Haughton Astrobleme: A Mid-Cenozoic Impact Crater Devon Island, Canadian Arctic Archipelago

T. FRISCH[1] and R. THORSTEINSSON[2]

ABSTRACT. Haughton Astrobleme is a nearly circular impact crater with a diameter of about 16 km and a central uplift in Devon Island. Bedrock exposed in the crater comprised the following mainly carbonate Lower Ordovician to Upper Silurian formations in order upward: Eleanor River, Bay Fiord, Thumb Mountain, Irene Bay and Allen Bay. The Eleanor River Formation in the centre of the crater is raised about 480 m above its normal stratigraphic position outside the crater. The much shattered and faulted lower Paleozoic rocks within the crater contrast markedly with the subhorizontal surrounding strata. The Allen Bay Formation constitutes surface exposure around all but the easternmost part of the crater's border where the Thumb Mountain and Irene Bay Formations are exposed. Also exposed in the crater are two newly recognized, and as yet unnamed, formations: a polymict impact breccia that overlies the lower Paleozoic rocks, with marked angular unconformity and crops out over about a quarter of the area of the crater; and a unit of lake sediments near the western border of the crater that lies disconformably on the impact breccia and with angular unconformity on the lower Paleozoic rocks.

The impact breccia is composed chiefly of carbonate rocks, but locally contains clasts of Precambrian crystalline basement from a depth estimated to be at least 1700 m. The basement clasts show varying degrees of shock metamorphism, the highest being that displayed by rocks with vesicular, flow-banded feldspar or quartz glass. Coesite has been identified in a sample of gneiss.

The lake sediments are interpreted as an infilling of the crater that occurred shortly after impact. On the basis of fossils, these sediments are dated as Miocene or, possibly, Pliocene. From this and other evidence, it is concluded that the impact took place in the Miocene or Pliocene.

RESUMÉ. "Haughton Astrobleme" est un cratère quasi-circulaire, causé par un impact; il a un diamètre d'environ 16 km avec un mamelon central et se situe dans l'Ile de Devon: Les affleurements du cratère sont datés de l'Ordovicien au Silurien supérieur: les formations carbonatées représentées sont dans l'ordre "Eleanor River, Bay Fiord, Thumb Mountain, Irene Bay et Allen Bay." La formation Eleanor River au centre du cratère est montée d'environ 480 mètres au-dessus de sa position stratigraphique normale, en dehors du cratère. Les roches les plus brisées et faillées du Paléozoique inférieur, à l'intérieur du cratère, font un contraste marquant avec les bancs sub-horizontaux qui les entourent. La formation Allen Bay représente les afflueurements entourant l'ensemble mais ce sont des affleurements des formations "Thumb Mountain" et "Irene Bay" que l'on observe sur la bordure la plus orientale du cratère. De plus, deux formations nouvelles et pas encore "baptisées" ont été reconnues dans le cratère: une brèche d'impact polygénique qui repose sur les roches du Paléozoique inférieur en discordance angulaire accusée, dans environ un quart de la surface du cratère — un affleurement de sédiments lacustres près de la bordure ouest du cratère, reposant en discordance sur la brèche d'impact et avec une discordance angulaire sur les roches du Paléozoique inférieur.

La brèche d'impact est composée principalement de roches carbonatées mais localement contient des clastiques du socle cristallin Pre-Cambrien, situé à au moins 1700 mètres de profondeur. Les clastiques du socle montrent des degrés variés de

[1]Geological Survey of Canada, 588 Booth Street, Ottawa, Ontario K1A 0E8

[2]Institute of Sedimentary and Petroleum Geology, 3303 - 33 Street N.W., Calgary, Alberta T2L 2A7

métamorphisme de contact, le plus haut degré étant représenté par des roches à feldspaths zonés ou à verre quartzitique. La coésite a été identifiée dans une échantillon de gneiss.

Les sédiments lacustres sont interprétés comme un remplissage du cratère qui se serait situé rapidement après l'impact. Au vu des fossiles, ces sédiments sont datés du Miocène ou peut-être du Pliocène . De cette constatation et d'autres indices, on a conclu que l'impact s'est situé au Miocène ou au Pliocène.

Traduit par Alain de Vendegies, Aquitaine Co. of Canada Ltd.

INTRODUCTION

Haughton Astrobleme is a nearly circular impact crater about 16 Km in diameter situated near the north coast of Devon Island in the Canadian Arctic Archipelago (Fig. 1). The centre of the crater is at Latitude 75°22'N and Longitude 89°40'W. The name Haughton Astrobleme is here proposed for what has been previously known as Haughton Dome, a name given to this structure by Greiner (1963b), who concluded that is was possibly an evaporitic diapir. Greiner's publication is an account of the geology of the crater and the immediately surrounding area, and was based on nine days of field work carried out in 1955. The impact origin was first suggested by Dence (1972), and later confirmed by Robertson and Mason (1975) on the basis of shatter cones discovered within the crater.

