Journal of Nepal Geological Society, 1998, Vol. 18, pp. 197-203

Petrography and depositional environment of Permo-Triassic carbonates of Pahalgam Formation, Kashmir Himalaya, India

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ABSTRACT

The Permo-Triassic carbonates of the Pahalgam Formation are exposed in the vicinity of the Pahalgam area. The Pahalgam Formation is characterised by fossils like productus, bryozoans, *Spirifer Rajah*, crinoids and molluscs. The rocks of this formation are represented by white grey muddy limestones followed by grey crinoidal limestones with brachiopods and lamellerbranchs. The rocks extend towards, Chandanwari, Sheshnag, Amarnath Cave, Sonamarg and then to the Ladakh region of Jammu and Kashmir State. The outcrops of this formation, extending from the Pahalgam village up to Aru via Mammal village, can be traced along the Lidder River. The formation is equivalent to the well-known Zewan Formation of the Vihi district both in lithology and fossil assemblages. On the basis of lithology, the Pahalgam Formation has been divided into three units i.e. Pahalgam unit, Mammal unit, and Aru unit. Thin sections from each unit of the Pahalgam Formation were prepared for the present study and examined with respect to texture, framework grains, cementation and palaeo-petrographical criteria. The textural parameters used to indicate different energy levels in deposition of these carbonates were the attrition of the bivalve fossils (brachiopods and pelecypods) and the context of the sparite cement. The Pahalgam Formation is of platform type on which carbonate sedimentation took place during the Permo-Triassic times. It is a type of lime mud cycle with essentially low energy carbonate deposition, representing restricted open marine environment.

INTRODUCTION

A rock sequence of Permo-Triassic carbonates is well-exposed in the vicinity of the Pahalgam area, Kashmir Himalaya. It extends towards the rugged terrain and high altitudes of famous Amarnath Cave and onwards to the Ladakh region. The study area falls between the latitudes 34°05' to 34°15' N and longitudes 75°15' to 75°25' E (Fig. 1). Pahalgam, a famous tourist resort and base camp for the pilgrimage to the sacred cave of Amarnath, is situated at the junction of the Lidder and Sheshnag streams at a distance of 96 km from Srinagar.

This area of Kashmir Himalaya has remained untouched except some petrographic works done in some adjacent areas by Bhatia and Singh (1978), Bhatia and Bhat (1984). The works were mainly aimed to understand the physiographic build up and physio-chemical set up of carbonate sedimentation during the Permo-Triassic times by microfacies analysis. According to the model of Wilson (1975), this type of cycles is widespread feature of broad platform and interior of major offshore banks in which most of the deposition has occurred during the marine aggression.

In view of the proximity of the present study area with that of the Pirpanjal and Zewan formations exposed in northern slopes of the Vihi district and similarity of the nature of carbonates with crinoids, bryozoans, brachiopods, gastropods and calcareous sediments, it is presumed that the Pahalgam Formation was developed on a broader platform with low energy carbonate deposition.

The Permo-Triassic sequence developed in the adjoining Kashmir valley occurs in ellipse shaped

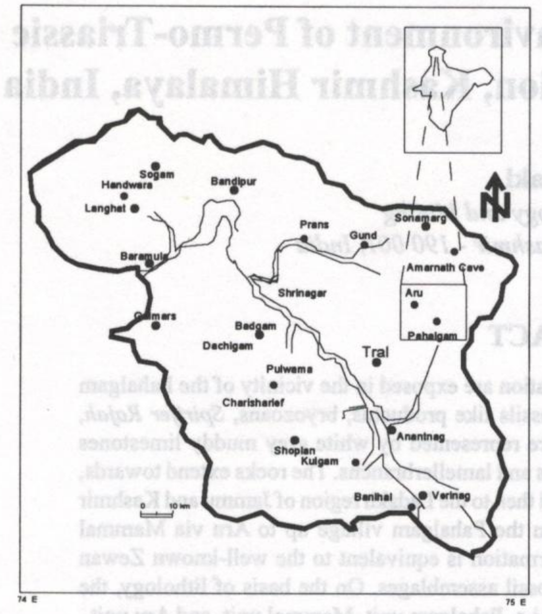

Fig. 1: Location map of Pahalgam and adjoining areas.

