winterte. Das erste Gesamtbild über die Physiographie Grönlands wurde vom Verfasser 1923 publiziert: (1) Der von Inlandeis überdeckte Felsgrund Grönlands besteht aus zwei nordwärts gekippten Blöcken. (2) Die Trennfuge hängt mit der aus Basalt gebauten Querschwelle Färör-Island zusammen. Gestützt auf Messungen der Inlandeisexpeditionen von P. E. VICTOR, skizzierte BAUER[2] eine erste topographische Karte des grönländischen Felsgrundes (Figur 2). Die Darstellung bringt eine quer durch Grönland streichende Bruchblockzone konkret zum Ausdruck (Figur 3).

Neuere bathymetrische Forschungen im arktischen und atlantischen Ozean erweiterten diese physiographischen Erkenntnisse über Grönland.

Die Küstengebirge Nord- und Ostgrönlands sind paläozoische Orogensysteme. Es wird in diesem Zusammenhang der Wandel des geologischen Bildes von Geosynklinal- und Gebirgsbildung und der Kontinentaldrift erwähnt. Ein Grossteil der Gesteine Grönlands besitzt präkambrisches Alter; Korrelationsprobleme des Präkambriums und einige neuere radiometrische Einteilungen werden diskutiert.

The Cambro-Ordovician Geology of East Greenland

By J. W. COWIE*

That part of East Greenland which now lies between latitudes 72° and 75° N was the site of sedimentation during part, at least, of the Cambrian and Ordovician Periods. No Silurian rocks or fossils have been found in this region. The strata, which attain a maximum thickness of 3000 m, are part of a thick pre-Devonian sequence which has been folded and in places, metamorphosed. The Cambro-Ordovician rocks (COWIE and ADAMS[1]) in the roughly north–south zone of outcrops show a striking uniformity of succession—in both lithology and faunas they vary little along the regional strike: if rocks of the same age occur to the east or the west they have either not yet been discovered or are now covered by ice.

On structural grounds the Lower Palaeozoic outcrops of Northeast Greenland between latitudes 79° and 82° N. can be linked with those of East Greenland: they are west and east respectively of the main folded belt. The successions and faunas of this region in the north-east show affinities with those found in Peary Land, in Northwest Greenland and in the Queen Elizabeth Islands of Canada and from the stratigraphical and palaeontological points of view they are better discussed with them. They are excluded from consideration here.

The pre-Devonian sediments of East Greenland do not display striking unconformities with angular discordance of bedding. By careful detailed study of well-exposed sections and consideration of regional relationships, however, it can be shown that an important regional unconformity, which must represent a considerable period of time, is present at the base of the Kløftelv Formation (see Table). This horizon is taken as the base of the Cambrian System. The Tillite, Canyon and Spiral Creek Formations are therefore considered to be of late Pre-Cambrian age; they have yielded no recognizable fossils except for stromatolites which may be algal in origin.

The glaciation represented by the East Greenland tillites continued for a considerable time and this cold climate was interrupted by an interglacial period of long duration. The *Canyon Formation* contains rhythmic deposits which have often been called varves. If correct, this diagnosis indicates the proximity of glaciers with an annual melt cycle giving laminated sediments. The *Spiral Creek Formation* indicates a change in climate and in depth of the sea from those prevailing when the underlying formations, including the tillites, were deposited in cold seas. Sun-cracking, ripple-marking, cross-bedding, intraformational breccias, salt casts and the presence of felspar all indicate shallowing, intermittent drying-out and pene-contemporaneous erosion in a warm, humid climate (SCHAUB[2]).

The unconformity at the base of the *Klöftelv Formation* is expressed by overstep from the Spiral Creek Formation on to the Tillite series. The main lithology of this formation is a massive pure quartzite which varies considerably in colour, and frequently shows cross-bedding, ripple-marks and 'swash' marks. The uniformity of the thickness and of the lithology over the whole region suggests rapid marine transgression over a peneplained land area. The only indications of the existence of organisms in the Kløftelv Formation are numerous tracks and trails and these are also seen in the lower part of the *Bastion Formation*. The sandstones of this subdivision succeed after a stratigraphical break with a basal conglomerate containing phos-

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[1] J. W. COWIE and P. J. ADAMS, Medd. om Grønland, Copenhagen *153*, 1 (1957).

[2] H. P. SCHAUB, Medd. om Grønland *114*, 1 (1950).

phatic bodies composed of collophane: this mineral could be organic in origin. The upper part of the formation is undoubtedly fossiliferous and the predominant shale suggests a deepening of the sea although quartz is still present as a component of the rocks along with the argillaceous minerals. To begin with the only trilobites found belong to the olenellids and this may indicate that the older beds belong to the lower subzone of the *Olenellus*-zone. In the higher beds of the formation eodiscid trilobites occur along with olenellids and these strata can therefore be assigned to the upper sub-zone of the *Olenellus*-zone.