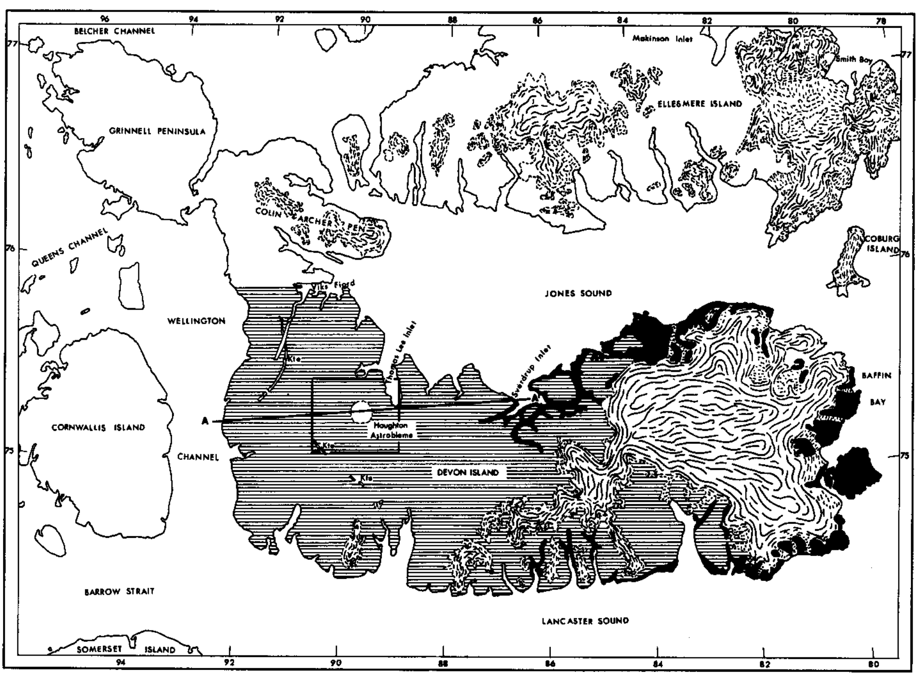

FIG. 1. Index map showing location of Haughton Astrobleme and distribution of Precambrian rocks (solid black), lower Paleozoic rocks (horizontally lined) and Eureka Sound Formation (KTe) of Late Cretaceous to early Tertiary age, within principal part of Devon Island. Area of geological map (Fig. 2) is outlined. A-A' is line of section (Fig. 3).

LEGEND

CENOZOIC

QUATERNARY

Qal — *Alluvium (Mapped only where underlying bedrock geology cannot be inferred with reasonable certainty)*

TERTIARY

Unnamed formation: dolomitic silt

Tb — *Unnamed formation: mainly dolomite and limestone breccia (coarse stipples indicate outcrops of formation in which clasts of Precambrian metamorphic rocks are common; fine stipples indicate outcrops in which clasts of these rocks are small and scarce*

MESOZOIC

CRETACEOUS AND TERTIARY

EUREKA SOUND FORMATION: quartzose sandstone, siltstone, shale

PALEOZOIC

UPPER SILURIAN

Scs — *CAPE STORM FORMATION: dolomite, minor limestone*

UPPER ORDOVICIAN TO UPPER SILURIAN

OSa — *ALLEN BAY FORMATION: dolomite, limestone*

MIDDLE ORDOVICIAN

Octi — *Undivided*
IRENE BAY FORMATION: limestone, shale
THUMB MOUNTAIN FORMATION: limestone, minor dolomite (Rocks of these two formations appear to be scarce within the limits of Haughton Astrobleme, and are included with the Allen Bay Formation)

Ocb — *BAY FIORD FORMATION: dolomite, gypsum, minor limestone*

LOWER ORDOVICIAN

ELEANOR RIVER FORMATION: limestone

Geological boundary (defined, approximate, assumed) ....
Bedding, tops known (inclined) 20
Bedding (from aerial photograph or observed from aircraft) ....
Fault (defined, approximate, solid circle indicates downthrow side) ....
Boundary of Quaternary sediments ....

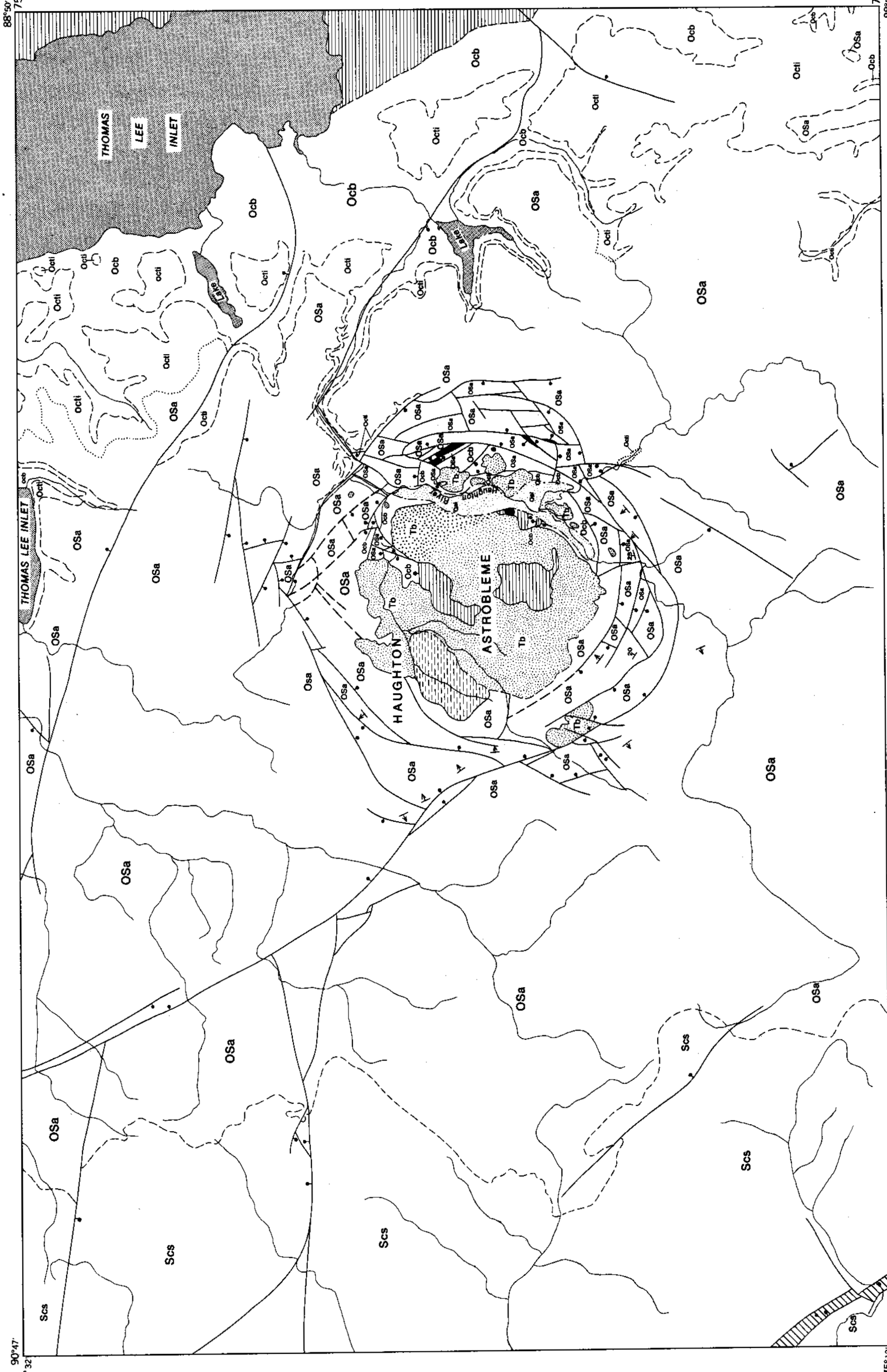

FIG. 2. Generalized geological map (1:250 000) of Haughton Astrobleme and immediately surrounding area.

