chariocrinus leuthardti* to *Hispidocrinus* solely on the presence of large conical spines (Salamon & Zato 2007).

Hispidocrinus cf. *schlumbergeri* Simms (1989)
Figs. 2 & 5(1–8)

Holotype. Specimen GLAHM 131417 Hunterian Museum, University of Glasgow.
Material. SE1- Small pebble of encrinite packed with nodals and columnals (not in-situ). Description conducted using 4 thin sections (Fig. 4) and a polished surface (Fig. 2).
Occurrence. Pliensbachian Scalpay Sandstone Formation from near the Scarf Caves (NG510427), east of Portree and Holm and Bearreraig Bay, Staffin peninsula, north of Portree, Isle of Skye, Scotland.
Diagnosis. Columnals are pentalobate to subpentalobate some distal columnals sub-pentagonal elliptical petals marginal and adradial crenulations diminish in size towards the luman. Crenulations are wide. Pluricolumnnals have three to four columnals per nodi taxa. Cirri rounded in section.
Description. Described with the aid of a hand specimen and a thin section only the ossicles of the stem are informative. Stem: The articular of the internodals are

pentastellate but they frequently appear less angular and sometimes with pronounced lobes. Some smaller presumably distal columnals have a sub-pentalobate to pentagonal shape in outline. Maximum internodal diameter is about 6 mm whilst the smallest columnals found have a diameter of 4 mm, with usually three to four columnals per noditaxis. Internodal height varies. The articulation between nodal and internodal is unclear, however the articulation between internodals is symplectial. The aerolae or symplectial articula have an elongated and wide with elliptical outline and have numerous crenulae. Brachial ossicles are also preserved but not informative. Remarks. Although identified from thin section when cut 90(to the latera it is possible to identify the diagnostic pentastellate shape of the columnals and in some cases the crenulae can be distinguished in thin section. Examination of *Metacrinus rotundus* at the University of Tokyo demonstrate that crenulae or through ligamentation do not change significantly through the columnal in this species. In polished hand specimen the number columnals per noditaxis can be clearly seen. Simms (1989) distinguishes the two members of the genus of *Hispidocrinus* by the number of columnals per noditaxies (*Hispidocrinus scalaris* = five and nine & *Hispidocrinus schlumbergeri* = four). Strictly adhering to Simms's species concept this new form has three to four columnals per noditaxis thus is best assigned in open nomenclature to *H. schlumbergeri*. With no sufficient distinction in terms of the noditaxis to warrant a new species.

