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THE DEVONIAN OF WESTERN AUSTRALIA.

A PRELIMINARY REVIEW.

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PART I.

ABSTRACT. A great thickness of Middle and Upper Devonian occurs in the Kimberly District of Western Australia with a fauna that is considerably richer than was hitherto suspected. In the Middle Devonian, *Amphipora* biostromes are of great importance and towards the end of the Middle Devonian, a rich fauna, which is closely related to Asiatic and European faunas of that age, immigrated from the northwest. This fauna consists mainly of brachiopods with associated stromatoporoids, corals, gastropods, and lamellibranchs. The Upper Devonian is characterized by a succession of ammonoid faunas which correspond to those of the European Upper Devonian stages I to IV. Of particular interest is the occurrence of a large and typical *Manticoceras* fauna. While the goniatites flourished in a restricted area, a bioherm facies was prevalent elsewhere and a very extensive barrier reef was built, mainly by the activity of stromatoporoids. At the same time a large delta advanced into the basin from the east, so that in some respects the palaeogeographical setting of the Kimberley Devonian province is comparable to conditions as they existed at the same time in New York State. The Devonian faunas of Western Australia comprise numerous genera that have not before been known to occur anywhere outside Europe. Faunistic relations with the Middle Devonian of Manitoba and the Upper Devonian of New York are also very strong.

The Devonian faunas of Western Australia are compared with those of eastern Australia and southeastern Asia and their general European relationships and derivation is suggested. Direct American ("Chemung") relationships may have to be discounted and no direct communication may have existed between North America and Australia.

The world-wide distribution of Upper Devonian ammonoid faunas is discussed and it is concluded that the distribution of ammonoid faunas, along existing migration routes is entirely dependent on facies. The Devonian ammonoids were benthonic, not planktonic, animals; they never moved away from the restricted habitats in which they found suitable living conditions; and even the possibilities of transport of the empty shells must have been rather limited.

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INTRODUCTION.

IN the western half of the Australian continent, Devonian strata are only known to occur in the northern part (Kimberley District), of Western Australia, where they form extensive outcrops in the region of the Lennard River and the Fitzroy River and its tributaries Margaret River and Mount Pierre Creek (Fig. 1).² The existence in that region of strata of Devonian age was first discovered in 1890 by palaeontologists of the British Museum in London who had never seen Australia, but although the very small fauna then made known by Foord, Hinde, and Nicholson in papers which appeared simultaneously in that year, was of considerable interest and was later referred to and discussed in many papers and textbooks, progress in our knowledge of these strata and their fossils was, until quite recently, very slow indeed, as will appear from the historical summary below. Opportunities for the examination of the area were few and generally beyond the financial resources of a University Department, so that, when I had returned from a short visit to the Fitzroy River area in 1939, I believed that it was rather safe to predict that owing to the remoteness of the Devonian outcrops, from any centres of research no further additions to our knowledge were likely to be made in the near future. (Teichert 1941.) Fortunately, this prophecy proved quite wrong. Little did I anticipate that even before those remarks were to appear in print, I should have an opportunity of revisiting the Devonian area, for the purpose of a detailed study of many parts of the Devonian section.

The progress thus achieved is due entirely to the initiative of Caltex (Australasia) Oil Development, Pty. Ltd., which began geological prospecting in the northern part of Western Australia in the middle of 1940. The following report is based on my own field work with that company in September-October 1940, and to a minor extent on the examination of fossils col-

² Quite recently indications have been obtained which make it seem possible that Devonian strata are also present in the Ord River area whence they might extend further eastwards into the Northern Territory. In September, 1941, Mr. F. G. Forman, Government Geologist of Western Australia, collected a limestone specimen about 15 miles east of Ivanhoe Homestead, containing numerous specimens of a productid, possibly *Productella*, as well as ostracodes among which one representative of *Haploprimitia* could be recognised. The general aspect of these species is Devonian, although none of them is known from the Devonian of the Fitzroy River area which is described in this paper. The location of the new find is indicated on the map, Fig. 1.

lected by geologists of the same company since that time. Since the prospecting work is still in progress, it has not been possible—and may not be possible for some time—to communicate figures of thicknesses or to make detailed statements on particular sections and localities. However, such considerable additions to the Devonian stratigraphy and paleontology of the Kimberley have been made, that even a preliminary report

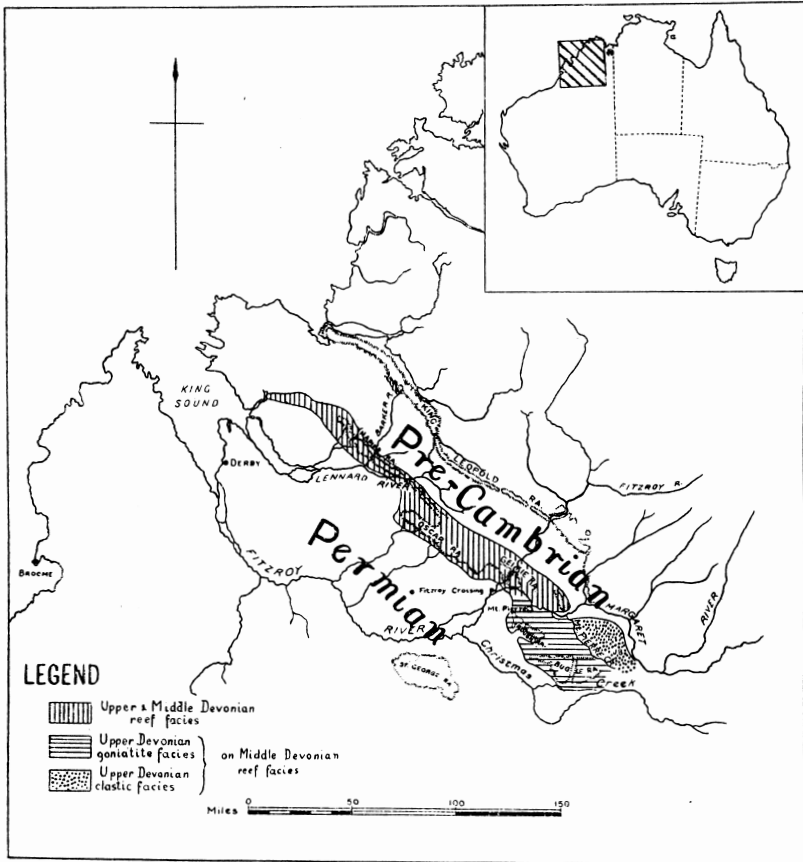


Fig. 1. Geological sketch-map of the Kimberley District of Western Australia, showing the distribution of the Devonian rocks. The ● on the index map indicates a probable occurrence of Devonian outside the map area.

on the results seems to be justified, since many years must pass until this new material can be presented in greater detail. Roughly 6,000 specimens of Devonian fossils have been examined, although it is obvious that determinations must be regarded

as preliminary. The faunas are richer than would appear from this review, and although fossils which could not be determined with a fair degree of certainty with the facilities at my disposal have not been considered here, yet they offer many points of interest.