patches and stretches from northwest to the south end of Kashmir to Ladakh, where it merges into the Spiti sedimentary basin. The broader framework of classification of the Permo-Triassic sequence of Kashmir (Middlemiss, 1910) is modified by Grabau (1926), Teichert (1970), Nakazwa (1970), introducing the local nomenclature based mainly on faunal assemblages. In this paper, a lithostratigraphic classification within the Middlemiss's framework has been proposed to correlate various faunal units (Table 1).

TEXTURAL COMPONENTS OF CARBONATES

The presence or absence of lime mud and its percentage together with their grain size, percent framework, broken or intact fossils, grain to grain relations such as solution packing fabric, cement amount and kind of porosity constitute the textural peculiarities of the given carbonates. Dunhum (1962) emphasised the amount and kind of mud in a carbonate and recognised four major groups viz, mud supported, grain supported, lack of mud and grain supported and boundstones.

The Pahalgam Formation comprises of organic and skeletal grains, in situ organic structures, lumps and coated grains. Pore spaces are partially or completely filled up with calcite or sparry-calcite. In situ skeletons of bryozoans (colonial and encrusting) forms are present. In the present work, classification of Dunhum (1962) for textural properties and Folk's (1959) method of petrographic study and Wilson's model (1975) for depositional environment were taken into consideration. The skeletal detrital grains found in the Pahalgam carbonates are as follows:

Bryozoans

The Pahalgam carbonates are rich in bryozoans. Most of them occur as encrustation over carbonates (flat, hemispherical or irregular). The commonly found bryozoans are fenestrate in character. Bryozoans were assigned to two broad informal categories based on the geometery and mode of

Table 1: Lithostratigraphic classification of Permian-Triassic sequence of Carbonates of Pahalgam formation.

Formation	Unit	Lithological features	Age
Pahalgam	Aru	Grayish black carbonates consisting of biosparites and having cephalopods, Crinoidal Plates, Bryozoans with other bivalves etc., characteristic of packstones, wackstones around mud mounds.	Permo-Triassic
	Mammal	Brownish silty carbonates with mostly wackstones, mudstones, consisting of Gastropods, Cephelopods and bivalves.	
	Pahalgam	White grayish carbonates with encrenites and bryozoan, crinoids - mostly packstones and grainstones, characteristic of mud mounds.	Permian

growth of Zooecia within colonies, viz. tabular bryozoans and box bryozoans (Boardman and Checktham, 1969). Three suborders of gymnolaema viz cyclostomata, frepostomata and cryptostomata are well represented by genera like festillipora having zoorium varying from encrusting to massive types and in order cryptostomata fenestelloidea are represented in the Pahalgam Formation characterised by delicate lace like fronds and dentroidal zooria with the zooecia arranged in different patterns on the branches. Three types of wall microstructures, i.e. laminated, granular and fibrous distributed in various combination in different bryozoan groups are found.

Brachiopods

Brachiopods are found in plenty and are represented by genera like *Spirifer rajah*, productus, semi-reticulata, etc.

Crinoids

It consists mostly of individual stemplates and fragments of stemplates. Individual crinoidal plates and fragments consist of single crystal that shows well-developed cleavage. The calcite has been precipitated in optical continuity around these plates which have not only filled up the hole in the centre but also has extended up to the outer edges acting as a rim cement. Many crystalline carbonates are cemented accumulations of echinodermal plates that have been broken along calcite cleavages.

Molluscs

Pelecypods are the most common in some of the carbonates of all the three units of the Pahalgam Formation. Prismatic structure is a columnar of polygonal blocks which may be simple or composite, crossed lamellar structure, consists of elongated inter-digitating sheets with preferred orientations are the most common ones. Foliated structure, however, is also met frequently. The shells are filled with calcite and are septate.