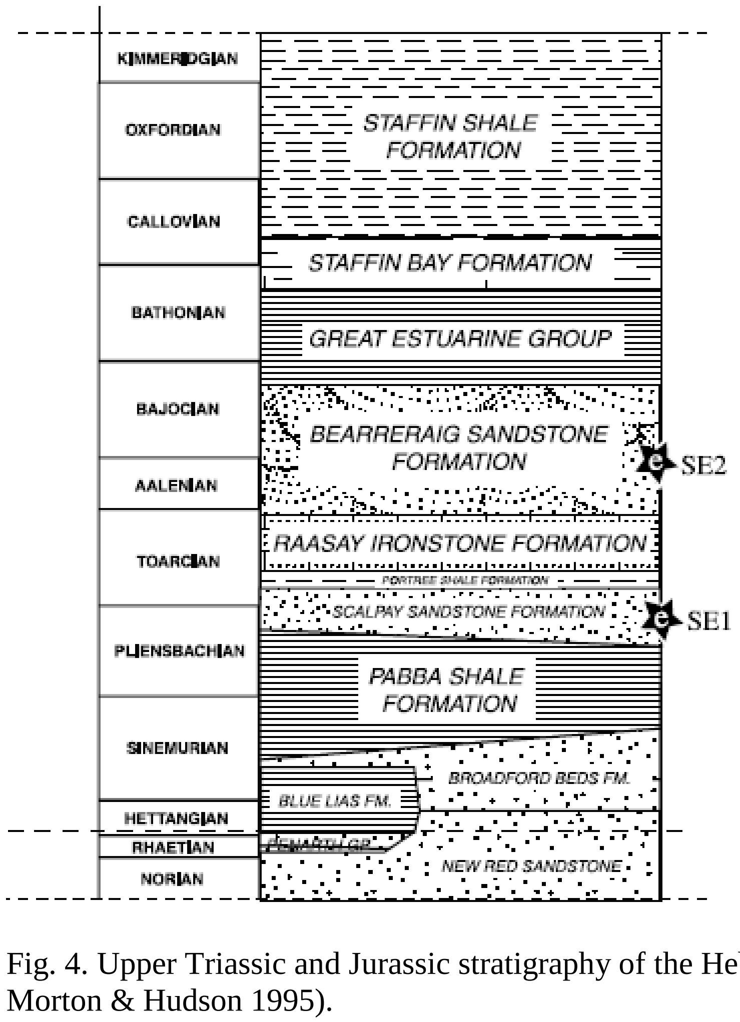

Fig. 4. Upper Triassic and Jurassic stratigraphy of the Hebrides Basin (adapted from Morton & Hudson 1995).