I am indebted to C. St. J. Bremner, Chief Geologist, Caltex (Australasia) Oil Development, Pty. Ltd., for permission to use this interesting material for publication. Thanks are also due to P. S. Kraus and H. G. Higgins for collaboration in the field and to Dorothy Hill, of Queensland University, who readily supplied me with preliminary information regarding a number of coral species.

Fairly complete notes on previous investigations are given below, because most of the papers on this subject will not be easily accessible abroad.

PREVIOUS INVESTIGATIONS.

The pioneer geologist of the Kimberley District was E. T. Hardmann, first Government Geologist of Western Australia, who in 1883-1884, made observations in and collected from areas now recognised as consisting of Devonian rocks, viz. Mount Pierre, and the Oscar and Napier Ranges. In his report, published in 1884, he assigned the strata exposed in those areas to the Carboniferous system.

However, Hardmann's fossil collections were forwarded to the British Museum in London and H. A. Nicholson, G. J. Hinde and A. H. Foord, in three papers published in the "Geological Magazine" in 1890, recognised that this collection contained fossils of Devonian age. Two species of stromatoporoids were described by Nicholson, four species of corals by Hinde and four species of brachiopods and three species of cephalopods by Foord. For many years to come this was the only available record of Devonian fossils from Western Australia.

It seems that no further visit to the sedimentary areas of the West Kimberley District was made by any geologists until 1905-1906, when R. L. Jack traversed the country between Wyndham and Derby and on this occasion visited Minnie Pool and the Oscar Range. In his report (1906) he says that at Minnie Pool he "observed some indications that the limestone region mapped as Carboniferous consists partly of limestones of an older date" and that he was "at once struck" by its strong Devonian aspect. He collected three fossils which were sent

to R. Etheridge, Sydney, who recognised them as stromatoporoids of either Silurian or Devonian Age. Etheridge published descriptions of these fossils in 1918, in an appendix to the "Narrative of an Expedition of Exploration in North-Western Australia" by Herbert Basedow.

In 1906, H. P. Woodward collected some fossils from Barker Gorge in the Napier Range. These specimens were forwarded to the British Museum and Henry Woodward reported the presence of seven species of fossils (communicated by L. Glauert in 1910) some of which were said to be of decidedly lower Upper Devonian aspect.

A compilation by Glauert in 1910, gave the number of Devonian species reported from Western Australia up to that date as twenty-seven, only a few of which had, however, been described. Further collecting in the Napier Range was done by H. Basedow in 1916, who obtained one specimen of a stromatoporoid which was described by Etheridge in 1918.

The next investigations in the Devonian area were made for the Freney Oil Company by A. Wade in 1924, and a report was published in the same year. He regarded the "massive coral limestones" of the Rough Range as well as the goniatite limestone of Mount Pierre, as Lower Carboniferous, though he intimated that the series may pass downward into the Upper Devonian; he thought that the Mount Pierre limestone was older than the Rough Range limestone.

The fossils collected by Wade were identified by F. Chapman, the Paleontologist of the National Museum in Melbourne, who, in a pamphlet apparently published slightly later than Wade's report, records five species of Hydrozoa and corals from the Rough Range and "Prince's [Price's] Spring" as of "Upper Devonian or Lower Carboniferous" age and ten species of crinoids, corals and cephalopods from Mount Pierre as of "Middle Devonian to Carboniferous age."

Thus by 1926, the number of known Devonian species from the Kimberley District had increased to thirty-two (Glauert 1926), but it must be remembered that the only descriptions of fossils available were those of the few species published by Nicholson, Hinde and Foord in 1890, and by Etheridge in 1918.

In 1922, T. Blatchford had made a study of the Prices's Creek area, the results of which were published in 1927. He regarded the limestone series as of Lower Carboniferous age.

In 1929, T. Blatchford and H. W. B. Talbot brought home

a collection of fossils from Minyu Gap, Rough Range, among which Hosking, in 1933, recognised six species of brachiopods, two of which had not been recorded before. The same author also gave a list of nine fossil species obtained from Barker Gorge, by J. E. Wells in 1922, and she also had at her disposal a small collection of species of *Atrypa* from a locality one mile south of Mount Pierre Gorge. In the same paper the then known localities of Devonian fossils were compiled and the recorded species were reviewed. Hosking thought that on the strength of differences in the matrix of the specimens, it would be possible to distinguish "two bands of limestone" in the Margaret River area, viz. (a): the *Atrypa* limestone of Upper Devonian age, and (b): the goniatite limestone of "assumed Devonian age." The generally accepted view with regard to the limestones of the Napier and Rough Ranges was still that which had been handed on since Hardmann's time, viz. that they were Carboniferous.

However, Hosking's paper is the first attempt at a classification of the Devonian rocks of the Kimberley District on the basis of the fossils and it marks the first advance in the understanding of Devonian stratigraphy since the occurrence of Devonian fossils had been announced in 1890.

In 1935, Prendergast described a new brachiopod from the Price's Creek area and a few other brachiopods from various localities of which one was referred to a Carboniferous species. Also in 1935, the first attempt was made to determine the age of some of the Devonian strata in greater detail, although stratigraphical information was still most unsatisfactory. This was the description by the French paleontologist Delépine of a few goniatites from the Mount Pierre area, which had been collected by E. de C. Clarke and H. W. B. Talbot in 1927. Delépine concluded that they were indicative of a Famennian age and most probably came from strata equivalent to the European Upper Devonian Stage III.

A further important step was made in 1936 when Dorothy Hill described the corals from all the earlier collections (Hardmann, Woodward, Wells, Wade). Nine species were now recognised and in the absence of exact stratigraphical information regarding these collections the author concluded that the corals came from strata of upper Middle Devonian (Givetian) and/or lower Upper Devonian (Frasnian) age.

In 1937, E. A. Ripper demonstrated that the important

stromatoporoid *Amphipora ramosa* was present in Western Australia.

Renewed field investigations were carried out by A. Wade for the Freney Oil Company in 1934 and 1935. From his Final Report, published in 1936, and a further summary published in 1938, it appears that Wade distinguished:

- (a) A basal complex: Old coastal talus between rocky headlands of the pre-Cambrian and the coral reefs of the Devonian. Distribution: north of Napier Range and in the axis of the Oscar Range.
Age: Devonian to Lower Palaeozoic. (In 1938 the age was given as pre-Middle Devonian.)
- (b) Rough Range Series (Barrier Reef Limestones) of the Napier, Oscar, Geikie, Hull and Rough Ranges.
Age: Frasnian and Givetian. Thickness approximately 1300 feet.
- (c) Mount Pierre Series. Lagoon deposits within a barrier reef.
Age: Famennian. Thickness around 500 feet.

