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Sedimentological study of Khalsi Formation of Ladakh "Implications for Paleogeographic reconstruction"

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Abstract: **Carbonates of the Tethys Himalaya in the Ladakh region present a complex relation with rocks of the Indus group and subduction-related volcanics. The present study involves field recognition of the limestone units, collection of mega fossils, petrographic analysis, elemental and mineral composition of Khalsi Formation of Indus group. We present the results on depositional environment, field relation, paleogeographic conditions, and regional significance of Khalsi Formation. The field relation of Khalsi Formation suggests a complex interaction with the igneous intrusion, foredeep turbidite association, metamorphism, and tectonic deformation. The structural disturbance is evidenced by the folding in shale, imprints of sinistral movement, and localized compaction of limestone. The fossil assemblage collected during this study includes Auroradiolites biconvexus, rudists, crinoids, forams (Orbitolinid) corals, colonial bryozoans, belemnite, and some unidentified marine organisms. The faunal assemblage reflects a shallow-water depositional environment. The petrographic analysis of the samples of Khalsi Formation suggests bioclasts as a major component mainly enriched with the fragments of forams, micrite as cementing material, and pyrite and zircon crystals as non-carbonate constituents. The SEM-EDX data suggest significant calcite content in the samples. The SEM-EDX data suggest significant calcite content in the samples. We suggest the rudists, corals, forams (Orbitulina), crinoids, and bryozoans colonies were widely distributed as a reefal framework along tropical and sub-tropical tethyan ocean margin having a close affinity with the south Asian-Pacific faunal province. These fossils represent a shallow warm water environment of deposition for Khalsi Formation due to the uplifting of the ocean floor in this region after completion of subduction of the Indian plate beneath Eurasian.**

Keywords: Khalsi Formation, Fossils assemblage, Auroradiolites biconvexus, Paleogeographic reconstruction.

I. INTRODUCTION

The stratigraphic record of India -Eurasian plate collision and their drift history is well-preserved in the sedimentary succession along the plate margin in Ladakh (Robertson, 1994). The Tethys Himalaya presents Upper Cretaceous to Eocene sedimentary succession that summarizes the stratigraphical record of this region (Nicora et al., 1987). The Tethys Himalayan Sequence were deposited between Late-Precambrian and Middle Eocene on the northern margin of peninsular India (Baud et al., 1982). The history of passive margin began with the rift-related basaltic lavas during Late-Paleozoic i.e. Permian, followed by platform carbonate succession from Triassic to Jurassic (Baud et al., 1984). The northern Indian margin i.e. Ladakh was affected by the Early Cretaceous volcanism which is related to the spreading and subsequent extension of Gondwanaland fragments (Gaetani et al., 1986; Johnson et al., 1990). The limestone units in Ladakh are interbedded with the Indus Flysch and not exotic (Frank et al., 1977 and Thakur et al., 1981). The eastern Ladakh mainly preserves calcareous shale, limestone, quartzose siltstone which are again overlain by limestone having lenses of debris material whereas, succession in western Ladakh are deformed due to intense shearing, folding, faulting and are inverted (Robertson, 1993). The prominent transition from shallow water limestone to deep water siliciclastics and shale has been reported by Robertson et al., 1993. The marine transgression in this area is as a result of rifting of Indian plate during early to late Triassic that after a hiatus started to accumulate again during early Jurassic whereas, post-Albian time the deposition of pelagic carbonate deposition started in the outer margin towards Fatula (Gaetani and Garzanti, 1991; Garzanti et al., 1987). During the early Tertiary, the continental deposition started with continental sandstone followed by late Palaeocene open shelf carbonates (Dibling Unit). The Dibling unit is overlain by the Shingo-La unit which is an open shelf pelagic carbonates that are again overlain by nummulitic limestone of Palaeocene thereby representing the latest marine phase. Significant work on the geology of the Ladakh region in relation to plate collision had been done to establish a base map of the region using conventional techniques by Stoliczka (1865,1866), Lydekker (1883), Oldham (1888), McMohan (1901), Hayden (1909), De Terra (1935), Heim and Gansser (1939) and the contributions through advanced techniques lead to establish lithostratigraphy of the area. The molasses facies were earlier represented by Indus flysch in western Ladakh which after getting regional recognition with Kumaon and Spiti analog were characterized as molasses (Tewari, 1964). The present study involves field recognition of the limestone units, collection of mega fossils, and samples of Khalsi Formation from three different regions (i.e. Kargil, Narula, and Khalsi) for petrographic analysis, elemental and mineral composition to get an idea of depositional environment.. The aim of the present study is to present the preliminary results on the depositional conditions of the Khalsi Formation and its field relation.