The limestones of the *Ella Ø Formation* are sandy also, so the sea may not have deepened very much with the introduction of a strong chemical factor in the sedimentation. Presumably the seas were warmer and the reduction in the clastic factor in the sediments may have been due to the reduction of relief and increased distance from the land. The trilobite faunas include dorypygids and ? *Protypus* but olenellids persist to the highest beds where *Proliostracus* and other genera suggest a late Lower Cambrian age. A chemical change in the sediments, which may be primary and/or secondary, gave rise to the dolomites of the *Hyolithus Creek Formation* and these massive, stylolitic dark rocks which contain intraformational conglomerates at many horizons have little or no quartz in them. The environment suggested is of warm seas with increased depth but still intermittently becoming shallow enough for the newly deposited sediments to be disturbed by storms. Land was either distant or of low relief. Organisms must have been largely absent from these seas unless their remains have been subsequently destroyed by secondary dolomitization: *Salterella*, a mollusc which is probably confined to the Lower Cambrian, occurs at a few horizons in the lower part of the formation.

Except for stromatolites (?algal) there are no fossils in the upper part of the Hyolithus Creek Formation nor in the overlying *Dolomite Point Formation* which is broadly similar in lithology, although containing more shale and a great deal of chert. There is no evidence of a break between the formations and these unfossiliferous strata may be tentatively dated as Middle Cambrian. The stratigraphical break between the Dolomite Point Formation and the overlying Lower Ordovician Cass Fjord Formation may represent a considerable interval of time: possibly there are no Upper Cambrian deposits in East Greenland.

The assignment of regions to the Pacific Province of the faunas of the Lower Cambrian is based mainly on the occurrences of certain genera of trilobites including *Olenellus*, *Paedeumias*, *Bonnia*, *Bonniella*, *Bathynotus* and *Protypus*. Characteristic trilobites of the Acado-Baltic or Atlantic Province are *Holmia*, *Kjerulfia*, *Callavia*, *Strenuella*, *Strenuaeva* and *Protolenus*. In East Greenland the Lower Cambrian faunas include *Olenellus*, *Paedeumias*, *Bonnia*, *Bonniella* and *Protypus* and this assemblage suggests Pacific Province affinities. Presumably an incursion of Atlantic Province faunas took place for a time for *Holmia* is also found (COWIE[3]).

The *Cass Fjord Formation* is typically formed by thinly-stratified, nodular, muddy limestones and shaly partings, alternating with bands of a purer and more homogeneous limestone. Intraformational conglomerates make up a considerable part of the limestone bands and occur in the limestone-shale beds as thin,

Formation, main lithology and maximum thickness in metres	Selected fossils	Age	
Angular unconformity		Cincinnatian	
Heimbjerge (320) limestone	? *Eofletcheria*, *Leptaena*		
	Rafinesquina, *Öpikina*, *Receptaculites*, *Bumastus*, *Illaenus*, *Calliops*, *Pliomerops*, *Sphaerexochus*	Mohawkian	
Narhval Sund (460) limestone and dolomite	bathyurids, *Ceraurus*	Chazyan	Ordovician
Kap Weber (1100) limestone	*Pliomerops*, *Remopleurides*, *Raymondaspis*		
	Carolinites, *Pseudomera*, *Petigurus*, *Isoteloides*, *Goniotelina*, *Bolbocephalus*	Upper Canadian	
	Benthamaspis, bathyurids	Middle	
Cass Fjord (230) limestone and shale	*Hystricurus*, *Symphysurina*, graptolites	Canadian	
		Lower Canadian	
stratigraphical break			
Dolomite Point (400) dolomite	stromatolites	? Middle	Cambrian
Hyolithus Creek (210) dolomite	none known		
	Salterella sp.		
Ella Ø (90) limestone	olenellids, *Proliostracus*	upper *Olenellus*	
	olenellids, *Bonniella*, *Kootenia* and ? *Protypus*	sub-zone	
Upper Bastion (100) shale	olenellids and eodiscids		
	olenellids, horny brachiopods, and hyolithids	lower	
stratigraphical break			
Lower Bastion (50) sandstone and shale	tracks and trails organic (?) phosphate	*Olenellus*	
stratigraphical break		sub-zone	
Kløftelv (70) quartzite	tracks and trails		
regional unconformity			
Spiral Creek (25) dolomite and siltstone			Pre-Cambrian
Canyon (300) shale, dolomite, siltstone	stromatolites		
Upper Tillite shale, tillite, dolomite			

[3] J. W. COWIE, Rep. int. geol. Congr., XXI Session, Norden, Copenhagen (1960), Pt. VIII, Late Pre-Cambrian and Cambrian Stratigraphy, p. 57.

impersistent lenses and pockets. The frequent occurrence of intraformational conglomerates and other sedimentary relationships suggest an unstable, comparatively shallow water environment for the duration of the formation. Although the age of the basal beds is given only by the brachiopods and gastropods which are poorly preserved, the main subdivisions are relatively fossiliferous with trilobites represented, for example, by *Micragnostus*, *Hystricurus*, *?Pseudohystricurus* and *Symphysurina* and accompanied by graptolites.