It will be seen that now, in 1936, the assumption of a Carboniferous age of the limestones of the Napier, Oscar and Rough Ranges had been finally abandoned, an advance which was essentially due to D. Hill's determination of the corals from earlier collections. The Devonian had now been recognised in outcrops extending from the Napier Range to the Oscar and Geikie Ranges, then further up the Margaret River as far as Minnie Pool and southward as far as the country beyond Bugle Gap.

In 1940, D. Hill published further information on corals collected by Wade in 1934-35 and was able to confirm her earlier conclusions on the age of the fossils.

In 1939 and 1940, I published papers containing descriptions of nautiloids from A. Wade's and my own collections and pointed out that the mutual relationships of the brachiopod and cephalopod facies was one of the unsolved problems of Devonian stratigraphy in Western Australia.

Finally in 1939, after a short visit to a few Devonian localities I was able to show (Teichert, 1941) that three stages were recognisable in the Upper Devonian goniatite series which were equivalent to the European Upper Devonian Stages I, II, and III. A number of characteristic fossils of these stages were enumerated.

Summary: In the beginning of 1940, Devonian rocks were known to extend from the Napier Range in the northwest to the

Oscar Range and further east, to the area between Geikie Gorge and Mount Pierre and as far east as Minnie Pool. In a southern direction it was known that the Rough Range and the range from which Price's Creek originates were composed of Devonian limestones. These limestones had been traced in a southeastern direction somewhat beyond Bugle Gap.

The possible occurrence of the Middle Devonian had been indicated and the possibility of a more detailed subdivision of the Upper Devonian goniatite beds had been suggested. The number of Devonian species which had been put on record up to September 1940 was about 50.

It should perhaps be pointed out that, while in eastern Australia the Devonian was a period of considerable igneous activity, there are no igneous rocks of Devonian age known in Western Australia. A statement to the contrary can be found as recently as 1936 in Kossmat's generally very reliable book "*Palaeogeographie und Tektonik*" (1936, p. 75) which is evidently based on earlier literature when at one time the pre-Cambrian sedimentary Nullagine series, which covers extensive areas in the North of Western Australia was thought to be of Devonian age. The only indication of igneous activity having affected the Devonian strata here under consideration is a small silver-lead-zinc ore-deposit in the Napier Range, presumably genetically related to the post-Permian (probably Tertiary) lamproite magma of the Fitzroy Basin (for latest information see Prider, 1941).

OUTLINE OF THE STRATIGRAPHY.

In the area is found a conformable sequence of strata which range in age from late Eifelian or early Givetian to the upper part of the Upper Devonian (Upper Devonian Stage IV).

Middle Devonian: The Middle Devonian is almost exclusively developed in a calcareous facies. The series begins locally with unfossiliferous limestones which are overlain by a considerable thickness of limestones with *Amphipora ramosa*, but in places the *Amphipora* limestone rests directly on the pre-Cambrian basement. This part of the series is very monotonous, *Amphipora ramosa* often being the only fossil present. This little stromatoporoid fills the limestones in untold numbers and the mode of occurrence is such that these *Amphipora* limestone layers may serve as an excellent illustration for *biostromes* as this term was defined by Cumings in 1932: "purely bedded structures, such as shell beds, crinoid beds, coral beds, etc.,

consisting of and built mainly by sedentary organisms, and not swelling into moundlike or lenslike forms." Although *Amphipora* biostromes form the section for a considerable vertical extent, other fossiliferous layers are occasionally intercalated. Some of them may be described as *Thamnopora* biostromes: limestones almost entirely composed of specimens of a small species *Thamnopora*. In addition to *Amphipora* other stromatoporoids may occur and *Stachyodes* biostromes are not infrequent in the lower part of the section. Other fossils which are restricted to definite layers without, however, forming typical biostromes are some species of rugose corals, notably of *Prismatophyllum*, and gastropods which are mostly indeterminate.

Higher up in the section, the biostrome facies is gradually replaced by typical bioherms. Small reefs of concentrically built stromatoporoids (probably mostly *Actinostroma*) begin to appear and at the same time the limestones become more fossiliferous. Since *Atrypa* is an ubiquitous member of the fauna of these higher Middle Devonian limestone horizons, this part of the section has been provisionally distinguished as *Atrypa limestone*.

Upper Devonian: All along the Napier and Oscar Ranges there is no change in lithology as we ascend in the sequence and it is often found difficult to locate the boundary between the Middle and the Upper Devonian in this monotonous limestone series. As a rule, however, reef building activity increased during the Upper Devonian and huge bioherms, mainly composed of *Actinostroma*-like stromatoporoids were being built. These formed the "Great Devonian Barrier Reef" whose existence was already recognised by Wade (1936) and whose remnants now crop out along a belt which extends about 150 miles along the northeastern boundary of the Fitzroy River basin.

East and southeast of this belt, however, conditions are different and in the region of Margaret River and Mount Pierre Creek and in the Rough Range and Bugle Range the Middle Devonian limestone series is overlain by a variety of rocks: conglomerates, sandstones, shales, and variegated limestones in which the main interest centres around the rich goniatite faunas which are here found in numerous places. The Middle Devonian limestones contain here more bioherms than anywhere else. A particularly interesting example was studied at one place near Bugle Gap. The core of the bioherm was

formed by a large stromatoporoid reef whose erosion remnants rose to about 60-70 feet above the plain. This was surrounded by a great variety of reef formations, formed by large colonies of *Thamnopora*, *Disphyllum*, *Amphipora*, and *Receptaculites*. Between the reef formations, reef breccias and limestones with a rich brachiopod fauna had been deposited and the foot of the bioherm had then been covered by goniatite bearing sediments of the Upper Devonian *Manticoceras* Stage.

No justice can be done in this brief summary to the great variety of facies which is exhibited by the sediments of Upper Devonian age in this district, but it can be stated that as a rule the amount of terrigenous material and the grain size of the deposits increases from west to east in all stages of the Upper Devonian, except in the highest which is represented by a uniform limestone throughout the entire area. It may suffice here to state that any attempts to find "mappable" lithological units in the course of our brief field survey would have been doomed to failure, and would have resulted in an utterly chaotic picture of the geology of the area. Instead, the classification of rocks was made on a purely palaeontological basis and the Upper Devonian was divided into four "stages," numbered I to IV, which correspond closely to the same numerical units in the Upper Devonian section of Germany and western Europe. Of these, stages I, II, and III comprise every variety of sedimentary rocks from very coarse conglomerates with boulders up to 3 meters in diameter to reef limestones.

The following nomenclature is here applied to these Upper Devonian Stages:

- Stage IV = *Productella* limestone
- Stage III = *Sporadoceras* beds
- Stage II = *Cheiloceras* beds
- Stage I = *Manticoceras* beds

Stages I to III will be more fully discussed below. The *Productella* limestone is mainly composed of limestone conglomerate, crinoidal limestones and small stromatoporoid bioherms. It is a uniform formation which extends without any great lithological and palaeontological changes throughout the entire area of investigation.

