DEPARTMENT OF MINERALS AND ENERGY
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN 159

Cymbric Vale Fauna of New South Wales
and
Early Cambrian Biostratigraphy

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AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA 1975

CORRIGENDA

Page 8, line 4 of caption to Figure 3

In place of *Somniurna adjusta* read *Somniurna adusta*

In place of *Myopsolenites* read *Myopsolenus*

Page 37, last line

In place of *Yorkella australia* read *Yorkella australis*

Page 43, line 4

In place of *p. ??* read *p. 8*

Page 43, line 26

In place of *Crossocharda* read *Crossochorda*

Page 43, 4 lines from bottom

In place of *(see below, p. ??)* read *(see below, p. 58)*

Page 74, 3 places

In place of *ZHURAVLEVA, J. T.* read *ZHURAVLEVA, I. T.*

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Published for the Bureau of Mineral Resources, Geology and Geophysics by the Australian Government Publishing Service

ISBN 0 642 01809 X

MANUSCRIPT RECEIVED: AUGUST 1973
REVISED MANUSCRIPT RECEIVED: JUNE 1974
ISSUED: DECEMBER 1975

Printed by Graphic Services Pty Ltd, 86a Pirie Street, Adelaide 5000

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SUMMARY

PART I

The Cymbric Vale Formation and its fauna occur in two isolated enclaves in the Mootwingee Ranges, about 120 km northeast of Broken Hill. In the same area in isolated outcrops fossiliferous strata of Ordian, followed by Middle Cambrian, Mindyallan, late Late Cambrian, and Early Ordovician ages are present. The Cymbric Vale strata rest above volcanics and limestones with archaeocyathids.

Trilobites are common in the Cymbric Vale fauna; Eodiscina and polymerids are present. Blind Eodiscina are *Serrodiscus daedalus* sp. nov. and *Meniscuchus* gen. nov., of two new species, and *Pagetia* sp. indet. Polymerids are represented by Ellipsocephalacea—*Strenax* and *Sematiscus,* new genera; a *Dinesus* and fragments of a *Redlichia;* and most abundant, *Estaingia bilobata* Pocock, previously described from the Emu Bay Shale, South Australia. Notable are *Scenella reticulata* Billings, a mollusc previously known from the American Atlantic coast province, and the brachiopod *Botsfordia* cf. *celata.* The fauna indicates the 'Upper *Olenellus* Zone', and its Eodiscina recall Taconic faunules of the State of New York.

The new genera of the suborder Eodiscina (*Meniscuchus,* blind and with a pygidial cuff; and *Discomesites,* oculate) are placed in different families, the first in Weymouthiidae (a revived name) and the second in Eodiscidae (replacing the junior synonym Pagetiidae); Calodiscidae, as a third family, is also accepted.

The presence and absence of eyes are not taken as characters above generic rank; the proposed system of the Eodiscina is based in the first place on pygidial structures; its tabular presentation supplements the earlier published classification of the suborder Agnostina and completes the classification of the Order Miomera.

In a supplement, two trilobites (*Bigotina tina* sp. nov. and *Dolerolenus?* sp. nov.) from South Australia are described and their stratigraphic significance discussed.

PART II

The published record (*in* Rodgers, ed., 1956) of the fossiliferous Lower Cambrian in Australia is reviewed and amplified in respect of later discoveries in the Northern Territory and Queensland; the Camooweal Dolomite is placed on fossil evidence in the Ordian; the Mount Birnie Beds of Queensland are regarded as low in the Epoch; the Ngalia Beds in the Northern Territory contain, among other fossils, Pennatulacea.

In the Amadeus Basin the upper part of the Arumbera Sandstone is Lower Cambrian and the lower possibly Upper Proterozoic. The Todd River Dolomite contains archaeocyathids. The fossils from these and some other finds are undescribed. In the Eastern MacDonnell Ranges the Mopunga Group possibly straddles the Precambrian/Cambrian boundary: the Elyuah Formation is possibly contemporaneous with the Central Mount Stuart Beds of the Barrow Creek area; the Grant Bluff Formation may represent the earliest part of the Lower Cambrian on the evidence of a find of *Helcionella* from the Barrow Creek area; the Mount Baldwin Formation contains undescribed archaeocyathids, brachiopods, and a trilobite, possibly *Bigotina.*

In the literature the Lower Cambrian in Australia is presented in terms of rock units; there is no biostratigraphic scale based on described fossils; published correlations refer to Siberian archaeocyathid stratigraphy, which is not quite applicable in Australia. Also the Russian concept of (what should be) the Lower Cambrian is rather large. An upper boundary for the Olenellian Epoch in Siberia is therefore proposed in this paper as a result of a survey of published global and Siberian data.

From published sources it appears that the earliest trilobite genera in South Australia are *Bigotina, Dolerolenus, Eoredlichia,* and *Wutingaspis,* which indicate a rather early date within the Early Cambrian. Walter (1967) indicated that even older trilobites are present and that the earliest Archaeocyatha in the South Australian Hawker Group indicate a correlation with a part of the Siberian basal Tommot *yarus* ('the pre-trilobite beds'). Russian authors favour a much younger age, which, however, is erroneous; if accepted, the Cymbric Vale fauna should be lifted up and out of the Olenellian altogether.

In the Early Cambrian of South Australia a provisional biostratigraphic operational unit distinguished by the trilobite family Emuellidae Pocock includes also the Cymbric Vale

fauna, as concluded from the presence in it of *Estaingia bilobata,* originally described from Kangaroo Island. The correlation involves the Emu Bay Shale fauna (Daily's assemblage 12) and the fauna of the early part of the Billy Creek Formation in the Flinders Ranges. In the Cymbric Vale area the Mount Wright volcanics contain archaeocyathid limestone lenses possibly referable to a part of the Parara Limestone sequence of South Australia.

On the Fleurieu Peninsula in South Australia the beginning of the Early Cambrian and local sedimentation is taken as the advent of *Hyolithes* and associated (undescribed) fauna within the Mount Terrible Formation; the sedimentation of the whole formation begins, however, at a paraconformity which is tangible, leaving open the age of the formation below *Hyolithes.* In the Flinders Ranges a hiatus separates the Lower Cambrian strata from the Pound Quartzite of a late Proterozoic age.

Biostratigraphically, the top of the Lower Cambrian is incomplete, as seen on the Yorke Peninsula and in the Flinders Ranges; the sediments above the Early Cambrian fossils (Emuellidae) are unfossiliferous and are followed by an Ordian fauna. The situation is similar between the Early Cambrian and the Ordian in central Australia.

The base of the Cambrian is the base of the scale division of that name; downward extensions of usage of the name are referable to Eometazoic Time. A tangible base of the Early Cambrian refers to the presence of fossils assigned to, and interpreted as, the earliest by trial-and-error; the base in the Geological Scale marks an interval of transition in terms of biostratigraphy of a relatively short but indeterminable duration. As regards Australia, the chart by Noakes (1956) is briefly discussed and modifications and amplifications are indicated; the line separating the Cambrian and the Precambrian in his model is constructed by a general extrapolation and, in particular columns, by interpolation; hiatuses and unconformities are dominant; the continuity at the turn of the Eras in the Arumbera Sandstone, Mount Terrible Formation, and Mopunga Group remains a challenging problem.

The current status of Russian stratigraphic classification, terminology, and nomenclature of the Lower Cambrian is reviewed briefly; owing to linguistic and philosophical peculiarities of Russian procedures, translation and interpretation of terms remain inaccurate. All names are geographic and adjectival: the same name stands for a rock unit, a time and time-rock unit, and a fossil complex; the formal classification into different categories is unacceptable. *Gorizonts* are regional operational subsidiary planar units alien to the geology of the western world. Stratigraphic schemata are subjected to modification, collated, approved as standards by authorities, and subsequently modified again to account for new information.

Siberian stratigraphic charts of the Early Cambrian and the concepts of *yaruses* (stages) and their subdivisions as published from 1960 on are viewed and commented upon, especially regarding the change from the two-*yarus* division (Aldan and Lena) to the threefold division into Aldan, Botoma, and Lena by Repina et al. (1964, 1965). This new scheme is incorporated in our stratigraphic chart and amplified in respect of the position of the novel *Tommot yarus* of Rozanov. The discussion refers also to the various usages of the names Aldan, Zhura, and Tolba.

The names *Olenellus* zone and Georgian (Epoch) occur once each in the literature of Siberia, in correlations, but otherwise are not employed. The ceiling of the Olenellian Epoch is, however, recognizable as halving the *Botoma yarus* and referring to the occurrence of the Olenellidae *Judomia, Judomiella,* and *Sinskia.* It appears also that species of *Judomia* have been described under the genus *Olenellus* from the American Arctic and California; *Paedeumias* and Fallotaspidinae occur in the Atdaban, suggesting a faunal and palaeogeographic connexion with the Pacific American, rather than the Atlantic and North European *Holmia* province. It is concluded from recent literature that the genera *Holmia* and *Wanneria* share the stratigraphic range of *Olenellus.*

Remarks follow regarding the Early Cambrian of Estonia, its current stratigraphic nomenclature, and the regional distribution of *Platysolenites.* Early Cambrian sea pens (Gorgonacea) different from the Ediacara forms are mentioned from Vermont, the Blue Clay of Estonia, and Central Australia.

The *Tommot yarus* stands as a biostratigraphic subdivision of the Early Cambrian of Siberia on the basis of the low position indicated by its fossils. The lack of trilobites in that fauna, however, cannot be taken as evidence that pretrilobite time ended at the onset of the Early Cambrian and is of doubtful value in stratigraphy. Once it was considered as the characteristic of the Etcheminian, causing later erroneous correlations. In sections remote from each other the top of the *Tommot yarus* is drawn between 2 and 20 m below the 'first trilobite'. Some 30 genera of trilobites have been described from strata above the 'pretrilobite beds'; several well known families are represented; their advent is believed to be evidence of a simultaneous and general mass scleritization. The exoskeletal organization, however, indicates that the mechanics for their articulation should have been present in the soft bodies of their predecessors. Before scleritization the trilobites should have possessed at the same time, or acquired, the endocrinal apparatus for moulting. Trilobites were 'soft-body' animals producing and dismantling periodically their external skeletons, and not simply skeletal, as animals possessing a single and permanent skeleton. All known trilobites were 'phanerotrilobites' as opposed to 'cryptogenics'—never observed but postulated by phyletic reasoning. The absence of trilobites in the 'pretrilobite' *Tommot gorizont* is the result of environmental barriers that prevented their earlier advent.

Evaporitic conditions prevailed in the Early Cambrian Siberian sea; the pre-Tommotian Tolba and Yudoma sequences consist of dolomite precipitated in conditions inimical to life; limestone deposition, combined with dolomite, began in Tommotian time and marine life entered the region; trilobites that live elsewhere arrived soon after, in the early Atdaban, and populated areas within reach of normal marine conditions. Shallow evaporitic lagoons remained as salt-generating environments; and extended banks in euphotic waters of various degrees of salinity were populated by animals and algae; the Archaeocyatha dwelt on the sea floors and remained confined to the photosynthetic environment; also, the structural and functional morphology of their skeletons is algal as in the Dasycladacea; hence, the Archaeocyatha are regarded as a class of the phylum Chlorophyta.

The limestone with archaeocyathids and *Tommotia* at Mount Wright, already described in Part I, is by its position in the sequence older than the Cymbric Vale Formation; in biostratigraphic terms, however, its position is still inconclusive: the volcanics of the Mount Wright Formation and the igneous material in the Billy Creek sediments could represent the same episode of magmatic activity; hence the limestone, of a pre-Billy Creek age, cannot be younger than the Oraparinna Shale archaeocyathids; it may be of Oraparinna age or correspond to a not yet definable part of the Parara, or of any other limestone of the Hawker Group.

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PART 1: PALAEONTOLOGY

INTRODUCTION

Preliminary information regarding the occurrence of an Early Cambrian fauna in New South Wales has been published earlier (Öpik, 1968); the full report was, however, delayed until the map of the Broken Hill area compiled by G. Rose (1st edn, 1970) provided published geological data. The systematics of the suborder Eodiscina (also represented in the Cymbric Vale Fauna) are revised, completing the revision of the trilobite order Miomera, the first part of which was published earlier (Öpik, 1967). The biostratigraphy of the Lower Cambrian is reviewed so as to place the Cymbric Vale fauna within the scale of that Epoch. The described fossils and the rest of the collection are kept in the Bureau of Mineral Resources, Geology and Geophysics, Canberra.

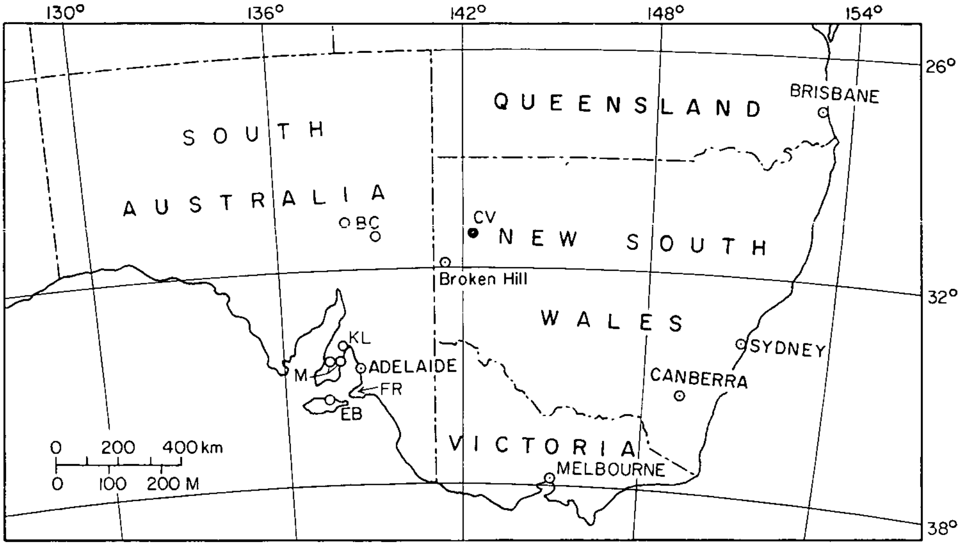

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Fig. 1. Positions of sites with Lower Cambrian and Ordian fossils discussed here. BC—Billy Creek and Wirrealpa sites in the Flinders Ranges; CV—Cymbric Vale and Mount Wright, New South Wales (detail in Text-fig. 2); EB—Emu Bay on Kangaroo Island; FR—Fleurieu Peninsula; KL—Kulpara, Yorke Peninsula; M—Minlaton Bore and Curramulka, Yorke Peninsula.

THE GEOGRAPHIC OCCURRENCE OF THE CYMBRIC VALE FORMATION AND FOSSILS

Geography and outcrops

The location of the Cymbric Vale Formation is shown on the map of the Broken Hill Sheet, compiled by Rose (1970); the outcrops are about 110 km northeast from the town of Broken Hill in the far west of New South Wales. Öpik (1968, p. 146) described the location as 'at Mount Wright in the Mootwingee Range area' about lat. 31°12'S, long. 142°20'E. Two outcrops of the Cymbric Vale Formation are known so far; they are referred to below as site A and site B (Fig. 2).

Site A lies about 7 km west of Mount Wright and is a small enclave in Lower Ordovician sandstone. Site B refers to outcrops adjacent to the fault line at Mount Wright, and is the larger; the northern area of B, some 7 km from Mount Wright, is the source of the assemblage of *Strenax cerastes*.

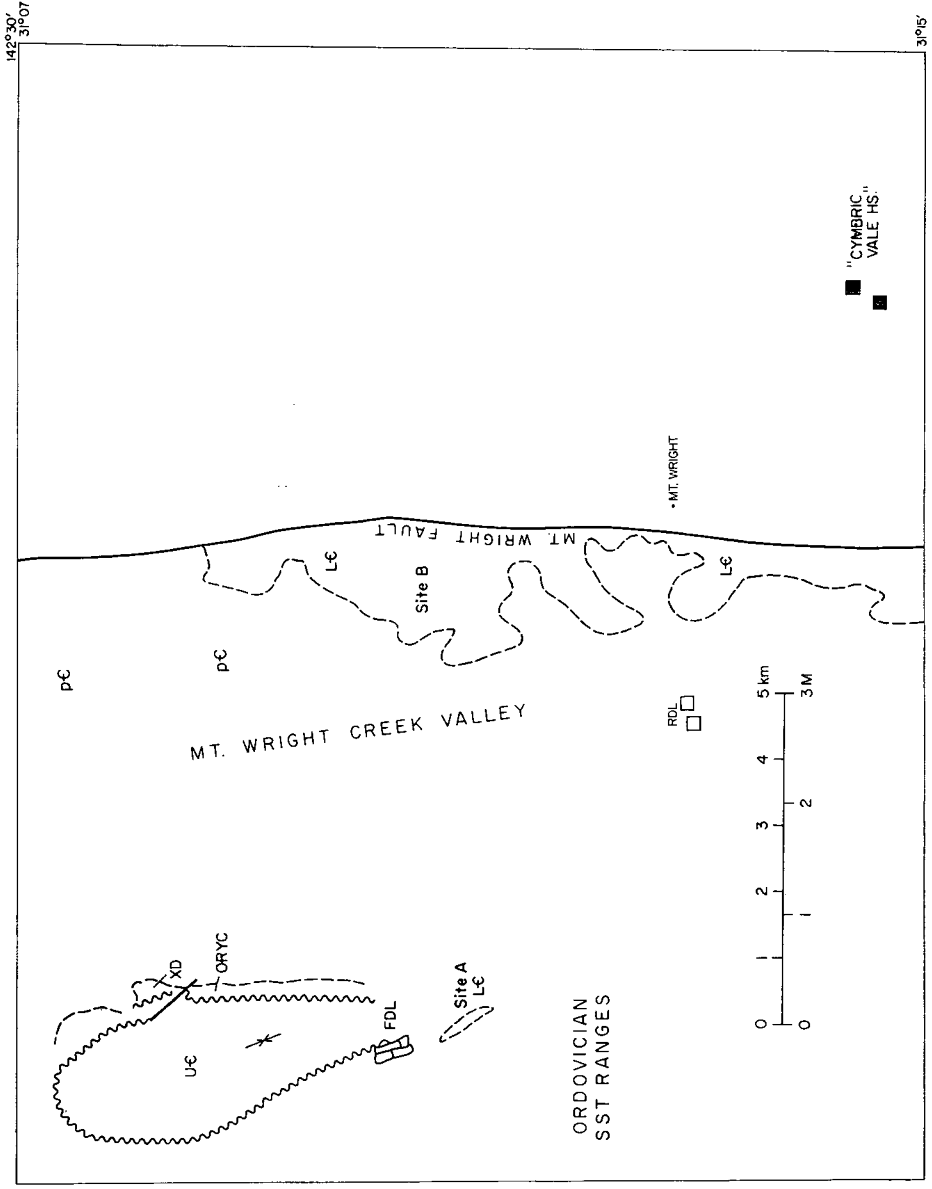

Fig. 2. Cymbric Vale/Mount Wright area (CV in Text-fig. 1). Site A—the enclave of fossiliferous Lower Cambrian (Cymbric Vale Formation); Site B—Cymbric Vale Formation and Mount Wright Volcanics; RDL—*Redlichia petita* shale at Mount Wright Tanks; FDL—First Discovery Limestone; XD—*Xystridura* and *Pagetia* in limestone; ORYC—shale with Oryctocephalidae and Agnostacea; UC—Upper Cambrian, syncline and unconformity.

At site A about 6 m of a grey, hard, and apparently tuffaceous siltstone (a fine-grained sandstone) can be seen, green with glauconite in its lower (larger) part; within site B (Packham, 1969, p. 67), limestone with archaeocyathids, unfossiliferous dolomite, shales and cherts, and volcanics (including tuff) are present. These are the Mount Wright Volcanics (Rose, 1970), lying below the Cymbric Vale Formation.

In reference to the Geological Map of New South Wales (1962) the outcrops of the Cymbric Vale Formation are part of the Mootwingee Ranges—a train of outcrops of lower Palaeozoic strata extending east-southeast from Mount Arrowsmith in the north (Wopfner, 1967) to the Darling River over a distance of some 200 km. Represented are fossiliferous Lower Cambrian, Ordian, Templetonian, late Upper Cambrian, and Lower Ordovician deposits (Fletcher, 1961; Öpik, 1968); and north of Mount Wright, at the Koonanberry fault, late Middle Cambrian is represented by fossils in a black limestone—a collection given to me several years ago by Dr B. Daily; and, finally, in a letter of 25 June 1965, I dated for Mr G. Rose (Geological Survey of New South Wales) a collection from Kayrunnera as Mindyallan (Öpik, 1966, p. 11). In this place, some 55 km north from Mount Wright, at the western edge of the Whitecliffs area (Rose et al., 1964), in an isolated small site, a limestone contains *Agnostoglossa, Palaeodotes, Blackwelderia, Ascionepea, Aulacodigma* and *Meteoraspis*—a fauna already described from Queensland (Öpik, 1967).

Composition of the fauna

In the list of fossils below, the letters A and B designate the collecting sites; the letters in parenthesis indicate material too fragmentary for description. The collection from site A is representative of that site; collection B is a pilot collection (courtesy Messrs Lavers and Jones; *vide* Öpik, 1968a, p. 147) only; more and better preserved fossils can be expected. A piece (CPC 13151, site B) of an indurated impure and siliceous rock irregular in shape, 7 x 9 cm, exhibits on its surface the following silicified fossils: *Discomesites lunatulus*, cranidia and pygidia; *Dinesus* aff. *granulosus*—segments of thorax and a free cheek; *Strenax cerastes*—cranidia and free cheeks; '?*Helcionella*'—fragments of two forms, one with cancellate ornament; *Hyolithes;* plates of Eocrinoidea.

Serrodiscus daedalus sp. nov.	A	—
Meniscuchus menetus gen. nov., sp. nov.	A	—
Discomesites fragum gen. nov., sp. nov.	A	—
Discomesites lunatulus sp. nov.	A	B
Pagetia sp. indet.	—	B
Strenax cerastes gen. nov., sp. nov.	(A)	B
Sematiscus fletcheri gen. nov., sp. nov.	A	—
Estaingia bilobata Pocock	A	(B)
Dinesus aff. *granulosus* (Lermontova)	A	(B)
Redlichia sp. indet.	(A)	—
Scenella reticulata Billings	A	—
Scenella aff. *antiqua* Kiaer	A	—
Neobolus sp. indet.	A	—
Botsfordia cf. *caelata* (Hall)	A	—
Lingulella sp. indet.	(A)	—
Helcionella' indet. (? two forms)	(A)	(B)
Hyolithes sp. indet.	(A)	(B)
Eocrinoidea	(A)	(B)
Spongia (spicules) indet.	A	—

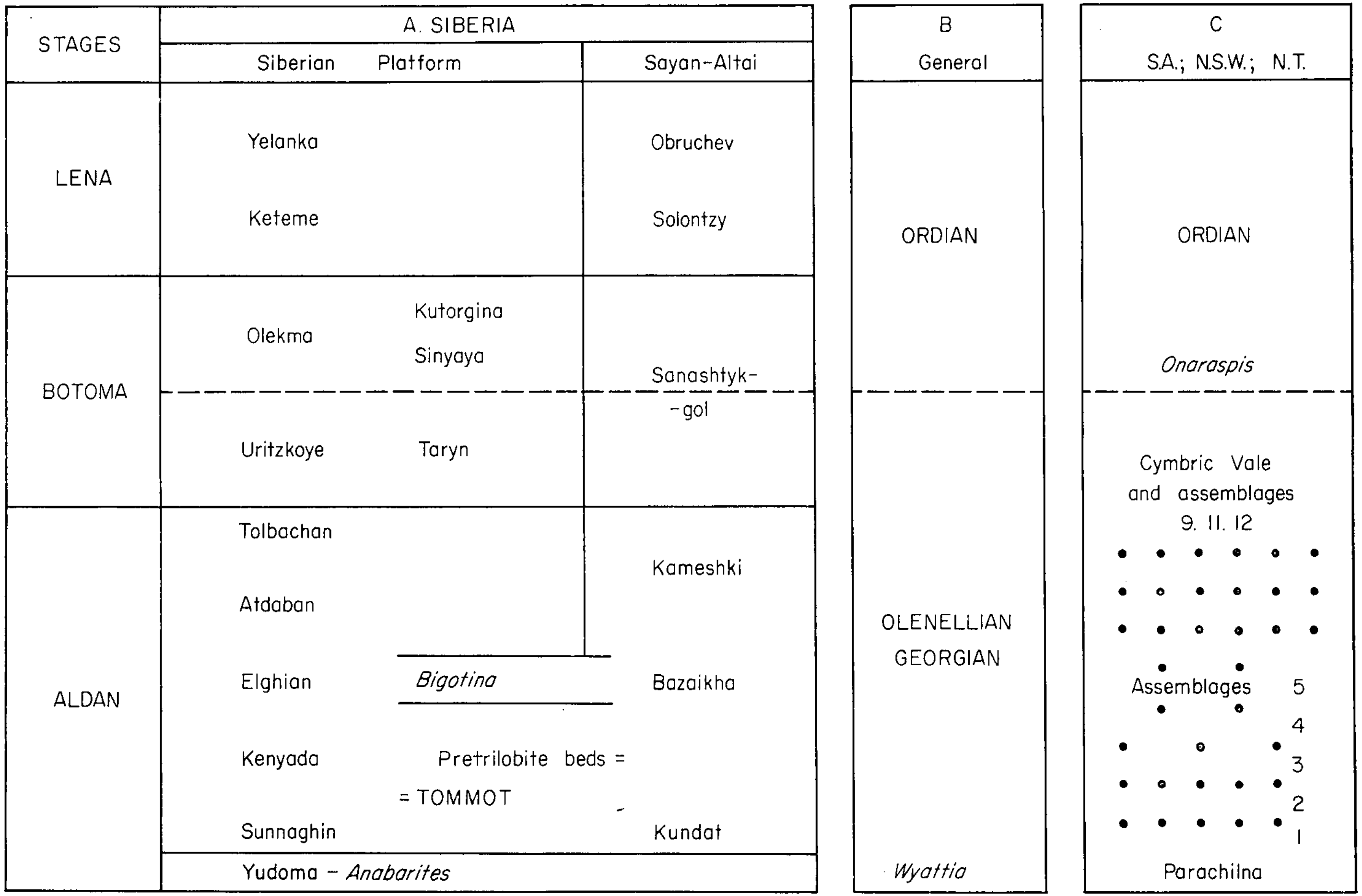

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Fig. 3. Correlation chart. (A)—Leno-Aldanian Lower Cambrian in Siberia; (B)—Olenellian-Georgian Lower Cambrian in relation to Ordian; (C)—position of Ordian, and Cymbric Vale fauna in relation to the sequence in South Australia.

In the grid A the divisions of stages are gorizonts; *Bigotina* (trilobite) indicates correlation with *Bigotina tina* sp. nov. about the time of assemblages 4-5 of Daily; *Onaraspis* (*somniurna* and *adjusta*) in Northern Territory points to the correlation of *Myopsolenites palmeri* in Israel; *Anabarites* (Siberia) and *Wyattia* (California) are the earliest known conical shells; black spots in column C mark intervals with archaeocyathid limestones in South Australia, New South Wales, and Northern Territory. Extended explanation of chart in Part II.

The age of the Cymbric Vale Formation and its fauna is late Early Cambrian (late Olenellian) as suggested by Öpik (1968, p. 146); its position in the scale is shown in column C in the chart, Text-figure 3, and is discussed in relation to the Early Cambrian sequence in South Australia and the Northern Hemisphere. The composition of the Cymbric Vale fauna suggests comparisons with the late Olenellian *Elliptocephala asaphoides* faunas of the American Taconic region (Rasetti, 1967, p. 18) remarkable for their Eodiscina associated with 'three species referred to *Olenellus* and six species referred to *Paedeumias*'. At all events these faunas belong to the 'upper *Olenellus* subzone' in terms of Lochman (1956, p. 1350). The late Olenellian age of the Cymbric Vale is based in particular on *Meniscuchus menetus,* whose related species (*helena* Walcott, *nanus* Palmer, and quasi-*helena* of Lazarenko) are of a similar age, and also on *Discomesites,* which is related to the Taconic *Pagetides* and *Neopagetina. Dinesus* whose species occur in the Lower, as well as in the Middle Cambrian, is, however, stratigraphically inconclusive, as is the brachiopod genus *Botsfordia.* The presence of the mollusc *Scenella reticulata,* a species of the Olenellian in the Atlantic region of North America, is zoogeographically unique.

The Cymbric Vale fauna antedates the Ordian, which is represented in the Wirrealpa limestone above the Billy Creek Formation in the Flinders Range; the base of the Ordian in Text-figure 3 is identified by the trilobite *Onaraspis somniurna* Öpik, 1968. The same or a closely related species has been recently described from Har 'Amram (Israel) by Parnes (1971) under the name of *Myopsolenus palmeri* and dated as latest Georgian in age; early Middle Cambrian is also suggested in the stratigraphic chart (ibid., p. 187).

