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The Upper Permian and the Lower Triassic in Kashmir, India

By

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Abstract

It has been known since more than seventy years ago that the fossiliferous Permian-Triassic rocks are well developed around the Vihi plain near Srinagar in Kashmir. It is confirmed that the Upper Permian-Lower Triassic boundary is actually conformable and gradational, and that the basal part of the Lower Triassic beds contains survived Permian-type fossils.

The geography and the general geology of Kashmir are briefly introduced, and a history of research on the Permian and the Triassic is given in some detail. The stratigraphy of the beds, not only near the erathem boundary but also belonging to the Upper Permian and the Lower Triassic, is fully described from Guryul ravine and a spur 3 km north of Barus spur.

The Permian rocks around Vihi plain are usually classified into the Panjal volcanic rocks, the Gangamopteris Beds (the Lower Gondwana Beds), and the Zewan Formation, in ascending order. The Zewan Formation consists of limestone, sandy limestone, calcareous sandstone, and sandy shale or shale, and is lithologically divisible into four members, A to D, in ascending order at Guryul ravine, and five members, a to e, at a spur 3 km north of Barus. The succeeding Lower Triassic strata are collectively named the Khunamuh Formation in the present paper, of which the basal part belongs to the Permian. The formation is composed mostly of alternations of limestone and black shale, and is subdivided into six members, E to J, at Guryul ravine, and three members, f to h, to the north of Barus, on the basis of the amount of limestone.

The Zewan Formation and the lowermost Khunamuh (Unit E_1 and Unit f_1) are classified into four divisions, I to IV, by characteristic fossil assemblages, although the brachiopod fauna does not change essentially throughout the sequence.

Division I corresponding to Member A yields rich foraminifera, bryozoans, and crinoid-stems. Brachiopods are locally concentrated. *Colaniella* cf. *minima*, *C. cylindrica*, and *Abadehella* cf. *coniformis* are the characteristic foraminifera which enable to correlate the division with the *Lepidolina kumaensis* zone in Japan, and the lower Wuchiapingian in south China. It is compared to the Kalabagh Member of the Wargal Formation in the Salt Range by brachiopods and bryozoans.

Division II corresponding to Member B is rather poor in organic remains, and it is not ceratin whether it is correlated to the Kalabagh or the Chhidru. It differs from the underlying one in the remarkable decrease of foraminifera and bryozoans due to environmental change.

Division III includes Members C and D, and is characterized by a predominance of gastropods and bivalves similar to those of the Upper Chhidru Formation. *Cyclolobus walkeri* is found from the middle of this division in association with *Anchignathodus typicalis* and *Neogondolella carinata*. These fossils strongly suggest the very late Permian (early Dzhulfian, Araksian) age.

Division IV coincides with Unit E_1 or Unit f_1 of the Khunamuh Formation, and is marked by *Claraia bioni*, n. sp., *Etheripecten haydeni*, n. sp., and brachiopods survived from the lower division. Conodonts are represented by rare specimens of *Anchignathodus typicalis*, *Neogondolella carinata*, and *Ellisonia triassica*. The division is probably correlated to the uppermost Permian (upper Dzhulfian, Dorashamian or Changhsingian).

The Khunamuh Formation is common in ammonoids, bivalves, and conodonts, by which the formation can be divided into several zones, that is, the *Otoceras-Glyptophiceras*, the *Ophiceras*, the *Paranorites-Vishnuites*, the *Prionites-Koninckites*, and the *Owenites-Kashmirites* by ammonoids; the *Claraia bioni-Etheripecten haydeni*, the *Eumorphotis benetiana- E.* aff. *bokharica*, the *Claraia* cf. *griesbachi-Eumorphotis multiformis*, the *Claraia concentrica*, the *Leptochondrian minima*, and the *Claraia decidens* by bivalves; and the *Anchignathodus typicalis*, the *Neogondolella carinata*, the *Neospathodus cristagalli*, and the *N. waageni* by conodonts. Among them the *Anchignathodus typicalis* zone covers the *Cyclolobus walkeri* horizon of the

Zewan up to the *Otoceras-Glyptophiceras* zone of the Khunamuh crossing over the Permian-Triassic boundary as in the Salt Range and Iran (Abadeh and Julfa regions).

The Permian-Triassic boundary is referred to as the base of the *Otoceras woodwardi* zone taking into the consideration the worldwide recession of the sea and the extinction of the major groups flourished in the late Paleozoic in addition to the faunal changes observed in Kashmir. The boundary in Kashmir is in the lowermost part of the Khunamuh, not at the base but at slightly higher horizon, and does not coincide with the lithological classification. Several Permian species, such as *Claraia bioni, Etheripecten haydeni, Marginifera himalayensis,* and *Pustula* sp. are rarely found from the basal part of the *Otoceras* beds, and are considered to have survived into the beginning of the Triassic.

The carbonate layers alternating with argillaceous beds of Member C of the Zewan Foramtion and the Khunamuh are developing in internal sedimentary structures, such as graded bedding, cross and parallel laminations, and convolute structure which suggest the turbidity current origin of these layers, especially in the Khunamuh. Detailed comparison of the sedimentary rocks between the two formations in the field and under the microscope as well, shows that a relatively shallow sea condition during the late Permian rather rapidly changed into the deeper, more off-shore environment at the beginning of the Triassic.

I. Introduction and Acknowledgments

It is well known that the greatest faunal change or biological revolution in the geologic past took place around the Paleozoic-Mesozoic transition, but an exact boundary has not yet been settled. The many problems of the erathem transition have attracted many paleontologists and geologists over the world. The stratigraphy and faunas of areas of most complete, or presumed to be most complete, sequences of fossiliferous Permian-Triassic rocks have recently been investigated in detail. These include Dzhulfa in Transcaucasia (RUZHENTSEV and SARYCHEVA, 1965), Iranian Julfa (STEPANOV *et al.*, 1969; TEICHERT *et al.*, 1973), Abadeh region in Iran (TARAZ, 1969 and 1972), and the Salt Range and Trans-Indus Ranges of West Pakistan (KUMMEL and TEICHERT, 1970).

Kashmir and the Central Himalayas were believed to be examples of areas of continuous sequences of the Permian-Triassic transition, but they have not been thoroughly re-examined yet since the pioneer works of MIDDLEMISS (1909 and 1910) and DIENER (1899 to 1913) in Kashmir and of STOLICZKA (1866), GRIESBACH (1880 and 1891) and others in the Himalayas. Accordingly, a Japanese research group of eight members was organized in 1968, by NAKAZAWA, to study the Permian-Triassic transition in Kashmir in collaboration with the Geological Survey of India. The project was brought to fruition in 1969 with participation of the G. S. I. and financial support of the Japanese Ministry of Education. The survey was carried out from the last of July to the last of August with about 25 days in the field. The participants were: K. NAKAZAWA, D. SHIMIZU, Y. NOGAMI, T. TOKUOKA, and S. NOHDA* of Kyoto University, T. MAEGOYA of Kyoto Industrial University, K. ISHII

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of Osaka City University, Y. BANDO of Kagawa University, and H. M. KAPOOR of the Geological Survey of India.

After reconnaissance around Srinagar under the guidance of KAPOOR, Guryul ravine was selected as the best place for a detailed study and a spur 3 km north of Barus spur as the next. Attention was focussed on the beds near the Permian-Triassic contact, but the whole section of the Zewan and the most part of the Lower Triassic were also measured and examined in detail. By good fortune, the *Otoceras* fauna accompanied with Permian-type fossils was found at Guryul ravine and a preliminary report of this result was published in 1970 (NAKAZAWA *et al.*, 1970).

In October of the next year TOKUOKA and KAPOOR spent several days at Guryul ravine examining sedimentary features and collecting rock samples. This work was incidental to TOKUOKA's participation in research on the Siwalik Series under the leadership of Prof. T. KAMEI of Kyoto University. In 1972, the Japanese party visited Iran, Turkey and Greece to investigate the Permian-Triassic beds, especially those of the Julfa and Abadeh regions in Iran, in collaboration with the Geological Survey of Iran. On the way to Iran, NAKAZAWA, ISHII, BANDO and KAPOOR made additional observations in Kashmir for a couple of days, and on the way back to Japan MURATA, SAKAGAMI, SHIMIZU and NAKAMURA collected in Kashmir again.

Studies on all the Kashmir collections have now been completed. The present article covers the stratigraphy, zonation, correlation, and the sedimentological features. Paleontological descriptions will be published in another paper.

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II. Outline of the Geography and General Geology of Kashmir

Geography

The Kashmir mountains are of great interest to workers on Himalayan geology. Here, within a small area there is a development of a fossiliferous stratified record, and many geological sections are easily accessible.

In general the fossiliferous Cambrian-Triassic sedimentary rocks of the Himalayas lie north of the "Crystalline Axis" (Central Himalayan Axis). However, this is not the case in Kashmir where they occupy a position bewteen two arms formed by a bifurcation of this axis–negating the distinction of "Himalayan" and "Tibetian" zones that is applicable elsewhere. Near Kulu in Himachal Pradesh, the Central Himalayan Axis bifurcates one branch (the Zanskar range or the Great Himalayan range) trends toward the northwest. The other (Dhauladhar range) trends toward the west. A continuation extending further to the northwest forms the Pir Panjal range (Fig. 1). Kashmir valley with a NW–SE trend lies between the Zanskar and Pir Panjal ranges. Kashmir valley is about 135 km long and 40 km wide in its middle, where it has its maximum width. Mountain-ranges surround the valley on all the sides, except at the narrow gorge of river Jhelum at Baramulla. Generally they

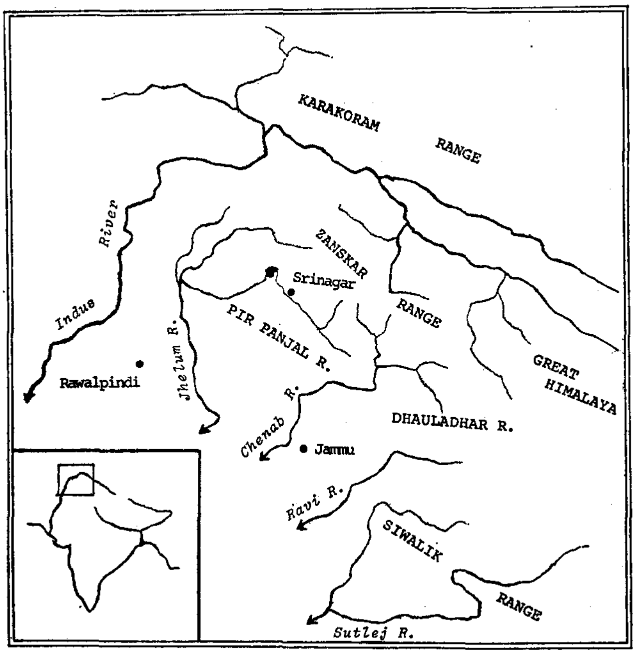


Fig. 1. Generalized map around Kashmir.

attain high elevations to the northeast and northwest. Some of the peaks rise above 5,480 m.

For geographical purposes BURRARD (in BURRARD and HAYDEN, 1908) divided the Himalayas into four sections. Kashmir lies in his Punjab Himalayas. This section was further divided into three parallel belts characterized by orographical features known as the Outer Ranges (or Outer Himalayas or Sub-Himalayas or Siwalik Ranges); the Middle Ranges (or Lesser Himalayas or Middle Himalayas or Panjal and Dhauladhar Ranges) and Great Himalayas (or Inner Himalayas). The Paleozoic-Mesozoic sequences of Kashmir lie partly in the Middle Himalayas and partly in the Inner Himalayas.

Several rivers drain Kashmir Himalaya, the Indus, Jhelum, Chenab, Ravi and Sutlej and their tributaries. In Kashmir valley, Jhelum river and its tributaries Sind, Liddar and others are important and there are many springs and lakes.

The approach to the Kashmir valley is easy. Srinagar, the summer capital of Jammu and Kashmir State is on an air route from New Delhi. It is also connected by a highway from Jammu, the railhead, served by direct trains from Delhi or Calcutta. The 300 km between Jammu and Srinagar can be covered by bus or car 8 hours, if the road is clear and the weather is not overcast. Kashmir valley has a network of surfased roads. Many of the sections of geological importance can be reached by fair-weather roads and in many cases one can reach the working point by jeep.

General geology

Crystalline rocks, granites, gneisses, schists, phyllites, quartzites and limestones occupy large areas of Kashmir Himalaya, to the north of Middle Ranges, forming the core of the Dhauladhar, the Zanskar and the ranges beyond Ladakh. These rocks were grouped together as the Central Gneiss by STOLICZKA (1866). At first, they were all regarded to be of igneous origin and referred to as of Archean age. Later, it was shown that a considerable part of the crystalline complex is of sedimentary origin having been metamophosed in Precambrian times. It provided the basement on which the subsequent geological formations were deposited in the Kashmir-Hazara areas, the Salkhala Series (WADIA, 1928). The Central Gneiss is separated from the younger rocks by a profound unconformity or by thrust faults.

An understanding of the geology of Kashmir and adjoining areas emerges with the contributions of GODWIN-AUSTEN (1864–1866) and VERCHERE (1866–1867). A different stratigraphic classification was suggested by LYDEKKER (1883). He maintained the names of the series used in the neighboring Himalayas, but grouped them into different Systems. MIDDLEMISS, after extensive work in Kashmir, brought to notice fundamental modifications of LYDEKKER's contributions and suggested his own classification in 1910. He grouped the Cambrian-Triassic sequences in two divisions taking into consideration the volcanic activity, during which events of revolutionary character moved quickly. The following is the stratigraphy as given by MIDDLEMISS.

DIVISION A (above the Panjal Volcanics)

11. Upper Trias
10. Muschelkalk
9. Lower Trias
8. Zewan or Permo-Carboniferous
7. Gangamopteris Beds (Lower Gondwana)

PANJAL VOLCANIC FLOW

AGGLOMERATIC SLATE

DIVISION B (below the Panjal Volcanics)

6. Fenestella Series (?Middle Carboniferous)
5. Passage Beds
4. Syringothyris Limestone Series (Lower Carboniferous)
3. Muth "Quartzite"
2. Upper Silurian
1. Lower Silurian and ?Cambrian

MIDDLEMISS retained two formational names, Zewan and Panjal Trap (Panjal Volcanic Flow) proposed by GODWIN-AUSTEN (1866) and LYDEKKER (1883), respectively. His scheme is still in usage, though some modifications have been made by WADIA (1928, 1934) and other workers. WADIA's additions are Salkhala Series, Dogra Slate and certain modifications in the Cambrian rocks. The Salkhalas and Dogras are considered by him to be of Precambrian age. The above scheme of MIDDLEMISS does not include his contributions to the Tertiary and Quarternary beds. A modified scheme based on MIDDLEMISS, WADIA and others is given in Table 1, with geologic ages as now viewed. Many formations not pertinent to this paper are not included.

WADIA (1928) gave a clear portrayal of the structure of Kashmir Himalaya. The Inner Himalaya rocks are considered as a nappe zone (WADIA, 1961). That is, sedimentary rocks have been carried over a long distance along an almost horizontal thrust (the Panjal Thrust) so as to lie in places against a wide belt of autochthone. The Kashmir nappe is composed mostly of Salkhala Series (Precambrian) with a superjacent Dogra Slate, forming the floor of the Himalayan geosyncline that has been raised up and thrust forward in a nearly horizontal sheet-fold. On this ancient basement lies the synclinal basin of the Cambrian-Triassic marine deposits supposed to be detached outliers of the Tibetian marine zone, roots of which are supposed to be in the Zanskar Range.

Table 1. General stratigraphy in Kashmir Himalaya (Based on WADIA, 1961, and RAINA and KAPOOR, 1964 with some modification)

Formation	Thickness (m)	Age
Alluvial deposits, terrace deposits and Recent morains		Recent to subrecent
Karewa Beds	2130	Late Pliocene to Pleistocene
Siwalik System Upper	1830–2740	Early Plioc. to Early Pleist.
Siwalik System Middle	1830–3740	Late Miocene
Siwalik System Lower	1230–1520	Middle Miocene
Muree Series	2440	Early Miocene
Nummulitic Limestone (Subathu Series)	90–180	Late Eocene to ?Oligocene
Volcanics of Dras & Astor Flysch Series		Cretaceous (?Danian-Wealden)
Orbitolina Limestone		
Jurassic of Banihal, Baltal and Ladakh		Jurassic (Lias and Oolite)
Triassic Upper	1520	Carnian to Norian
Triassic Middle	270	Anisian to Ladinian
Triassic Lower	100	Scythian
Zewan Formation	230	Late Permian
Lower Gondwana (a number of plant beds including Gangamopteris beds)	240	Early (partially Late) Perm.
Panjal Volc. Series Panjal Trap	1520–2130?	Early Permian (and Triassic?)
Panjal Volc. Series Agglomeratic Slate	1520	?Uralian to Early Permian
Fenestella Shale	610	Middle Carboniferous
Syringothyris Limestone	910	Early Carboniferous
Muth Quartzite	910	Devonian
Cambrian to Silurian (not easily differentiated)	2500	Cambrian to Silurian
Dogra Slate	1520	Precambrian to Early Cambrian
	great unconformity	
Salkhala Series	many thousand meters	Proterozoic?

In recent years a number of finds of the fossiliferous beds in Jammu region of Kashmir, neighboring Himachal Pradesh Himalaya and also in Uttar Pradesh Himalaya have divided the opinion on the nappe theory of Kashmir. FUCHS and GUPTA (1971) based on their work on Kishtwar which FUCHS named Kishtwar window, favor the nappe theory. The Bhallesh area further south, however, may indicate the continuity of beds with Spiti and other beds in between the two regions irrespective of the position with central axis (RAINA *et al.*, 1971).

III. Permian and Triassic–History of Research and Review

Earlier discoveries

The earliest scientific notice on Kashmir geology comes as early as 1837–38 by H. FALCONER who gives some observations on the geology between Kashmir and Skardu and he reports the existence of Carboniferous limestone in the Kashmir valley. It is necessary to mention here that the usage of Permian in Himalayan geology was applied very late, even though MURCHISON introduced the System in 1841. Most of the brachiopod-bearing beds of Kashmir were compared to the Carboniferous of Europe.

VIGNE's record of Nummulitic limestone (1842) from Kashmir valley was later found to be a crinoidal limestone of Carboniferous age. The earliest description of a brachiopod is made by DAVIDSON (1862) who gives details of *Productus longispinosus* SOWERBY (=*Productus flemingi*) collected by a physician A. FLEMING from a locality near Srinagar. The credit of recognizing volcanic rocks in Kashmir goes to VIGNE (1842) who mentioned that "the mountains around Srinagar are consisting of amygdaloidal traps". The earliest record of ammonites is a collection of a missionary PROCH and described by E. BEYRICH in 1864 and 1866. FRECH (1902) re-examined *Ammonites peregrinus* and inferred the presence of the Lower Triassic in Ladakh. He considered this to be *Flemingites* WAAGEN referred to the *Hedenstroemia* stage. DIENER (1912), however, comments "from the illustrations and descriptions, I did not dare to decide whether the poorly preserved fragments belong to an ammonite of Muschelkalk or Lower Triassic or even Permian age".

The first authentic record of the presence of the Triassic in Kashmir and Ladakh Himalaya comes from the work of STOLICZKA (1866) who carried out geological investigation in the Himalayas including Ladakh and Sindh valley. He reported the occurrence of *Ptychites gerardi* BLANFORD from a locality close of the village of Thajwaz in Sindh valley. In Hundes, the beds in which the above-mentioned fossil occurs are referred by GRIESBACH (1880) to the upper part of the Lower Triassic. STOLICZKA also collected *Megalodon columbella* from Dras valley. BITTNER (1899) re-examined these specimens and suggested them to be *Myophoria* (=*Neoschizodus*) *ovata* of the Alpine Werfen beds. DIENER (1912), on the other hand, notes that this species is not always confined to the Werfen beds, but ranges into the Mschelkalk, and therefore concludes that there is no convincing proof of Lower Triassic beds in Dras valley.

NOETLING (1905) reported Lower Triassic beds near Pastuni (now known as Pastun and in the literature it is referred as Pastannah) in Kashmir, considering them to be an equivalent of the *Hedenstroemia* beds.

NOETLING's most important discovery, however, was plant beds in Risin Spur near Srinagar showing elements of peninsular Gondwana. This attracted a number of geologists to re-examine the area. Its special interest lay in its position below the marine beds providing some evidence for dating the Gondwanas of peninsular India with bearing, also, on the limits of the Gondwana continent. NOETLING's collection besides plants also included vertebrates later described by SEWARD and WOODWARD (1905).

As already mentioned, stratigraphic schemes were proposed by GODWIN-AUSTEN (1864), VERCHERE (1867), LYDEKKER (1883) and MIDDLEMISS (1910). LYDEKKER carried out the first systemic mapping which was finally revised by MIDDLEMISS and later extended by WADIA.

Review of stratigraphy and fauna

Table 2 shows comparative positions of different schemes for the Permian-Carboniferous and Triassic of Kashmir proposed by different pioneer workers. In the early literature undifferentiated sedimentary rocks of Carboniferous and Permian age, commonly were called "Anthracolithic System", a term introduced by WAAGEN (1895). DIENER (1899) adapted this name for the "Anthracolithic fauna". Many of the workers, however, preferred to use the term Permo-Carboniferous or Carbo-Permian. The former includes the whole Permian and Carboniferous Systems, but it is not clear whether the latter represents an uncertain zone between the Permian and Carboniferous or both the systems.

Table 2. Correlation of "Permo-Carboniferous" and Triassic beds of Kashmir by different workers

GODWIN-AUSTEN (1866)		VERCHERE (1867)	LYDEKKER (1883)	MIDDLEMISS (1910)
Carboniferous Series	Barus Beds Zewan Beds	Kothiar Beds Weean Beds Zeeawan Beds	Supra Kuling Kuling (including Fenestella Series of MIDDLEMISS	Upper Trias Muschelkalk Lower Trias Zewan Series Gangamopteris Beds (Lower Gondwanas)
Palaeozoic Series		Volcanic Rocks	Panjal System {Panjal Trap, Panjal Conglomerate} (Silurian-?Cambrian)	Panjal Volcanic Series {Panjal Trap, Agglomeratic Slate} Fenestella Series

(1) Fenestella Shale

This name was introduced by Middlemiss (1910) for a thick sequence of fossiliferous shales and unfossiliferous sandstones, exposed in southern and eastern Kashmir. The fauna is rich in bryozoans and brachiopods, crinoids, a few bivalves and trilobites. It was studied by Diener (1915). Earlier this fauna was considered as Kuling by Lydekker (1899) and it was also examined by Diener (1899). Middlemiss, on the basis of its stratigraphical position considered it to be ?Middle Carboniferous and Diener (1915) agreed. Recently, Sarkar (1968) includes the Fenestella Shale in the Permian and "Permo-Carboniferous" based on the trilobites. On the other hand, Tewari and Singh (1967) believe in Upper Carboniferous based on arenaceous foraminifera, while Verma (1963, 1969) considers it be Lower Carboniferous from the fossils of *Paraconularia*. Such divergent opinions are probably due to the fact that the investigaters ignored the associated fossils and the sequence of faunas.

Very thick strata overlie this horizon. They certainly are Carboniferous. Probably the formation is of Middle Carboniferous age, although at a number of places it may reach to Upper Carboniferous.

(2) Agglomeratic Slate

The beds called Agglomeratic Slate by Middlemiss occur in association with Panjal Trap flows. Godwin-Austen divided the rocks of this formation into Older Slate and trap rocks named "hornblendic rock". Lydekker on the other hand, noted the special characteristics of the formation and included it in his Panjal System named after Pir Panjal. This system includes both slaty shales and volcanic rocks. The Panjal System was referred to the Silurian and Cambrian thought to be here totally devoid of organic remains with the possible exception of some possible graptolites. In the same system he also included Panjal Trap for the volcanic flows and Panjal Conglomerate lying below the Trap, which he compared to the Blaini Conglomerate of Simla area (=Talchir boulder bed of glacial origin). Lydekker's Panjal Conglomerate therefore was renamed as Agglomeratic Slate by Middlemiss, after properly defining it. This formation always lies above the Fenestella Shale and below Panjal Trap according to Bion and Middlemiss (1928). At a number of localities plant fossils have been found in the uppermost part of this formation, without any marine intercalation. This suggests a non-marine origin for the plant beds.

Middlemiss (1910) and Bion (1928) favored the 'explosive volcanic theory' for the formation of Agglomeratic Slate and this theory got further support by Wadia (1928), and Ganju and Srivastava (1961) on petrological studies. The rocks included volcanic ash. Volcanic bombs were reported by Misra (1948), and Hazra and Prasad (1963). Fuchs and Gupta (1971) think that the volcanic influence was not as strong as might be expected, because non-volcanic rocks predominate over pyroclastic rocks, and included tilloids and tillites? suggest glacial origin.

One of the present authors (HMK) believes that the formation is the effect of composite diastrophic changes in the basin. The lower part of the formation is formed on depression in a rising crust, while the ash and volcanic bombs, confined to the upper part, are of explosive type and were deposited both in depressions and raised portions. The plant beds which were considered by BION and MIDDLEMISS as part of this, outline the subaerial parts.

The fauna of the Agglomeratic Slate was described by BION (1928) and REED (1932). BION subdivided the formation into two parts, an upper, Nagmarg beds — zone of *Spirifer nagmargensis* (=*Syringothyris nagmargensis* by MUIR-WOOD, 1941) and a lower, Marbal beds — zone of *Syringothyris cuspidata* var. *lydekkeri* DIENER. According to him the fossils of the lower zone resemble those of the underlying Fenestella Shale and suggest Moscovian age, while the upper is considered to be Uralian. Subsequently, number of workers have given views on the age and faunas: MUIR-WOOD (1941), DICKINS and THOMAS (1959), DICKINS (1961, 1964, 1966), DICKINS and SHAH (1963), SASTRY and SHAH (1964), THOMAS (1967), and WATERHOUSE (1965, 1966, 1970).

DICKINS and THOMAS pointed out that the faunas probably range in age from late Carboniferous to early Artinskian. The Lyons fauna of Australia shows closest affinity with the fauna from the Nagmarg beds and approximately contemporary lower beds of Bren Spur. They consider the Marbal beds to be possibly late Carboniferous age, but they suggest that the fauna needs to be restudied. *Taeniothaerus* in the upper beds of Bren Spur suggests a correlation with the Lower Productus Limestone of Salt Range of Artinskian age. According to DICKINS (1961), the rare occurrence of *Eurydesma* in the Artinskian strata suggests a lingering of the species in Kashmir. In Australia also this genus occurs through many horizons. Recently HMK found *Eurydesma* in the strata of Bhallesh a still higher horizon than the youngest faunal zone of Bren. WATERHOUSE (1970) reports that in Bren the older horizon is characterized by *Eurydesma, Deltopecten, Oriocrassatella,* and the younger by *Teaniothaerus, Palaeolima, Discina,* and "*Grantonia*". FUCHS and GUPTA (1971) conclude that the age of the formation is middle Carboniferous to late Permian.

Recently HMK studied the Bren section in detail and also made observation in several other sections. The following succession has been established in the Bren section.

8. II volcanic flow
7. *Buccania-Warthia* assemblage zone with a few brachiopods and rare bryozoans
6. *Sanguinolites-Spirifer* assemblage zone with a few bryozoans
5. *Taeniothaerus-Buxtonia-Polypora* assemblage zone
4. I volcanic flow
3. Barren zone

2. *Eurydesma-Deltopecten* assemblage zone
1. *Fenestella* zone

Compared with WATERHOUSE's scheme (1965), the *Eurydesma-Deltopecten* zone is probably somewhat older or almost the same as the Allandale fauna of Sakmarian stage of the Sydney basin, and the younger zones of Bren including the Nagmarg beds which are referred to as Aktastinian, that is, lower Artinskian. It is possible that the faunas of Bhallesh (RAINA *et al.*, 1971) and Sikkim (SAHNI and SRIVASTAVA, 1956; SASTRY and SHAH, 1964) may represent the upper Artinskian, Baigendzhinian substage.

There is a thick and poorly fossiliferous sequence of the formation below the Marbal beds. The formation certainly represents a part of the Upper Carboniferous, but whether the lower limit is Middle Carboniferous can not now be ascertained. Now the question arises where the boundary between the Carboniferous and Permian should be placed. Fusulinids have not been found in Kashmir except records from Ladakh (GUPTA *et al.*, 1968) and the Mamali-Leh road section (GUPTA *et al.*, 1970). *Eurydesma* is also reported from the latter area. But the relationship between the fusulinid-bearing beds and the Agglomeratic Slate is still uncertain. The Permian-Carboniferous boundary is provisionally placed between the *Fenestella* zone and the *Eurydesma-Deltopecten* zone at Bren. It is believed that the *Eurydesma-Deltopecten* zone should be present between the Marbal and Nagmarg beds and the *Fenestella* zone is probably the youngest layer of the Marbal beds at Bren.

The *Eurydesma-Deltopecten* assemblage certainly indicates cold water, but a temperature amelioration is suggested by the succeeding faunas. The persistent, but rare, occurrence of *Eurydesma* at higher horizons is probably due to adaptability of some species of this declining genus.

(3) Panjal Trap

Volcanic rocks in Kashmir have been known since 1824 (VIGNE), but they were not named until Panjal Trap was introduced by LYDEKKER (1883) in the Pir Panjal range where the rocks are widely developed throughout the range. In the nineteenth century these rocks were considered to be early Paleozoic in age but MIDDLEMISS (1910) showed them to be of the upper Paleozoic from flora and fauna of overlying sedimentary rocks. The petrological study of the Panjal Trap was carried out by a number of workers. The brief historical review and general lithology are referred to in NAKAZAWA and KAPOOR's paper (1973).

The Panjal Trap consists mainly of basic rocks, and a few intermediate and acidic rocks. Basic types are mainly basalt, and andesitic basalt, while acidic and intermediate rocks are represented by augite-andesite, trachyte, keratophyre, rhyolite and acidic tuffs. Acidic flows are mainly confined to the uppermost horizons. A few recorded as a product of differentiation by WAKHALOO (1969) usually occur in the middle part of the trap. The glomeroporphyritic variety according to PAREEK (1972), is the product of selective differentiation. NAKAZAWA and KAPOOR (1973) reported the occurrence of pillow lavas of spilitic composition at Guryul ravine approximately 20 m below the contact with Gangamopteris Beds. The spilite is very similar chemically to geosynclinal oceanic green rocks of Japan. However, it is probable that the Khunamuh rocks erupted at very shallow depth: presumably they were coastal if not lagoonal.

The maximum thickness of the flows is not yet certain though they have been estimated at more than 2130, 2500 and 1800 m (MIDDLEMISS, 1911; WADIA, 1934). The exact number of flows is not yet known. Individual flow varies from a few centimeters to about 30 m in thickness. The presence of intertrappean limestones and pillow lavas suggests at least a part of the volcanics erupted below sea level. According to WADIA (1961) the traps were laid subaerially in northwest Kashmir, while under submarine conditions in southern and eastern part. PASCOE (1959), however, believed the eruptions took place either on a coastal land subjected to occasional transgressions or on a submarine shelf.

WADIA (1934) considered the chief centre of the volcanic activity to be in western Kashmir, there the eruptions persisted for the longest interval. On the other hand, NAKAZAWA and KAPOOR (1973) believed that the activity started in the west and gradually shifted to the south and southeast.

According to WADIA (1961), the flows vary in age, i.e., Moscovian, Uralian and Permian in different localities with its upper limit reaching the Lower Permian in some places, the Upper Triassic in others. The lower and upper limits are generally precisely dated by intercalations with fossiliferous horizons. The volcanic activity was most intense during the Early Permian and diminished in the Middle Permian. One of the Upper Triassic Panjal Trap outcrop of earlier workers in the Wular Lake area has shown to be Upper Permian beds, though the contact is a fault. The term Panjal Trap, we believe, should now be used for Permian flows; the volcanic activity was confined to Sakmarian-Artinskian time only or at the most extend up to Kungurian in the far east of Jammu-Kashmir Himalaya. The so-called Triassic flows, even if they are proved to be Triassic, are known only in Gurez-Sind valley areas, and the volcanic activity should be viewed as a part of another episode rather than the Panjal, because there is a long gap between the two, that is, the late Permian and early Triassic span a period of sedimentation with no volcanic activity.

(4) Gangamopteris Beds (Lower Gondwana beds)

The discovery of plant beds in Kashmir was in 1902 by NOETLING (1903) and OLDHAM (1904) revisited NOETLING's locality, Risin spur near Sringar to ascertain its relationship within the sandstones and shales of LYDEKKER's Zanskar System. He further paid attention to other localities of the Vihi area (Zewan spur, Guryul ravine, Mandakpal, Ladoo spur, the spur 3 km north of Barus, and Barus), since Risin spur has no marine strata. These sections exhibit the Zewan beds of VERCHERE and GODWIN-AUSTEN, and Kuling (the term used by LYDEKKER for the same with a wider scope). These were the first reports of marine Permian in Kashmir. He also believed that the plant-bearing beds belong to the same series as the Zewan beds, and are Permian because of the occurrence of *Gangamopteris*.

NOETLING's collection of plant and animal fossils from Risin spur was studied by SEWARD and WOODWARD (1905). HAYDEN re-examined a number of sections of Vihi area to find the relation of the plant and marine beds. He (1907) paid much attention to the Zewan spur, where plant beds are well developed directly below the marine Zewan beds. He introduced the name Gangamopteris beds for the former. OLDHAM (1904) postulated an unconformity between the two. The relation of the plant beds with the overlying Zewan beds and their correlation with the Gondwana of peninsular India were discussed by many workers. HAYDEN and MIDDLEMISS stressed a conformable sequence through the plant beds to the Zewan beds, but MIDDLEMISS thought that he noticed some overlapping of the marine beds, since the plant beds are rather variable in thickness.

In most localities the Gangamopteris Beds were reported to overlie the Panjal Trap but BOSE (1925) brought to light the presence of such beds below the Panjal Trap at Bren spur. Subsequently BION and MIDDLEMISS (1928) reported another locality with this relationship at Nagmarg. They explained the position of plant beds at two different horizons as "the *Gangamopteris* layer at Nagmarg and Guryul ravine (Risin) were identical and of Artinskian age. It is obvious that apparent difficulty of their appearance at the base of the Panjal Trap at Nagmarg, on the one hand, and at the top of them at Guryul ravine, on the other, may not signify much, since the outpouring of the trap might have been a rapid proceeding in spite of its colossal scale." These authors believed the plant beds to be the part of the Agglomeratic Slate. The two Gondwana beds, below and above the Panjal Trap, have different lithology. The earliest plant beds lying below the trap differ from the Gangamopteris beds proper in the absence of vertebrate fossils, presence of *Glossopteris* and stunted growth of leaves except the leaves referred to *Glossopteris indica?*. Trace fossils (burrows) are also known, which are not seen in the younger beds; limestone or novaculite are not present in the older beds.

The plant beds overlying the trap everywhere show constant features, that is, they consist of tuffs, tuffaceous shales, limestones, sandstones, etc, but a close study shows marked changes probably due to overlap and different basins of deposition. Most characteristic is a gradual change of the flora from lower to upper horizons. The so-called Gangamopteris beds are exposed at Zewan spur, Risin spur, Guryul ravine and other localities in Vihi area, Pastun in Tral valley, Marahoma spur, Lower Plant beds of Golabgarh, and others. They are characterized by vertebrate fossils and *Gangamopteris kashmirensis* (no *Glossopteris*). The fauna and flora studied by many workers are as follows:

Vertebrates: *Amblypterus kashmirensis* WOODWARD, *A. symmetricus* W., *Palaeoniscus* sp., *Phlyctaenichthys pectinatus* WADIA, *Archaegosaurus ornatus* WOODWARD, *Actinodon risinensis* WADIA and SWINTON, *Chelydosaurus marahomensis* VERMA, etc.

Invertebrates: "*Estheria*" *risinensis* KALAPESI and BANA, *Cypridina* sp., *Prognoblattina columbiana* SCHUDDER, etc.

Plants: *Gangamopteris kashmirensis* SEWARD, *Psygmophyllum haydeni* SEWARD, *Cordaites hislopi* BUNBERY, Lycopod stem (? *Lepidodendron*), etc.

Gradual shifting of the trap towards the east made way for deposition of younger sediments and other Gondwana plants, as is clear at Maraham spur, where Gangamopteris beds follow other plant beds (KAPOOR, 1958 MS; VERMA, 1960–62). In these beds the frequency of *Gangamopteris* reduces and a number of species of this genus appear together with *Glossopteris*. The beds comparable to this are Upper plant beds of Golabgarh, Apharwat, Tataakutii and others. They contain; *Glossopteris indica* SCHIMPER (=*G. communis* FEISTAMANTEL), *G. cyclopteroides* FEIST., *Gangamopteris kashmirensis* SEWARD, *G.* spp., *Schizoneura gondwanensis* FEIST., *Sphenopteris* cf. *polymorpha* FEIST., *Vertebraia indica* ROYLE, etc. Vertebrate fossils are absent in these beds.

The next floral beds probably pass gradually into the younger horizon, but so far no section has been seen to show both the younger and the older in a common section. The beds contain rare *Gangamopteris*, while ferns are frequent. The floral composition is similar to that of the preceeding beds.

Beds containing the youngest flora are known from Pahlgam to Aru in Upper Liddar valley. The flora includes the following species:

Lepidostrobus kashmirensis SRIVASTAVA and KAPOOR, *Glossopteris indica* SCHIMPER, *G.* spp., *Gangamopteris* sp. (very rare), *Schizoneura* sp., *Pecopteris* cf. *hirta* HALLE, etc.

At cursory inspections the flora is similar to the Shihotse flora of China.