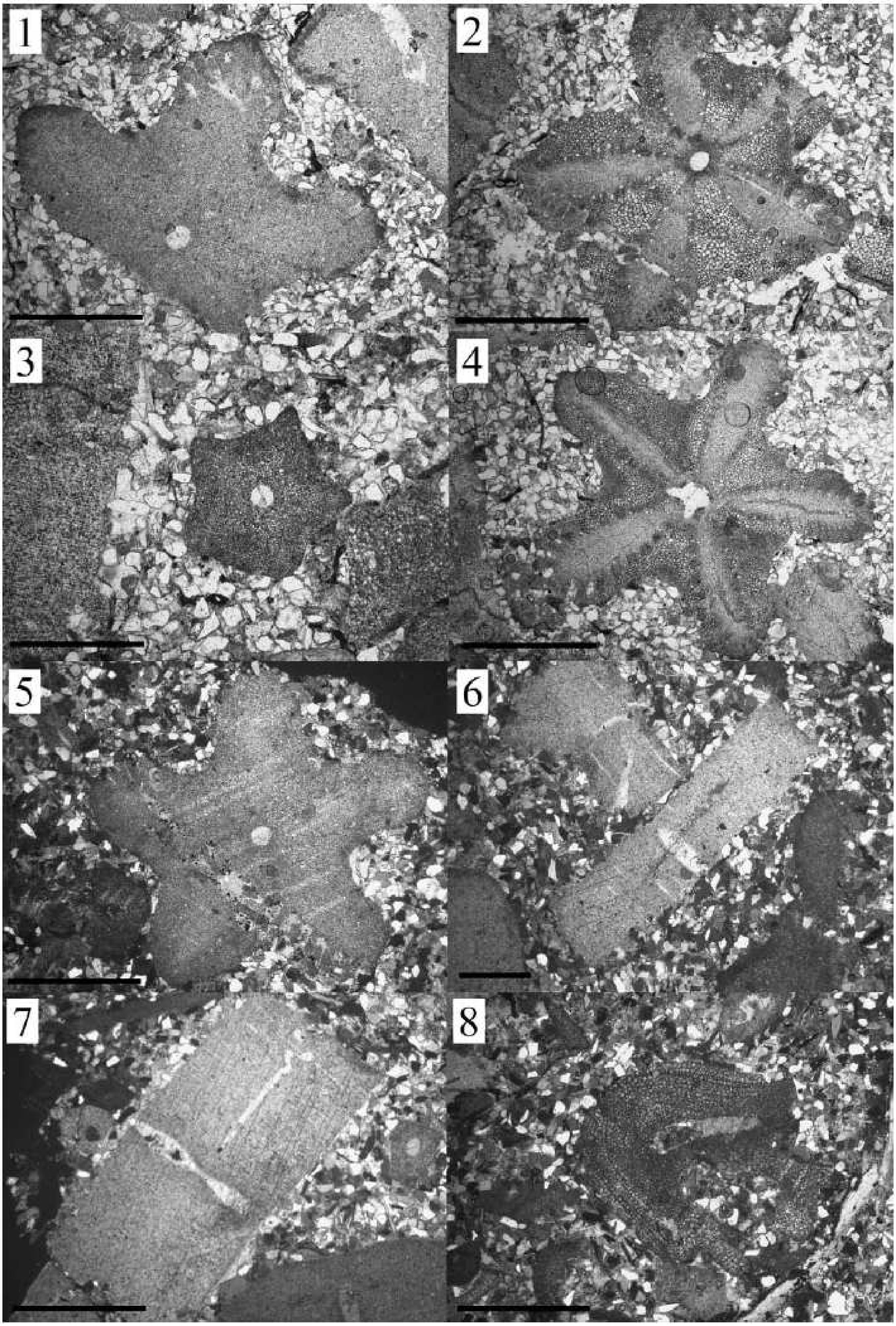

Fig. 5. Thin section photo-micrographs of sample SE1:1–5, Cross-section of columnals in PPL. 6–7, Longitudinal section of columnals in PPL & XPL. 8, Section of brachial in XPL. (Scale 5mm)

Genus BALANOCRINUS Agassiz in: Desor, 1845

Diagnosis. After Simms 1989: Slender Isocrinidae. Stem circular to rounded sub-pentalobate. Noditaxes moderate to long. Cirral scars moderate to large, directed outwards and strongly upwards. Cupule above and aboral lip below each cirral scar. Symplectial areolae broad elliptical to pyriform. Adradial crenulae of adjacent areolae fused or reduced to granulose band. Cryptosymplectial articula with first order crenulae only. Radial pores on proximal columnals distinct, often persisting as shallow elongate pits on more distal columnals. Basals small to moderate, separate or just in contact, smooth. Arms slender. Moderate to long brachitaxes.

Discussion. Genus typified by continuous basal ring, but more obviously distinguished by very rounded columnals and long noditaxis. Junction of 1Br1 and 1Br2 synarthrial. Nodals bear one to five cirrus sockets. Under SEM, stereom well regulated or chaotic (labyrinthic), ligament pores are bordering; rarely, bordering and inner.

Balanocrinus donovani Simms 1989

Fig. 6(1–7)

Holotype, After Simms (1989); BNI E70376, a wellpreserved nodal colmunal from the Amaltheus gibbosus Sub-biozone in the lower part of the Marlstone Rock Bed on Gretton Hill. near Cheltenham, Gloucestershire (Grid Ref. SP 010298) Lectotype GLAHM 131418 Hunterian Museum, University of Glasgow.

Occurrence, Bearrereaig Sandstone Formation and are thought to have been collected from the Ollach Sandstone Member (SE2). This crinoid is found in the Amaltheus subnodosus Sub-biozone, on the Dorset Coast, and north Gloucestershire.

Diagnosis. Adapted from Simms (1989): Small *Balanocrinus*. Number of columnals per noditaxis remains unknown but is probably a high number. Internodals usually very circular or sub-circular.

Description. Only the columnals are preserved: Stem length is unknown. Distal internodals are very circular or subcircular. more proximal internodals could be weakly sub-pentagonal. No nodals are preserved. Nodal spacing frequency is unknown although the rarity of nodals suggests a large number of columnals per noditaxis. Internodal height varies from 125% of intermodal diameter in small specimens to only 36% at large diameters. Cirral scars or cupules are not preserved; Articulation between nodal and infra-nodal are not viable. All other columnals articulations are symplectial. The arrangement of the crenulae is typical of the genus. The marginal crenulae are short and the adradial crenulae are well-developed and perpendicular to the marginal crenulae except for an outer, transitional pair of crenulae.