II. LOCAL GEOLOGICAL SETUP

The "Khalsi section" is located in Tethyan Himalaya, north of the Zanskar range and south of Indo-Tsangpo Suture Zone (ITSZ) (Raz and Honegger., 1989). The area presents a thick package of limestone around 1500m that occurs in association with the rocks of the Indus group. The sediments are amalgamated with the clastic rocks of Indus group which were deposited post date of the India-Eurasian collision. The Indus Group and Ladakh granite complex also underlie the Khalsi Formation in different areas thereby making a complex structural relationship (Srikantia and Bhargava, 1979; Srikantia, and Razdan, 1981). The Indus group in this area is characterized by the non-ophiolitic sedimentary succession that occurs unconformably over the Ladakh granite complex (LGC). Khalsi Formation comprises *Orbitolina* limestone, greyish white limestone, splintery shale, tuffaceous shale, volcanogenic sediments, and minor gritstone and quartz arenite representing flyschoid, lagoonal and molassic stages (Fig.1). The basal part of the Khalsi Formation comprises *Orbitolina* Limestone bands of 5 to 250m thickness which are largely exposed in the Khalsi area and extend as far as Abunche -Bimbat nala and Marpo La section. The *Orbitolina* limestone bands, at many places, particularly in the Khalsi-Nurla section and Hagnis, occur as tectonic slices within the Karit Formation of the Indus Group (Bhandari *et al.*, 1979 and Juyal, 2006). The LGC represents a heterogeneous association of granitoid, gabbroid, and basic rocks into which the older metamorphic rocks of the Kharbu group got intruded at Drass and Kargil (Rai, 1983; Thakur, 1990). The Kharbu group comprises garnetiferous marble, phyllite, slate amphibolites, gneiss, migmatites, and metavolcanics (Rai, 1983; Thakur, 1990). Based on the occurrence of Upper Cretaceous fauna from the oldest sediments overlying the granite, the upper limit of the granite and the deposition of rocks of the Indus group is fixed at this age. The Khalsi Formation is overlain by Drass volcanics, which comprises of a thick sequence of basic lava flows i.e. pyroclastic and agglomerates with occasional lenses of limestone (De Terra, 1935). Drass volcanics are overlain by Nidam Formation that comprises of shale, sandstone, siltstone, diamictite, and subordinate pale-purple limestone representing turbidite sequence i.e. flyschoid sediments. The Nidam Formation is succeeded by Shergol Formation comprises of complex sequence of sediments with ophiolite association, mafic rocks, and pyroclastics (Klootwijk et al., 1984) (Fig.1).

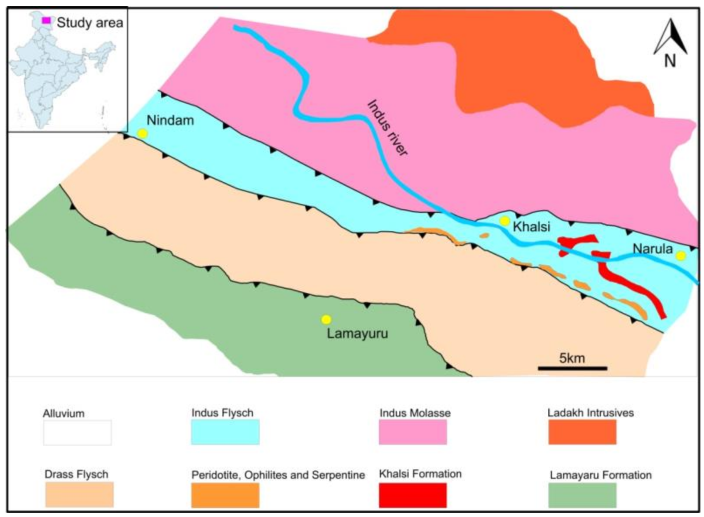

Fig.1. Geological map of the study area (after Frank,1977)