GENERAL REVIEW OF DEVONIAN FAUNAS.

The total number of species which can now be recognised in the Kimberley province is about 380 of which only fifteen or

twenty have been described in detail. The species are distributed among various groups in approximately the following way: Porifera, 2 species; Hydrozoa at least 10; Conularida, 1; Anthozoa, over 30; Crinoidea, 2; Vermes, 1; Bryozoa at least 6; Brachiopoda, 170; Lamellibranchiata, 23; Gastropoda, 33; Cephalopoda, about 83; (Nautiloidea, 34; Goniatitoida, 44; Clymenoidea, 5 or 6); Trilobita, 9; Ostracoda, 3; Vertebrata, 2 or 3.

These figures indicate an advance of about 330 over the number of species which had been recorded (not described) in various publications up to the time of the beginning of these investigations. This advance is most marked in the brachiopods where the number of species was increased from 9 to 170 and in the cephalopods which show an increase from 13 to 83 species. But also the knowledge of other groups has been greatly increased: Anthozoa from 13 to over 30, Lamellibranchiata from 2 to 23, Gastropoda from 2 to 33, and Trilobites from 1 to 9 species. About one-third of the species is Middle Devonian and two-thirds Upper Devonian.

Corals are numerous in the reef facies of the Middle and Upper Devonian, *Disphyllum*, *Thamnopora*, and *Alveolites* abound in places in the Middle Devonian. Among the brachiopods the Orthoidea and Strophomenoidea are not represented by a great variety of forms, though often representatives of *Rhipidomella*, *Schizophoria*, *Leptostrophia*, and others occur in great numbers.

Further genera are represented, but have not yet been determined with certainty. The Pentameroidea which became extinct at the end of the Devonian are represented by a few, though typical, genera: *Gypidula* and *Sieberella*, perhaps also *Glassia*. The Rhynchonelloidea appear in a variety of typical Devonian genera: *Leiorhynchus*, *Uncinulus*, *Pugnax*, *Hypothyridina*, and *Camarotoechia* each represented by several species. The Terebratuloidea are only represented by stray specimens of *Dielasma* and *Rensselaeria*. The Productoidea are well represented by about ten species of *Productella*, but peculiarly enough the genus *Chonetes* seems to be altogether absent. As can be expected the Spiriferoidea which reach their maximum in the Devonian, are the most prolific group in the collection. It is well represented by numerous species of *Spirifer* (s. l.), *Athyris*, *Atrypa*, *Meristella*, and by other genera.

Lamellibranchs and gastropods apparently found fewer

favourable environments. Among the former we note the almost entire absence of the Pteriidae, an important Devonian family. Characteristic genera are *Palaoneilo*, *Goniophora*, *Mecynodon*, *Myalina*, *Macroodus*, *Schizophoria*, and *Paracyclas* as well as the neritic forms *Buchiola*, *Ontaria*, and *Praecardium*. Among the shallow water littoral and reef facies we find *Eumegalodon* (or some closely related genus), typical of similar facies in England and in Germany.

Among the gastropods the important group of the Capulidae is almost entirely absent, but a number of typically Devonian genera make their appearance, such as *Turbonellina*, *Macrochilina*, *Murchisonia*. Other genera represented are *Lepe-topsis*, *Bellerophon*, *Euphemites*, *Straparollus*, and perhaps *Turbonopsis*.

The Nautiloidea comprise a great proportion of rather undiagnostic—and often poorly preserved—forms, but the presence of a number of species with actinosiphonate siphuncle should be noted. This group is rather typical of the Devonian of Europe and North America, although it makes its first appearance prior to Devonian time (Teichert 1939, 1940). Also, numerous breviconic forms, some of considerable size, have become known, and the Pseudorthoceroids also seem to be represented. Strangely enough there seem to be no coiled forms among the nautiloids.

Ammonoids and trilobites are essentially restricted to the Upper Devonian and will be discussed in more detail in the introduction to the Upper Devonian Fauna.

THE FAUNA OF THE MIDDLE DEVONIAN.

The lower part of the Middle Devonian is almost everywhere characterized by an abundance of the stromatoporoid *Amphipora ramosa* which makes its first appearance either at the base or only slightly above the base of the Devonian section. This species is widespread in the Middle Devonian, more particularly the higher Middle Devonian, of England, Germany and Estonia, although isolated occurrences have been reported from the Lower Devonian of Belgium and from the Frasnian (lower Upper Devonian) of the Timan (*see* E. Ripper, 1937). The general appearance of the facies, however, is that of the Amphiporabänke of the *Stringocephalus* limestone in western Germany, and a Middle Devonian, probably Givetian, age of the *Amphipora* limestones of Western Australia seems to be fairly certain.

In certain horizons *Amphipora* is accompanied or replaced by other fossils, mostly corals, among which various species of *Disphyllum* are prominent and also *Prismatophyllum brevilmellatum* Hill. Also, gastropods, probably mostly *Macrochilina* and *Murchisonia* occur, but are never well preserved.

Amphipora characterizes a certain thickness of the section and then gradually disappears in most places to give way to a more varied fauna in which brachiopods are the predominating element. These include *Dowwillina*, *Leptaena*, *Rhipidomella*, *Schizophoria*, *Productella*, a number of species of *Spirifer*, several species of *Atrypa*, *Ambocoelia*, *Gypidula*, *Camarotoechia*, *Leiorhynchus*, *Uncinulus*, *Hypothyridina*, *Pugnax*, and *Rensselæria*. *Amphipora ramosa* is still represented in places together with other stromatoporoids. *Receptaculites* occurs as a member of reef formations and in one place interesting representatives of the related genus *Sphaerospongia* have been found, a genus which so far has only been known from the upper Middle Devonian *Stringocephalus* limestone of Germany and of Manitoba (Whiteaves 1892, Rauff 1892). Corals are locally important, *Disphyllum*, *Alveolites*, and *Thamnopora* being the most common genera.

Lamellibranchs occur in some types of facies. They include *Macroodus*, *Mecynodon*, *Conocardium*. One species cannot be distinguished from *Paracyclas antiqua* (Goldfuss) which is characteristic of the *Stringocephalus* limestone of Germany (see Beushausen, 1895, p. 173) and of the upper Middle Devonian of N. E. Canada, and a very large species of *Myalina* is most closely related to *Myalina bilsteinensis* Roemer from the German *Stringocephalus* limestone (see Frech 1891, p. 150).

The gastropods are also restricted to local facies and quite often occur together with lamellibranchs in numbers. They include species of *Bellerophon*, *Ectomaria*, *Trepospira?*, *Bembexia*, *Euryzone*, *Straparollus*, *Macrochilina*, *Loxonema*, *Naticopsis*, and others.