The Kashmir Permian flora has Gondwana elements but also some different elements of the northern hemisphere as well as South Africa (Ecca flora). SAHNI (1926) considered that *Gangamopteris kashmirensis* SEWARD shows close similarity with *Glossopteris angarica*, which he believed to be a *Gangamopteris*. MAITHY (1964) recorded a new species *G. karharbariensis* from peninsular Gondwana which differs from *G. kashmirensis* in having less prominent median subparallel veins. According to SAHNI (1926) *Psygmophyllum*, so abundant in Kashmir, is a northern element; and *Calliperidium* was compared by SEWARD (1912) to *Callipteris conferta*, a northern form. The presence of floral elements of the northern hemisphere in a southern continent, and vice versa, is an attractive problem in paleobotany. The Kashmir flora plays an important part in this problem of interest to both paleobotanists and geologists.

SAHNI (1921–1939), WADIA (1937, 38) and KRISHNAN (1953) presumed a land connection between the two continents, Gondwana and Angara, perhaps through Kashmir. In addition to Kashmir such a mixed flora was noticed in Anatolia (WAGNER, 1962; KON'NO, 1965).

Recent studies in paleobotany have given to this so-called mixed flora a different aspect. Zalessky (1933) put the northern *Glossopteris* into a new genus *Pursognia*; MEYEN (1967) endorsed this view that this form has nothing to do with the *Glossopteris*, but he further stated that it does not mean that *glossopteris* was entirely absent in the northern continent during the Permian. Typical *Glossopteris* is known from the Permian of Far East (ZIMINA, 1967), and MEYEN (ibid.) included many of the rare species of *Pursognia* in *Glossopteris*. But SURANGE (1971) questioned this action. MEYEN (1967, 1971) and ASAMA (1966, 1969) dealt with the problem and considered that mixing of many of the forms may be due to misinterpretations; it may only be the result of parallelism or in many "homoplasy" (analoby).

(5) Zewan Formation

The Zewan beds were named by GODWIN-AUSTEN (1864) from Zewan village in the Vihi area. They include fossiliferous calcareous shale (20 feet) and crystalline limestone. VERCHERE (1866) also used the same terminology for fossiliferous beds but embracing many more rock types. GODWIN-AUSTEN also used the "Barus beds," after Barus spur of Vihi valley. This later was shown by other workers to be the same as the Zewans. LYDEKKER (1883), on the other hand, preferred to call this "Kuling Series" of the Zanskar System. It is clear from the section that LYDEKKER's Kuling Series includes both Permian plant beds and Zewan beds. In Liddar valley MIDDLEMISS (1910) pointed out that the synclinal folds showing repetition of Kuling and Supra-Kuling by LYDEKKER actually represent a normal sequence of beds from Carboniferous to Triassic; thus LYDEKKER's Kuling also includes Carboniferous formations of Kashmir. HAYDEN (1908), who reported the presence of Lower Triassic at Guryul ravine, redefined the Zewan Series as "this generally has been taken to comprise the fossiliferous series with bryozoa and brachiopods as seen in part of the Zewan, and more completely in the Guryul ravine and other localities around the Vihi plain, as to include all the beds between the *Gangamopteris* series and the Lower Trias." OLDHAM (1904) was first to recognize its Permian affinity; all the previous workers called this formation Carboniferous. HAYDEN (1907) made a detailed study of the type area, Zewan spur, and felt it was important as the earliest record of fossiliferous Zewans and its relationship with the plant bearing beds. However, Guryul ravine actually gives a better picture. MIDDLEMISS (1909, 1910, 1911) described a number of sections in his publications. He distinguished several faunal zones or horizons in the Zewan, which he dated as Permo-Carboniferous. They are:

Lamellibranch beds

Spirifer rajah (prominent) zone

Spirifer rajah, Marginifera, Productus, Lyttonia etc. horizon

Productus semireticulatus etc. horizon

Protoretepora ampla zone

In his classification (1910), however, he has shown three more fossil layers, one below *Protoretepora ampla* exposed at Barus and Guryul ravine, second above *P. ampla* exposed at Mandakpal, and the third below *Spirifer rajah* exposed also at Mandakpal. He did not ascribe any faunal affinities to these three.

The earliest description of the fauna is by DAVIDSON (1862) based on collections obtained by GODWIN-AUSTEN. He concluded that the beds was Lower Carboniferous and believed that the fauna included several common and widespread European and American species plus a few new ones. The collection made by VERCHERE was partially examined by him and partially by VERNEUIL (VERCHERE, 1866, 1867). WAAGEN (1891) compared the fauna of the Salt Range to the brachiopod fauna of Zewan and Barus beds described by DAVIDSON, and came to a conclusion that "the Kashmir Carboniferous strata should either be placed on a level with the lower Speckled Sandstone of Salt Range, or else they should be considered as intermediate in age between the latter and the Lower Productus Limestone or Speckled Sandstone." DIENER (1899), who revised the fauna of VERCHERE-VERNEUL and GODWIN-AUSTEN-DAVIDSON also described a small collection of LYDEKKER. He did not agree in all points with WAAGEN. The list includes the species described from the beds now considered as Permian. Most of the collections are from Zewan spur, Guryul ravine and Barus spur.

DIENER (1915) carried out further identification of the collections made by HAYDEN and MIDDLEMISS. This made him to review his ideas which he had based entirely on the work of pioneers. DIENER further added that at the base of *Protoretepora ampla* Zone in horizon (Z1) of Golabgarh, (1–3) 24–8–08 of Barus and (1) 4–8–08 of Guryul ravine the following species are present;

"Productus" cora d'ORD., *"P." gangeticus* DIEN., *"Marginifera" spinocostata* ABICH, *"Spirifer" fasciger* KEYS., *Spiriferella derbyi* WAAG., *"Camarophoria" purdoni* DAV. and *Hemiptychina himalayensis.*

In spite of its scantiness the fauna shows a typical Permian habit, and GRABAU (1923–24) introduced the name for this the *Hemiptychina* zone. According to DIENER the complete absence of all Producti of the section semireticulati is indeed a remarkable feature of distinction between the fauna of *Marginifera himalayensis* and the fauna of *Productus semireticulatus.* On the other hand two horizons are connected by so many identical species, that for the purposes of stratigraphy no sharp boundary can be drawn between the main layer of *Marginifera himalayensis* and the zone of "*Productus*" *indicus* (=*P. semireticulatus* horizon of MIDDLEMISS). Although DIENER (1915) recognized *Spirifer rajah* zone by its preponderance, he noticed that all zones of Zewans are very closely related to one another, and faunistically the Zewan beds may be considered as a single entity. GRABAU (1923–24) suggested a slight modification in the faunal scheme of MIDDLEMISS and DIENER as shown in the following.

Super Formation	(*Meekoceras* zone)	Lower Triassic
	Hiatus and Disconformity	
Zewan Series	*Xenaspis carbonaria* zone	shale and thin-bedded limestone (100 feet)
	Marginifera himalayaensis zone with *Spirifer rajah* subzone, *Marginifera himalayaensis* subzone, and *Productus semireticulatus* subzone	dark micaceous and carbonaceous shales with intercalations of limestones (300 feet)
	Protoretepora zone	shale and limestone (30 feet)
	Hemiptychina zone	dark fragmentary limestone with shale partings (60 feet)

GUPTA (in FUCHS and GUPTA, 1971) suggested that a threefold classification would be more apporopriate for the Zewans, that is, Upper Lamellibranch zone, Middle Brachiopod zone, and Lower *Protoretepora* zone. The correlation of fossil zones or horizons around Vihi plain distinguished by these workers is given in Table 3.

Many workers on Gondwana shelf have given their views on the Zewan fauna, including REED (1931), MUIR-WOOD (1941, in MUIR-WOOD and OAKLEY), WATERHOUSE (1966, 1970), THOMAS and DICKINS (1954) and others. MUIR-WOOD compared the Zewans to the Upper Lachi Series of Assam and assigned Kazanian age; THOMAS and DICKINS correlated the fauna with assemblage II of Carnarvon basin of Australia (especially the "*Dielasma*" *latouchi* DIEN.).

In recent years several papers have been published on the Zewans and its faunas. HAZRA and PRASAD (1957, 1963) reported fossiliferous Zewans from Banihal region of Pir Panjal. VERMA (1968) reported *Xenaspis* from Marahom, and KAPOOR, from Pahlgam. BHATTACHARYA and BOSE (1965) recorded an additional bryozoan from Zewan spur, hitherto not known from the Zewan, that is, *Batostomella* aff. *spiniger* BASSLER (=*Geinitzella* sp. of WAAGEN from Productus Limestone). BANA (1958) from the same locality records *Leptodus* aff. *tenuis* (WAAG.), and FURNISH *et al.* (1973)

Table 3. Correlation of fossil horizons and stratigraphic divisions of the Permian-Triassic around Vihi plain in Kashmir.

Guryul Ravine				2 mi north of Barus				Barus	Mandakpal	Division or zonation by various workers			
Middlemiss, 1909 and 1910		present paper		Middlemiss, 1909 and 1910		present paper		Middlemiss, 1909 and 1910		Diener, 1915	Grabau, 1923-24	*2	*3
Shales and thin-bedded Limestones 100'	(1) 9-8-08 and (1) 7-8-08	Khunamuh Fm.	F	Shales and interbedded Limestones and Shale band 100'		Khunamuh Fm.	g		Sandy Shales with a few Limestone beds, 360'				Otocerat.
			$E_{2\cdot3}$				f_2						
	(5) 25-10-06 *1		E_1	Brachiopod and Lamellibranch beds, 20', (4), (3 1/2), (3) 26-8-08			f_1			"Lamellibranch z."	*Xenaspis carbonaria* z.	Upper, Lamell. z.	IV
Dark Gray Shales 280'		Zewan Formation	D	Sandy Shales as before with more micaceous Limestoe, 150'		Zewan Formation	e	*Spirifer rajah* zone, (1) 23-8-08		zone of *Spirifer rajah*, (1) 23-8-08; (1), (2) 2-10-09	*Marginifera himalay.* zone { *Sp. rajah* subzone	Middle, Brachiop. zone	III
	(2) 10-10-09		C	*Spirifer rajah* (alone) zone			d ∫ c		(0) 2-10-09 (1) 2-10-09 (2) 2-10-09				
				Dark sandy micaceous Shales with a few Limestones, 140'					unproductive Shales, 40'				
	(1) 10-10-09		B	*Spirifer rajah* and *Marginifera* bed, 4-5', (5) 26-8-08			b		(2) 14-8-08	horizon of *Marginif. himalayensis*, (2) 14 8-08; (5) 26-8-08	*M. himalayensis* subzone		II
				Dark sandy, micaceous Shale, 100'					unproductive Shales, 80'				
Limestone 1-2'	(1) 2-8-08		A_4 ∫ A_3	*Protoretepora* Shales and interbedded Limestone, 20-30'	(1) 27-8-08		a_2	(2) 22-8-08	Limestone, 2', (1) and (2) 16-8-08	horizon of *Product. semireticulatus* gr. (1), (2) 16-8-08; (1) 10-10-09, (1) 2-8-08 "*Protoretepora* zone"	*P. semiretic.* subzone		I
Protoretepora Shales and Limestone, 30'	*Protoretepora* zone							*Protoretepora* bed	*Protoretepora* beds 20-30'		*Protoretepora* zone	Lower, *Protor.* zone	
Shales and Limestones, 10'	(1) 4-8-08												
Dark Gray Limestone, 50-60'			A_2 ∫ A_1	Gray Limestone, 60'			a_1	Gray Limestone (3) 24-8-08 (2) 24-8-08 (1) 24-8-08	Massive, clear gray Limestone, 60'	horizon of (1-3) 24-8-08 and (1) 4-8-08	*Hemiptychina* zone		
Siliceous rocks		Gangam. Beds		Black Shales, 6'		Gangam. Beds		Cherty Shale, 28'	missing				
Novaculite, 6-10'				Novaculite, traces				Novaculite, Limestone	Novaculite bed, 6'				
Panjal Trap		P. V.		Panjal Trap		P. V.		Panjal Trap, (1) 25-8-08	Panjal Trap				

*1 Hayden's horizon (1907), *2 Gupta (1928) and Fuchs and Gupta (1971), *3 present paper.

indicate the occurrence of *Cyclolobus walkeri* DIENER from Guryul ravine.

From limestone near the contact of *Gangamopteris* beds and Zewans at Zewan spur SRIVASTAVA and MANDWAL (1966) recorded the following microfossils;

Involutina semiconstrictus LOEBLICH and TAPPAN, *Tolypammina, Agathammina, Spiroloculina, Triloculina, Trochammina, Nodosaria, Textularia* spp. A and B, *Amphissites* cf. *rothyi* BRADFIELD, *Bairdia ardmorensis* HARLTON, *Bairdia* spp. A and B, *Healdiacypha, and Silenites.*

CHANDRA (1964) made a systematic study of the bryozoans from Mamal (near Pahlgam) and shows the presence of the following species;

Fistulipora cf. *parasitica* WAAGEN and WENTZEL, *Goniocladia* sp., *Batostomella collumnaris* (SCHLOTHEIM), *Acanthocladia anceps* (SCHLOTH.), *Fenestella* cf. *internata* LONSD., *F. fossula* (LONSD.), *F. perelegans* (MEEK), *Polypora haimeana* KON., *P. ampla* (LONSD.), *P. gigantea* WAAG. and PICH., and others.

CHANDRA's speculation of the age as lower Permian is rather not satisfactory, as most of the evidence including the bryozoan layers supports a late Permian age of the Zewan.

The Zewan fauna is undoubtedly closely allied to that of Upper and Middle Productus Limestones in the Salt Range and the Productus Shales in Central Himalayas, as noted by DIENER (1915). The correlation and age of the Zewans have been recently discussed by various authors. This will be examined in the later section.

(6) Triassic System

The Permian Zewan beds seemingly pass gradually upward into the Triassic. This is divisible into Lower, Middle and Upper, with thicknesses of about 300, 900 and 4,000–6,000 feet, respectively (WADIA, 1961).

Several Triassic ammonoids were collected by LYDEKKER and were examined by DIENER (1895, 1899, 1907) and compared to those of Muschelkalk. HAYDEN (1907) first reported definite Lower Triassic from Guryul ravine, and stated "At about 10 feet above this horizon (*Marginifera himalayensis*) is a band of dark shale weathering white and not unlike the carbonaceous shales of the *Gangamopteris* series; it does not however, contain plant remains, but yields a few specimens of *Pseudomonotis* cf. *griesbachi* BITTNER. Immediately above this is a thin band of very hard limestone with species of *Danubites*, *Flemingites* and *Bellerophon*. This is followedby rapidly alternating beds of similar hard limestone and shale: the whole sequence bears a striking lithological resemblance to the Lower Trias of Spiti and the fossils at the base have no doubt as to its identity."*

MIDDLEMISS (1910) suggested the following scheme for the Triassic of Kashmir:

* Judging from this statement, ammonoid beds seem to correspond to *Otoceras-Glyptophiceras* beds in the present paper.

Upper Trias	Unfossiliferous massive limestone
	Spiriferina stracheyi and *S. haueri* zone
	Lamellibranch zone
Middle Trias	*Ptychites* horizon (sandy shales with calcareous layers)
	Ceratites beds (sandy shales with calcareous layers)
	Rhynchonella trinodosi beds (sandy shales with calcareous layers)
	Gymnites and *Ceratites* beds (sandy shales with calcareous layers)
	Lower nodular limestone and shales
	Interbedded thin limestones, shales and sandy limestones
Lower Trias	*Hungarites* shales (position uncertain)
	Meekoceras limestones and shales
	Ophiceras limestones

WADIA (1934) slightly modified this scheme based on the reported occurrence of *Otoceras* by BION (1913 in HAYDEN, 1914). His scheme also included a comparison of the Trias of southeast Kashmir with northwest Kashmir, and he (1961) used the same scheme for all of Kashmir with addition of *Otoceras* beds (seen occaisionally in a few localities) just below the *Ophiceras* limestone and modifying the uppermost division to include unfossiliferous massive limestone with occaisional corals, crinoids and *Calamophyllia.*

It is noteworthy that BION (1914) reported the occurrence of *Productus* in association with *Otoceras,* he stated "Good collections have been obtained from Nagaberan in the Dachhigam State Rakh and from Pahlgam-Aru basin. Some thirty feet above the *Otoceras* layer there is another fossiliferous horizon characterized by *Ophiceras* from which one specimen of *Otoceras* was also procured, but the rest of the black shale division seems to be barren. A surprising element of the fauna of the basal *Otoceras* layer is furnished by the presence of the genus *Productus,* of which three specimens have been obtained from Pahlgam."

VERMA and SASTRY (1963) also established the position of *Hungarites* shales, by collecting specimens *in situ* from Pastannah. The position is correlated with the *Hedenstroemia* beds of Central Himalaya. They are also credited to record the Ladinian stage in Kashmir, which they demonstrated by the presence of characteristic fossils *Daonella* cf. *lommeli* WISSM. and *D. indica* BITTNER.

The best Triassic sections are mainly confined to Vihi and Tral areas and include Guryul ravine, Pastun (Pastannah) and Narastan sections, where a complete sequence of Triassic beds is exposed; another section at Khreuh is supposed to be good section for Middle Triassic. In the geological literatures much importance is given to Pastun, because of the rich supposed fauna of the "*Ophiceras* zone," though Guryul ravine was always felt to have a better development of this System. KAPOOR and BANDO (1973) have recorded the presence of the lower Triassic in Pir Panjal with typical Scythian ammonoids and bivalves. However, Middle and

Upper Triassic is not known there.

(a) Lower Triassic

Pastun is famous for the occurrence of splendid specimens of Lower Triassic ammonites since MIDDLEMISS (1909, 1910). Many of them were procured from loose blocks and the outcrops are poor due to prevailing forest and soil-covering.

DIENER (1913) described the following species after examining the MIDDLEMISS's collection:

Xenodiscus himalayensis GRIESB., *X.* cf. *lissarensis* DIEN., *X. aequicostatus* DIEN., *X. salomoni* DIEN., *X.* cf. *ellipticus* DIEN., *X. comptoni* DIEN., *Ophiceras sakuntala* DIEN., *O. ptychodes* DIEN., *O. demissum* DIEN., *O. chamunda* DIEN., *O.* cf. *gibbosum* GRIESB., *O.* cf. *tibeticum* GRIESB., *Vishnuites pralambha* DIEN., *Pseudosageceras clavisellatum* DIEN., *Pseudomonotis* (*Claraia*) *griesbachi* BITTN., *P.* (*C.*) *aurita* HAUER, *P.* (*Eumorphotis*) *tenuistrata* BITTN. and others.

The fauna of the *Ophiceras* layer according to DIENER agrees with that of *Otoceras* beds of the Shalshal cliff and of the *Ophiceras* beds in Spiti in all essential features. He also noticed the Mediterranean facies of the bivalve species. Regarding the absence of *Otoceras,* DIENER thinks that it is either not discovered or really absent; the same being rare in Spiti and if it is present in Pastannah it is confined to the deepest zone of the *Ophiceras* layer. BION (1914) did not agree to the age assigned by DIENER. He concluded that the Pastannah fauna occurred at a horizon some two to three hundred feet above the *Otoceras* beds proper, and that there was very little difference of horizon between it and that of the Guryul ravine (*Meekoceras* horizon). SPATH (1934) who placed species of *Xenodiscus* of Pastun in *Glyptophiceras,* also came to the conclusion that the Pastannah fauna was slightly younger than the *Ophiceras* fauna of the Spiti region and transitional to the next higher zone. KUMMEL (1970), on the other hand, referred to all the species of *Xenodiscus* described by DIENER as *Glyptophiceras himalayensis* (GRIESBACH), and correlated the Pastun fauna with the *Otoceras*-*Ophiceras* fauna of Spiti and other regions in Himalaya. On the contrary TOZER (1969) insisted the Smithian age (nearly equivalent of late Eo-Triassic Owenitan of SPATH) of this fauna, and stated "Some of the ammonoids are almost certainly Smithian, for example '*Xenodiscus*' *comptoni* DIEN., which clearly shows the characteristic peripheral constrictions of Smithian genus *Xenoceltites.* A Smithian age for Pastannah fauna is also indicated by the hitherto unrecorded occurrence of '*Pseudomonotis*' *himaica* Bittner." KAPOOR (1971) re-examined the Pastun section. He was able to locate thick strata probably referable to lower Eo-Triassic below the supposed *Ophiceras* zone of MIDDLEMISS, and compared the "*Ophiceras*" layer to the *Meekoceras* zone of MIDDLEMISS at Guryul ravine, as BION did.

The true *Otoceras* layer was recently confirmed by NAKAZAWA and his collaborators at Guryul ravine section (1970). *Meekoceras* beds of MIDDLEMISS lie at about 70 meters higher than the top of the *Otoceras* layer. According to DIENER (1913) the *Meekoceras* beds contain following species:

Flemingites sp., *F.* cf. *muthensis* KRAFFT, *Meekoceras* aff. *jolinkense* KRAFFT, *M.* (*Koninckites*) cf. *yudishthira* DIEN. (=?*Pseudoaspidites* SPATH), *Pseudosageceras* sp., *Prionites guryulensis* DIEN., *Sibirites kashmiricus* DIEN., *Kashimirites blashkei* DIEN., *Stephanites* aff. *superbo* WAAG., *Nannites* sp., *Claraia decidens* (BITTNER), and others.

Its corresponding outcrop in Mandakpal (Hor. 4, 14–8–08) contains *Sibirites* aff. *ibex* WAAG., *Kashmirites* sp. and *Claraia decidens*. This horizon has been referred to the *Meekoceras* zone by MIDDLEMISS (1909), but DIENER (1913) believed it to have a still younger fauna of the *Hedenstroemia* stage of Spiti and Painkhanda as indicated by the presence of *Flemingites, Koninckites* cf. *yudishthira, Sibirites* and *Claraia decidens*. *Kashmirites* is not known from Central Himalaya but reflects its close relationship with the Ceratite formation of Salt Range, which is also supported by *Prionites* and *Stephanites* aff. *superbo*. The collection of MIDDLEMISS, however, is insufficient to justify two zonal subdivisions as are known in the Salt Range.

The third horizon of the Lower Triassic is again from Pastun (X 4–9–09 of MIDDLEMISS, 1910), but from fan debris. MIDDLEMISS believed that NOETLING's earlier collection (1905) probably belongs to these loose blocks and probably is equivalent to *Hedenstroemia*. DIENER (1913) recognized in MIDDLEMISS's collection only *Hungarites middlemissi* DIEN. (=*Prohungarites*) and *Inyoites kashmiricus* (=*Subinyoites*), all the rest are indeterminable. SPATH (1934) included this zone in Prohungaritan division. VERMA and SASTRY (1963) have located this bed *in situ* from Pastun, but details are not yet known.

(b) Middle and Upper Triassic

The Middle Triassic strata were treated as Muschelkalk by MIDDLEMISS (1910). Their occurrence was recorded from Pastun, Khreuh, Lam, neighborhood of Narastan, southeast of Vernag, Liddar valley near Pahlgam and Sind valley (Thajwas). MIDDLEMISS distinguished eleven fossil horizons in Pastun, and grouped into five zones, such as

Ptychites (*megalodisci* group) and *Pseudomonotis* zone
Ceratites sp. zone
Rhynchonella trinodosi and *R.* sp. zone
Gymnites and *Ceratites* etc. zone
Lamellibranch horizon

DIENER (1913) examined the fossils of MIDDLEMISS from Kashmir Muschelkalk and commented that two characteristic horizons of the Muschelkalk known in Spiti and lacking here, that is, *Pseudomonotis himaica* BITTNER and *Rhynchonella griesbachi* BITTNER. The steep escarpment of Muschelkalk comparable to the Niti limestone of Painkhanda and Spiti is not developed in Kashmir. In the Himalaya, the Muschelkalk is divisible into the following horizons in descending order:

5. Upper Muschelkalk, very rich in cephalopods
4. Horizon of *Spiriferina stracheyi* SALTER
3. Horizon of *Keyserlingites* (*Durgaites*) *dieneri* MOJS.
2. Nodular limestone (Niti limestone)–unfossiliferous
1. Horizon of *Rhynchonella griesbachi* BITTNER

This uniformity in the Central Himalaya is widespread, but does not hold for the Eastern Johar (Byans) and Kashmir. The fauna of *Durgaites dieneri* is entirely absent in all the materials of MIDDLEMISS. *Spiriferina stracheyi* does not maintain a distinct horizon in Kashmir, but it seems to occur in two sections only, and both contain a rich fauna of *Ceratites trinodosus*. A fact of particular interest is the restriction of *Gymnites* to the lower and of *Ptychites* to the higher beds, while *Ceratites thuilleri* are indiscriminately distributed throughout the Upper Muschelkalk.

A long list of Muschelkalk fossils reported by DIENER (1913) includes 40 species of ammonoids, 7 species of nautiloids, one species of conularia, 5 species of gastropods, 16 species of bivalves, and 6 species of brachiopods. According to him this represents *trinodosus* zone of Central Himalaya. There are only *Sibirites* cf. *prahlada* DIEN. and *Durgaites dieneri* as elements of the Lower Muschelkalk, but it is probable that the Lower Muschelkalk fauna occurs in sections from which fossils were not collected. Horizons equivalent to *Daonella* shales have recently been reported by VERMA and SASTRY (1963) as mentioned already.

Upper Triassic formations are well developed in every part of Kashmir, though poor in fossils. The strata include only a few zones of coarls, bivalves and brachiopods in the lower part. Ammonoids have not been found so far. DIENER (1913) reported the species of *Myophoria, Trigonodus, Hoernesia,* "*Pseudomonotis*", *Lima, Mysidioptera, Pecten* (*Chlamys*) and *Pecten* (*Velopecten*) among bivalves, and *Dielasma julicum* BITTNER, *Spiriferina* aff. *lilangensis* STOLICZKA, *S. stracheyi* SALTER, *S.* (*Mentzelia*) *mentzelii* DUNK., *Rhynchonella lamana* DIEN. among brachiopods.

A few data have been added by WADIA (1935), de TERRA (1933) and PASCOE (1959) from various parts of Kashmir.

The Triassic strata gradually pass into the Jurassic (probably Liassic), the base of which is yellowish limestone with rich bivalve fauna and a few brachiopods and ammonoids in the Anihal Tunnel region.

IV. Permian-Triassic Stratigraphy and Lithology at Guryul Ravine and Spur 3 km North of Barus Spur

Permian-Triassic sequences in Kashmir have been studied by many geologists as described in the preceeding chapter. The authors selected the Guryul ravine section and that 3 km north of Barus as the most promising places for clarifying the systemic boundary problems. The geological succession, in ascending order, includes Panjal volcanic rocks, the Gangamopteris Beds (Lower Gondwana beds), the Zewan Formation, and the Khunamuh Formation. The Khunamuh Formation, newly proposed here, includes the Lower Triassic and the so-called mixed zone in the previous paper (NAKAZAWA *et al.*, 1970) (Fig. 2).

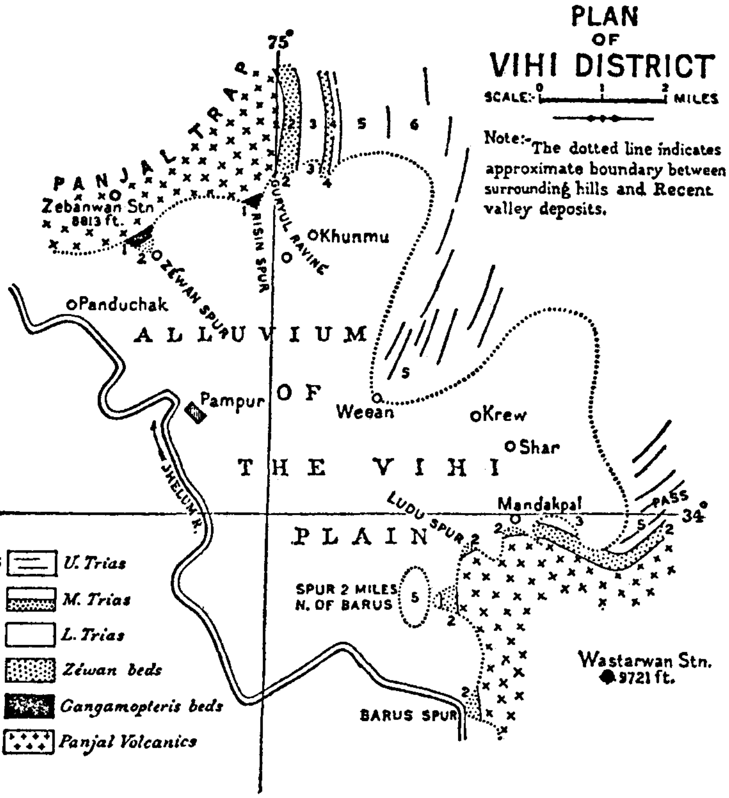


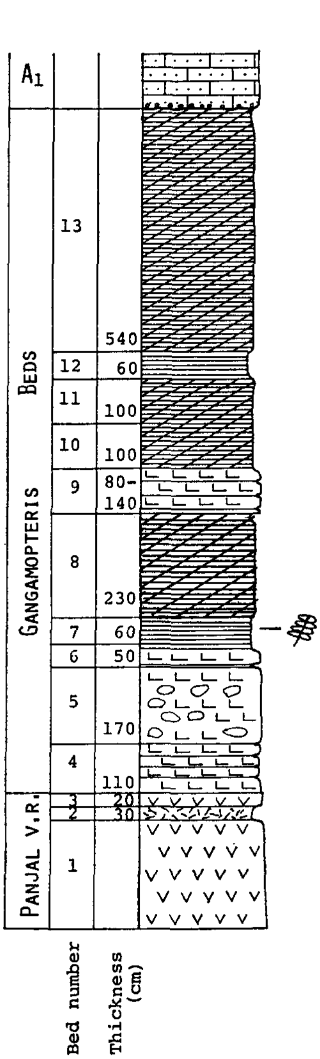
Fig. 2. Geology around Vihi plain.
(Reproduced from MIDDLEMISS, Geol. Surv. India, Rec., vol. 37, pt. 4, pl. 14, 1910)

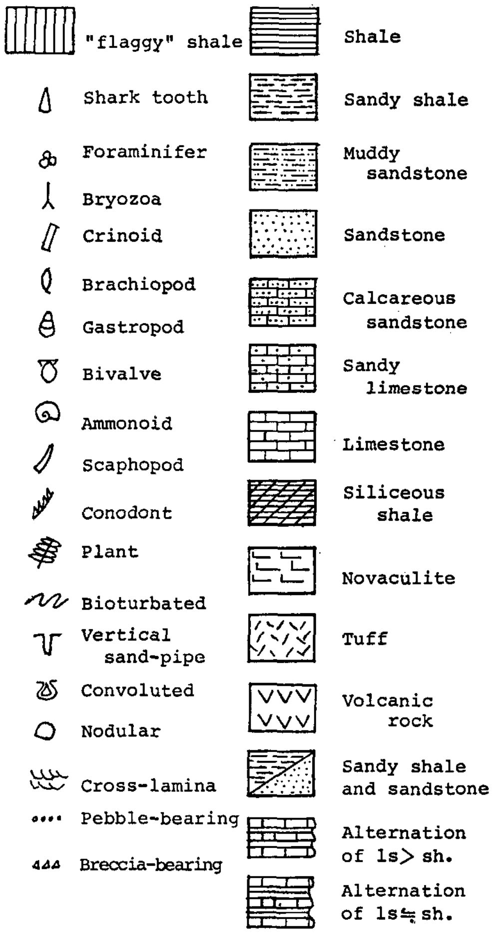
Guryul ravine section

At Guryul ravine, the Permian-Triassic sequence is continuously and well exposed (Pl. 1). The Panjal volcanic rocks constitute the western slope of the ravine, running along NNW–SSE direction and dipping gently to ENE. A detailed survey was carried out from the uppermost part of the Panjal volcanic rocks on the right bank of the ravine up to the top of the *Meekoceras* beds of MIDDLEMISS (1909) which coincides with the foot of the third cliff on the opposite side. A detailed geologic column and a generalized one are shown in Figs. 3–9, and Fig. 12.

1. Panjal volcanic rocks (Beds 1–3)

The Panjal volcanic rocks cropping out on the west side of the entrance of the ravine are composed of alternations of basic to intermediate lava, tuff and agglomerate. The existence of a spilitic pillow lava suggesting the subaqueous eruption has already been reported (NAKAZAWA and KAPOOR, 1973). The pillow structure, although





LEGEND OF FIGS. 3 TO 10

Fig. 3. Columnar section of Gangamopteris Beds.

somewhat obscure, is also developed higher, in the rocks just above the described pillow lava.

2. Gangamopteris Beds (Lower Gondwana beds) (Beds 4–13, 15.6 m)

The Gangamopteris Beds conformably overlie the Panjal volcanic rocks. The lower half (Beds 4–9) consists mainly of white novaculite, while the upper half (Beds 10–13) is mainly made of black to gray, siliceous, laminated shale. The basal part (Bed 4) is a novaculite that has irregular banding about 5 cm thick. Bed 5 is a massive, white novaculite in which a gray, nodule-like structure is sometimes seen. These novaculites are constituted by microcrystalline and/or cryptocrystalline quartz, containing no other minerals excepting a few secondary ones. Novaculite of Bed 6 has a brecciated texture of interlocking white and yellowish brown parts. In the brownish part, dark, circular or ellipsoid structure similar to that of pelletal or oolitic limestone can be observed under the microscope, and in some cases shelly materials are contained which reminds one of disarticulated ostracod carapaces (Pl. 2, Fig. 1). All these are made of siliceous materials. HAYDEN (1907) traced the replacement of oolitic limestone by silica in the novaculite at Zewan spur. He also noticed that the silicification was not confined to the limestone but had extended to associated shales and sandstones. Although siliceous, sponge-like spicules have been detected in the novaculite, it may be concluded that at least a part of novaculite is replaced limestone.

Beds 7 and 8 consist of black, laminated, siliceous shale 10–15 cm bedded (Pl. 2, Fig. 2), and sometimes alternating with laminated, non-siliceous shale of 2–5 cm in thickness. A white siliceous band less than 1 cm thick is frequently intercalated in Bed 8 (Pl. 2, Fig. 3). In these muddy rocks, secondary minerals, such as biotite, chlorite, zoicite and sphen are commonly visible under the microscope, and zoicite spots are visible to unaided eyes in the black shale (Pl. 1, Fig. 4). It is uncertain whether such minerals have been formed by thermal metamorphism or through diagenesis. Stylolitic seams are sometimes developed in siliceous shale. Black siliceous shale of the upper half, 20–50 cm bedded, is less siliceous than that of the lower half. Micaceous minerals of secondary origin can be frequently seen under the microscope, arranged parallel to a certain trend. Bed 12, whose thickness is 60 cm, is light gray, parallel laminated, carbonaceous shale (Pl. 2, Fig. 5). Plant fragments assigned to *Gangamopteris* are rare in it, indicating a northernmost limit of the Lower Gondwana flora. The uppermost bed (No. 13) is siliceous shale of which uppermost 40 cm part has a crushed and somewhat phyllitic structure along the contact plane with the overlying Zewan Formation (Pl. 2, Fig. 6).

3. Zewan Formation

The Zewan Formation lies on the Gangamopteris Beds with a sharp, flat, and locally undulatory contact plane, which, together with a crushed structure of the underlying bed, indicates some dislocation between the two. However, the dislocation took place along a bedding surface, and there is no structural discrepancy. Comparing the sequence 3 km north of Barus, it is considered that there probably is not any part of the section missing due to mechanical dislocation.

The Zewan Formation, whose total thickness attains to 97.3 m, can be divided into four members, A to D, two of which are subdivided into several units (Table 4). The exact horizons of fossils are referred to in the range chart (Table 8).

Table 4. Division of Zewan Formation at Guryul ravine

Member D	(Beds 32–46, 18.2 m)	Thick-bedded, sanday limestone and calcareous sandstone, partly convoluted and nodular, intercalating thin shale layers
Member C	(Beds 26–31, 23.2 m)	Alternation of calcareous sandstone and sandy shale, predominant in the latter
Member B (29.3 m)	Unit B_3 (Beds 24–25)	Alternation of thick-bedded sandy shale and sandstone, intercalating calcareous sandstone, 6.4 m
	Unit B_2 (Bed 23)	Alternation of calcareous sandstone and sandy shale, 2.1 m
	Unit B_1 (Beds 21–22)	Sandy shale, 20.8 m
Member A (26.6 m)	Unit A_4 (Beds 20-2–4)	Calcareous sandstone and micaceous sandy shale, 5.8 m
	Unit A_3 (Bed 20-1)	Calcareous sandstone and micaceous shale, 3 m
	Unit A_2 (Beds 18–19)	Thick-bedded, sandy limestone, 9.6 m
	Unit A_1 (Beds 14–17)	Calcareous sandstone and alternation of sandy limestone and shale, 8.2 m

(1) Member A

Member A is composed mainly of carbonate rocks* accompanied by sandy shale.

It is divisible into four units, from A_1 to A_4, of which the lower two consisting mainly of calcareous sandstone and sandy limestone correspond to Gray Crinoid limestone of MIDDLEMISS, and the upper two are made of calcareous sandstone and sandy sahle roughly corresponding to *Protoretepora ampla* beds.

* Carbonate rocks in this region are exclusively represented by calcium carbonate with some terrigenous materials, and are classified in this paper based on the amount of terrigenous materials as follows. (See Chapter VII)
limestone: terrigenous material less than 4%, sandy limestone: 4–18%, calcareous sandstone: 18–30%, sandstone: more than 30%.