III. MATERIAL AND METHODS

The present study involves collection of 12 samples from Khalsi Formation for petrographic analysis and examination under Scanning Electron Microscope (SEM) to know the textural characteristics of rock type and to determine the non-carbonate constituents particularly the pyrite crystals. The samples were analyzed under the scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX) to image the surface features and elemental composition of the material. The representative polished thin sections were made for petrographic examination to know the carbonate constituents like, fabric, presence of micrite, sparay calcite and to decipher the depositional and diagenetic history. The sub-micron sized spots were selected from SEM images using energy-dispersive X-ray spectroscopy (EDX) under a voltage of 2.150 KeV. The spectral data stored at each pixel have been used to the calculate the quantitative data. The study is incorporated with the field observations and collection/identification of mega fossils from the Khalsi Formation which had improved our understanding about the sedimentary environment. The SEM experimental work was conducted at Chandigarh University Patiala and the petrographic examination were done at University of Jammu under petrological microscope supported with Lieca camera setup.

IV. RESULTS

A. Field Observations

The field observations of Khalsi Formation suggest complex interaction of the carbonate of Khalsi Formation with the overlying Nidam Formation and the underlying Indus group i.e. sedimentary succession and Ladakh granite complex. The complexity of Khalsi Formation is represented by the interaction of these rocks with igneous intrusion; foredeep turbidites association, metamorphism and tectonic deformation (Fig.2a,b,c,d). The metamorphism is evidenced by the presence of baked zone representing typical contact metamorphism. The structural disturbance is witnessed by the folding in shale and the imprints of shear forces in limestone representing sinistral movement (Fig.2e). The limestone of Khalsi Formation shows fracture-veins and cataclastic deformation bands which suggest localized compaction (Fig.2f). In Khalsi area the carbonates are associated with the grey shale and muddy material suggesting a stable carbonate sedimentary environment. The Khalsi Formation is characterised by serpentinite, diabase and gabbro occurring as pods and lenticles. Near Hangru, a continuous band of serpentinite is traceable up to Hemar for about 9 km, west of Takmachig. There is a broad concordance between the direction of elongation of tabular and lensoid serpentinite bodies and the trend of bedding of the enclosing rocks. The ultramafics are represented by slickensided and polished serpentinite of greenish grey, dark green and at places pitch black colours. Black shale associated with thin lenticular bands of diamictite and resinous looking quartz arenite and limestone interbeds form the dominant lithology of the Khalsi Formation. Locally shales are highly splintery, greyish green, and greyish black with chert bands.

B. Fossil Collection and Identification

The mega fossils having wider distribution reported from Khalsi Formation during this study include globular colonized bivalves (rudists) and forams from Hagnis, Chickten and Bimbhat nahalla of Drass respectively (Fig.3a-l). Besides, several unidentified fossils very close to belemnites in appearance have also been reported from Drass and Khalsi (Fig.3,b,f). The distinctly biconvex valve shaped fossil having a radial undulations of outer calcite layer is identified as Auroradiolites biconvexus (Fig.3a). The fossil is 25-30 mm in diameter with both convex valves similar to those reported by Rao et al., (2017) from Lhasa block, Tibet. The stem shaped fossils ranging 15-20 mm in length are crinoids, where arms were although not preserved (Fig.3b,d,i). The fossils ranging in diameter from 15-20 mm and having valves joined by hinge are bivalve (Fig.3c). Tiny colonized animals, elongated and branched shaped are bryozoans which suggest tropical condition that favour their growth (Fig. 3e). The broadly conical and curved valves of equal size ranging in diameter of 25-30 mm in diameter is a typical rudist bivalve that represent the shallow carbonate platformal region (Fig.3f,h,g). Beside these there are some unidentified and poorly preserved fossils collected during this study which are very close to the interpreted fossils like, rudists (Fig.3g), overlapped and poorly preserved crinoids (Fig.3i) and benthic foraminifera (Fig.3k). Along these fossils the careful examination of rock sample show the presence of pyrite crystals suggesting reducing condition during their deposition (Fig.3l) which is also supported by the presence of crinoid fossils indicating a rapid burial in quiet and poorly oxygenated water condition (Fig.3b). The colonization of rudist bivalves in loose to dense cluster made them suitable life form of meadows or low mounds particularly the carbonate platform succession (Fig.4).