The present report is a geological and physiographical study of Haughton Astrobleme based on six days of field work conducted by the authors in August of 1976 from a base camp established near Haughton River in the crater. This work brought to light several important features of the Haughton structure. The rocks exposed in the crater are mainly intensely faulted shelf-type limestone and dolomite having an age range of Early Ordovician to Late Silurian, and comprising, in ascending stratigraphic order, the formations Eleanor River, Bay Fiord, Thumb Mountain, Irene Bay and Allen Bay. Also cropping out in the crater are two newly recognized, as yet unnamed, formations: a polymict impact breccia that overlies with marked angular unconformity the lower Paleozoic rocks and extends over about a quarter of the area of the crater; and a unit of lake sediments that occupies a limited area near the western border of the crater, where it lies partly on the impact breccia and partly on the lower Paleozoic rocks, its surface of separation with the former being a disconformity, and that with the latter an angular unconformity. The much faulted nature of the lower Paleozoic rocks within the crater contrast markedly with the slightly deformed surrounding terrane, which is also of early Paleozoic age. The Allen Bay Formation constitutes surface exposure around the crater except in the east where the Thumb Mountain and Irene Bay Formations are exposed.

This report and particularly the accompanying geological map (Fig. 2) are preliminary. The map is based largely on observations taken from aerial photographs, or made from over-flights in a fixed-wing aircraft, and observations on the ground were limited to central and southeastern parts of the crater, including, however, a stop by aircraft on the lake sediments. Most of the stratigraphic thickness given here are no more than rough estimates. More field work is planned for this interesting feature.

PHYSIOGRAPHICAL AND GEOLOGICAL SETTING

The Haughton Astrobleme is situated in the part of Devon Island which lies within the Central Stable Region of the continent (Fig. 1). Two major geological provinces are exposed there: the Canadian Shield, consisting mainly of Precambrian metamorphic rocks, and exposed in the largely ice-covered eastern quarter or so of the island; and the Arctic Platform that lies to the west. In this part of the Archipelago, the Arctic Platform is underlain mainly by a structurally conformable succession of marine sedimentary rocks ranging in age from Early Cambrian to Early Devonian. The present-day erosion surface of the rocks is a dissected plateau, bordered in most places by spectacular sea cliffs. It is in a youthful stage of erosion and, though much dissected in coastal areas, is notably featureless over large parts of the interior. The plateau is clearly an ancient peneplain, regionally tilted in a westerly direction, highest in the east where it is up to 600 m above sea level, and sloping gradually westward to elevations of about 250 m near Wellington Channel. Throughout most of its extent, the lower Paleozoic succession forms a westerly dipping homocline with the beds somewhat more steeply inclined (about 4 degrees) than the plateau. It is these circumstances that are responsible for the fact that the various Paleozoic formations form bands of north-trending outcrops with progressively younger formations appearing to the west (Figs. 2, 3).

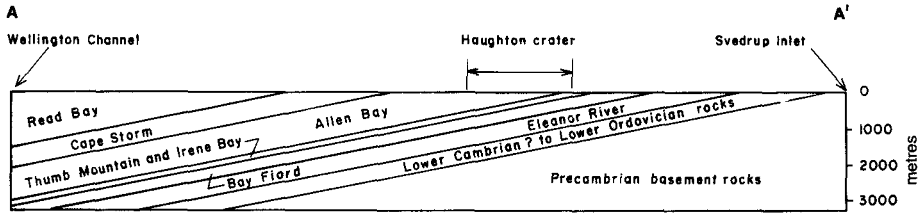

FIG. 3. Sketch section, west to east, from Wellington Channel through location of Haughton crater (Astrobleme) to Sverdrup Inlet (Fig. 1) showing succession of lower Paleozoic formations above Precambrian basement rocks. No attempt has been made to show lithologies or deformation of rocks affected by impact. Dip of homoclinal sequence is greatly exaggerated.

In addition to the faults associated with the crater, the main part of Devon Island is broken by rather numerous and commonly long normal faults. These normal faults form two areally segregated systems: one trending mostly northeasterly in the country west of about Longitude 91°N; the other trending mostly westerly and northwesterly to the east of that longitude. Several faults of the latter system are shown in the environs of the crater on Figure 2. Of particular interest to the present study is the fact that some faults of both systems form grabens that preserve isolated exposures of the Eureka Sound Formation, a largely nonmarine unit of Late Cretaceous (Maastrichtian) to early Tertiary (Eocene) age that lies unconformably on the lower Paleozoic rocks. This suggests that the Eureka Sound was at one time more widely distributed over Devon Island, and that all the faults of the two systems probably belong to a single episode of faulting younger than that formation. About 210 m of Eureka Sound beds that occur in a graben near the head of Viks Fiord (Fig. 1) have been described by Fortier (1963). The trends of the two fault systems, discussed above, are illustrated on Figure 1 by the orientation of grabens preserving strata of the Eureka Sound Formation.

The Eureka Sound is the most widely distributed formation in the archipelago. It consists mainly of nonmarine quartzose sandstone and siltstone, and shale, including in some places coal seams up to several metres thick, and marine clastic sediments (West *et al.*, 1975; and references given therein). In the Sverdrup Basin, the Eureka Sound is the youngest formation in a structurally conformable succession that includes rocks as old as Early Carboniferous. The Eureka Sound occurs also as downfaulted outliers overlying unconformably: the orogenic belt that developed in lower Paleozoic rocks of the Franklinian Geosyncline; deformed lower Paleozoic rocks of the cratonic Boothia Uplift; and Precambrian and lower Paleozoic rocks of the Central Stable Region. In one part of the latter structural province, namely Banks Island, the Eureka Sound is the youngest in a conformable succession that includes rocks as old as the Lower Cretaceous Isachsen Formation (Thorsteinsson and Tozer, 1962).

With the exception of the Eureka Sound on Banks Island and throughout most parts of the Sverdrup Basin, as noted above, all other occurrences of the formation are preserved as downfaulted outliers. It is therefore reasonable to attribute the faults displacing this formation to a widespread episode of normal-fault adjustment to regional uplift that occurred in Eocene or later time.