Unit A_1 (Beds 14 to 17, 8.2 m thick)

The lower half of Unit A_1 (Beds 14 to 16) is thick-bedded, calcareous sandstone with abundant fossils of brachipods, bryozoans, crinoids, algae and foraminifera. In the basal part (Bed 14) there exist many exotic clasts, such as well-rounded or sub-rounded pebbles of quartzite, granite, novaculite, and siliceous shale (Pl. 3, Fig. 1). In calcareous sandstone, rounded or well-rounded quartz-grains, considered to be aeolian, can be seen under the microscope (Pl. 3, Fig. 2). These grains suggest that the provenance may have been only sparsely vegetated or had aeolian sandstone outcrops. Exotic clasts of granule to small-pebble size and aeolian quartz-grains are also contained sporadically in Bed 15.

The upper half (Bed 17) is an alternation of sandy limestone and shale, in beds 10–20 cm thick. Abundant bryozoans, and a few brachiopods, crinoids, algae, and foraminifera are found in it.

Unit A_2 (Beds 18 and 19, 9.6 m)

This unit is composed mostly of thick-bedded, gray, sandy limestone. Thin shale layers alternate with limestones in the upper part (Pl. 3, Fig. 5). Terrigenous grains, mostly quartz, are commonly contained in sandy limestone, some of which are well-rounded like those of the preceeding unit. Black shale is usually parallel laminated, and bioturbated by burrowing animals.

Bryozoans and brachiopods are commonly found concentrated along bedding surfaces (Plate 3, Fig. 4), and the former are especially abundant in the muddy intercalations. Foraminifera and crinoids are also common. All these fossils show indications of transportation (Plate 3, Fig. 2).

Unit A_3 (Bed 20–1, 3.0 m)

Unit A_3 is composed of micaceous sandy shale, thinly and parallel laminated, and sometimes bioturbated (Plate 3, Fig. 5).

Unit A_4 (Beds 20–2 to 20–4, 5.8 m)

The lower half of the unit (Bed 20–2) is made of calcareous sandstones in beds 5 to 10 cm thick, with very thin shale seams, while the upper half (Besd 20–3, 4) is constituted of micaceous sandy shale and intercalated thin-bedded limestone.

Brachiopods and bryozoans are commonly contained in the limestone and calcareous sandstone. Foraminifera are rare.

Fossils of Member A

Bryozoans, crinoids, and brachiopods are most common fossils of Member A. Foraminifera, though not abundant, are found throughout the member. As the specimens are enclosed in hard, compact rocks, it is difficult to get isolated specimens,

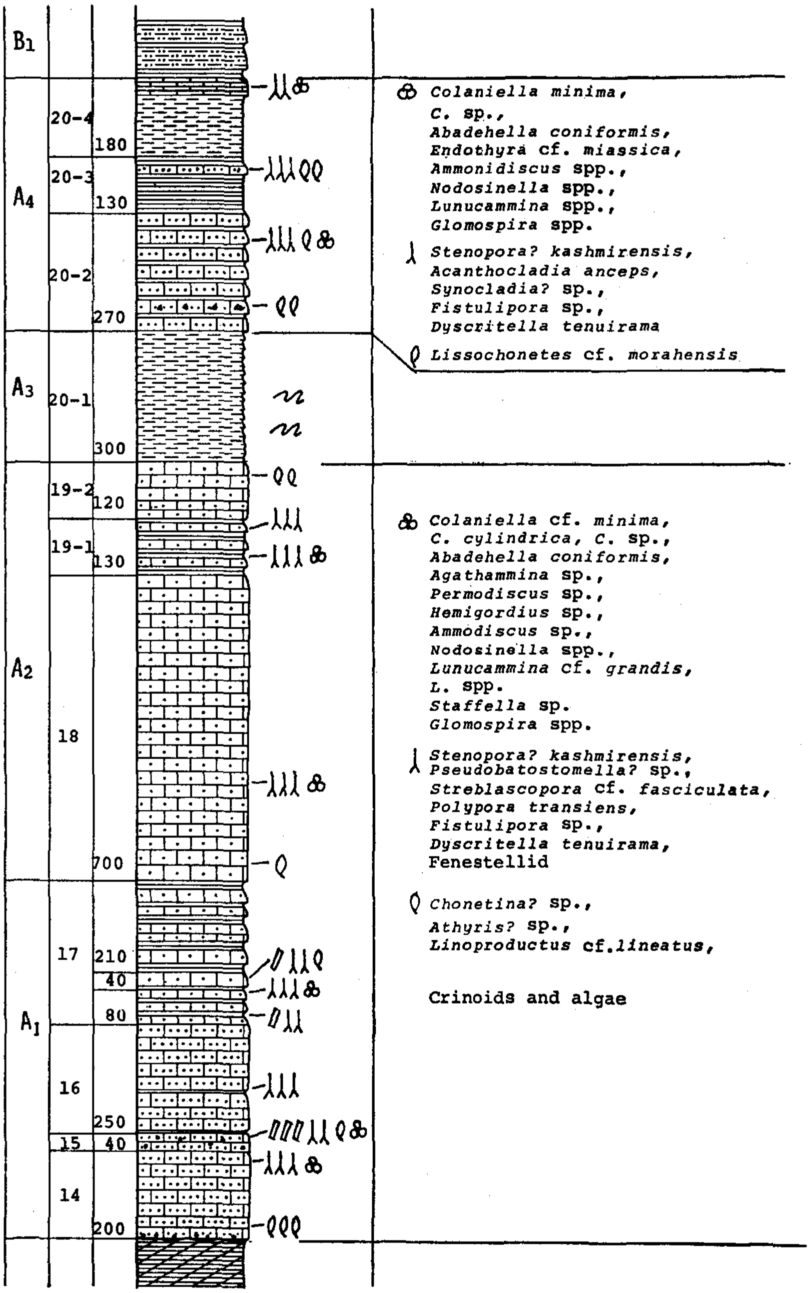


Fig. 4. Columnar section of Member A of the Zewan Formation.

and only a few species can be identified among the brachiopods. They are: *Chonetina?* sp., *Athyris?* sp., *Cleiothyridina* cf. *subexpansa* (WAAGEN), *Linoproductus* cf. *lineatus* (WAAGEN), *Lissochonetes* cf. *morahensis* (WAAGEN), and *Waagenoconcha* spp.

Foraminiferal and bryozoan assemblages do not vary greatly in content throughout the member. As the tests of foraminifera are more or less destroyed through transportation, and furthermore recrystallized secondarily, a specific determination is rather difficult. The identified fossils are enumerated below.

Foraminifera: *Ammodiscus* spp., *Glomospira* spp., *Nodosienella* spp., *Lunucammina grandis* (LIPINA), *L.* spp., *Pachyphloia* spp., *Colaniella* cf. *minima* WANG, *C. cylindrica* M-MAKLAY, *Abadehella coniformis* OKIMURA and ISHII, *Agathammina* sp., *Permodiscus* sp., *Hemigordius* sp., *Endothyra* cf. *miassica* KALAKHOVA, *Staffella* sp., and palaeotextulariid.

Bryozoa: *Fistulipora* sp., *Stenopora? kashimrensis* SAKAGAMI, n. sp., *Dyscritella tenuirama* CROCKFORD, *Pseudobatostomella?* sp., *Streblascopora* cf. *fasciculatus* (BASSLER), *Hayasakapora grossa* SAKAGAMI, n. sp., *Polypora transiens* WAAGEN and PICHL, *Acanthocladia anceps* (SCHLOTHEIM), *Septopora* sp., and *Synocladia* sp.

Gastropods and bivalves were not found. Stems of crinoids, and algae are common, but they have not yet been identified.

(2) Member B

Member B is distinguished from Member A in predominance of shale and poor carbonate rocks.

Unit B_1 (Beds 21 and 22, 20.8 m)

Unit B_1 consists of micaceous sandy shale, muddy sandstone and alternation of sandstone and thin shale. Trace fossils are common. Platy partings are developed in sandy shale by the parallel distribution of detrital micaceous flakes (Pl. 4, Fig. 1). Muddy sandstone is also micaceous, sometimes calcareous, and irregularly bedded, in beds 10–50 cm thick, with intercalated shaly partings, strongly bioturbated. The primary sedimentary structures are obliterated to various degrees. No skeletal remains were found.

Unit B_2 (Bed 23, 2.1 m)

Unit B_2 is alternations of sandstone and sandy shale, all micaceous and irregularly bedded. Sandstone is more or less calcareous, mostly medium-grained. Parallel and/or cross laminations are disturbed by burrowing animals sometimes more than 10 mm in diameter (Pl. 4, Fig. 2). Many brachiopods and a small number of bivalves, crinoids, bryozoans, and foraminifera are found in calcareous sandstone beds. This fossiliferous unit probably corresponds to Hor. (1) 10–10–09 of MIDDLEMISS.

Foraminifera: *Nodosinella* spp.

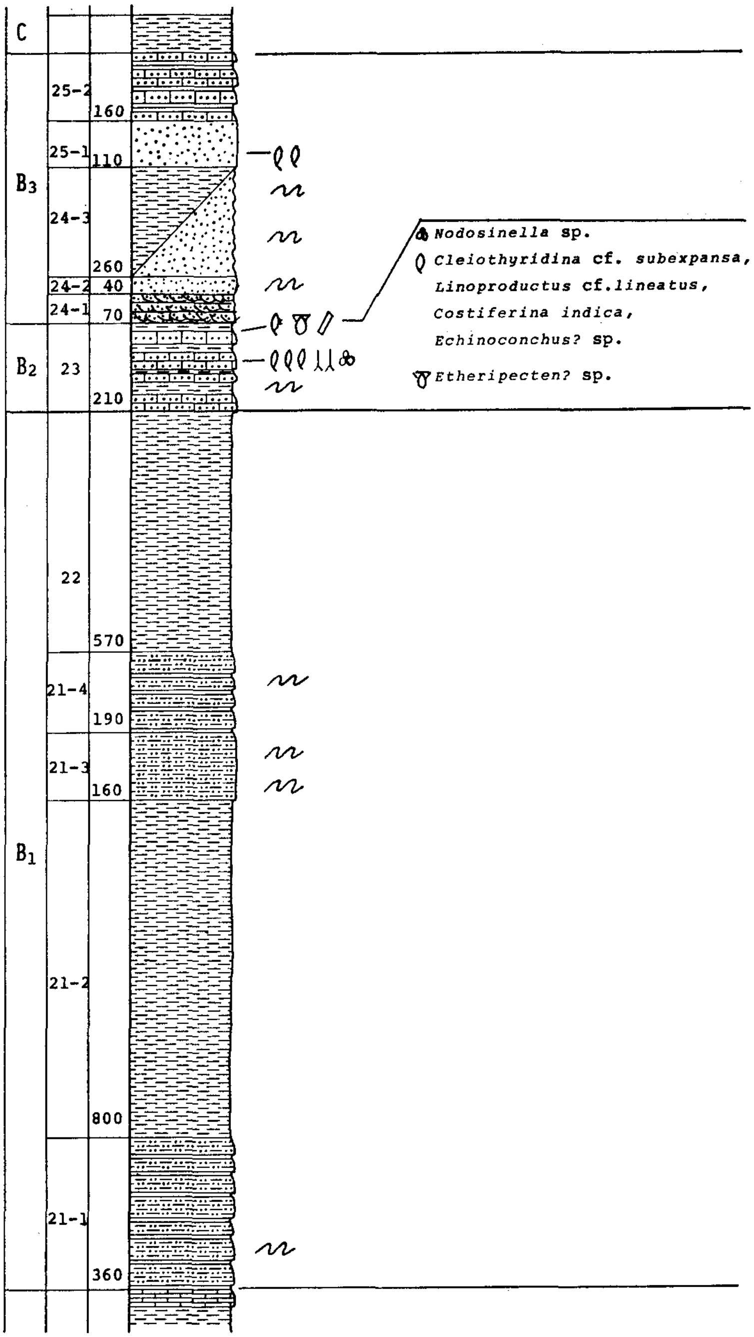


Fig. 5. Columnar section of Member B of the Zewan Formation.

Brachiopoda: *Cleiothyridina* cf. *subexpansa* (WAAGEN), *Linoproductus* cf. *lineatus* (W.), *Costiferina indica* (W.), *Echinoconchus*? sp., *Marginifera himalayensis* DIENER.

Bivalvia: *Etheripecten*? sp.

Unit B_3 (Beds 24–1 to 25–2, 6.4 m)

The unit consists mostly of bedded, micaceous sandstone and sandy shale. Laminations are often disturbed by burrowing animals. Cross lamination is developed in the lowermost sandstone. The uppermost portion (Bed 25–2) is represented by an alternation of calcareous sandstone in beds about 10 cm thick and sandy shale in beds about 5 cm thick.

Brachiopods are contained at two horizons (Beds 24–1 and 25–1), but can not be identified.

(3) Member C (Beds 26 to 31, 23.2 m)

Member C is characterized by rhythmic alternation of calcareous sandstone and sandy shale, in which the shale is predominant. Calcareous sandstone is usually in beds 10–20 cm thick, with diverse sedimentary structures such as parallel and cross laminations and graded structure (Pl. 4, Figs. 3–5). Burrows oblique to lamination also occur (Pl. 4, Fig. 6). The sandy shale is micaceous, irregularly or parallel laminated. Fine- to very fine-grained and muddy sandstone is developed in parallel, muddy laminations. These muddy rocks are strongly bioturbated (Pl. 5, Figs. 1, 2, 4–6).

Gastropods, bivalves, brachiopods and others swarm in calcareous coquinoid sandstones at several horizons. Hor. (2) 10–10–09 of MIDDLEMISS is considered to be included in this member. The following species are discriminated.

Foraminifera: *Glomospira* sp., *Nodosinella* spp., *Lunucammina* spp., *Glovivalvulina* cf. *cyprica* REICHEL, *G.* sp., and *Pachyphloia*? sp.

Bryozoa: *Dyscritella* sp., fenestellid gen. et sp. ind.

Brachiopoda: *Lissochonetes bipartita* (WAAGEN), *Dielasma*? sp., *Waagenoconcha* sp., and *Costiferina*? sp.

Bivalvia: "*Streblochondria*" sp., *Permophorus* sp. aff. *subovalis* (WAAGEN), "*Palaeolima*" *middlemissi* NAKAZAWA, n. sp., *Phestia*? sp., *Aviculopecten*? sp.

Gastropoda: *Bellerophon* (*B.*) *branfordianus* WAAGEN, *B.* (*B.*) cf. *branfordianus* W., *B.* (*B.*) sp.

Scaphopoda: *Plagioglypta* sp.

An ammonoid, *Cyclolobus walkeri* DIENER was reported from a coquinoid limestone of the uppermost bed (Bed 31) of this member (FURNISH *et al.*, 1973). Conodonts first appear in the same horizon as *Cyclolobus*; they are identified as *Anchignathodus typicalis* SWEET and *Neogondolella carinata* (CLARK).

(4) Member D (Beds 32 to 46, 18.2 m)

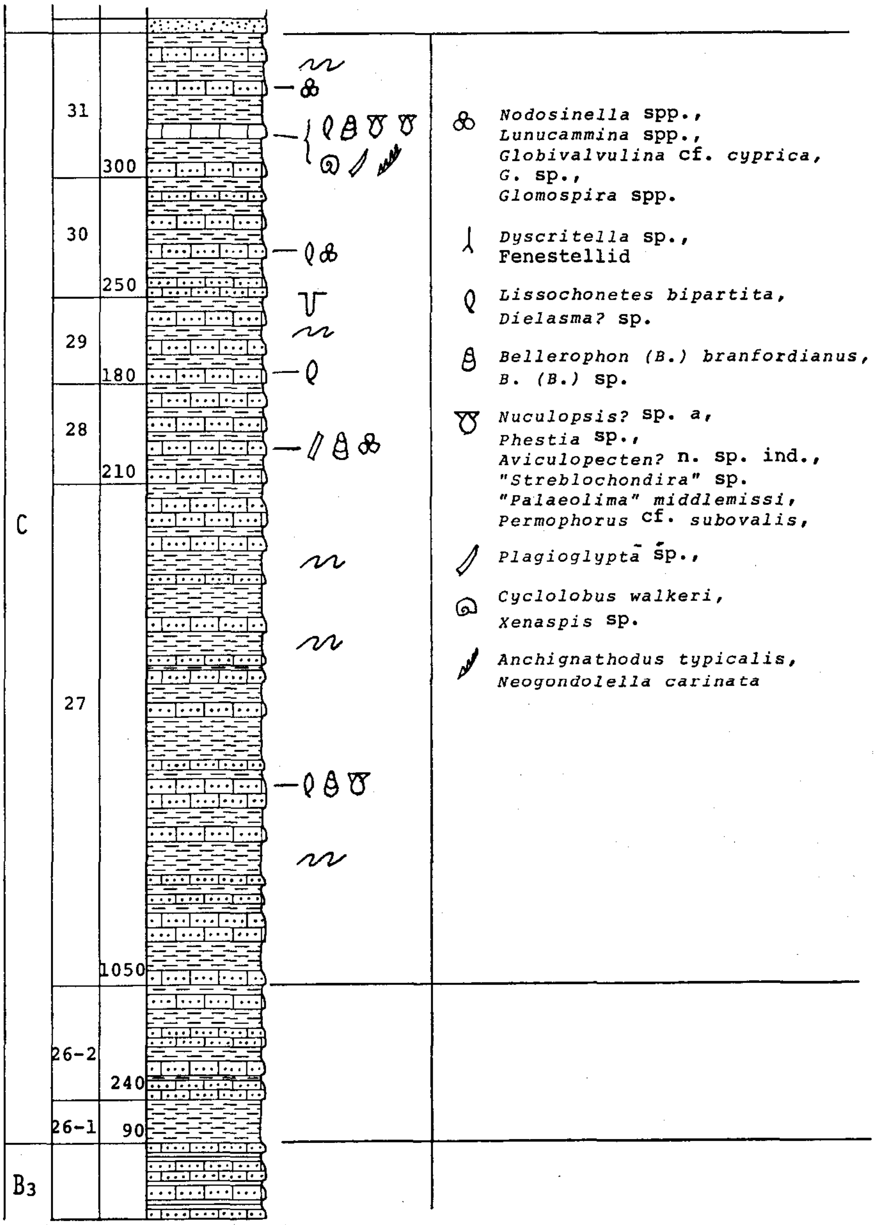


Fig. 6. Columnar section of Member C of the Zewan Formation.

Member D is mainly represented by thick-bedded sandy limestone. Sandy shale including laminated muddy sandstone is frequently intercalated in the lower part, while calcareous sandstone and muddy sandstone are predominant in the upper part. A small slump structure is observed on the polished surface of Bed 40–1 and large-scale convolute bedding is seen in Beds 41 and 43 (Pl. 6, Fig. 5). Parallel and cross laminations are often developed in the sandstones (Pl. 6, Figs. 3 and 4). The uppermost bed (Bed 46) consists of sandy limestone that has many nodules of micritic limestone weathered dark brown in color (pl. 6, Fig. 6). Well-rounded or rounded quartz grains probably of aeolian origin are contained in sandstones (Pl. 7, Figs. 3 and 6).

Many fossils of bivalve, gastropod, and brachiopod are concentrated at several horizons. Foraminifera and bryozoans are rare.

Foraminifera: *Glomospira?* sp., *Nodosinella* spp., *Lunucammina postcarbonica* (SPANDEL), *L.* spp., *Globivalvulina* cf. *cyprica* REICHEL, *G.* sp., *Staffella?* sp.

Bryozoa: *Fistulipora* sp., *Stenodiscus* cf. *chaetetiformis* (WAAGEN and WENTZEL), *Dyscritella tenuirama* CROCKFORD, *D.* sp., *Hayasakapora grossa* SAKAGAMI, n. sp., and *Stenopora* sp.

Brachiopoda: *Linoproductus* cf. *lineatus* (WAAGEN), *Dielasma?* sp., *Waagenoconcha purdoni* (DAVIDSON), and *W.* sp.,

Gastropoda: *Bellerophon* (*B.*) *branfordianus* WAAGEN, *B.* (*B.*) cf. *branfordianus*, *B.* (*B.*) sp., *Retispira ornatissima* WAAGEN, and *R.* cf. *kattaensis* W.

Bivalvia: *Palaeoneilo* sp. a, *Aviculopecten?* n. sp. ind., "*Streblochondria*" sp., "*Palaeolima*" *middlemissi* NAKAZAWA n. sp., *Permophorus* cf. *subovalis* (WAAGEN), *Etheripecten haydeni* NAKAZAWA?, *E.* aff. *haydeni*, *E.* aff. *hiemalis* (SALTER), *Cyrtorostra* aff. *lunwalensis* (REED), "*Loripes*" *atavus* WAAGEN, and *Schizodus?* sp.

A shark tooth, *Ctenacanthus ishii* was described from the upper part of Bed 45 by KAPOOR and SAHNI (1971). Conodont fossils identified as *Neogondolella carinata* and *Ellisonia triassica* rarely occur in the middle part of this member, and *Xenaspis* sp. was collected from Bed no. 43.

4. Khunamuh Formation

The strata succeeding Bed 46 are characterized by alternation of shale and limestone, gradually increasing limestone content upward and changing into bedded limestone. They are clearly distinguished from the underlying Zewan Formation in lithology as will be discussed in Chapter VII. So, it is reasonable to separate them as a distinct lithostratigraphic unit, no matter where the Permian-Triassic boundary is located. Formerly, the boundary was drawn between the top of Bed 46 and the base of the 'mixed zone' (NAKAZAWA *et al.,* 1970). In the present paper, however, the base of the *Otoceras* zone (the base of Bed 52) is referred to as the erathem boundary. Accordingly, the time-stratigraphic boundary does not coincide with the

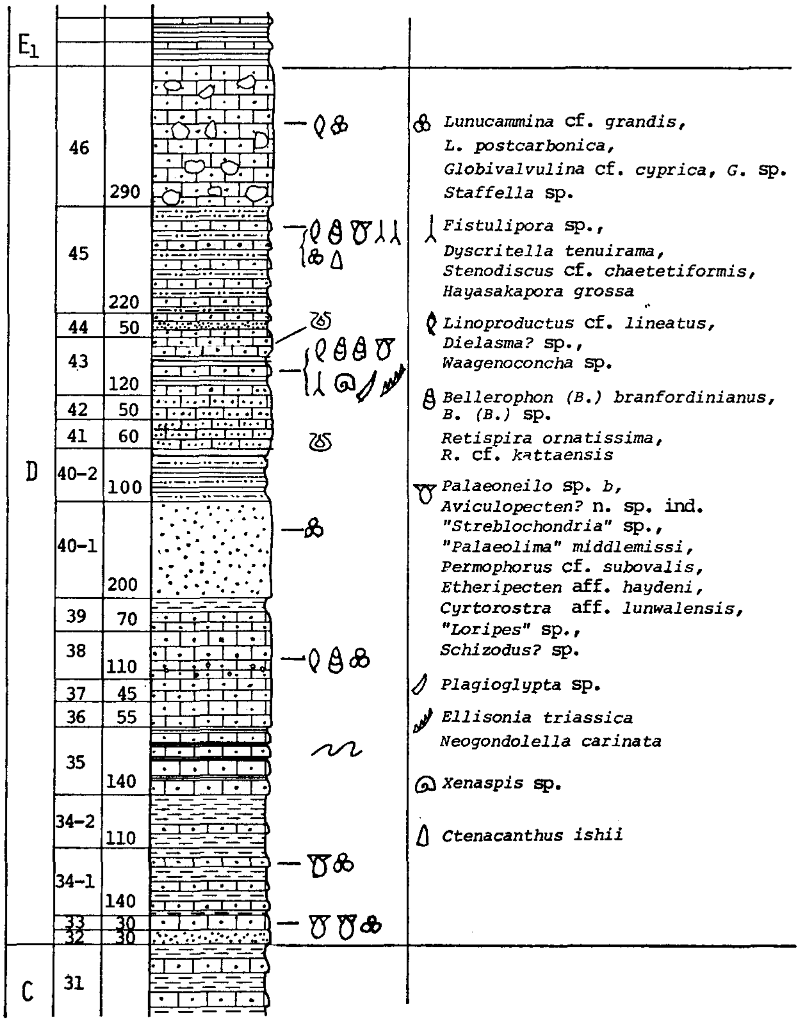


Fig. 7. Columnar section of Member D of the Zewan Formation.
(Read *branfordianus* for *branfordinianus*)

lithostratigraphic boundary.

The Khunamuh Formation overlies conformably the Zewan Formation with a rather abrupt lithological change. The formation is divisible into four members, E to H, based mainly on the limestone/shale ratio. (Table 5; Pl. 8, Fig. 1).

(1) Member E (Beds 47 to 70, 18.6 m)

Member E is composed of alternation of shale and subordinate limestone (Pl. 8, Fig. 1), and is divided into three units by different lithologic nature of shale.

Table 5. Division of Khunamuh Formation at Guryul ravine

Member J	(Bed 93)	Muddy calcareous sandstone alternating with thin shale, more than 15 m
Member I	(Beds 91–92)	Alternation of limestone and shale, 8.4 m
Member H	(Beds 86–90)	Lower 12 m alternation of limestone and sahle, upper 32 m sandstone and shale intercalating limestone
Member G	(Beds 78–85)	Bedded limestone with thin shale parting, 36.4 m
Member F	(Beds 71–77)	Alternation of limestone and shale, 18.8 m
Member E	(Beds 47–70, 18.6 m)	
Unit E_3	(Beds 60–70)	Alternation of shale and subordinate limestone, 9.9 m
Unit E_2	(Beds 52–59)	Flaggy shale intercalating thin limestone, 6.1 m
Unit E_1	(Beds 47–51)	Black shale intercalating thin limestone, 2.6 m

Unit E_1 (Beds 47 to 51, 2.6 m)

Unit E_1 is constituted by dark gray to black shale intercalating several limestone layers, each 10 to 20 cm thick. The shale is clayey or silty, usually not so micaceous as that of the Zewan, excepting in thin, sandy lamina-part where the Permian brachiopods and bivalves are crowded parallel to the bedding surface together with micaceous minerals. It tends to be broken off in two directions, the one along laminations parallel to the bedding plane and the other along cleavage planes oblique to the bedding plane.

Fossils are mostly found in the shale. The "Triassic-type" bivalve, *Claraia bioni* NAKAZAWA, n. sp., occurs scattered in the shale, and does not coexist with the other fossils excepting rare cases. Some of *Claraia* are preserved in an articulated state, while the other fossils are densely aggregated on the bedding plane sometimes making a coquinite. Judging from such occurrences, specimens of *Claraia* are considered to have been buried nearly *in situ*, and the rest of fossils were more or less transported from other, probably shallower sea-bottom before burial. The fossils are represented mostly by brachiopods and bivalves as follows.

Brachiopoda: *Linoproducuts* cf. *lineatus* (W.), *Lissochonetes morahensis* (W.), *Dielasma*? sp., *Waagenoconcha purdoni* (W.), *Athyris*? sp., *Schellwienella* sp., *Derbyia* sp., *Marginifera himalayensis* D. and *Pustula* sp.

Bivalvia: *Palaeoneilo* sp. b, *Etheripecten haydeni* NAKAZAWA, n. sp., *E.* cf. *hiemalis* (SALTER), *Cyrtorostra* aff. *lunwalensis* (REED), *Nuculopsis* sp., *Claraia bioni* NAKAZAWA, n. sp., and "*Palaeolima*" *middlemissi* NAKAZAWA, n. sp.

In addition to these fossils listed above, two species of Foraminifera, *Nodosinella longissima* M-MAKLAY and *Lunucammina* sp., and one gastropod, *Pagodina*? sp., are found in the limestone. Conodonts are very few and poorly preserved, that are determined as *Neogondolella carinata* and *Ellisonia triassica*. An indeterminable ammonoid specimen similar to *Xenaspis* or ophiceratid was obtained from the shale.

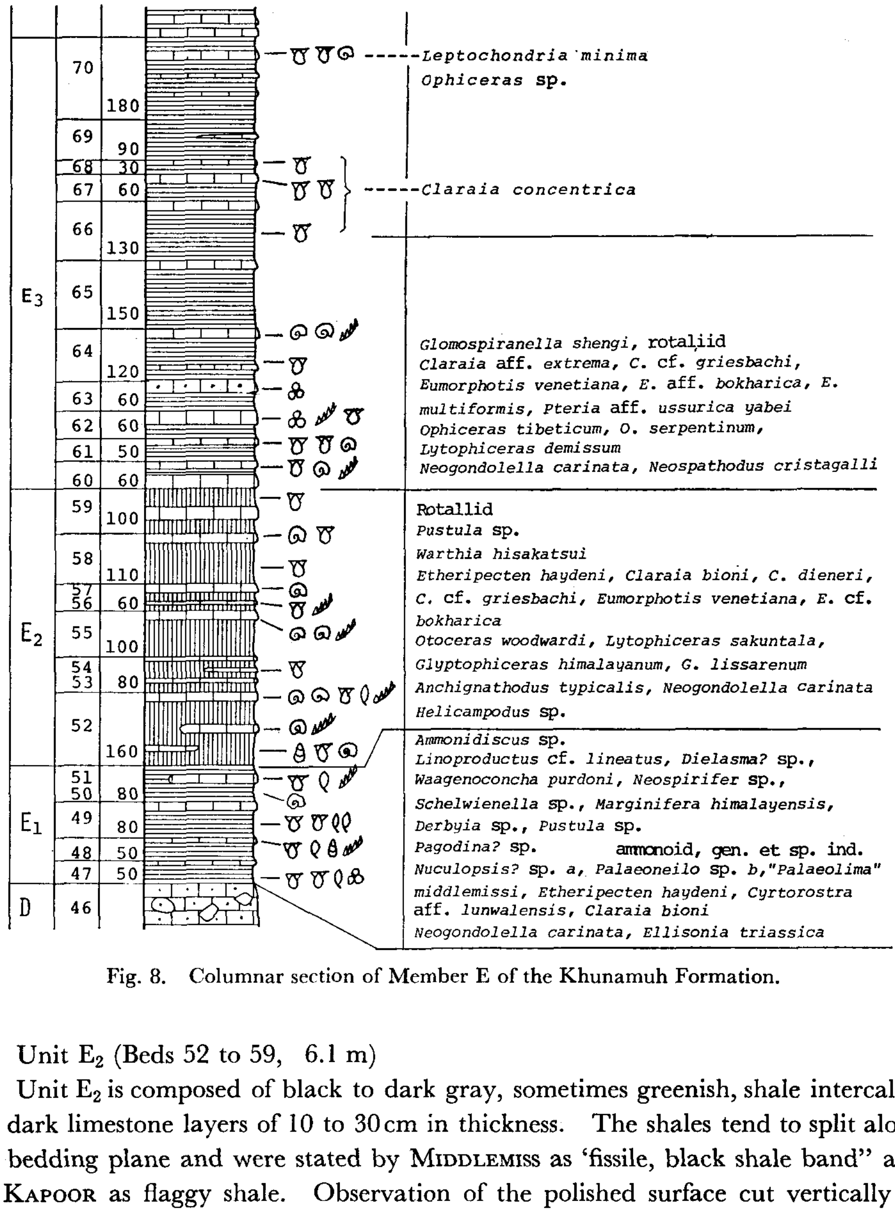


Fig. 8. Columnar section of Member E of the Khunamuh Formation.

Unit E_2 (Beds 52 to 59, 6.1 m)

Unit E_2 is composed of black to dark gray, sometimes greenish, shale intercalating dark limestone layers of 10 to 30 cm in thickness. The shales tend to split along the bedding plane and were stated by MIDDLEMISS as 'fissile, black shale band" and by KAPOOR as flaggy shale. Observation of the polished surface cut vertically to the bedding plane shows that the sandy laminae several to ten mm thick well continue laterally and are graded upward with a sharp lower boundary suggesting the transportation by a kind of turbidity current. Muddy particles are arranged parallel to the bedding plane when observed under the microscope. Limestone is graded and/or parallel or cross laminated (Pl. 9). A convolute structure is sometimes visible containing shale patches derived from the underlying shale bed (Pl. 10, Fig. 3). Trace fossils could not be detected in the field, but a tiny burrow is observed on the polished cross-section of limestone (Pl. 10, Fig. 1). The limestone is rich in ammonoids and bivalves. The latter are also rarely found in the shale. The following species are identified in this unit.

Bivalvia: *Eumorphotis venetiana* (HAUER), *E.* aff. *bokharica* (BITTNER), *Leptochondria minima* (KIPARISOVA), *Promyalina*? sp., and from the upper part, *Claraia dieneri* NAKAZAWA, n. sp., *C.* aff. *extrema* SPATH, and *C.* cf. *griesbachi* (BITTNER)

Ammonoidea: *Otoceras woodwardi* GRIESBACH, *Lytophicreas sakuntala* (DIENER), *Glyptophiceras himalayanum* (GRIESBACH), *G. lissarensis* (D.), *G.* sp., *Proptychites* sp.

A few fragmental specimens belonging to *Claraia bioni*, *Etheripecten haydeni* and *Pustula* sp., common in the preceeding strata, have been collected from the basal part of this unit, but it is not certain whether these are relict or derived fossils.

Conodonts become suddenly predominant, represented by *Anchignathodus typicalis* and *Neogondolella carinata*, both continue from the Zewan. A bellerophonid species, *Warthia hisakatsui* MURATA, n. sp. is found crowdedly in the basal limestone in association with *Otoceras woodwardi*. An indeterminable rotaliid species and a bryozoa rarely occur in the limestone. An excellent specimen of shark tooth belonging to *Helicampodus* was obtained from a floating block of this unit (Pl. 9, Fig. 4).

Unit E_3 (Beds 60 to 70, 9.9 m)

Unit E_3 consists of black shale intercalating limestone layers of about 10 cm in thickness. The unit is distinguished from Unit E_2 in a less fissile character of shale parallel to the bedding plane. Sedimentary structures suggesting turbidity currents are commonly observed in limestone layers (Pl. 10, Figs. 5, 6; Pl. 11, Figs. 1–4). One of limestones (Bed 63) is sandy.

The fossils are represented by ammonoids, bivalves and conodonts as in Unit E_2. Ammonoids are represented almost exclusively by the genus *Ophiceras*, and bivalves by *Eumorphotis* and *Claraia*.

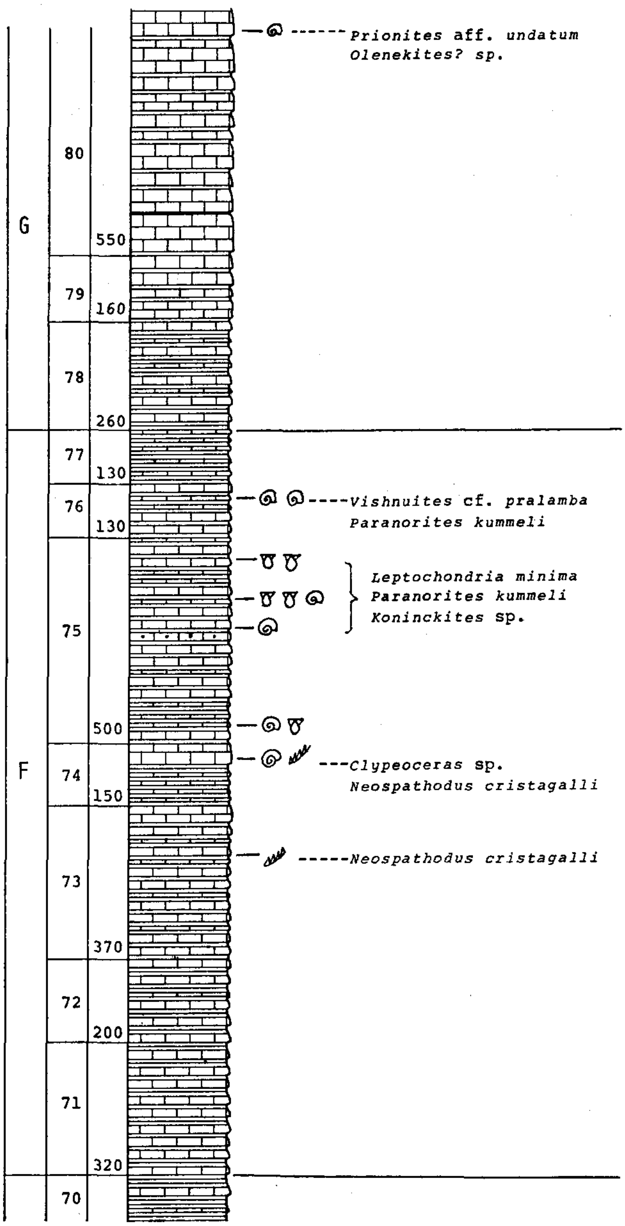
Ammonoidea: *Ophiceras subdemissum* (SPATH), *O. tibeticum* GRIESBACH, *O. serpentinum* DIENER, and *O.* spp.

Bivalvia: *Eumorphotis* aff. *bakharica* (BITTNER), *E. venetiana* (HAUER), *E. multiformis* (BITTNER), *Claraia* aff. *extrema* SPATH, *C.* cf. *griesbachi* (BITTNER), *C. concentrica* YABE, *Leptochondria minima* KIPARISOVA, and *Pteria* aff. *ussurica yabei* NAKAZAWA.

Conodonts: *Neogondolella carinata* (CLARK) and *N. cristagalli* (HUCKRIED).

According to SWEET (1973) *Anchignathodus typicalis* occurs from the middle part of this unit.

A foraminiferal species, *Glomospirella* cf. *shengi* Ho and rotaliid species are examined in the lower part.



Fg. 9. Columnar section of Members F and G of the Khunamuh Formation.

(2) Member F (Beds 71 to 77, 18.8 m)

Member F is made of alternation of shale and limestone, each 5–10 cm in thickness. Shale layers are nearly equal to or a little less than limestones in amount. This member is distinguished from Member E in the development of limestone, which is more thinly bedded (Pl. 11, Figs. 5, 6).