Remarks. The unmistakable circular shape of B. donovoni is very evident on this specimen, although slightly abraded on one side the diagnostic characters of this genus are clear, and there are no additional informative characters that warrant the diagnosis as a new species.

Taphonomy & palaeoecology

The Jurassic seas in which these crinoids lived were part of the Hebrides Basin, which in turn formed part of a network of narrow waterways that was connected to the Tethys in the south, and to the Boreal ocean in the north and referred to as the Laurasian Seaway (Hesselbo & Coe 2000). The marine connection between the different polar and equatorial water masses via the seaway was established and broken several times throughout the Jurassic (Hesselbo & Coe 2000). In the vicinity of Skye and Raasay, deposition was relatively continuous with few pauses, although the depositional rates varied substantially with two high phases; the Sinemurian–Pliensbachian and Bajocian–Bathonian with condensation during the Aalenian, possibly related to regional shallowing indicated by the presence of basal sandy facies of the Bearreraig Sandstone of shallow-water origin (e.g. Mellere & Steel 1996).

According to Simms (1989) the upper part of the Scalpay Sandstone Formation is rich in columnals. There are three taxa recorded in the monograph of Simms from the Isle of Raasay and N. Portree. These include *Balanocrinus solentis* (*Subnodosus* or *gibbosus* Sub-biozone) *Balanocrinus donovani* (*Dactylioceras tenuicostatum* Biozone) and *Hispidocrinus schlumbergeri* (*tenuicostatum* Biozone). Of these, three *B donovani* and *H. schlumbergeri* are recorded from N. Portree. However, none of these occur at the same stratigraphic interval as sample SE1 and thus are not informative about the community palaeoecology of these crinoids. In their account, Oak & Donovan (1984) noted Isocrinid columnals where extremely common in the Middle Lias (spuiatum Zone) Scalpay Sandstone Formation at certain horizons, the same locality as SE1, thus it is likely that these columnal have the same specific designation.
Articulate crinoid material can be interpreted using a relative scale of lithofacies and taphofacies used by Hunter (2006) and Hunter & Zonnerfield (2008). The lithofacies classification by Hunter (2006) was developed using Middle Jurassic crinoids from the carbonate facies of England and northern France and has since been applied to the encrinites of North America (Hunter & Zonnerfield (2008). The stratigraphy and sedimentology used in Hunter (2006) along with the complete lack of any associated fauna make it difficult to apply to both SE1 and SE2. Nevertheless, the crinoids are preserved in a clastic matrix consisting of medium- to fine-grained, sorted angular quartz grains with a carbonate matrix and could thus be interpreted as being deposited in a near-shore environment and rather rapidly (Hank Sombroek, pers. comm., 2004). In contrast, the SE2 crinoids are preserved in a fine-grained siltstone with some quartz, and are presumably far more distal in setting.

The taphofacies classification used in Hunter & Zonnerfield (2008) is applicable to both SE1 and SE2 as it involves looking at the articulation of the crinoids themselves. As explained earlier crinoid columnals disintegrate rapidly following even localized transport and thus are sensitive indicators of palaeoenvironment. Both SE1 and SE2 can be classified as crinoid taphofacies 2 of Hunter & Zonnerfield (2008); that is, both encrinite samples can be interpreted as para-autochthonous as they have articulated columnals and articulated pluracolumnals which are relatively unabraded, and there has been minimum transport or reworking. In Hunter (2006) taphofacies 2 tends to be associated with lithofacies either from the deeper neritic off-shore lithofacies or the near-shore lower energy shelf, embayment or marine lagoons. This interpretation is consistent with the sedimentological interpretation above and thus the crinoid material preserved in SE1 Scalpay Sandstone Formation is interpreted as a near-shore setting, while the crinoids in Bearreraig sandstone SE2 are interpreted as belonging to a more offshore setting.