Mount Wright Volcanics

In the limestone with Archaeocyatha attributed to the Volcanics, neither in slides nor in residuals from etching with acid is there any igneous material; it is therefore possible that the volcanic activity postdates the limestone. The limestone itself consists of granular calcite and of banded aphanitic calcareous siltstone. Besides the Archaeocyatha, layers of algal pellets are present; the algal microstructures suggest *Vermiculites,* for example *V. tortuosus* and *angularis* Reitlinger (1959, pl. 19; also *in* Rozanov et al., 1969, pl. 46, fig. 5). The acid residuals contain a few fragmentary phosphatic and phosphatized microfossils; delicate tubes with densely or widely spaced annulations, and conical tubes, all 0.5 mm thick or less; spicules of the sponge *Chancelloria;* fragments of phosphatic brachiopods, one with an eccentric foramen; and numerous fragments of a *Tommotia* represented by its mitral and sellate sclerites (Bengtson, 1970). *Tommotia* Missarzhevsky has been previously found in the *Tommot yarus* in Siberia and in Sweden (Bengtson, op. cit.). *Tommotia* is believed to be one of the earliest Early Cambrian fossils; its time range is, however, unknown, and it is quite possible that the Australian material is not as old as the Siberian or Swedish finds. Its occurrence in sites so remote from each other is remarkable.

DESCRIPTION OF FOSSILS

Order CORYNEXOCHIDA

Family DINESIDAE Lermontova, 1940

Lermontova (1940, p. 144) proposed the name Dinesidae without any explanatory text and without a clear reference to a superfamily (ibid, p. 143, footnote). The name, however, stands as valid because at the time of its proposal it was monotypical—*Dinesus ida* Etheridge being the only known species and genus. Kobayashi (1935, p. 132-136, pl. 22, fig. 3) (before Lermontova) examined the relevant literature and described a complete specimen of *Dinesus ida* Etheridge from Australia; he placed it with good reason in the Corynexochida and was followed by Hupé (1953, p. 162, fig. 85) and Harrington et al. (1959, p. 0230, fig. 169—in passing, the illustration of *Dinesus* given in the Treatise is erroneous). Whitehouse (1936, p. 228) however, found it 'difficult to believe that it is a dolichometopid', and placed *Dinesus ida* in the Ellipsocephalidae.

According to Pokrovskaya (1959), Suvorova (1960), N. Tchernysheva (1961), and Repina (1964) the Dinesidae are a family of the Solenopleuracea.

Finally, Palmer (1968, p. B60) accommodated the Dinesidae in the Ptychopariida.

Genus DINESUS Etheridge, 1896

DINESUS aff. GRANULOSUS (Lermontova, 1940)

(Pl. 3, figs 3, 4)

Material: One cranidium (CPC 13165), retaining its convexity.

The species described by Lermontova as *Erbia granulosa* belongs, according to Palmer (1968), to the genus *Dinesus;* the type species of *Erbia* Lermontova is *Cyphaspis sibirica* Schmidt, 1886, quoted by Lermontova as *Solenopleura*(?) *sibirica;* the synonymy is given by N. Tchernysheva (1961, p. 251).

Description: The cranidium of *D.* aff. *granulosus* is 2.3 mm long; its test is prominently granulose, including the palpebral lobes; in *granulosa* according to N. Tchernysheva (op. cit., p. 255) the palpebral lobes are smooth; furthermore, in our specimen the glabella has two pairs of lateral furrows (in front of the posterior furrows), a slightly forward expanded glabella and small and oblique palpebral lobes placed somewhat forward and relatively far from the axial furrow; an occipital spine seems absent. These characteristics distinguish the specimen in hand from *Dinesus ida, D. granulosus,* and *D. arcticus* Palmer. The frontal area is, however, ill preserved; the rim is an elevated roll and the pair of lobules anterolateral to the glabellar front are small.

Occurrence and age: Dinesus aff. *granulosus* is a rare fossil of the Lower Cambrian Cymbric Vale Formation; the described shield belongs to the collection, site A; fragments are also present in the material from site B.

Superfamily PARADOXIDACEA

Family XYSTRIDURIDAE

Genus ESTAINGIA Pocock, 1964

The genus is monotypical, based on *Estaingia bilobata* Pocock.

Pocock classified *Estaingia* as ?Family Paradoxididae; but I believe that *Estaingia* is less related to the Paradoxididae than to *Xystridura* Whitehouse and the Xystriduridae, which are a separate unit of the Paradoxidacea. I have elsewhere given reasons for placing *Estaingia* in the Xystriduridae (Öpik, 1975).

Repina (1969, p. 44-46, text-figs 21, 22) accommodated *Estaingia* in the Protolenidae, but commented on the peculiar structure of the pygidium—with the proviso that in the protolenids 'the structure of the caudal shield in detail varies not only within the limits of a subfamily but also of a genus'. The diagram (ibid., fig. 22-11) of the pygidium of *Estaingia* is closest to *Xystridura*. The family Protolenidae in terms of Repina is quite large and still growing by the addition of new genera: the more genera the more niches are available to accommodate newcomers contributing to the heterogeneity of the already diffuse concept of the taxon.

ESTAINGIA BILOBATA Pocock, 1964

(Pl. 1, figs 1-7)

Material: Four cranidia, one free cheek, and two pygidia are illustrated, from an ample supply of specimens from a layer of siltstone.

Estaingia bilobata has been described in great detail by its author and the material in hand supplies no additional information on its structure.

Comment on illustrated specimens

All illustrated specimens came from site A.

Figure 1: The cranidium CPC 13152 is 14.0 mm long; it is deformed (telescoped), and the anterior sutures are therefore about horizontal; the fulcral point on the right side is prominent.

Figure 2: The cranidium CPC 13153 is 12.7 mm long; the frontal tips of the palpebral lobes are drawn out and sigmoidal. The anterior glabellar furrows lost their relief. The frontal glabellar lobe is relatively wide.

Figure 3: The free cheek CPC 13154 is 8.0 mm long as preserved; the ventral side with the doublure and the marginal flange is illustrated.

Figure 4: The cranidium CPC 13155 is 8.5 mm long; it is askew to the left and owing to the deformation the glabella seems slender.

Figure 5: The cranidium CPC 13156 is 9.5 mm long; it is askew to the right and only the posterior glabellar sutures are, apparently, in their original position, or almost so.

Figure 6: The pygidium CPC 13157 is 2.2 mm long; it is the left pygidium in figure 7.

Figure 7: Two pygidia, CPC 13158; the axial lobe in both is flattened and has almost lost the *bilobata* relief. The two pairs of pleurae with the marginal spines are visible; the border behind the axis is narrow.

Occurrence and age: Estaingia bilobata is a common fossil at site A of the Lower Cambrian Cymbric Vale Formation.

Family PROTOLENIDAE

(Text-fig. 10)

The family Protolenidae was established by R. & E. Richter (1948); its concept in the first place depends on *Protelenus paradoxoides* Matthew (Richter, op. cit., text-fig. 1); but this species, as well as *P. elegans* Matthew, needs a material revision; at the same time *Lusatiops* R. & E. Richter (1941) was included in the new family, with the type *Lusatiops lusaticus* (Scharzback), and the Richters (ibid., fig. 3) also illustrated its cranidium. A full reconstruction of *L. lusaticus* is published by N. Tchernysheva et al. (1960, text-fig. 51), but with the cranidium of another trilobite and with the indication of a junior synonym—*Paratermierella* Hupé (1953, p. 239, fig. 58); but this in its turn has a quite different cranidium.

Repina (in a diagram, 1969, p. 42, fig. 29-11) contemplated for *L. lusaticus* a cranidium with the palpebral lobes short in the rear. The Richters (ibid., p. 32-34, pl. 1, figs 1-6) also described a new species *Lusatiops ribotanus*—a species with bacculae ('Bäckchen'); the cranidium fig. 5 (also with the 'Bäckchen') was exempted from *L. ribotanus* by Hupé (1953, p. 166, p. 228, fig. 35) under the name *Jalonella celtiberica* nov. gen., nov. spec.

Superfamily ELLIPSOCEPHALACEA Matthew, 1887

In brief, a species attributable to the superfamily Ellipsocephalacea has the following cephalic characters: (1) the posterior facial sutures are straight, short, oblique, defining the posterolateral limbs as two small triangular pieces behind the palpebral lobes (in ptychopariids a sigmoidal suture results in a blade-like more or less large posterolateral limb); and (2) the palpebral lobes and the ocular ridges are confluent, defining broad (large) interocular cheeks.

In the families Ellipsocephalidae and Protolenidae the posterior tips of the palpebral lobes are distant from the axial furrows and in contact with the posterolateral (pleuro-occipital) furrow.

The forms in which the posterior palpebral tips have no such contact are attributable to separate subfamilies (as for example, Palaeoleninae) or excluded from the Ellipsocephalacea altogether.

In the family Ellipsocephalidae the glabella can have its flanks parallel or slightly converging forward or concave; the glabellar front is broadly rounded, or somewhat expanded; the free cheek is narrow. In the Protolenidae the glabella is conical and the free cheek relatively broad.

The particular structure of the posterior facial suture and the diminutive posterolateral limb constitute a character separating the Ellipsocephalacea from the contemporaneous Redlichiacea and Ptychopariacea: in these the sutures cut the rear margin some distance abaxially from the posterior palpebral tips, creating transversely long posterolateral limbs.

In some instances the separation of ellipsocephalids and protolenids from each other appears inconclusive; but an arbitrary decision can be based either in the 'ellipsocephalid' or 'protolenid' aspect of the specimen in question.

Family ELLIPSOCEPHALIDAE Matthew, 1887

Subfamily STRENUELLINAE Hupé, 1953

Genus STRENAX nov.

The type species of *Strenax* is *S. cerastes* nov.; another species is described as *Strenax* (subgenus *Sematiscus*) *fletcheri* nov.

Diagnosis: The generic characters of *Strenax* are the normal, moderately narrow, convex rim, the convex brim, the transverse furrows in front of the ocular ridges, and the clavate glabella with concave flanks.

Differential diagnosis: Strenax is close to the genera *Strenuella* Matthew and *Strenuaeva* R. & E. Richter regarding the position of the rear tips of the palpebral lobes in close contact with the posterolateral marginal furrows. But in *Strenuella* the glabella tapers forward and transverse furrows are not evident along the front of the ocular ridges; in *Strenuaeva* the cranidial frontal margin is rimless and the glabella tapers forward, but as in *Strenax,* the furrows along the ocular ridges are well developed.

The name *Strenuella* was proposed by Matthew (1887, for 1886, p. 154) for *Agraulos strenuus* Billings, 1874; Cobbold (1931, p. 482, pl. 39, figs 14, 15) was the first to examine (in plaster casts) the originals of Billings; R. & E. Richter (1940, p. 40) selected a lectotype from these cranidia and later (1941, p. 48, pl. 4, fig. 73) produced a line drawing of it; the lectotype is Cobbold's (op. cit.) fig. 14. The original material came from Newfoundland. In the lectotype the rim is strong and no brim is apparent in front of the glabella. Shaw (1950) in describing specimens from North Attleboro (Massachusetts) indicated that *Ptychoparia mucronata* Shaler & Foerste (1888) is a synonym of *S. strenua* and that an exoskeleton with its thorax and pygidium is also preserved. In this exoskeleton (Shaw, op. cit., pl. 79, fig. 13) remnants of fulcral spines seem present, and axial spines are prominent; a segment of the thorax of *Micmacca walcotti* Matthew (1899b, p. 80, pl. 4, figs 5a-5d) also possesses an axial spine and a 'weak spine on the posterior margin at the geniculation'; the cranidium itself indicates a *Strenuella* (*'Acanthomicmacca'* Hupé, 1953). Several species of *Strenuella* have a brim, short in *Strenuella polonica* Czarnocki (Samsonowicz, 1959) and quite long in *S. onyx* (R. & E. Richter, 1940); the type of the genus, *S. strenua,* is brimless. *Strenuaeva* R. & E. Richter (1940) is typified by *Arionellus primaevus* Broegger (1879, for 1878, p. 58); in the description Broegger refers to earlier illustrations by Kjerulf. Kiaer (1916, p. 31-38, pl. 4, figs 1-4 and pl. 5, figs 1-6) described the species exhaustively, and Samsonowicz (1959) described material from Poland. In all published cranidia of *Strenuaeva primaeva* the transverse furrows in front of the ocular ridges are deep and wide, the brim is tumid, but no rim is evident; the glabellar flanks are straight, and the frontal lobe (beyond the ocular ridges) is small as compared with *Strenax.* In passing, Sdzuy (1962) regards *Hindermeyeria* Hupé, 1953, as a synonym of *Strenuaeva,* which should be accepted.

A clavate glabella and concave glabellar flanks occur in some forms of the Ellipsocephalidae, as, for example, in *Ellipsocephalus hoffi, E. galeatus* Matthew, 1895, and *Micmacca matthevi* Matthew. *Ferralsia Cobbold,* 1935, placed by R. & E. Richter (1948) with the Protolenidae, also has a clavate glabella. *Palaeolenus fengyangensis* Chu (1962) is classified with the Ellipsocephalidae, but Chu herself (op. cit., p. 391) thinks also in terms of *Schistocephalus* Lermontova, a paradoxidid according to N. Tchernysheva (1961, p. 53). Finally, *Bajangolaspis*

Sivov (1960, fig. 12) recalls *Palaeolenus fengyangensis* as well as *Strenax*. The type species is *Bajangolaspis bajangolica* from the Lower Cambrian of Tuva; another species is *B. asiatica* Repina (1960, p. 278, pl. 28, fig. 13) from the eastern Sayan Lower Cambrian (Kameshki). The glabella, as in *Strenax,* is expanded in front and *B. bajangolica* seems to possess a short plectrum; but neither an occipital spine nor a furrow along the ocular ridges is apparent.

STRENAX CERASTES sp. nov.

(Pl. 2, figs 1-6; Text-fig. 4)

Material: The examined material comprises about 25 cranidia and four recognizable free cheeks; the matrix consist of indurated siltstone and silicified limestone pods; the matrix in collection B is slightly metamorphosed.

Holotype: The cranidium Plate 2, fig. 1, CPC 13159, is selected as the holotype. Its posterolateral border is defective but its structure is evident in the cranidia figs 2 and 5.

Diagnosis: The species *Strenax cerastes* possesses the characters included in the diagnosis of its genus and is distinguished by its strong occipital spine with a node at its base, the moderate concavity of the glabellar flanks and the broadly rounded glabellar front.

The differential diagnosis is the same as that of *Strenax (Sematiscus) fletcheri* (q.v.).

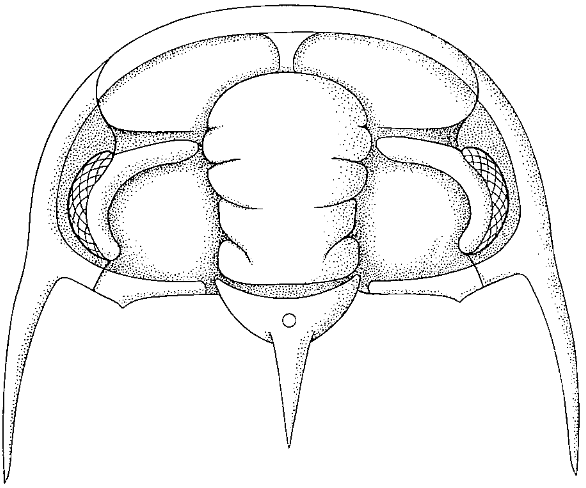

Fig. 4. Cephalon of *Strenax cerastes* gen. et sp. nov., reconstructed.

Description: Strenax cerastes has a prominently convex cephalon en grande tenue with a well developed relief of furrows and lobes; the largest cephala known, about 15.0 mm long, indicate exoskeletons some 45-50 mm long. The margin of the cranidium is close to an arc of a circle but is usually tectonically deformed. The rim is convex and well defined by the narrow marginal furrow; the median plectrum between the rim and the glabella observable in most of the specimens reminds one of *Strenuella polonica* Czarnocki, in Samsonowicz (1959, pl. 1, figs 3, 4, and 9).

The brim is broad, moderately convex and venulose. The anterior sutures are abaxially convex and at the same time divergent; the posterior sutures are straight and oblique and the posterolateral triangular limbs are very small—a feature separating the Ellipsocephalidae from the ptychopariids, for example; the fulcral points are prominent. The palpebral lobes are strong and fused with the equally strong ocular ridges; the posterior tips of the palpebral lobes are in contact with the broad posterolateral marginal furrows which merge with the palpebral furrows. The transverse furrows along the front of the palpebral lobes widen abaxially.

The free cheek is narrow, especially at the base of the eye—as usual in the Ellipsocephalidae; the marginal furrow is much narrower than the rim and the long, slender, and slightly deflected genal spine; the spine itself is advanced with an angle of about 75° between the posterior and lateral margins of the shield. Delicate terraced lines cover the rim and the spine; on the spine they run obliquely to its adaxial margin.

The occipital furrow is narrow and deep and the crescentic to triangular occipital lobe carries close to its margin a spine and a small node; the spine is curved and inclined and varies in length and thickness. The axial furrows, of an even depth, surround the glabella; the glabella is widest about the ocular ridges, evenly rounded in front and narrow in the rear about the posterior glabellar furrows; glabellar flanks are gently concave. Four pairs of glabellar furrows are evident; the lateral glabellar lobes between the two foremost furrows are a little expanded laterally against the adaxial tips of ocular ridges. The test is smooth except for the terraced lines on the cephalic rim and genal spines.

The cranidial rim and brim together (the frontal area) are as long as 0.25-0.3 of the glabella and the palpebral lobes 0.5-0.6; there is no space for longer palpebral lobes if such were present; the size seems, however, small owing to the length of the glabellar front; the width of the glabella at its narrowest is about 0.8 of the widest part on the level of the ocular ridges; and the interocular cheeks (which are gently tumid) together with the palpebral lobes are about as wide as the posterior part of the glabella.

Comment on illustrated specimens (Pl. 2)

The holotype cranidium, rubber cast of CPC 13159, Figure 1, is 18.0 mm long to the tip of the occipital spine and the spine is about 6.6 mm long; it is deformed, but the symmetry is restored in Text-figure 4. There is a small node at the base of the occipital spine; the plectrum is deformed.

The cranidium Figure 2, CPC 13160, is 12.0 mm long; it is worn, but retains the original shape of the glabella and the left posterolateral (fulcral) spine. Associated is a cranidium of *Discomesites lunatulus.*

The cranidium Figures 3 and 4, CPC 13161, is 7.7 mm long; the matrix is a silicified limestone pod—a coquinoid of cranidia, fragmentary segments of the thorax, and free cheeks. The two illustrations between them show the relief of the furrows. The glabella retains its shape.

The cranidium Figure 5, CPC 13162, is 14.0 mm long; the plectrum is clear, the posterolateral furrows and the margin are preserved, and the brim is convex and venulose.

The free cheek Figure 6, CPC 13163, is 11.0 mm and its spine 6.0 mm long; the terraced lines on the spine slant towards its adaxial edge.

Occurrence and age: Strenax cerastes occurs in the Lower Cambrian Cymbric Vale Formation at sites A and B; all illustrated specimens are from collection B.

STRENAX subgenus SEMATISCUS nov.

Sematiscus is monotypical; its type species is *S. (Sematiscus) fletcheri* nov.

Characters of the subgenus: Strenax (Strenax) and *S. (Sematiscus)* have the following common characters: (1) a rim with a plectrum, (2) a convex brim, (3) transverse furrows along the fronts of the ocular ridges, and (4) a glabella with concave flanks and expanded frontal lobe. *Sematiscus* is distinguished by its transversely expanded cranidium, subtrigonal glabellar front, a relatively wide glabellar rear, and more concave glabellar flanks.

The subgeneric status is proposed because (1) both are monotypical and their type species are based on incomplete material; and (2) the cranidia resemble each other structurally as regards the characters of the subfamily Strenuellinae; but separation at the generic level still remains a possibility.

Comparison with the Aldonaiidae Hupé, 1953: The original guess (Öpik, 1968a, p. 146)—Lermontoviinae(?)—cannot be substantiated; a resemblance to *Tuvanella* Pokrovskaya (1959) of the Aldonaiidae is, however, apparent, especially with the type species *Tuvanella gracilis*. Repina (1966, p. 155) described it in detail and (1969, p. 46) revised the genera attributed to the Aldonaiidae. In *Tuvanella gracilis* the glabella is evenly slender, but it has an expanded and bluntly rounded frontal lobe; there are only three lateral furrows (*S. fletcheri* has four), the anterior sutures are almost parallel, and the posterior tips of the palpebral lobes are clear of the posterior marginal furrow; so *S. fletcheri* cannot be united with *Tuvanella*.

Aldonaia Lermontova has been revised by Suvorova (1960, p. 76; pl. 5, figs 14-17; and pl. 6). In *Aldonaia tersa* Suvorova the free cheek (ibid., pl. 6, fig. 1) is of the same structure as in *Rinconia schneideri* (R. & E. Richter, 1941) described by Sdzuy (1962, text-fig. 2)—almost semicircular, with an advanced, deflected, and transmarginal genal spine; also, both *tersa* and *schneideri* have a macropleural segment with a long pleural spine. *Aldonaia ornata* Lermontova (1940, p. 133, pl. 37, figs 2, 21-e)—the type species—is very close to *A. tersa,* but less well described. The pygidium of *A. tersa* Suvorova (op. cit., text-fig. 25) differs little from *Ellipsocephalus hoffi.*

STRENAX (SEMATISCUS) FLETCHERI sp. nov.

(Pl. 3, figs 1 and 2; Text-fig. 5)

Material: One cranidium, the holotype CPC 13164, is illustrated; three more cranidia, all fragmentary, have been noted in the collection; it is a rare species.

Diagnosis: The characters of *Sematiscus fletcheri* are (1) the relative narrowness of the cranidial rims, (2) the length of the frontal area (0.75 of the glabella), (3) the sigmoidal shape of the palpebral tips, and (4) the absence of the occipital spine.

Differential diagnosis: S. (Sematiscus) fletcheri differs from *Strenax cerastes* in the subgeneric characters and the characters included in the specific diagnosis.

Description: The holotype cranidium is 3.8 mm long; its lobes and furrows are clear in relief; the frontal margin is an arc of a relatively large circle centred on the occipital furrow. The rim is gently convex and narrow and the plectrum fades out before reaching the glabellar front. The brim is moderately convex and the whole frontal area is transversely quite wide owing to the almost straight, short, and divergent anterior facial sutures. The posterior sutures are straight and oblique.

The palpebral lobes and the ocular ridges are defined by the transverse *Strenuaeva*-like furrows in front and the palpebral furrows, which are confluent in the rear with the posterolateral (pleuro-occipital) furrows. The anterior tips of the palpebral lobes are not quite completely fused to the ocular ridges; they are separated from them by vestigial furrows and retain their own sigmoidal shape and relief. The interocular cheeks are a little convex and entirely surrounded by furrows. The occipital furrow is straight, the occipital lobe trigonal and spineless.

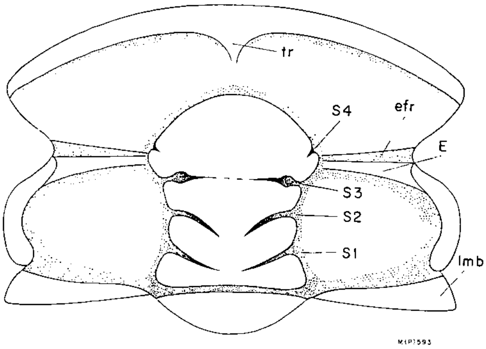

Fig. 5. Cranidium of *Strenax (Sematiscus) fletcheri* sp. nov. S1, S2, S3, and S4—lateral glabellar furrows; E—ocular ridge; efr—transverse furrow in front of E; lmb—diminutive posterolateral limb; tr—plectrum.

The glabellar flanks are concave; the glabellar front in spite of its rounded form appears almost subtriangular. Four pairs of glabellar lateral furrows are present; the foremost (S4) furrows, beyond the ocular ridges, are short and inclined; the S3 furrows behind the ridges are transformed into pits. Between these furrows the glabella is laterally expanded (as in *Strenax cerastes*) and angulate.

The other furrows are relatively long and oblique, the posterior furrows are almost transcurrent, and the glabella in the rear is almost as wide as on the level of the ocular ridges. An ill preserved external granulosity is indicated and the brim is rather weakly striate.

The frontal area (the brim and the rim together) is 0.45 and the palpebral lobes 0.6 of the glabella in length; the glabella at its narrowest is 0.7 its width between the ocular ridges; the interocular cheeks are as wide as 1.3 of the glabella in its middle.

Occurrence and age: Strenax (Sematiscus) fletcheri is a rare species in the Lower Cambrian Cymbric Vale Formation, collection site A.

Order MIOMERA

Suborder EODISCINA Kobayashi, 1939

The order Miomera comprises two suborders, the Agnostina and the Eodiscina; the systematics of the Agnostina have been already reviewed (Öpik, 1967) and the results of the survey are condensed in a chart—the 'tabular classification of agnostids' (ibid., p. 65); the review of the Eodiscina that follows completes the revision of the Order. Comparatively few genera of the Eodiscina are known, and

Proposed system	Current system	STRUCTURES / TAXA		Relief			Eyes				Thorax			Cephalic rim								Glabella				Gl. furrows			Occiput				Pygidium									
				En grande tenue	Semieffaced	Effaced	Sighted	Degenerate	Eye- and sutureless	Ocular ridges	Three segments	Two segments	Spine on 2nd segm.	Narrow	Wide	Crescentic	Median swelling	Smooth	With nodes	Venulose	Crenellate	Broad	Slender	Pointed	Blunt	Absent	Lateral	Transcurrent	Free	Fused	Spine glabellar	Spine occipital	Axis stout	Axis slender	Axial rings	Terminal spine	Pleurae smooth	Pleurae furrowed	Doublure normal	Serrate	Spinose in plan	Cuffed
I	II			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
WEYMOUTHIIDAE	*EODISCIDAE*	*SERRODISCUS*	A	│	│				│		│				│				│			│		│		│	│	1-2	│			│	│		10-15		│			│		
		WEYMOUTHIA	B			│			│		│				│				│			│				│			│				│		0		│					
		○ *DELGADELLA*	C			│	│				│				│			│				│				│			│				│		0		│					
		○ *PAGETIELLUS*	D			│	│				│				│			│				│				│			│				│		9-15		│			│		
		○ *HEBEDISCUS*	E	│	│		│			│	│			│		│		│	│			│	│	│	│	│	│			│	│		│		5-7		│			│		
		MENISCUCHUS	F	│					│	│	│				│	│		│	│			│			│			2		│			│		4-7		│					│
		ANALOX	G	│					│		×	×											│		│			1		│	│		│		7		│					│
		BATHYDISCUS	H		│				│		×	×			│			│				│			│				│				│		0		│					│
		BOLBOPARIA	I	│					│		×	×				│		│	│			│		│			│		│		│		│		12		│			│		
		ACIMETOPUS	K	│					│		×	×				│		│				│						2	│		│		│		8		│					
EODISCIDAE		*EODISCUS*	L	│	│				│		│		│	│							│		│	│			│			│	│			│	7-11		│	│	│			
	PAGETIIDAE	*PAGETIDES*	M	│	│		│			│	│				│	│	│				│		│	│			│			│	│			│	7-8			│	×			
		NEOPAGETINA	N	│			│			│	×	×	│	│				│					│	│			│		│	│	│			│	6-8			│	×			
		DISCOMESITES	O	│			│			│	×	×			│	│	│			│			│	│			│			│	│			│	6-7			│	│			
		PAGETIA	P	│	│		│			│	│	│	│	│							│		│	│			│				│			│	4-6	│		│	│			
		OPSIDISCUS	Q	│				│		│	×	×		│							│		│	│	│		│	1		│	│			│	2-3			│	×			
		△ *DAWSONIA*	R	│					│			│	│		│	│					│		│	│	│		│		│			│		│	6-7			│	×			
		△ *EODISCUS BOREALIS*	S	│					│	│	│			│							│		│	│			│			│	│			│	7			│	×			
		KISKINELLA DECORA	T	│			│			│	×	×		│							│		│	│			│			│	│			│	7			│	×			
CALODISCIDAE	*CALODISCIDAE*	△ *CALODISCUS*	U	│					│		│			│				│	│			│			│	│		2	│				│		2-4			│	×		│	
		NEOCOBBOLDIA	V	│			│				│	│		│				│				│			│				│			│	│		3			│	×		│	
		△ *STIGMADISCUS*	W	│					│		×	×		│				│							│				│			│		│	14			│	×		│	

Fig. 6. Tabular classification of eodiscids. Detailed explanation in the text.

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the chart of the eodiscids is therefore much simpler than the 'Tabular Classification of Agnostids' of 1967.