Fossils are represented by ammonoids, bivalves, and conodonts. The ammonoids are common in the upper part of the member, that is, near the foot of the second cliff (Beds 74 to 76).

Ammonoidea: *Proptychites* sp., *Ophiceras* sp., *Paranorites kummeli* BANDO, n. sp., *Vishnuites* cf. *pralambha* DIENER, and *Koninckites* sp.

Bivalvia: *Leptochondria minima* (KIPARISOVA) (Beds 70, 75)

Conodont: *Neospathodus cristagalli* (HUCKRIED) (Beds 73, 74)

(3) Member G (Beds 78 to 85, 36.4 m)

The member consists of limestone intercalated with thin shale parting. It makes a conspicuous and continuous cliff (Pl. 1). The limestone is usually in beds 5 to 10 cm thick, while the shale is in beds less than 2 cm.

Fossils are poor, and only a few specimens of *Prionites* aff. *undatus* WAAGEN and *Olenekites*? sp. from the lower part (Bed 80) and *Koninckites* sp. from the middle part (Bed 82) could be obtained. SWEET (1970) reported two conodont species, *Neospathodus cristagalli* and *Ellisonia triassica* from the basal part.

(4) Member H (Beds 86 to 91, 43.1 m)

The slope between the above-described cliff and a higher small cliff is made of alternation of limestone, shale, and calcareous or muddy sandstone, reaching to about 43 m in total thickness. This part is named Member H. The basal part of 11.1 m in thickness (Beds 86 to 90) consists of alternation of limestone 10 to 20 cm thick and shale less than 5 cm thick, and yields rich ammonoids. It undoubtedly corresponds to the *Meekoceras* beds of MIDDLEMISS. Above this the exposure becomes very poor, presumed to be constituted mainly of calcareous sandstone and shale with a few limestone intercalations with ammonoids (Bed 91). The estimated thickness of this part is about 32 m.

The following ammonoids and conodonts are distinguished from Beds 88 to 90.

Ammonoids: *Koninckites* sp., *Owenites koeneni* HYATT and SMITH, *Kashmirites subarmatus* DIENER, *K. brashkei* DIENER, *K.* sp., *Wasatchites* sp., *Meekoceras* cf. *jolikense* KRAFFT and DIENER, *M. gracilitatus* WHITE, *Anakashmirites* cf. *kapila* (DIENER).

Conodont: *Neospathodus waageni* SWEET.

(5) Member I (Beds 92 to 94, 8.4 m)

Above Member H there is a cliff-forming alternation of limestone and shale. The thickness of limestone layers varies from 10 to 30 cm, while that of shale layers is less than 10 cm. No fossils could be obtained from this member.

(6) Member J (Bed 95, more than 15 m)

The uppermost part of the measured section is represented by alternation of muddy, calcareous sandstone (5 to 10 cm thick) and shale (less than 1 cm thick) and barren in organisms. This part can be separated from the underlying strata as Member J.

Section at a spur 3 km north of Barus

The Permian-Triassic strata are continuously exposed at a spur 3 km north of Barus as at Guryul ravine, but they are not so well preserved and fossil horizons are less numerous than those of the latter section. Our efforts were concentrated at Guryul ravine, so that the Barus collections are poor. The stratigraphic description will be stated briefly based on the simplified column (Fig. 10) from data made at the same scale (1/100) as for Guryul ravine.

1. Panjal volcanic rocks

The Panjal volcanic rocks are widely exposed in the mountain behind the spur, seemingly conformably overlain by the Gangamopteris Beds.

2. Gangamopteris Beds (Lower Gondwana Beds)

Table 6. Division of Zewan Formation at a spur 3 km north of Barus

Member e	(Beds 24–46)	Alternation of calcareous sandstone and shale with limestone, 16.0 m
Member d	(Bed 23)	Dark gray shale with limestone, 9.8 m
Member c	(Beds 20–22)	Mainly composed of shale, sandy shale, and sandstone, 31.8 m
Unit c_3	(Bed 22)	Micaceous shale, 11.8 m
Unit c_2	(Bed 21)	Micaceous sandy shale, 12.0 m
Unit c_1	(Bed 20)	Sandstone and subordinate shale with limestone, 8.0 m
Member b	(Beds 15–19)	Micaceous shale or sandy shale with muddy limestone, 45.9 m
Unit b_2	(Bed 19)	Calcareous shale and micaceous sandy shale, 17.5 m
Unit b_1	(Beds 15–18)	Micaceous shale, 28.4 m
Member a	(Beds 1–14)	Cyclic alternation of sandy limestone and shale with calcareous sandstone at the base, 21.2 m

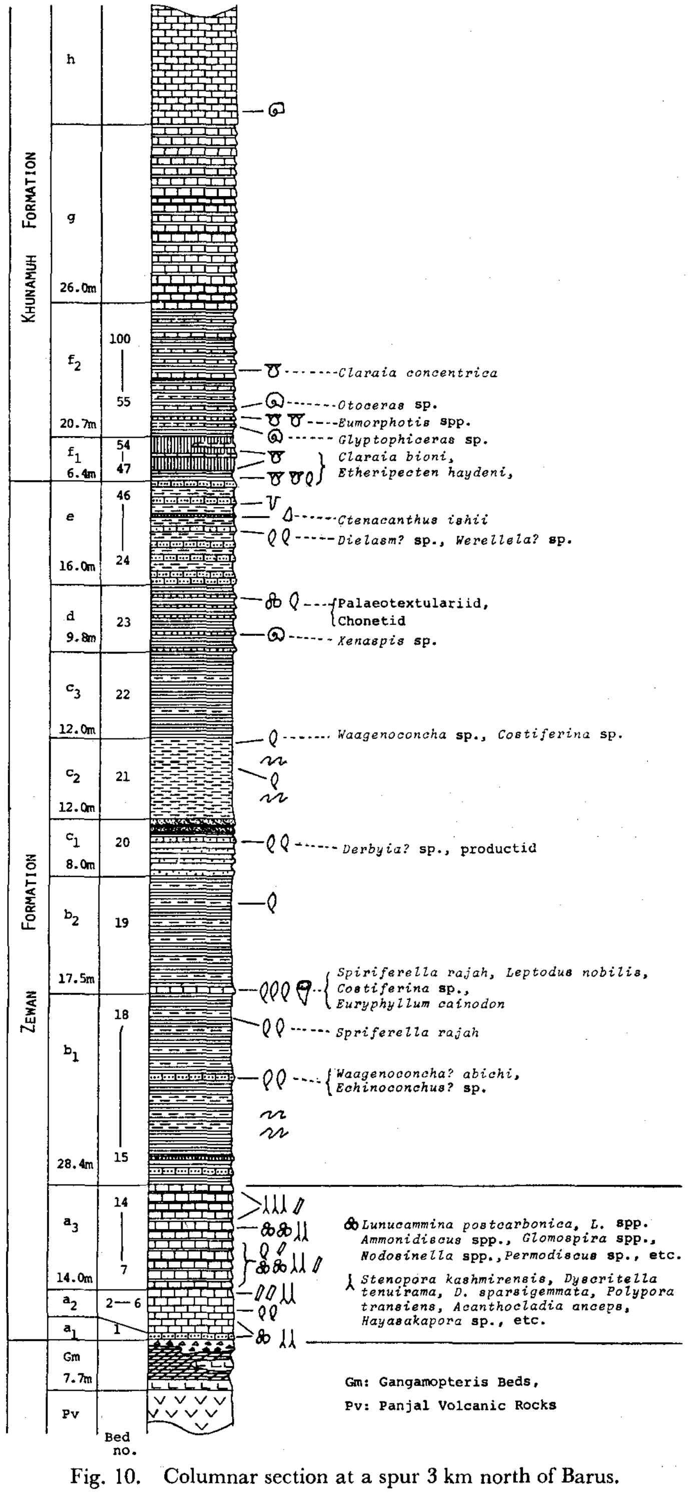


Fig. 10. Columnar section at a spur 3 km north of Barus.

The Gangamopteris Beds consist of white to gray novaculite, black to gray, hard siliceous shale, and novaculite breccia. Two novaculite layers are intercalated in shale beds, both about 2 m thick, of which the upper one is lenticular. Novaculite breccia occupying the uppermost part of the beds consists of hard, black, muddy to sandy matrix containing many angular fragments of novaculite that attain to 30 mm in size. The breccia decreases the size of fragment downward merging into granule-bearing, siliceous shale, and the lower boundary is gradual and uneven (Fig. 11). The silicification that brought about novaculite must have proceeded mainly before the deposition of the Zewan, because calcareous organic remains of the basal sandstone and succeeding limestone of the Zewan immediately above the breccia suffer only slight silicification. Furthermore novaculite granules are abundantly found at the base of the sandstone. This suggests the silicification was related to some volcanic acivity as supposed by HAYDEN (1907) at the Zewan spur.

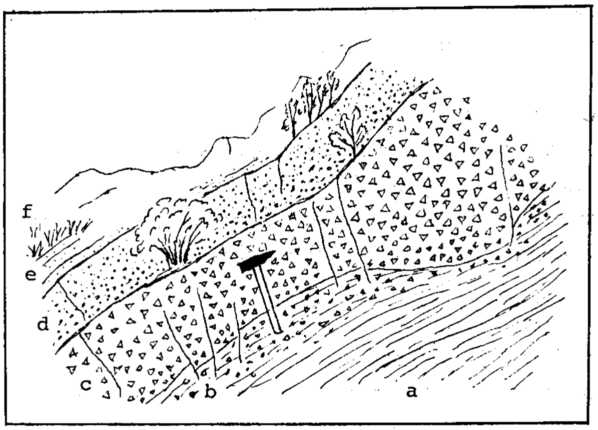


Fig. 11. A sketch showing a contact relation between the Gangamopteris Beds (a–c) and the Zewan Formation (d–f).
a: black siliceous shale, b: black siliceous shale containing many novaculite fragments of granule-size, c: novaculite breccia, d: coarse-grained, siliceous sandstone and granule conglomerate, e: coarse-grained, calcareous sandstone, 10–20 cm bedded, f: gray, bedded limestone. Length of hammer about 35 cm.

The origin of the breccia is difficult to explain, but certainly it is not tectonic. It may have been connected with the volcanic activity and/or syndepositional crustal movement.

3. Zewan Formation

The Zewan Formation overlies the breccia of the Gangamopteris Beds by a sharp, flat plane seemingly with conformity, but the presence of novaculite granules in the basal sandstone and a sharp lithological change suggest a presence of some crustal movement between the two formations. The Zewan is divisible into five members, a to e, as shown in Table 6.

(1) Member a (Beds 1 to 14, 21.2 m)

The member consists mostly of limestone and alternating muddy limestone or calcareous shale. Bryozoans, crinoids, and brachiopods are common throughout the member. It is lithologically divided into three units.

Unit a_1 (Bed 1)

The unit consists of about 1.3 m sandstone, of which the lower part is represented by hard, siliceous, coarse- to medium-grained sandstone containing many granules of novaculite, quartz, and acidic rocks; the upper part is medium-grained, calcareous sandstone. Bryozoans, foraminifera, and indeterminable shell fragments are common. Some of them are partly silicified.

Unit a_2 (Beds 2 to 6, 5.9 m)

The unit is made of bedded, gray limestone, which is classified as biomicrudite. Bryozoans are common throughout the unit, usually in good preservation. Brachiopods and crinoids are concentrated at several horizons, but difficult to identify because of hard and compact matrix. Foraminifera are also common under the microscope.

Unit a_3 (Beds 7 to 14, 14.0 m)

Unit a_3 is characterized by cyclic alternation of limestone and muddy limestone or calcareous shale. The texture indicates transportation of the constituent sediments. Bryozoans are crowded in the muddy portion and foraminifera are common, but crinoids decrease in number and other organic remains are rare. The upper part of the unit corresponds to the *Protoretepora ampla* horizon of MIDDLEMISS, Hor. (1) 27-8-08.

Fossils of Member a

As stated above, bryozoans are predominant, and foraminifera are common throughout the member. Brachiopods and crinoids are crowded at several horizons, but not specifically determined. The following species have been identified so far.

Foraminifera: *Lunucammina postcarbonica* (SPANDEL), *L.* spp., *Ammonidiscus* spp., *Glomospira* spp., *Nodosinella* spp., *Pachyphloia* sp., *Permodiscus* sp., *Staffella* sp., palaeotextulariid gen. et sp. ind.

Bryozoa: *Fistulipora* sp., *Stenopora kashmirensis* SAKAGAMI, n. sp., *Dyscritella tenui-*

rama CROCKFORD, *D.* cf. *iwaizakiensis* SAKAGAMI, *D. sparsigemmata* (WAAGEN and WENTZEL), *S.* sp., *Fenestella* sp., *Polypora* sp., *P. transiens* WAAGEN and PICHL, *Acanthocladia anceps* (SCHLOTHEIM), *Hayasakapora* sp., and *Sulcoretepora* sp.

(2) Member b (Beds 15 to 19, 45.9 m)

Member b is characterized by predominant argillaceous beds and very poor carbonate layers. It is divided into two units by a fossiliferous muddy limestone bed at the middle.

Unit b_1 (Beds 15 to 18, 28.4 m)

The unit is mostly composed of micaceous shale, more or less developed in slaty cleavage, partly finely laminated by sandy intercalation and sometimes strongly bioturbated. Small brachioods are found in a clacareous sandstone (Bed 17) of the middle part, which can be identified as *Waagenoconcha* cf. *abichi* (WAAGEN) and *Echinoconchus?* sp.

Unit b_2 (Beds 19–1, 2, 17.5 m)

The unit begins with a fossiliferous, muddy limestone of 1.5 m in thickness, crowded with brachiopods belonging to *Spiriferella rajah, Costiferina?* sp., and *Leptodus nobilis,* and this horizon is considered to be an equivalent of *Marginifera* bed of MIDDLEMISS, Hor. (5) 26–8–08. A solitary coral, *Euryphyllum cainodon* (KOKEN) has been collected from this horizon. Succeeding strata are composed of micaceous shale and sandy shale very similar to those of Unit b_1. Brachiopods are rare and not identified.

(3) Member c

It consists mostly of shale, sandy shale, and sandstone, divided into three units on the basis of predominant rock type.

Unit c_1 (Bed 20, 8 m)

The unit consists of sandstone and less amount of shale. Lower 5 m is bedded sandstone, micaceous and partly calcareous; above it an impure limestone layer 30 cm thick is intercalated, which contains brachiopods referred probably to *Derbyia,* and productids. Succeeding beds are composed of micaceous sandstone (30 to 50 cm thick) and alternating shale layers (each about 10 cm thick). Cross lamination is common.

Unit c_2 (Bed 21, 12 m)

This is made of micaceous, laminated sandy shale. Bioturbation structures are common in it. Near the top of the unit *Waagenoconcha* sp. and *Costiferina?* sp.

are encountered.

Unit c_3 (Bed 22, 11.8 m)

This is black, micaceous shale similar to that of Member b. No fossils could be detected.

(4) Member d (Bed 23, 9.8 m)

The member is composed of micaceous shale intercalating thin limestone layers of 10 to 20 cm in thickness. The shale is bioturbated at many horizons. *Xenaspis* sp. was obtained from the middle part, and chonetid and palaeotextulariid were from the upper part.

(5) Member e (Beds 24 to 46, 16.0 m)

Member e is characterized by frequent alternations of calcareous sandstone and sandy shale, rarely, sandy limestone, all micaceous and developed in lamination. Fossils are rare. *Dielasma*? cf. *latouchei* DIENER and *Wellerella*? sp. were collected from a horizon at about the upper one-third (Bed 31), and shark teeth referred to *Ctenacanthus ishii* KAPOOR and SAHNI were found from still higher horizon. A swarm of nearly vertical sandpipes (7 to 10 mm in diameter), which suggest a shallow environment, are observed at about 6 m below the top of the member.

4. Khunamuh Formation

The Khunamuh Formation is represented by alternations of limestone, sandy limestone, and shale, lithologically very similar to those of the Guryul ravine section, but owing to the low, hilly topography and soil cover, the shale beds are not well exposed. The limestone is generally more sandy than at Guryul ravine. The formation is divided into three members, f to h, based on the amount of limestone as at Guryul ravine.

(1) Member f (Beds 47 to 100, 27.1 m)

The member is characterized by poorer intercalation of carbonate layers than the other members. It is subdivided into two units, f_1 and f_2, by a little different character of shale.

Unit f_1 (Beds 47 to 54, 6.4 m)

The unit starts with dark gray to black shale lithologically similar to Unit E_1 at Guryul ravine, about 1 m thick. A thin flaggy shale bed 30 cm thick is intercalated in the lower part. MIDDLEMISS's Hor. (4) 26–8–08 is considered to correspond to this bed. Fossils are arranged on the micaceous sandy lamina. *Marginifera* cf. *himalayensis*, "*Productus*" sp., *Claraia bioni*, "*Palaeolima*" *middlemissi*, *Cyrtorostra* aff. *lunwalensis*, and *Etheripecten haydeni* occur from this.

The rest of the unit is composed of flaggy shale intercalating several limestone layers of 10 to 20 cm thick. In its fissile nature, the shale is similar to the lower Triassic flaggy shale of Unit E_2 rather than to that of the underlying "mixed zone" (E_1). Fossils are rather rare; *Claraia bioni, Etheripecten haydeni,* and *Cyrtorostra* aff. *lunwalensis* are found at the middle horizon (Bed 51). Hor. (3 1/2) 26–8–08 of MIDDLEMISS may belong to Bed 52 or 53.

Unit f_2 (Bed 55 to 100, 20.7 m)

It is constituted by alternation of shale and subordinate limestone, of which the former ranges from 10 cm to more than 1 m in thickness, while the latter usually less than 20 cm. *Ophiceras* (*Lytophiceras*) *sakuntala, Glyptophiceras* spp., *Otoceras* aff. *fisselellatum,* and *O.* sp. are limited to lowermost 5 m of the unit (Beds 55 to 61). *Claraia griesbachi, C.* n. sp. indet, *Eumorphotis* cf. *venetiana, E.* aff. *bockarica,* and *E. multiformis* occur from relatively lower part (Beds 58 to 69), while *Claraia concentrica* appears from the higher bed (Bed 76).

(2) Member g

The member is distinguished from Member f in the predominance of limestone. Detailed observation has not been accomplished.

(3) Member h

The member consists of bedded limestone with thin shale parting.

5. Correlation with the Guryul ravine section

The lithofacies of this area somewhat differs from that of Guryul ravine. Generally speaking, the Zewan Formation is much less developed in carbonate layers ex-

Table 7. Correlation of Guryul ravine section and Barus section

	Guryul ravine	Barus	
	Member H		
Khunamuh Formation	Member G	Member h	Lower
	Member F	Member g	Triassic
	Member E	Member f	
	Member D	Member e	
Zewan Formation	Member C	Members c, d	Upper
	Member B	Member b	Permian
	Member A	Member a	
Gangamopteris Beds (Lower Gondwana Beds)			
Panjal Volcanic Rocks			

cepting the lowermost member, and was supplied more terrigenous detritals. The limestone of the lower part of the Khunamuh is also more sandy than that of Guryul ravine.

Member a is undoubtedly compared to Member A at Guryul ravine from lithofacies as well as fossil contents, although carbonate rocks are more calcareous and belong to limestone. Member b is roughly correlated to Member B in predominance of argillaceous sediments and being almost devoid of carbonate rocks. Member c and d are comparable to Member C stratigraphically, but differ from the latter in greater thickness and very poor carbonate layers. Member e and Uint f_1 of Member f are considered to be coeval with Member D and Unit E_1, respectively, based on the similarity of lithology and fossil content.

V. Division and Zonation

Zewan Formation and the lowermost Khunamuh Formation

The lowermost part of the Khunamuh (Unit E_1 at Guryul ravine and Unit f_1 near Barus) is faunistically combined with the underlying Zewan formation, and is considered here together with the latter. As introduced in the previous chapter and shown in the Table 3, several fossil horizons or zones were distinguished in the Zewan by DIENER (1915), GRABAU (1923–24), and GUPTA *et al.* (1971) mainly based on the field investigation of MIDDLEMISS (1909, 1910) and the paleontologic study of DIENER (1898, 1915).

Our insufficient collection shows that *Cleiothyridina* cf. *subexpansa* and *Costiferina indica* are limited to Member B in stratigraphic distribution, while *Lissochonetes morahensis, Waagenoconcha purdoni* and *Marginifera himalayensis* are found only from Unit E_1 of the Khunamuh. However, according to DIENER, *C. indica* occurs in the Lamellibranch zone 3 km north of Barus. *W. purdoni* occurs in the lowermost part of the Zewan Formation at Barus, and *Marginifera himalayensis* from the lower part 3 km north of Barus and Mandakpal. Thus the zoning of the Zewan by brachiopods is difficult. DIENER (1915) pointed out the close affinity of brachopod faunas at various horizons in the Zewan and stated, "All these faunas are evidently very closely related to one another. Faunistically the Zewan beds may safely be considered as a single entity, notwithstanding the possibility of distinguishing several horizons of local stratigraphical value. The importance of the faunistic differences between certain horizons following immediately above one another is always lessened by the stronger resemblance existing between the first and a third or fourth horizon overlying the second." Similarly, GRANT (1973) commented on the brachiopod faunas of the Salt Range, "Considering only the brachiopods, the entire Chhidru Formation and the Kalabagh Member of the Wargal Limestone would be regarded as a faunal unit of essentially one age, that is, of deposition within one age of the Permian." But if we take the faunal assemblages of various taxa into consideration, it is possible to divide the Zewan into three divisions, I to III, in addition to the lowermost Khunamuh, IV, at the Guryul ravine section.

Division I coincides with Member A, characterized by common occurrence of bryozoans and foraminifera along with brachiopods. Member B, though relatively poor in fossils, is referred to Division II. On the other hand, Members C and D differ from the underlying beds in predominance of bivalves and gastropods, and are grouped together as Division III. Unit E_1 of the Khunamuh is linked with the Zewan by occurrence of bivalves and brachiopods common to the latter, but is distinguished therefrom as Division IV in the common occurrence of *Etheripecten haydeni* and the Mesozoic type bivalve, *Claraia bioni*. This corresponds with the Lamellibranch zone of DIENER. In considering the fauna of each division and its correlation it is necessary to examine the faunas of the correlative beds in the other places around Vihi plain, such as Barus, Madakpal, and 3 km north of Barus where the stratigraphy of fossil horizons are clarified by MIDDLEMISS.

1) Division I

This includes Member a or Hor. (1) 27–8–08 of 3 km north of Barus, (1) 4–8–08 and (1) 2–8–08 at Guryul ravine, (1) to (3) 24–8–08 and (2) 22–8–08 at Barus, and (1) and (2) 16–8–08 at Mandakpal. As most of the foraminiferal tests have more or less been destroyed during transportation, and furthermore recrystallized through diagenesis, it is not easy to specifically identify them. The following occurrences are important for age determinations.

Lunucammina cf. *grandis* (LIPINA), *Colaniella* cf. *minima* WANG, *C. cylindrica* M-MAKLAY, *Abadehella coniformis* OKIMURA and ISHII, and *Endothyra miassica* MALAKOVA

The first species was originally reported from the S_3 limestone of Donetz Basin (upper lower Permian), and the last species from the Permian of the eastern slope of the Ural. The most important fossils are *Colaniella* cf. *minima, C. cylindrica,* and *Abadehella coniformis,* because the genus *Colaniella* has a limited distribution ranging from the *Lepidolina kumaensis* zone to the *Palaeofusulina sinensis* zone so far known, and the genus *Abadehella* is also confined to from the *L. multiseptata* zone to the *Palaeofusulina sinensis* zone in Cambodia, Malaysia and Japan (OKIMURA *et al.*, 1975).

It is also noteworthy that the genus *Colaniella* is commonly found in the Wargal Limestone and more rarely in the Chhidru Formation (KUMMEL and TEICHERT, 1970, p. 63).

Among bryozoan species from Guryul ravine and Barus the following should be mentioned:

Acanthocladia anceps SCHLOTHEIM, *Polypora* cf. *transiens* WAAGEN and PICHL, *Dys-*

critella tenuirama CROCKFORD, *D.* cf. *iwaizakiensis* SAKAGAMI, *D. sparsigemmata* (WAAGEN & WENTZEL), *Stenopora? kashmirensis* SAKAGAMI, n. sp., and *Streblascopora fasciculata.*

Dyscritella tenuirama was originally described from the Nookanbah and Liveringa formations (Artinskian to lower Guadalupian) of West Australia, and known also from the Khao Ta Mong Rai Limestone which is considered to be upper Sakmarian to lower Artinskian, and the Ko Kuk Limestone that may be upper Artinskian to Guadalupian, both in peninsular Thailand. *D. iwaizakiensis* occurs from Member h (between *Lepidolina multiseptata shiraiwensis* zone and *L. kumaensis* zone) of the Iwaizaki Limestone in northeast Japan. *Dyscritella sparsigemmata* was recorded throughout the Middle and Upper Productus Limestones of the Salt Range. *Polypora transiens* was reported from the Middle Productus Limestone, and *Acanthocladia anceps* was also recorded from the Middle Productus Limestone and from the Permian in Europe. *Stenopora? kashmirensis* is allied to *S. parvulipora* (BASSLER) from the Amarassi bed of Timor, and recently found in the basal part of the Abadeh Formation in Iran. *Streblascopora fasciculata* was originally described from the Basleo bed of Timor and subsequently from the Kazanian formation (upper Guadalupian) of the Russian Platform and Gnishik horizon of Transcaucasia by SHHISHOVA (1965).

Thus, the bryozoan assemblage cannot indicate the exact age, but it is considered to be allied to that of the Middle Productus Limestone of the Salt Range, Amarassi and Basleo beds of Timor.

Our brachiopod materials are very poor; only *Linoproductus* cf. *lineatus* and *Lissochonetes* cf. *morahensis* are noteworthy, both of which occur in the Middle and Upper Productus Limestones in the Salt Range. DIENER, however, described the following many species from the Vihi region.

Leptodus nobilis (WAAGEN)	
Hemiptychina himalayensis DIENER	L–U Productus
Costiferina indica (WAAGEN)	M–U Productus
Cancrinella cancrini (VERNEUIL)	
C. cancriniformis (TSHERNYSCHEW)	Sak.–Art., Loping
Waagenoconcha abichi (WAAGEN)	M–U Productus, Loping, Amarassi
W. gangeticus (DIENER)	Productus Sh.
Spiriferellina cristata fastigata SCHELLW.	L–U Productus, Loping
S. vercherei (WAAGEN)	U? Productus
Spirigerella extra (DIENER)	
Stenoscisma purdoni (DAVIDSON)	M. Productus, Amarassi
Whitspakia biplex WAAGEN	M. Productus
Cleiothyridina royssi (DAVIDSON)	M–U Productus
Haydenella vihiana (DIENER)	
Dictyoclostus? (=*Alexenia?*) *gratiosus* (W.)	M–U Productus

Marginifera himalayensis DIENER	Productus Sh., Amarassi
Spinomarginifera spinosocostata ABICH	Khachik-Dzhulfian

The list clearly indicates a close similarity of the brachiopod fauna of this division with that of the Middle to Upper Productus Limestones, and some alliance to that of the Loping of China, Amarassi in Timor and Productus or Kuling Shales in central Himalaya. *Stenoscisma purdoni* and *Whitspakia biplex* are confined to the Middle Productus Limestone, and there is no species limited in range to the Upper Productus. So, Division I is correlated to the Middle Productus, especially its upper part (Kalabagh Member of Wargal Formation), rather than to the Upper Productus.

2) Division II

Division II is rather poor in fossils, aside from brachiopods. Hor. (1) 10–10–09 at Guryul ravine, (5) 26–8–08 3 km north of Barus, and (2) 14–8–08 at Mandakpal are contained in this division. Among our collections the following species are identified.

Linoproductus cf. *lineatus* (WAAGEN)	L–U Productus
Cleiothyridina cf. *subexpansa* (WAAGEN)	M–U Productus
Costiferina indica (WAAGEN)	M–U Productus
Spiriferella rajah (SALTER)	Productus and Kuling Sh., Amarassi
Waagenoconcha cf. *abichi* (WAAGEN)	M–U Productus, Loping

DIENER reported the following species in addition to these species.

Waagenoconcha gangetica (DIENER)	Productus & Kuling Sh.
Linoproductus waagenianus (GIRTY) (=*Anidanthus*? *fusiformis* WAAGEN)	
Chonetes? *lissarensis* DIENER	Productus & Kluing Sh.
Neospirifer fasciger (KEYSER)	
Spiriferellina cristata fastigata SCHELLW.	
Spiriferella zewanensis (DIENER)	
Callispirina ornata (WAAGEN)	U. Productus
Fusispirifer nitiensis (DIENER)	Productus & Kuling Sh.
Marginifera himalayensis DIENER	Productus & Kuling Sh.
Stenoscisma purdoni (DAVIDSON)	M–U Productus, Amarassi
Dielasma latouchi DIENER	Productus & Kuling Sh.
Leptodus nobilis (WAAGEN)	M–U Productus,
Cancrinella aff. *cancrini* (VERN)	
Chonetes? *vishnu* SALTER	Productus Sh.
Cleiothyridina subexpansa (WAAGEN)	L–U Productus
Costiferina spiralis WAAGEN	L. Productus

A bivalve, *Aviculopecten* (=*Etheripecten*?) cf. *hiemalis* SALTER originally described from the Productus Shales, occurs in this division at Guryul ravine.

The brachiopod fauna strongly resembles that of the Middle and Upper Productus Limestones and the Productus or Kuling Shales as well. A solitary coral collected from the middle part of Member b (Bed 19) 3 km north of Barus is determined as *Euryphyllum cainodon* (KOKER). This species was first described from Basleo (probably the Basleo stage) by KOKER (1924), then by WANG (1947), and SCHOUPPE & STACUL (1959) also from Timor. The species is dubiously recorded from Cambodia by FONTAINE (1961). ISHII *et al.* (1969) reported the species from Sisophon C (*Sumatrina longissima-Lepidolina multiseptata* zone) in Cambodia.

3) Division III

Division III includes Members C and D at Guryul ravine and Members c and d 3 km north of Barus. The following fossil horizons of MIDDLEMISS are contained in this Division; (1) 23–8–08 at Barus, (0) to (2) 2–10–09 at Mandakpal.

The foraminiferal assemblage of this division is quite distinct from that of Division I. It is represented by a simple fauna consisting of a few genera; only *Glomospira, Nodosinella, Lunucammina,* and *Globivalvulina* have been discriminated. They are all characterized by a uniserial arrangement of the chambers. On the other hand, the fauna of Division I contains foraminifera of various shell-forms which belong to ten genera. This may correspond to the environmental change between the two divisions. Such a change of assemblage is similar to that between the lower and upper Dzhulfian in Transcaucasia (M-MAKLAY, 1954). Among rather simple foraminifera, two species are considered to be useful for correlation. *Lunucammina postcarbonica* (SPANDEL) is a rather long-ranging species reported from the "Permo-Carboniferous" formations of Europe, southeast Asia, Australia, and U. S. A. It also occurs in the *Bellerophon* limestone of Turkey and the *Palaeofusulina* aff. *sinensis* zone in Japan. *Glovivalvulina cyprica* occurs in the Permian of Cyprus in association with species of *Hemigordiopsis, Climacammina, Trochammica, Calcivertella, Neoschwagerina craticulifera,* etc. (Erk, 1941), and from the Pamirian in Pamir accompanied with *Palaeofusulina pamirica,* etc. (LEVEN, 1967). So, it is difficult to estimate an accurate age of this division by foraminifera.

Specifically determined bryozoans are *Hayasakapora grossa* SAKAGAMI, n. sp., *Dyscritella tenuirama* CROCKFORD, and *Stenodiscus* cf. *chaetetiformis* (WAAGEN and WENTZEL). *D. tenuirama* is common to Division I and occurs throughout the Middle and Upper Productus Limestones. *S. chaetetiformis* is known from the Upper Productus. The new species, *H. grossa* is similar to *H. gracilis* MOROZOA from the Osakhtinsky horizon of Siberia, that was considered to be Guadalupian. Judging from the bryozoan assemblage, the division may be correlated to the Upper Productus Limestone in the Salt Range.

Brachiopods are subordinate here in comparison with the lower divisions. The following species have been collected by us and former workers.

Linoproductus cf. *lineatus* (W.)	L–U Productus
Lissochonetes bipartita (W.)	M–U Productus
Waagenoconcha abichi (W.)	M–U Productus, Loping, Amarassi
W. gangetica (W.)	Productus & Kuling Sh.
Cancrinella aff. *cancrini* (VERN.)	
Chonetes? cf. *vishnu* SALTER	Productus & Kuling Sh.
Spiriferella rajah (SALTER)	Productus & Kuling Sh., Amarassi
Neospirifer fasciger (KEYS.)	

The fauna is almost identical with that of the preceeding division, but contains more Himalayan species.

Among five species of gastropods, two are specifically identified, that is, *Bellerophon* (*B.*) *branfordianus* WAAGEN and *Retispira ornatissima* W., both Upper Productus species.

Bivalves are common, but none can be strictly identified species. Many of the comparable species are from the Upper Productus Limestone, such as *Permophorus* cf. *subovalis, Schizodus? rotundatus,* and "*Loripes*" *cf. atavus. Cyrtorostra lunwalensis* are common in the Middle Productus but rare in the Upper Productus.

Cyclolobus walkeri DIENER was originally described from an exotic block in Tibet (Chichitin I). The species is known from the upper Chhidru, upper Kuling Shales and the Ankitohazo beds of Madagascar (FURNISH *et al.*, 1973). *Xenaspis* cf. *carbonarius* is another ammonoid from this division. *X. carbonarius* ranges from the Karabagh to the upper Chhidru. Judged by the ammonoids this division is correlated with the Upper Productus Limestone (Chhidru Formation), probably its upper part.

Conodonts are obtained from two horizons, the uppermost horizon of Member C (Bed 31) and the upper third of Member D (Bed 43). They are identified as *Anchignathodus typicalis* SWEET and *Neogondolella carinata* (CLARK). SWEET (1969) reported *A. typicalis, Ellisonia teicherti* SWEET, and *E. triassica* MÜLLER from his sample no. K 28. From his figure, we judge that the horizon roughly corresponds to Bed 40, that is, several meters below Bed 43. All these conodonts range into the lower Scythian bridging the Permian-Triassic boundary (SWEET, 1973). The conodont fossils mentioned above indicate that the Division III is comparable to the uppermost Chhidru, and the upper Abadehian? to Dzhulfian in Iran as will be discussed later.

4) Division IV

Division IV corresponds to the "mixed zone" of the preliminary report (NAKAZAWA *et al.*, 1970) or Brachiopod and Lamellibranch beds of MIDDLEMISS (=Lamellibranch zone of DIENER) at the locality 3 km north of Barus. At Guryul ravine it is only 2.6 m thick. At the Barus locality the fossiliferous part is about 3 m, but there is an unfossiliferous part of 2.6 m in thickness between this part and the base of the *Otoceras-Glyptophiceras* beds. A limestone (Bed 52 b) about 1.3 m below the *Otoceras-Gyptophiceras* horizon has a turbidite texture very similar to that of the Lower Triassic limestones at Guryul ravine and may belong to the Lower Triassic. So that, the Permian-Triassic boundary may be slightly lower than this limestone.

The fauna of this division as a whole is similar to that of the preceeding one, but the marked difference is in the paucity of foraminifera and bryozoans, and in common occurrence of *Claraia*. Only one species of foraminifera, *Nodosienella longissima* M-MAKLAY and an indeterminable bryozoan were found. *N. longissima* was reported from the Kazanian of Russian platform.

Brachiopods are common, and the following are noted.

Linoproductus cf. *lineatus* (WAAGEN)	L–U Productus
Lissochonetes morahensis (W.)	M–U Productus
Waagenoconcha purdoni (W.)	M–U Productus
Marginifera himalayensis DIENER	Productus & Kuling Sh.

In addition, Diener described the following species.

Linoproductus cora (d'ORB.)	
Costiferina indica (W.)	M–U Productus
C. spiralis W.	L Productus
Spinomarginifera cf. *helica* (ABICH)	Dzhulfian, upper Nesen
Waagenoconcha abichi (W.)	M–U Productus
W. gangetica (DIENER)	Productus & Kuling Sh.
Chonetes lissarensis D.	Productus & Kuling Sh.
Chonetes? aff. *variolata* d'ORB.	

These brachiopods do not differ essentially from those of the underlying divisions and the presence of Dhzulfian species is noteworthy.

Among bivalves, four species are abundant; such as *Cyrtorostra* aff. *lunwalensis* (REED), "*Palaeolima*" *middlemissi* NAKAZAWA, n. sp., *Etheripecten haydeni* NAKAZAWA, n. sp., and *Claraia bioni* NAKAZAWA, n. sp. The first two species survived from the underlying strata, and questionable *E. haydeni* also occurs in the lower horizon. *C. bioni* is very similar to the Lower Scythian *C. stachei* BITTNER in outline and ornament and was formerly identified with that species. It slightly differs from the latter in less convex left valve and consequently in less inequivavle shell and is considered to be an ancestral form of *stachei*. In addition to these forms, DIENER reported *Permophorus* aff. *complanatus* (WAAGEN), *Schizodus* cf. *rotundatus* BROWN, and *Eumicrotis* sp. aff. *radialis* PHILL. The first two are allied to the species from the upper Chhidru. These bivalves strongly suggests that the division is correlated with the upper Chhidru.