Cephalopods are as a rule rare in this part of the section. A few nautiloids of somewhat doubtful affinities have been found and among goniatites only *Bactrites* has been recognised with certainty. The occurrence of *Maenioceras*, typical in Europe of the upper part of the Middle Devonian, has not yet been established beyond doubt.

None of these species would enable us to date the fauna exactly and some species of *Pugnax* and *Hypothyridina* have a

decidedly Upper Devonian aspect. However, at present it is believed that the limestones with this fauna are overlain by strata which contain *Koenenites*, representing the lowest goniatite zone of the Upper Devonian. Thus it seems that this fauna is of late Middle Devonian age, but further investigations into the boundary between the Middle and the Upper Devonian are necessary.

GONIATITE FACIES

INTRODUCTION AND PRINCIPLES OF CORRELATION.

In many countries, particularly in Europe, two principal facies of the Upper Devonian can be distinguished, viz. an ammonoid and a brachiopod facies. These two facies seldom mix; that is, ammonoids are usually rare where brachiopods preponderate and *vice versa*. The brachiopod facies of the Upper Devonian has a rather cosmopolitan distribution. In the southwest Pacific realm it is known from Burma, Indochina, China, New Guinea and eastern Australia. The brachiopods are commonly closely associated with corals and stromatoporoids so that the brachiopod facies may anywhere grade into a pure reef facies and *vice versa*. Brachiopods, however, are not very well suited for intercontinental correlation, although the general aspect and composition of a brachiopod fauna may furnish valuable criteria for the determination of the age of an occurrence.

The ammonoid facies, although much more restricted geographically, is of far greater importance and the Upper Devonian stratigraphy of Western Australia cannot be fully understood unless some pertinent facts regarding the distribution of that facies are called to mind.

A. K. Miller (1938) has given an excellent summary of the distribution, both vertical and horizontal, of Devonian ammonoid faunas to which the reader must be referred.

There are but a few places known in the world where the entire Upper Devonian is represented by ammonoid-bearing strata; the best known of these are in Germany, and ammonoid occurrences elsewhere are usually referred to in terms of the standard classification established in that country.

Six major stages of the Upper Devonian have been recognised in Germany (A. K. Miller 1938, p. 3) of which only the first four need concern us here:

- Stage IV = *Laevigites-Gonioclymenia* stage
Stage III = *Prolobites-Platyclymenia* stage
Stage II = *Cheiloceras* stage
Stage I = *Manticoceras* stage

We are here adopting the classification recently proposed by O. H. Schindewolf (in Miller, 1938) which differs slightly from that originally introduced by Wedekind who worked out the first detailed goniatite stratigraphy in Germany. In order to avoid mistakes in the perusal of earlier papers it should be remembered that in papers published prior to 1938 Stage IV corresponds to the upper part of Stage III as here understood and Stage V to Stage IV.

In some areas, particularly Belgium and France, only the *Manticoceras* stage can be clearly distinguished and is here known as *Frasnian*, whereas the balance of the Upper Devonian, representing Stages II to VI has been termed *Famennian*.

Each of these six stages is characterised by a very definite assemblage of genera which are restricted to that stage. Thus *Manticoceras* is not found in Stage II or higher beds; *Cheiloceras* is never found below or above II and so on. In addition there are in most stages other genera associated with those by whose names the individual stages are known, and which frequently have a still more restricted vertical distribution. They are then used to characterise fossil zones which are designated by the addition of Greek letters to the Roman numbers. For example the genus *Koenenites* is not known to occur outside the zone Ia, at the base of Stage I; *Beloceras* is restricted to I β - γ , *Crickites* to I δ and so on.

This classification of the Upper Devonian, as based on standard sections in Germany, has for a long time been recognised in Central and Western Europe and it was also found to be applicable in North Africa, the Ural Mountains, and Novaya Zemlya. In 1935, Delépine, as mentioned above, recognised the occurrence in Western Australia of goniatites indicative of Stage III and, in 1941 I demonstrated that in addition Stages I and II were also present there.

It was thus a matter of considerable importance in connexion with the present investigations to establish the detailed relationships of the Western Australian ammonoid sequence with that of Central Europe. The results obtained have been better than could have been hoped for at the beginning of the work.

GENERAL REVIEW OF UPPER DEVONIAN FAUNA.

The total number of Upper Devonian species so far found in the Kimberley is in the vicinity of 250. Most of these seem to be fairly restricted vertically and probably not more than 20 or 25 species range through more than one of the four Upper Devonian stages as here recognised.

The area in which the goniatite facies predominates is not exclusively made up of rocks of that type. Stromatoporoids are found locally in large and small bioherms in all stages except II. As a rule these local areas of stromatoporoid reef facies are characterised by associated brachiopod and coral faunas, whereas goniatites occur only occasionally in any abundance. Also *Receptaculites* which lingers on from the Middle Devonian is sometimes a member of the reef facies.

Brachiopods are altogether absent from Stages I and II, but are richly represented in Stages III and IV wherever local stromatoporoid and coral reefs are developed. Lamellibranchiata are rare and gastropods, too, are of little importance. Nautiloids are found in all stages. Gomphoceroid and brevionic forms are quite common in Stage III. Goniatites are represented in Stages I to III and will be discussed below in more detail. Clymenoids occur in Stages III and IV, but are mostly in a very poor state of preservation. Trilobites are locally important in Stage I, where eight species were found; only one species each occurs in Stages II and III. Ostrocods are quite subordinate in Stage I and fish remains are known from Stages I and II.

It is hard, in compiling such remarks, to avoid conveying the impression of much greater completeness of our knowledge than is actually the case. Extensive outcrop areas have never been visited yet and there is no doubt that further very considerable additions to the knowledge of the faunas could be made, if an opportunity arose.

THE FAUNA OF THE MANTICOCERAS BEDS (Stage I).

The occurrence of the *Manticoceras* fauna in Western Australia, was first announced by me in 1941, when only four species were known. The fauna now comprises 44 species, viz: stromatoporoids; *Receptaculites*; a few rugose corals; one crinoid; *Buchiola*, *Ontario*, and other pelecypods; a few gastropods (*Straparollus*, *Turbonellina*?); *Tentaculites*, nautiloids (including *Kionoceras*, and *Wadeoceras*); the goniatites

Bactrites, *Manticoceras*, *Koenenites*, *Timanites*, and *Beloceras*; the trilobites *Cyrtosymbola*, *Pteroparia*, *Drevermannia*, *Chaunoproetus*, *Harpes*, and *Scutellum*; a few ostracods and fish remains.