Explanatory notes to the Classification Table (Text-fig. 6)

1. Columns I and II on the left illustrate the difference of the nomenclature of the families as proposed now and in currently used systems;

2. The taxa (generic names) are arranged to satisfy the family concepts of the proposed system, but this arrangement conflicts with the currently used arrangement (of the 'Treatise', that is of Rasetti);

3. The arrangement of the taxa is convertible to the currently used arrangement—

(a) by transfer (note circles) of C, D, and E in any position below *Eodiscus,*

(b) by lifting the items (note triangles) R, S, U, and W up in any position above M (*Pagetides*), and

(c) by dropping the family name Calodiscidae. These operations performed, the names Eodiscidae and Pagetidae regain their validity as divisions of Column II.

4. The heading 'Structures' stands for 'morphological criteria used or usable in diagnosing genera'; the selected 39 criteria are arranged from left to right in a sequence of items suitable as a routine in descriptions; crosses (x) in the chart indicate 'absence of information'. Three genera (O, P, and Q) possess a unique character each; the diagnoses and differential diagnoses are, however, combinative in all genera. An example from the chart:

> *Discomesites* (O) refers to species of Eodiscidae (Pagetidae) en grande tenue (1); with eyes, sutures (6), and ocular ridges (7); with a cephalic rim wide (12), crescentic (13), swollen medially (14), and uniquely vasculose (17); a glabella slender (20) and pointed (21), with lateral furrows (24); an occiput fused with the occipital lobe (27) and having a spine (28); pygidial axis slender (31), of 6-7 annulations (32), furrowed pleural lobes (35), and normal doublure (36). Furthermore, there is no pygidial axial spine; with this negative character *Discomesites* comes close to the two oculate *Pagetides* and *Neopagetina* of the Eodiscidae, as discussed also in the text.

5. I acknowledge three families as operational aggregates of genera attributable to the suborder Eodiscina (1) Calodiscidae Kobayashi, 1943—originally a subfamily of the Eodiscidae; (2) Eodiscidae Raymond, 1913—a senior synonym of Pagetiidae Kobayashi, 1935; and (3) Weymouthiidae Kobayashi, 1943.

The essential points of the proposed classification can be summarized as follows:

(1) The presence or absence of eyes and facial sutures are not diagnostic of the families: sighted and blind forms exist in each.

(2) *Eodiscus* is sutureless and eyeless but is co-familial with *Pagetia;* consequently the name Eodiscidae Raymond, 1913 takes the place of its junior synonym Pagetiidae Kobayashi, 1935; the blind *Dawsonia* is also transferred to the Eodiscidae.

(3) The genera *Delgadella, Pagetiellus,* and *Hebediscus* are oculate but co-familial with the sutureless and eyeless *Serrodiscus* and *Weymouthia,* but not *Eodiscus* and *Pagetia;* the dormant name Weymouthiidae Kobayashi, 1943, has priority in naming this family.

(4) The dormant name Calodiscidae is also available for the blind *Calodiscus* and oculate *Neocobboldia.*

(5) The structures of the pygidium, the pygidial rim, and the doublure, and the form of the glabella, the pygidial axis and the cephalic rim supply the diagnostic character of the families.

Extant Classifications

Classification by R. & E. Richter (1941, p. 21): the eodiscids are aggregated in a single family Eodiscidae, of three genera (*Eodiscus, Pagetia,* and *Hebediscus*); these are visualized as composed of the subgenera *Eodiscus, Serrodiscus,* and *Weymouthia;* the family includes sutureless and blind as well as oculate forms. The authors hold (1) that the absence of sutures and eyes is the result of the degeneration of eyes incidental in different stocks of originally oculate parentage; (2) that in originally or secondarily blind forms no eyes are likely to develop; and (3) that the notion of existence of 'primary blind trilobites' lacks any evidence.

Classification by Kobayashi (1943, 1944): I refer to the clarifying review (Rasetti, 1952, p. 438) of the taxonomic nomenclature introduced by Kobayashi, who employed five families and six subfamilies in 1943 and added one more (Hebediscidae) in 1944. I appreciate Kobayashi's reference to furrowed and ribbed, and unfurrowed pygidial pleural lobes and to the simultaneity of blind and oculate genera in the family Weymouthiidae.

Classification by Rasetti (1952, p. 439): 'In view of the incomplete knowledge of the group, it seems expedient to divide the eodiscids into two families, the Pagetiidae including all the forms with eyes and facial sutures, and the Eodiscidae comprising all the sutureless forms, even though such groups may not represent phylogenetic units'. At the same time 'the writer agrees with the conclusion reached by R. & E. Richter that the sutureless forms are degenerate descendants of more primitive species with eyes and facial sutures; it is also likely that eyes and sutures were independently lost in several lines of descent'. Rasetti based his classification on North American eodiscids.

Classification in the 'Treatise' (Harrington et al., 1959) *by Rasetti:* the bipartite division into Eodiscidae (sutureless and blind) and Pagetiidae (oculate and proparian) is adapted from Rasetti (1952)—a classification based on a single criterion, although 'it is now abundantly clear that no single feature can be used to classify trilobites' (op. cit., p. 0160). The classification covers also *Opsidiscus, Delgadella, Pagetiellus,* and *Pagetina* and is therefore a general classification (Rasetti's original classification is confined geographically to North America).

Comment on the criteria 1-39 in the classification chart

Relief: (1) en grande tenue—'displaying all lobes and furrows' (Öpik, 1967, p. 56), (2) semi-effaced, and (3) effaced—descriptive of a selective or full levelling out of features of the relief.

Eyes: (4) sighted, with eyes and sutures; (5) degenerate eyes and sutures as in *Opsidiscus;* (6) blind and sutureless—self-explanatory; incidental in all families. The degeneration of eyes (organs) proceeded independently of the effacement of relief, which involves no organs. (7) Ocular ridges are usual in sighted forms; the blind *Meniscuchus* seems an exception.

Thorax: (8) and (9)—numbers of segments in the thorax; in the known Weymouthiidae three segments are dominant (see below, *Chelediscus*), but in the rest two and three are possible even in a single genus; in many forms, however, the thorax is unknown (crosses X); (10) axial spine in the second segment is evident in *Pagetia,* and short in *Eodiscus* and *Dawsonia*—forms whose thorax is known.

Cephalic rim: (11) narrow means visibly narrow irrespective of the narrow or wide marginal furrow; (12) wide—a generalization in need of a statistical study of specimens of all known species; (13) a crescentic rim has lateral tips truncated by sutures in sighted forms; its shape depends also on its sagittal width; (14) the median swelling is variably strong in *Pagetides,* weak in *Discomesites,* and not discernible in the Weymouthiidae; (15) smooth—without surface markings; (16) nodes on the rim are evident in *Serrodiscus, Weymouthia,* and *Calodiscus;* in *Meniscuchus* nodes can be replaced by pits (*'Calodiscus' helena* of Lazarenko, 1964), or by posterolateral swellings in *Meniscuchus menetus* nov. and *Bolboparia* Rasetti; (17) the rim is venulose in *Discomesites lunatulus* nov., but the venulosity is either absent or masked by the dense pustulosity in *D. fragum;* (18) crenellation of the whole rim, or its lateral parts (in *Pagetides*) serves in identification of the Eodiscidae; but *Chelediscus* (discusssed below) is an exception.

Glabellar shape: 'the glabella shows considerable variety of form' (Rasetti, 1966, p. 7); the items (19) broad, (20) slender, and (21) pointed are generalizations; it seems, however, that a 'slender' and 'pointed' glabella constitutes a combination helpful in the identification of Eodiscidae; (22) blunt means a rounded glabella front.

Glabellar furrows: (23) absence of furrows is a result of effacement; (24) lateral glabellar furrows combined with a pointed and slender glabella serve in the identification of Eodiscidae; (25) transcurrent glabellar furrows constitute a significant complication in the structure of the Weymouthiidae; *Opsidiscus* (Eodiscidae), however, is an exception with its transcurrent furrow.

Occipital lobe: (26) the lobe is free when defined by an occipital furrow, which, however, can be effaced; (27) it is fused in forms whose glabellar rear is enlarged and inseparable from the middle part of the occipital lobe; (28) the occipital spine is an extension of the glabellar rear, as for example in *Bolboparia* Rasetti (1966, pl. 3, fig. 1), where it stands clear of the occipital spine of the occipital lobe; (29) the occipital spine of the occipital lobe has a marginal position.

According to Rasetti (1966, p. 9) 'the pygidia present less variety than the cephala'; as seen in our chart, the families have a different pygidial structure independent of the distribution of eyes or blindness.

Pygidial axis: (30) the axis in the Weymouthiidae is stout—broad in relation to the pleural lobes; (31) the slender axis is dominant in the Eodiscidae; (32) the number of axial rings is variable, and of course, not evident externally in effaced forms; (33) the terminal axial spine is a character of the genus *Pagetia; Neocobboldia spinosa* Palmer (1968, p. 1334) also has an axial spine, but not in a terminal position as seen in *Pagetia.*

Pygidial pleural lobes: (34) pygidial pleural lobes are smooth without furrows and ribs in the Weymouthiidae; in *Eodiscus* ribs and furrows are not evident in large specimens but are present in small (Rasetti, 1952, pl. 53, figs 14, 15; Hutchinson, 1952, pl. 11, fig. 7), and the number of ribs is larger than the number of segments in the thorax; in *Pagetides* Rasetti, 1945, the furrows and ribs are effaced but discernible; (35) the pleural lobes are furrowed and ribbed in the Eodiscidae and Calodiscidae, but some cases of effacement are known.

Rim and Doublure: (36) the normal doublure as a lining of the rim is very narrow and insufficiently explored; (37) the serrate rim (downward directed spines) is evident in *Serrodiscus* Richter, 1941, and also in Rasetti's (1961) *Acidiscus, Bolboparia, Litometopus, Leptochilodiscus;* the same structure is also present in *Hebediscus* Whitehouse, 1936, as described by Lazarenko (1962; 1964) and in *Pagetiellus* Lermontova, 1940 (Lazarenko, 1964, pl. 5, fig. 8, p. 184; Jegorova, 1969, p. 100); (38) the cuff of the pygidial rim (Pl. 5, figs 7-9), already found in three genera (*Meniscuchus* nov., and Rasetti's 1966 *Analox* and *Bathydiscus*) can be taken as a modification of the serration; (39) a pygidial rim spinose in plan and reminiscent of some polymerid trilobites (for example *Kootenia*) is characteristic of the Calodiscidae.

Comment on the genera

The Weymouthiidae

(A) *Serrodiscus* R. & E. Richter (1941) is well known; *Serrodiscus daedalus* nov. is a species en grande tenue; most of the species are about semi-effaced.

(B) *Weymouthia* Raymond, 1913 is based on *Agnostus nobilis* Ford, revised by Shaw, 1950, and Rasetti, 1952; it is externally a completely effaced *Serrodiscus,* but retains the nodes on its cephalic rim; whether or not its pygidium is serrate is unknown; *Weymouthia nobilis* from Shropshire (Cobbold, 1931, pl. 38, fig. 20) is effaced less than the American specimens and possesses ten pygidial axial annulations to its cast.

(C) *Delgadella* Walcott (1912, p. 272, pl. 29, figs 5-5b) is based on *Lingulepis lusitanica* Delgado, which is a trilobite; the latest revision is given by Sdzuy (1962, p. 188-181); *Delgadella* is sighted, but otherwise effaced; nodes on the rim are absent and nothing is known regarding its pygidial doublure; the presence or absence of a serration remains open; the pygidial axis is effaced.

(D) *Pagetiellus* Lermontova, 1940, is possibly a synonym of *Delgadella* (=*Alemtejoia,* Hupé, 1953, p. 115; Sdzuy, op. cit. p. 189); in *Pagetiellus,* however, the pygidial rim is serrate and the axial rings in the pygidium (criterion 32) can be counted. It seems, therefore, that for the time being the synonymy of the two remains inconclusive.

(E) *Hebediscus* Whitehouse (1936, p. 80): the type species, designated by Whitehouse, is *Ptychoparia attleborensis* Shaler & Foerste (1888, p. 39, pl. 2, fig. 14); the specimen itself is a cranidium; the concept of the genus refers to *Pagetia attleborensis* from Comley, Shropshire (Cobbold, 1931, p. 462, pl. 38, figs 1-5), which represents *Hebediscus cobboldi* Resser (1937, p. 13). The original cranidium of *Ptychoparia attleborensis* was also re-figured by Matthew (1899, p. 77, pl. 4, fig. 4C) as *Strenuella*(?) as well as *Agraulos (Strenuella?) attleborensis* mut. *vigilans;* Walcott (1890, p. 649, pl. 95, fig. 2) published a cranidium from Newfoundland as *P.? attleborensis,* and Harrington et al. (1959, fig. 131—figs 2a-2c) illustrated shields from Newfoundland as *Hebediscus attleborensis.* Furthermore, Shaw (1950, pl. 79, figs 15-17) assigned two cranidia and one pygidium from North Attleboro to *'Dipharus' attleborensis* and to the Eodiscina and Pagetiidae (*sensu* Kobayashi, 1938). Finally, additional material from Newfoundland has been published by Hutchinson (1962, p. 61, pl. 3, figs 3, 4). To recapitulate, the type cranidium of *Ptychoparia attleborensis* is insufficient in itself to justify its classification with the Eodiscina, but this classification should be accepted because of the supporting pygidia published by Shaw from the type locality and by Hutchinson from Newfoundland—conditions already indicated by R. & E. Richter (1941, p. 17, 18).

In the classification chart the morphological characters of *Hebediscus* refer to the descriptions and illustrations of Siberian material published by Lazarenko (1962; 1964) and Jegorova (1969). *Hebediscus attleborensis* of Lazarenko (1964, p. 179, pl. 2, figs 17-23) is, of course, a different species from *H. attleborensis* and *H. cobboldi* on account of its occipital furrow, prominent cephalic rim, and clearly segmented pygidial axis; the pygidia of *Hebediscus ponderosus* Lermontova, 1951, in Lazarenko (op. cit., p. 180) are serrate in the manner of *Serrodiscus;* the first to observe the serration was Lermontova (op. cit., p. 21). The same structure has been observed by Jegorova (1969, p. 90, 91) in *H. attleborensis* and *H. vagus.* Jegorova's *attleborensis* seems close to *H. cobboldi.*

To speculate, *Hebediscus ponderosus, H. cobboldi, Pagetiellus porrectus* (Lazarenko, 1964), *P. lenaicus* (ibid.), and *Delgadella* can be visualized as a chain of forms arranged according to the progressive effacement of the external relief.

The synonymy of *Hebediscus* 1936 and *Dipharus* 1923 (Shaw, 1950; Rasetti, 1952; Hutchinson, 1962) cannot be accepted. *Dipharus* is indeed an 'unrecognizable genus' (Harrington et al., 1959, p. 39) and so is the family Dipharidae Kobayashi, 1943. In passing, Kobayashi (1944, p. 41, 44, 60) retains *Dipharus* and *Hebediscus* in a single family under the names of Dipharidae and of Hebediscidae in the one paper. Chang (1953, p. 137-139) in describing *Hebediscus orientalis* and *Dipharus spinosus* remarks that '*Hebediscus* and *Dipharus* are valid genera, and *Dipharus* can never be the immature form of *Hebediscus*'.

After all, the novel name *Hebediscina* Rasetti (1972) is acceptable as a substitute for '*Hebediscus*' in our chart for forms with serrate pygidial margin.

(F) *Meniscuchus* nov. is described in the present paper; it is eyeless but possesses faint ocular ridges.

(G-K) These genera have been established by Rasetti (1966; 1967); this part of the list is, however, incomplete because between *Acimetopus* and *Eodiscus* the following blind genera of Rasetti should be placed; *Acidiscus, Litometopus,* and *Leptochilodiscus,* all with a serrate pygidium; also *Oodiscus* and *Chelediscus* Rushton, 1966. *Chelediscus* is aberrant; it is almost an agnostid as regards its cephalon with basal lobes and the thorax of two segments, but its pygidial axis is completely annulated and eodiscinid; *Chelediscus chathamensis* Rasetti, 1967, has a crenellated cephalic rim. Furthermore, '*Calodiscus*' *fissifrons,* '*Calodiscus*' *reticulatus,* and '*Calodiscus*' *walcotti* (all by Rasetti) cannot be retained in *Calodiscus;* according to Rasetti (1966, p. 23) *fissifrons* is related to *Meniscuchus helena* and so is *reticulatus;* these species are 'so strikingly different from *Calodiscus lobatus* that, were intermediate forms unknown, reference to the genus would hardly be suggested' (Rasetti, op. cit., p. 24). As regards the pygidia no intermediate forms, however, are evident between *Calodiscus lobatus* and the rest. '*Calodiscus*' *walcotti* Rasetti (1952; 1957, p. 45, pl. 1, fig. 4) may also belong to the Weymouthiidae but has a rather distinctive slender pygidial axis. Finally, *Cobboldites* Kobayashi, 1943 and *Tannudiscus* and *Ladadiscus,* both by Pokrovskaya, 1959, are also Weymouthiidae; Solovyov (1964, p. 34) proposed for *Ladadiscus* the monotypical subfamily Ladadiscinae.

(L) *Eodiscus* Hartt, published in Walcott, 1884; revised by Rasetti (1952). In the known species of *Eodiscus* the pygidial pleural lobes are unfurrowed as in the Weymouthiidae; as seen from the comment on the criteria (34), however, it is the result of effacement during morphogeny; the test of *Eodiscus punctuatus* and *scanicus* is punctate and granulose—an ornament apt to veil any vestiges of furrows; *Eodiscus* and *Pagetia* are similar regarding the structure of the cephalic rim, glabella, and occipital spine and the spine on the second segment of the thorax; the cephalic posterolateral spines of *Eodiscus* resemble *Pagetia ocellata* Jell (1970, text-fig. 2). *Eodiscus* is, however, blind and sutureless, its pygidial axis is multi-segmented and has no terminal spine; in respect of these characters *Eodiscus* and *Pagetides* resemble each other, except for the vestigial pleural furrows of the latter, which is free of the marking ornament of *Eodiscus.*

(M) *Pagetides* Rasetti, 1945, is discussed separately in connexion with *Discomesites.*

(N) *Neopagetina* Pokrovskaya, 1960, is also discussed separately.

(O) *Discomesites* is described in the present paper; *D. fragum* possesses a masking ornament and *D. lunatulus* is smooth—examples supplementing the discussions of *Eodiscus* and *Pagetides.*

(P) *Pagetia* Walcott, 1916, revised by Rasetti, 1966b. It ranges from the Early Cambrian well up to the Middle Cambrian and its longevity is expressed in a succession of numerous species. *Eodiscus* postdates *Pagetia.*

(Q) *Opsidiscus* Westergaard, 1950. According to Westergaard (1946, p. 28) *Aulacodiscus bilobatus* 'displays closer resemblance to *Pagetia* than to any other eodiscid' and 'is believed to descend from that genus'. *Opsidiscus* is the youngest known eodiscid. Siberian species are *O. altaica* Poletaeva, 1970, and *O. depolitus* Romanenko, 1970, an aberrant form; the age of all known species is of late Middle Cambrian. Hupé (1953, p. 59) proposed a family Aulacodiscidae to be replaced by Opsidiscidae—a possible synonym of Dawsoniidae Resser, 1937.

(R) *Dawsonia* Hartt *in* Dawson (1868) as revised by Rasetti (1952). The type species, *Dawsonia dawsoni* Hartt, has two segments in the thorax and a short spine in the second segment similar to *Eodiscus;* three segments are also indicated in the chart in respect of *Microdiscus sculptus* Hicks, which is discussed by Rasetti (op. cit., p. 449); this species is the type of *Metadiscus* Kobayashi, 1943, which is probably a subjective synonym of *Dawsonia.*

(S) *'Eodiscus' borealis* Westergaard (1946, p. 23, pl. 1, figs 3-5); revised by Rushton (1966, p. 26). The cephalon is that of an *Eodiscus* with isolated bacculae, but the pygidial pleural lobes are emphatically furrowed and ribbed; a subgeneric name for *borealis* may be appropriate to conserve the diagnosis of *Eodiscus,* which itself is derived from a form with a ribbed pygidium.

(T) *Kiskinella decora* Jegorova (1967; 1969, p. 98); the genus *Kiskinella* M. Romanenko, 1962, is originally monotypical and based on the species *cristata.* Jegorova describes *K. decora* in terms of an oculate *Dawsonia* with sutures (as in *Pagetia*).

Yukonia Palmer (1968, p. B28) is not included in the chart; it is an oculate but sutureless eodiscid.

The Calodiscidae

(U) *Calodiscus* Howell, 1935, as revised by Rasetti (1952, p. 441). The type species of the genus is *Agnostus lobatus* Hall, 1847, and Rasetti's revision refers to Hall's type material; Lochman (1956) also described *lobatus* and related forms and there is a supplement by Rasetti (1967). The thorax is unknown, but Solovyov (1964, p. 35) produced a plausible reconstruction with three segments. The genus in the current literature is overloaded with inadmissible species having pygidia with unfurrowed pleural lobes and too many annulations in the axis. The names Brevidiscidae and *Brevidiscus* Kobayashi are synonyms of Calodiscidae Kobayashi and *Calodiscus* Howell; the synonymy is subjective because *Brevidiscus lunulatus* is not based on the type specimen of *Calodiscus lobatus,* but on a specimen attributed to *lobatus* by Lake (1907).

(V) *Neocobboldia* Rasetti, 1952; the type species is *Cobboldia dentata* Lermontova, 1940. It is oculate and *Calodiscus* is eyeless, but otherwise the two differ little from each other, as evident from the illustrations in Harrington et al. (1959, figs 29 2a-2c and 131 3a-3b respectively).

(W) *Stigmadiscus* Rasetti, 1966, supplemented by Rasetti (1967), is included in the Calodiscidae on account of its pygidial marginal spines and furrowed pleural lobes; the multisegmented pygidial axis, however, and the cephalic structure, especially the 'intergenal' spines well off the corners, seem to indicate a separate family taxon.

Doubtful forms

Glabrella Lermontova (1940, p. 120, pl. 35, figs 9, 9a-9d) is a recognizable and valid taxon whose suprageneric classification (Eodiscina?) remains inconclusive (incertae sedis).

Lenadiscus Repina (1965, p. 109, pl. 1, figs 9, 10) remains a morphological and classifactory problem.

Parapagetia Repina (1964, p. 258, pl. 38, figs 1-3) belongs possibly to the suborder Eodiscina(?); its palpebral lobes are very large.

Shivelicus Pokrovskaya (1959, p. 180) is a valid taxon of trilobites incertae sedis.

Triangulaspis Lermontova (1940) belongs to the Ellipsocephalidae (vide Sdzuy, 1962).

Triangullina Repina (1965, p. 107) is probably related to *Triangulaspis* (Ellipsocephalidae).

Dipharus Clarke, 1923 and Dipharidae Kobayashi, 1943: a polymerid trilobite incertae sedis (see above, under *Hebediscus*).

Identifying the suborders of the Miomera and families of the suborder Eodiscina

The suborders

The species of the suborder Agnostina are all sutureless and eyeless (a possible exception is *Discagnostus spectator* Öpik, 1963, p. 54-57), with the constant number of two segments in the thorax, with a cephalothoracic aperture, with cephalic and postcephalic basal lobes, and a pygidial axis consisting of an anterior segmented and a posterior fused lobe. The cephalon (glabella) consists of five metamers.

The Eodiscina are oculate and proparian, as well as secondarily eyeless and sutureless forms, of four cephalic metamers and with a thorax of three or of two segments, without basal lobes in the thorax and without a cephalothoracic aperture and with a long pygidial axis which reaches the border and is segmented over its full length in a polymerid style. The total number of described genera is about 30 to 32. The effaced and semi-effaced forms may contribute to the number of genera and species but not to the fundamental taxonomic concepts (Öpik, 1967, p. 79).

The families of the Eodiscina

In the Weymouthiidae the glabella and the pygidial axis are prominent and relatively broad; the glabella, of a 'considerable variety of form' (Rasetti, 1966, p. 7) has a pointed to bluntly rounded front and is commonly divided by one or two transverse furrows; the cephalic rim is smooth, but also ornate with nodes, and even pits replacing the nodes; the pygidial pleural lobes are unfurrowed; the edge of the pygidial rim is serrate or developed into a continuous cuff; in some genera a normal doublure is possibly present, but no clear evidence of such a doublure has come to light as yet.

Eighteen genera are attributable to the Weymouthiidae so far and their cephala and pygidia are known; the thorax, however, is known in seven genera only: six have three segments and one (*Chelediscus*) has two. Three genera are oculate and proparian and the rest are eyeless and sutureless; in seven genera pygidia are known as serrate, and in three cuffed; nodes on the cephalic rim occur in five genera, and in one species of *Chelediscus* the cephalic rim is crenellate. Within the Weymouthiidae two morphologically distinct groups of genera are apparent—possibly of subfamily status: (1) forms with a serrate pygidium, and (2) forms with the pygidial cuff. These criteria are not yet applicable to six genera or to a seventh, *Chelediscus,* which may be suae subfamiliae.

In the Eodiscidae the glabella and the pygidial axis are slender and the glabella is pointed in front; the cephalic rim is crenellate or smooth or venulose, but nodes are absent; the pygidial pleural lobes are furrowed and ribbed (but also semi-effaced and effaced), and the pygidial doublure is normal without serration or cuffs or any special structure and therefore different from the Weymouthiidae.

Ten genera are attributed to the Eodiscidae; the thorax of six is known; four have three segments, one (*Dawsonia*) has two, and one (*Pagetia*) two except in one undescribed species, which has three. Three genera are eyeless and sutureless; in one (*Opsidiscus*) sutures are absent, and the eyes are reduced; five are oculate and proparian.

In the Calodiscidae the glabella is bluntly rounded, and relatively short and shows one or two shallow transverse furrows; the cephalic rim is narrow and smooth, and in one species nodose; the thorax can have three or two segments; one genus is sutureless and eyeless (*Calodiscus*), another is oculate and proparian. The pygidial pleural lobes are furrowed and ribbed and the axes are prominent; the pygidial rim, spinulose in plan, is diagnostic, and a similar pygidial rim belongs also to *Stigmadiscus*. Excluded from the Calodiscidae are *'Calodiscus' fissifrons, reticulatus,* and *walcotti* (see under *Meniscuchus* gen. nov.).

Family WEYMOUTHIIDAE Kobayashi

Genus SERRODISCUS R. & E. Richter, 1941

SERRODISCUS DAEDALUS sp. nov.

(Pl. 3, figs 5-9)

Material: Four cephala and one pygidium are illustrated; three more cephala and three pygidia have been noted in the collection.

Holotype: The best preserved cephalon, Plate 3, fig. 6, CPC 13167, is the holotype.

Diagnosis: Serrodiscus daedalus is a species en grande tenue with well impressed furrows including a transcurrent glabellar furrow and distinguished by its very wide cephalic, and pygidial rim. The cephalic rim is thickened along the margin.

Differential diagnosis: Another species en grande tenue is *Serrodiscus fossuliferus* Repina (1964, p. 260, pl. 38, figs 12-14), but its rim is narrower than in *daedalus*. The rim is also conspicuously wide in *Eodiscus llarenai* R. & E. Richter (1941, p. 23, pl. 2, figs 25, 26; pl. 4, fig. 58); its glabella and pygidial axis are, however, short and the glabella is furrowless. Rushton (1966, p. 24) included *llarenai* in *Ladadiscus* Pokrovskaya, 1959, but also illustrated cephala with a *Serrodiscus*-like nodose rim. *Ladadiscus* as revised by Solovyov (1964, p. 36) is structurally different from *Serrodiscus llarenai.*

Description: Serrodiscus daedalus may have attained a length of about 11-12 mm —a relatively small size for the genus. The cephalic rim, about 0.4 of the glabella in length, is rather conspicuous; the marginal furrow is deep and abrupt and the axial furrows are also deep; the posterolateral cephalic spines (fulcral spines) are triangular and large. The anterior, transverse, glabellar furrow, the elongate and pointed anterior glabellar lobe with convex flanks, and the conical shape of the glabella recall a *Ptychagnostus.* There are two pairs of short and deep lateral furrows and a pair of deep isolated occipital apodemal pits. The pygidium is described in the comment below. The test is smooth except for the arc of about twenty rather prominent nodes on the rim.

Comment on illustrated specimens

The holotype cephalon is 4.3 mm long. The median part of the rim is a little tumid and projected retrally; nine pairs of nodes are clear and a tenth pair is just visible close to the midline; the glabella is slightly distorted; its furrows are deep and so is the left occipital apodemal pit; the marginal thickening (outside the arc of nodes) is well defined.

The cephalon Plate 3, fig. 5, CPC 13166, is 4.4 mm long; more than half of it is preserved. The left posterolateral spine lost its tip.

The cephalon Plate 3, fig. 7, CPC 13168, is 2.7 mm long; it is slightly telescoped and the front of the anterior glabellar lobe owing to the deformation appears blunt.