Xenaspis cf. *carbonarius* described by DIENER probably is not identical with *carbonarius*. It was compared to *Glyptophiceras* by FURNISH *et al.* (1973) which has

Table 8. Range chart of fossils from Zewan Formation and lowermost Khunamuh (E_1)

	ZEWAN FORMATION																			KH.				
	A_1		A_2			A_3	B	C					D							E_1				
	14	15	17	18	19	20	23	27	28	29	30	31	33	34	38	40	43	45	46	47	48	49	50	51
FORAMINIFERA																								
Colaniella cylindrica					*																			
C. cf. *minima*					*	*																		
C. sp.				*	-	*																		
Abadehella coniformis			*	—	*	*																		
Agathammina sp.	*	—	?	*	?																			
Permodiscus sp.	*	—	—	—	*																			
Hemigordius sp.	*																							
Endothyra cf. *miassica*						*																		
Pachyphloia spp.						?																		
Palaeotextulariid	*																							
Ammonidiscus sp.			*	—	—	*																		
Nodosinella longissima																				*				
N. spp.	?	-	-	*	*	*	*	-	*	*	*	*	?	?		?								
Lunucammina cf. *grandis*					*																			
L. postcarbonica																		*						
L. spp.	*	*	*	*	*	*																		
Globivalvulina cf. *cyprica*									*	—	—	—	—	—	—	—	—	*						
G. sp.									*	*	—	—	—	—	—	—	—	*						
Staffella sp.	*																							
Glomospira spp.		*	*	?	-	*	-	-	-	*	-	-	-	-	?	-	-	?						
BRYOZOA																								
Stenopora sp.																	*							
Stenopora? kashmirensis, n. sp.	*	*	—	*	—	*																		
Pseudobatostomella?	*																							
Streblascopora cf. *fasciculata*				*																				
Polypora transiens sp.					*																			
Acanthocladia anceps						*																		
Synocladia? sp.						*																		
Fistulipora sp.		*	—	—	—	*	—	—	—	—	—	—	—	—	—	—	—	*						
Fenestellid	*	*	-	*	-	-	-	-	-	-	*													
Dyscritella tenuirama	*	*	—	—	—	*												*						
D. sp.											*	*	-	-	-	-	*							
Stenodiscus cf. *chaetetifomis*																	*							
Hayasakapora grossa, n. sp.																	*	*						
BRACHIOPODA																								
Chonetina? sp.		*																						
Athyris? sp.					*																			
Cleiothyridina cf. *subexpansa*							*																	
Martinia sp.					*																			
Linoproductus cf. *lineatus*					*	—	*	—	—	—	—	—	—	—	—	—	*	—	—	—	*	*		
Lissochonetes morahensis																					*	*		
L. cf. *morahensis*						*																		
L. bipartita											*													
Costiferina indica							*																	
Echinoconchus?							*																	
Dielasma? sp.											*	—	—	—	—	—	*	—	—	—	—	*		
Waagenoconcha purdoni																						*	*	
W. sp.													*	—	—	—	—	—	*					
Neospirifer sp.																					*			
Schellwienella sp.																							*	
Marginifera himalayensis																				*	*	*	*	—
Dictyoclostid?																					*			
Derbyia sp.																							*	
Pustula sp.																						*		
GASTROPODA																								
Bellerophon (B.) branfordianus												*	—	—	—	—	*							
B. (B.) cf. *branfordianus*									*	—	—	—	—	—	*	—	*	*						
B. (B.) sp.									*	—	—	—	—	—	*	—	*	*						
Retispira ornatissima																	*							
R. cf. *kattaensis*																	*							
Pagodina? sp.																					*			

BIVALVIA							
Nuculopsis? sp. *a*							*
N.? sp. *b*					*		
Phestia					*		
Palaeoneilo sp. *a*						*	
P. cf. *b*							*
Aviculopecten? n. sp. ind.					*——	*	
"*Streblochondria*" sp.					*——	——*—*	
"*Palaeolima*" *middlemissi*, n. sp.					*——*	*——*—*——	*—*
Permophorus cf. *subovalis*					*	——*	
Etheripecten haydeni, n. sp.							*—*—*——
E. aff. *haydeni*						*	
E. aff. *hiemalis*						*——	——*
Cyrtorostra aff. *lunwalensis*						*——	*—*—*
"*Loripes*" *atavus*						*	
Schizodus? sp.						*	
Claraia bioni, n. sp.							*—*—*—*
SCAPHOPODA							
Plagioglypta sp.					*	——*	
AMMONOIDEA							
Xenaspis sp.					*	——*	
Cyclolobus walkeri					*		
CONODONTOPHORIDA							
Anchignathodus typicalis					*	————	——?——
Neogondolella carinata					*	——*——	*——
Ellisonia triassica						*——	*
SHARK TOOTH							
Ctenacanthus ishii						* *	

hitherto been considered to be confined to Eo-Triassic in age.

Conodonts are scarce, and found only from the basal part (Bed 47). They are represented by *Neogondolella carinata* and *Ellisonia triassica,* both continue into the Lower Triassic.

5) Correlation with the Salt Range and Central Himalayas

The result of our correlation based on the various taxa is shown in Table 8. Division I is correlated with the Upper Wargal (Kalabagh). It is not clear whether Division II is comparable to the Kalabagh or Chhidru based on brachiopods, but tentatively correlated to the Kalabagh taking the occurrence of *Euryhyllum cainodon* into consideration. Division III is undoubtedly coeval with the Chhidru, and IV may correspond to the uppermost Chhidru or later. Divisions II to IV are as a whole correlated with the Productus Shales or the Kuling Shales of central Himalayas, and GRANT and COOPER's opinion (1973) that the Productus Shales are absent at Guryul ravine cannot be accepted. The international correlation will be discussed in the later section in connection with the Lower Triassic.

Khunamuh Formation

The Khunamuh Formation excepting Unit E_1 is rich in ammonoids, bivalves, and conodonts, and can be classified based on these fossils (Table 11).

Table 9. Range chart of fossils from Khunamuh Formation (E_2-H)

	KHUNAMUH FORMATION																											
	E1	E2							E3										F					G		H		
		52	53	55	56	58	59	60	61	62	63	64	65	66	67	68	69	70	71	73	74	75	76	80	82	88	89	90
FORAMINIFERA																												
Glomospiranella shengi											*																	
Rotaliid		*								*																		
BRACHIOPODA																												
Marginifera himalayensis	—	*																										
Pustula sp.	—	*																										
GASTROPODA																												
Warthia hisakatsui, n. sp.		*																										
BIVALVIA																												
Etheripecten haydeni, n. sp.	—	*																										
Claraia bioni, n. sp.	—	*?																										
C. dieneri, n. sp.							*																					
C. aff. *extrema*										*																		
C. cf. *griesbachi*								*	*																			
C. concentrica														*	*	*												
C. n. sp. ind. *a*																												
C. decidens																										*		
C. *b*																												
Eumorphotis venetiana		*	—	—	—	*	?	*	*																			
E. aff. *bokharica*		*	—	—	—	*	—	—	*																			
E. multiformis									*	*																		
Leptochondria minima		*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	*	—	—	—	*	—	—	—	*		
Pteria aff. *ussurica yabei*									*																			
Promyalina sp.			*																									
CEPHALOPODA																												
Otoceras woodwardi		*	—	—	—	*																						
O. sp.		*	- -	- -	- -	*																						
Ophiceras (O.) tibeticum												*																
O. (O.) serpentinum												*																
O. (Lytophiceras) sakuntala		*																										
O. (L.) demissum												*																
Ophiceras spp.									*	- -	- -	- -	- -	- -	- -	- -	- -	*										
Glyptophiceras himalayanum		*																										
G. lissarenum		*																										
G. subdemissum												*																
G. sp.		*																										
Vishnuites cf. *pralambha*																							*					
V. sp.																							*					
Kyamites sp.				*				*																				
Proptychites sp.					*																				*			
Paranorites kummeli, n. sp.																						*	*					
Koninckites sp.																					*	*	—	—	*	*		
Owenites koeneni																										*		
Kashmirites subarmatus																										*		
K. brashkei																										*		
K. sp.																										*		
Prionites aff. *undatus*																								*				
Olenekites? sp.																								*				
Clypeoceras sp.																					*							
Wasatchites sp.																										*		
Meekoceras gracilitatus																										*		
M. jolinkense																										*	—	*
Anakashmirites cf. *kapila*																												*
Meekoceras sp.																												*
CONODONTOPHORIDA																												
Anchignathodus typicalis	—	*	—	*	*																							
Neogondolella carinata	—	*	—	*	*	*	—	—	—	*	—	*																
Neospathodus cristagalli												*	—	—	—	—	—	—	—	*	*							
N. waageni																										*	*	*
SHARK TOOTH																												
Helicampodus sp.				(*)																								

Table 10. Correlation of the Zewan Formation by various taxa

	I	II	III	IV
Foraminifera	*Lepidolina kumaensis Zone,* Wuchiapingian, Lowermost Abadeh			
Bryozoa	Amarassi-Basleo, Kalabagh		Chhidru	
Brachipoda	Kalabagh	Kalabagh-Chhidru, Productus & Kuling Shales, Amarassi	(Kalabagh)-Chhidru, Productus & Kuling Shales, Amarassi	(Kalabagh)-Chhidru, Productus & Kuling Shales
Gastropoda			Chhidru	
Bivalvia			Upper Chhidru	Upper Chhidru or later
Ammonoidea			(Kalabagh)-Chhidru	post-Chhidru?
Anthozoa		*Lepidolina multiseptata* Zone, Basleo		
Conodont			Upper Abadeh to Dzhulfian, Uppermost Chhidru	

a) Ammonoid zone

Five ammonoid zones are distinguished in the Khunamuh Formation at Guryul ravine, that is, *Otoceras-Glyptophiceras, Ophiceras, Paranorites-Vishnuites, Prionites-Koninckites,* and *Owenites-Kashmirites* zones, in ascending order.

Otoceras-Glyptophiceras zone

The strata from Bed 52 to 58 roughly corresponding to Unit E_2 are characterized by species of *Otoceras* and *Glyptophiceras*: such as *O. woodwardi, G. himalayanum* and *G. lissarenum. O. clivei* and *O. draupadi* formerly reported from this part (NAKAZAWA *et al.*, 1970) are treated here as synonyms of *O. woodwardi. Ophiceras* (*Lytophiceras*) *sakuntala, Proptychites* sp., and *Kyamites* sp. are also found, but *Ophiceras* s. s. is absent. This zone is referred to the lower Otoceraton of SPATH or the lower Griesbachian of TOZER. Species of *Claraia* and *Eumorphotis* are common, and a bellerophonid, *Warthia hisakastui* MURATA, n. sp. is abundant in the lowermost *Otoceras* limestone.

Ophiceras zone

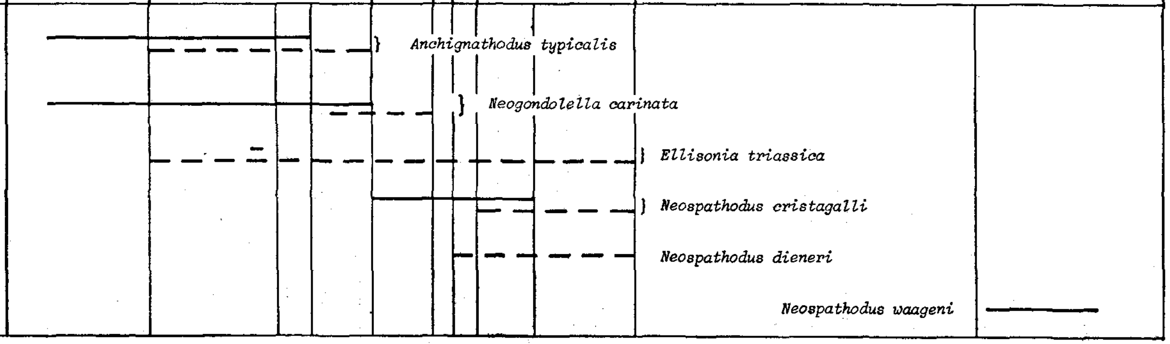
Ophiceras s. s. ranges in vertical distribution from Bed 61 to 76, and a part from Bed 61 to 70 is represented exclusively by *Ophiceras,* and this part is named as the

Table 11.

-20 -10 0 10 20 30 40 50 60 70 80 m

Formation	ZEWAN		KHUNAMUH							
Bed no.	31	46	70		76		86			
Member	C	D	E_1	E_2	E_3	F	G			H
Ammonoid zone	*Cyclolobus* ×		*O-G*		*Ophiceras*		*P-V*		*Prionites-Koninckites*	*Owenites-Kashmirites*
Bivalve zone		*Cb*	*Eu*	*C-E*		*Cc*	*Leptochondria minima*			*Claraia decidens*
Conodont zone: Compiled		*Anchignathodus typicalis*		*Nc*	*Neospathodus cristagalli*					*Neospathodus waageni*
Conodont zone: Present paper		*Anchignathodus typicalis*		*Nc*	*Neospathodus cristagalli*					*Neospathodus waageni*
Conodont zone: SWEET (1970)		*Anchignathodus typicalis*		*Nc*		*d*	*Neospathodus cristagalli*			

Range chart of conodonts (solid line; this paper, broken line; SWEET,1970)



O-G: Otoceras-Glyptophiceras, P-V: Paranorites-Vishnuites, Cb; Claraia bioni, C-E: Claraia cf. *griesbachi-Eumorphotis multiformis, Cc: Claraia concentrica, Nc: Neogondolella carinata,*

d: Neospathodus dieneri

Ophiceras zone. This zone coincides with Unit E_3. *O. subdemissum*, *O. tibeticum* and *O. serpentinum* occur at a middle horizon of this zone (Bed 64). *Claraia* and *Eumorphotis* are common bivalves. A foraminifera obtained from Bed 62 is identical with *Gromospiranella shengi* Ho reported from the Middle to Upper Triassic Chialingchin limestone in China. The *Ophiceras* zone is referred to the upper Otoceratan or the lower part of the upper Griesbachian.

Paranorites-Vishnuites zone

The upper part of Member F (Beds 75 to 76) is marked by the occurrence of *Paranorites kummeli* BANDO, n. sp. and *Vishnuites* cf. *pralambha*. Indeterminable species of *Ophiceras* and *Koninckites* are also contained. *Leptochondria minima* occurs crowded at several horizons, but *Claraia* was not found. This zone corresponds to upper Gyronitan to Flemingitan? of SPATH or Dienerian of TOZER. The unfossiliferous lower part of Member F may belong to the lower Gyronitan or the upper part of the upper Griesbachian.

Prionites-Konickites zone

The cliff-forming limestone included in Member G is poor in fossils; only *Prionites* aff. *undatus* WAAGEN and *Olenekites*? sp. are obtained from a horizon about 12 m above the base (Bed 80), and *Koninckites* sp. at about 23 m above the base (Bed 82). This ammonite-bearing part is tentatively assigned to the *Prionites-Koninckites* zone. It may belong to Owenitan or Smithian.

Owenites-Kashmirites zone

The alternation of limestone and subordinate shale above the cliff (Beds 87 to 90) called the *Meekoceras* beds by MIDDLEMISS yields many specimens of ammonoids. The following species were identified here:

Flemingites cf. *muthensis* KRAFFT, *F.* sp., *Koninckites* cf. *yudishthira* DIENER, *Owenites koeneni* HYATT & SMITH, *Kashmirites subarmatus* DIENER, *K. braschkei* DIENER, *Meekoceras* cf. *jolikense* KRAFFT & DIENER, *Anakashmirites* cf. *kapila* (D.), and *Wasatchites* sp.

In addition to these, DIENER (1913) described the following species: *Aspidites* sp., *Pseudosageceras* sp., *Prionites guryulensis* DIENER, *Sibirites kashmiricus* D., *Stephanites* aff. *superbo* WAAGEN, etc.

As indicated by SPATH (1934) this fauna represents the Owenitan, probably its upper part.

b) Bivalve zone

Based on the bivalves, represented mainly by species of *Claraia* and *Eumorphotis*, six assemblage zones can be distinguished in the Khunamuh Formation; *Claraia* *bioni-Etheripecten haydeni, Eumorphotis venetiana-E.* aff. *bokharica, Claraia* cf. *griesbachi-E. multiformis, C. concentrica, Leptochondria minima,* and *C. decidens.*

Claraia bioni-Etheripecten haydeni zone

The lowermost Unit E_1 of the Khunamuh is characterized by *Claraia bioni, Etheripedten haydeni, "Palaeolima" middlemissi* and *Cyrtorostra* aff. *lunwalensis.* Excepting for the first species all are known Permian genera and species.

Eumorphotis venetiana-E. aff. *bokharica* zone

Two species of *Eumorphotis, venetiana* and aff. *bokharica,* occur from Bed 52 of Unit E_2 up to Bed 61 of Unit E_3. *Claraia bioni, Etheripecten haydeni* and *Pustula* sp. were discovered from Bed 52, but they are represented by only one or two, fragmentary specimens, and it is not certain whether they really existed or were derived secondarily. Excepting these fossils, a part from Bed 52 to 58, that corresponds to the *Otoceras-Glyptophiceras* zone, has no *Claraia* and is marked by common occurrence of *Eumorphotis venetiana* and *E.* aff. *bokharica* with a few *Leptochondria minima.* This part is assigned to *E. venetiana-E.* aff. *bokharica* zone. One specimens probably belonging to *Promyalina* was collected from Bed 53.

Claraia cf. *griesbachi-Eumorphotis multiformis* zone

A part from Bed 59 to 62, that is, the upper part of Unit E_2 and the lowermost part of Unit E_3 are common in various kinds of *Eumorphotis* and *Claraia,* such as *E. venetiana, E.* aff. *bokharica, E. multiformis, Claraia* cf. *griesbachi, C. dieneri* NAKAZAWA, n. sp., *C.* aff. *extrema* SPATH, and *C.* sp. b. A specimen referable to *Pteria* aff. *ussurica yabei* NAKAZAWA was obtained from Bed 61.

Claraia concentrica zone

The upper part of Unit E_3 (Beds 66–68) is rich in *Claraia concentrica* YABE, but no other bivalves were found. This part can be separated from the others as *C. concentrica* zone.

Leptochondria minima zone

The top of Unit E_3 and Member F are both poor in bivalves. Only *Leptochondria minima* is crowded in Bed 70 (top of Unit E_3) and Bed 75 (upper part of Member F), and this part is tentatively defined as *L. minima* zone.

Claraia decidens zone

The lower part of Member H corresponding to the *Owenites-Kashmirites* zone locally yields abundant specimens of *Claraia decidens* accompanied by *Leptochondria minima,* and is termed *C. decidens* zone.

c) Conodont zone

Examining the collection of TEICHERT and KUMMEL from the Guryul ravine section, SWEET (1970) established four conodont zones, *Anchignathodus typicalis, Neogondolella carinata, N. dieneri,* and *Neospathodus cristagalli.* The stratigraphic distribution in our section is shown in Table 11. Our collections were studied by NOGAMI and MURATA. Conodonts are extremely rare in the Zewan Formation, but suddenly they become abundant in the *Otoceras* horizon. In the present study, *Neogondolella nevadensis* (CLARK), *N. planata* (CLARK) and *N. elongata* are included in *N. carinata* (Clark), and *Neospthodus dieneri* (HUCKRIEDE) and *N. pakistanensis* SWEET are included in *N. cristagalli.* Besides tabulated species, those belonging to *Hindeodella, Lonchodina,* and *Prioniodina* were also extracted, but excluded from zonal consideration because of their low biostratigraphic value. As the horizontal variation of conodont assemblages is great, even in a single bed probably due to transportation by turbidity currents, the species represented by only a few individuals are omitted in zoning the Khunamuh Formation. From our own data, four conodont assemblage zones can be established in the Khunamuh: *Anchignathodus typicalis, Neogondolella carinata, Neospathodus cristagalli,* and *N. waageni* zones, in ascending order. The first assemblage appears in Bed 31 of Member C of the Zewan, about 20 m below the top of the formation, and straddles the Permian-Triassic boundary as in the Salt Range and Iran (SWEET, 1973). This zone nearly corresponds to the *Otoceras-Glyptophiceras* zone in the Khunamuh. The *N. carinata* zone ranges from Bed 58 to Bed 64 where *Neospathodus cristagalli* first appears. The *Neospathodus cristagalli* zone includes Beds 65 to 74. The *Owenites-Kashmirites* zone is common in *N. waageni* and this zone agrees with the *N. waageni* zone. Comparing the range of conodont species of our collection with that of SWEET, it does not coincide with each other. It is uncertain whether this is resulted from insufficient collections of conodonts or different measurings of sampling horizons. However, the zonal sequences are identical with each other. The compiled zonation of the two is shown in Table 11 for comparison.

From our own data, the highest horizon of *Anchignathodus typicalis* is within the *Otoceras-Glyptophiceras* zone and *Neogondolella carinata* is within the *Ophiceras* zone. It is replaced by *Neospathodus cristagalli* who in turn is succeeded by *N. waageni.* Comparison of zonations by ammonoids, bivalves, and conodonts are indicated in the same table.

VI. Correlation and the Permian-Triassic Boundary

Zewan Formation

There are many conflicting opinions concerning the age and correlation of the Kalabagh-Chhidru of the Salt Range and the Zewan in Kashmir. Some pioneer workers believed in the conformable succession from the Chhidru to the Lower Triassic without hiatus (NOETLING, 1901; 1905). SCHINDEWOLF (1954) was also of the same opinion, and advanced a catastrophic theory to explain the sharp faunal change between the two systems. In this case, the Chhidru represents the latest part of the Permian. On the other hand, not a few authors postulated a hiatus between the Chhidru and the Lower Triassic of uncertain magnitude (WAAGEN, 1895; GRABAU, 1931). SPATH (1934), who referred the Chhidru ammonoids to be older than those of Dzhulfa, proposed the two stage names in the Neo-Permian; Xenaspian for the Chhidru and Prototoceratan for the Dzhulfa. Similarly, SCHENK *et al.* (1941) named these as Panjabian and Dzhulfian, and FURNISH (1966) as Chhidruan and Dzhulfian. The Dzhulfian, in these proposals, is characterized by araxoceratid ammonoids.

RUZHENTSEV and SARYCHEVA (1965) referred the beds ranging from "*Tompophiceras*" bed to the *Paratirolites* bed that overlie the Dzhulfian beds as Induan, that is, the lower half of the Lower Triassic. But the Early Triassic age was subsequently questioned by many authors. CHAO (1965) distinguished two ammonoid zones in the Lopingian of China, the lower *Prototoceras-Araxoceras* and the upper "*Pseudotirolites*"-"*Pleuronodoceras*" zones, and pointed out the possibility that the upper ammonoid zone (Changhsingian) is correlated with the "Induan" in Dzhulfa, and that this zone is lacking in the Salt Range. His correlation was recently confirmed by the discovery of "*Pleuronodoceras*", *Pseudogastrioceras*, "*Pseudostephanites*" and "*Pseudotirolites*" from the equivalent beds (Ali-Bashi Formation) in Iranian Julfa (TEICHERT *et al.*, 1973). The Permian age of these beds was also proved by a discovery of *Ophiceras* (*Lytophiceras*) cf. *sakuntala* and *O.* (*Metophiceras*) *subdemissum* from the overlying *Claraia* beds by ROSTOVTSEV and AZARIAN (1973) who proposed a new stage name, Dorashamian for the *Phisonites-Comelicania* to the *Paratirolites* beds.

FURNISH and GLENISTER (1970) used the Dzhulfian as the post-Guadalupian Series name, and divided it into three stages, Araksian, Chhidruan, and Changhsingian, in ascending order. Their Changhsingian roughly corresponds to the Dorashamian, and according to them, the Chhidruan is younger than the Araksian (Dzhulfian of many authors). All these authors mentioned above referred to the Chhidru beds as post-Guadalupian in age. On the contrary, GRANT (1970), GRANT and COOPER (1973), and WATERHOUSE (1972a, b) strongly insisted on the Guadalupian age of the Kalabagh-Chhidru mainly based on the brachiopods. KUMMEL and TEICHERT (1970) who confirmed a disconformity between the Chhidru and the overlying Kathwai, criticised GRANT's opinion and supported FURNISH and GLENISTER's view that only the Dorashamian is missing in the Pakistan section. Very recently TEICHERT *et al.* (1973) expressed the opinion that the uppermost 12 feet of the Chhidru characterized by *Neogondolella carinata carinata* represents the Changhsingian.

The same problem also applies to the Zewan, because it is certain that the

Zewan is the correlative of the Kalabagh-Chhidru, as already discussed.

WATERHOUSE (1972 a) distinguished six Permian faunal horizons or stages above the Chhidru, namely Kathwaian, Baisalian, Vedian, Waiitian, Ogbinan, and Makarewan. The Baisalian includes three Dzhulfian zones (*Araxilevis, Araxoceras-Oldhamina,* and *Vedioceras-Haydenella*). The Vedian corresponds to the *Comelicania-Phisonites* zone, only 4.5 m thick in the type area, which represents the top-Dzhulfian according to RUZHENTSEV and SARYCHEVA but is referred to the base of the Dorashamian by ROSTOVTSEV and AZARIAN. The Ogbinan contains the "*Tompophiceras*" to the *Paratirolites* beds that are almost an equivalent of the Dorashamian. The Waiitian and Makarewan are established in New Zealand, but the relationship with stages in other areas is quite uncertain. Subsequently, he (1973) tentatively correlated the Waiitian to the Vedian, the upper Kathwai to the Baisalian, and the Makarewan to the Dienerian which is referred to be latest Permian of his definition. According to his new interpretation, therefore, there is no marked gap between the Chhidru and the Kathwai, but several stages are missing between the Kathwai and the Mittiwali Member (=Ceratite beds of WAAGEN) of the Mianwali Formation in West Pakistan. This is based on the implication that the Chhidru is Guadalupian and the Kathwai is "Abadehian"-Baisalian.

It should be mentioned that the correlation between the Kalabagh-Chhidru and the type Guadalupian is mainly based on the similarity of generic composition of brachiopods (GRANT, 1970; GRANT and COOPER, 1973), or indirect comparison through Amarassi, Basleo or Sisophon fanunas (WATERHOUSE, 1972 a). But the generic composition may reflect other factors, such as paleobiogeography and paleoenvironment. GRANT and COOPER's dendrodiagrams clearly show that the United States and the Indian subcontinent belong to the different paleogeographic provinces, and are therefore difficult to correlate (KUMMEL and TEICHERT, 1970). Examination of common species is considered to offer more reliable criteria for correlation in the same or neighboring paleogeographic province, and the comparison by means of common species of various taxa will be examined in the followings.

1) Brachiopods

It is remarkable that the common brachiopod species between the Kalabagh-Chhidru and the Lopingian attain to more than twenty species, while those common to the Maokouan are less than five as based on the HUANG's (1933) monograph on the Permian brachiopods. Although the Lopingian fauna requires re-description and the horizons are also to be re-examined, the similarity of the two faunas is worthy of note. Recently, ZHANG and CHIN (1961) described 29 species belonging to 20 genera from the upper Jungxian Series (upper Wuchiapingian) in Anhui Province. Five species are common to the Salt Range, among which three species (*Martinia semiplana, Compressoproductus compressus,* and *Notothyris warthi*) are confined to the

Kalabagh, one (*Alexenia gratiosa*) occurs from the Kalabagh-Chhidru, and another species (*Streptorhynchus pelargonatus*) ranges from the Wargal to the Chhidru, but flourished in the Kalabagh. Judged from these common species, the Jungxian fauna is most allied to the Kalabagh. On the other hand, the fauna comprises seven species common to Armenia. Among them, three species (*Argentiproductus*=*Haydenella kiangsiensis, Alexenia gratiosa,* and *Tyloplecta yangtzeensis*) occur from the Dzhulfian (Araksian), one species, *Spinomarginifera lopingensis,* ranges from the Gnishik to the basal Khachik, one species (*Uncinunella timorensis*) from the Gnishik to the Dzhulfian, and two species (*Neophrycadothyris asiatica* and *Aulosteges poyangensis*) are limited to the Gnishik. From these fossils, it is rather difficult to make an accurate correlation, but the Wuchiapingian may be correlated with the Khachik rather than the Gnishik, in this case.

RUZHENTSEV and SARYCHEVA (1965) pointed the simiarity of the Dzhulfian brachiopods to those of the Chhidru enumerating eleven common species. There are six Gnishik-Khachik species that are common to the Kalabagh but not extending into the Dzhulfian, namely, *Notothyris nucleolus, Dielasma elongata, Terebratuloida minor, T. davidsoni, Richthofenia lawrenciana,* and *Martiniopsis inflata.* It is noticeable that all these species excepting the last one did not persist into the Chhidru in Pakistan. Furthermore, *M. inflata,* in Armenia, may not be conspecific with the Salt Range species judged from our own collection (NAKAMURA, personal information). So, based on the common species the Kalabagh is compared to the Gnishik-Khachik. These data, discussed above, suggest that the Chhidru is Dzhulfian (s. l.) and post-Guadalupian.

On the other hand, it must be mentioned that the Kalabagh brachiopod fauna is very similar to the Sisophon C fauna in having 12 sepcies in common as indicated by ISHII *et al.* (1969) and WATERHOUSE (1972 a). Curiously the Sisophon fauna has only 2 species in common with the upper Maokou contrary to 12 common species with the Loping, in spite of the fact that the Sisophon bed is characterized by the *Lepidolina multiseptata* fauna and correlated with the upper Maokou by fusuline fossils.

In Japan, not a few species of the Loping barchiopods are found from the *L. kumaensis* zone and the *L. multiseptata* zone or even lower horizon. Taking the known occurrences of brachiopods into consideration, the Kalabagh-Chhidru and the Zewan are as a whole correlated with the upper Maokouan to Lopingian or the Khachik to Dzhulfian, and the more precise comparison of the brachiopods is premature at present, because most of them seem to be long-ranging. There are many characteristic Dzhulfian and Dorashamian brachiopods in Armenia and Iran, but most of them are endemic and have limited stratigraphic value.

2) Foraminifera

Another approach to the international correlation can be made by foraminifera.

Among them, the occurrence of *Colaniella* cf. *minima, C. cylindrica,* and *Abadehella coniformis* from Member A of the Zewan has a special importance.

The genus *Colaniella* is known from the Pamirian of northern Caucasus (M-MAKLAY, 1954 and 1956), the Upper Permian (in the sense of threefold division) of the eastern Mediterranian province (RENZ and REICHEL, 1954), Pamirian of Pamir (M-MAKLAY, 1958; BARKHATOV *et al.,* 1959; LEVEN, 1967), the upper Permian (*Palaeofusulina* limestone) of north Viet-Nam (COLANI, 1924), middle and upper Lopingian in south China (WANG, 1966), the upper Permian of Ussuri region (SOSNINA, 1960), and the *Lepidolina multiseptata* zone to *L. kumaensis* zone in Japan. It is also reported from Afghanistan (VILLA, 1961), Yugoslavia (KACHANSKY, 1957 and 1964), and southern Italy (LUPERTO, 1963) along with the upper Permian foraminifera. So the range of the genus is confined to the Late Permian and late Middle Permian of the threefold division. Furthermore, the genus is classified into two groups; a primitive group represented by *C. minima* and an advanced one represented by *C. parva.* The former group usually coexists with the *Codonofusiella-Reichelina* fanua and the *Lepidolina kumaensis* fauna, while the latter occurs in the *Palaeofusulina* zone (ISHII, OKIMURA, and NAKAZAWA, 1975, in press).

The type-species of *Abadehella, A. tarazi,* was described from the base of the Abadeh Formation in central Iran (OKIMURA *et al.,* 1975) together with *A. coniformis* and *A. biconvexa. A. coniformis* is at present reported from the Sisophon D of Cambodia (=*L. multiseptata* zone), the *L. kumaensis* zone of the Maizuru belt and Shikoku in Japan, the *Palaeofusulina* aff. *sinensis* zone of the Maizuru, the horizon between *L. multiseptata* zone and the *L. kumaensis* zone in northeast Japan, and the *Paleaofusulina* aff. *sinensis-Colaniella parva* limestone of Malaysia (OKIMURA *et al.,* op cit.). The Abadeh Formation, the stratotype of the Abadehian, is referred to post-Guadalupian and pre-Dhzulfian age by TARAZ (1971, 1973). Accordingly, the genus *Abadehella* seems to be limited in stratigraphic range from the *Lepidolina multiseptata* zone to the *Palaeofusulina sinensis* zone like *Colaniella.* The assemblage of *Colaniella minima* and *Abadehella coniformis* is known only from the *L. kumaensis* zone in Japan. Judged from the available data mentioned above, it is most probable that the Member A or Division I is correlated with the *L. kumaensis* zone or lower Wuchiapingian in China, and less probably with *L. multiseptata* zone in Japan, Cambodia, and China (the top of the Maokou limestone).

It seems necessary to give here a comparison of fusulinid zones of Japan and China. As shown in Table 12, the fusulinid zones of these countries are quite similar and can be correlated with confidence, except for the *L. kumaensis* zone which has not been confirmed in China. The *kumaensis* fauna in Japan associates with the *Codonofusiella-Reichelina* fauna very similar to that of China, and the former zone interfingers with the latter in the Maizuru. The absence of *kumaensis* zone in China is reasonably explained as follows: the highly specialized genus *Lepidolina* disappeared from China by the emergence of the land after the deposition of the Maoukou limestone, while it evolved into a specialized form, *L. kumaensis* in Japan where the strata deposited continuously. The latter species coexisted there with the *Codonofusiella-Reichelina* fauna (OKIMURA *et al.*, 1975).

It is highly probable that the *Lepidolina kumaensis* zone is mostly lacking in China but may be partially represented by the lower part of the *Codonofusiella* zone (Wuchiapingian).

Table 12. Correlation of fusulinid zones between south China and Japan

SOUTH CHINA*				JAPAN**	
		fusulinid zone	ammonoid		fusulinid species zone
Lopingian	Changhsing.	*Palaeofusulina* zone *Palaeof. sinensis* *Colaniella parva* *Reichelina* *Parareichelina*	"*Pseudotirolites*" "*Pleuronodoceras*" "*Pseudostephanites*" "*Tapashanites*" *Stacheoceras*	"Mitaian"	*Palaeofusulina sinensis* zone *Palaeofusulina sinensis* *Colaniella parva* *Reichelina* *Codonofusiella*
Lopingian	Wuchiaping.	*Codonofusiella* zone *Codonofusiella* *Reichelina* *Gallowayinella* *Colaniella minima* *Eoverbeekina*	*Araxoceras* *Prototoceras* *Anderssonoceras*	Kuman	*Colaniella minima* *Reichelina* *Palaeofusulina simplex* *Lepidolina kumaensis* zone *Lepidol. kumaensis* *L. multiseptata* *Codonofusiella*, *Reichelina*
				Kuman	*Lepidolina multiseptata* z. / *Yabeina globosa* zone
Yangsinian	Maokouan	*Yabeina* zone *Lepid. multiseptata* *Colania douvillei* *Neomisellina*	*Paragastrioceras* *Altudoceras* *Waagenoceras* *Mexicoceras* *Kufengoceras* *Paraceltites*	Akasakan	*Colania douvillei* zone / *Neoschwagerina margaritae* z.
Yangsinian	Maokouan	*Neoschwagerina* zone *Neoschwagerina* *Verbeekina* *Sumatrina* *Pseudodoliolina*		Akasakan	*Neoschwagerina craticulifera* zone *Neoschwagerina* *Verbeekina*
Yangsinian	Chihsian	*Parafusulina* zone: *Cancellina* subz. *Cancellina* *Verbeekina* *Parafusulina* *Yangchienia*	*Pseudohalorites* *Artinskia* *Propopanoceras* *Neocrimites*	Nabeyaman	*Neoschwagerina simplex*-*Cancellina nipponica* z. *Neoschwagerina* *Cancellina*, *Parafusulina*
Yangsinian	Chihsian	*Parafusulina* zone: *Misellina* subzone *Misellina* *Pseudofusulina* *Schwagerina*		Upper Sakamoto.	*Misellina claudiae* zone *Misellina*, *Pseudofusulina* *Schwagerina*

* Based on Sheng (1963), Wang (1966), and Sheng and Lee (1974).
** Based on Toriyama (1967), Ozawa (1970), and others.
(Read *Palaeofusulina* aff. *sinensis* for *Palaeofusulina sinensis*, in Japan)

3) Conodonts

Conodonts are considered to be important elements for correlation because of their wide geographic distribution and limited stratigraphic range. As shown in Table 11, four conodont zones are recognized from the upper Zewan to the Khunamuh, inclusive: *Anchignathodus typicalis, Neogondolella carinata, Neospathodus cristagalli,* and *N. waageni.* A similar succession is confirmed in Pakistan and Iran by SWEET (1970a, 1973). He recognized nine conodont zones in the uppermost Chhidru to the Lower Triassic, that is, zones of *Anchignathodus typicalis, Neogondolella carinata, Neospathodus kummeli, N. dieneri, N. cristagalli, N. pakistanensis, N. waageni, Neogondolella jubita* and *Neospathodus timorensis,* in ascending order. The first zone includes the top 12 feet of the Chhidru and the lower Kathwai-basal upper Kathwai, of which the latter is characterized by *Ophiceras connectens* and *Glyptophiceras* sp. In Julfa of Iran, *A. typicalis* is limited to the Ali Bashi Formation and the lowermost part of the Elikah Formation (the *Claraia* beds). We collected ophiceratid ammonites from the latter beds. According to SWEET *A. typicalis* and *N. carinata* first appeared in the upper third of TARAZ's Unit 4 (upper Abadeh Formation) and survived into the lowermost part of Unit 8 (the *Claraia* beds), from which ophiceratid ammonites were also obtained by us. From our own collections, however, *typicalis* is found only from Unit 7 (Dorashamian) and the basal part of Unit 8, and *carinata* is confined to Unit 7. Unit 6 (Dzhulfian equivalent) is marked by another species of *Neogondolella,* tentatively called *N. abadehensis* (personal information of NOGAMI). On the other hand, the type Guadalupian in the United States is represented by *Neospathodus arcucristatus, Neogondolella rozenkrantzi,* and *Neospathodus divergens* in ascending order, and has neither *typicalis* nor *carinata* (SWEET, 1973)*.