Gastropods

Prismatic-nacreous microstructure in gastropods is found in this formation, whereas cross-lamellar microstructures are also met within some of the samples. Shells are infilled with sparry calcite and micritic materials.

PETROGRAPHY OF CARBONATES OF PAHALGAM FORMATION

More than 50 thin sections from each unit of the Pahalgam Formation were prepared and examined under microscope to study texture, frame work grains, cementation and palaeo-petrographical criteria. The unit-wise petrographic description of the carbonates is presented.

Pahalgam Unit

This unit consists of flancky encrinites and biosparites. Encrinite biosparites largely made up of crinoidal material consisting of large crinoid, ossicles and stem plates are the commonest in the Pahalgam unit. Most of these plates are circular, but some are pentagonal and occur with large fragments of brachiopods and fenestrate bryozoa. The large fragmental grains are set in a matrix of crystalline calcite and finely communicated organic grains with scattered fragments of molluscs. Each individual plate of a crinoid acts optically as a single crystal of calcite and acted as a nucleation sites for calcite cements. Many of the plates have fine perforation structure. Most of these perforations have radial arrangement, but in most of the plates, the perforations have either disappeared or become indistinct due to filling up by calcite. Centre of each plate has been filled up with calcite that is optically continuous (Fig. 2), is a type of a crinoid stem, rim cement continuous with stem plates. The surface perforations have become indistinct by filling up with calcite, central hole is clearly visible and is filled with calcite. Surface pores of these plates are marked with radial patterns in the transverse sections.

Bryozoan biosparites are also equally well represented in the Pahalgam unit. The most conspicuous feature of these rocks is the abundant fenestrate bryozoan zooria. In these sections, the network of complete and broken fenestrate bryozoan zooria is surrounded by matrix of bioclastic calcarenite. The vertical section of fenestulipora incrustanes show zooecias with thin

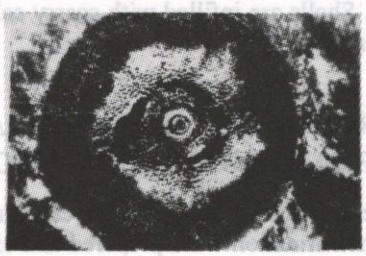

Fig. 2: Transverse section of a large fragment of crinoidal stem plate showing the central hole of the stem plate filled up with calcite. The rim cement is in optical continuity with stem plate. Radial patterns are well marked with numerous pores.

horizontal, straight diaphragms almost a whole tube width apart with crystopods, which are relatively simple. The walls are well laminated while the zooecial openings are filled with calcite. The difference in zooecial diameters represents differentiated zooids (Fig. 3). The smaller openings associated with bigger openings are acanthopores or mesopores representing accessory tubes of bryozoans.

Mammal Unit

The rocks of this unit are mostly mudstones and wackstones (biomicrites) and represents the core

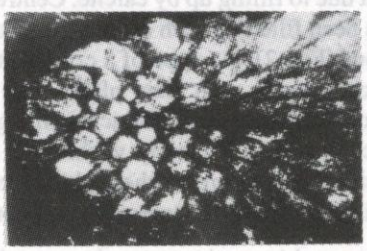

Fig. 3: Transverse section of a stick like bryozoan colony showing the rounded shape of the stem and of the Zooecia are the central cavity as well as the Zooecia are infilled with calcite. Rim cement has been developed around the colony which is in optical continuity with the cement.

facies of mud mound. These carbonates are aphanitic, composed of microcrystalline mud. Mostly, the skeletal material is composed of bryozoa and cephelopod shells infilled by sparry calcite. The outer margin of these shells is occupied by crystalline lime mud within which a very small petetoidal material is also visible (Fig. 4). Echinoidal spines are also found in thin sections with other skeletal debris. In some cases, skeletal debris of bryozoan and crinoids is also met along with the molluscan shells, but the total percentage of skeletal debris does not exceed 10%. Thus, many of the rocks met within this unit of the Pahalgam Formation stand on the boarder line of packstones.