Much of Devon Island which represents the Arctic Platform has not been geologically mapped, even by reconnaissance standards, and the stratigraphy is incompletely understood. Published accounts of the stratigraphy of Phanerozoic rocks are those of Kurtz *et al.* (1952), Fortier (1963), Glenister (1963a), Glenister and Thorsteinsson (1963), and Greiner (1963a).

For purposes of the present account, the lower Paleozoic rocks are divided into three packages, of which the lower two were affected by the impacting object. The salient features of these three packages are described below.

The lower package comprises the rocks that lie between the Precambrian crystalline rocks and the Eleanor River Formation, the basal beds of which are Early, but not earliest Ordovician in age. Much, if not all, of this package is represented in a section, 420 m thick, described by Glenister (1963b) at Sverdrup Inlet some 80 km east of the Haughton crater. The rocks are an interlayered succession of limestone, dolomite and subordinate amounts of shale and quartzose sandstone. Only the uppermost beds have yielded fossils, and these indicate an Early Ordovician age. Unfortunately none of these rocks can be correlated satisfactorily with the section that includes Lower and Middle Cambrian, and Lower Ordovician beds as established by Kurtz *et al.* (1952) on the south coast of Devon Island. This lower package is far from adequately understood.

The middle package includes: 1) About 400 m of limestone and dolomite that overlie the rocks studied by Glenister (*op. cit.*) and underlie the Bay Fiord Formation. Most, if not all, of this interval is referrable to the 1) Eleanor River Formation; 2) Bay Fiord Formation, about 330 m thick, and consisting of an upper dolomite and limestone member and a lower member of relatively pure gypsum and anhydrite; 3) Thumb Mountain Formation consisting mainly of limestone, and about 100 m thick; 4) Irene Bay Formation, made up of limestone and shale, and about 10 m thick; and 5) Allen Bay Formation, made up of limestone and dolomite, and about 900 m thick. The total thickness of this package is thus roughly 1750 m, and it ranges from Early Ordovician to Late Silurian in age.

The upper package includes the Cape Storm and Read Bay Formations. It consists largely of carbonate rocks, ranges from Late Silurian to Early Devonian in age, and has a total thickness of at least 1950 m.

The presence of numerous unsorted clasts of Precambrian metamorphic rocks in the impact breccia established the fact that basement was affected by the impacting object and, consequently, the question of the thickness of lower Paleozoic strata between the Precambrian-Paleozoic nonconformity and the stratigraphic level of the crater is one of special interest. The youngest beds in the impacted sequence are about 450 m from the top of the Allen Bay

Formation, i.e. near the top of the middle package (Figs. 2, 3). It therefore follows that the thickness of the sedimentary column affected by the impacting object in the area of the crater was about 1700 m and, in view of the fact that the platform formations on Devon Island are known to thicken to the west, this figure is probably a minimum.

Although the Haughton crater is a nearly circular depression, the rim of which has a maximum elevation of about 240 m above sea level while the lowest part lies within about 60 m of sea level, it is not a well-defined feature in the topography. This is partly because neither an upturned rim nor a bordering escarpment is preserved, and partly because the crater is in fact only the inner part of a still larger circular depression in the topography, about

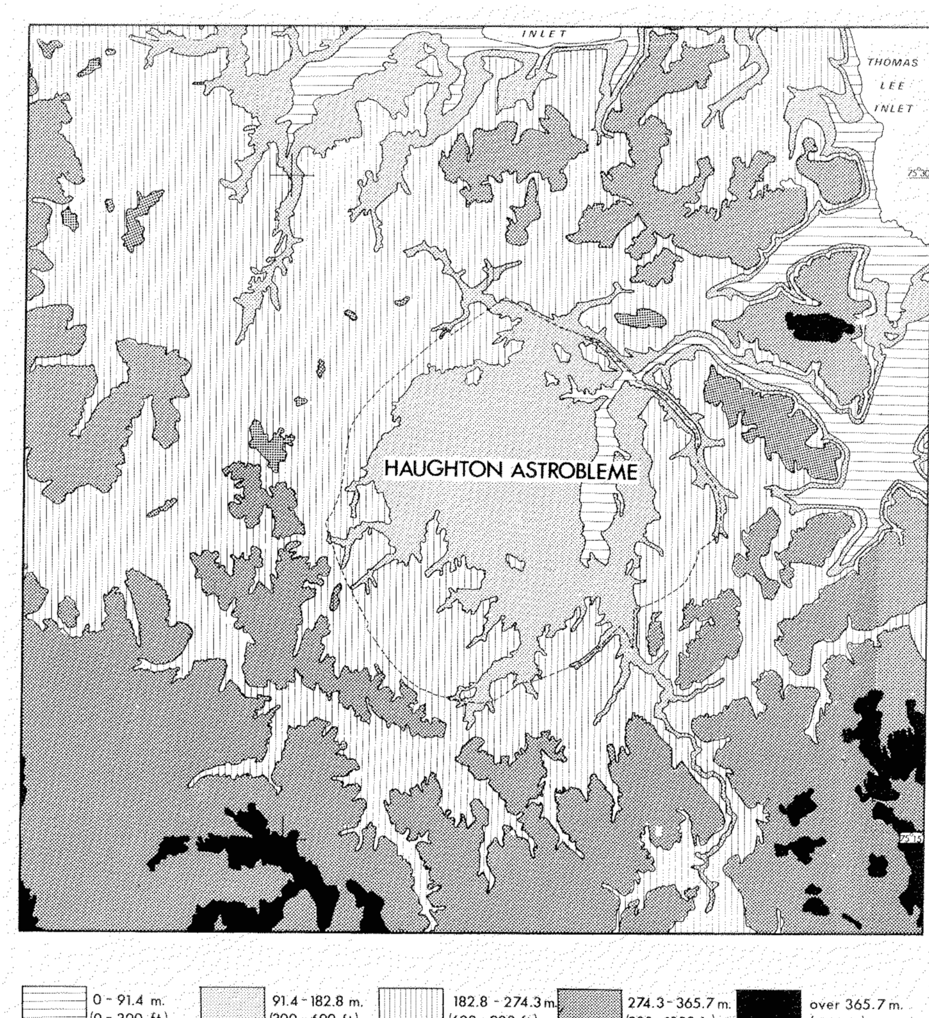

FIG. 4. Topographic map of Haughton Astrobleme designed primarily to illustrate the topographic expression of the crater and the fact that it is the inner part of a larger topographic depression. Dashed line marks outer limit of astrobleme.