From the view point of conodont zones, the upper Zewan and the lowermost Khunamuh are compared to the uppermost Chhidru to the Kathwai in West Pakistan, the upper Abadeh to the lowermost *Claraia* beds in Abadeh, and the Ali-Bashi Formation to the lowermost Elikah in Julfa, but the lowest horizon of *typicalis* and *carinata* may not be at the same level in all of these places.

4) Ammonoids

Cephalopods are scarce in the Zewan, and no nautiloids could be obtained. Only one specimen identified as *Cyclolobus walkeri* DIENER and several incomplete examples of *Xenaspis* are found in the uppermost part of Member C, about 20 m below the top of the Zewan (TEICHERT *et al.,* 1973). The latter species are also found at nearly the same horizon in the section north of Barus.

Ammonoids are more common in the upper Chhidru than in the Zewan, although few in number. They are *Cyclolobus oldhami* (WAAGEN), *C. teicherti* FURNISH and GLENISTER, *C.* cf. *walkeri* DIENER, *Stacheoceras antiquum* (W.), *Xenaspis carbonarius* (W.), *X. plicatus* (W.), *Eumedlicottia primas* (W.), and *Episageceras wynei* (W.) (TEICHERT, 1966; SCHINDEWOLF, 1954; FURNISH and GLENISTER, 1970). The occurrences of

* According to the recent paper of BEHNKEN (1975), *typicalis* occurs from the uppermost Wordian and Capitanian in the United States. Leonardian and Guadalupian (Permian) Conodont Biostratigraphy in Western and Southwestern United States. *J. Paleont.,* v. 49, no. 2. p. 284–315.

three species of *Cyclolobus* are from 36 to 60, or possibly 77, feet below the top of the Chhidru (KUMMEL and TEICHERT, 1970). Based on the lineages of Cyclolobidae, FURNISH and GLENISETR (1970) proposed six stages in the upper Permian, that is, Wordian, Capitanian, Amarassian, Araksian, Chhidruan, and Changhsingian, placing the *C. oldhami* etc. horizon of the Chhidru above the *C. kullingi* (=*Krafftoceras* n. sp. of SHEVYREV) horizon of the *Oldhamina-Araxoceras* beds in Armenia. Against this opinion WATERHOUSE (1972), who correlated the Chhidru with the Amarassi on brachiopods, claims that the Chhidru is older than the *Araxoceras* beds (Baisalian) referring to *C. kullingi* as a last survivor from the Chhidru.

The correlation of the Amarassi with the uppermost Guadalupian (La Colorada beds) in New Mexico is generally accepted from similar ammonoids: *Stacheoceras* cf. *tridens* (ROTHPLETZ), *Episageceras* cf. *nodosum* WANNER, and *Timorites* sp. (SPINOSA *et al.*, 1970; FURNISH and GLENISTER, 1970). The genera *Cyclolobus, Stacheoceras* and *Xenodiscus* of the Amarassi are common to the Chhidru, but they also occur in the Dzhulfian. It is noteworthy that there is no species in common between the Amarassi and the Chhidru in contrast to the affinity with the distant La Colorada, notwithstanding the both are considered to belong to the neighboring, if not the same, paleobiogeographic province judged from brachiopod similarity. So, the Chhidru is correlated equally with the Dzhulfian and the Amarassi.

On the other hand, FURNISH's view is not verified. Only one species, *Eumedlicottia wynei* is common to the Salt Range and Armenia. It is from the *Araxoceras* beds in Armenia, and judged from the list of RUZENTSEV and SARYCHEVA Araksian nautilods are most allied with those of the Kalabagh-Chhidru. The *Cyclolobus* horizon in the Chhidru and the Zewan is most probably correlated with the Araksian of FURNISH and GLENISTER or the Baisalian of WATERHOUSE.

Khunamuh Formation

The age and correlation of Unit E_2 and the younger strata of the Khunamuh are well established by the successive ammonoide zones of *Otoceras-Glyptophiceras, Ophiceras, Paranorites-Vishnuites, Prionites-Koninckites,* and *Owenites-Kashmirites,* as discussed already. The problem is in Unit E_1. Before going into this problem, the Zewan-Khunamuh transition at Guryul ravine should be re-examined. The basal part of the Khunamuh (Unit E_1) contacts with the calcareous sandstone of the Zewan seemingly without any stratigraphic gap. The faunas of the two formations are very similar to each other having many species in common. Among abundant forms of Unit E_1, *Claraia bioni* and *Etheripecten haydeni* are lacking in the Zewan. Lithologically, however, Unit E_1 is more similar to Unit E_2 and younger beds than to the Zewan. The shale of Unit E_1 can be distinguished from that of Unit E_2 only by less fissile character and a little more micaceous materials than the latter.

The boundary is rather gradational, and is drawn somewhat artificially. The lithology of the limestones of Unit E_1 and E_2 is intermediate between that of the Zewan and the Khunamuh as will be discussed in a later section. Furthermore, the beds (Unit f_1) north of Barus correlative with Unit E_1 are mainly composed of flaggy shale and similar to the *Otoceras* beds at Guryul ravine. The limestone contained in the upper part of Unit f_2 has a turbidite texture commonly found in the limestone of the *Otoceras* and later beds. This part is considered to include hor. (3) 28–8–08 of MIDDLEMISS, from which DIENER (1915) described many Permian-like fossils along with *Xenasipis* cf. *carbonaria.* Based on this evidence, we concluded the Zewan-Khunamuh are conformable without a marked sedimentary gap such as represented by stage or fossil zone.

Unit E_1 was correlated with the *Otoceras concavum* zone of Arctic Canada in the previous report (NAKAZAWA *et al.,* 1970) and included in the Lower Triassic. However, the species identified as *Claraia stachei* is now referred to a new species named *C. bioni.* *Xenaspis* cf. *carbonaria* was considered as indeterminable Triassic ophiceratid, possibly *Glyptophiceras* by TEICHERT *et al.* (1973), but it differs from the type species, *G. aequicostatum* (DIENER) of Smithian age, or the Griesbachian *Glyptophiceras* which is included in *Xenodiscus* by TOZER (1971), or the late Permian *Xenodiscus* (s. s.) by almost smooth inner whorls, and it is more similar to *Ophiceras* or *Xenaspis* (included in *Xenodiscus* by SCHINDEWOLF, 1954 and KUMMEL, 1970).

Unit E_1 and the main part of Unit f_1 are included in the Permian by a close faunal similarity with the Zewan. The correlation of these with the latest Permian, such as the Dorashamian or Changhsingian, is mainly based on the stratigraphic position, conodonts, and the appearance of *Claraia bioni* similar to the Griesbachian *C. stachei.*

So-called *Ophiceras* beds of Pastun

The occurrence of the Lower Triassic ammonoids at Pastun was first noticed by NOETLING (in HOLLAND, 1904). Many beautiful specimens collected by MIDDLEMISS were described by DIENER (1913). He concluded the close similarity of this fauna to that of the *Otoceras-Ophiceras* beds of Spiti and Painkhanda in the Himalayas. BION (1914), on the other hand, correlated the Pastun beds with the *Meekoceras* beds at Guryul ravine. Later, SPATH (1934) suggested a slightly younger age of the Pastun fauna than of the *Otoceras-Ophiceras* pointing that the commonest forms of the latter, such as *Ophiceras sakuntala,* were very rare at Pastun, but KUMMEL (1970) favored Otoceratan age. Against these opinions, TOZER (1969; 1971) insisted that the Pastun fauna should be Smithian in age in having characteristic Smithian fossils, such as "*Xenodiscus*" (=*Xenoceltites*) *comptino* DIENER, "*Pseudomonotis*" *himaica* BITTNER and others. According to him, "The ammonoids assigned to *Ophiceras* from Pastannah could just as well assigned to a Smithian genus like *Dieneroceras*". One of us (YB) also confirmed TOZER's view by examining the Pastun specimens kept at the British Museum. Recent field survey by KAPOOR (unpublished data) endorsed the BION and TOZER's opinion confirming that the "*Ophiceras*" beds of Pastun occupy a nearly same stratigraphic position as that of the *Meekoceras* beds of Guryul ravine section.

We collected many specimens of bivalves in addition to ammonoids. DIENER (1913) described several species of "*Pseudomonotis*" from Pastun, that is, "*Pseudomonotis*" *griesbachi* BITTNER, "*Ps.*" *aurita* HAUER, "*Ps.*" *painkhandana* BITTNER, "*Ps.*" aff. *austriaca* BITTNER, and "*Ps.*" *multiformis* BITTNER. The first species cannot be identified as *griesbachi* in having strongly convex left valve as stated by TOZER (1969), but is more allied to "*Ps.*" *decidens* BITTNER described from the *Meekoceras* beds of Guryul ravine by DIENER (1913, p. 43, pl. 5, figs. 14 a–c), and is identical with our specimens collected from the same beds. "*Ps.*" *tenuistriata* by DIENER (ibid., p. 44, Pl. 5, fig. 11) is certainly conspecific with *Leptochondria minima* (KIPARISOVA) that occurs from the *Otoceras-Glyptophiceras* zone to the *Owenites-Kashmirites* zone, and flourished in the *Paranorites-Vishnuites* zone at Guryul ravine. *Ps. multiformis* (ibid., p. 44, pl. 5, fig. 13) is more properly referred to *Leptochondria bittneri* as stated by KIPARISOVA (1938). According to NOGAMI (personal information) conodonts of Pastun are identified as *Neogondolella milleri* (MÜLLER), *N.* aff. *carinata* (CLARK), and *Neospathodus waageni* SWEET, the assemblage of which strongly suggests an Owenitan or Smithian age.

In conclusion, the "*Ophiceras*" beds of Pastun is assigned to Smithian age as claimed by TOZER and roughly correlated with the *Meekoceras* beds (=the *Owenites-Kashmirites* zone) of Guryul ravine. It is noticeable, however, that there is no common ammonoid species between the two in spite of the short distance (about 22 km). It is probable that the Pastun horizon is slightly lower than the latter and comparable to the upper part of Unit G of the Khunamuh Formation immediately below the *Meekoceras* horizon, although no fossils have been collected from this part.

Correlation

An accurate correlation here has a prime importance of drawing the erathem boundary and to consider the faunal changes near the boundary. Our scheme of correlation is summarized in Table 13 based on the foregoing discussion, but there still remain several problems as follows.

1) Permian-Triassic "mixed" fauna

At several places in the world, Permian-type fossils are found mixed with the Otoceratan or Griesbachian fossils or from the equivalent horizon, such as in Kashmir,

Table 13. Correlation of the upper Permian in the world.

	S. Alps (Italy)	USSR / Iran: Dzhulfa	Iran: Abadeh	Salt Range	Kashmir	Pamir	China
TRIASSIC: Smith. – Owen. Dien. – Flem. Dien. – Gyron. Gries. U. / L. – Otoce. PERMIAN: Dzhulfian – Dorasham. Dzhulfian – Araksian Abadeh. / Khachik Gnishik	Werfen Fm.: Campil Gas. Ool. Siusi B. Andraz–Mazzin Bellerophon Form. / Gardena F.	Claraia Beds Gyronit. Ophice. ? "Indian" 4–1 Dzhulfian 5, 4, 3, 2, 1 Ali Bashi F, E D C Khachik – B Gnishik – A	8 Gyro. Ophi. ? Dzhulfian 7 6 Abadehian 5 4 Guadalupian 3 ? 2	Mianwali Fm. Mittiwali Memb. Kathw. Chhidru Fm. Kalabagh M. (Up.Warg.) ? Wargal	Khunamuh Formation: H Owe. G Prio. F Para. E_3 Oph. E_2 Oto. E_1 IV Zewan Formation: D C III B II A I ? Gangamopt. Beds / Panjal Volcanics	*Claraia, Lytophic.* Kalaveles / Up. Gansk Pamirian ? Murgabien – Lower Gansk	Tayeh Limestone Yehlang Formation Lopingian: Changsing / Talang Fm. Wuchiaping / Lungtan Fm. Upper Yanghsin: Maukou Limestone

Japan	Sichote-Alin	Wyoming, USA	East Greenland	West Australia	Ammonoid zone	Fusulinid zone (Foram.)
Inai Se. Yakuno Gr. Kanura Gl? Toyoma Series Gujo f. Maizuru Group Mitai Fm. f. Kuma Formation f. Kanokure Series f. Yonagu Fm.	*Anasibirit.* *Flemingit.* *Gyronites* Sitsinsk Formation Kaluzinsk Formation Chandalaz Formation	Thaynes Woodside Dinwoody ? ? Park City Formation Phosphoria Formation	Nordensk Fm. Woody Creek Fm. ? Product. limest Posidonia shale	Blink shale ? Liveringa Formation: upper marine part Middle non-marine part	*Owenites, Meekoceras* *Flemingites* *Gyronites* *Ophiceras* *Otoceras* *Paratirolites* *Shevyrevites* *Phisonites* *Araxoceras, Prototoceras, Cyclolobus, Xenodiscus* *Eoaraxoceras, Timorites, Xenodiscus* *Timorites, Waagenoceras* *Waagenoceras, Mexicoceras*	*Palaeofusulina -Reichelina* (*Colaniella parva*) *Codonofusiella -Reichelina* (*Colaniella minima*) *Lepid. kuma.* *Lepid. multisep.*, *Yabeina globosa* *Colania*, *Neoschwagerina*

Para- or disconformity
Clinounconformity
● Occurrence of "Permian" fossils
(●) Derived Permian fossils

the Salt Range, the United States, and East Greenland. Recently SHENG and LEE (1974) called attention to the presence of a mixed fauna in Szechuan in China, but the details are unknown.

At Guryul ravine, Kashmir, *Pustula*? sp., *Marginifera himalayensis, Etheripecten haydeni*, and *Claraia bioni* are found from the *Otoceras*-bearing limestone or the same stratigraphic horizon as the latter, continuing from the underlying beds referred to the Permian. Unfortunately, the specimens are so few and fragmentary that it is not sure whether they actually lived where found or were derived secondarily. But, BION (1914) already reported the occurrence of productids in the *Otoceras* beds in Pahlgam, and according to WATERHOUSE (pers. inform., Dec., 1973) *Otoceras* beds containing "Permian" brachiopods are widely distributed in Nepal. So, it is possible that the Permian-type fossils mentioned above survived into the very early stage of the Otoceratan in Kashmir.

In the Salt Range GRANT (1970) reported 16 brachiopod species belonging to 14 genera, including *Crurithyris*? *extima* GRANT and *Orthotetina* cf. *arakeljani* SOKOTSKAYA, from the dolomite unit of the Kathwai Member (Lower Kathwai). This assemblage was compared to the Dzhulfian by GRANT, and later to the Changhsingian by GRANT and COOPER (1973). The dolomite unit, as well as the overlying limestone unit of the Kathwai, are characterized by *Ophiceras connectens* SCHINDEWOLF and *Glyptophiceras* sp. (SCHINDEWOLF, 1954; KUMMEL, 1970). KUMMEL and TEICHERT (1970) considered the brachiopods as survivors from the Permian in the earliest Triassic. On the other hand, WATERHOUSE (1973) thought them to be older than, or nearly contemporaneous with, the Baisalian (Dzhulfian of authors), describing a new ophiceratid species, *Durvilleoceras woodmani* from the "middle" Permian Greville Formation of New Zealand. It is out of the question that *O. connectens* is closely allied to the Otoceratan species of *Ophiceras* and it differs from the Permian ophiceratid from New Zealand in details of suture-line and shell-shape. The Otoceratan age of the main Kathwai is here preferred. In this we agree with SCHINDEWOLF and KUMMEL after taking the successive ammonoid zones of the Mianwali Formation into consideration. *Durvilleoceras* is considered to be another ophicratid offshoot from Xenodiscidae.

A problem is in the occurrences of ammonoids and brachiopods, since the most of brachiopods are obtained from a coquinoid lens at the base of dolomite unit and do not coexist with the ammonoids. However, *Spinomarginifera* occurs in association with *Ophiceras* at one locality and *Crurithyris*? *extima* ranges to 5 feet above the base. There are three possible lines of explanation for these occurrences. GRANT, who rejected reworking of the brachiopods, presumed the presence of an unconformity between the *Ophiceras* beds and the brachiopod beds, and KUMMEL and TEICHERT perferred their survival as mentioned above, while NEWELL (1973) suggests that the fossils were reworked.

Another problem is whether the Kathwai Member contains the *Otoceras* horizon (lower Griesbachian) or not. We are now inclined to consider that this horizon is lacking in the Salt Range, because the *Otoceras* commonly occurs below the *Ophiceras* zone in the neighboring Kashmir.

In Wyoming, United States, the Permian brachiopods have recently been reported from the very base of the Dinwoody formation (GRANT and COOPER, 1973). Elsewhere, the Dinwoody has yielded upper Griesbachian fossils, such as *Ophiceras subkyoticum* SPATH, *Metophiceras subdemissum* SPATH, *Claraia stachei* BITTNER, *Eumorphotis multiformis,* and others (NEWELL and KUMMEL, 1942). According to NEWELL (personal information, April 1975) the brachiopods are not associated with the Griesbachian fossils. He wrote to one of us (KN), "The brachiopods were classed as Dinwoody only because they overlie the Park City (Phosphoria) and an intervening stratigraphic unit had not yet been named.... Probably the Permian part of the Dinwoody will become a member of the Phosphoria formation. The *Claraia stachei* beds are high in the Dinwoody so there is ample room for Lower Griesbachian below *Claraia* beds." WATERHOUSE referred the so-called *Mentzelia* described by NEWELL and KUMMEL from the *Lingula* beds as Permian *Crurithyris.*

In East Greenland many Permian brachiopods were reported to occur from the lower Woodie Creek Formation (the Lower Griesbachian and lower Upper Griesbachian) (TRÜMPY, 1960; DEFRETIN-LEFRANC, 1969), but according to KUMMEL (1970) and WATERHOUSE (1972) these were certainly derived from the underlying "Productus" Limestone of Guadalupian age.

In summary the occurrence of the "Permian" brachiopods from the Otoceratan or Griesbachian, in many case, requires further examination, although some of them most likely survived into the Otoceratan or Griesbachian.

2) Dorashamian and Changhsingian

The base of the Dorashamian is defined as the base of *Phisonites-Comelicania* beds by ROSTOVTSEV and AZARIAN (1973) which were included in the Dzhulfian by RUZHENTSEV and SARYCHEVA (1965). This view was supported by TEICHERT *et al.* (1973) who named the Ali Bashi Formation for the Dorashamian beds in Iranian Julfa, and by WATERHOUSE (1973) who stressed the incoming of a xenodiscid genus, *Phisonites.* The Permian age of this has been discussed by many authors (e.g., TOZER, 1969; TEICHERT *et al.,* 1973) and it is not necessary to quote here. The correlation of the Dorashamian with the Changhsingian was first suggested by CHAO (1965), and confirmed by TEICHERT *et al.,* by discovering characteristic Changhsingian genera, "*Pseudostephanites*", "*Pleuronodoceras*", and "*Pseudotirolites*" from the Ali Bashi Formation as already stated. The type Changhsingian is represented by the *Palaeofusulina*-bearing Changhsing limestone in the Changhsing coal-field, Chekiang, south China. According to CHAO (1965) the ammonoids occur in siliceous beds called the Talung Formation, considered to be a lateral equivalent of the Changhsing limestone by Chinese geologists. However, he stated, "The basal part of this section is a thick-bedded whitish limestone, containing *Palaeofusulina,* is followed by a great thickness of siliceous beds and shales, containing *Pseudogastrioceras, Pseudotirolites* (4 spp.), *Pleuronodoceras* (2 spp.) and other new forms of ammonoids" in the Tuyung district, southern Kweichow.

ROSTOVTSEV and AZARIAN (1973) expressed the opinion that the Dorashamian is younger than the Changhsingian referring to SUN (1947) who stated the Hoshan Formation (Dorashamian equivalent) overlaps the Changhsing limestone in Kiangsi province. But according to SHENG and LEE (1974) the Changhsing limestone in the type area contains a large number of beautiful ammonoids comparable to the Talung fauna. Furthermore, in Kiangsi there are 55 to 186 m sandstone and shale beds between the Changhsing limestone and the Laoshan shale containing the Dzhulfian ammonoids (*Araxoceras, Vestococeras, Kiangsiceras = Vedioceras, Prototoceras,* etc.) (CHAO, 1965). Then, it is reasonable to correlate the Dorashamian and the Changhsingian with each other, even though the latter possibly contains still lower horizons (NAKAZAWA *et al.,* 1975).

3) Abadehian

The Abadeh region in Central Iran is considered to be one of the best places in the world for a nearly complete Permian-Triassic sequence. TARAZ (1971, 1973) divided the Upper Permian-Lower Triassic strata into 12 units after a detailed field survey. Units 8 to 12 belong to the Lower Triassic, units 6 and 7 are certainly Dzhulfian (including Dorashamian), and the lower units are pre-Dzhulfian. Units 4 and 5 together, about 230 m thick, are called the Abadeh Formation. The formation contains brachiopods similar to the Dzhulfian fauna and is characterized by small fusulines, such as *Codonofusiella, Reichelina* and *Staffera.* TARAZ considered the age as pre-Dzhulfian and post-Guadalupian, and proposed the new stage name Abadehian. FURNISH (1973) tentatively compared the Abadehian to his Amarassian established on the Amarassi fauna in Indonesian Timor. Stratigraphic relation of the Amarassi "beds" to the neighboring beds is not clear, because the geologic structure is very complicated and most of the fossils were obtained from loose blocks. So the Amarassian is considered to be inadequate for the stage name. The La Colorada beds of Mexico considered to be Amarassian occupy the highest position of the Guadalupian. The basal part of the Abadeh may be correlated with the Kalabagh, Member A of the Zewan, the *Lepidolina kumaensis* zone, and possibly the Amarassi, as already stated. It is noticeable that the early Dzhulfian ammonoids in China occur from the middle part (Laoshan shale) of the Wuchiapingian. Below the ammonoid beds there exists a Kushan sandstone interbedded with sandy shales of 210 to 320 m in thickness. The Abadehian is tentatively referred to include the

"Amarassian" and the lower Wuchiapingian, although further paleontological study is needed in connection with the fossils of the underlying units.

4) Permian-Triassic boundary

It is a remarkable fact that the most of the marine organisms rapidly declined and were extinguished during the late Permian and reached minimal in the earliest Triassic throughout geologic time exhibiting an example of mass extinction or group extinction (NEWELL, 1962, 1967), and it is reasonable to draw the erathem boundary between the Permian and the Triassic. But it is not easy to settle the exact boundary which wins general approval, because disappearance of Paleozoic fossils and appearance of Mesozoic fossils are not synchronous among different taxa and in different provinces.

The traditional view since GRIESBACH (1880) followed by many later authors (e.g., DIENER, 1912; TOZER, 1967; KUMMEL, 1970) is that the boundary is drawn at the base of the *Ophiceras-Otoceras* zone, that is, *Otoceras woodwardi* zone. The main reason was the complete absence of the Permian brachiopods and bryozoans and the appearance of bivalves of Werfenian affinities in the *Otoceras* beds in the Himalayas. But now the "Permian" fossils are found from this zone at several places in the world. NEWELL (1973) concluded that the erathem boundary should be drawn at the top of the *Ophiceras-Otoceras* zone, that is, at the top of the Otoceratan, considering that the extinction of the *Otoceras-Ophiceras* fauna corresponds with the minimum of faunal diversity in the world. Similarly but in a somewhat different way, WATERHOUSE (1973) proposed to draw the boundary at the base of Smithian. His proposal is based on the new incoming of many Triassic ammonoids at that time and the extremely sparse faunas of the preceeding Dienerian. But it must be noted that the several major groups characteristic of the Paleozoic were extinct in the Dorashamian or Changhsingian. Fusulinacea, one of the most useful index foraminifera of the Carboniferous-Permian, completely disappeared at the end of the Changhsingian; Tetracorallia, the largest group of the Paleozoic corals, was also extinct at the end of the Dorashamian; and the last survivors of Goniatitina, the most divergent ammonoid group in the upper Paleozoic, are the Dorashamian and Changhsingian *Pseudogastrioceras* and the Changhsingian *Changhsingoceras*. The complete extinction of such typical Paleozoic major groups is considered to have an equal right to define the Paleozoic-Mesozoic boundary. It is logical to draw the boundary somewhere in the time of group extinction having its acme ranging from the "latest Permian" to the "earliest Triassic", but the exact boundary is more or less artificial in nature. In this connection, it must be mentioned that the greatest recession of epicontinental sea took place around the Dorashamian-Otoceratan (or Griesbachian) boundary all over the world as shown in the correlation chart. In Iranian Julfa the *Claraia* beds begin with red shale 80 cm thick and in Abadeh region with greenish shale about 30 cm thick, both contains a small ophiceratid ammonite and *Claraia* sp. It is probable that the *Otoceras* horizon is missing there as in the Salt Range. This stage may correspond to the time of great expansion of arid climate and evaporite deposits, and the minimal diversity of organisms during the Griesbachian-Dienerian. We prefer the Dorashamian (Changhsingian)/Otoceratan (Griesbachian) boundary as the erathem boundary as commonly used.

VII. Sedimentological Analysis

Petrography of carbonate rocks at Guryul ravine section

In the previous paper (NAKAZAWA *et al.*, 1970) carbonate rocks of the Permian-Triassic at Guryul ravine were tentatively called "limestone" or "calcareous sandstone" by field observation. Here the properties of carbonate rocks are described on the basis of microscopic observation in addition to that of polished specimens, and the classification of the carbonate rocks is re-examined.

Allochemical constituents in the carbonate rocks consist of various organic skeletons and calcite grains. The former are made of brachiopods, bryozoans, pelecypods, gastropods, ammonoids, foraminifera, algae, etc., and are in many cases broken up into small fragments. The latter are made mostly of micrite, and sometimes sparite and comminuted organic fragments. Intraclast, oolite, pellet and orthochemical constituents represented by micrite and sparry calcite cement are quantitatively not important elements excluding the lower part of the Zewan Formation. It is worthy of note that dolomitization is not observed and no dolomite rhombohedra are found in the carbonate rocks. Terrigenous detrital materials of sand to clay size, consisting mostly of quartz and minor amount of feldspar, mica and opaque minerals are commonly contained in various amount. No glauconite grains are observed.

The carbonate layers alternate with argillaceous layers exhibiting a sharp contact with underlying shale in every case, and also a sharp boundary with overlying shale in many cases. There can be frequently observed current sorting and stratification. Graded bedding, parallel and cross laminations, convolute lamination are often found in them. These characteristics strongly suggest allochthonous (or detrital) origin of the carbonate layers. It is apparent that calcareous materials were derived somewhere outside the present area, probably under shallow marine or shelf environment. They were secondarily carried into a comparatively deep basin as biogenetic clasts and calcite grains by turbidity currents or strong waves and they were accompanied by terrigenous detrital materials supplied from external sources as will be discussed in detail later.

As to the classification of carbonate rocks, FOLK (1959) proposed a triangle diagram with three end-members, such as allochem, orthochem and terrigenous components, and differentiated the carbonate rocks having 10 to 50 percent terrigenous materials as "impure limestone" from "limestone" that has terrigenous materials less than 10 percent. The carbonate rocks at Guryul ravine are characterized in having terrigenous detritals whose amount varies widely between less than a few percent to more than 30 percent. FOLK's division of limestone and impure limestone, however, seems inappropriate for actual usage.

The practical petrographical classification of limestones proposed by FOLK (1959, partly revised in 1962) has currently been used by many researchers. In the carbonate rocks of Guryul ravine the organic remains are usually contained as constituents of rudite size. The orthochemical constituents are quantitatively not important, as mentioned already. The sparry calcite cement exists exceptionally in the carbonate rocks of Member A, which may be called as "poorly washed biosparudite" according to FOLK's (1962) classification. The so-called micrite occurs abundantly in all the carbonate rocks, but most of them were transported and deposited as allochemical rather than orthochemical constituent, and not deposited as orthochemical one. Generally speaking the carbonate rocks of the Guryul ravine belong mostly to "biomicrudite" and not any litho-stratigraphic change can be expressed notwithstanding the visual stratigraphic differences. So, it is necessary to devise another method for further detailed description. In order to describe carbonate rocks at Guryul ravine more adequately, especially to show their litho-stratigraphic changes more precisley, we are introducing the following method of description of carbonate rocks.

1. Method of description

The carbonate rocks at Guryul ravine can be illustrated more adequately by combining the following three major characteristics observed under the microscope: the properties of contained fossils (F), terrigenous grain percent (T), and size of calcite grains (C).

F: indicates the existence of organic skeletons, mostly fragmentary

- F1: thick skeletons (>1 mm)–sessile shells (barchiopod and bryozoa), molluscan shells, some foraminiferal tests, etc. (mostly neritic organisms)
- F2: thin skeletons (<1 mm)–shells of ammonoids and some bivalves, some foraminifera, etc. (mostly more off-shore organisms)

T: indicates percent of terrigenous detrital materials

- T1: terrigenous materials less than 4 percent.........(limestone)
- T2: terrigenous materials between 4 percent (mostly 7 percent) and 18 percent ....(sandy limestone)
- T3: terrigenous materials between 18 percent and 30 percent

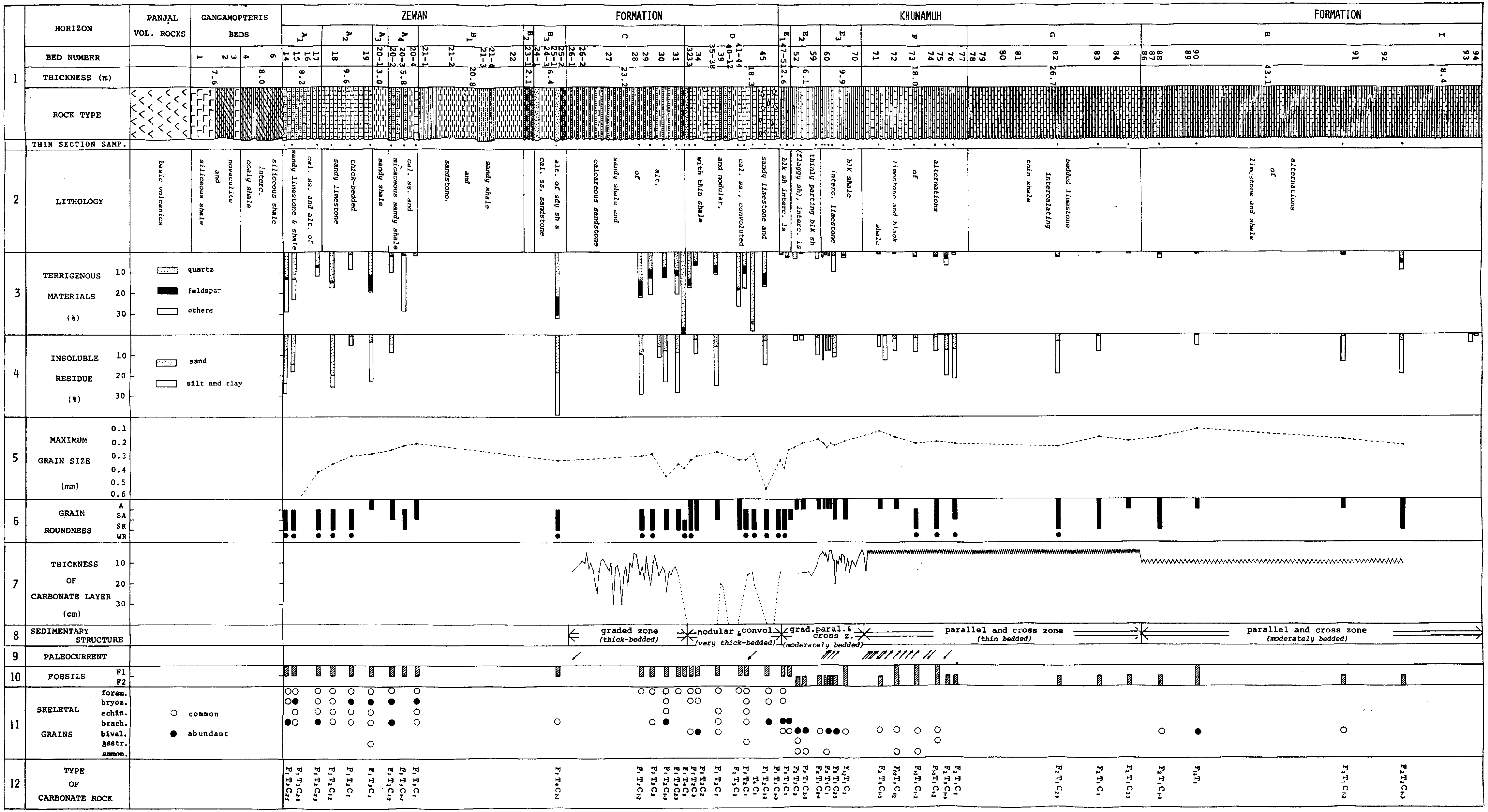

HORIZON
PANJAL VOL. ROCKS
GANGAMOPTERIS BEDS
ZEWAN FORMATION
KHUNAMUH FORMATION
BED NUMBER
THICKNESS (m)
ROCK TYPE
THIN SECTION SAMP.
LITHOLOGY
TERRIGENOUS MATERIALS (%)
quartz
feldspar
others
INSOLUBLE RESIDUE (%)
sand
silt and clay
MAXIMUM GRAIN SIZE (mm)
GRAIN ROUNDNESS
THICKNESS OF CARBONATE LAYER (cm)
SEDIMENTARY STRUCTURE
graded zone (thick-bedded)
nodular & convol. (very thick-bedded)
grad. paral. & cross z. (moderately bedded)
parallel and cross zone (thin bedded)
parallel and cross zone (moderately bedded)
PALEOCURRENT
FOSSILS
SKELETAL GRAINS
foram.
bryoz.
echin.
brach.
bival.
gastr.
ammon.
common
abundant
TYPE OF CARBONATE ROCK

Fig. 12.

.........(calcareous sandstone)

T4: terrigenous materials more than 30 percent.........(sandstone)

In the present paper the carbonate rocks are named on the basis of the amount of terrigenous materials as defined above. PETTIJOHN (1957) reported that admixture of 82 percent carbonate and 18 percent quartz might be taken as the natural dividing line between sandstone and limestone instead of the arbitrary 50–50 division, and such a convention probably would more closely approximate actual usage by field worker and seems reasonable for the present study, too.

C: indicates the mean grain-size of calcite roughly determined under the microscope

C1: fine silt to clay (fine and very fine calcilutites)

C2: medium to coarse silt (medium and coarse calcilutites)

C3: fine to medium sand (calcarenite)

As mentioned already orthochemical constituents are rarely found, and allochem grains (mostly of micrite) occupy a large amount. Although quantitative grain-size analysis could not be made accurately due to irregular grain-shape, mean grain-size was roughly estimated in each thin-section.

The results of the FTC description are collectively shown in Column 12 in Fig. 12.

2. Petrographical description

Petrographical properties of the carbonate rocks were examined under the microscope on forty-eight specimens.

(1) Fossils and their occurrences

Fossil types of F1 and F2 were marked in column 10 in Fig. 12. Although it is not easy to distinguish the taxa of fossils due to fragmentation of organic skeletons, fossils such as brachiopods, bryozoans, foraminifera, gastropods, echinoderms, bivalves, ammonoids of rudite were roughly discriminated under the microscope, and their occurrences are shown in the same table. The fossil fragments of sand-size were also examined in the same manner wherever possible. The Zewan Formation is characterized by fossils of brachiopods and bryozoans, while the Khunamuh by ammonoids and bivalves. Generally speaking the carbonate rocks in the Zewan consist of skeletons of F1 type and in a few layers of the upper part of Member C and Members D–F two type skeletons are found additionally. On the other hand those of the Khunamuh are composed of F2 type skeletons. This reflects the syngenetic fragmentation and transportation of organic remains. In addition to the microscopic occurrence of fossils, the megascopic observation on the fossiliferous beds are mentioned here.

Zewan Formation: The Zewan fossils are mostly represented by benthonic animals, and the texture of the fossiliferous beds is similar throughout; all may be called biomicrudite of FOLK's classification (1959). The shells or skeletal parts are not so fragmented, although sedentary fossils are separated from the attached materials excepting some bryozoan fossils and small plates of crinoids are dispersed by disassociation of the tegmen after death.

The fossil occurrence of Member A, however, differs from that of the succeeding members. The benthonic fossils of Member A are characterized by a predominance of sessile animals, such as crinoids, bryozans, brachiopods, and some foraminifera (*Ammonidiscus, Glomospira,* and *Agathammina*), which are rare or lacking in other members excepting brachiopods. Furthermore, the shells are usually poorly oriented, while those of the other members are more or less arranged parallel to the bedding plane. These suggest a less allochthonous occurrence of fossils in Member A than in the younger members. Most of the carbonate layers of Member A may be called crinoid biomicrudite and shell-bearing intramicrudite, and a part of them belong to bryozoa-bearing intramicrudite or bryozoa-bearing crinoidal biomicrudite. Fossil beds of Member C and D are mostly referred to shelly biomicrudite, of which shells are mainly constituted by brachiopods and bivalves and in part gastropods.