The smallest cephalon, Plate 3, fig. 8, CPC 13169, is about 1.9 mm long. The glabellar furrows are obscure but the frontal lobe is pointed; the margin (outside the arc of nodes) seems depressed.

The pygidium Plate 3, fig. 9, CPC 13170, an external mould, is 4.4 mm long. The preserved pleural lobe is unfurrowed; the axis consists of ten rings; the rim widens retrally, and along the margin the bases of some of the rather delicate spines are barely detectable, but the downward pointing spines themselves are not preserved.

Occurrences and age: Serrodiscus daedalus is a rare species of the Lower Cambrian Cymbric Vale Formation, found only at Site A.

Genus MENISCUCHUS nov.

The type species of *Meniscuchus* is *M. menetus* nov.

Diagnosis: In the species of *Meniscuchus* (1) the pygidial pleural lobes are smooth without furrows and ribs; (2) the pygidial margin is spineless; (3) the frontal part of the cephalic rim is a large and prominent crescent; (4) the glabella is divided by two transverse furrows into three lobes and the middle lobe is narrow (short longitudinally); and (5) the ventral edge of the pygidial rim bears a cuff-like, gently inclined, plate surrounding and enlarging downward the cavity of the pygidial test. The pygidial pleural lobes lack ribs and furrows.

The following three previously described forms attributed to *Calodiscus* Howell (1935) are also species of *Meniscuchus:* (1) *Microdiscus helena* Walcott, 1890; revised by Rasetti (1952, p. 443), a Newfoundland species; (2) the arctic Siberian form attributed to *Calodiscus helena* by Lazarenko (1964 p. 167; pl. 1, figs 1-7); and (3) ?*Calodiscus nanus* Palmer (1968, pl. 2, figs 20, 21, 25, 26), from Alaska; this accepted, *Calodiscus fissifrons* Rasetti (1966, p. 22, pl. 9, figs 17-21), which closely resembles *C. nanus,* may be also placed in *Meniscuchus.*

Differential diagnosis: The characters of *Meniscuchus* enumerated in its diagnosis are in contrast with the structure of *Calodiscus.* The type species of *Calodiscus* is *Agnostus lobatus* Hall, 1847, revised by Walcott (1886; 1890) and placed in the genus *Microdiscus;* Rasetti (1952, p. 441) examined the type material exhaustively and Lochman (1956) studied its synonymy and cephalic morphogeny. The characters of *Calodiscus* are as follows: (1) the pygidial pleural lobes are ribbed and pleural furrows and interpleural grooves are present; (2) the pygidial margin is serrate in plan; (3) the cephalic rim is prominent but relatively narrow and no crescentic structure is evident; (4) the occipital lobe is clear from, and not overgrown by, the occipital part of the glabella; and (5) the glabella (Lochman, op. cit., text-fig. 2, p. 1379) appears more or less trilobate, but its middle lobe is relatively long longitudinally. I share the doubts of Rasetti (1966, p. 24) regarding the generic classification of his new species *Calodiscus fissifrons* and *C. reticulatus.* Indeed, these forms recall *helena* and are 'strikingly different from *Calodiscus lobatus*'; in passing, I note the unfurrowed pygidial pleural lobes of *fissifrons* Rasetti (op. cit., pl. 9, figs 20, 21). *Calodiscus walcotti* Rasetti, 1952 (Rasetti, 1967, p. 45, pl. 1, fig. 4) resembles an *Eodiscus* but is distinguished by its glabella, visibly longer than in *Eodiscus punctatus.*

Kobayashi (1944, p. 50) placed *Microdiscus helena* Walcott in his new genus *Paradiscus* (type: *Microdiscus speciosus* Ford)—a subjective synonym of *Serrodiscus* R. & E. Richter, 1941. The pygidia of *Meniscuchus* and *Serrodiscus* are externally very similar and the downward-directed spines of *Serrodiscus* and the cuff of *M. menetus* are structural homologues. The cephala, however, are disparate and cannot be confused.

MENISCUCHUS MENETUS sp. nov.

(Pl. 4, figs 1-10; Text-fig. 7)

Material: Illustrated are three cephala and three pygidia; about 15 shields have been identified in the collections.

Holotype: The cephalon Plate 4, figs 1-2, CPC 13171, is selected as the holotype because it is well preserved.

Diagnosis: Meniscuchus menetus is distinguished by its relatively wide cephalon (about 1.25-1.3 of its length), a rather prominent frontal rim without nodes, and a multiannulated pygidial axis of seven clear annulations.

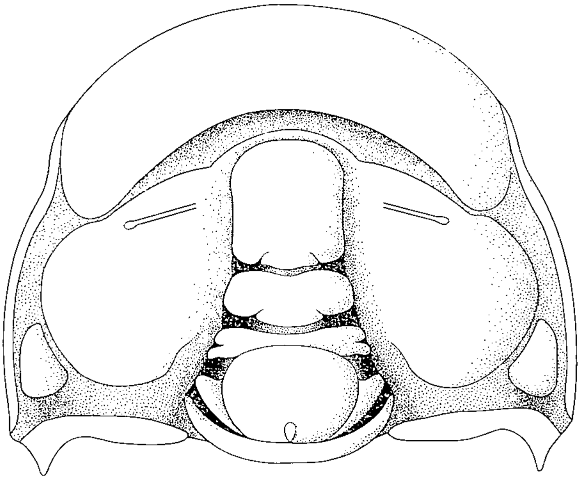

Fig. 7. *Meniscuchus menetus* **gen. et sp. nov., cephalon.**

Differential diagnosis: In *M. helena* the cephalic rim has six nodes (none in *M. menetus*) and the pygidial axis has five annulations (*M. menetus* has seven). In the form attributed to *helena* by Lazarenko (1964) the middle glabellar lobe consists of two lobules (simple in *menetus*) and the cephalic rim is ornate with eight pits (*helena* has six nodes and in *menetus* the rim is smooth), and the pygidial axis has six annulations (one more than in *helena* and one less than in *menetus*). In *M. nanus* Palmer the transverse glabellar furrows are relatively shallow, the cephalic rim is shorter than in *menetus* and has a characteristic median swelling and a retral projection not seen in *menetus;* but, as in *M. menetus,* the rim is smooth (without nodes and pits), and six (or seven?) pygidial axial annulations can be counted.

The structure of the pygidial doublure in *M. helena* and *nanus* is not evident in the published illustrations. In all species of *Meniscuchus* the pygidial rim is externally similar—a narrow and well defined elevated ridge with a vertical margin; I presume that in exfoliated specimens a doublure (as a duplication of the dorsal marginal test) should be noted if present; hence, it is possible that a cuff-like structure seen in *M. menetus* exists in other species, but has escaped detection so far. Rasetti (1966) detected cuff-like structures of the doublure in *Analox* and in *Bathydiscus* Rasetti (1966, p. 17, pl. 1, fig. 3, pl. 9, figs 1-16), which otherwise have no similarity with *Meniscuchus.*

Acimetopus Rasetti, 1966, also has a trilobate glabella whose middle lobe is bipartite as in the *Meniscuchus* attributed to *Calodiscus helena* by Lazarenko (1964, pl. 1, fig. 1); the glabellar structure, however, is the only character shared by *Acimetopus* and *Meniscuchus.*

Description: Meniscuchus menetus is relatively small to medium in size when compared with several other species of its family. The cephalon is a little longer than the pygidium; the thorax, of three segments, is about half the pygidium, as seen in a worn exoskeleton (collection, and courtesy, Mr P. Jell).

The cephalon is widest in the rear and wider than long; the frontal margin is an arc of a circle and the lateral margins are gently convex; the frontal arc and the lateral margins meet at a wide angle on each side almost on the level of the glabellar front—a structure also seen in *Meniscuchus helena* (*Calodiscus,* Rasetti, 1952, pl. 14, fig. 18). I know of no other trilobite with a similar two-phase cephalic outline. The lateral border consists of a narrow rim separated from the acrolobe by a fairly wide and shallow furrow. A pair of swollen nodes fill the rear of the furrows, as in *Bolboparia canadensis* Rasetti, 1966; *B. superba,* however, has two pairs of such nodes. The posterolateral spines are relatively small and a little hooked. The cheeks are very tumid (as in *Bolboparia*), almond-shaped, and joined together in front of the glabella by a thin band. Oblique ocular ridges are just visible in the anterior part of the cheeks and each ends abaxially in a tiny tubercle without reaching the acrolobe margins. Palpebral lobes, eyes, and sutures are absent. The marginal frontal furrow separating the acrolobe from the crescent of the rim is also crescentic and is deep in its median part. The axial furrows, shallow at the glabellar front, deepen and widen retrally and merge with the equally strong posterolateral furrows; the joined furrows also cross the corner at the posterolateral spines. The occipital furrow—a pair of narrow but clear incisions—is discontinuous in the middle, where the glabellar rear and the occipital lobe are fused together; the occipital lobe is a reclined arc.

The flanks of the glabella are concave and its rear is broadly rounded. It is trilobate, dissected by two transverse furrows. The frontal lobe is parallel-sided and bluntly rounded in front; the middle lobe is relatively short and tripartite, with a pair of weak lateral lobules; the posterior lobe, about as long as the frontal, and near pentagonal, consists of a tumid and large central part and a short anterior depression. There are two pairs of lateral furrows: the anterior furrows are short and weak indentations, and the larger posterior pair are bifurcate pits. The rear of the glabella is marked by a little node—either a degenerate or an undeveloped glabellar occipital spine.

The pygidium is about as wide as long or somewhat wider. The rim in plan is a narrow ridge, the pleural lobes are unfurrowed, and the axial lobe, relatively broad and of seven annulations and a tiny terminus, reaches the rim in the rear—a structure of a *Serrodiscus;* low axial nodes resemble *Serrodiscus bellimarginatus* (Shaler & Foerste). (See also Shaw, 1960; Rasetti, 1952; Hutchinson, 1962; and Rushton, 1966.) In profile, however, the pygidium is arched as a whole (axis and rim), and equipped with a cuff in place of a doublure (see diagnosis and comment). The fulcra are quite prominent, and the facets are clear; the pleural lobes appear minutely and densely granulose.

The ventral structure of the cephalon remains unknown; at all events it should accommodate the pygidial cuff in coiled state of the animal.

Comment on illustrated specimens

All specimens belong to the collection from site A.

The holotype, Plate 4, figs 1-2, is preserved as a mould of the external surface on a bedding plane of siltstone; it is 4.4 mm long; details are evident in Text-figure 7. Associated is a fragmentary pygidium of the same species; it is worn, having lost the axial nodes, but the seven axial annulations are evident. The right ocular ridge with its abaxial tubercle seen in figure 1 is masked in figure 2 by a thicker layer of chlorammonia.

The cephalon Plate 4, fig. 3, CPC 13172, is 2.4 mm long; it is flattened but displays the posterolateral border with spines.

The cephalon Plate 4, fig. 4, CPC 13173, is 2.0 mm long and quite small; the latex reflects the granulation of the matrix.

The pygidium Plate 4, figs 5-9, CPC 13174, is 2.7 mm long; its cuff is exposed and surrounds the cavity; the fulcral points are strong and facets are evident; the axial nodes are preserved. The latex cast of the exterior indicates a delicate granulosity of the pleural lobes.

The pygidium Plate 4, fig. 10, CPC 13175, is 1.5 mm long as preserved; it is deformed (telescoped); its cuff is intact but not exposed in places.

Occurrence and age: Meniscuchus menetus is relatively common in the Lower Cambrian Cymbric Vale Formation, at site A; fragments occur also at site B.

Family EODISCIDAE

Genus PAGETIDES Rasetti, 1945

(A review)

Rasetti (1945) in establishing the genus *Pagetides* described five species, including the type species *Pagetides elegans;* in 1948 he added one more species and established that the thorax of *P. elegans* consists of three segments.

Any of the six species of *Pagetides* can be used in identification and generic classification of new species, on the basis of the diagnosis of the genus (Rasetti, 1945, p. 311-312). Likewise, *Pagetia latelimbata* Chien (1961, p. 114, pl. 1, figs 5-7) from China also belong to *Pagetides.*

In brief, the combination of the following characters seems essential in recognition of *Pagetides:* (1) the cephalic rim is convex crescentic, widest and swollen in front and very narrow on the flanks; (2) a terminal axial spine is absent in the pygidium; (3) the pygidial axis is long, slender, and multisegmented; and (4) the pygidial pleural lobes are smooth, without ribs.

Furthermore, it should be noted that *Pagetides* and *Pagetia* possess an occipital spine and in *Pagetia,* depending on the species, the pygidial pleural lobes can be effaced as well as ribbed and furrowed; ribbing is unknown in *Pagetides,* but in some of its pygidia (Rasetti, 1945, pl. 1, figs 4, 10 and 18) vestigial pleural furrows are discernible. I presume therefore that all species of *Pagetides* attained a similar degree of effacement. The age of the American species of *Pagetides* is Early Cambrian (Olenellian), as determined by Rasetti (1967) on the evidence of associated olenellids (op. cit. p. 4-7, 10) cited in the integrated list of the *Pagetides elegans* faunule (ibid., p. 20).

Lazarenko's (1959) Middle Cambrian *Pagetides sibiricus, P. sibiricus calvus,* and *P. spinosus* belong to the genus *Pagetia,* as shown by Rasetti (1966b, p. 502 and 508). In passing, their thorax (Lazarenko, op. cit., p. 10 and 13), as in *Pagetia* consists of two segments.

The generic classification of three Alaskan Early Cambrian forms attributed by Palmer (1968, p. 36-37) to *Pagetides* seems inconclusive: of these *Pagetides granulosus* (op. cit., pl. 2, figs 15, 16 and 24) has a rather narrow cephalic rim and well ribbed and furrowed pygidial pleural lobes; according to Palmer it is most similar to the type species of *Neopagetina.*

Genus NEOPAGETINA Pokrovskaya (1960)

(A review)

Neopagetina Pokrovskaya (1960) replaces the name *Pagetina* Lermontova (1940, p. 121)—a synonym as indicated by Rasetti (1952, p. 438). The type species of the genus as designated by Lermontova is *Pagetina rjonsnitzkii* Lermontova (1940, pl. 35, figs 7-7b), based on cephala and pygidia. A cephalon and a pygidium which are almost identical with Lermontova's figs 7a and 7b are illustrated in N. Tchernysheva et al. (1960, pl. 2, figs 20, 21), and are attributed to Pokrovskaya; Lermontova's original locality (river Peleduy) is mentioned. *Neopagetina* has a narrow cephalic rim, ribbed and furrowed pygidial pleural lobes, a long and multiannulated pygidial axis with median (axial) nodes, and a spineless terminus.

American species are *Neopagetina taconica* Rasetti (1967, p. 66, figs 20-28) and *Neopagetina granulosa* (Palmer). Other described Siberian species are *Neopagetina primaeva* (Lermontova, 1940) and a form attributed by Lazarenko (1962; 1964, p. 177, pl. 1, figs 21-27) to *N. rjonsnitzkii.* Lazarenko's (1964, pl. 2) *Neopagetina orbiculata* and *N. venusta* appear close to *Pagatia.*

Genus DISCOMESITES nov.

The type species of *Discomesites* is *D. fragum* nov.

Diagnosis: Discomesites refers to species of the family Pagetidae without a terminal pygidial axial spine, distinguished by the combination of a cephalon with a large crescentic frontal rim whose middle is thickened, and a pygidium with furrowed and ribbed pleural lobes. The cephalic rim is pustulose and/or venulose.

Differential diagnosis: In *Pagetia* the terminal pygidial spine is present; in *Pagetides* Rasetti, 1945, the cephalic rim is also large, crescentic and thickened in the middle, but furrows and ribs are not present in the pygidial pleural lobes; in *Neopagetina* Pokrovskaya, 1960, the cephalic rim is narrow but the pygidial pleural lobes are furrowed and ribbed; in these forms the pygidial axis also has no terminal spine. The characters of *Pagetides* and *Neopagetina* are discussed above in some detail.

The species of *Discomesites* are *D. fragum* and *D. lunatulus,* and the genus is known so far only from the Cymbric Vale Formation of New South Wales.

DISCOMESITES FRAGUM sp. nov.

(Pl. 5, figs 1-8; Text-fig. 8)

Material: Illustrated are three cephala and one pygidium selected from a larger number of less well preserved shields collected at site A.

Holotype: The cephalon, CPC 13177, Plate 5, fig. 2, is selected as the holotype because of its well preserved occipital point.

Diagnosis: Discomesites fragum is distinguished by the dense papillosity of its test, a very short, pointed occipital spine, and a relatively broad pygidium with six axial annulations.

Differential diagnosis: In *Discomesites lunatulus* sp. nov. the test is smooth, the occipital spine is slender and relatively long, the pygidium is slightly wider than long, is somewhat triangular, and has seven annulations in its axis; its cephalic rim is venulose.

Description: Discomesites fragum may have reached a length of 12 mm—an average size for a species of Pagetidae. All its furrows are well impressed and the lobes are convex; the test is thin without loss of relief in internal casts. The intensity of its pustulosity recalls *Dawsonia* and the less prominent granulose ornament of *Pagetia walcotti* Rasetti (1966b, pl. 60, figs 26, 27).

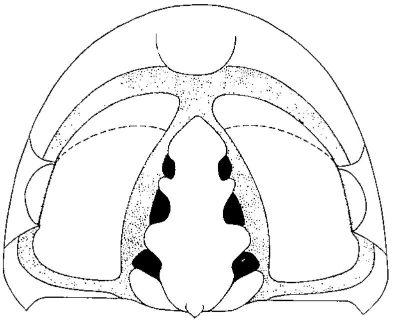

Fig. 8. ***Discomesites fragum*** **gen. et sp. nov., cephalon reconstructed.**

The cephalon is slightly wider than long and semielliptical save for the rearward tilted occipital part of its axial lobe in deformed specimens. The crescentic rim is prominent, broad, and swollen in the middle, and projected retrally opposite the glabellar front; marginal scrobicules (radial impressions) seen in *Pagetia* and *Pagetides* are absent. The marginal furrow is very deep and crescentic and is connected by a short and broad median preglabellar furrow with the axial furrows. The cheeks are moderately tumid; the palpebral lobes, about 0.30-0.32 of the axial lobe in length, are estimated to be larger than in *Pagetia, Pagetides*, and *Neopagetina*; the palpebral furrows are straight and distinct and the eyes (palpebral lobes) are depressed below the summits of the cheeks and placed a little in advance of the middle of the glabella. The ocular ridges are weak, as seen in the holotype, and mostly invisible or possibly absent. The posterolateral (fulcral) spines are short, broad, and trigonal. The occipital lobe is exposed in the holotype as a separate element of the cephalic axis—in plan as a narrow crescentic ridge; the whole structure, however, when undeformed by tilting is an upright arc confluent in the middle with the glabellar arear.

The glabella itself is conical to oval and pointed in front; in profile (Pl. 5, fig. 4) it rises upward and terminates as a short occipital spine well above the level of the cheeks. Two pairs of short, deep, and pit-like lateral furrows are evident and a third (posterior) pair is sunk in front of the lateral parts of the occipital lobe.

The pygidium is about semicircular in outline and the acrolobe convex. The rim is very narrow and prominent and the marginal furrow is narrow and deep; the fulcral points are distinct and the facets are developed as well as in polymerid trilobites. Six pairs of pleural ribs are defined by deep and regular pleural furrows, and behind the axis a pair of very small nodes separated by a median posterior furrow can be interpreted as a seventh rudimentary pair of ribs. Interpleural partitions (grooves) are also indicated on the crest of ribs, but are weak as well as masked by the coarse ornament. The axial lobe has straight converging flanks and is long, but remains separated from the marginal furrow by the pair of the rudimentary pleural ribs. There are six well defined annulations, the seventh being the terminus; each of the six annulations bears a median node and in profile the axis slopes in a gentle arc rearward.

Comment on illustrated specimens

The holotype cranidium, CPC 13177, Plate 5, fig. 2, is 3.8 mm long. The palpebral lobes are lost; the median swelling of the rim is low and its retral projection is gentle; the lateral glabellar furrows are well developed; the occipital point (spine) is intact; the right posterolateral spine is preserved and recalls an agnostid by its position and shape. The ocular ridges are indicated. The glabellar furrows are oblique owing to the retrally directed collapse of the glabella.

The cranidium Plate 5, fig. 1, CPC 13176, is 3.2 mm long. The left palpebral furrow is visible; the retral projection of the rim is angular; ocular ridges are not evident.

The fragmentary cranidium Plate 5, figs 3-4, CPC 13178, is 3.7 mm long. The glabellar furrows are deep pits; the free cheek is displaced inward but part of it is visible under the palpebral lobe and its outline is indicated by the gap. The anterior suture truncates the rear of the rim, which slopes down and is relatively broad, indicating a similar broad subocular rim. The coarse granules visible under the palpebral lobe belong, apparently, to the ornament, but their regular linear arrangement and position recall coarse ocelli of a schizochroal eye —much coarser and less in number than in *Pagetia* (Öpik, 1963, p. 57, text-fig. 15). The glabella preserves its relief and the original attitudes of its lateral furrows, which are deformed in the holotype.

The pygidium Plate 5, figs 5-8, CPC 13179, is 2.6 mm long. There are worn median nodes on the axial lobe; on the ribs interpleural grooves are evident in spite of the masking effect of the dense ornament.

Occurrence and age: Discomesites fragum sp nov. is a common fossil in the Lower Cambrian Cymbric Vale Formation; the illustrated specimens came from site A, but the species is also present at site B.

DISCOMESITES LUNATULUS sp. nov.

(Pl. 6, figs 1-4)

Material: Illustrated are two cranidia and two pygidia selected from about ten shields; it is a relatively rare species.

Holotype: The cranidium, Plate 6, fig. 1, CPC 13180, is selected as the holotype.

Diagnosis: Discomesites lunatulus is distinguished by a smooth test, an irregularly pitted and venulose cephalic rim, a slender occipital spine, and seven pygidial axial annulations.

Differential diagnosis: D. lunatulus differs from *D. fragum* in all characters which are included in the diagnosis; the characters of the genus *Discomesites* in *D. lunatulus* are the crescentic and large cephalic rim and the furrows and ribs in the pygidium.

Description: Essential descriptive data are given in the diagnosis and in the comment that follows below. The cephalic rim is large and its venulose and pitted caecal relief is unique—in other eodiscids the radial scrobicules are straight furrows. The marginal frontal furrow is deep but narrow, narrower than in *D. fragum.* The ocular ridges occur sporadically and are indicated in the holotype. The palpebral lobes are placed just in front of the middle of the glabella. The anterior glabellar furrows are rather weak, but the others are well impressed. In the pygidium the interpleural partitions are well visible owing to the absence of the masking papillosity of *D. fragum.* The pygidial axis is arched in profile and its terminus touches the marginal furrow. The material available indicates exoskeletons up to 7 mm long—smaller than *D. fragum.*

Comment on illustrated specimens

The holotype and the two pygidia belong to the collection from Site A.

The holotype, CPC 13180, Plate 6, fig. 1, is 3.0 mm long; it is somewhat distorted but shows a part of the occipital spine.

The cranidium Plate 6, fig. 2, CPC 13181, collection from site B, is 2.3 mm long; the glabellar furrows and the base of the occipital spine are preserved; the frontal marginal furrow is narrower and the frontal crescent larger than in *D. fragum*.

The pygidium Plate 6, fig. 3, CPC 13182, is 2.5 mm long; it is laterally deformed.

The pygidium Plate 6, fig. 4, CPC 13183, is 2.25 mm long and 2.5 mm wide; the axial nodes and the silicified test are preserved.

Occurrence and age: Discomesites lunatulus occurs at both sites of the Lower Cambrian Cymbric Vale Formation.

Genus PAGETIA Walcott, 1916

PAGETIA sp. nov.

(Pl. 6, fig. 5)

The illustrated pygidium, CPC 13184, a rubber cast, is 1.5 mm long; it is assigned to *Pagetia* by virtue of its terminal axial spine, which, however, could not be reproduced by the latex. The shield is strongly convex and triangular; its rim is very narrow; the pleural lobes are furrowed and ribbed and four pairs of ribs are evident; the axis, of five annulations and the terminus, is rather broad, elevated, and equipped with median nodes.

It recalls *Pagetia resseri* Kobayashi (*vide* Rasetti, 1966b, pl. 60, figs 19, 22, and 25) as regards the number of ribs and axial annulations; in *P. maladensis* the rim is wider and the axis narrower than in our specimen. The ribbing of the pygidium conforms with the concept of the subgenus *Eopagetia* Kobayashi, 1942.

Occurrence and age: The illustrated pygidium of *Pagetia* has been found in a silicified limestone part of the Cambrian Cymbric Vale Formation, Site B.

BRACHIOPODA

The Brachiopoda are represented by a small *Lingulella,* CPC 13147, and the Neotremata *Botsfordia* and *Neobolus;* the shells are ill preserved and are unsuitable for specific interpretation.

Genus BOTSFORDIA Matthew, 1892

See Walcott (1912); Schindewolf (1955)

BOTSFORDIA sp. indet. cf. B. CAELATA (Hall)

The examined material consists of some twelve isolated valves; three, one ventral and two dorsal, are included in the collection of type specimens (CPC 13148, CPC 13149, and CPC 13150 respectively) but none is illustrated. The largest dorsal valve is about 6.0 mm and the ventral 2.5 mm long; the test is not preserved. The resemblance to *Botsfordia caelata* is apparent in the external concentric ornament, suppressing the radial striation, which may be even absent altogether. The ventral valve is recognized from the retral position of the low apex and the open delthyrium; a low median septum is present in the dorsal valve; these are the characters of the genus *Botsfordia.*

Occurrence and age: Botsfordia sp. indet. occurs in siltstone, site A, of the Lower Cambrian Cymbric Vale Formation.

Genus Neobolus Waagen, 1885

Revised by Schindewolf (1955).

Neobolus? sp. indet.

(Pl. 6, fig. 6)

The illustrated specimen, CPC 13185, represents the sole material found so far. It is 12.00 mm long; it is partly the outer layer of the phosphatic test and partly the corroded visceral part in the middle; embedded convex upwards, it is illustrated from a rubber cast. It is a fragment of a dorsal valve whose internal features, especially the prominent median septum, recall *Neobolus warthi* Waagen as published by Schindewolf (1955, pl. 14, fig. 3); nevertheless it belongs to a different species.

Occurrence and age: In siltstone of the Lower Cambrian Cymbric Vale Formation, site A.

MOLLUSCA

MONOPLACOPHORA

Genus Scenella Billings, 1872

Scenella reticulata Billings

(Pl. 6, fig. 8; Text-fig. 9)

The material consists of the illustrated shell, CPC 13187, apparently the external surface, in siltstone.

Knight (1941, p. 309, pl. 2, figs 5a-c) described the holotype of *Scenella reticulata* and stated that 'Billings never figured the species'.

The specimen in hand is 7.0 mm long, a little flattened, deformed and defective at the top and edge. The ornamental radiating lirae seem wider spaced than in the holotype; but this is only apparent because our illustration is magnified seven and Knight's figures four times; furthermore, the culmination appears subcentral because our specimen is not photographed with its edge horizontal; its profile, however (Text-fig. 9), shows the culmination in an excentral position in the direction of the arbitrary rear of the shell, as in the holotype (Knight, op. cit., pl. 2, fig. 5a). There are also the 'somewhat irregular concentric rugae' as in the holotype. The width of the holotype is 0.75 of its length against 0.7 in our specimen—a difference in shape of no taxonomic meaning in view of the secondary deformation.

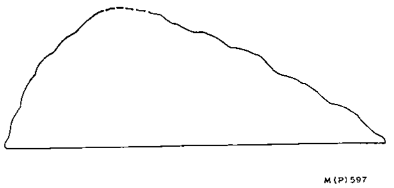

Fig. 9. *Scenella reticulata,* **profile of specimen Plate 6, fig. 8.**

Occurrence and age: The illustrated shell came from the Lower Cambrian Cymbric Vale Formation, site A.

Scenella sp. indet. (aff. Scenella antiqua Kiaer, 1916)

(Pl. 6, fig. 7)

The illustrated fragment, CPC 13186, is 3.5 mm long; its ornament is dominated by concentric growth-lines; the radiating lirae, however, are weak and concentric rugae are apparently absent. This ornament is different from *Scenella* *reticulata,* but recalls *Scenella antiqua* Kiaer (1916, pl. 2, figs 1-1b). The fragment is, however, insufficient for a conclusive specific identification; even a modification of *Scenella reticulata* cannot be excluded.

Occurrence and age: The fragment came from the Lower Cambrian Cymbric Vale Formation, site A.