24 km in diameter. This large depression is marked by a series of flat-topped upland remnants, rising to elevations of about 330 to 360 m above sea level, forming an encircling watershed, the inner side of which slopes gradually toward the centre of the crater (Fig. 4). The crater is nevertheless distinguished by detailed characteristics in the landscape. It is drained by the Haughton River that flows into Thomas Lee Inlet, and there is a close correlation between drainage and structure with the river and its tributary streams exhibiting a marked tendency to annular and radial patterns that are controlled, in large measure at least, by the faults in the lower Paleozoic rocks within the crater. Moreover, what are probably the best developed annular streams are those that follow the outermost faults that mark the rim of the crater. Also, there are noteworthy differences in the landscape that has developed on the impact breccia and that on the lower Paleozoic rocks within the crater. The breccia is a rather weakly consolidated rock of uniform composition and tends to erode to smoothly rounded hills and ridges (Fig. 5), whereas the much faulted, more resistant and less homogeneous lower Paleozoic rocks form a ridged and rugged landscape that is especially well developed in the eastern half of the crater. Nevertheless, the relatively widespread distribution of the breccia demonstrates that the original surface of the Paleozoic rocks that developed within the crater upon impact has not been lowered significantly by subsequent erosion.

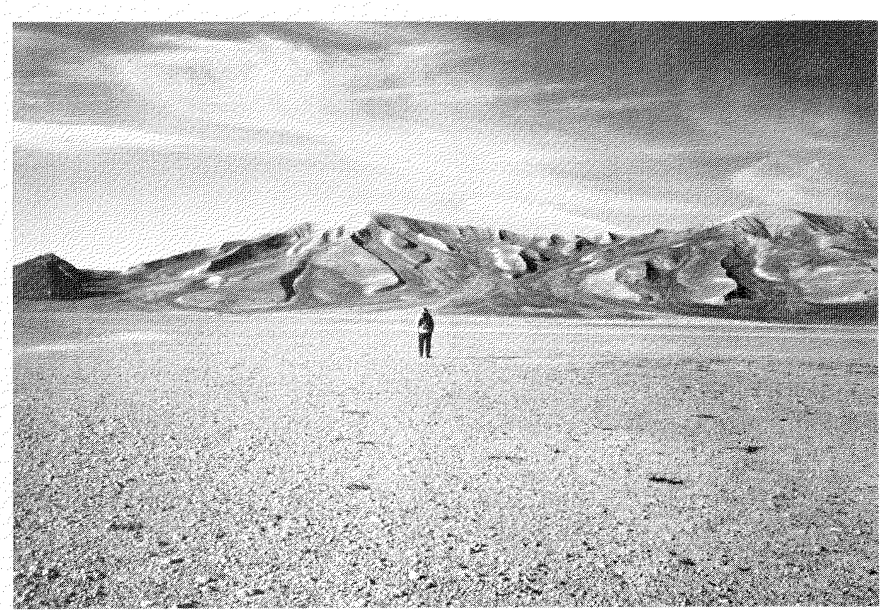

FIG. 5. Hills of impact breccia rising to elevations of about 68 m above the alluvium-filled valley on the east side of the crater (Haughton River). View is to the west. The photograph illustrates the soft-weathering characteristics of the breccia and that actual exposures of the formation are rare. The dark outcrop in the extreme left of the photograph consists of cherty limestone of the Eleanor River Formation.

STRUCTURE OF CRATER

The lower Paleozoic rocks within the crater are deformed by a series of more or less annular and radial faults, and folding appears to have been minimal. The gross structural features of the crater, as presently understood, include: a central horst area, which, though covered largely by the impact breccia, is probably about cylindrical in shape; and an outer graben area. The Eleanor River Formation is the oldest rock unit exposed in the crater where it is particularly well displayed in two rather large inliers that are more or less surrounded by breccia. The Eleanor River rocks are highly deformed and only the upper part of the formation, estimated to include about 150 m of beds, is exposed, but as such the formation is raised about 480 m above its normal stratigraphic position outside of the crater. From the central uplift to the rim of the crater are fault blocks that include more or less progressively younger Paleozoic formations. The crater is bounded by an interconnected series of annular faults, and at the outermost of these the Allen Bay Formation appears to be invariably downdropped toward the crater's centre. That the Paleozoic rocks are much more intensely faulted in the eastern half of the crater than in the western half (Fig. 2) seems to indicate that the impacting body may have entered the earth at an oblique angle.

Clearly, in terms of its overall structure and size, the Haughton crater is classifiable as a complex hypervelocity crater in the terminology of meteorite craters by Krinov (1963) and Dence (1965).

BRECCIAS

The impact breccia is distributed mainly over an area of some 56 km^2 in about the centre of the crater, and it occurs also as several small outliers between this central distributive area and the crater's rim. The breccia is made up principally of dolomite and limestone, but it includes also various other kinds of sedimentary rocks and a relatively small amount of materials from the Precambrian basement. The components range in size from the finest grains to boulders. Although clasts of Precambrian metamorphic rocks occur throughout the areal extent of the breccia, they are rare indeed outside of a limited area somewhat north and east of the crater's centre (Fig. 2) where clasts of these rocks are not only numerous but also larger (up to 3.5 m in diameter) than elsewhere in the formation. Furthermore, outside of this area all clasts are seldom larger than cobble-size. Here it is of some interest to note that on casual inspection most hand specimens of the breccia appear to consist only of very light to dark grey granules and pebbles embedded in a very light grey groundmass, and to resemble ordinary concrete (Fig. 6).

The principal weathering colour of the formation is very light grey but, as viewed from a distance, the formation exhibits a distinctive light bluish grey colour that differs markedly from the generally sombre weathering shades of grey, brown and green (parts of the upper member of the Bay Fiord Formation) that characterize the underlying Paleozoic terrane. Because of the

FIG. 6. Detail of a typical exposure of impact breccia in the valley of the Haughton River. The banded clast in the centre is a fragment of shock-metamorphosed gneiss from the Precambrian basement. Most of the other clasts and the matrix are carbonate. The lens cap has a diameter of 5 cm.

poorly consolidated nature of the breccia, outcrops are generally scarce. The best exposures occur in a series of bluffs developed along the eastern boundary of the main distributive area that overlook the alluvium-filled valley of Haughton River, particularly at about Latitude 75°19'N and Longitude 89°31'W. There also the breccia appears to attain its greatest thickness of about 90 m. The formation is notably porous, and it is crudely bedded and jointed. Shatter cones are ubiquitous and especially well displayed in some of the darker coloured limestone cobbles and boulders that were presumably derived from the Eleanor River Formation. Locally, pseudotachylite veins traverse clasts in the breccia.