With the exception of *Buchiola*, *Manticocera*, *Beloceras*, and *Scutellum*, whose presence in the Kimberley District was announced previously (Teichert 1941), this is an entirely new fauna and, considering the very considerable distance by which this fauna is separated from contemporaneous faunas elsewhere, its composition is of more than ordinary interest. Least surprising perhaps is the characteristic association of the goniatite genera *Manticoceras*, *Koenites*, *Timanites*, and *Beloceras* which are the most important genera of the *Manticoceras* beds in Germany. But also the associated fauna of lamellibranchs and trilobites bears a striking resemblance to corresponding faunas abroad. All over Europe and in eastern North America, *Buchiola* occurs together with *Manticoceras* and *Ontaria* and *Praecardium* are likewise common associates. The trilobites *Harpes* and *Scutellum*, both originating in the Ordovician, survive in Germany, England and New York, into Upper Devonian I and become extinct before the beginning of II. *Pteroparia* was previously only known from the *Manticoceras* beds of central Germany. The genera *Cyrtosymbola* and *Chaunoproetus* apparently make their first appearance here in Australia. They have not been previously reported from Stage I. Somewhat surprising is the absence of *Tornoceras* which, though not restricted to this stage, is as a rule found associated with *Manticoceras*.

On the whole it must be said that the correlation of the *Manticoceras* beds of the Kimberley district is firmly established, probably more so than that of any other unit of the Palaeozoic scale of the Australian continent. The *Manticoceras* fauna falls into two readily distinguished assemblages, which are also well separated in the field. The one consists of the goniatites *Koenenites* very similar to *K. cf. cooperi* Miller, *Timanites*, one small species of *Manticoceras*, and *Bactrites*, which are associated with a few pelecypods (including *Buchiola cf. eifelensis* Holzapfel) and fish remains. This assemblage is undoubtedly of the age of Oberdevonstufe Ia to which *Koenenites* and *Timanites* are restricted in Europe.

More material has been obtained from the second assemblage which has no species in common with the first one. It is especially characterised by the association of several species of *Manticoceras* with *Beloceras sagittarium* (Sandberger). Some specimens of *Manticoceras* reach considerable sizes (up to 25 cm. diameter) and the largest specimen of *Beloceras* measures 10 cm. across. These species are accompanied by *Receptaculites*, *Buchiola* cf. *retrostriata* (v. Buch), a few gastropods, *Tentaculites*, a number of nautiloids and by all the trilobites mentioned before. This assemblage is clearly of the age of Oberdevonstufe I β –I γ which Matern (1929) proposed to unite into one stage I (β, γ).

THE FAUNA OF THE CHEILOCERAS BEDS (Stage II).

The *Cheiloceras* fauna is an almost pure cephalopod fauna which comprises about 25 species. None of the non-cephalopod species is represented in the collection by more than one or two specimens, whereas cephalopods, in particular goniatites, could be collected in great numbers.

The goniatites seem to be most abundant in the upper part of the stage throughout about 120 feet of section. The most important genus is of course *Cheiloceras* (Fig. 2) of which three, perhaps four, species can be recognised. It is, however, necessary to bear in mind that *Cheiloceras* is easily confused with *Imitoceras* from which it is sometimes indistinguishable externally, and no detailed studies of the internal sutures have yet been made. Whereas *Cheiloceras* is restricted to Stage II, the range of *Imitoceras* is from II throughout the Upper Devonian and into the lower Carboniferous. Two other important goniatite genera are *Tornoceras* and *Dimeroceras* which are represented by several species each. The association of these genera with *Cheiloceras* is quite characteristic of the fauna of the *Cheiloceras* beds in Europe. *Dimeroceras*, in particular, appears in greater numbers in II β .

THE FAUNA OF THE SPORADOCERAS BEDS (Stage III).

The genus *Sporadoceras* in Europe makes its first appearance in the upper part of Stage II (II β), but is more abundant in III. In the Kimberley the lowest zone with *Sporadoceras* has proved to be a very persistent horizon and it seems that *Cheiloceras* does not go up into the first beds with *Sporadoceras*. A succession of species of *Sporadoceras* is found in the series

above the highest beds containing *Cheiloceras* and it seems therefore most natural to draw the boundary between II and III at the base of the lowest beds with *Sporadoceras*. This is also supported by the fact that *Dimeroceras* reaches its greatest development in the strata just below these beds which agrees well with conditions in the German II β .

Altogether 84 species of fossils have been recognised in the *Sporadoceras* beds among which brachiopods and cephalopods are by far the most numerous. Among the brachiopods the genera *Rhipidomella*, *Spirifer*, and *Pugnax* are especially prominent with five or six species each. Other important genera represented are *Leptaena*, *Productella*, *Meristella*, *Ambocoelia*, *Gypidula*, *Camarotoechia*, and *Leiorhynchus*. The cephalopods comprise about a dozen species of nautiloids, including *Wadeoceras*, though many of them are represented by specimens which are probably too poorly preserved for more exact determination, and about 16 species of goniatites which include *Tornoceras*, *Sporadoceras*, *Dimeroceras* and *Pseudoclymenia*. There is also one clymeniid, *Platy Clymenia*. Among other groups of fossils the corals are locally important, wherever a reef facies is developed in this stage.

Lamellibranchs and gastropods are quite subordinate, but one rare trilobite, *Perliproetus*, is known which has never before been recorded with certainty from anywhere outside Germany.

The sequence of the *Sporadoceras* beds contains a fine succession of species of *Sporadoceras* which developed out of *Cheiloceras* (Fig. 2). *Cheiloceras* disappears quite suddenly at a certain level and is followed by a species of *Sporadoceras* which resembles closely *Sporadoceras latilobatum* Schindewolf from the zones II β and III a of the Gattendorf section in Germany (*Sporadoceras* sp. A. of Fig. 2). About 80 feet higher up in the section another species appears in which the lateral lobe next to the external side has been increased in size, but is not yet quite as large as the second lateral lobe (sp. B). The final stage is reached another 40 feet higher up in the section with a species of *Sporadoceras* (sp. C) somewhat intermediate between the European *Sporadoceras münsteri* and *Sporadoceras contiguum*; some specimens have sutures approaching that of *Sporadoceras posthumum* (see Wedekind, 1917, p. 148). The first two species are characteristic of the upper part of Stage III, whereas *Sporadoceras posthumum* appears early in Stage IV.