SUPPLEMENT: TRILOBITES FROM 'NEAR KULPARA', SOUTH AUSTRALIA

Two trilobites, *Bigotina tina* sp. nov. and *Dolerolenus*(?) sp. nov. are described here. These fossils are not part of, and are much older than, the Cymbric Vale fauna; I presume, however, that the Early Cambrian faunas of western New South Wales and of South Australia lived in closely communicating seaways and in geographical proximity to each other—an integrated sequence of biostratigraphic events. The occurrence of *Bigotina* indicates a rather early step in the deposition of the South Australian Parara Limestone and, by extrapolation, an even older Early Cambrian age of the strata below, as for example, the Ajax Limestone, whose age in terms of archaeocyathids has been underestimated; the Lower Cambrian of South Australia is as complete as in Sonora, in Newfoundland, or in the Baltic region, or in Siberia.

The trilobites were collected by Barnes & Kleeman (1934, p. 7-9) in material from a 'pipe track' (trench) about 3 km east of Kulpara, Yorke Peninsula; the position of the site is relatively low in the Parara Limestone, dipping east and separated in the west from the older Kulpara Limestone by a fault; the lower part of the Parara Limestone is, therefore, not expected, as can be seen from the locality plan (op. cit., p. 8). Further information regarding the Parara Limestone near Kulpara has been given by Daily (1956; 1957, p. 105-106, 131), and by Glaessner & Parkin (1958, p. 48 and 53).

Daily (op. cit.) assigned the fossils from 'near Kulpara' to his assemblages 5, 6, and 7; the site of the described collection (the track, locality plan, Barnes & Kleeman) has a low position in the outcrop and the trilobites therefore belong to, or are older than, assemblage 5. *Bigotina tina* occurs also in assemblage 4, in association with *Bigotina tatei* (Woodward), at Curramulka (Kobayashi, 1942, p. 493, fig. 4).

Quoting from the paper of Barnes & Kleeman (1934, p. 9)—

> 'The trilobite remains found were submitted to Mr F. Chapman, F.L.S., etc., Commonwealth Palaeontologist, who kindly supplied the following note; "They seem to represent a Middle Cambrian facies and are all referable to two species of the genus *Ptychoparia.* The species with the smaller cephalon bears a close resemblance to Woodward's *Dolichometopus tatei,* but as the original type specimen is very imperfect there is a doubt about it and it may be a new species. The other species is related to *Ptychoparia howchini,* but as the apex of the glabella in your specimen is much more pointed, this also is probably new".'

The genus *Bigotina* Cobbold (1935) was unknown in 1934; *Ptychoparia howchini* Etheridge (1919, p. 385, pl. 40, fig. 7) is based on an imperfect cranidium; according to Daily (op. cit., p. 130) it belongs to assemblage 3 and is a synonym of *Yorkella australia* (Woodward); it may belong, however, to an unknown form of Dolerolenidae or Anadoxididae. *Yorkella australia* itself, in my opinion, is akin to *Dolerolenus.*

The collections of the Commonwealth Palaeontologist were subsequently transferred to the Bureau of Mineral Resources in Canberra; in 1949 I commenced the study of the Barnes & Kleeman collection; in 1952 the study was interrupted by a fire; the specimens were recovered from the cinders—two singed and black pieces of the originally yellow shale; the fossils are intact but unfit for further dematrication.

Superfamily ELLIPSOCEPHALACEA Matthew, 1887

Subfamily BIGOTININAE Hupé, 1953

Genus BIGOTINA Cobbold, 1935

Pararaia Kobayashi, 1942 is a subjective junior synonym of *Bigotina;* the type species of *Pararaia* is *Dolichometopus tatei* Woodward, 1884. At first Kobayashi (1935, p. 209, pl. 24, fig. 7) illustrated a replica of a plaster cast of the type specimen of *Dolichometopus tatei* as a *Lorenzella,* which he replaced later by the name *Pararaia* (Kobayashi, 1942, p. 494, figs 2-3, (?) 4). The illustrations of *Lorenzella tatei* represent a *Bigotina* with an angulate frontal margin seen also in *Bigotina angulata* Suvorova (1960, p. 38).

Dolichometopus tatei Woodward (op. cit., pl. 11, fig. 3) is monotypical and based on a cranidium with a forward arched frontal margin—subangulate in Etheridge's illustration of the same type (1919, pl. 39, fig. 2). The type cranidium is interpretable as a *Bigotina* with a strong relief, relatively long frontal area, moderately wide interocular cheeks, and evenly arched ocular ridges and palpebral lobes.

Kobayashi (1942) attributed three more cranidia to *Pararaia tatei;* one of them (op. cit., fig. 2) has a long frontal area and probably belongs to *tatei;* at the same time he queried the specific identity of the cranidium in his figure 4; a similar but better preserved cranidium is described below under the name of *Bigotina tina* sp. nov.

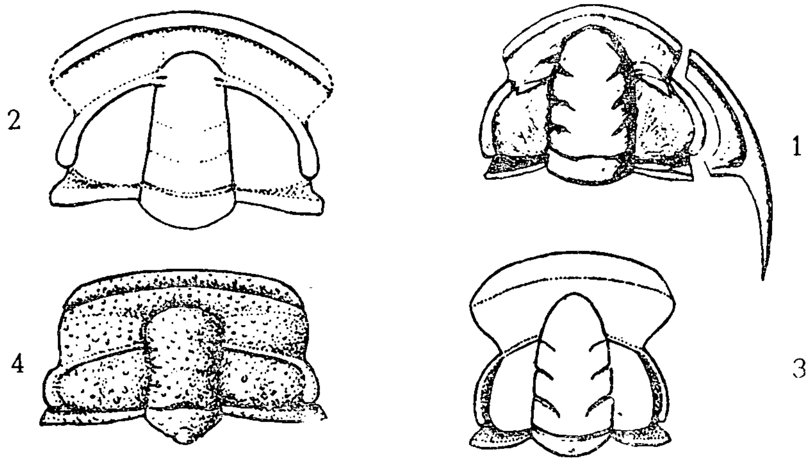

Fig. 10. 1—*Protolenus paradoxoides*; 2—*Bigotina bivallata*; 3—*Lusatiops*; 4—*Aldonaia*. Facsimile from R. & E. Richter (1948, p. 28).

The type species of *Bigotina* is *B. bivallata* Cobbold (1935, p. 383, pl. 27, figs 1-10); the holotype designated by Cobbold (p. 391, fig. 1) is a cranidium, 5.0 mm long; the species occurs at a single site in Normandy, and its age is given as 'Cambrian; zone unknown'. According to Cobbold *Bigotina* (Text-fig. 10) is related to *Protolenus;* R. & E. Richter (1948), Hupé (1953), and Harrington et al. (1959) placed it in the Protolenidae R. & E. Richter, 1948. Öpik (1968, p. 151) indicated that *Bigotina* is close to the ellipsocephalids and protolenids; Protoleninae and Bigotininae are anyway subfamilies of the Ellipsocephalacea. Sdzuy (1961, p. 540) also lists as belonging to the Bigotininae Hupé's (1953) genera *Bigotinops, Pruvostina,* and *Ouijjania,* which should be accepted together with *Bigotinella* Suvorova (1960, p. 40). According to Sdzuy (loc. cit.), however, the Bigotininae are Dolerolenidae, which is not acceptable for reasons given by Öpik (1958, p. 151); Suvorova (1960) kept it in the Neoredlichiidae; Repina (1960) placed *Bigotina* in the Aldonaiidae, but settled later (1965; 1966) for Protolenidae.

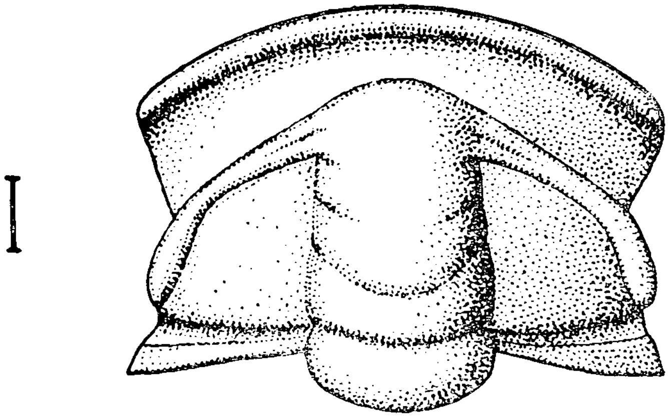

Fig. 11. *Bigotina bivallata,* **facsimile from Hupe (1953, p. 212).**

Cobbold's *Bigotina bivallata* has been re-examined by Hupé (1953, p. 212, text-fig. 47; see Fig. 11). His reconstruction of the cranidium, based on an ample supply of material, lacks the frontal boss seen in Cobbold's specimens and the shape of the glabella is also different (less elongate and less tapering) than in the type and its plausible reconstruction by R. & E. Richter (1948, fig. 2). According to Hupé the species is very polymorph and specimens with a subconical glabella and others with a frontal boss are also present. Of the three Siberian species of the genus, *Bigotina egregia* Repina (1960, p. 178, pl. 20, fig. 3) and *B. angulata* Suvorova (1960, p. 38, pl. 2, figs 20, 21, and text-fig. 10) are quite close to *B. bivallata* and *B. tina;* the third species, *B. coniferica* Repina (1960, pl. 2, fig. 4), differs by its concave brim and upturned frontal margin, but Repina (1966, p. 138) regards it as a synonym of *B. egregia.*

Bigotina is known only from its cephalon—the cranidium and isolated free cheeks; the free cheek is relatively narrow, with a border continuous to a slightly deflected and not advanced genal spine. The anterior sutures diverge moderately; close to the ocular ridges the sutures curve slightly abaxially and meet like palpebral lobes at an acute angle—a peculiar structure seen in *B. bivallata* (in Richter's reconstruction), *B. angulata* Suvorova (1960, pl. 2, fig. 20), and *B. tina*

(Text-fig. 12). The posterior sutures are short, straight, oblique, retral, and define rather tiny posterolateral limbs—requisites of the ellipsocephalids and protolenids, as is the position of the posterior tips of the palpebral lobes in contact with the posterolateral furrows. The palpebral lobes are relatively short and inseparable from the ocular ridges; these are duplicated adaxially. The interocular cheeks are visibly wide and defined by furrows all round. The frontal rim is well defined, narrow and convex, and a median boss separates the rim from the glabellar front. The glabella has straight flanks and tapers moderately to a bluntly rounded front; there are three pairs of shallow lateral furrows. The occipital furrow is distinct and the occipital lobe lacks a spine.

Bigotina is an ingredient of the Olenellian Lower Cambrian in Siberia; Suvorova (1960) described *Bigotina angulata* from the river Lena, and Repina (1960) describes *B. egregia* from the Sayan Mountains. According to Khomentovsky & Repina (1965, table 9) *Bigotina* is an early Aldanian trilobite of the same age as the olenellids *Fallotaspis* Hupé and *Profallotaspis* Repina and slightly older than those associated by *Paedeumias, Archaeaspis* Repina, and *Pagetiellus anabarus* (Weymouthiidae, q.v.). The scale position of *Bigotina* is shown in our chart (Text-fig. 3); according to Khomentovsky & Repina (loc. cit.) it belongs to the Kenyada horizon as well.

BIGOTINA TINA sp. nov.

(Pl. 7, fig. 1; Text-fig. 12)

The species *Bigotina tina* is monotypical; the illustrated cranidium CPC 13188 is the holotype; it is 10.0 mm long and preserved as a mould in shale.

Diagnosis: Bigotina tina has an evenly curved frontal cranidial margin, a relatively wide (sagitally) frontal area with a boss, and a moderately tapering glabella, and is distinguished by the kink (geniculation) of the distal ends of the ocular ridges and the relatively broad glabella.

Differential diagnosis: In other species of the genus the ocular ridges and the palpebral lobes together are evenly arcuate (kinkless); in *B. angulata* Suvorova, 1960, the front is angulate and the frontal area relatively short; in *B. egregia* Repina, 1960, the glabella is slender and the interocular cheeks together with the palpebral lobe are visibly wider than in *tina;* in *B. bivallata* Cobbold, 1935, the glabella is slender (Cobbold's illustrations and Richter's interpretation, 1948) or broad and almost cylindrical according to Hupé, 1953. Finally, in *B. tatei* (Woodward) the frontal area is very wide, the margin projects forward, and the cranidial relief is strong.

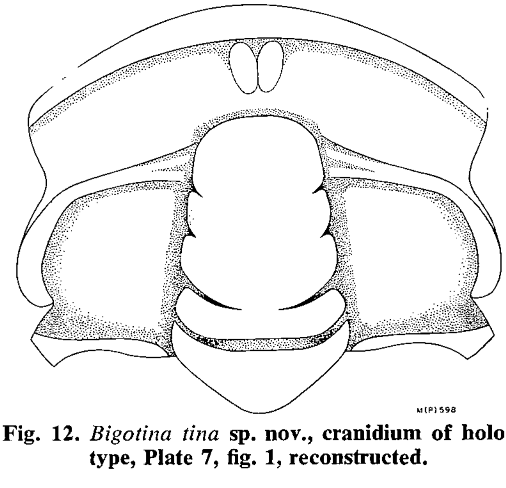

Fig. 12. *Bigotina tina* **sp. nov., cranidium of holotype, Plate 7, fig. 1, reconstructed.**

Description: In brief, the cranidial frontal rim is relatively prominent and convex; the boss is low and indistinctly bilobate, reminiscent of *B. bilobata* Suvorova; the anterior sutures diverge apparently less than in *B. bivallata;* the adaxial duplication of the ocular ridges is weakly indicated (strong in *B. bivallata*); the interocular cheeks together with the palpebral lobes are slightly wider than the glabellar rear; the glabella (without the occipital lobe) is twice the length of the frontal area; the glabella in outline is flowerpot-shaped, its front is bluntly rounded, and as a whole its design is ptychopariid.

Occurrence and age: Bigotina tina occurs in the Parara Limestone, east of Kulpara and at Curramulka in association with *Bigotina tatei* (Woodward); its age is early Olenellian.

Family DOLEROLENIDAE Kobayashi, 1951
(pro Olenopsidae Kobayashi, 1935)

According to Nicosia & Rasetti (1970) the genus *Metadoxides* is unrecognizable and the name Metadoxidinae (-idae) Whitehouse, 1939, shares the fate of its type genus. The published concepts of these taxa, however, refer to the genus *Anadoxides* Matthew, 1899—erroneously suppressed in favour of *Metadoxides* Bornemann, 1891—and the family name Metadoxididae is replaced by Anadoxididae Nicosia & Rasetti, 1970. Consequently *Onaraspis* Öpik (1958) is also a genus of the Anadoxididae; this change in nomenclature, however, has no influence on the concepts of the Dolerolenidae and 'Metadoxididae' as discussed by Öpik (op. cit., p. 150-151); in *Anadoxides armatus* (the type of the genus) the frontal area is short and 'compacted' and the pleural lobes of the pygidium are ribbed, but in *Dolerolenus* the frontal area is large with a rim and a brim, and the pygidial pleural lobes are undeveloped. A subfamily Anadoxidinae of the Dolerolenidae seems a possibility, of course.

DOLEROLENUS(?) sp. nov.
(Pl. 7, fig. 2; Text-fig. 13)

The specimen (CPC 13189) of singed shale contains three cranidia, and latex casts of two are illustrated. The largest is 20.0 mm long; on the left side (in the picture) the test is preserved and adheres to the matrix; on the other side parts of the test are lost and the mould (here its cast) exhibits the exterior of the cranidium. The rim is fractured, the front of the glabella collapsed, the antero-lateral corners of the frontal limb and the posterolateral limb beyond the fulcrum are missing; the occipital spine is indicated by its imprint. In the reconstruction (Text-fig. 13) the posterolateral limbs are shown relatively short—a probability indicated by the very wide interocular cheeks and the advanced position of the palpebral tips.

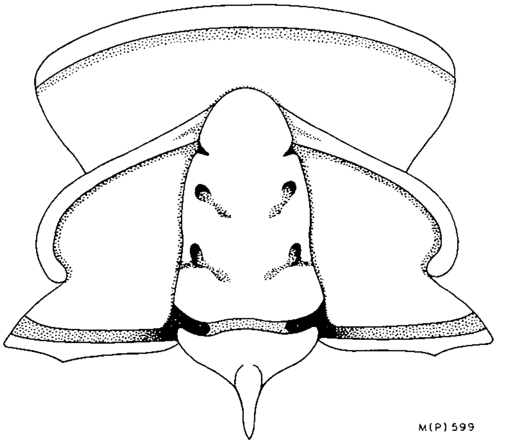

Fig. 13. *Dolerolenus(?)* **sp. nov., cranidium of specimens Plate 7, fig. 2, reconstructed.**

The generic classification is tentative (*Dolerolenus*?); it is queried because the pygidium is unknown and the interocular cheeks are very wide, wider than in the known species of *Dolerolenus* and the dolerolenids *Sibiriaspis, Sajanaspis,* and *Tungusella* (all by Repina, 1960; see Repina, 1966). Another possibility is *Lunolenus* Sdzuy (1962, p. 196) in which the frontal area is also large; but the interocular cheeks are still narrower than in *Dolerolenus*(?) sp. nov. In general terms the latter recalls also *Parabadiella* Chang (1966, pl. 1, fig. 1), which itself, however, cannot be attributed to the *Dolerolenidae.*

Description: In *Dolerolenus*(?) sp. nov. the cranidial furrows are narrow but clear; the rim is narrow and convex and the brim, apparently flattened, seems convex. The palpebral lobes are relatively short and almost hooked in the rear, and pass into the prominent ocular ridges; these are split adaxially and terminate close to the glabellar front. The glabella is relatively long and slender and tapers evenly forward. Three pairs of lateral furrows are evident and in the furrows of the two posterior pairs pits are developed—two in each furrow. Similar pits are also evident at the end of the otherwise shallow occipital furrow. The brim is delicately venulose and possesses a pair of strongly divergent veins arising from the ocular ridges. The test is granulose.

GLOSSARY

(Explanation of taxonomic names)

cerastes (*Strenax*): Greek 'horned'.

daedalus (*Serrodiscus*): Lat., Greek, 'curiously wrought', 'artful'.

Discomesites, Masc.: Greek, *discus*—quoit; *mesites*—'mediator', alludes to characters intermediate between several related genera; the word 'discus' is a recurrent ingredient in eodiscid names.

fletcheri (*Sematiscus*): dedication to the palaeontologist H. O. Fletcher of Sydney.

fragum (*Discomesites*): Lat., strawberry; alludes to the granulose ornament—recalling the achene of the berry.

lunatulus (*Discomesites*): Lat. small and with crescent.

menetus (*Meniscuchus*): Greek; steadfast.

Meniscuchus, Masc.: Greek; *meniscus*—crescentic head protection; *uchus* (*ouchus*) —bearer (of the crescent).

Sematiscus, Masc.: Greek, *sema,* token—'small token'.

Strenax, Masc.: Greek, *strenes,* harsh; gen. *strenac-os;* recalls the *Lat. Strenuella strenua* (brisk) but not derived from it.

tina (*Bigotina*): the ending—*tina*—of the name of the genus.

PART 2: EARLY CAMBRIAN STRATIGRAPHY

THE RECORD OF FOSSILIFEROUS LOWER CAMBRIAN (GEORGIAN) IN AUSTRALIA

(Chart, Text-fig. 3, p. ??)

Geographical distribution and problems of correlation

The geographical distribution of Lower Cambrian in Australia was reviewed by Öpik (1957, p. 248-250) and its palaeogeography contemplated. The main occurrences known at that date were the MacDonnell Ranges in the Northern Territory and the South Australian region (Daily, 1956).

In the Northern Territory fossiliferous Lower Cambrian occurs in the Amadeus Basin (Wells et al., 1970) and in the Huckitta area (Smith, 1964). The Arumbera Sandstone (Amadeus Basin) contains trace fossils of a Lower Cambrian aspect in its upper levels, and *Rangea arborea* (*R.* cf. *longa* in Glaessner, 1969), a late Proterozoic (Ediacara) form. Another formation, the Todd River Dolomite, may be a biostratigraphic equivalent of the lower part of the Hawker Group of the Flinders Ranges. In the Huckitta area the Mount Baldwin Formation (the youngest of the Mopunga Group) has an interbed of dolomite with archaeocyathids and another with trilobite cranidia attributable to a species of *Bigotina.* This collection, unfortunately, is not at hand now. The Grant Bluff Formation (below the Mount Baldwin) contains casts of a form of 'double spiral' fossils (Öpik, 1956, p. 30) indicating a possible Early Cambrian (Estonian) age. A more recent discovery is fossiliferous Lower Cambrian in the Ngalia Basin.

The fossils from the Northern Territory still remain undescribed, but some progress has been made in South Australia, as discussed below; Lower Cambrian has been also discovered in Queensland (Öpik, 1960)—the Mount Birnie Beds with *Diplocraterion* and *Crossocharda,* and the Sun Hill Arkose with *Protichnites* and *Rusophycus*—and in New South Wales—the Cymbric Vale fauna. All these areas are east of the eastern limit of the Lower Cambrian seaway of Öpik (1957, map, p. 249). On the same map the bank of the Camooweal Dolomite is included in the Lower Cambrian; it is, however, Ordian (Öpik *in* Öpik, Carter, & Randal, 1973) at least on its outcropping top, on the evidence of its fossils, including cranidia of the trilobite *Parapolliella* sp. nov.—a genus of the Siberian Lena Stage (Keteme). The area allotted to the Camooweal Dolomite on maps includes outliers of younger strata which have no bearing on the concept of that formation. Likewise, the dolomite de Keyser (1973, p. 15) calls Camooweal Dolomite resting on the Middle Cambrian Currant Bush Limestone in the Lawn Hill area is evidently a part of the Louie Creek Limestone sequence (Öpik, *in* Carter & Öpik, 1961, p. 10-11), which contains a fauna of the *Euagnostus opimus* Zone (Öpik, 1970a, p. 2 and 4). Thorntonia Limestone (de Keyser, loc. cit.) is represented in the same area by its lowermost part with *Redlichia* and *Girvanella,* and is of a late Ordian age (Öpik, op. cit.). The presence of the Camooweal Dolomite in the Canyons area (Öpik, op. cit., p. 10) remains a matter for further inquiry. In the Ngalia Basin, northwest of Alice Springs (Quinlan, 1962; Cook & Scott, 1967) in the Yuendumu Aboriginal Reserve, Early Cambrian fossils occur in a sequence of sandstone and limestone (see below, p. ??).

Early Cambrian in sequence with late Proterozoic has also been described from Central Mount Stuart and the Eastern MacDonnell Ranges. The Central Mount Stuart Beds in the Harrow Creek Sheet area (Smith & Milligan, 1964) rest conformably below the glauconitic sequence attributed to the Grant Bluff Formation regarded as Proterozoic to Early Cambrian in age: it yielded a shell of *Helcionella* (op. cit., p. 10)—an Early Cambrian fossil postdating the Proterozoic/Cambrian transition; the Central Mount Stuart Beds are placed with Upper Proterozoic, but Quinlan (1962) mapped them as Lower Cambrian.

The medusae described by Wade (1970) from the Mount Skinner area are novel and therefore their age is inconclusive, but they are attributed to the Central Mount Stuart Beds. If this is correct the age of the medusae is probably late Precambrian rather than Cambrian.

The presence of *Helcionella* in the glauconitic strata at BC3, 36 km southeast of Barrow Creek, means Early Cambrian, and the glauconitic lithology refers to the Grant Bluff Formation, whose nearest outcrop is 160 km south, at Native Gap in the Hann Range; from here eastward, about the parallels 22°40′-23°15′, sites of folded Grant Bluff Formation have been identified for some 600 km towards and close to the Queensland border. The most easterly sites have been mapped in the Hay River Sheet area (Smith et al., 1962). In these sites I have found no shelly fossils, and the Barrow Creek BC3 *Helcionella* remains unique; its Early Cambrian age, when applied to the whole sequence, vertically and regionally, appears a reasonable but still audacious extrapolation.

The Grant Bluff strata contain in places trace fossils and a Problematicum structurally similar to, but not identical with, the fossil I have described (1956,

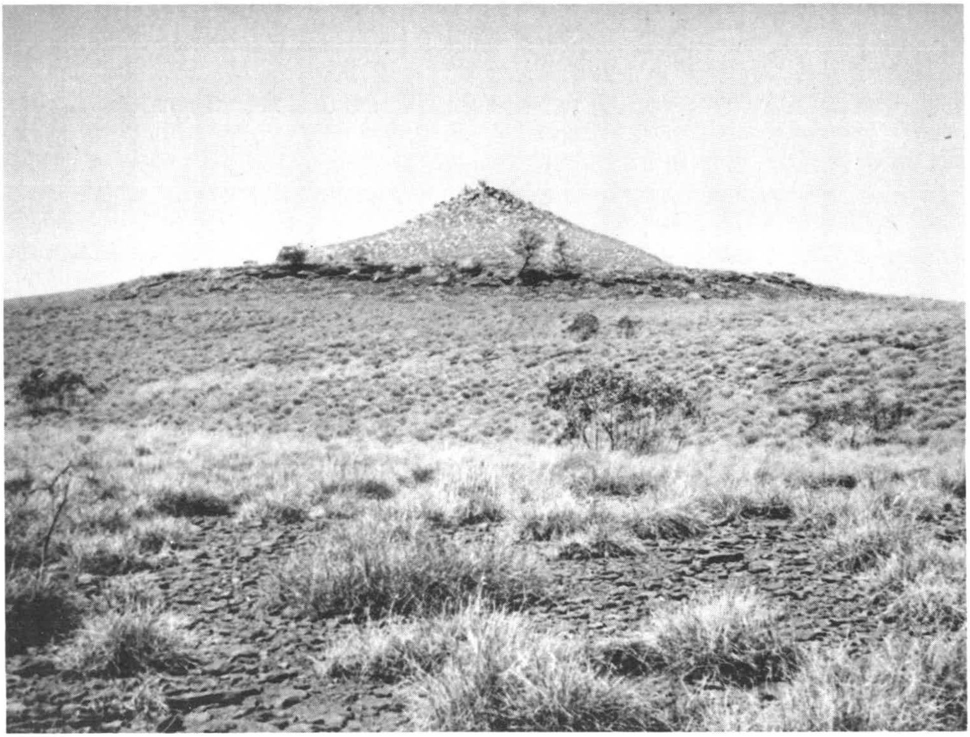

Fig. 14. Scenery 19 km southwest from Barrow Creek. A butte of rock over arkose of the Central Mount Stuart Beds (author's photo).

p. 29-30) as a 'double spiral' object. I have observed it on Grant Bluff itself and in outcrops of the Hay River area, and it is common in sandstone (below siltstone or shale) in the Hann Range just east of Native Gap (110 km north of Alice Springs). On the west side of the Gap these objects are absent, but I have noted vestigial *Scolithus* pipes.

Smith & Milligan (op. cit., p. 9, 10) indicate that the Grant Bluff Formation lies conformably on the Central Mount Stuart Beds, but show the contact as unconformable in their stratigraphic table; and indeed an interformational hiatus may separate them. Three small residuals of sandstone near Mount Stirling, one of which is a 10 m high butte (Text-fig. 14), and another tiny butte of conglomerate and sandstone over bleached arkose in a low erosional depression on the Stuart Highway 20 km southwest of Barrow Creek, could be expressions of such a hiatus. Smith & Milligan mapped the Mount Stirling residual as Tomahawk Beds (Upper Cambrian to Ordovician); but the *Scolithus* sandstone that caps the 10 m butte could represent a *Scolithus* bank at the base of the Grant Bluff Formation, resting disconformably or even unconformably on truncated Central Mount Stuart Beds.

In the Mopunga Group (Smith, 1963, 1964) the Grant Bluff Formation is overlain by the Mount Baldwin Formation, whose fossils indicate an Early Cambrian (but apparently not the earliest) age. Below the Grant Bluff in the Group, the Elyuah Formation in the Huckitta area and the Central Mount Stuart Beds near Barrow Creek are both arkosic and occupy similar positions in analogous sequences. It appears therefore that the Central Mount Stuart and the Elyuah Formation were deposited concurrently and probably within the Precambrian/Cambrian interval of transition.

Some problems of correlation and dating

In the existing literature the Lower Cambrian in Australia is treated in terms of formations and groups adapted to mapping requirements and no scale of stages and zones has been presented; the biostratigraphy is, therefore, obscure. Operational in correlations are the 'fossil assemblages' of Daily (1956), of quite abundant but undescribed material; and the archaeocyathids (Hill, 1964a, b, 1965; Walter, 1967) are interpreted in terms of their Siberian *gorizonts,* which themselves are subject to dating by the more reliable trilobites.

The correlation of the Australian Lower Cambrian is discussed here as regards the Cymbric Vale (N.S.W.) and the South Australian faunas, the Ordian, and the faunas in the Northern Hemisphere. The survey is based on the distribution of genera of trilobites; some genera but no species are interprovincial, and correlations remain therefore approximate. I use 'Early Cambrian' in the sense of the traditional priority concept of that Epoch—Walcott's 'Lower Cambrian or *Olenellus* Zone', and the extended Early Cambrian as the 'Leno-Aldan' (Öpik, 1968a, p. 137). This concept is illustrated in column B of the chart (Text-fig. 3). The upper interpolated limit of the Olenellian in the chart (a dashed line) separates it from the Australian Ordian as proposed by Öpik (1968a); in the Siberian column the same line indicates the ceiling of the occurrence of Olenellidae, which are known in the lower and unknown in the upper horizons of the Botoma *yarus*.