Khunamuh Formation: As mentioned in Chapter IV, the fossil occurrence of the Unit E_1 shows that *Claraia bioni* was buried nearly *in situ* while the other fossils were transported from the shallower sea bottom. Almost all fossils from Unit E_2 to Member H belong to Ammonoidea, Bivalvia, and Conodontophorida, among which ammonoids are confined to limestone layers. Bivalve shells, all separated, and ammonoid tests filled with matrix are usually concentrated in the lower half of a limestone layer graded into finer, laminated, upper part (Pl. 9 and Pl. 11, Fig. 2), and empty shells of ammonoids are arranged randomly occupying a main part of a layer (Pl. 11, Fig. 3). Such occurrences are harmonious with the transportation by turbidity current deduced from other sedimentary structure. The fossiliferous limestone may be classified as shelly biomicrudite, but the origin differs considerably from that of the Zewan.

Fossils from the shale of the lower part of Member E, where limestone layers are few, are represented by species of *Claraia* and *Eumorphotis,* but in the rest of the Khunamuh only *Claraia* is found in the shale, crowded on a bedding surface of pelagic muddy part immediately above the limestone or in the shale. Presumably *Claraia* lived in more off-shore environment than other fossils as in the case of Unit E_1. Only exception is *Claraia decidens* provided with strongly inflated left valves.

It occurs in the limestone (Bed 88) accompanied with *Leptochondria* and Owenitan ammonoids. Thus, megascopic occurrence of fossils is considerably different in the two formations.

(2) Terrigenous constituents

Terrigenous content was determined by point-count method (about 1,000 points in one section). The terrigenous materials consist of detrital grains of quartz, feldspar, mica, opaque minerals, etc. and fine silt to clay-size particles. Their amounts cannot be indicated so accurately because it is difficult to determine the size under the microscope due to fine grain-size and disseminated state. The exact amount was calculated by means of the acid-insoluble residues as will be mentioned later. The results are collectively shown in column 3 of Fig. 12. Quartz grains are abundant in most specimens, and sometimes occupy the whole detrital grains. Feldspars are plagioclase and microcline, whose amounts are nearly equal to each other in many specimens. There exists a remarkable difference between the Zewan and the Khunamuh in terrigenous contents, which usually exceed 7 percent and attain up to 30 percent in the former, while mostly less than 4 percent in the latter.

(3) Calcite grains

Calcite grains are mainly composed of secondarily transported clastic grains of various sizes. The mean size of calcite grains was roughly determined under the microscope. They were divided into three classes, such as C1 (fine silt to clay), C2 (medium to coarse silt) and C3 (fine to medium sand). The results are also collectively shown in the 12th column of Fig. 12. Most specimens have grains of various sizes and there exists no clear stratigraphic change, although coarser grains seem to be somewhat more numerous in the Zewan Formation, than in the Khunamuh.

Diagenesis of calcite grains has proceeded to a considerable degree, sometimes make it difficult to identify the original grain boundaries. The crystal growth of shell fragments and other diagenetic change are advanced, especially in the limestones of the Khunamuh Formation (Plate 12, Figs. 1~6). In Members A and C of the Zewan, the original fine detrital texture of micrite is incompletely retained (Plate 4, Fig. 4). It requires, however, further study to deduce the difference of sedimentary environment from the different grades of diagenesis in the two.

(4) Results of the petrographic description

The carbonate rocks at Guryul ravine belong to the two divisions of limestone and impure limestone, as defined by Folk (1958 and 1962), and those belonging to the former are mostly assigned to biomicrudite. The successive litho-stratigraphic change of carbonate rocks could be briefly expressed by the FTC description instead of Folk's classification. The results are clearly shown in Table 14.

Table 14. Litho-stratigraphic change of carbonate rocks

Member		Fossils and Fossil Fragments	Terrigenous Contents	FOLK's Classification
E–I	F 2	ammonoid, bivalve, (arranged parallel to bedding)	T 1	biomicrudite
D	F 1	brachiopod, bivalve, gastropod (arranged paralled to bedding)	T 2 and T 3	biomicrudite
C	F 1	brachiopod, bivalve, gastropod (arranged paralled to bedding)	T 3	biomicrudite
B		(no carbonate rocks contained)		
A	F 1	brachiopod, bryozoa, crinoid (not so fragmented and poorly oriented)	T 2 and T 3	biomicrudite and/or fossiliferous intramicrudite (sometimes poorly washed biosparudite)

3. Acid-insoluble residues

Thirty-five samples were prepared from carbonate rocks examined by thin-sections. About 10 grams of each sample were dissolved by dilute HCl solution, and residual materials were weighted. Then the residuals were divided into two fractions (sand size and silt to clay size) by grinding to pass a 200 mesh sieve. The results are shown in column 4 of Fig. 12. In the percent of residues are involved fossil fragments insoluble to HCl, because it is difficult to exclude them from the terrigenous materials. In comparison with the results obtained by thin-section analysis the difference between the two methods is not great, and the stratigraphic change has a similar tendency. It is apparent that there exists striking differences between the Zewan and the Khunamuh in the quantity of acid-insoluble residues, that is, a far larger amount in the Zewan.

It is to be noticed that minute spheroids of magnetic iron mineral probably of cosmic origin are rather commonly found in the residues throughout the Zewan and Khunamuh Formations though few in number.

4. Maximum size of terrigenous detrital grains

The maximum grain-size was determined by measuring the apparent longest diameter of grain under the microscope. The results are shown in column 5 of Fig. 12. The maximum grain-size is very large in the lowermost part of the Zewan Formation, decreasing rapidly toward the upper horizon. It becomes larger again at the uppermost part of the Zewan, and in the Khunamuh it remains small. It is apparent that there exists a sharp contrast in terrigenous detrital grain-size between the two formations and the change is rather rapid.

5. Roundness of terrigenous grains

The terrigenous detrital grains vary widely in angularity, and the precise determination of grain roundness is very difficult. It was determined in thin sections by identifying roughly angular, subangular, and subrounded grains, whose ranges of distribution are shown in column 6 of Fig. 12. If rounded and/or well-rounded grains are observed, it was marked by circular symbol in the column. In the Zewan Formation there are found many abraded grains, while the Khunamuh has abundant non-abraded grains. Rounded and/or well-rounded grains, which are mostly quartz, are commonly contained in the Zewan Formation. On the contrary such grains are rarely found in the Khunamuh. In Member E, a transition of the Permian and the Triassic, there are very few rounded grains. The well-rounded grains may suggest a desert condition or an existence of aeolian sandstone in Gondwanaland which is considered to have been a source area situated to the south of the sedimentary basin.

Sedimentological study of carbonate layers

1. Occurrence of carbonate layers and the sedimentary structures.

In the Guryul ravine section carbonate layers alternate with argillaceous or arenaceous layers, and in the former there are frequently found primary sedimentary structures of inorganic origin. On the other hand only a few sedimentary structures could be observed in the section 3 km north of Barus. Generally speaking sedimentary structures in carbonate rocks reflect strongly the condition of weathering, which favored preservation in the Guryul ravine section. Guryul ravine seems to be one of the best places for studying sedimentary structures in carbonate rocks as clearly shown in many photographs in the present paper.

The occurrence of the carbonate layers at Guryul ravine is briefly summarized in Table 15.

Excluding Member B of the Zewan Formation, carbonate rocks are major constituents in both the Permian and Triassic sequences. Their bedded features, alternations of carbonate and argillaceous layers and the evidence of current sorting and stratification indicate mechanical deposition. Especially in Member C of the Zewan, and all members of the Khunamuh, sedimentary structures suggestive of turbidity currents are common, as enumerated below. Bioturbation, frequently encountered in sandy shales and non-calcareous, muddy sandstones of the Zewan, is rarely observed in the carbonate layers. This may be related to more rapid and intermittent deposition of carbonate materials in the sedimentary basin.

Table 15. Occurrence of carbonate layers at Guryul ravine

	lithofacies	bed-thickness of carbonate layers
Khunamuh	rhythmic alternation of limestone and shale (developing in abundant sedimentary structures)	5–20 cm
Member D	thick bedded sandy limestone (large-scale convolute bedding and nodular limestone in the uppermost part)	thick-bedded
Member C	rhythmic alternation of calcareous sandstone and sandy shale (developing in sedimentary structures)	10–20 cm
Member B	poor in carbonate rocks, only in the upper part alternations of calcareous sandstone and sandy shale	10 cm
Unit A_4	(upper) thin-bedded limestone in sandy shale	5–10 cm
	(lower) calcareous sandstone with thin shale	5–10 cm
Unit A_3	poor in carbonate rocks	
Unit A_2	thick-bedded sandy limestone, in the upper part alternating with thin shale (sometimes parallel and cross laminated)	thick-bedded
Unit A_1	(upper) alternation of sandy limestone and shale	10–20 cm
	(lower) thick-bedded, calcareous sandstone (with exotic pebbles)	thick-bedded
Gangamopteris Bed	(lower) pelletal or oolitic limestone (now altered to novaculite)	

1) Member C and Members E to I consist of repetitive sequences of carbonate and argillaceous layers.

2) The lower boundaries of carbonate layers are sharp and sometimes erosional, while the tops are sometimes in an indistinct gradation to the overlying shale.

3) Many layers are characterized by a vertical size-grading, an upward diminishing of grain-size.

4) Internal sedimentary structures found commonly in the turbidites are developed in these layers, such as grading (and/or massive), parallel lamination, cross lamination (or current-ripple lamination) and convolute lamination. Furthermore their vertical association in a single layer is in agreement with BOUMA's (1962) idealized sequence of turbidite, although in many cases all intervals (a–e intervals) are not completely developed.

5) Fossils in the carbonate layers are more or less fragmented and are arranged

parallel to the bedding plane, suggesting their transported origin. Especially in the Khunamuh Formation bivalve and ammonoid shells are usually concentrated in the lower half of a limestone layer constituting the graded interval and empty shells of ammonoids are arranged randomly occupying a main part of a layer as already mentioned.

Sole markings and trace fossils typically developed in the turbidites are few in this region, but such evidences may suggest that these layers were deposited as carbonate turbidites in the sedimentary basin as reported by several authors, such as KUENEN (1956), MEISCHNER (1964), SESTINI (1970) and SCHOLLE (1971) in Alpine geosynclines, CRIMES (1973) in North Spain, and DAVIES (1968) in the present day oceanic basin. SCHOLLE described Cretaceous carbonate turbidites in Northern Appenines composed mainly of materials finer than medium silt, but occurring in thick beds under one meter thick. In these turbidites a-interval is always lacking, b-interval is rarely found, and c- and d-intervals are commonly developed. DAVIES reported the carbonate turbidites recovered from cores of Pleistocene-Recent sediments in the abyssal plain of the Gulf of Mexico. Each layer is 2–120 cm thick, composed of calcisiltite and calcilutite in addition to a small amount of calcarenite. The sedimentary structures are constituted by c-, d- and e-intervals, lacking in a- and b-intervals. On the basis of WALKER's (1968) definition of proximal and distal turbidites, these layers were appropriately called distal turbidites. Compared with these instances, the carbonate layers of Member C of the Zewan Formation are richer in coarse materials and have lower BOUMA-intervals (a- and b-intervals), which may be assigned to a proximal turbidite. On the other hand most limestone layers in the upper horizons of the Khunamuh (F to I Members) may be classed as distal turbidites because of the dominantly fine materials and upper BOUMA-intervals. Turbidites of intermediate type between proximal and distal types are found in the lower part of Member E. To confirm the turbidity current origin, two samples were selected for detailed observation as described in the next section.

2. Sedimentological study of two selected carbonate layers —Turbidity current origin —

Bed 55 of Unit E_2 and Bed 65 of Unit E_3 were carefully examined under the microscope after a preliminary inspection under the unaided eye.

(1) Bed 55 (Plate 9 and Text-fig. 13)

Bed 55 is a multiple bed composed of two units (55–a and 55–b). The unit 55–a is massive in the lower part. Many shell-fragments are concentrated in this part. It changes gradually upward to weakly parallel laminated interval decreasing shelly materials, and cross lamination is partly observable. Then, with a sharp and slightly erosional contact, it is succeeded by pelitic interval of calcilutite. Faint parallel lamination is found in the last interval under the microscope, although these cannot be detected with the naked eye. The unit 55–b overlies the preceeding layer with a sharp and erosional contact, and a small vertical burrow about 1 mm in diameter is found at the bedding plane. The unit 55–b can be divided into three intervals, such as graded, parallel laminated and faintly cross laminated intervals in ascending order. The mutal relations are gradational. Shell fragments decrease in amount upward as in the lower unit. This unit is succeeded by another black shale layer with a distinct boundary.

Thin-sections were made parallel and perpendicular to the bedding plane as shown in Text-figure 13 for precise examination. Plate 9 is a composite photomicrograph of Bed 55 obtained from vertical thin-sections, showing continuous textural and structural changes. For the amount of terrigenous detrital grains, the median and quartiles were obtained by measuring about 200 grains. Determination was made in each thin-section parallel to the bedding plane. Calcite grain-size was also examined in each thin-section. The results are shown in Text-figure 13.

(2) Bed 65 (Plate 10, Fig. 6 and Text-fig. 14)

Bed 65 has typical sedimentary turbidite structures, which can be clearly observed on the weathered surface. These structures are divided into three intervals: parallel lamination in the lower, current ripple lamination in the middle and convolute lamination in the upper part, as shown in Plate 10, Fig. 6. Another parallel laminated zone seems to develop between the current-ripple and convolute-laminated intervals. The graded interval is lacking in the present layer. The base of the layer shows a sharp contact with underlying shale. The bed is overlain by pelagic shale with a sharp and flat boundary, which may be an eroded surface.

Eighteen thin-sections parallel to the bedding plane were examined. The maximum terrigenous grain-size instead of grain-size distribution was determined in each thin-section because terrigenous detritals are very small in amount being less than a few percent in each thin-section. Mean calcite grain-size was also determined.

The followings were clarified by the above two observations.

1) The carbonate layers have a sharp and erosional contact with underlying layers, which can be clearly observed in units 55–a and 55–b.

2) Internal sedimentary structures such as grading, parallel lamination, cross (or current-ripple) lamination and convolute lamination are clearly observed. The succession is in good accordance with the BOUMA's turbidite sequence. Although graded structure cannot be observed in Bed 65 with the naked eye, its existence was confirmed by thin-section analysis.

3) In units 55–a and 55–b the size distribution of terrigenous detrital grains (mostly quartz), and in Bed 65 the maximum grain-size were determined under

the microscope in successive thin-sections. However, these occupy only less than 5 percent of the total composition in each thin-section. The results shown in Figs. 13 and 14 seemingly show an overall upward fining of texture in the carbonate layers. In the major part of each carbonate layer, the mean grain-size of carbonate grains was roughly determined under the microscope in each thin-section. The results are also shown in the same figures. It can be inferred that there exists a tendency for decreasing in grain-size upward in unit 55–a and 55–b, although in Bed 65 no significant trend was found.

It can be safely concluded that these layers were deposited secondarily as car-

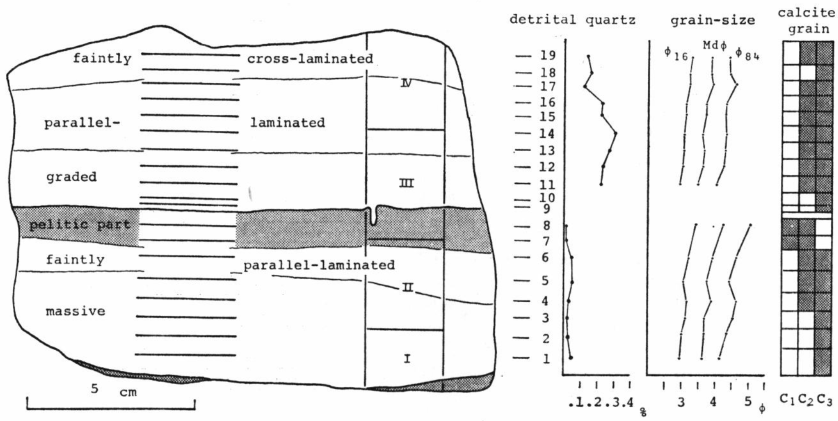


Fig. 13. Sketch of cross section of a limestone layer of Bed 55 showing the position of horizontal and vertical thin-sections (left), and results of thin-section analyses (right). (See also Pl. 9)

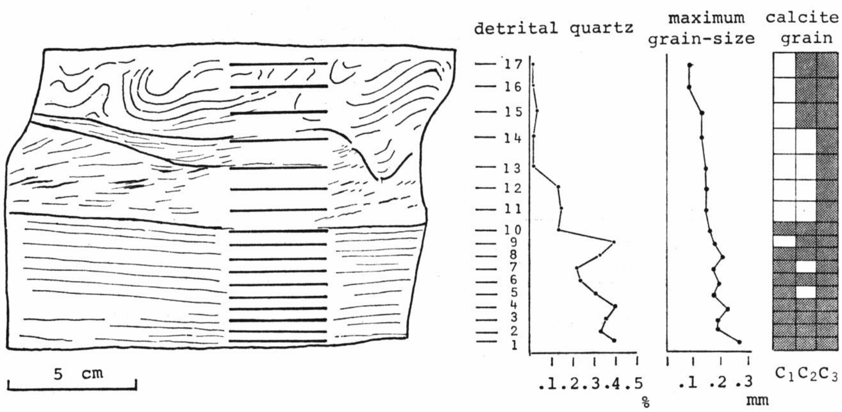


Fig. 14. Sketch of weathered surface of a limestone layer of Bed 65 showing the position of horizontal thin-sections (left), and results of thin-section analyses (right). (See also Pl. 10, Fig. 6)

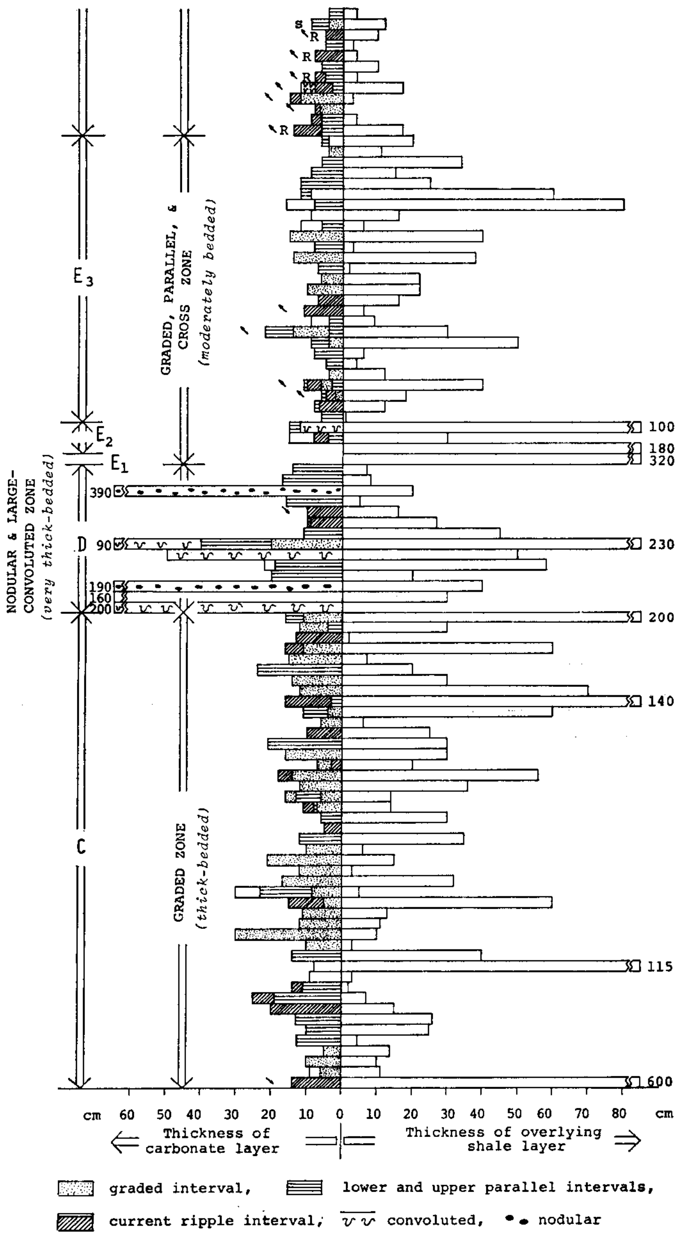
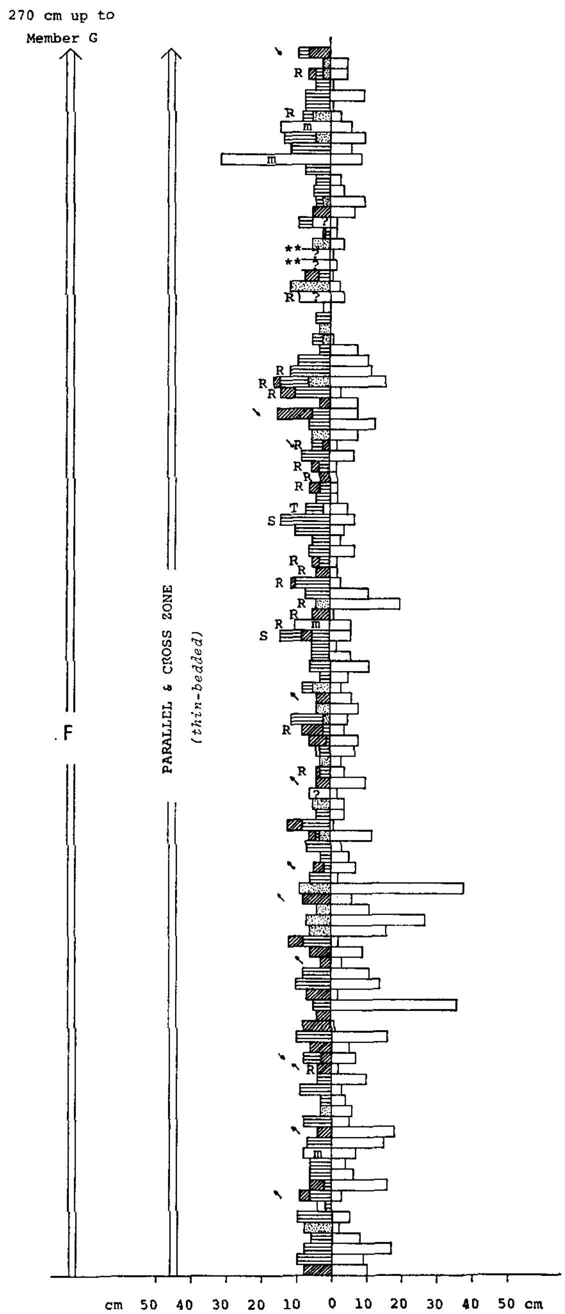


Fig. 15. Figure showing the results of sedimentological analyses on carbonate layers near the Permian-Triassic boundary. Arrow indicates a relative sense of paleocurrent direction. (See text)


270 cm up to
Member G
F
PARALLEL & CROSS ZONE
(thin-bedded)
cm 50 40 30 20 10 0 10 20 30 40 50 cm

bonate turbidites in the deeper sedimentary basin along with pelagic lutites.

3. Bed thickness and sedimentary structures of the carbonate layers near the Permian-Triassic Boundary

Sedimentary features near the Permian-Triassic boundary at Guryul ravine were closely examined, from Member C of the Zewan Formation to Member I of the Khunamuh, 150 m in total thickness. The thickness of carbonate layers and alternating muddy layers was measured bed by bed successively and sedimentary structures of the former were also described. The results are collectively shown in Fig. 15. Generalized results are shown in Fig. 12.

(1) Bed thickness

The bed thickness distribution of carbonate layers is distinctive for each member. In Member C, the carbonate layers are 5 to 30 cm thick, about 15 cm in average. In Member D they are usually thicker than 1 meter with several layers 10 to 15 cm in thickness. On the other hand, Member E is composed of thin carbonate layers about 5 to 10 cm thick, a strikingly abrupt change from Member D. In Member F they have a constant thickness of about 5 cm, showing rhythmic alternations with shale, in which multiple (or composite) carbonate layers are frequently found. Although we did not make a close study of Members G, H and I, the first two have characteristics similar to Member F, and in Member I the carbonate layers become slightly thicker than in the preceeding members.

It is worth stressing that the change of the thickness of carbonate layers from Member D to E is very remarkable, suggesting an abrupt change of sedimentary environment or condition of source areas near the Permian-Triassic boundary.

(2) Internal sedimentary structures

Internal sedimentary structures of the carbonate layers in Member C of the Zewan Formation and Members E and F of the Khunamuh were examined in the field bed by bed by TOKUOKA and KAPOOR. The structures were divided into three classes: grading (or massive structure), parallel lamination, and cross lamination (and/or current-ripple lamination). The convolute lamination, which is sometimes found, was included in the last class. In parallel lamination there exist two intervals, lower parallel and upper parallel. The results are collectively shown in Fig. 15.

The examined sequence can be divided into several parts on the basis of sedimentary structures. It is apparent that there exists a close relation between this and the lithostratigraphic criterion. Furthermore, it is apparent that there is an intimate relation between the properties of sedimentary structure and bed thickness. The lithostratigraphic units from Members C to I are characterized by their respective internal sedimentary structures and bed thickness as summarized in the following:

	sedimentary structure	bed thickness
Member I	parallel and cross laminations	moderate
Members F, G, H	parallel and cross laminations	thin
Member E	grading, parallel and cross laminations	moderate
Member D	nodular and large-convoluted	very thick
Member C	grading and massive	thick

(3) Paleocurrent direction

Sole markings were not found except for a scour-and-fill structure in Member E at Guryul ravine. Ripple marks are sometimes observed at the top of the carbonate layers. Cross lamination and/or current-ripple lamination are developed frequently as internal sedimentary structures. The crests of ripple marks are asymmentrical and relatively straight but discontinuous. The trend could be measured only in two layers. One was N60°W, in Member C, the other, S40°E in Member E. In these layers the trend of ripple marks and the orientation of cross laminations are in good accordance with each other. The orientation of cross laminations was roughly estimated in the field observation. The results are collectively shown in Figs. 12 and 15. In Members C and D, current-ripple laminations are developed only in a few layers, having a NW to SE dip, while in members E and F they are developed frequently, having dip direction mainly of SE to NW and sometimes the reverse direction. It may be inferred from the above-mentioned observation that there might have been some changes in the sedimentary basin between the Zewan and Khunamuh Formations, although such estimation must be confirmed by future detailed paleocurrent analysis.

The differences of carbonate layers in Member C of the Zewan and the Khunamuh Formation are briefly summarized here. Member C contains a greater frequency of thick-bedded layers than the Khunamuh, and the lower BOUMA-intervals (a- and b-intervals) also tend to occur more frequently in the former. As stated in the preceeding chapter, the fossil content and amount of terrigenous grains are very different between the two, that is, more thick-shell fragments and more terrigenous detritals in the former than in the latter, although calcite grain-size is not so different. Furthermore the layers that alternate with the carbonate layers are quite different between the two. Those of the Zewan Formation consist of micaceous sandy shales frequently intercalated with laminated, non-calcareous sandstones or siltstones, while the Khunamuh Formation is mostly composed of black shale, in other words, pelagic lutites. Only a few thin layers of fine sandstone and siltstone are intercalated in units E_1 and E_2. The type of biogenic sedimentary structures commonly found in the Zewan is not typical for turbidites as described by SEILACHER (1967) and others, but the Khunamuh is almost lacking in trace fossils.

Sedimentary environment

The Panjal volcanic rocks are considered to have erupted in places on the land and in other places on the sea floor. At Guryul ravine the latest eruption took place under subaqueous, presumably submarine condition.

The overlying Gangamopteris Beds are inferred to have been deposited in a shallow, calm embayment of the sea judging from a predominance of thinly laminated, siliceous shale and plant-bearing black shale. The presence of novaculite derived from oolitic limestone suggests the agitation by waves at certain times. The great variability of the beds in lithofacies and bed thickness first pointed out by HAYDEN (1907) and MIDDLEMISS (1910) suggests variable coastal environments around the Vihi plain during this stage.

The first stage of the Zewan represented by Member A at Guryul ravine and Member a 3 km north of Barus, we think, indicates a shallow neritic sea as judged from the sedimentary texture, composition, and fossil contents and their distributions. The materials are mostly composed of skeletal remains, and calcareous muddy matrix. The texture reminds one of a fore-reef environment, but no biolithite fragment can be seen in the carbonate layers at Guryul ravine and scarse in Barus section.

The second stage is represented by Members B and C or Members b to d. This stage is characterized by rich terrigenous clastic sediments, of which the later stage (Member C and Member d) is distinguished from the earlier stage by frequent intercalations of carbonate beds, but the sedimentary features of terrigenous clastic rocks of the latter are quite similar to those of the earlier stage. Although the carbonate layers of Member C, show sedimentary structures similar to those of turbidite, such as grading, and parallel or ripple lamination, the alternating sandy shale and sandstone and trace fossils in them do not suggest a deep bathyal or abyssal environment. Considerable variation of lithofacies around the Vihi plain during this stage is also more suggestive of shallow waters. Infra-neritic to shallow bathyal (frontal part of shelf-edge) environment may be preferred for this stage.

The last Zewan stage is again characterized by a development of carbonate rocks, in Member D. Thick bedding and convolution, small slump structures and nodular structures distinguish this stage from the carbonate layers of preceeding stages. The grain-size of terrigenous clastic materials tends to increase. These characteristics suggest the uplift of the land and probably shallowing of the sea. A swarm of vertical burrows, about 10 mm in diameter, in Member e, and large-scale wavy lamination, in Member D, are considered to be indirect evidence of shallowing, but there are no signs of emergence above sea-level.

The rapid deepening of the sedimentary basin in the next Khunamuh stage is indicated by the common occurrence of typical limestone turbidite alternating with black shale, probably of pelagic origin, especially in Unit E_3 and later stages. A relatively uniform lithofacies of the Khunamuh around the Vihi plain supports such origin of sediments. Marked contrast in lithology and lithofacies and paleocurrent direction between the Zewan and the Khunamuh indicates a remarkable change in the sedimentary regimen. Decrease of rounded and well-rounded quartz grains in the Khunamuh, as compared with the Zewan also harmonizes with the general conclusion.

VIII. Conclusion

The Upper Permian-Lower Triassic strata at Guryul ravine and a spur 3 km north of Barus in Kashmir are continuous without any evident hiatus. They are classified into two formations, the Zewan and the overlying Khunamuh. The lowermost part of the Khunamuh is lithologically transitional to but faunistically combined with the Zewan, and referred to as latest Permian.

The age of the Zewan Formation was a matter of debate among authors, but it becomes clear that the lowermost member is correlated to the Kalabagh Member of the Wargal Formation in the Salt Range, the *Lepidolina kumaensis* zone in Japan, and the lower Wuchiaping in south China by brachiopods, bryozoans, and especially by small foraminifera belonging to *Colaniella* and *Abadehella.* The main part of the Zewan is compared to the Chhidru Formation by assemblages of ammonoid, bivalve, gastropod, and conodont, and the two are correlated with the upper Wuchiaping in China and the lower Dzhulfian (Araksian) in Iran and Armenia. The lowermost Khunamuh, which is probably lacking in the Salt Range, may represent the uppermost Permian, that is, the upper Dzhulfian (Dorashamian) or Changhsingian, although no characteristic ammonoids or fusulines of this stage could be found in this part.

Four ammonoid zones, in the overlying beds, *Otoceras-Glyptophicers, Ophiceras, Paranorites-Vishnuites,* and *Owenites-Kashmirites,* establish the Lower Triassic sequence in the Guryul ravine section, representing Otoceratan to Owenitan or Griesbachian to Smithian.

The lowermost Zewan is characterized by a crinoid-bryozoa-foraminifera-brachiopod assemblage. This assemblage is replaced by bivalve-brachiopod-gastropod assemblage of Members C and D through unproductive Member B. This change coincides with lithological change, that is, a rapid increase of terrigenous clastic materials.

The greatest faunal change took place in the lowermost Khunamuh, that is, between *Etheripecten haydeni-Claraia bioni* zone of Unit E_1 and the *Otoceras-Glyptophiceras* zone of Unit E_2. Almost all the characteristic Permian species disappeared at the end of Unit E_1; only a few specimens of *Claraia bioni, Etheripecten haydeni, Marginifera himalayensis* and *Pustula* sp. occur in the basal part of the *Otoceras* beds.

The conodonts pose an exception. *Anchignathodus typicalis-Neogondolella carinata* assemblage is found from the upper Zewan (*Cyclolobus walkeri* horizon) to the *Otoceras* beds of the Khunamuh. The upper Zewan fauna is completely replaced by the ammonoid-bivalve assemblage of the Khunamuh. It seems be reasonable to draw the system boundary at the base of the *Otoceras-Glyptophiceras* zone.

The sedimentary environment was estimated by sedimentological study. The shallow, neritic environment of the early Zewan stage changed to somewhat deeper condition in the middle, and again became shallow in the late Zewan but not emerged above sea. In the earliest Khunamuh stage, the basin was rather rapidly deepened to probably bathyal environment. The contrast of lithofacies between the Zewan and the Khunamuh is remarkable, but no signs of disconformity could be detected. The great faunal change was, at least partly, related to such environmental change, which occurred during very short time. But more detailed comparative studies are needed in other parts of the world to clarify the true cause or causes of mass extinction of organisms.

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Explanation of Plates 1-12

(All the photomicrographs are taken under parallel nicols, unless otherwise indicated.)

Plate 1

Upper Permian Zewan (A–D) and Lower Triassic Khunamuh (E–J) Formations at Guryul ravine, and distant view of Panjal Volcanic Rocks and Gangamopteris Beds (left hand) and Middle and Upper Triassic (right hand).

Plate 2

Figure 1. Novaculite of Gangamopteris Beds (Bed 6) retaining pelletal and/or oolitic structures which suggest the alteration from limestone. Double bar, 1 mm.

Figure 2. Siliceous shale of Bed 7 (Gangamopteris Beds) with styloritic seam developed parallel to bedding plane. Solid bar 0.5 mm.

Figure 3. Alternation of finely laminated siliceous shale and laminated black shale of Gangamopteris Beds (Bed 8).

Figure 4. Photomicrograph of siliceous shale (Bed 8). Black spots are aggregate of secondary zoicite. Double bar, 1 mm.

Figure 5. Bedded carbonaceous shale containing Lower Gondwana flora of Gangamopteris Beds (Bed 12).

Figure 6. Bedded siliceous shale of Gangamopteris Beds (G) and overlying thick calcareous sandstone of Zewan (Z). The uppermost 30 cm part of the former is crushed, indicating some dislocation along the boundary.

Plate 3

Figure 1. Calcareous sandstone of Member A of Zewan Formation (Bed 14). Rounded clasts of granite, quartzite and others are sporadically included in the lower part of the bed. Solid bar, 5 cm.

Figure 2. Photomicrograph of sandy limestone of Bed 14. Fragments of bryozoa, algae, and foraminifera are commonly found. Rounded quartz grain in the lower right is noticeable. Double bar, 1.0 mm.

Figure 3. Photomicrograph of calcareous sandstone of Member A (Bed 18–1). Terrigenous detrital grains are mostly subangular to subrounded quartz. Solid bar, 0.5 mm.

Figure 4. Fossiliferous limestone (biosparudite) of Member A (Bed 19). Brachiopod shells are arranged parallel to the bedding plane in the lower two-thirds, and slightly obliquely in the upper one-third.

Figure 5. Exposure of Member A of the Zewan (Units A_2 to A_4). A white layer of the lower part (a) is Bed 19. Units A_3 and A_4 are composed mainly of micaceous sandy shales and shales intercalating several calcareous sandstone beds.

Plate 4

Figure 1. Close-up of sandy shale of Member B. Platy parting resulted from parallel arrangement of detrital micaceous flakes is well developed.

Figure 2. Bioturbation (burrowing) of laminated, non-calcareous, muddy sandstone of Member B (Bed 23). Solid bar, 5 cm.

Figure 3. Thick-bedded calcareous sandstones of Member C (Bed 30).
Figure 4. Photomicrograph of calcareous sandstone of Member A (Bed 23). Terrigenous grains are mostly quartz, some of which are rounded. Micaceous flakes are commonly contained in parallel arrangement. Solid bar, 0.5 mm.
Figure 5. Close-up of a calcareous sandstone layer of Member C (Bed 27), showing parallel lamination in the main and cross lamination in the uppermost portion.
Figure 6. Another close-up of Bed 27 about ten meters south of the preceeding figure, showing a burrow obliquely cutting the parallel lamination. Solid bar, 5 cm.

Plate 5

Figure 1. Micaceous sandy shale of Member C (Bed 26). Parallel and cross laminated, discontinuous sandstone seams are frequently intercalated.
Figure 2. Bioturbated calcareous sandstone of Member C (Bed 27).
Figure 3. Photomicrograph of calcareous sandstone of Bed 28 (Member C). Terrigenous detrital grains are mostly quartz, sometimes rounded. A foraminiferal test (F) is visible at the center.
Figure 4. Upper surface of a calcareous sandstone layer of Member C (Bed 28), showing many burrows perpendicular to the bedding surface.
Figure 5. Polished cross section of a laminated sandstone layer of Member C (Bed 29), quartzose and slightly calcareous. Detrital micas are concentrated in the muddy lamination. Parallel lamination is disturbed by burrow. Ripple mark is seen on the upper surface.
Figure 6. Photomicrograph of a part of burrow of Fig. 5, showing a bending of muddy lamina by burrowing.
(Solid bars of Figs. 1, 2 and 5, indicate 5 cm, solid bar of Fig. 3, 0.5 mm, and double bar of Fig. 6, 1.0 mm)

Plate 6

Figure 1. Photomicrograph of quartzose sandstone of Member D (Bed 37), micaceous and slightly calcareous. Some of quartz grains are well rounded.
Figure 2. Photomicrograph of sandy limestone (biomicrudite) of Member D (Bed 38). Terrigenous grains are mostly quartz.
Figure 3. A sandstone layer of Member D (Bed 34) intercalated in sandy shale, parallel and cross laminated with ripple mark on the surface.
Figure 4. A sandstone layer of Bed 44 (Member D), showing parallel and weak cross laminations. Rippe mark is visible on the surface.
Figure 5. Convolute bedding of calcareous sandstone of Member D (Bed 41), presumably due to slumping. A yardstick at right hand is 1 m.
Figure 6. Nodular limestone of Member D (Bed 46).
(Solid bars of Figs. 1 and 2 indicate 0.5 mm; those of Figs. 3 and 4, 5 cm)

Plate 7

(Photomicrographs of Member D)
Figure 1. Calcareous sandstone of Bed 44.
Figure 2. Micaceous sandy shale of Bed 45.
Figure 3. Calcareous sandstone of Bed 46. Terrigenous grains are mosly quartz, sometimes well-rounded.
Figure 4. Sandy limestone of Bed 46 (biomicrudite).