Most of the sedimentary clasts are very finely granular carbonate rock of lighter and darker shades of grey than any of the lower Paleozoic rocks penetrated by the impacting body. Some of the shocked clasts in thin-section show intense microtwinning. Other clasts are carbonate breccias comprising extremely fine grained fragments surrounded by slightly coarser grained, recrystallized carbonate material. However, many carbonate clasts appear to be entirely unshocked, and at any given outcrop it is commonly possible, on the basis of lithological and/or faunal characteristics, to identify some as having been derived from one or the other rock unit that occurs between the Precambrian basement and the stratigraphic level of the crater.

Clasts of basement rock include gneisses shock-metamorphosed to varying degrees and highly altered mafic rocks presumed to be samples of diabase dykes. Terminology used here follows that of Stöffler (1971).

Many of the gneiss clasts outwardly do not appear to be particularly deformed and are readily identified as garnet gneiss, biotite gneiss and the like. In thin-section, however, unusually severe deformation is invariably evident. Garnets are cracked along myriad, closely spaced, irregularly oriented planes, sillimanite prisms show numerous transverse fractures [parallel to (010)], and biotite flakes are kinked. Quartz and feldspar are commonly fractured and partly to wholly isotropic (diaplectic glass). Birefringent grains exhibit undulose extinction, mosaicism and/or planar elements. Brown glass occurs in the interstices between grains of diaplectic quartz and feldspar glasses.

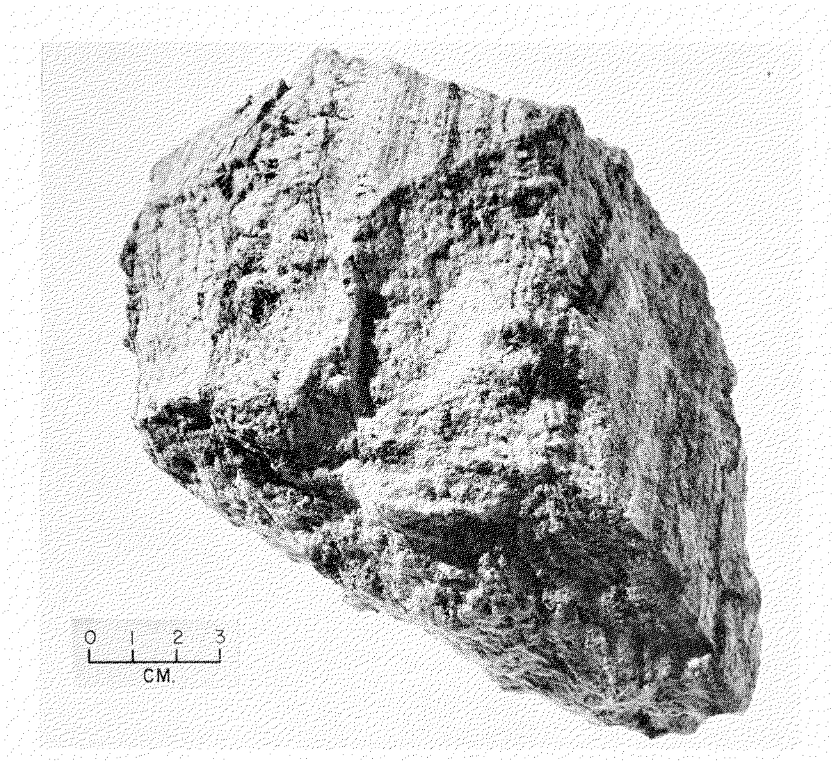

FIG. 7. Fragment of vesiculated gneiss from a large clast of highly shock-metamorphosed Precambrian basement from impact breccia in the Haughton River valley.

With increasing shock metamorphism, the gneiss clasts become more poorly banded, paler and vesicular; extreme varieties resemble pumiceous volcanic rock (Fig. 7). Thin-sections show the vesicles to be especially abundant in glass that appears to have formed from molten quartz or feldspar. This glass, in plane light, is colourless and swirls around vesicles and fragments of variably isotropic feldspar and other minerals. One sample contains two species of glass: one like the type just described but devitrified; the other grey-green in hand specimen and brown to opaque in thin-section. The latter variety forms thin lenses and veinlets containing numerous fragments of strongly shock-metamorphosed minerals - chiefly feldspar and sillimanite - finely comminuted mineral material and abundant vesicles. The opaque areas in the glass may be due to accumulated fine-grained Fe-Ti oxide derived from the oxidation of biotite (Stöffler, 1972). The coloured glass in this and other samples may possibly be quenched rock melt.

Coesite has been identified in a vesicular gneiss comprising isotropic quartz, feldspar and glass with minor sillimanite. The sample was ground and then treated by a modification of the chemical method described by Lehtinen (1976). X-ray diffraction patterns obtained from the quartzose residue remaining after solution show clearly diagnostic lines for coesite at 3.09 Å and 3.43 Å. Coesite has not been positively identified by optical means.

The breccia matrix consists predominantly of loosely bound, granular carbonate rock studded with angular fragments of basement rocks and minerals, of which the most common are feldspar and quartz with planar elements.

Certain phenomena observable in the basement clasts are indicative of various degrees of shock metamorphism as defined by Stöffler (1974), who used the Ries structure in Germany as a model. Of Stöffler's five stages of shock metamorphism, stage III is the highest for which we have evidence: feldspar or quartz glass with vesicles and flow structure, and porous or pumiceous texture of clasts. Stöffler (1974) estimates peak pressure and post-shock temperature in stage III at Ries to have approximated 450 kb and 900°C. According to Stöffler, coesite in Ries is typical of stage II. More common features such as planar features in quartz and feldspar and diaplectic glass pseudomorphs of quartz and feldspar characterize stages I ($\simeq$100 kbar and $\simeq$ 100°C) and II ($\simeq$350 kbar and $\simeq$300°C), respectively.