In the recent literature (Hill, 1964a, b, 1965; Walter, 1967; Rozanov & Missarzhevsky, 1966; Rozanov et al., 1969) concerned with the biostratigraphy of the Early Cambrian in Australia, the concept of the Olenellian Epoch remains suppressed in favour of the 'extended concept'—the Leno-Aldanian.

Biostratigraphy of the early part of the Georgian Epoch in South Australia

In the chart, Text-figure 3, the early part of the Epoch refers to the succession of fossil assemblages 1 to 5. According to Daily (*in* Sdzuy, 1967, p. 6), the earliest fossils belong to the 'lowest horizons of the Lower Cambrian'; in particular, Sdzuy refers to *Bigotina, Dolerolenus, Eoredlichia, Wutingaspis,* and the olenellid *Fallotaspis* (not yet found in Australia); I have described *Bigotina tina* and *Dolerolenus*(?) sp. nov. (p. 41). These trilobites are much older than the Cymbric Vale fauna and indicate a rather early beginning of Lower Cambrian deposition in South Australia, and Walter suggests a similar age for archaeocyathids in the lower part of the sequence; this however, has not been accepted yet by Rozanov (1969).

The position of Daily's assemblages 4 and 5 (*Bigotina tatei, B. tina,* and *Dolerolenus?* sp. nov.) in our scale, about Elghian time, needs, of course, supporting evidence from the undescribed subsequent faunal assemblages of the Parara Limestone, as well as from Walter's 'first trilobites'. In passing, Daily (op. cit., p. 131) found in assemblage 4 'a proparian trilobite similar to *Pagetia* Walcott but combining features which recall both *Dipharus* Clark and *Calodiscus* Howell'; it represents a species of *Hebediscus* of Lazarenko's Siberian *Hebediscus-Judomia* zone, mentioned here in the discussion of the Olenellian part of the Leno-Aldanian.

Walter (1967) examined the sequence of the archaeocyathids of the Hawker Group (Dalgarno, 1964)—the Wilkawillina Limestone, the biohermal bank, and the Oraparinna Shale; he identified some 33 genera from a sequence of four collections, aiming at a correlation with the succession of the archaeocyathid assemblages (complexes) of the Siberian Lower Cambrian. Walter (table 2, p. 147) selected nine genera as useful for the correlation, with the rational result of dating the Hawker Group as Lower Cambrian. His correlation of the Oraparinna Shale and its archaeocyathids is, however, underestimated: they are older than Sanashtykgol, because the trilobites in the basal Billy Creek Formation above Oraparinna are not younger than the Taryn (= early Sanashtykgol by correlation); of the nine selected archaeocyathid genera, seven are transcurrent in the Hawker Group and occur also in the Aldanian; the Siberian sequence in Walter's table 2 is compiled partly from the literature before 1964 (no 'Botoma *yarus*') and partly modern, with the Tommotian; the lower part of the Wilkawillina (below Daily's assemblage 4) is correlated with the late Tommotian, depending (1) on the degree of reliability of the archaeocyathid genus taxa as time markers, (2) on the unidentified 'first trilobites', and (3) on the position below, or low within, the *Bigotina* assemblage of trilobites. The accuracy of the correlation cannot be therefore evaluated, but it is not far off its Tommotian target.

Rozanov & Missarzhevsky (1966; 1967) originally dated Daily's assemblages 1 and 2 (the early Wilkawillina) as Tommotian—a plausible concept. Nevertheless, Rozanov (1969) later discarded this correlation because of Walter's (1967, p. 45) discovery of trilobites about 200 m lower than any recorded from Daily's section, which have no place in the Tommotian 'pre-trilobite time', and because of being convinced (op. cit. p. 92) that Daily's assemblages 3 and 4 leave no doubt regarding their correlation with the Botoma *yarus* (Sanashtykgol *gorizont*) of the Altai-Sayan folded region. If this guess were acceptable assemblages 9, 11, and 12, the early Billy Creek, and the Cymbric Vale faunas would have an impossible Lena age or even younger. The trilobites of assemblages 4 and 5, however, indicate an Elghian-Bazaikha age, about the end of Tommotian time.

To conclude, the Hawker Group of the Flinders Ranges, beginning with the Parachilna Formation and terminating with the Oraparinna Shale, and the whole sequence of its gardens of archaeocyathids in the biohermal bank, were deposited during Aldanian time in terms of the chart, Text-figure 3. (The upper punctate interval in column C of the chart refers to the archaeocyathids of the Oraparinna shale attributed to the Sanashtykgol in Walter's (1967) table 2.)

Relating the Cymbric Vale fauna with the Lower Cambrian in South Australia

In Text-figure 3 the Cymbric Vale fauna and Daily's fossil assemblages 9, 11, and 12 are shown close to each other within a relatively short interval of time; the Emuellidae described by Pocock (1970) from the early part of the Billy Creek Formation share the same scale position with the Cymbric Vale fossil assemblages and the Emu Bay trilobites in Kangaroo Island (assemblages 11 and 12).

The duration of the interval is short, and when compared with that of the Epoch as illustrated by the thickness of the corresponding sediment, is a small fraction of Georgian strata in the Flinders Ranges. In particular the fossil assemblage refers to the uppermost 10 m of the Oraparinna Shale (Daily, op. cit., p. 114;) and follows the fossiliferous lower part of the Billy Creek Formation, of some 150-160 m (Pocock, 1970, p. 523). Assemblages 11 (White Point Conglomerate) and 12 (Emu Bay Shale) in Kangaroo Island (Pocock, op. cit., p. 524) together refer to a fossiliferous sequence of about 100 m.

The Billy Creek and Kangaroo Island sequences can be referred to a provisional biostratigraphic operational unit distinguished by the trilobite family Emuellidae and especially by the genus *Balcoracania* Pocock, which occurs in both sites.

The Cymbric Vale faunal assemblage, in its turn, contains an abundance of *Estaingia bilobata* Pocock—a rather prominent species of the Emu Bay Shale (Daily's assemblage 12) and the reason for the correlation of the two faunas. In passing, the fossiliferous strata in the Billy Creek Formation are tuffaceous (Dalgarno, 1964, p. 137), like the Cymbric Vale Formation.

No position in the scale lower than that shown in the chart can be allotted to the Cymbric Vale fauna and no connexion with the faunas of the Parara Limestone and the Hawker Group is evident. The Cymbric Vale Formation itself rests on the Mount Wright Volcanics (Rose, 1970) with undescribed archaeocyathids in limestone lenses; these may or may not be relevant in correlation with the Hawker Group. As regards the Parara Limestone and the Oraparinna Shale Daily's brief remarks on his fossil assemblages 9 to 6 cannot be interpreted in terms of biostratigraphy; in the chart the position of the succession of these faunas, below the Cymbric Vale, is indicated by punctation.

The time scale (duration) of Early Cambrian deposition in South Australia

In the South Australian region as a whole sedimentation was continuous during the Early Cambrian Epoch, though a discontinuity within the Epoch is apparent (postdating the fauna of the Emuellidae) in Kangaroo Island (Daily, 1956, p. 138) and the Yorke Peninsula (Glaessner & Parkin, Eds., 1958, p. 55).

The notion of the continuity of sedimentation from the late Proterozoic to the Early Cambrian and the location of the base of the Cambrian has been discussed in the literature repeatedly; this continuity refers to sections south of Adelaide on the Fleurieu Peninsula. According to Daily (1963, p. 597) the Cambrian-Precambrian boundary should be placed 'below the first appearance of *Hyolithes* and associated fauna'—a provisional solution of local significance. South of Adelaide, on the Fleurieu Peninsula, Daily placed the boundary in the upper part of the Mount Terrible Formation; the sequence from this point should be taken as proven Cambrian. This formation itself is about 90 m thick; its basal stratum (op. cit., p. 595) is described as transgressive, but the 'transgression does not imply unconformity between it and the Marino Group'; it seems to me therefore that the lower part of the Mount Terrible Formation is possible but not yet proven Cambrian, marked by a tangible paraconformity at its base. According to Daily (1969, p. 50 and table 1), 'evidence of organic activity as given by bioturbated rocks extends almost to its base' and the contact at its base is described (Daily & Milnes, 1971) as an unconformity—a provisional but realistic solution. Finally, according to Daily (1972) in South Australia the Cambrian/Precambrian contact is a regional unconformity unveiled by regional mapping.

In the Flinders Ranges the Cambrian-Precambrian boundary (Dalgarno, 1964; Mary Wade, 1970) is developed as a hiatus at the eroded surface of the Proterozoic Pound Quartzite with its Ediacara fauna. The identification of the Parachilna Formation in the Barrier Ranges in western New South Wales (Thomson, 1969, p. 62) is not supported by Webby (1960).

The upper limit of the Lower Cambrian in the Flinders Ranges is placed below the sole of Wirrealpa Limestone and Aroona Limestone by Daily (1956); the fossils in these formations indicate an early Middle Cambrian (Ordian) age. The position of this series boundary is inconclusive within the unfossiliferous upper 900 m of the Billy Creek Formation, whose early part is Lower Cambrian; the boundary on Kangaroo Island, within the Boxing Bay Formation, is similar (Daily, op. cit., p. 109). In the Yorke Peninsula (Horwitz & Daily, 1958, p. 55-56) some 250 m of 'red bed clastics and evaporites' also intervene between the Wirrealpa Limestone and the Lower Cambrian Parara Limestone. Similarly in the Amadeus Basin the early Ordian strata with *Onaraspis somniurna* Öpik (1968) and *Redlichia amadeana* (Öpik, 1970) rest above dolomite with archaeocyathids, and a break, or evaporites, or both separates them; the Cymbric Vale fauna or its equivalent is missing.

The base of the Cambrian in Australia

The name Cambrian designates (1) the earliest Palaeozoic period of geological inorganic and biological events, (2) the system of rocks deposited or emplaced during the period, and (3) the corresponding major division (compartment) of the Geological Scale of Periods. The base of the Cambrian is the base of its scale division; which is also the base of the Early Cambrian and the base of the Palaeozoic. Proposals regarding the downward extension of the usage of the names Cambrian and Palaeozoic have been already discussed by Glaessner (1963) in some detail and, with good reason, rejected. The downward extensions should have a nomenclature of their own and Glaessner quotes as examples 'Eocambrian' of Holtedahl and 'Vendian' of Sokolov. In the meantime the advance in the study of the early Metazoa and their evolution (Cloud, 1968) suggests the name 'Eometazoic Time' to cover the downward extensions.

The Early Cambrian is defined by its fossils: (1) the roll of taxa, (2) the general aspect of the fauna, and (3) the difference from younger Cambrian faunas. These criteria serve in dating concrete sequences and in estimating the position of the lower limit to which that date is applicable. This limit, reached by trial and error (see Öpik, 1963, p. 11, 12; 1967, p. 5-7), may be adjusted to a clear lithological boundary or to a hiatus which, for the sake of convenience, is taken as the local or regional base of the Cambrian. Such a tangible base of a sequence probably marks a level within the Cambrian/Precambrian transition; this transitional interval is symbolized by the horizontal line as the base of the Cambrian in the Geological Scale. I presume that the shell *Wyattia* (Cloud & Nelson, 1966; Palmer, 1971) marks the lower limit of the Early Cambrian sequence in the White-Inyo Mountains in California but probably postdates somewhat the base of the scale division called 'Early Cambrian'.

The quest for a tangible base of a scale division of any rank is a recurrent topic in geological literature; the Cambrian problems are treated in the symposia edited by Rodgers (1956), Pruvost (1957), and Asklund & Poulsen (1960). A model interpreting the transition at the turn of the Eras in Australia has been published by Noakes (1956, p. 213-236) as the chart (op. cit., p. 224) 'Correlation of Australian Upper Proterozoic'. The ceiling of the Upper Proterozoic strata is a horizontal line (the turn of the Eras), an interpolation between the contact of the Cambrian with the Pound Sandstone in column 1 and the inferred boundary of the Pertaknurra Series in the MacDonnell Ranges in Central Australia, column 8. The model stands improved with the hiatus subsequently discovered between the Cambrian Parachilna Formation (Adelaide Geosyncline) over the Pound Quartzite with the (Eometazoic) Ediacara fauna (Dalgarno, 1964; Mary Wade, 1970); though the Pound Sandstone was retained in the Cambrian for a while after Noakes' publication (Glaessner & Parkin, 1958). The continuity from the Pertaknurra into the Cambrian is supported by the stratigraphy of the Arumbera Sandstone, as discussed earlier. The correlation (within limits) of the fauna of the Mount House Beds, the upper part of the Victoria River Group, and the Tolmer Group, all in northwestern Australia, agrees with the model. Generally, however, unconformities and hiatuses separate the Cambrian strata from the Proterozoic in the north of Australia.

The chart of Noakes should be amplified and brought up to date in the light of more recent work. For example, a separate column is appropriate to show the Mount Birnie Beds above the 'transition line' and a wide hiatus separating the Early Cambrian from the basement in Queensland; also column 7 is out of date and needs an amendment: the Camooweal Dolomite and a larger part of the Mopunga Group should be moved up in the model and only the lowermost formation of the Group (the Elyuah Formation) and the Central Mount Stuart Beds can be retained in the uppermost Precambrian.

THE LENO-ALDANIAN

Introduction

This is a brief comment upon some main aspects of the modern Russian rules of stratigraphic nomenclature, terminology, and classifications; these rules are applied also in the stratigraphy of the Leno-Aldanian Lower Cambrian; it is necessary to keep them in mind when operating with Russian stratigraphic scales. The Leno-Aldanian stratigraphy is more advanced than elsewhere and is substantial in comprehending the life history of the Early Cambrian in general.

The stratigraphic nomenclature and terminology employed in Russian publications is complicated, involved and flexible, and is not translatable consistently into a simple form, as for example, the Australian usage of the day. But meanings can be interpreted if the context is respected: Stepanov (1958, p. 28-29) writes that jumble ('raznoboy') prevails in establishing stratigraphic units and terminology, which are differently employed in different systems, as for example in the Carboniferous and the Devonian of the same region.

Rules, however, were compiled and published in 1956. The comment that follows is based on the second edition (Zhamoida, 1965) of the 'Stratigraphic classification, terminology and nomenclature', approved as an obligatory statute for all geological organizations of the USSR. Nevertheless I presume that not all stratigraphic papers published after the date of the first edition (1956) conform to the rules of the statute.

The recently published 'Review of foreign stratigraphic codes' (Zhamoida et al., 1969) supplements the 'Statute' as a guide for Soviet geologists; it offers translations and interpretations of terms, but also indicates that the results are inaccurate on linguistic and philosophical grounds.

The nomenclature is geographical and the place names are nouns or adjectives, and some are plural; but some are also names of persons (Obruchev) or fossils (*Kutorgina*) or descriptive ('pestrotsvetnaya'); the grammatical form of the names is adjectival and employed in masculine, feminine, or neuter depending on the gender of their terms: for example 'sveeta' is feminine, 'yarus' and 'gorizont' are masculine, and 'vremya' is neuter. Most of the adjectives are in the singular, but the term 'sloi' demands the plural; the statute on p. 58-65 regulates the use of the adjectival endings in stratigraphic names; a name starts with a lower case letter.

The same geographic adjectival name coupled with an appropriate term stands as a valid name of a rock as well as of a corresponding time division of the stratigraphic scale; in particular, the formal classification into different (litho-, bio-, chrono-, stratigraphic etc.) categories is unacceptable.

I feel that the transliteration of the Cyrillic of the Russian stratigraphic adjectival names results in unpronounceable words—impediments in writing and memorizing. I find it, however, convenient to quote the geographic names instead: (1) a geographic name starts with a capital letter; (2) it can be coupled with a term of any category; (3) the reference of the time aspect which is included by deposition in any unit can be expressed by the English adjectival ending; (4) it is obtainable from the 'Stratigraphic Dictionary of the USSR' (VSEGEI, Moscow, 1956). Some of these place names can be found from larger atlases transliterated into English.

Note that a name according to the statute denoting a division of a rank smaller than series—epoch can be coupled with such terms as 'yarus', 'sveeta', 'gorizont', 'complex', and a time connotation (vyek, vremya). As regards the stratigraphic terminology the word 'yarus' (= tier)) corresponds to 'stage' (see below under gorizont); 'sveeta' is interpretable as 'formation' or 'member', and a particular 'sveeta' may have a definition corresponding to the concept of a 'group' or 'sub-group'; 'seriya' cannot be translated as 'series' but is interpretable as 'formation' or 'group' depending on the description of a particular 'seriya'; a first-order subdivision of a system is 'otdyel' but its time equivalent is 'yepokha' = epoch. The term 'gorizont', usually translated as 'horizon' designates a stratigraphic unit whose concept is alien to, and not operated with, in the geology of the west; 'gorizonts' are regional stratigraphic operational subsidiary units; the nomenclature is stratigraphic and geographic; when proposed, 'gorizonts' are taken as divisions in regional scales. A 'gorizont' is conceived as a planar stratigraphic division composed of concurrently deposited 'sveetas' (formations) and slices of out-of-step or of larger sveetas, and named by the name of a selected (a best known) ingredient 'sveeta'. The base and the top of the 'gorizont', by definition, are isochronous planes; the limited regional extent of a 'gorizont' is its main difference from a 'yarus', which is defined as a regular division of a series-epoch and of universal application or almost so. A 'gorizont' can be divided into 'slo-i' (beds, or layers, or strata); when statutory the names are geographical; a 'yarus' is also divisible: a division is termed 'podyarus'—lower, middle, or upper without (or with) a separate geographic name each; a composite yarus is termed 'nadyarus' = over? or super? 'yarus', and retains its original name. A 'sveeta' may consist of two or more 'podsveetas'; these are numbered when their number exceeds three; a 'podsveeta' cannot be described as a 'member'; but a 'subdivided sveeta' has the characters of a group of formations.

Revising authors may change the 'volume' and the name of any established unit and trimming of boundaries is also practised: the Leno-Aldanian stratigraphic schemata have been modified repeatedly and new modified charts were approved from time to time by all-union or interdepartmental councils. Basic is the scheme accepted by the all-union stratigraphic council in 1956, as published by Suvorova (1960, p. 191) with the following remark: 'The given scheme in connexion with the arrival of new materials is subject to amplifications, corrections and modifications'. This and several subsequent charts are out of date; published, however, in palaeontological monographs, the age of the fossils dated with such charts should be re-checked in terms of the 'latest schemes'.

The Leno-Aldanian stratigraphic scales

Recapitulating, the designation 'Leno-Aldanian' (Öpik, 1968a) describes the Lower Cambrian concept in terms of Russian stratigraphers, not answering to the traditional priority concept of Walcott's 'Lower Cambrian or *Olenellus* Zone', or Georgian Epoch-Series; Pokrovskaya (1961, table 2) applied the name Georgian to the whole of the Leno-Aldanian; N. Tchernysheva (1965) in her correlation chart included the name of the *Olenellus* Zone but not of Georgian; these quotations, however, remained without further response in the literature. Demokidov (1969) in his exhaustive compilation of the Cambrian stratigraphy in the Arctic and its fringes (actually the Northern Hemisphere), operates with the two-*yarus* division of the Early Cambrian. Remarkably enough, in his charts (e.g. 114-117) Demokidov placed several sequences with *Olenellus, Paedeumias,* and *Wanneria* in the Lena *yarus* and, consequently, collided with the evidence as regards the vertical distribution of the Olenellidae as evident in the Siberian region.

In passing, Zhuravleva (1970, p. 440) 'calls for discussion on the merits of the Lower Cambrian as an independent geological system'. She refers to the Leno-Aldanian, whose lower part is the Olenellian; once not Cambrian the system should be designated 'pre-Cambrian'.

For the purpose of this paper I compiled in the chart, Text-figure 3, a simplified and abridged scale of biostratigraphic subdivisions (stages = *yaruses* and *gorizonts*) operational in the Siberian Leno-Aldanian Cambrian; this chart refers in the first place to the sequence of trilobites as presented by Soviet authors during the past decade. The earliest biostratigraphic chart of 1956 (*vide* Suvorova, 1960, p. 191) refers already to assemblages of trilobites of the eastern part of the Siberian platform; it was amplified by Suvorova (1960). She visualized a large Lena *yarus* of two subdivisions—the Botoma (below) and the Angara (above), the latter corresponding to the Lena stage as shown in our chart. In the chart of Suvorova the Tolbachan *gorizont* is shown over Sinyaya, but the reverse sequence, also shown in our Text-figure 3, came later in use; Demokidov (*in* Demokidov & Lazarenko, 1964, p. 87) adopted Suvorova's version in placing the Sinyaya at the base of the Lena *yarus* over Atdaban; finally, Suvorova's original concept of a large Lena *yarus* of two subdivisions (Botoma and Angara) remained in the picture as adopted by Jegorova & Savitzky (1969).

In the meantime Suvorova's bipartite scheme of the Lower Cambrian (Siberian brand) was replaced by a tripartite scale of stages (*yaruses*)—Lena, Botoma, and Aldan—which is now adopted in our chart, Text-figure 3; it is, of course, not 'the latest' in view of the innovations introduced by Rozanov (1967, 1969).

The 'gorizont-stratigraphy' is sometimes supplemented by scales of zones. For example, Jegorova & Savitzky (op. cit.) produced a scale of local zones and sub-zones of trilobite species, and other authors employ genera; a scale of zones named after species of Archaeocyatha is published by Zhuravleva (1970). Subsidiary scales of sequences of *sveetas* (formations) supply the nomenclature of *gorizonts;* this kind of tautonomy, however, may be sometimes confusing when only a slice of a *sveeta* gives its name to a unit of another category; for example, the Sinyaya *gorizont* and the Sinyaya *sveeta* may have different positions regarding the superpositional order of divisions.

The three-stage scheme (Aldan-Botoma-Lena), introduced by Repina et al. (1964, p. 140-150), was developed further by Khomentovsky & Repina (1965); Suvorova's substage Botoma became promoted in rank, Sinyaya *gorizont* was placed in Botoma, and Tolbachan in Aldan. Khomentovsky & Repina (op. cit., table 10) based their findings on the vertical distribution of some 82 'basic' trilobite genera collected from numerous sections along a stretch of some 450 km of the Lena river and its tributaries (Olekma in the west; Sinyaya, Keteme, and Botoma in the east); furthermore, they presented the trilobite biostratigraphy in the already known three distinctive environments (normal marine to the east, dolomitic-evaporitic in the west, and transitional in between); the Cambrian in the Siberian platform is dominated by the 'stationary' dolomitic-evaporitic depositional environment as discussed below in respect of the absence of trilobites in the Tommot *gorizonts*.

The chart, Text-figure 3, is rather close to the correlation table 10 of Khomentovsky & Repina (1965, p. 95) in quoting the sequence of the Sayan-Altai mountains; but some variations in the platform part are apparent: (1) I left out the names of the trilobite zones; of these the *Judomia* zone corresponds to Tolbachan, but the Olenellidae (*Judomia, Judomiella* and *Sinskia*) have been recorded by the same authors also higher up, in the Taryn *gorizont;* (2) *Kutorgina* and Sinyaya are shown as two separate steps, and not hyphenated together; (3) a special supplement is the name *Bigotina* in its earliest scale position, whose stratigraphic significance is discussed in the description of *Bigotina tina* sp. nov. (p. 37); and (4) the position of the Tommot *yarus* is given because of its bearing on the stratigraphy of the Lower Cambrian in Australia; the phrase 'pretrilobite beds' corresponds to the designation 'beds without trilobites' already utilized by Khomentovsky & Repina (1965, p. 95). These beds (Sunnaghin—Kenyada and Kundat—lower Bazaikha) constitute the Tommotian stage (*yarus*) of Rozanov and are followed by the Atdaban *yarus*—the promoted Atdaban *gorizont;* in consequence the name Aldanian *yarus* became excluded from recent Siberian charts, as for example, by Rozanov (1967), but remains nevertheless operational with other authors. At all events, the town of Tommot stands on the River Aldan and the Tommotian *gorizonts* are Aldanian by the same token in the first place. Operational is also the designation 'Zhura sub-yarus' (for example in the Arkhangelskaya et al., 1960; Tchernysheva, 1961; Zhuravleva, 1970, p. 438)—the restricted Aldanian without the dolomitic Tolba (*Judomia*) at its base.

THE OLENELLIAN WITHIN AND WITHOUT SIBERIA

In the existing Russian literature the Olenellian as a division of the biostratigraphic scale remains unemployed except by N. Tchernysheva (1965, p. 441), who placed the names of upper and lower *Olenellus* for matters of comprehensive planetary correlations in a column of a chart, as can be read in the next pages. As discussed in these, the upper boundary of the Olenellian in Siberia is recognizable as the ceiling of the olenellid trilobites, some of which also occur in the New World. The Aldan *yarus* has been considered (Öpik, 1968a, p. 142) as an equivalent of the Olenellian Epoch; the new evidence from the distribution of trilobites, however, indicates that the Aldanian as originally conceived by its author represents an early part, and not the whole, of that Epoch. Originally, the Leno-Aldanian biostratigraphy refers to the vertical, temporal, distribution of assemblages ('complexes') of archaeocyathids; in the past decade, however, the study of trilobites supplied a large volume of reliable stratigraphic information to the benefit of archaeocyathid stratigraphy in Siberia and the global correlations also.

The present status of the biostratigraphy of the Epoch of the Olenellidae has been presented recently by Palmer (1971); the upper limit is accepted as top of the Mule Spring Limestone within which *Fremontia* marks the end of the Olenellidae; in the same section the trilobite *Ogygopsis* is already present and if alone it could be taken as evidence for a Middle Cambrian age of the strata. Nelson (1963, p. 247), therefore, writes of the possibility that these olenellids may represent 'an endemic fauna that lingered on into Middle Cambrian Time'. This is a situation normal at any biostratigraphic boundary and should be considered as a provision in interpreting the biostratigraphy of the Leno-Aldanian in anticipating the publication of an American scale of the Early Cambrian Epoch in a stabilized operational form suitable for the purpose of correlation. I discuss here Siberian and American trilobites against the background of selected data from the Northern Hemisphere sequences; there the olenellids (*Judomia, Sinskia*) may have disappeared before, or after, the Epoch boundary seen in Nevada and California.

The depositional continuity in the Early Cambrian in California and in Siberia poses the problem of correlation of subdivisions of the Epoch: in the Leno-Aldanian, depending on the author and area, four to six subdivisions are operational, and Zhuravleva (1970, p. 438) indicates a scale of some fifteen numbered 'levels'. In the type region of the Olenellian concept, however, according to Palmer (1971, p. 56) in western United States, 'the Early Cambrian faunal succession is at present rather loosely divided into upper and lower "*Olenellus*" subzones' (Lochman-Balk & Wilson, 1958) and 'potentially as many as seven different biostratigraphical entities'.

The ceiling of the Olenellian-Georgian in Siberia is shown in our chart, Text-figure 3, by the dashed line separating the Olekma from the Uritzkoye-Taryn *gorizonts* below; the last Olenellidae (Khomentovsky & Repina, 1965, table 9) that are described from the Taryn *gorizont* are *Sinskia* Suvorova, *Judomiella* Lazarenko, and *Judomia* Lermontova. Of these, disguised under different names, there are represented outside Siberia (but not in the Acado-Baltic Province contrary to Repina, 1969, p. 73), and in the American Pacific realm of faunas: (1) *Olenellus troelsoni* Poulsen (1958, p. 12, figs 1-3) from the Inglefield Land, interpretable as a species of *Judomia* by similarity with *Judomia tera* Lazarenko (1960; 1964) and especially *Judomia lata* Repina (1965, p. 118, pl. 4, figs 3-7), from the Taryn; and (2) the material described by Walcott (1910, p. 298; 411-412; pl. 38, figs 15-24) as *'Wanneria? gracile,* new genus and new species' from California, Nevada, and Alberta, which represents in part a *Judomia,* especially the cephalon plate 38, fig. 20. Related to, but not congeneric with, *Judomia* is *Nevadella* Raw, based on *Callavia eucharis* Walcott (1913, p. 315, pl. 53, fig. 1) from Alberta. In *Nevadella* as in *Judomia* the cephalic rim is wide, the glabella tapering and reaching the rim, but the eyes are short and the preocular part of the glabella is visibly larger than in *Judomia.*

These Pacific-American forms occur together with *Olenellus* and are referable to the upper *Olenellus* subzone in terms of Christina Lochman. The occurrence of *Judomia* in western USA is also mentioned by Palmer (1971, p. 11, 17) According to Khomentovsky & Repina (op. cit., p. 6) E. W. Toll was the first to identify the presence of Lower Cambrian in the Siberian Platform in referring to the zone of *Olenellus kjerulfi* (= *Holmia*).