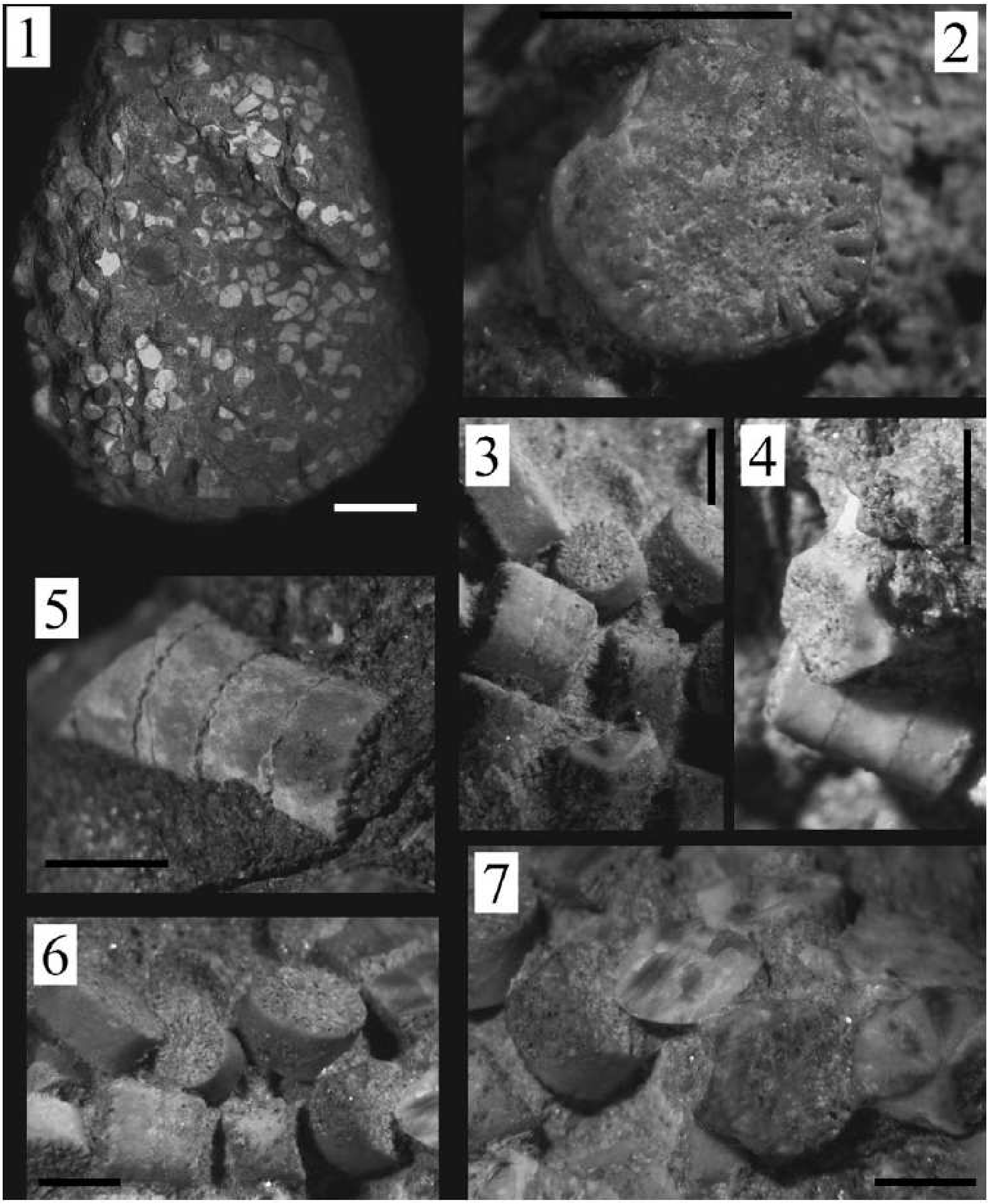

Fig. 6. Reflected-light micrographs of sample 1, SE2 encrinite sample (Scale 10mm). 2, Columnal articula. 1, 3–4; Pluri columnals. 4–6 Disarticulated columnal. (Scale 5mm)

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