There appears to be no stratigraphical break at the top of the Cass Fjord Formation.

The *Kap Weber Formation* is mainly a thick relatively uniform sequence of massive limestones, with intercalations in the lower beds lithologically similar to the underlying formation, and with dolomitic limestones near the top which are overlain conformably by the dolomites of the succeeding formation. Intraformational conglomerates are more common near the base and chert can be important; fossils are sparse. The faunas indicate an Upper Canadian age and include *Lingulella sculptilis* Ulrich and Cooper, *Carolinites* aff. *genacinaca* Ross, *Pseudomera barrandei* Billings, *Petigurus*, *Isoteloides*, *Goniotelina*, *Bolbocephalus*, *Benthamaspis* and bathyurids. Limestone, probably part of a fault block, which is lithologically identical with the limestone of the Kap Weber Formation yielded *Pliomerops*, *Remopleurides* and *Raymondaspis* which indicate a possible Chazyan age.

The *Narhval Sund Formation* may be Middle Ordovician in age. Dolomites predominate in the succession but limestones are found and dolomitic limestones are common.

The *Heimbjerge Formation* shows a return to limestone in its lithology and the fairly extensive faunas include *Rafinesquina*, *Öpikina*, *Receptaculites* '*arcticus*' Etheridge, *Bumastus* aff. *fronto* Troedsson, *Illaenus* cf. *groenlandicus* Troedsson, *Calliops*, *Pliomerops* and *Sphaerexochus* which indicate a Middle Ordovician (Champlainian) age which is probably Mohawkian. A faulted area of limestone in the same area yielded a fauna which includes *?Eofletcheria* and *Leptaena* cf. *richmondensis praecursor* Foerste which suggests a late Mohawkian or even Cincinnatian (Upper Ordovician) age for those particular beds.

The predominantly carbonate deposition during that part of the Ordovician Period which is represented in East Greenland probably occurred in warm seas of no great depth in a slowly subsiding trough. The faunas give clear evidence that deposits were laid down in Middle Ordovician (Champlainian) times and possibly this sedimentation continued into early Upper Ordovician (Cincinnatian) times. Although there has been continued search for later faunas in the Lower Palaeozoic of East Greenland both in new outcrop areas and in the boulders of Devonian conglomerates, none have so far been found.

The junction between the youngest Lower Palaeozoic and the Upper Palaeozoic is an irregular erosion surface and the oldest Devonian rocks known, of Middle Devonian age, rest with angular discordance on eroded folds formed in the older rocks. The period of mountain building which affected the Pre-Cambrian, Cambrian and Ordovician beds evidently took place between the Middle, or possibly the early Upper, Ordovician and the Middle Devonian. It would seem reasonable to postulate that as sedimentation evidently ceased in the Ordovician then the earliest stage of movement of the East Greenland Lower/Upper Palaeozoic orogeny occurred towards the end of the Ordovician and can be termed Taconic. The date of the peak of the orogeny cannot be decided on the local stratigraphical evidence alone.

Recently KULP et al.[4,5] have published a series of isotopic ages for igneous and metamorphic rocks of the East Greenland mountain chain. Ten determinations fall within the Palaeozoic era and are from scattered points along a roughly north–south line which is approximately 1000 km long. One of these (490 m.y.) must evidently be disregarded because it comes from the Pre-Cambrian basement, but the remaining nine fall between 435 and 365 million years ago (allowing in both cases for the given limits of accuracy). How absolute ages in millions of years should be correlated with the geological column based on relative stratigraphical ages is, of course, not generally agreed. The potassium-argon dating method used is claimed to give a reliable minimum absolute age but if the rock or mineral being analysed has not remained a closed mineral system subsequent to its formation then the calculated isotopic age will not be the actual time of formation. According to the various absolute geological time scales put forward by different workers these absolute age determinations from East Greenland could be correlated with one or more of the Ordovician, Silurian or Devonian Systems. KULP states ([4] p. 954–5) 'In Eastern Greenland the climax of the main orogeny occurred just at the Silurian-Devonian boundary or slightly into the Lower Devonian'. It seems that although sedimentation ceased in Middle, or possibly early Upper, Ordovician times—and presumably this event was contemporaneous with earth movements—the climax of the orogeny was delayed until Siluro-Devonian boundary times. Further absolute age data should help to resolve outstanding doubts raised by the present state of the research.