As a matter of record, N. Tchernysheva (1965, p. 440-1, table 10) had already proposed a rather plausible upper limit of the Olenellian with a dashed line over the zone of *Bergeroniellus asiaticus* and a little step higher than in our chart, Text-figure 3; Olenellidae are absent in that zone, but *Hebediscus* and *Pagetiellus* have survived from the earlier faunas. According to Khomentovsky & Repina (1965, p. 84, table 6) the *B. asiaticus* zone coincides with the Sinyaya *gorizont,* which can be taken, if necessary, as transitional from the Olenellian.

The transitional aspect of the Botoma *sub-yarus* in the western fringe of the Anabar Shield (Jegorova & Savitzky, 1969, chart, text-fig. 5), is also evident from the presence of *Pagetiellus lenaicus* and *tolli,* species of *Hebediscus,* even *H. attleborensis?* (species queried, A.A.Ö.), and *Triangulaspis annio,* in association with *Bergeroniellus asiaticus* and above strata with Olenellidae (*Judomia, Sinskia*), of the *Hebediscus-Judomia* zone of Lazarenko (1962, p. 32-35) with *Paedeumias.*

Finally, rather satisfying is the total interval allotted to the Aldanian in the chart of Zhuravleva (1970, p. 438) in the column attributed to the Interdepartmental Committee, 1959: the upper limit of the Aldanian in this column coincides with the 'dashed' limit of the Olenellian-Georgian in our chart, Text-figure 3.

The trilobite genus *Holmia* Matthew (Olenellidae) emerged as having a life span identical with *Olenellus;* among the 'faunal zones of Norwestern Europe' (Howell et al., 1944) of the Acado-Baltic Province, the *Holmia* zone is indicated as the lowermost Cambrian trilobite zone, and the same position (below *Callavia*) is also suggested by Lochman-Balk & Wilson (1958, text-fig. 5). In Poland, however, the *Holmia* sequences (Czarnocki, 1927; Samsonowicz, 1956, 1960; Lendzion, 1968, 1969) contacts the base of the *Protolenus* horizon. Sdzuy (1960) operates with a similar scale; and Rozanov et al. (1969, table 13) equated the

'Holmian horizon' with the Atdabanian (substituted for Aldanian). *Holmia* is absent in Siberia, but is present in the *Olenellus* zone of the American Pacific Province (Walcott, 1919; Cloud & Nelson, 1966; Palmer, 1971, p. 17).* According to Lochman-Balk & Wilson (1958, figs 2, 3) the species of *Esmeraldina* occur in the upper *Olenellus* subzone—in the same scale position as the 'Holmian *gorizont*' of Lendzion and Rozanov. *Holmia* occurs also in Greenland (Poulsen, 1958; Cowie, 1960, 1963); it is still unknown in Siberia, but in Siberia *Paedeumias? greenlandicus* Poulsen (Jegorova, 1969, p. 111) occurs in the Arctic and *P.* cf. *greenlandicus* and *P. subgreenlandicus* Repina, 1965 (*in* Khomentovsky & Repina) occur on the Lena River. The *Olenellidae* of Siberia, therefore, imply a correlation with the American rather than with the Acado-Baltic faunas. The designations *Holmia* zone and *Wanneria* zone (see Poulsen, 1969) are possible as substitutes for the priority name *Olenellus* zone of Walcott.

The olenellids Fallotaspidinae Hupé and Daguinaspididae Hupé, however, are of an early Olenellian age, but are worldwide: originally found in Morocco (Hupé, 1953), then in California (Nelson & Hupé, 1964), and finally in the Aldanian of Siberia (Khomentovsky & Repina, 1965). Repina (op. cit.) described two new species of *Fallotaspis* and two species of her new genus *Profallotaspis,* and attributed these to the Kenyada *gorizont,* in association with the Bigotininae. I know of no illustrations of the Californian material, but it is described in terms of two Moroccan species (*tazemmourtensis* and *longa*). Remarkable enough is Repina's description referring to the same species. Regarding the Daguinaspididae N. Tchernysheva (1967) established a new genus and species, *Wolynaspis unica,* from the core of a well in northwestern Ukrainian SSR; it is associated with *Platysolenites antiquissimus.* These fossils tally with the lower part of the Estonian Lower Cambrian (Öpik, 1956, p. 1-7) and *Wolynaspis unica* is contemporaneous with *'Schmidtiellus'* (*'Olenellus'*) *mickwitzi* and another trilobite described by Schindewolf (1927) as *Holmia mickwitzi.* Similar genera (*Holmia* and *Daguinaspis*) occur in the Montenegro Member in California (opera cit.) in association with *Fallotaspis;* thus, a relatively short span of time seems to confine the trilobites of the Californian Montenegro, the Lontova of Estonia, the *Fallotaspis* of Morocco, and possibly the Elghian-late Kenyada of the Siberian platform.

In Estonia below the Lontova Blue Clay lies the arenitic-lutitic sequence (the Lomonosov beds) with *Platysolenites antiquissimus;* it rests on the uneven surface of the basement; *Platysolenites* has been recorded in the basal conglomerate and reaches into the Blue Clay covering some 100 m of the section. The Estonian sequence is topped by a sandstone (Tiskri) with *Scolithus* and *Diplocraterion* which, in Russian literature (for example, N. Tchernysheva, 1965), is attributed to the Middle Cambrian. It should be retained, however, in the Lower Cambrian because of the *Diplocraterion,* which is present according to Öpik (1929, p. 39, 40) in deeper shale as well. The Lomonosov beds constitute the earliest division of the Estonian stage which, under its synonym 'Baltic seriya' (Mannil, 1958; Tchernysheva, N., et al., 1965), became integrated with the Aldanian. The same 'seriya' is quoted by Sokolov (1968, p. 32) as 'Baltic stage' (= Tommot stage)—pretrilobite beds; it is the Estonian stage, containing trilobites and a rather small

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* Poulsen (*in* Harrington et al., 1959, p. 0195) indicated that *Esmeraldina* Resser & Howell, 1938, is a junior synonym of *Holmia* Matthew; the type species of *Esmeraldina* is *Holmia rowei* Walcott, 1910, and the genus includes also *Wanneria occidens* Walcott, 1913, and *Holmia? macer* Walcott, 1913; the latter includes also two cephala attributed by Walcott (1910) to *Wanneria walcottanus* (Wanner).

number of other fossils. Strata with *Platysolenites antiquissimus* are placed close to the Proterozoic contact (Kiryanov & N. Tchernysheva, 1967, p. 127), an aspect discussed already by Glaessner on several occasions (e.g., 1963). In a similar stratigraphic position in California is the Andrews Mountain Member of Campito (still with a *Fallotaspis*) and the Deep Springs Formation below it.

Lower Cambrian Gorgonacea

The Deep Spring is one of the oldest known fossiliferous formations (Cloud & Nelson, 1966; Palmer, 1971; p. 16, 20). It produced an ill preserved specimen of *Pteridinium*(?) and several kinds of arthropod tracks. *Pteridinium* is a late Proterozoic genus, attributed by Richter (1955) to the Gorgonacea, the recent 'sea-pens', 'sea-plumes', and 'sea-fans'; the occurrence of a sea-pen related to Proterozoic forms in the Lower Cambrian may or may not be significant in dating of strata, and diverse forms can be expected in the Cambrian as well. Two Early Cambrian Gorgonacea have been described from Vermont by Walcott (1886, p. 92, 93, pl. 11, figs 4 and 5) as *Diplograptus simplex* Emmons, 1855, and *Climacograptus? 'emmonsi'* n.sp. respectively, and once more by Walcott (1890, p. 604, 605) as *Phyllograptus? cambrensis* and *C. emmonsi*. Of these the *'Diplograptus'* or *'Phyllograptus'* is represented by fronds reminiscent of Gorgonacea; the *'Climacograptus'* is described from a single fragment of a frond with narrow and deep indentations 'leaving short, strong pinnula-like projections between them'. I have found but never described a similar specimen in the Blue Clay (Lontova beds) in the clay pit of Lontova, Estonia (Öpik, 1956, p. 110); it is preserved as a thin carbonaceous film.

In passing, in the Bureau of Mineral Resources Canberra in a collection of Lower Cambrian fossils from the Yuendumu Aboriginal Reserve, northwest of Alice Springs, I identified *Rusophycus, Protichnites,* and *Helcionella* (Cook & Scott, 1967) associated with fragments of a sea-pen. In sequence with these beds a limestone (or dolomite) contains hyolithids and fragments of a trilobite (Dolerolenidae?).

THE TOMMOTIAN AND THE PRETRILOBITE TIME

The Tommot *yarus* (Rozanov & Missarzhevsky, 1966; Rozanov, 1967 (in English); Rozanov et al., 1969) is a scale division of the Lower Cambrian of Siberia comprising the three earliest known archaeocyathid zones and a fauna of shells of molluscs (gastropods, hyolithids) and 'forms of an obscure systematic position'. These fossils and the scale position of the sequence constitute the concrete, objective, basis of the Tommotian stratigraphic concept.

In South Australia, Walter (1967) refers to the Tommot stage an assemblage of early archaeocyathids, and in Sweden Bengtson (1970) in describing species of *Tommotia* from the zone of *Mobergella holsti* correlates that zone with the uppermost Tommotian zone.

The fauna of the Tommot limestones in Siberia is devoid of trilobites—an observation that precipitated the notion of Tommotian time as part of a 'pretrilobite time' in general. It seems to me, however, that absence of trilobites, or of any kind of fossils, provides no operational basis in stratigraphy. For example, the Etcheminian of Matthew (1895; 1899b, p. 52) is a probable senior synonym of the Tommotian; it was proposed as a name for 'a Palaeozoic terrane beneath the Cambrian'; in the Etcheminian beds Matthew found no trilobites. Matthew described the Etcheminian as 'distinct from the Cambrian' and representing 'the earliest Palaeozoic time'; Hutchinson (1962, pp. 10, 11) regards the Etcheminian strata of Newfoundland as basal Cambrian and its fauna (*Coleoloides*) as marking 'a pre-trilobite Cambrian faunal zone'; but the trilobites above that zone, *Callavia broeggeri* (Walcott) and *Hebediscus attleborensis*, are not quite the oldest of the Early Cambrian Epoch. Presuming, however, that want of trilobites in basal strata of a Cambrian formation is indicative of the 'pretrilobite time', Matthew later dated as Etcheminian a sequence and its fauna in Cape Breton (see Öpik, 1968b, pp. 5, 6), which Walcott subsequently dated as Middle Cambrian in age.

The designation Tommot *yarus*, a concrete sequence of strata, connotes also an interval of time, the Tommotian of the Siberian scale of the Early Cambrian Epoch; this aspect of the Tommotian is instrumental in correlations of geological and biological events; it is, however, a junior synonym of the Baltic stage (Sokolov, 1968), which itself is a junior synonym of the Estonian. The name 'Tommot' as applied to a concrete sequence of strata is, of course, not applicable outside Siberia, but seems an elusive synonym of the Aldan *yarus* in its original sense. The strata in question (Tommot *yarus*) are the lower portion of the Pestrotzvet formation (Rozanov's 1967, p. 416 spelling)—a rock unit of variegated limestones, of a remarkable vertical uniformity and great areal extent; its name, Pestrotzvetnaya (variegated) is not geographical but descriptive of its multicoloured appearance; it is heterochronous at its top; in its full span it covers the Aldan stage of our chart, Text-figure 3. In the same chart, the Atdaban, as the name of a substage, or an enlarged *gorizont,* covers the trilobite *gorizonts* of the Aldanian above the Tommotian units. The boundary between the Atdaban and the late Tommotian Kenyada *gorizont* is explicit biostratigraphy; in published sections it is drawn some 2 to 3 m (Kuteynikov & Missarzhevsky, 1971, section 2194) and up to 20 m below the first trilobites.

This boundary may be displaced downward but still will remain as a divisional line in the time scale; according to Zhuravleva (1970, p. 432) 'there is, of course, little doubt that trilobites did exist at this time [Tommotian]. Their future discovery is confidently expected'. This expectation seems already supported by Walter's first trilobites in the Flinders Ranges. In passing, according to Semikhatov et al. (1970, p. 85) in the western part of the Aldan region 'the lower horizons of the Cambrian are replaced by dolomites lithologically inseparable from the Judomian complex and are included in it'. As discussed later, the deficiency in trilobites is a function of lithological and environmental conditions.

The basal boundary of the Tommot sequence in the Aldan region is the contact of the sole of the Pestrotzvetnaya limestone with the underlying dolomites of the Judoma and Tolba complexes (*sveetas,* formations): it is a concrete and clear dividing boundary; but in places where the Pestrotzvetnaya is dolomitic the boundary is diffuse and conjectural. The contact of limestone over dolomites is at the same time the change from the earlier depositional dolomitic-evaporitic environment to reasonably normal marine conditions. The Pestrotzvetnaya is fossiliferous from its base, the Sunnaghin *gorizont,* whose thickness is some 2 to 5 m. The fossils are archaeocyathids and a variety of phosphatized shells described by Missarzhevsky (1966; 1969). The Judoma dolomites (Semikhatov et al., 1970) contain stromatolites and a 'flora of oncolites and catagraphs' and otolites, spastolites, and pellets; the matrix is precipitated dolomite. Close to the top, however, small conical shells occur, described by Missarzhevsky (1969) as *Anabarites* incertae sedis; of the six described species three have been found in the Sunnaghin only and three others have passed from the Judomia dolomites into the Sunnaghin *gorizont*. It seems therefore that the vertical continuity of the *Anabarites* population suggests a Cambrian age for the Judoma-Tolba sequences which are regarded by some authors as latest Precambrian. Missarshevsky (p. 155) in describing the species of *Anabarites* referred also to the Lower Cambrian. This accepted, the contact of the Pestrotzvetnaya limestones against the Judomian dolomite cannot be confidently regarded as the Cambrian/Proterozoic boundary. Seeing, however, that the older, lower part of the Judoma is unfossiliferous, the age of the Judoma-Tolba complex can be described rationally as Cambrian and (?)Precambrian—a device suggested by Neuman & Palmer (1956, p. 433). In the Altai-Sayan region the Tommotian Kundat *gorizont* rests on dolomite of the Yenissei 'seriya', but the character of the contact remains inconclusive (Rozanov *in* Rozanov et al., 1969, p. 66).

The notion of a pretrilobite time is rather plausible *a priori;* but the interpretation of the Tommotian as representing the pretrilobite time of the Early Cambrian Epoch is more doubtful. Trilobites existed presumably during the Tommotian and even before, but possessed exoskeletons of materials perishable in the chemistry that prevailed in the waters of the time. To quote Lochman-Balk & Wilson (1958, p. 318), the Olenellidae 'were apparently an old stock before they acquired a preservable exoskeleton'. Stubblefield (1959) in discussing the evolution of trilobites remarks that 'cryptogenesis in trilobites is as frustrating to palaeontologists concerned with evolution as in any other biological class'. The concept of cryptogenesis in trilobites is based on the observation that post-Cambrian stocks that emerged at different times in the Palaeozoic have no recognizable ancestry; their ancestral forms had no skeletons capable of fossilization. Nevertheless, such 'cryptic' trilobites, to be regarded as trilobites, should have possessed a functional articulating tests of sclerites and appendages and endocrinal glands necessary to initiate and to perform moulting.

The 'skeleton' in trilobites is the exoskeleton—the indurated cuticle, and moulting was a periodic necessity followed each time by a new exoskeleton, perishable or durable, but never permanent. Consequently, trilobites were 'soft-body' animals periodically secreting and dismantling their exoskeletons; in this respect trilobites, and anthropods in general, are totally dissimilar from such invertebrates as brachiopods, molluscs, and echinoderms, whose skeletal structures, when present, remained permanent.

The advent of phanerotrilobites in a multitude of taxa immediately after the pretrilobite time in Siberia, some 2 to 20 m above the Kenyada *gorizont,* supplied the spark of the hypothesis of a simultaneous skeletonization at the onset of the Cambrian and the Palaeozoic (Rozanov, 1967). In respect of the 'pretrilobite time' an appraisal of the first Siberian trilobites ('the first trilobites') seems necessary.

Species of some nineteen genera of trilobites have been described by Repina (1964) from the upper part of the Bazaikha *gorizont* immediately above its lower part, which lacks trilobites; and Khomentovsky & Repina (1965, table 9, p. 92-93) tabulated ten genera of first trilobites on the Lena River in the Siberian platform. Olenellacea, Ellipsocephalacea, Dolerolenidae, Corynexochida, and Eodiscidae are represented.

The Olenellacea are peculiar in having a semi-ovoid body (Raw, 1953, p. 112) and no fulcral apparatus; their exoskeleton has lost the facial sutures early, in the hypothetical perishable forms. All other trilobites, however, are fulcrate (Öpik, 1970, p. 45) and possess four-point hinges between the exoskeletal joints—mechanics passed on to the 'first trilobites' from earlier trilobites with exoskeletons; a fulcral apparatus would be meaningless in the absence of sclerites. Suvorova (1969, p. 381) refers to the occurrence of Fallotaspidids in the Kenyada *gorizont,* and Zhuravleva's (1970, p. 432) trust in the future discovery of Tommotian trilobites can even be specified; fulcrate forms (Ellipsocephalacea, Dolerolenidae) are expected and olenellids (related to *Fallotaspis* and *Holmia*) are also probable. I favour the idea that at the turn from the Proterozoic to Early Cambrian the invertebrates passed through an epoch of accelerated integumental scleritization; but I cannot share in the belief that trilobites of some thirty genera in Siberia were scleritized simultaneously with the fall of the Tommotian curtain in Early Cambrian time. Nevertheless, speculating further, the exoskeleton of early trilobites, possessing a relatively large component of proteins, was more perishable (and edible?) than the calcite and phosphate-rich armour of such trilobites as came to our knowledge owing to their fossilization.

THE DEPOSITIONAL ENVIRONMENT IN THE EARLY CAMBRIAN SEAWAYS OF THE SIBERIAN PLATFORM

The absence of trilobites in the Tommotian is a faunal deficiency attributable to the evaporitic regime that prevailed in the seaways of the Siberian platform during the depositional events of the Judomian and Cambrian times. Furthermore, shallow banks of the sea floor remained within reach of sunlight; archaeocyathids populated them and lived by photosynthesis in the euphotic and warm waters.

Zelenov (1957, text-fig. 6, pp. 36-37) recognized three facies realms of deposition on the rivers Lena, Aldan, and tributaries:

(1) an eastern realm, east of about longitude 127°, of a 'normal and open sea';

(2) a western realm of saline lagoons; and

(3) a realm of passage between them.

The Judoma complex of dolomites differs from the overlying fossiliferous Aldanian by its uniform lithology and, as a whole, was deposited in an environment of the evaporitic Olekminsk style. Zelenov (1957, p. 36) describes the 'conditions of formation of the rocks of the Tolba stage' (Tolbin-Judoma formations in terms of Rozanov, 1967, p. 416) as follows:

> 'Judging from the prevalence of dolomites with layers and inclusions of gypsum and anhydrite as well as from the complete absence of fauna—the region was of a marine lagoonal type, of a steeply increased salinity conditioned by the aridity of the climate; the frequency of interbeds of algal and oolitic dolomites testifies to the shallowness of this rather wide Cambrian lagoon.'

Khomentovsky & Repina (1965) in their study of the Siberian stratotype of the Early Cambrian (Leno-Aldanian) revised the sequence of trilobites in each of the three facies realms in detail; the eastern, normal marine, limestone development is very fossiliferous, and in the west dolomites prevail over limestone, and evaporites (anhydrite, gypsum, and halite) are widespread. In the transitional realm barren dolomites and fossiliferous limestone alternate in sections and secondary dolomite (dolomitized limestone) occurs also. According to Suvorova (1960, p. 11) in the Olekminsk facies (the western saline realm) normal marine facies are relatively rare.

A comprehensive description of the Cambrian saline basin of the eastern part of the Siberian platform has been published by Arkhangelskaya, Grigoryev, & Zelenov (1960); in their diagram (op. cit., p. 181), the basin is shown to cover an estimated 1.2 x 10^6 km^2, one half of which belongs to the 'salt generating core'. The taxonomic diversity of the fauna and flora depends upon the amount of primary (precipitated) dolomite in the sequences as illustrated graphically (op. cit., fig. 50, p. 153) in respect of seven *sveetas*. In brief. the limit of tolerance for trilobites is 20% and for archaeocyathids 30% of dolomite; above 30% the strata are barren.

According to Spizharsky (1968, p. 261, *in* Zhamoida, Ed.) a hot and arid climate prevailed over the waters of the basin and favoured the development of great salt deposits. To sum up, a wide-spaced and shallow sheet of marine waters covered the southern Siberian platform in late Precambrian and early Cambrian times; lasting evaporation resulted in a generally 'abnormal' salinity, saturation and precipitation of Ca and Mg carbonates in the first place; the evaporated water was steadily replaced by influx from the open sea, maintaining the condition governed by the loss of CO_2 by heating and by photosynthesis. At the same time 'permanent conditions are hardly ever realized in the natural environment' (Baas Becking et al., 1960, p. 264) and the conditions in waterways of the platform were also variable in space and time: limestone and dolomite indicate 'abnormal' alkalinity (pH between 8 and 9.4) and halite and gypsum acidity (pH down from 7 to 6) as illustrated by Baas Becking et al. (op. cit., p. 262, fig. 17). The salt and gypsum layers, like the dolomite discussed above, indicate an environment hostile to life at the time and place of their deposition.

The advent of the initial Aldanian fauna can be linked with the following chain of events: (1) the epicontinental region of the Siberian platform was dominated originally by the Judomian saline waters and precipitation of dolomite—a long-enduring environment inimical to life; (2) at the beginning of Aldanian time new seaways established communications between the evaporitic lagoon and normal marine waters, and marine animals began their advent to the west; (3) nevertheless, abnormal salinity remains as a barrier, but archaeocyathids and shells possessing a high tolerance to salinity settled first in the Tommotian shallows; and (4) the sensitive trilobites delayed their entry for a while. Phanerotrilobites already lived elsewhere during Tommotian time.

THE FLORA OF THE ARCHAEOCYATHA

In modern literature the Archaeocyatha are described as 'enigmatic animals' of unknown parentage and without progeny; they are, however, calcareous algae. According to Zhuravleva (ref. Hill, 1965, fig. 9, p. 29) the archaeocyathids lived attached to sea floors not deeper than 100 m and flourished at depths between 20 to 50 m. Zhuravleva's model of the habitat of archaeocyathids depicts the euphotic region of modern seas; the intensity of solar radiation at the time of archaeocyathids is unknown; but it may have been at times greater than now, especially in the blue and violet part of the spectrum. Being green plants, the archaeocyathids lived by photosynthesis. Sponges (Porifera) and other heterotrophic invertebrates, however, depend on environments containing organic matter and not on light.

The tolerance of archaeocyathids to high levels of salinity is also remarkable, as indicated by their presence in strata containing up to 30% of dolomite, whereas the coeval animals (trilobites) could not tolerate more than 20% dolomite precipitation. As regards the matrix, archaeocyathids occur in limestone containing noticeable amounts of clastic material (silt and clay) and in marls, as recorded, for example, by Khomentovsky & Repina (1965, text-fig. 6). Their intervallum is always filled with clear diagenetic calcite free of impurities of sedimentary origin, but the central cavity contains material of the matrix and debris of fossils.

Okulitch & de Laubenfels (1953) found it impossible to include the Archaeocyatha in either the Porifera or the Coelenterata and settled for a separate phylum of animals of the Subkingdom Parazoa. The general acceptance of the Archaeocyatha in the Animalia invoked speculations regarding their organization, reviewed by Hill (1964a). These include feeding on microplankton, the strainer function of the porous walls, presence and distribution of digestive organs, free larvae, the problem of the 'emptiness or fullness' of the central cavity, the function of the mostly porous peltae (opercula) over the top of the cup in some forms, and the organization of the intervallum.

The fossil material, however, consists of bare calcareous skeletons—a challenge in the search for preserved 'soft parts'. The skeleton is internal and writers presume that it possessed an external thin cover of an unknown but soft and perishable composition pierced by pores. Furthermore, Vologdin (1962, p. 93, fig. 2; pl. 1, fig. 10) discovered in the central cavity of a specimen of *Ajacicyathus demboi* a mass of remnants of vermicular canals and similar structures in the intervallum and interpreted these as fossilized internal organs. These filaments, however, may belong to an algal incrustation or to an algal fragment of the infilling of the central cavity of the skeleton. It stands to reason that a living archaeocyathid was not a collector of an ever-increasing load of sediments as long as its central cavity retained its stem of living matter.

In brief, Archaeocyatha are classified as animals by the external analogy of the univallate Monocyathida with the calcareous sponge *Olynthus,* both having a single and porous wall; the notion of that analogy is reflected in the genus name *Archaeolynthus* Taylor. The sponges are heterotrophic animals taking their food with the water sucked in through the pores; this method of nutrition is also ascribed by extrapolation to the Archaeocyatha, which otherwise are unrelated to sponges.

The possession of skeletal pores, however, is no proof that the porosity necessarily constituted or constitutes a plumbing system; in the archaeocyathids the skeletal pores and canals were sealed by the plasm integrated with the plasm of the central stem. Lately, P. S. Krasnopeeva (Zhuravleva et al., 1969, p. 65) also suggested that the organic tissue had to fill and pass through the pores for the sake of an even distribution of the nutrition.

Thus, the structure of the intervallum in bivallate archaeocyathids indicates absence of water inflow or outflow through the pores of the walls: (1) the intersepts contain secondary deposits of calcite but no silt or clay; (2) according to Zelenov (1957, p. 38, 39) the sediments with the archaeocyathids contain 15-20% of inorganic particles of grainsizes 0.01-0.001 mm, about one to two orders of magnitude less than the diameters of the pores; and (3) the archaeocyathids populated sea floors under shallow agitated waters; but (4) collected nothing of the inorganic turbidity present close to the bottom of the sea. Consequently, water and nutrition did not pass from outside and circulate in the skeletal pores and canals of the archaeocyathids; these ducts contained filaments which extended outward and functioned as organs of photosynthesis. The archaeocyathids presumed to be heterotrophic animals are photoautotrophic plants populating euphotic domains of the sea. This accepted, Archaeocyatha can be regarded as a class of the phylum Chlorophyta.

No tanglible evidence is available regarding the structure of the tissue of the archaeocyathids; it could be cellular or not; both forms occur within the Chlorophyta and an answer would have no bearing on the phylum classification of the archaeocyathids. The simplest possible contemplated model is briefly described below.

An individual of the Archaeocyatha is a large cell unit (or a 'no-cell') of rather perishable plasm containing a multitude of nuclei and enclosed in a calcareous skeleton; uni- or bivallate, the skeleton supports the soft central body of the plant, whose main part occupies the central cavity. Filaments from, or of, the central body occupy canals and pores of the internal skeletal elements in the intervallum, and also pass through the pores of the outer wall into the open as organs of photosynthesis. These filaments may be simple, or composed of strands of delicate threads where a microporous membrane envelops the cup, covering the much larger wall pores. The cup was also crowned by a tuft of filaments rising direct from the central body, or passing out through the pores of the pelta where it was present. The living plant had a velvety or furry (or hairy) habit. This model covers the structural and functional morphology of Archaeocyatha and disposes of the 'enigma' of their parazoan, animal concepts.

In forms wanting in external filaments the organs of photosynthesis were seated in the apertures of pores.

In general terms, their organization tallies with fossil and living calcareous algae Dasycladacea (hairy shoots)—the Siphonales as diagnosed by Seward (1898, I, p. 164-177) or by Kräusel (1950). The Archaeocyatha are, nevertheless, distinguishable by the bivallate structure in most of their known taxa and by the complicated skeletal elements in the intervallum exploited in the taxonomy within the class. Functionally these elements together with the walls and septa, all pierced by pores, constituted a light-weight filigree framework supporting the plasm in the vase and its external filaments.

Toll (1899, ref. in Taylor, 1910) placed the archaeocyathids in the calcareous algae, namely in the Siphoneae of the Chlorophyta, but Taylor (1910, p. 167-170) rejected this classification. Taylor and Toll both were referring to Seward's (op. cit.) description of *Acetabularia mediterranea* (latest references to the genus by Kochansky-Devidé, Vanda, & Gusic (1971) and by Elliott (1971); and Taylor, trusting in the analogy of the archaeocyathids with the sponges, placed them in the Porifera—and in the Animal kingdom. I can agree with Taylor that the similarity between the well-known recent alga *Acetabularia* and the archaeocyathids appeared unconvincing, but there was no reason to remove the latter from the vegetable kingdom altogether. Toll suggested also that in his material from Siberia sporangia are apparent and compared these with the sporangia of the living dasycladacean *Acetabularia* as illustrated by Seward (1898, fig. 33).