This succession of species of *Sporadoceras* parallels closely the development of the same genus as it is known from Germany where it has been studied in great detail by Schindewolf (Fig. 3). In 1923 (p. 311) Schindewolf arranged the species of *Cheiloceras* and *Sporadoceras* in the Gattendorf section in progressive series ("Progressionsreihen") in which it is demonstrated how the lateral lobe of *Cheiloceras* deepens during the time of Stage II and how towards the end of Stage II *Sporadoceras* develops from *Cheiloceras* by the addition of another

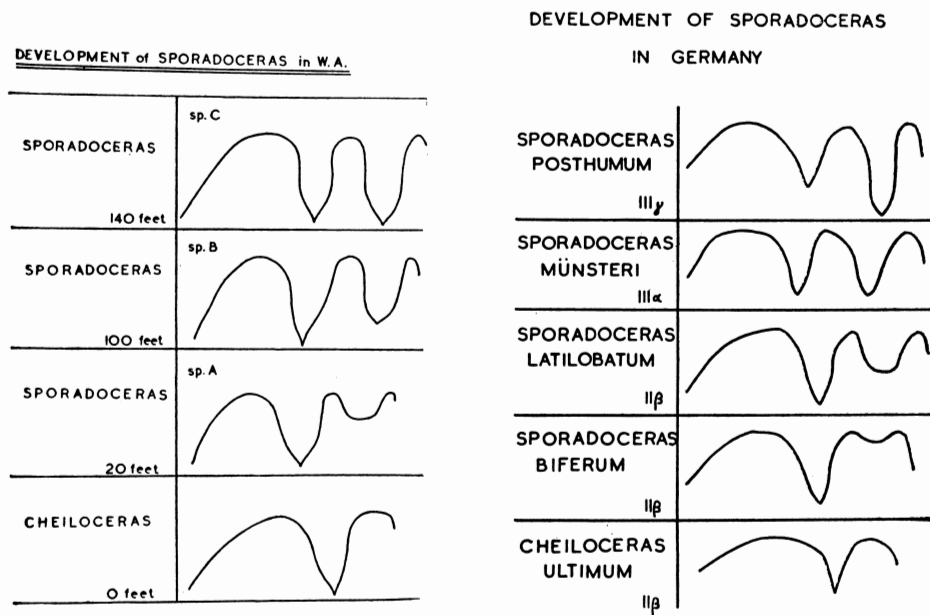


Fig. 2. Development of the sutures in the *Cheiloceras-Sporadoceras* series of Western Australia.

Fig. 3. Development of the sutures in the *Cheiloceras-Sporadoceras* series of Germany.

pair of external lobes which are very small at first, but increase gradually in size until in the terminal species they are larger than the first pair of lobes. In 1927 (p. 140) Schindewolf gave another very clear summary of these conditions from the standpoint of the evolutionist and taxonomist. Although the succession of species in Western Australia has not yet been studied in such detail as it is the case in Germany, it can be easily seen that the trend of the evolution of the genera *Cheiloceras* and

Sporadoceras is the same in both areas. The Western Australian series agrees most closely with Schindewolf's tegoid series *Cheiloceras ultimum*—*Sporadoceras biferum*—*Sporadoceras münsteri* (Fig. 3.).

The last and most advanced species of *Sporadoceras* extends throughout a greater thickness of strata than the preceding species, and in the uppermost 70 feet or so, it is associated with *Pseudoclymenia australis* Delépine and with a species of *Platyclymenia*.

THE FAUNA OF THE PRODUCTELLA LIMESTONE (Stage IV).

The *Productella* limestone as far as now known contains at least 100 species of fossils the majority of which are brachiopods. The name *Productella* limestone is applied because a species of *Productella*, closely resembling *Productella productoides* (Murchison), is a widely distributed and easily recognisable fossil of this stage. Several other species of *Productella* occur too, but none seems to have an equally wide horizontal distribution. Also, the genus *Spirifer* (s. l.) is most prolific and is represented by about 25 to 30 species which is more than half of the total number of species so far recognised in the Devonian of the Kimberleys. One of these species closely resembles *Cyrtospirifer disjunctus* (Sowerby), the widely distributed index fossil of the Upper Devonian. The vertical and horizontal distribution of most of the other species is still imperfectly known.

Other common brachiopods are *Schizophoria* of which three or four species can be distinguished; *Leptostrophia* and *Strophodontia* which are very numerous in places. Important index brachiopods seem to be a *Schuchertella*, closely resembling *S. chemungensis* (Conrad); several species of *Athyris*, among them one very similar to *A. spiriferoides* (Eaton); three or four species of *Meristella*; several pentamerids which have not yet been determined in detail (*Glassia?*, *Gypidula?*); and two or three species of *Pugnax*. Finally, *Camarotoechia* is an important genus, in particular one species closely resembling *C. pleurodon* (Phillips) is an important index fossil of the *Productella* limestone.

In addition to brachiopods the fauna contains a number of coral species. Among the few nautiloids found are *Conostichoceras hardmanni* and *Stereoplasmodoceras iniquiseptatum* which

are restricted to the higher parts of the *Productella* limestone and are thus considerably younger than previously supposed (Teichert 1939).

Perhaps the most interesting fossils of the *Productella* limestone are the Clymenoidea, a group whose presence in Australia was first announced by me in 1941. Unfortunately, all the specimens observed are in a very poor state of preservation, though three, perhaps four, different genera can be recognised. If the determination of one of them as *Laevigites* could be corroborated by better finds, the correlation of the *Productella* limestone with the Upper Devonian Stage IV would be definitely established.

Platyclymenia is probably and *Cyrtoclymenia* certainly represented, but neither of them has the same restricted range as *Laevigites*. Until it has been ascertained that one of the index genera of Stage IV (*Laevigites*, *Kalloclymenia*, *Gonioclymenia*, *Oxyclymenia*, *Striatoclymenia*) is definitely represented in the *Productella* limestone, its correlation with Stage IV cannot be regarded as established beyond doubt. However, the fact that goniatites are absent and clymenoids appear in increased numbers suggests that such a correlation is correct. Also, the appearance of *Platyclymenia* in the uppermost *Sporadoceras* beds supports this correlation. In Germany, *Platyclymenia* is especially characteristic of the upper part of Stage III, although the genus is not entirely restricted to that part of the section.

THE FAUNA OF THE UPPER DEVONIAN BIOHERM FACIES.

The Upper Devonian bioherm facies has already been described in a general way. Palaeontologically it is still very incompletely known, except for the uppermost part where equivalents of the *Productella* limestone are recognisable. Its fauna does not differ essentially from the fauna just described. Ammonoids are extremely rare in the bioherm facies and it has therefore proved very difficult to subdivide the reef limestones below the *Productella* limestone. Individual stromatoporoid reefs attain considerable sizes and may measure up to 50 to 60 feet in height and several hundred feet in length, but hardly ever are any other fossils associated with them. The only genus which is at all common in this reef series is a lamellibranch resembling *Eumegalodon* which is conspicuous on account of its

large size and its very heavy hinge. *Eumegadolon* is a typical form of shallow water-reef environments in the European Devonian (Germany, Devonshire), but does not seem to have been recorded elsewhere. A large species of *Straparollus* is also found in numbers in the reef series, but otherwise only occasional brachiopods have been found. *Goniatites*, mostly represented by indeterminable specimens, occur as great rarities in the reef series of the Napier Range.

SUMMARY OF GEOLOGICAL HISTORY AND PALAEOGEOGRAPHY.