Minor earth movements may be represented by the breaks in sedimentation, associated in some cases with unconformities, which have been noted above between the following formations:

[4] J. L. KULP et al., Nature, London *194*, 953 (1962).

[5] J. L. KULP and J. HALLER, Medd. om Grønland, Copenhagen *171*, 1 (1962).

(1) Spiral Creek and Kløftelv (Pre-Cambrian/Cambrian);
(2) Kløftelv and lower Bastion (intra-Cambrian);
(3) lower Bastion and upper Bastion (intra-Cambrian);
(4) Dolomite Point and Cass Fjord (?Middle Cambrian/Lower Ordovician).

Résumé. L'auteur passe en revue la succession stratigraphique cambro-ordovicienne en mentionnant les fossiles caractéristiques. Il fait des observations sur les phénomènes de sédimentation et en tire des conclusions paléo climatiques. Il constate les indices de mouvements tectoniques pendant le Précambrien supérieur et le Paléozoique inférieur et discute la question de l'âge de l'orogénie principale.

The Fossil Vertebrates from East Greenland and their Zoological Importance

By E. JARVIK*

The collections of fossil vertebrates brought together by the collaborators of Dr. LAUGE KOCH during the Danish expeditions to East Greenland in 1929–1957 include more than ten thousand specimens. Much of this enormous material has been or is being described, and since the beginning of the thirties the East Greenland material has played a prominent role in the discussions on the comparative anatomy and phylogeny of the vertebrates. However, the importance of these collections is due not only to the vast amount of material, to the excellent state of preservation of many of the specimens, and to the careful studies of the fossils. As a matter of fact, only a few of the numerous papers which have been published about East Greenland material deal exclusively with such material. Frequently specimens from other areas, too, have been used, sometimes to a large extent, and in many instances fossil vertebrates from East Greenland have been considered more or less in passing, in order to elucidate special problems. But to be able fully to understand the value of the East Greenland collections it is necessary to know, too, that studies of both fossil and recent vertebrates have often been made with the main aim to produce a safe basis for the subsequent treatment of Greenland material. And of course the successful collecting work in East Greenland which has been going on for many years has encouraged fossil hunting in other parts of the world as well.

For more than a quarter of a century the fossil vertebrates from East Greenland have thus in various ways stimulated the paleozoological research work, in particular that concerning the lower vertebrates, and the many elaborate studies have contributed much to the great advance in vertebrate paleontology during the last few decades. In this article it is of course impossible to account for even the most important results of these studies. Only a short and in many respects incomplete review of the collections from the various geological periods will be given and some interesting results, which have recently been gained partly on the basis of studies of East Greenland material, will be presented.

The Devonian was an important epoch in the history of the vertebrates and certainly the large and partly unique Devonian collections from East Greenland have attracted considerable interest. In a recent article[1], most of the papers dealing with these collections were recorded and the zoological importance of the fossils was briefly considered. However, with reference to what has been said above, it may be added that as a preparatory work for his description of the ichthyostegid material discovered in 1931, SÄVE-SÖDERBERGH[2] made a detailed study of the dermal bones and sensory canals of the head in *Osteolepis*; and, in order to be able to determine the important osteolepid material found in East Greenland mainly in 1936, he began a thorough revision of the Middle Devonian osteolepids from Scotland. Because of ill health he was regrettably unable to finish this work, which, however, later developed into a comprehensive morphological and taxonomic account[3] and led to revisions of other osteolepids as well. Finally, it may be worth mentioning that SÄVE-SÖDERBERGH'S paper[4] on *Rhynchodipterus* was a consequence of the discovery of peculiar dipnoans in East Greenland.

The Carboniferous vertebrates taken from East Greenland are few and only some paleoniscids have been described so far[5,6]. A slab with distinct tetrapod tracks figured by WITZIG[7] indicates the presence of stegocephalians in East Greenland in late Carboniferous times.

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1 E. JARVIK, *Devonian Vertebrates.* Geology of the Arctic (University of Toronto Press, 1961), p. 197.
2 G. SÄVE-SÖDERBERGH, Nov. Acta Reg. Soc. Sci. Ups. *9*, 1 (1933).
3 E. JARVIK, K. Vet. Akad. Handl. *25*, 1 (1948).
4 G. SÄVE-SÖDERBERGH, K. Vet. Akad. Ark. Zool. *29 B*, 1 (1937).
5 J. A. MOY-THOMAS, Ann. Mag. nat. Hist. *9*, 737 (1942).
6 E. S. GOODRICH, Quart. J. micr. Sci., London N.S. *83*, 459 (1942).
7 E. WITZIG, Medd. om Grønland *72*, 1 (1954).