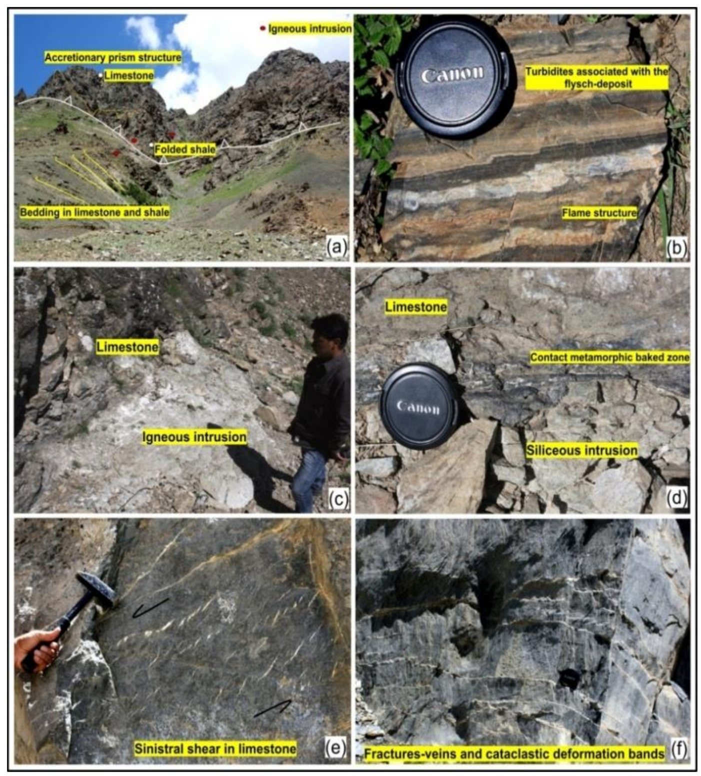

Fig.2. Field photographs showing (a) folding in the shale and igneous intrusion (b) sedimentary structure of flysch-deposit showing tectonic relation with the adjoining carbonates (c) contact of limestone and igneous intrusion (d) baking of rocks as a result of igneous intrusion i.e. typical field evidence of contact metamorphism (e) imprints in limestone showing sinistral shear (f) compaction of carbonates represented by, fracture veins and cataclastic deformation bands.

C. Petrographic Analysis:

The thin sections of the rocks of Khalsi Formation show the presence of both carbonate framework constutients as well as non-carbonate constituents. The carbonate constutients include micrites and bioclasts where the non-carbonate constituents include a minor amount of pyrite and zircon crystals (Fig.5a-f). Among carbonate constituents, bioclasts are the major component which include the forams species and calcite cement (Fig.5a,b,c &e). The bioclasts are present both as individual identity i.e. forams, as well as broken part of the forams and the cementing material is mainly micrite (Fig.5a,e,f).

Fig.3. Field photographs showing (a) Auroradiolites biconvexus (b) crinoids (c) bivalve (d) crinoid (e) bryozoan (f) bivalve rudists (g) unkown rudists (h) bivalve rudists (i) crinoids (J) rudists (k) benthic foraminifera (l) pyrite crystals indicating reducing conditions.