Monomict breccias consisting of fragments of individual formations occur at various places in the crater where they tend to form resistant and conspicuous outcrops in the landscape. In some places such breccias may be observed to intergrade with normally bedded outcrops.

SEDIMENTARY FILL

The unnamed formation of lake sediments is of special interest, particularly insofar as it provides an upper age limit to the impacting event. The maximum thickness is about 60 m with the present-day erosion surface marking the top of the formation. It is composed mainly of dolomite silt, lesser amounts of fine-grained dolomite sand, and a small admixture of calcite and quartz particles. It is thinly and evenly bedded, and varies in colour from very light grey to pale yellowish brown. It is unconsolidated except for a few concretionary layers, up to 10 cm thick, consisting of medium light grey limestone in stratigraphically lower parts of the formation, and dusky red dolomitic sandstone and dusky red ironstone in upper parts. A dolomite terrane appears to have been the dominant source of these beds.

The formation has yielded two microfloras, one of which occurs in a bed of concretionary limestone about 30 m stratigraphically above the basal contact

(GSC loc. C-63570), the other, in a red concretionary layer of dolomitic sandstone some 9 m stratigraphically higher. The microfloras are listed below:

GSC locality C-63570; UTM Zone 16, 8370150N, 420800E.
Alnus sp. (4, 5 and 6 pored, common)
Acer sp. (2 specimens)
Gramineae (?) pollen (2 specimens)
polyporate pollen (1 specimen)
Corylus (common)
?Castanea (1 specimen)
tricolpate pollen (scarce)
Lycopodiumsporites (common)
Sphagnum sp. (common)
Ericaceae pollen (scarce)
Laevigatosporites sp. (scarce)
Paraalnipollenites alterniporus (Simpson) Srivastava, 1975 (1 specimen)
Orbiculapollis globosus Chlonova, 1961 (1 specimen)
Tilia sp. (1 specimen)
Engelhardtia sp. (1 specimen)
dinoflagellates (5 specimens)

GSC locality C-63571; UTM Zone 16, 8369300N, 420750E.
Gramineae (?) pollen (1 specimen)
Corylus sp. (3 specimens)
Alnus sp. (4 specimens)
Engelhardtia sp. (1 specimen)
Lycopodiumsporites sp.
Sphagnum sp.
dinoflagellates (5 specimens)

The identifications are mainly by A. R. Sweet who comments as follows:

"The population appears to include three or more discrete assemblages. Ten specimens of dinoflagellates were observed, and these were identified by W. W. Brideaux as belonging to *Chatangiella* sp., *Exochosphaeridium* sp., and *Hystrichosphaeridium* sp., and interpreted as indicating a Late Cretaceous Santonian-Campanian age. *Paraalnipollenites* and *Orbiculapollis* possibly represent a Maastrichtian component as the former ranges in age from Maastrichtian to Paleocene, while the latter is restricted to the Cretaceous. *Engelhardtia* sp. and *Tilia* sp., on the other hand, are most indicative of an Eocene age.

Whether one accepts an Eocene age for the sample or a younger age is dependent upon the acceptance of the three specimens of probable Gramineae pollen as significant. According to Leopold (1969) pollen referable to the Gramineae is not known to occur in pre-late Eocene strata. However, in Alaska it is not known in rocks older than late Miocene-early Pliocene (Leopold, 1969, Table 67-6); it was reported by Martin and Rouse (1966) from late Miocene-early Pliocene strata of the Queen Charlotte Islands, but not by

Piel (1971) nor by Hopkins and Sweet (1976) from Oligocene-Eocene strata of British Columbia. Hence the presence of Gramineae pollen would suggest a maximum Miocene or late Miocene age for the present samples. The weakness in applying the above arguments in dating the samples is the uncertainty that surrounds the identification of the Gramineae pollen due to an apparent lack of a prominent annulus. In all other respects the morphological characteristics of the grains conform to Gramineae pollen. Nevertheless the age conclusions based on these grains should be treated with caution.

In Alaska, *Acer* (maple) pollen ranges into the lower Pliocene but not higher (Leopold, 1969, Table 17-6). Therefore the assumption that *Acer* is indigenous to the present flora argues for a pre-Pleistocene age.

In conclusion it appears that: 1) the assemblage contains reworked components of Late Cretaceous age; 2) the indigenous flora is not older than Eocene on the basis of *Tilia,* and not younger than Pliocene on the basis of *Acer;* and 3) the presence of Gramineae-like pollen might with some reservation be taken to suggest a post-Oligocene age."

The formation has yielded freshwater ostracodes including the genera *Candona, Pseudocandona,* and possibly *Cytherissa* (GSC loc. C-63569; UTM Zone 16; 420750E, 8369500N). The identifications are by L. D. Delorme, according to whom the species represented are probably new, and not known to occur in Pleistocene or Holocene sediments in North America; and furthermore, because of the similarities of shape and valve overlap, the specimens are similar to fossils found in endemic lakes of pre-Pleistocene or possibly even pre-Pliocene age (see Bronstein, 1939).

AGE OF IMPACTING EVENT

It is certain that the Haughton crater is younger than about the lower half of the Allen Bay Formation — the age range of the entire formation is Late Ordovician to Late Silurian — and older than the Tertiary lake sediments. There are, however, reasons, none of which is conclusive, to suggest that the crater may be younger than the entire succession of lower Paleozoic rocks that crop out between the longitude of the crater and the west coast of the island, and that it is also younger than the peneplanation represented by the present-day plateau surface.

The lower Paleozoic rocks situtated west of the crater include, in upward stratigraphic sequence: the upper half or so of the Allen Bay Formation which includes about 450 m of strata; the Upper Silurian Cape Storm Formation, about 580 m thick; and the Read Bay Formation which ranges from Late Silurian to Early Devonian in age, and is about 1370 m thick. On the basis of the regional distribution of these formations, there can be little or no doubt that these rock units were originally distributed to the east, to and beyond the site of the crater. The fact that no clasts in the impact breccia have been identified as belonging to any of these formations is convincing evidence that they had been stripped back to about their present outcrop positions by one or more episodes of peneplanation before the time of impact. Other arguments tend to support this conclusion. The overall structure of the crater, including its diameter-to-depth ratio and the widespread distribution of the impact breccia, comprises characteristics most comparable to those of other moderate-sized impact craters on earth that have undergone rather modest amounts of erosion. It is therefore virtually impossible to envisage the crater as an erosional remnant of what originally extended upward through all, or any significant part, of the column of strata totalling some 2400 m in thickness that occurs between the crater and the west coast. Moreover, and for the same reasons, it would appear that the point of impact was probably coincident with a land surface now indicated by the summit levels of the plateau remnants (330-360 m; Fig. 4) of the larger topographic depression of which the crater is but a part, and that the difference between the elevation of these summit levels and the rim of the crater (about 90-120 m) is more or less the result of erosion that has occurred since the impacting event.