This unit comprises of bryozoa and molluscan biomicrites, representing the mixed type of biota. The differential cementation of bioclasts and microcrystalline calcite occurs adjacent to and between the bryozoan zooeria. This suggests that zooeria may have influenced the deposition of the matrix by filtering and trapping action, thereby preventing the formation of more uniform type of matrix. The microcystalline calcite predominates and occurs with fenestric bryozoa. In some cases, one grain may predominate and occur with a few other grains in microcystalline calcite, where in other cases, microcrystalline calcite predominates and occur with fenestric bryozoa (Fig. 5). Abundance of fenestrate bryozoan zooecia is most conspicuous feature of this unit. Zooeria occur as flat, curved or undulating fronds, subcircular and occasionally showing a weak concentric ornamentation around one end. The laminated wall structure and the zooecia

Fig. 4: Mud and spar filled, thin walled bryozoan. Zooecia are oval shaped infilled by microcrystalline calcite and contain a few transverse partitions.

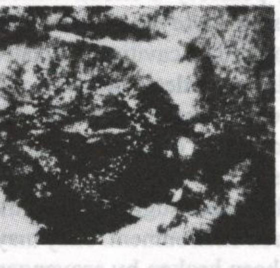

Fig. 5: Longitudinal section of a fenestrate bryozoan showing axial budding of Zooecia and composite pores infilled with calcite. The cement is sparry calcite.

are well preserved and it is possible that the zooeria were only snapped at their base because no visible surface of attachment is seen in the slide.

Aru Unit

This unit comprises of packstones and wackstones representing the cap rocks of the mud mound consists of skeletal debris of bryozoan and molluscan bivalves. These biosparrites of molluscs like pelecypods and gastropods along with other minor shells embedded in sparry calcite cement form the characteristic feature of this unit. In cephalopod shells, the septa are visible and in some cases the outer wall of shells have developed rim cement (Fig. 6). The shells are infilled with sparry calcite and microcrystalline matrix. Articulation of pelecypod valves at hinge line is also seen in some thin sections. Sparry calcite filling the shells becomes coarser away from the shell boundaries; crossed lamellar structure of shell valves is clearly seen in these sections.

In this unit, along with other faunal assemblages certain echinodermal spines are also seen with other skeletal debris with sparry calcite as groundmass (Fig. 7). Some of these are pure and structureless mudstones while others are micritic. Some petrographic types are even intersparrite and intramicrites. Diverse types of fossils like crinoids, bryozoans, molluscs, brachiopods and algae with some terrigenous grain material are also observed in this unit.

Fig. 6: A shell of cephalopod embedded in partly recrystallised mud, shell is infilled with sparry calcite, but still structural detail of septa are visible. The outer wall of the shell has developed rim cement.

DEPOSITIONAL ENVIRONMENT

According to Elias (1957), fenestella has no living relatives and the ecological relationships are inferred from the environments of the similar zones. However, he also states that colonies of fenestrate do connect and thus apparently produce the coherence needed for reef building. Some slender and erect fenestrate like zooeria in deep waters presumably unaffected by strong currents or waves have been recorded (Stach, 1936). The bryozoan lithologies on the low slopes of the Permian reef complex of the Gudaloupe Mountain in Germany and the Bay of Naples were studied by Newll (1953). The development of a shoal by wave action, followed by growth of colonies of animals and their subsequent death and the building up of the truncated

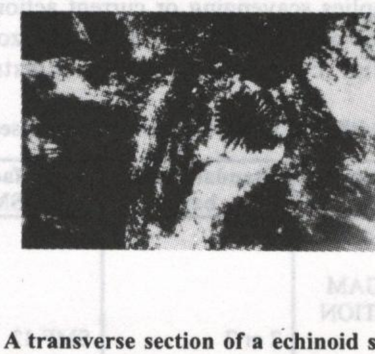

Fig. 7: A transverse section of a echinoid spine. The frame work includes pellets and other skeletal debris in sparry calcite groundmass.

comes of broken debris, was envisaged by Tiddeman (1892). Bryozoa, which functioned as mud catchers, were most abundant in flank beds and hardly be regarded as reef builders but were agents of sediment retention in quiet waters for short periods (Lowenstam, 1950). Troell (1962) recorded the possibility of fenestrate bryozoa and molluscs having a "sediment trapping and stabilising function and so helping to form and mud mounds or bioherms".