Taylor and all subsequent authors, however, gave no support to Toll's observations. But in most fossil Dasycladacea sporangia are unknown; in these the spores, presumably, were generated in the plasm of the stem or in the external filaments. A similar primitive method may have been inherent to the primordial Archaeocyatha. To speculate, in these the interseptal compartments of the intervallum were the sites of spore generation.

The spores were broadcast in the water and some settled on the ground in the 'home garden' or in the nearest banks; others travelled away with currents and perished gravitating into the lightless deep; or perhaps established footholds on remote calcareous banks and initiated new centres of further dispersal of the flora. In this manner the Archaeocyatha attained their global distribution as disconnected, sporadic stations known as 'archaeocyathid limestones'. Archaeocyathid sandstones and shales are unknown and, presumably, most calcareous banks remained barren of the flora. Nevertheless, the discoidal forms (e.g. *Okulitchicyathus*) of a possible pelagic mode of life and in no need of a 'pied-à-terre' should be found embedded in shales and siltstones deposited below the euphotic zone. Transported skeletons and debris of sessile archaeocyathids may occur in sediments fringing the banks. A garden of archaeocyathids preserved in metamorphics of the Arctic part of Norway has been described by Holland & Sturt (1970).

Hill (1965, p. 41 and map, text-fig. 11) reviewed exhaustively the known geographic distribution of Archaeocyatha and of archaeocyathid limestones.

The 'archaeocyathid limestones' are traditionally interpreted as reefs. It seems, however, that a concept of a reef in general cannot be derived from the term 'archaeocyathid reef' and vice versa. According to Teichert (1952) in Australia the Archaeocyatha were not reef builders, and to Daily (1956, p. 137) the archaeocyathids 'became practically rock forming, but never did they form reefs as so many people have suggested'. By the way, the rock-forming skeleton in a specimen is 10%, or less, of the total; the rest consists of the matrix and subsequently emplaced diagenetic calcite. Debrenne (1959) appraised the major occurrences of archaeocyathids in five continents and concluded that these fossils occur (1) as scattered in association with others; (2) in massive banks; and (3) as small bioherms. She also refers to the want of information regarding the reasons for the episodic incidence of archaeocyathid limestones. Likewise, Walter (1967, p. 141) operates with the term 'biohermal bank' of archaeocyathids in South Australia; such a bank is formed by skeletal organisms having no potential 'to erect a rigid, wave-resistant structure'. Banks, of course, are also topographic features of the sea floor formed without organic agents.

In Nevada and California, according to McKee & Gangloff (1969, p. 719), archaeocyathids occur in 'small lenticular' bodies of limestone less than 1.5 m thick, and 'other limestone units within the archaeocyathid biozone commonly are barren'; it seems therefore that transient and recurrent colonies of Archaeocyatha are embedded in these calcareous sequences. According to Okulitch (1969, p. 984), the lateral extent of such colonies may be of the order of several kilometres, 'but the thickness is usually only a few feet'.

The largest known region of archaeocyathids is Siberia. In the Siberian platform the Archaeocyatha, in combination with calcareous algae, formed bioherms—mounds a few metres high and smaller. According to Suvorova (1969), however, in the Altai-Sayan Mountains prominent calcareous reef-like bodies exist; these structures are algal; but Archaeocyatha occur 'as separate bioherms some centimetres to metres in size'.

In passing, Zhuravleva & Myagkova (1972) retreated finally from believing in the animal nature of the archaeocyathids, but never accepted Toll's algal hypothesis; the new kingdom Archaeata Zhuravleva & Myagkova received the Archaeocyatha instead.

THE PROCESSION OF ARCHAEOCYATHA

An individual garden of Archaeocyatha in its shallow marine environment depended on the sunlight and a hydrology of calcareous deposition; the archaeocyathids lived in danger of extinction between the chance of uplift out of the waters or of a lethal subsidence of the bank down into the darkness of the sea, below 80 to 100 m. Likewise, changes in the hydrological regime, changes from calcareous to detrital sedimentation, and even encrusting algae could destroy the garden.

For example, in the 'Blue Clay' province of Early Cambrian in Eastern Europe (Öpik, 1956), archaeocyathids (and limestones) are absent, in contrast to Siberia.

The global distribution of the archaeocyathid banks and bioherms in space and time, and in large numbers, ensured that the stock of the Archaeocyatha did not share the fate of its individual and transient gardens.

The geological date of the start of the procession of the Archaeocyatha is unknown, but it should be documented in some Proterozoic deposits not yet discovered, or investigated. The Archaeocyathids arrived in the earliest Cambrian as several taxa—all possessing the same skeletal structure inherited, presumably, from their predecessors; also it stands to reason that their heritage included the adaptation to the particular 'archaeocyathid limestone' environment linked to the dispersed and episodic calcareous banks.

A possible Proterozoic archaeocyathid (Coscinocyathidae) is *Misracyathus vindhianus* Vologdin, 1957 (*vide* Vologdin, 1962, p. 126, fig. 26) from the Vindhian of India. According to Misra (1949, p. 439, fig. 2) it comes from a carbonaceous limestone about the top of the Rohtas stage and is identified by Professor S. R. N. Rao as an alga (Dasycladacea); in its illustration the magnification is 110. Vologdin's illustration is a pen drawing from Misra's text-figure 2, but its magnification is given as 10 and not 110. Misra & Awasthi (1962, p. 756) describe the object once again as a 'slender microscopic verticillate structure with a globular head'. The illustrated section of this head recalls a dasyclade but also a transverse section of an unusually small regular archaeocyathid associated with sections of tabulate intervalla—as in a *Coscinocyathus*. In passing, Reed (1910, p. 58, pl. 6, fig. 33) described *Coscinocyathus* cf. *corbicula* Bornemann from Spiti associated with Middle Cambrian trilobites; this find could be the reason why Zhuravleva (*in* Repina et al., 1964, p. 219) refers to the occurrence of *Coscinocyathus* in India. At all events, Indian writers have considered as feasible a Palaeozoic age of the Vindhian sequence.

As is well known, the archaeocyathids are most abundant and diversified in the Early Cambrian-Olenellian time. The stock, however, became greatly depleted in the Ordian in numbers of taxa, as evident from published lists of the Siberian Lena *yarus* (Keteme and Yelanka, Solontzy and Obruchev *gorizonts*); the number of such sites in Siberia is also small as compared with older *gorizonts*. After Lena time the grand flora of archaeocyathids disappeared from the Siberian region except for a single site in Salair (Repina et al., 1964, p. 120), where an occurrence of *Archaeocyathus* may be of a 'true Middle Cambrian' age.

Remarkably enough, at the same time the earlier desiccating evaporitic environment in Siberia phased out and the shallow calcareous banks, the archaeocyathid grounds par excellence, disappeared as well. Consequently, the largest known source region of the dispersal of Archaeocyatha ceased to exist—an event of global consequences. In Australia Ordian Archaeocyatha occur in the Wirrealpa Limestone (South Australia) and in the Ranken Limestone in the Northern Territory; the latter is a limestone bank (or banks) in a sequence of predominantly precipitated dolomites. Isolated and rare specimens of a presumed *Archaeocyathus* occur also in the Northern Territory in the post-Ordian (hence 'properly Middle Cambrian') Templetonian strata (see Hill, 1965, p. 43), and I have observed ill preserved Archaeocyatha indet. in limestone about the zone of *Ptychagnostus atavus* in Queensland. The youngest known *Archaeocyathus* is Late Cambrian, found in the Antarctic by Webers (1966).

The problem of the extinction of the Archaeocyatha is approachable on two mutually exclusive assumptions: that Archaeocyatha are (1) a phylum of the Animal Kingdom or (2) a class of calcareous plants.

As animals, archaeocyathids existed and were abundant in the Olenellian, declined in the Ordian, and died out in Late Cambrian time; 'a sterile offshoot from the Porifera' (Cloud, 1968, p. 43), they underwent no significant modifications in their skeletal structure, and, indeed, left no progeny among the invertebrate faunas of later periods.

As plants (green algae) archaeocyathids occupied euphotic biotopes and retained the fundamental organization consisting of a stem of plasma and external filaments, supported by a calcareous framework; in the course of evolution the skeleton was modified into the diversity of the external form seen in the Dasycladacea, but retained the pores as passages of the filaments and as outlets for the spores. It stands to reason that the individual Cambrian species and genera of the Archaeocyatha proper disappeared, but that the flora as a whole was not depleted of its generative material in a phyletic sense.

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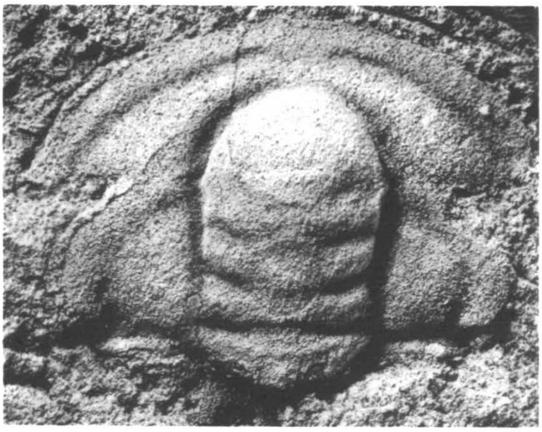
PLATE 1

Estaingia bilobata Pocock

Fig. 1. Cranidium, CPC 13152, x 3.
Fig. 2. Cranidium, CPC 13153, x 3.
Fig. 3. Right free cheek, from inside, with doublure, CPC 13154, x 5.
Fig. 4. Cranidium, deformed, CPC 13155, x 6.
Fig. 5. Cranidium, deformed, CPC 13156, x 3.
Fig. 6. Pygidium, CPC 13157, x 8. Same specimen in Fig. 7 on left.
Fig. 7. Two pygidia, x 8. Pygidium on the right, CPC 13158, with a spine preserved.



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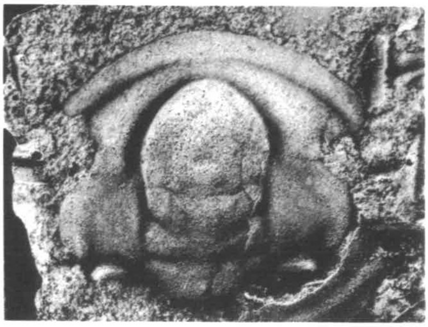

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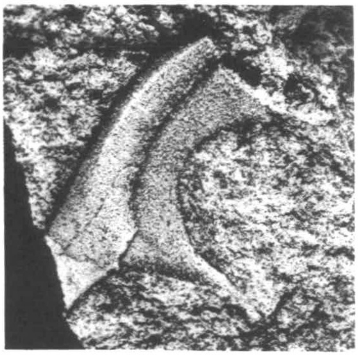

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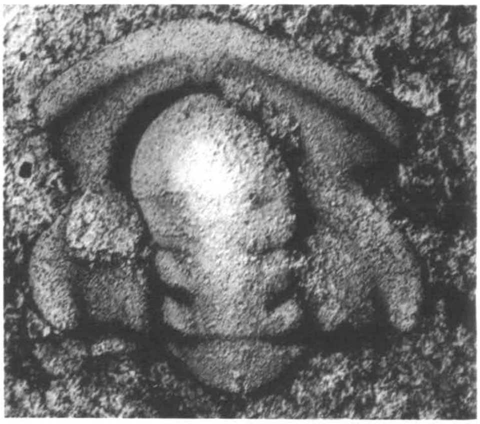

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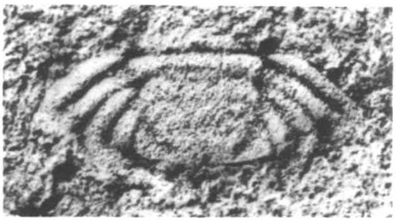

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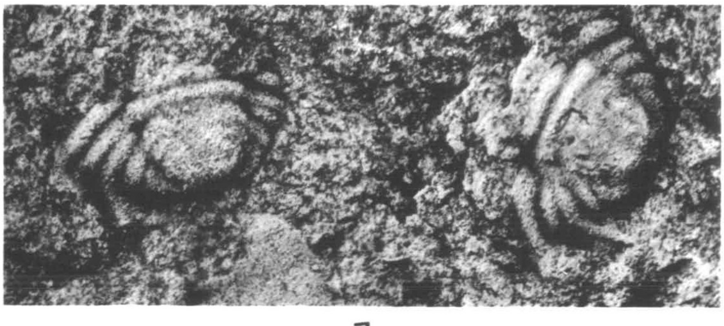

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PLATE 2

Strenax cerastes gen. et sp. nov.

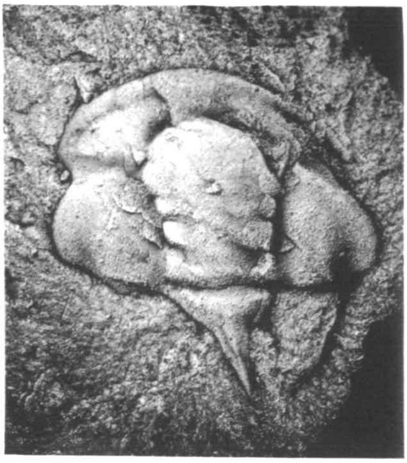
Fig. 1. Cranidium, **holotype**, CPC 13159, x 2.5 (latex).

Fig. 2. Cranidium, CPC 13160, x 3; it is worn but preserves the posterolateral margin, the tip of the left palpebral lobe and the fulcral projection (spine). Associated are two cranidia of *Discomesites lunatulus.*

Figs 3, 4. Cranidium, CPC 13161, x 5; two photographs.

Fig. 5. Cranidium, CPC 13162, x 3. Veins on the frontal limb preserved.

Fig. 6. Free cheek, latex of CPC 13163, x 6.5; the ornament is clear.



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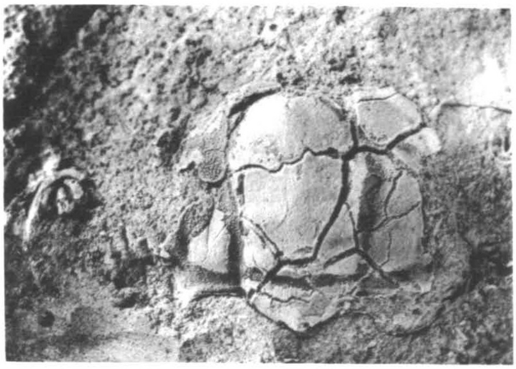

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PLATE 3

Sematiscus fletcheri gen. et sp. nov.

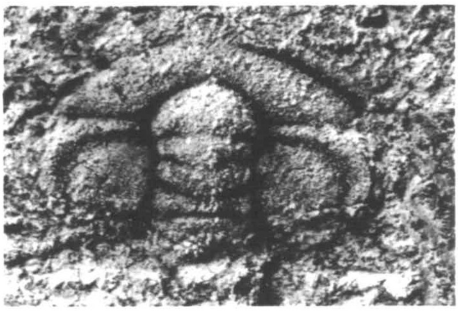
Figs 1, 2. Cranidium, **holotype,** CPC 13164, x 7. Fig. 2 is latex.

Dinesus aff. *granulosus*

Figs 3, 4. Cranidium, CPC 13165, x 10; in plan and profile.

Serrodiscus daedalus sp. nov.

Fig. 5. Cephalon, CPC 13166, x 15.
Fig. 6. Cephalon, **holotype,** CPC 13167, x 10.
Fig. 7. Cephalon, CPC 13168, x 10.
Fig. 8. Cephalon, CPC 13169, x 10.
Fig. 9. Pygidium, latex of CPC 13170, x 8.



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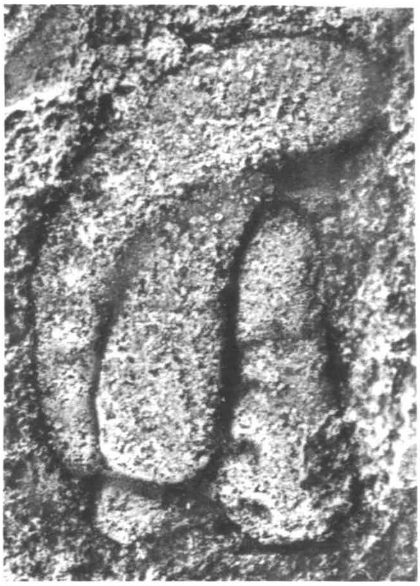

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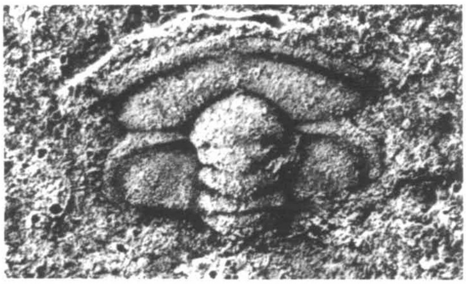

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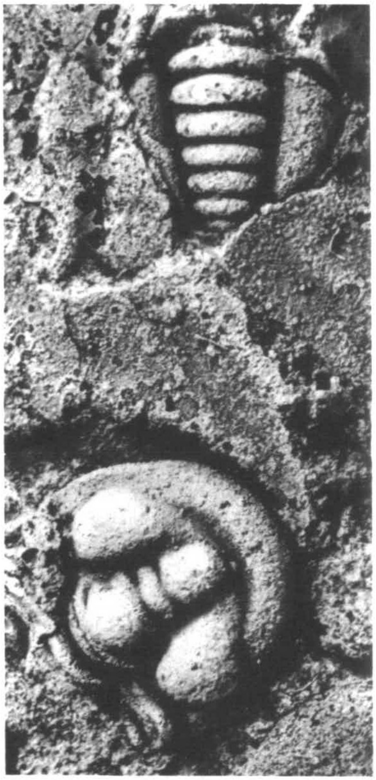
PLATE 4

Meniscuchus menetus gen. et sp. nov.

Figs 1, 2.	Cephalon, **holotype,** latex of CPC 13171. Fig. 1, x 7, associated with a pygidium of the same species; Fig. 2, x 11.
Fig. 3.	Cephalon, CPC 13172, x 15.
Fig. 4.	Cephalon, latex of CPC 13173, x 12.5.
Figs 5–9.	Pygidium, CPC 13174. Fig. 5, x 10; Fig. 6, Latex, x 11; Figs 7, 8, x 10; Fig. 9, x 11.
Fig. 10.	Pygidium, CPC 13175, deformed, x 20.



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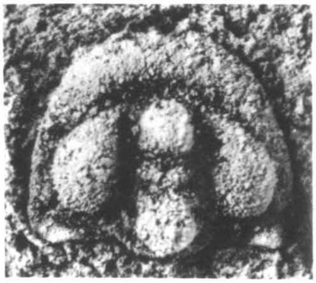

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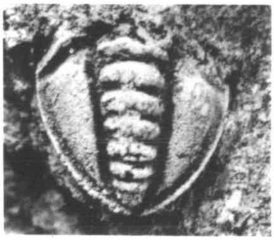

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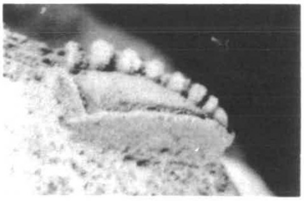

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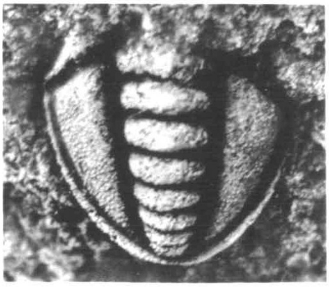

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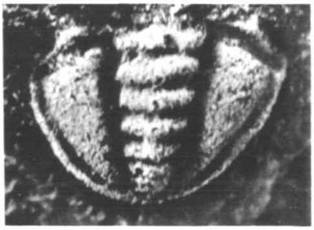

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PLATE 5

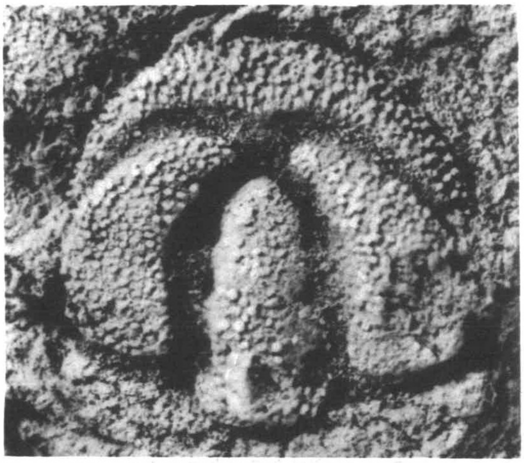
Discomesites fragum gen. et sp. nov.

Fig. 1. Cranidium, CPC 13176, x 17.

Fig. 2. Cranidium, **holotype,** CPC 13177, x 11.

Figs 3, 4. Cranidium, latex of CPC 13178; x 15 and 8 respectively.

Figs 5–8. Pygidium, CPC 13179; Figs 6 and 8 are latex casts; x 8 and 16 respectively.



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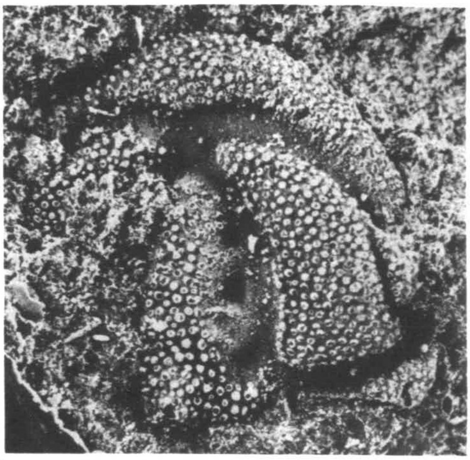

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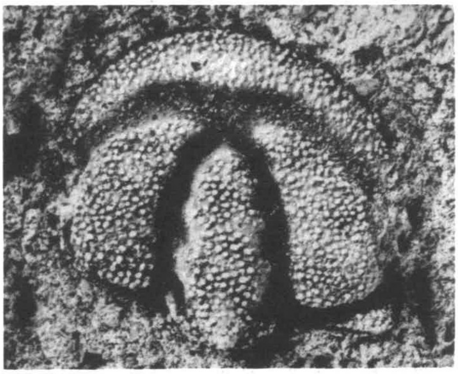

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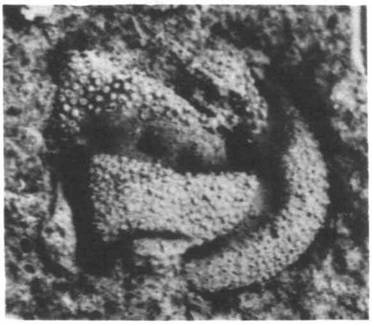

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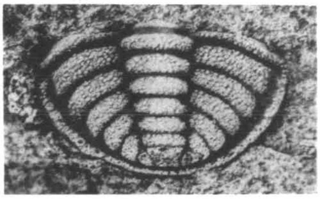

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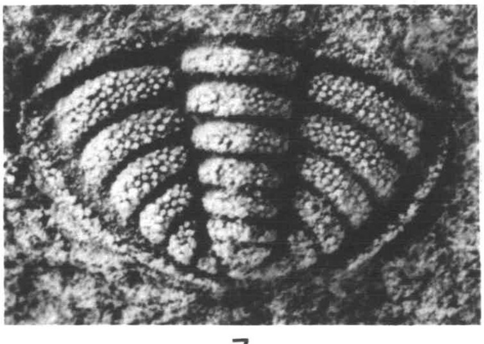

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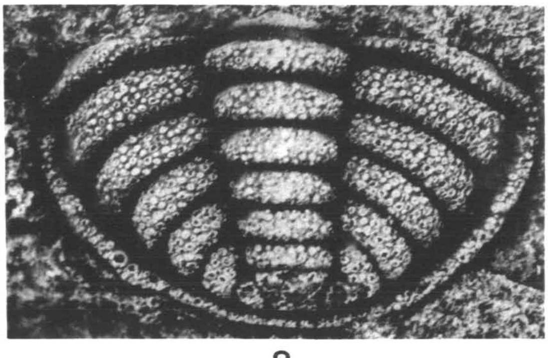

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PLATE 6

Discomesites lunatulus sp. nov.

Fig. 1. Cranidium, **holotype**, CPC 13180, x 10.
Fig. 2. Cranidium, CPC 13181, x 15.
Fig. 3. Pygidium, CPC 13182, x 15.
Fig. 4. Pygidium, CPC 13183, x 9.

Pagetia sp. indet.

Fig. 5. Pygidium, latex of CPC 13184, x 10.

Neobolus? sp. indet.

Fig. 6. A fragmentary dorsal valve, latex of CPC 13185, x 10.

Scenella aff. *antiquata*

Fig. 7. A fragmentary shell, latex of CPC 13186, x 10.

Scenella reticulata Billings

Fig. 8. A complete shell, CPC 13187, x 7.

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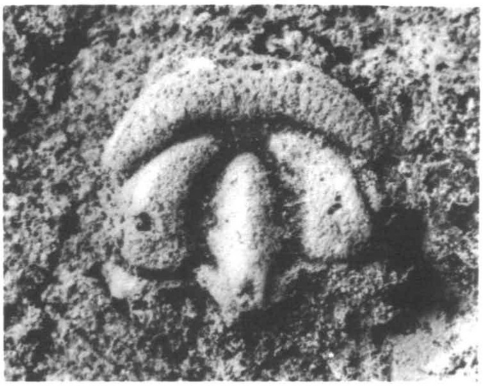

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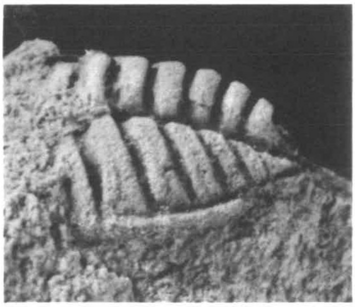

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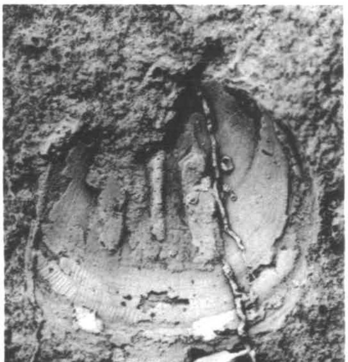

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PLATE 7

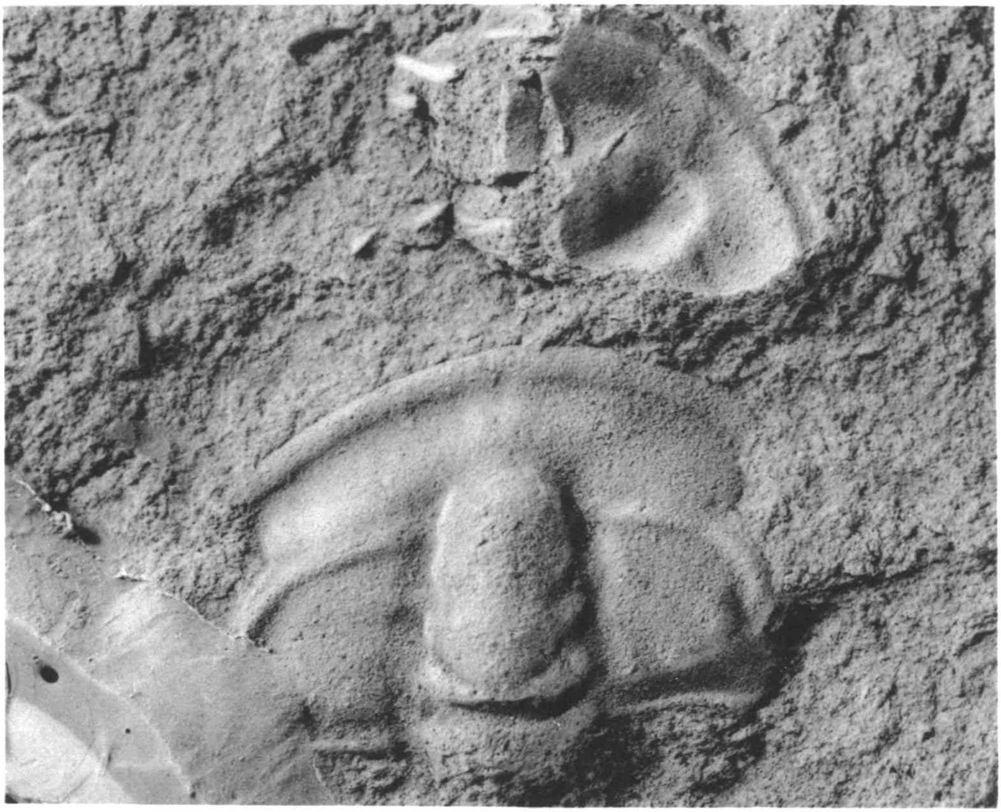
Trilobites from the Parara Limestone near Kulpara, Yorke Peninsula, South Australia

Bigotina tina sp. nov.

Fig. 1. Cranidium, **holotype,** latex of CPC 13188, x 6.

Dolerolenus(?) sp. nov.

Fig. 2. Two cranidia, latex of CPC 13189, x 4.



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