Figure 5. A thin sandstone layer overlying Bed 46, quartzose and slightly calcareous, parallel laminated.

Figure 6. Enlarged photomicrograph of the preceeding figure. Well-rounded quartz grains are not a few.

(Solid bars indicate 0.5 mm; double bar, 1.0 mm.)

Plate 8

Figure 1. Exposure of the lower part of the Khunamuh Formation. a–b is a boundary of Units E_1 and E_2, that is, the Permian-Triassic boundary in the present paper. c–d is a boundary of Members E and F.

Figure 2. Close-up of alternation of limestone and shale of Unit E_3.

Figure 3. Photomicrograph of fossiliferous limestone of Unit E_1 (Bed 47), crowed with thick shells of brachiopods and bryozoans of Permian-type. Quartz grains are contained in small quantity.

Figure 4. Photomicrograph of limestone of Unit E_2 (Bed 52) showing thin shell-fragments of ammonoid. Quartz grains are scattered in it.

(Solid bars of Figs. 3 and 4 indicate 0.5 mm.)

Plate 9

Photomicrographs taken from serial thin-sections (I to IV) cut perpendicular to bedding plane, showing two sublayers of a limestone layer, Bed 55 (Unit E_2). I to IV correspond to respective number in column marked by two brocken lines of upper left figure. See text-figure 13 for further description. Double bar, 1.0 mm.

Plate 10

Figure 1. Photomicrograph of limestone of Bed 55, showing a small burrow at the sole of the upper sublayer of Pl. 9.

Figure 2. Photomicrograph of Bed 58 (Unit E_2), showing graded texture from limestone (biomicrite) to the overlying pelitic layer. Calcite grains, mostly micrite, become smaller in size and less in amount upwards.

Figure 3. Convolute and parallel laminations of a limestone layer of Bed 59 (Unit E_2).

Figure 4. Beautiful shark teeth belonging to *Helicampodus* collected from a floating block of Unit E_2.

Figure 5. Close-up of a limestone layer of Bed 65 (Unit E_3), showing lower parallel, ripple and convolution, and upper parallel laminations in a single layer.

Figure 6. A limestone layer of Bed 65 having parallel, current-ripple, and convolute laminations. See textfigure 14 for further description.

(Single bars indicate 5.0 cm; double bars, 1.0 mm.)

Plate 11

Figure 1. A limestone layer of Bed 60 (Unit E_3) showing cross lamination in the upper part. Ammonoid shells are sporadically contained in the middle and lower parts.

Figure 2. A limestone layer of Bed 62 (Unit E_3) showing graded texture made of shell fragments.

Figure 3. Polished cross-section of a limestone layer obtained from a floating slab of Member E. An empty shell of ammonoid stands vertically in the very fine-grained middle part between upper parallel and lower parallel intervals. The occurrence of ammonoid shells strongly suggests the transportation and rapid deposition by turbidity current.

Figure 4. A parallel laminated limestone layer of Bed 69 (Unit E_3).

Figure 5. A limestone layer of Bed 72 (Member F), showing a scour-and-fill structure with cross lamination at the base and development of parallel lamination in the rest of the bed.

Figure 6. A limestone layer of Bed 72 showing parallel and cross laminations.

(Solid bars indicate 5 cm.)

Plate 12

(Photomicrographs of limestones of the Khunamuh Formation)

Figure 1. Biomicrite of Bed 60 (Unit E_2) containing thin shell-fragments of ammonoid. Detrital quartz grains are scattered. Diagenesis is proceeded to considerable degree.

Figure 2. Biomicrite of Bed 73 (Member F) containing both thick and thin shell-fragments.

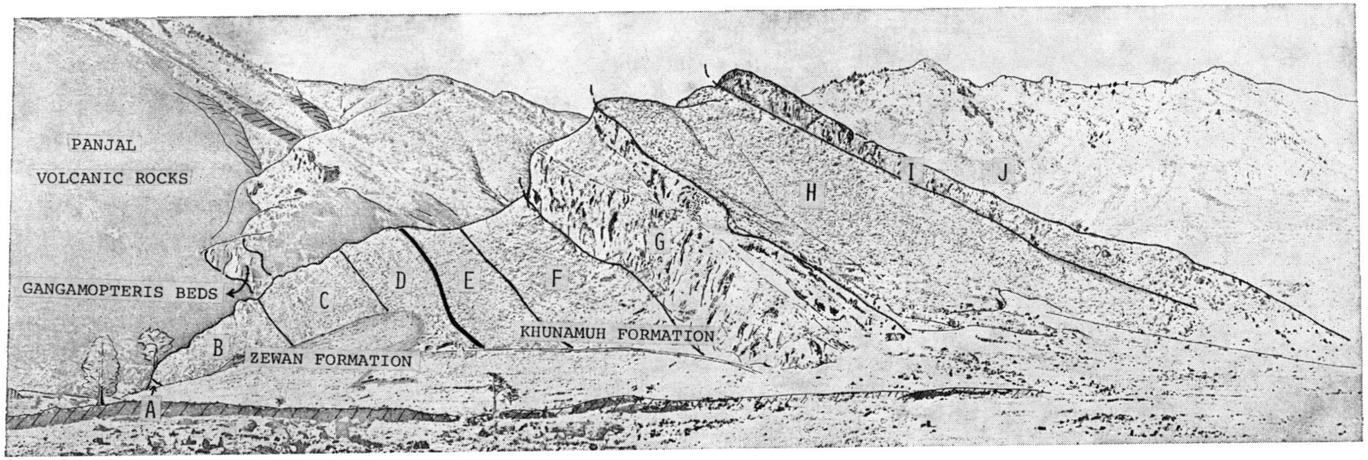
Figure 3. Biomicrite of Bed 84 (Member F) showing parallel lamination made by different grain-sizes of calcite.

Figure 4. Enlarged figure of the preceeding.

Figure 5. Biomicrite of Bed 75 (Member F) containing conodonts (black stripes).

Figure 6. Biosparudite of Bed 90 (Member H) composed of thick shells and sparry calcite cement (crossed nicols).

(Solid bars indicate 0.5 mm, and double bar, 1.0 mm.)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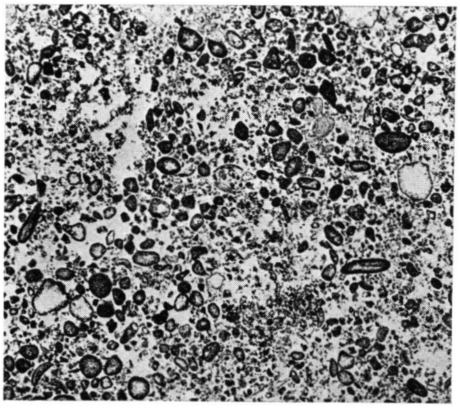

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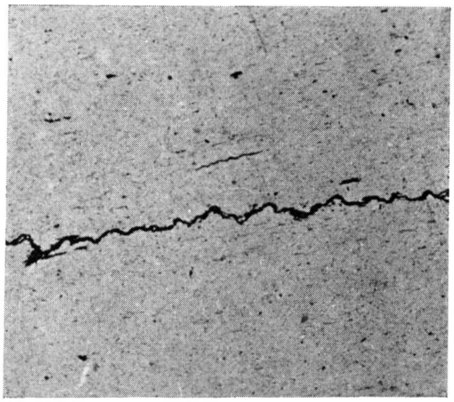

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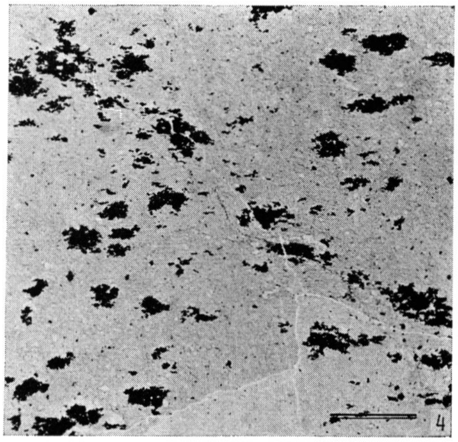

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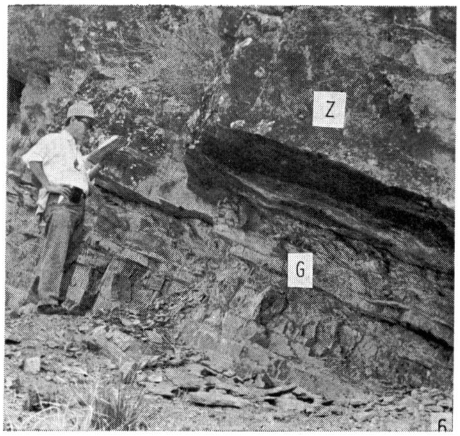

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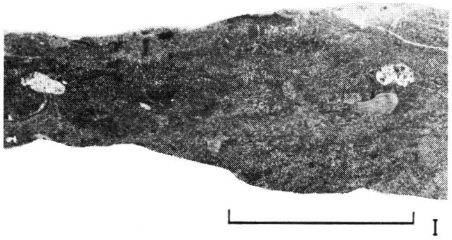

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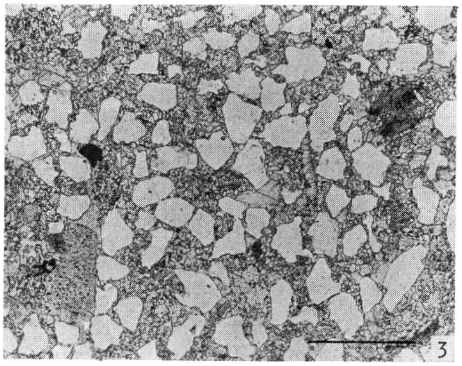

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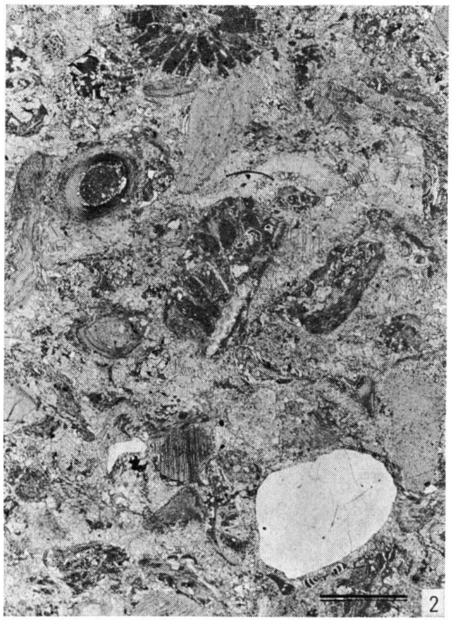

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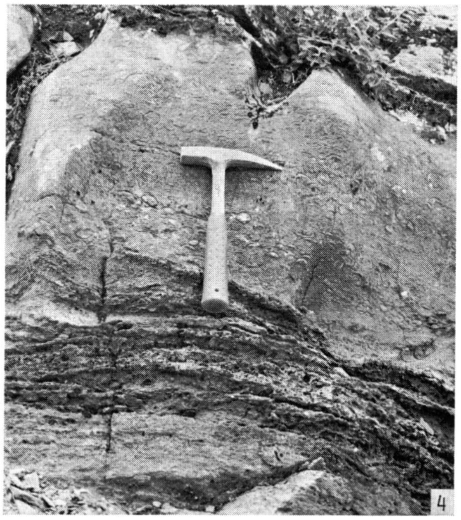

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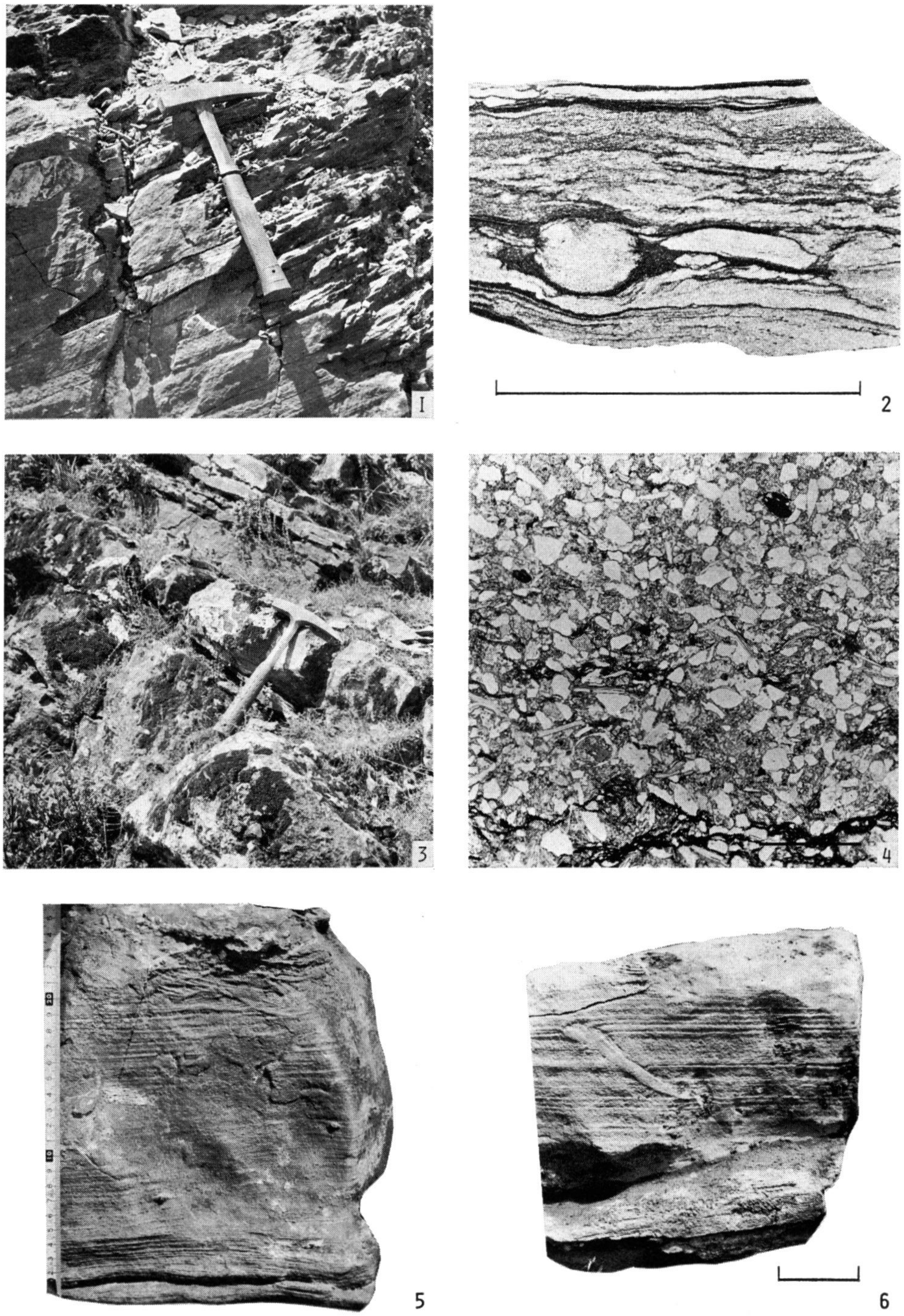

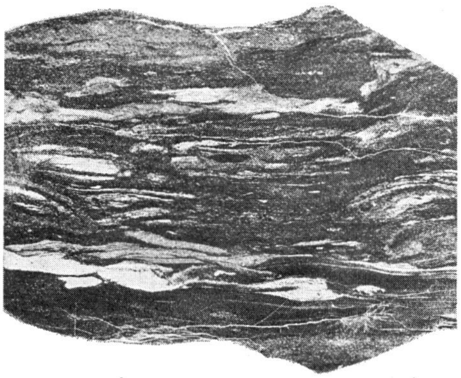

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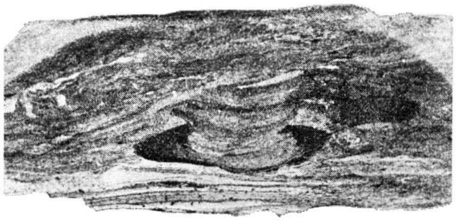

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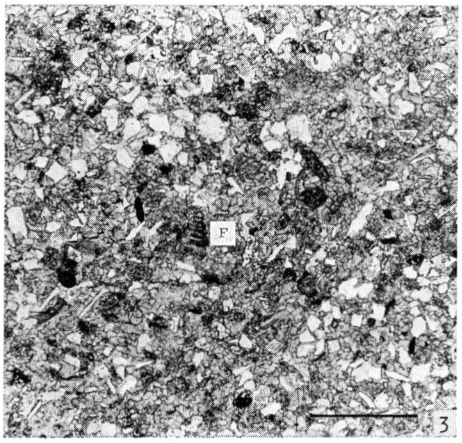

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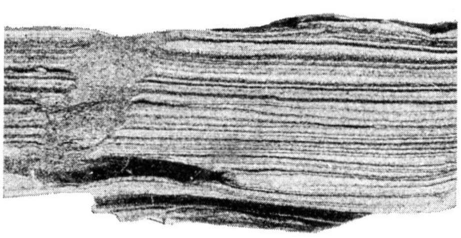

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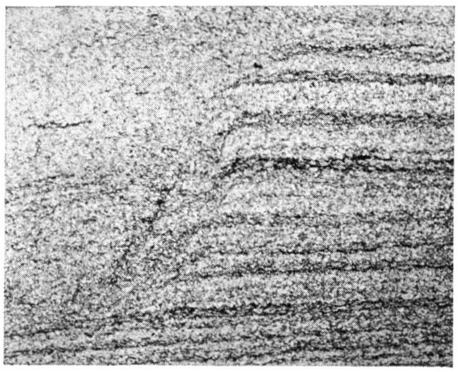

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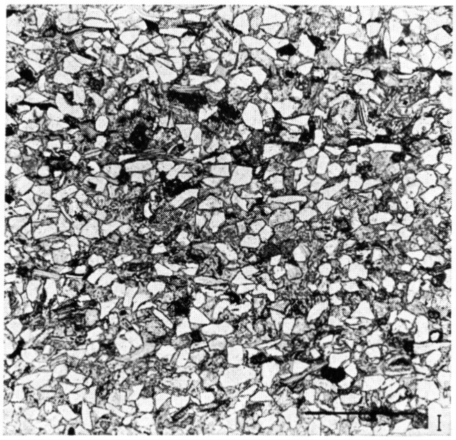

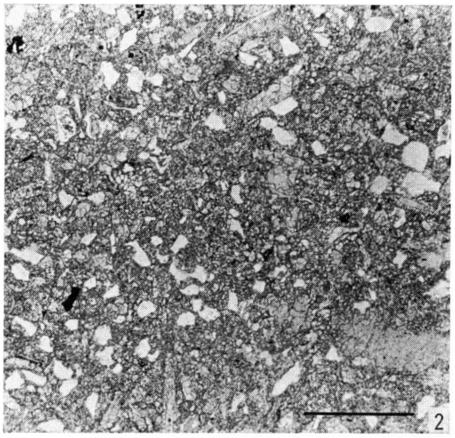

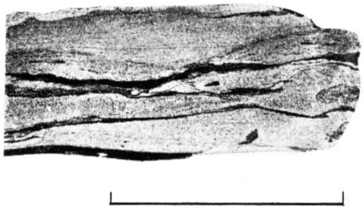

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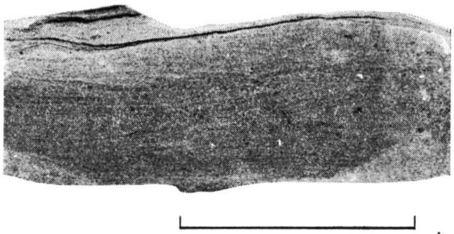

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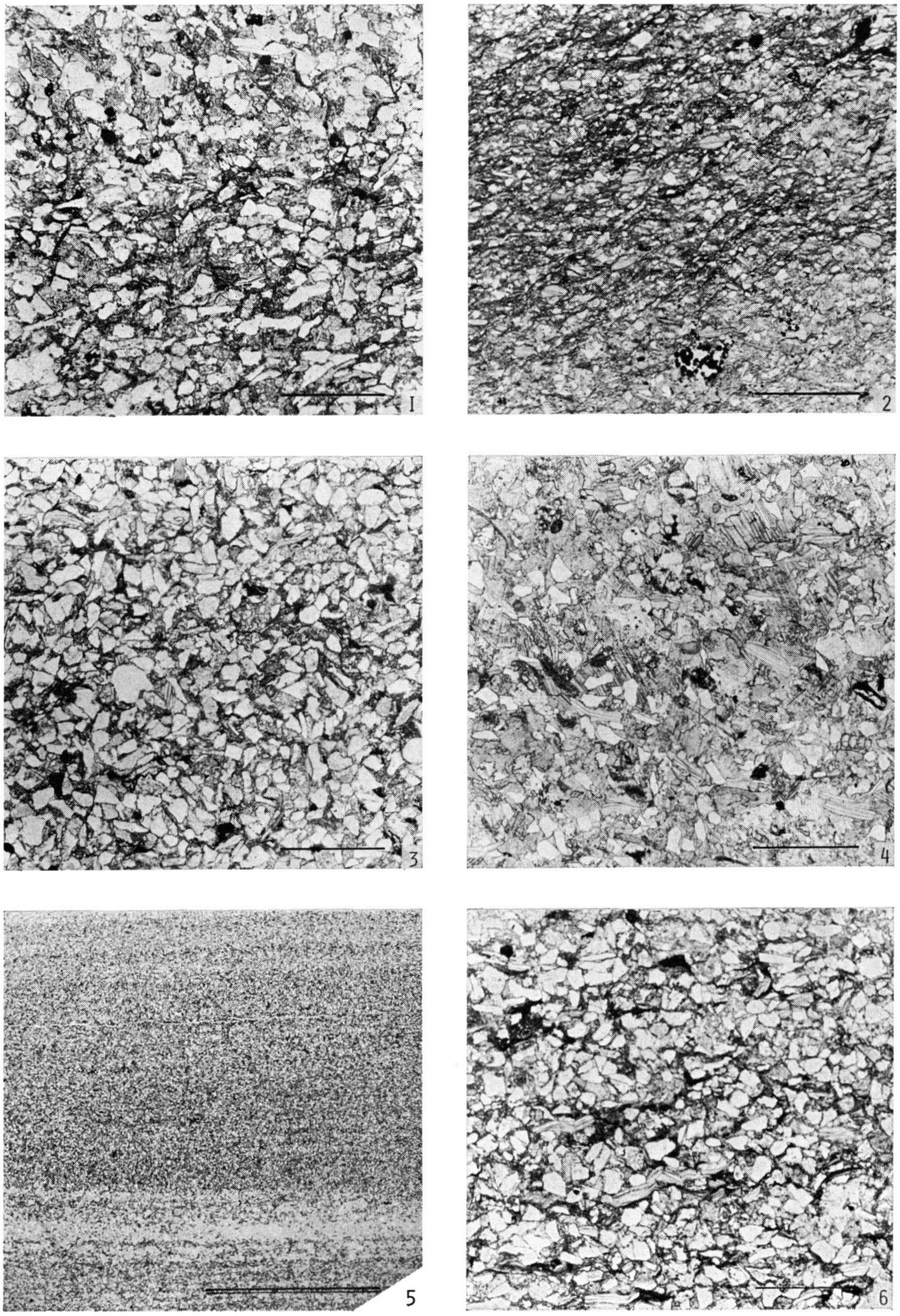
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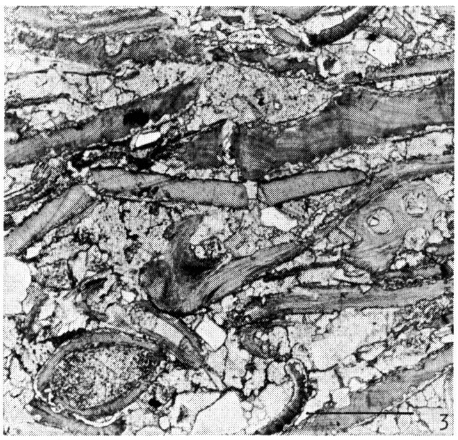

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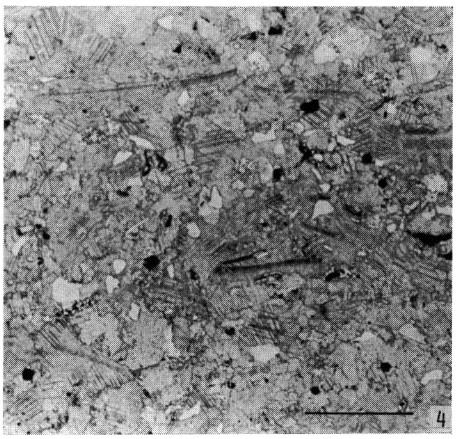

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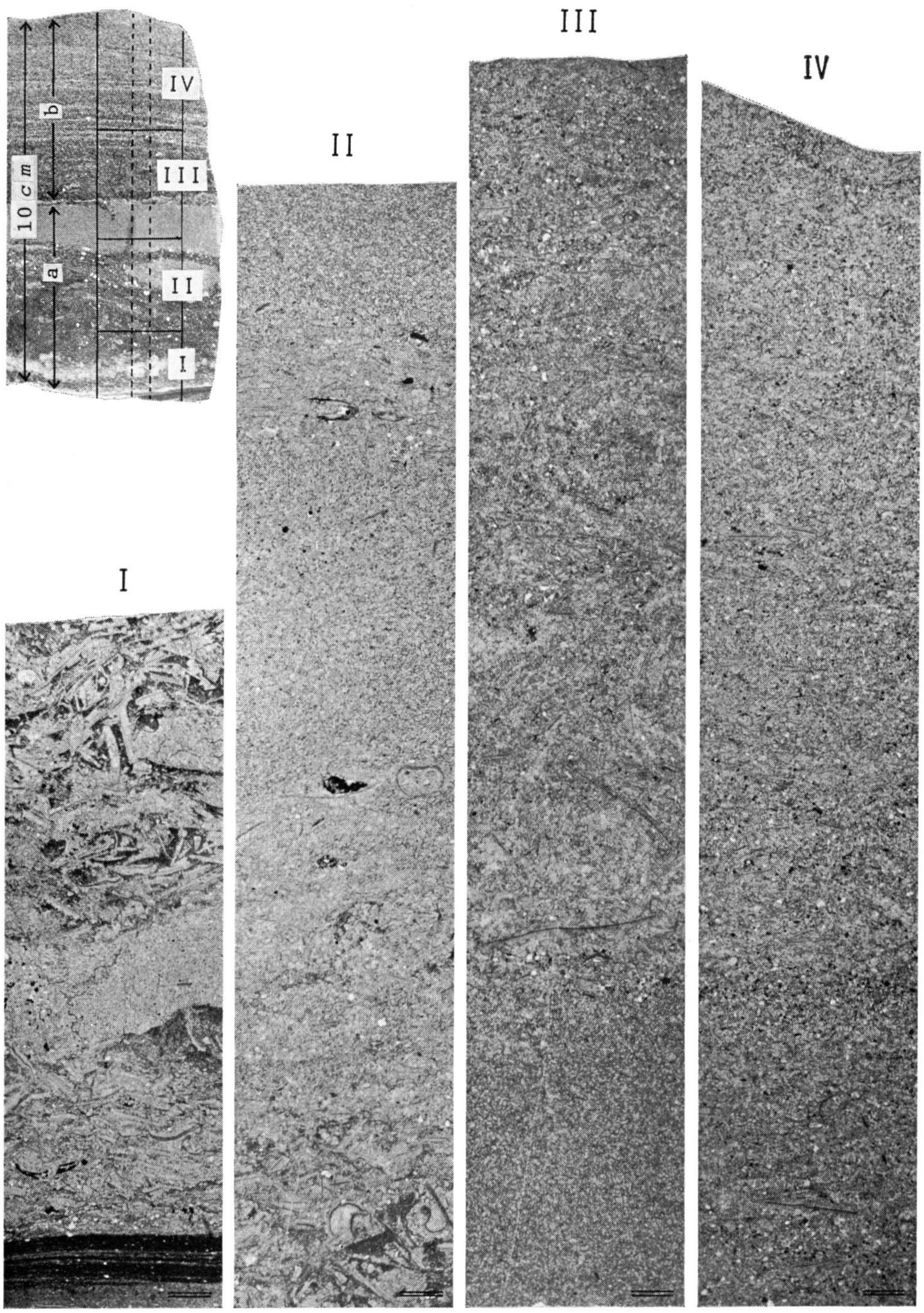
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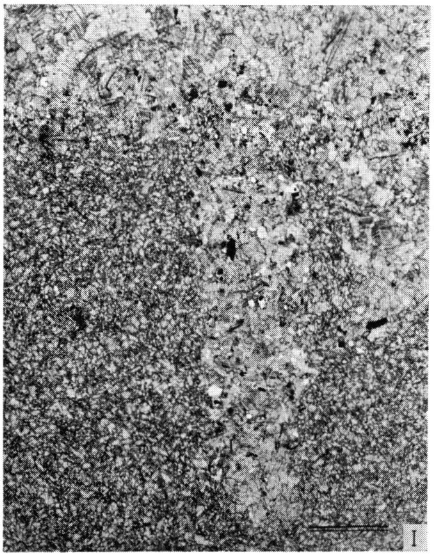

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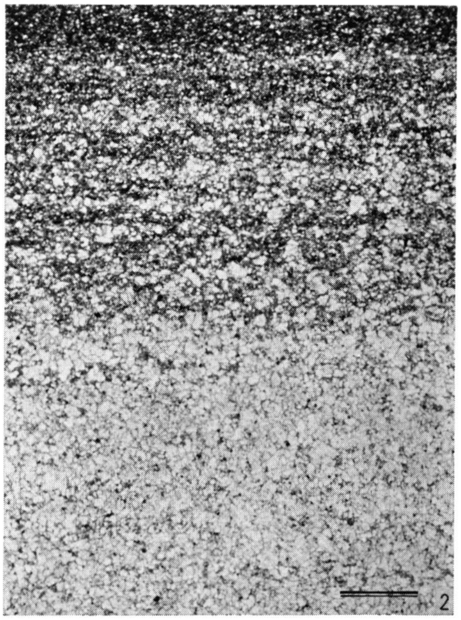

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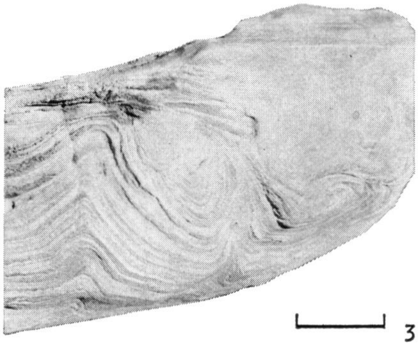

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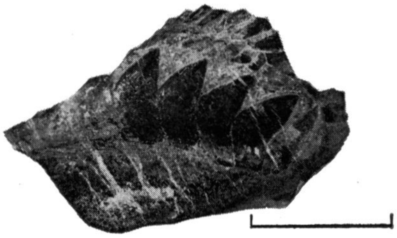

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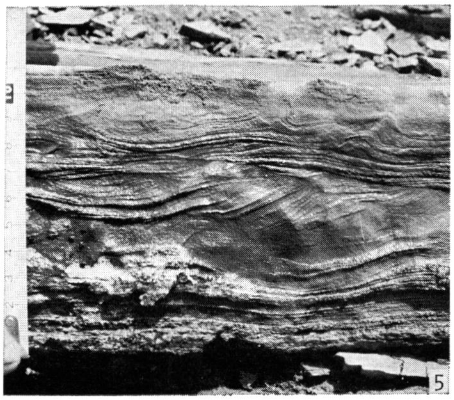

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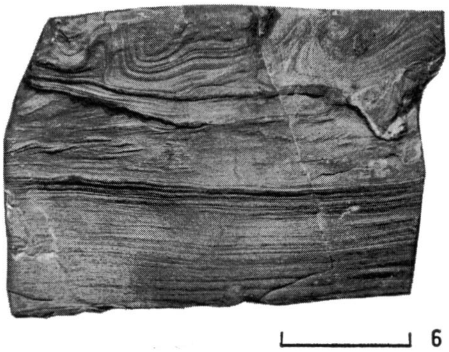

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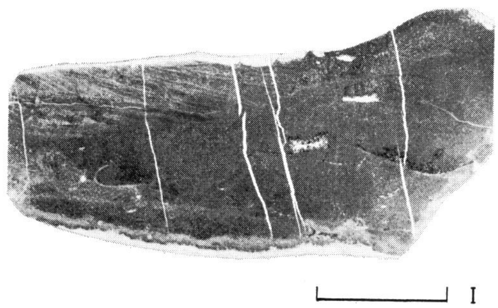

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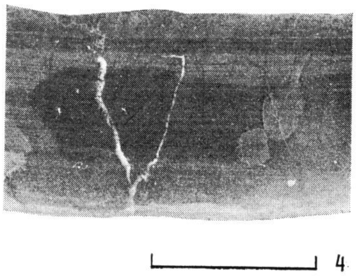

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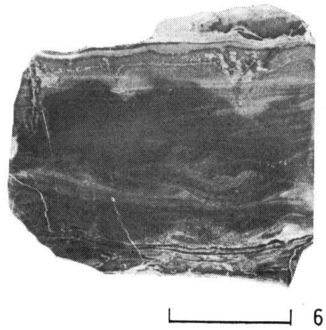

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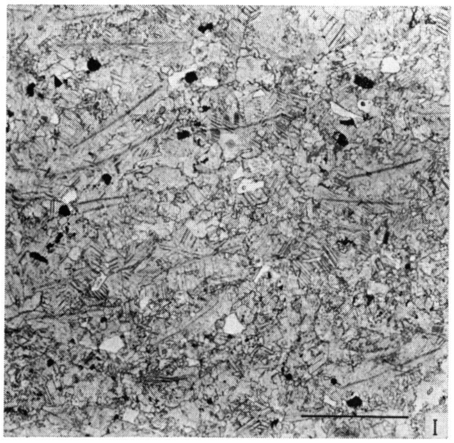
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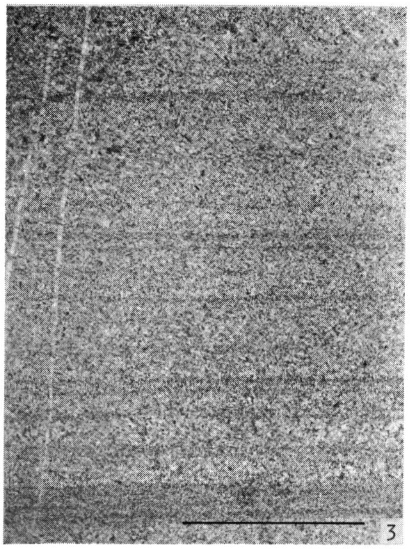
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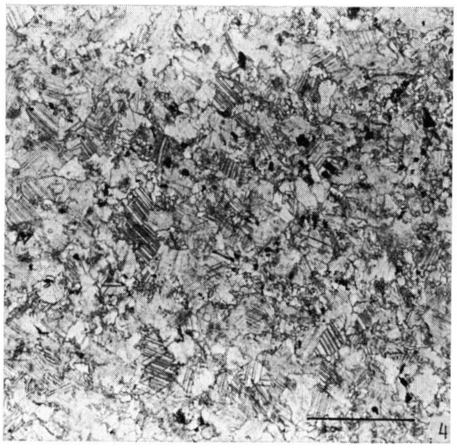
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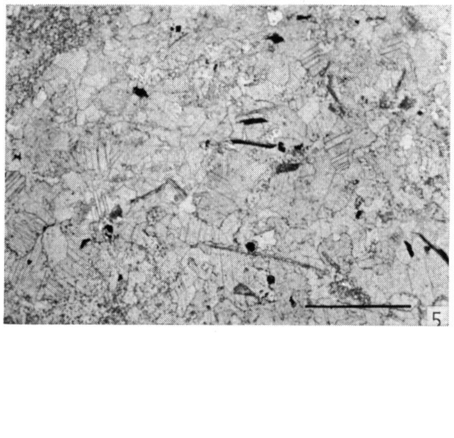
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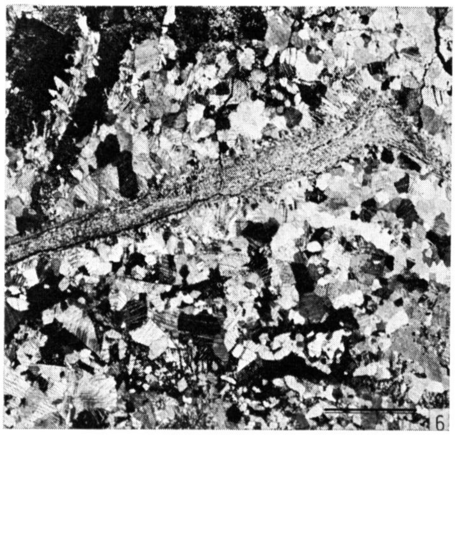
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