The petrographic evidence helped in arriving at the conclusion that this facies developed in the form of a small ramps and mounds consisting of lower belts of ecology (frame belt) knoll reefs on gentle slopes at the outer edge of the shelf margin. In the absence of strong wave or currents, there was a little massive frame building but many sessile and encrusting organisms flourished. The build-ups are produced falls by organic productivity, binding, trapping and by lack of removal of debris by organic in situ frame construction. The most of the debris is bioclastic and was derived from prolific growth on tops of the reef knolls. Water energy was sufficient to remove only the finest debris and hence mostly the lime sand accumulated in inter-reef areas. Core of the reef knoll contains lime because in the realm of moderate wave action, the frame builders offered enough protection to prevent its removal.

Furthermore, this discussion leads us to believe that the organic bioforms with fenestrate bryozoa during the development of the Pahalgam Formation in Kashmir Himalaya have formed an irregular shoal of mesh like zooerial fragments on the sea floor and trapped organic grains and microcrystalline calcite, which were also being deposited. This is supported by the fragmented bioclastic nature of the deposit, which implies scavenging or current action. The occurrence of abundant fenestrate bryozoa and differential concentration of bioclasts and microcrystalline calcite suggests the existence of a structure, possibly a shoa,l which would entrap sediments and prevent further winnowing. The presence of infilled cavities associated with bryozoan zooeria also provides evidence for the existence of sheltered or protected areas within an accumulation zone of organic debris. The presence of large crinoidal stems in microcrystalline calcite adjacent to a possible shoal suggested that the crinoids lived in a sheltered environment. They may have collapsed in situ or been broken by scavengers. It is possible that sheltered environment was protected by more massive accumulation of the bryozoan calcirudite.

According to Wilson (1975), the Pahalgam Unit is the characteristic enerinite type, which is special facies of SMF-12 and was formed under a constant wave or current action with mud removed by winnowing. In Mammal unit, the sediments showing textural inversions are formed in proximity to all shoals. This unit comes under SMF-10 type of shelf lagoon-shallow undatheum of open circulation. The Aru Unit is micritised with rock fabric of mostly mud and grain-supported with bioturbations. This unit falls under the SMF-9 type of shallow neritic waters of open circulation (Table 2). The Pahalgam Formation overall shows the characteristics of standard facies belts SFB-2 or 7.

CONCLUSIONS

The textural parameters used to indicate different energy levels in deposition of these carbonates were the attrition of the bivalved fossils (brachiopods and pelecypods) and the context of the sparite cement. The Pahalgam Unit represents encrinite type wackstones and packstones, whereas the Mammal Unit represents biomicrite type mudstone and wackstones, and the Aru unit by packstones and

Table 2: Outline of recurring environmental sequence in Pahalgam carbonates.

Strategraphic belt	Standard facies belt	MIcrofacies types (SMF)	Sub-environment	Phase of a cycle
PAHALGAM FORMATION	2 or 7	SMF-12 SMF-10 SMF-9	Immediate marine water of depth sufficient for circulation at or approaching wave base Widespread marine water of depth. sufficient for circulation at or approaching wave base.	Normal marine circulation phase.

wackstones. The Pahalgam Formation is of platform type on which carbonate sedimentation took place during the Permo-Triassic times reveals that it is a lime mud cycle with essentially low energy carbonte depsition, representing restricted open marine environment. While applying Wilson's Model (1975) to the Pahalgam carbonate sequence, it is revealed that the deposition took place within facies belt 2 or 7 with SMF - 9, 10 and 12.

ACKNOWLEDGEMENTS

The author is grateful to the Department of Geology, University of Jammu for giving all type of facilities to carry out the work. He is thankful to Mr. M.A. Janbaz for typing and to Mr. T.A. Zaki and Mr. B.A. Bhat for their kind help in designing the computer script of this paper.

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