With regard to the age of peneplanation that produced the Devon Island Plateau, it is necessary to consider whether the plateau represents an exhumed erosional surface that was coincident with the base of the Eureka Sound Formation before the episode of normal faulting, in which case it would not be possible to determine whether the crater was older or younger than the formation, or whether the plateau represents a peneplanation that occurred after the downfaulting of the Eureka Sound, and is therefore Eocene or younger in age. Two circumstances support the latter alternative: some of the faults on Devon Island have a stratigraphic displacement of several tens of metres and yet nowhere is the Eureka Sound preserved except in downfaulted situations; and nowhere is there evidence of differences in elevations (i.e. fault scarps) on the plateau surface across the traces of faults such as might be expected in the case of a stripped erosional surface.

Of further relevance in attempting to assess the age of the crater is the fact that there is nothing in the impact breccia that resembles the sediments of the Eureka Sound Formation, and the fact, noted earlier, that the lake sediments were derived from dominantly dolomitic rocks. Presumably, therefore, the Eureka Sound beds had been stripped from the crater area at the time of impact.

All of the foregoing lines of evidence leave little doubt that the impact took place not only after the deposition of the Eureka Sound Formation (i.e. Eocene or later), but also after the development of the present-day peneplain. Furthermore, an upper age limit for the time of impact is provided by the lake beds which, as already documented, are Miocene, or possibly Pliocene in age.

In summary, it appears reasonable to assume that the age of the lake sediments within the crater indicates also the approximate time of impact. In this regard it is of interest to note that two other impact structures, the much studied Ries crater and the Steinheim basin of West Germany, are dated as Miocene (*see* von Engelhardt, 1972; and references given therein).

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REFERENCES

BRONSTEIN, Z. S. 1939. On the origin of the ostracoda fauna of Lake Baikal; Comptes Rendus (Doklady) Academie des Sciences, l'URSS, 25, (4): 333-337.

DENCE, M.R. 1965. The extraterrestrial origin of Canadian craters; Annals New York Academy of Sciences, 123: 941-969.

——, 1972. The nature and significance of terrestrial impact structures; XXIV International Geological Congress Proceedings, Section 15: 77-89.

FORTIER, Y. O. 1963. South arm of Viks Fiord; *in* Geological Survey of Canada, Memoir 320: 219-221.

GLENISTER, B. F. 1963a. Burnett Inlet; *in* Geological Survey of Canada, Memoir 320: 179-184.

——, 1963b. Sverdrup Inlet to Cape Sparbo; *in* Geological Survey of Canada, Memoir 320: 184-189.

GLENISTER, B. F. and THORSTEINSSON, R. 1963. Herschel Bay and Rigby Bay; *in* Geological Survey of Canada, Memoir 320: 195-201.

GREINER, H. R. 1963a. Vicinity of Beechy Island to Radstock Bay; *in* Geological Survey of Canada, Memoir 320: 201-207.

——, 1963b. Haughton Dome and area southwest of Thomas Lee Inlet; *in* Geological Survey of Canada, Memoir 320: 208-216.

——, 1963c. Boat Point; *in* Geological Survey of Canada, Memoir 320: 216-219.

HOPKINS, W. S. and SWEET, A. R. 1976. A microflora from a short section of the Paleogene Kishenehn Formation, southeastern British Columbia; Geological Survey of Canada, Paper 76-1B: 307-309.

KRINOV, E. L. 1963. Meteorite craters on the Earth's surface; *in* The Solar System, the moon, meteorites and comets, Middlehurst, B. M. and Kuiper, G. P., eds.; University of Chicago Press, Chicago, 183-207.

KURTZ, V. E., McNAIR, A. H. and WALES, D. B. 1952. Stratigraphy of Dundas Harbour area, Devon Island, Arctic Archipelago; American Journal of Science, 250: 636-655.

LEHTINEN, M. 1976. Lake Lappajärvi, a meteorite impact site in western Finland; Geological Survey of Finland, Bulletin 282.

LEOPOLD, E.B. 1969. Late Cenozoic palynology; *in* Aspects of Palynology, Tschudy, R. H. and Scott, R. A., eds.; John Wiley and Sons, Inc., New York: 377-438.

MARTIN, H. A. and ROUSE, G. E. 1966. Palynology of late Tertiary sediments from Queen Charlotte Islands, British Columbia; Canadian Journal of Botany, 44: 171-208.

PIEL, K. M. 1971. Palynology of Oligocene sediments from central British Columbia; Canadian Journal of Botany, 49: 1885-1920.

ROBERTSON, P. B. and MASON, G. D. 1975. Shatter cones from Haughton Dome, Devon Island, Canada; Nature, 255 (5507): 393-394.

STÖFFLER, D. 1971. Progressive metamorphism and classification of shocked and brecciated crystalline rocks at impact craters; Journal of Geophysical Research, 76: 5541-5551.

——, 1972. Deformation and transformation of rock-forming minerals by natural and experimental shock processes. I. Behavior of minerals under shock compression; Fortschritte der Mineralogie, 49: 50-113.

——, 1974. Excursion B4: Ries meteorite crater, Germany. II. Crater mechanics, impact metamorphism and distribution of ejected masses of the Ries structure - an introduction; Fortschritte der Mineralogie, 52: 109-122.

THORSTEINSSON, R. and TOZER, E. T. 1962. Banks, Victoria and Stefansson Islands, Arctic Archipelago; Geological Survey of Canada, Memoir 330: 1-85.

VON ENGELHARDT, W. 1972. Impact structures of Europe; XXIV International Geological Congress, Proceedings, Section 15: 90-111.

WEST, R. M., DAWSON, M. R., HUTCHISON, J. H., and RAMAEKERS, PAUL. 1975. Paleontologic evidence of marine sediments in the Eureka Sound Formation of Ellesmere island, Arctic Archipelago, N.W.T., Canadian Journal of Earth Sciences, 12, (4): 574-579.