Sedimentation in the area began some time in the Middle Devonian, probably in late Eifelian or early Givetian time; the sea transgressed over the pre-Cambrian in a general easterly direction. The basement must have subsided at a rapid rate and the pre-Middle Devonian relief of the land on the whole must have been low, for there was apparently little deposition of clastic material and very soon the formation of limestone commenced in the entire area. A few corals, among which *Disphyllum* was prominent, began to populate this newly created basin. They were soon followed by immense numbers of a small stromatoporoid, *Amphipora ramosa*, which for a considerable time abounded at the bottom of the sea almost to the exclusion of any other form of life. It was responsible for the formation of a limestone series of considerable thickness. Few other animals managed to establish themselves in the midst of this profusion of *Amphipora* colonies. *Thamnopora* and *Prismatophyllum* seem to have been best adapted to these conditions, but of the higher life only a few gastropods (*Murchisonia*, *Macrocheilina*) found the environment suitable.

Stromatoporoids of the *Actionostroma* type began to appear very soon together with *Amphipora*, but their colonies remained small as long as *Amphipora* was predominant. Either the myriads of little *Amphipora* colonies extracted too much lime from the water to make the growth of larger bioherms possible or the conditions of the water and the sea-bottom were such that they were specially adapted to the requirements of the *Amphipora* colonies. The fact remains that whenever and wherever *Amphipora* disappeared, its place was almost immediately taken up by massive stromatoporoid bioherms which soon grew into reefs often of very considerable dimensions. It seems that *Amphipora ramosa* did not become extinct until the end of the Middle Devonian, but that it gradually abandoned one area

after another which were then taken up by other forms of life. Then, at the time just preceding the arrival of the *Atrypa* fauna, we must picture the area as characterised by numerous large stromatoporoid reefs, with the sea-floor in between, still covered by a dense population of *Amphipora* colonies. The coast at this time must have been to the east at some unknown distance. The only evidence of probably contemporaneous littoral sedimentation was seen in the northeast corner of the area covered by this investigation where conglomerates were accumulated in a sea inhabited by heavy-shelled mollusks, characteristic of the waters close to open sea shores (*Eumegalon*, *Platyceras*).

While up to this time the composition of the marine fauna had been rather monotonous and the number of species small, a rich fauna took possession of the area towards the end of Middle Devonian time when the *Atrypa* limestone was being formed. The main reef building activity now shifted to or became restricted to an eastern belt which can be traced in the eastern part of the area of the Devonian outcrops. Stromatoporoid reefs are predominant in this belt, but coral reefs (*Disphyllum*, *Thamnopora*) are found locally and *Receptaculites* was another active reef-builder. Among the bioherms lived the rich brachiopod fauna, which has been described above.

To the west of this reef belt was an area of predominant limestone formation with disconnected reefs scattered in the sea and where a brachiopod fauna similar to that of the reef belt lived. To the north this area might have been bordered by another reef belt running in an east-west direction, but the conditions in that part of the country have not yet been sufficiently studied.

The coast at this time must have been far to the east, but no indication of late Middle Devonian littoral facies has as yet been found.

A profound and very sudden change of conditions took place between the Middle and the Upper Devonian. There must have been a sudden uplift of the mainland in the east which also affected the eastern reef belt of late Middle Devonian age, and which caused a retreat of the sea in a westerly direction. The reef building activity ceased and massive conglomerates of pre-Cambrian rocks were piled up on top of the Middle Devonian reefs. Wade first studied this facies which he called J 8 beds and which he believed to be of Permian age.

To the west the conglomerates pass into a sandy and shaly facies. Conglomerates are still present sporadically.

Still farther west the water was deeper and we pass into a belt whose sediments are not well exposed, but where it is known that limestone concretions were being formed on a large scale.

The geological events which led to these profound changes in sedimentation must have occurred suddenly at the beginning of the Upper Devonian Stage I, for during the time of the substage Ia these new processes were already in operation and more stable conditions had been reëstablished; during Stages I, II and III the land in the east must have continued to rise slowly, because it furnished a constant flow of clastic material which was transported westward into the sea.

The only region which seems to have been undisturbed by these events is the limestone belt of the Napier, Oscar and Geikie Ranges, where reef building activity probably went on without interference since Middle Devonian time. As already recognised by Wade, a large barrier reef was formed in the region of the Geikie and Oscar Ranges and during the time of the Upper Devonian Stages I, II, and III, we witness the gradual filling of the wide lagoon between the barrier reef and the coast—a process which, however, was interrupted by further tectonic movements at the end of Stage III.

Details of the history of the area during Stage I and the beginning of Stage II are as yet hard to decipher, but during the later part of II conglomeratic material was being transported much farther west than at the beginning of I.

Between these conglomerates and the barrier reef in the northwest there was a wide zone, probably with sandy bottom in the east and more calcareous muddy bottom in the west, where a fauna existed which was composed almost exclusively of goniatites, and a few nautiloids. One has the impression that this may have been an almost completely enclosed basin with badly aerated bottom water which was unfavourable to benthonic life. However, cephalopods which were able, if necessary, to rise to the oxygen-rich surface layers of the water, must have found some means of existence.

During Stage III the accumulation of clastic material was proceeding in a westerly direction, as is clearly indicated by the conditions in the southeastern part of the Rough Range. Here sandy *Cheiloceras* beds are overlain by Lower *Sporadoceras* limestones with intercalated sandstones and conglom-

erates and the Upper *Sporadoceras* beds in this section seem to be predominantly sandy and conglomeratic. Farther west the Lower *Sporadoceras* beds are represented by bioherm facies, and sandstones and calcareous shale appear in the Upper *Sporadoceras* beds.

Living conditions must have been much improved as compared with the time of Stage II, for a rich fauna now invaded the lagoon. Close to the barrier reef, conditions must still have been reminiscent of those of Stage II and goniatites dominated the scene, although there was gradually increasing migration of other forms of life, mainly corals and brachiopods, into this zone.

A current close to the shore must have swept the water free of terrigenous material, because a belt of minor reefs is distinguishable between the clastic facies in the east and the goniatite facies in the west; remnants of this belt are exposed in the southeastern Rough Range and at Mount Pierre. It was here where the richest life of the lagoon flourished.

It looks as if the clastic sediments described above were deposited in a large delta formation and that the bulk of the material was transported in a westerly direction from an area somewhere north of Trigonometrical Station J 8.

If conditions had remained as they were, the newly formed reefs inside the lagoon would no doubt have been buried under clastic sediments which were advancing from the east. Instead, however, the entire area subsided, the coast receded eastward and uniform conditions, reminiscent of those of the Middle Devonian were restored over the entire area. These events led to the deposition of the limestones and limestone conglomerates of the *Productella* limestone. Small stromatoporoid reefs were scattered over most of the area which was now populated by a uniform and rather rich fauna, mainly of brachiopods. This subsidence must also have affected the outer barrier reef and the reefs must have been brought so far below sea-level that they died. The *Productella* limestone was deposited between them and on top of them in essentially the same facies as farther east and southeast on top of the older lagoon deposits.

To be continued.