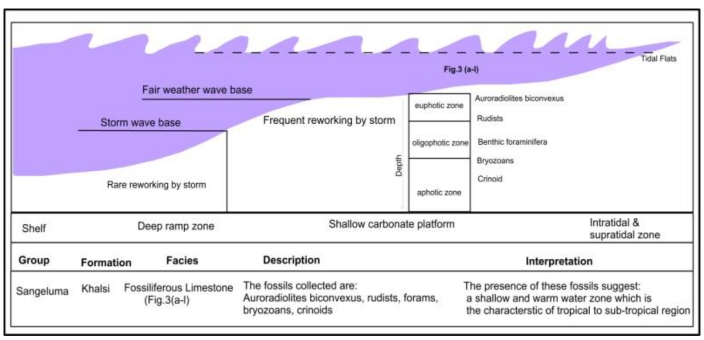

Fig.4. Schematic representation of carbonates sedimentation showing the depositional setting of Khalsi Formation (shallow carbonate platformal nature).

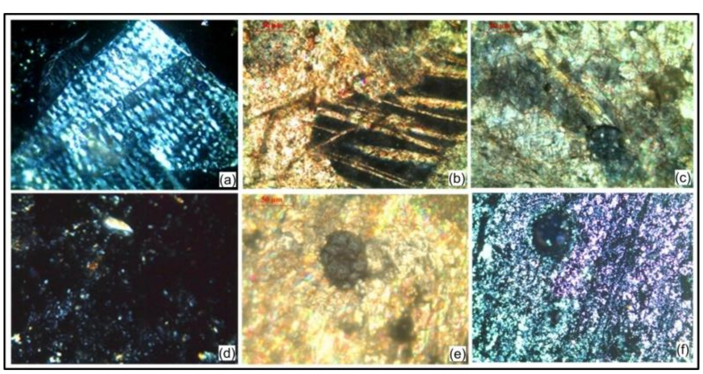

Fig.5. Photomicrographs showing (a) foram (Orbitulina) (b) calcite crystals (c) bioclasts i.e. broken fragments of foram and calcification (d) zircon crystal from plate boundary (e) foram and calcite mass (f) bioclasts with micrites.

D. SEM photography and EDX

The careful examination of Scanning Electron Microscope (SEM) photomicrographs and energy-dispersive X-ray spectroscopy (EDX) data suggest calcite mineral as dominant constituents. The EDX spots of those patches ascertain its weight percentage (Fig.6a,a'-c,c'). The EDX data suggest the presence of Ca, C, O, Mg which are the essential constituents of calcite (Fig.6a'-c'). Calcite in all the samples is a major constituent which is followed by the bioclasts and fine matrix. The samples for elemental composition were collected from three sites represented as site-1 (Khalsi), 2 (Kargil) and 3 (Drass). The sample-1 shows a range of values between 24.23 to 42.69% for calcium; 44.56 to 55.78% for oxygen and 6.05 to 15.99 for carbon making the CaCo3 in the sample as an essential constituents. The CaCo3 is followed by 3.02 to 4.97% of iron due to presence of pyrite crystals. The atomic percentage data show a value of 59.87 for oxygen; 22.90 for calcium; 15.01% for carbon and 1.16 for Iron/ferrous affinity. The weight percentage of Al, Si and Fe is 2.93, 5.39 and 4.97% respectively (Table.1). The sample-2 shows a range of values between 17.81 to 24.07% for calcium; 57.16 to 65.35 for oxygen; 5.24 to 11.49 for carbon, making them as essential component of the sample. However, significant percentage of other elements include a range of values between 1.58 to 8.14 for iron, 0.29 to 4.32% for magnesium, 0.23 to 3.35 for silicon. The atomic percentage values corresponds to 8.61, 8.78 and 71.51 for carbon, calcium and oxygen. The atomic percentage of magnesium, iron and aluminum is 3.51, 2.88 and 2.06 respectively (Table.1). The normalized value of sample-3 show an atomic percentage of 55.83 for oxygen, 30.70 for carbon, and 12.49 for calcium. The weight percentage value ranges between 49.91 to 55.34% for oxygen, 7.05 to 20.60% for carbon, 27.98 to 36.90% for calcium and 0.12 to 2.49% for silicon (Table.1). The data show calcium, oxygen and carbon as essential constituents of the sample with some silica sourced by the continental sediments.

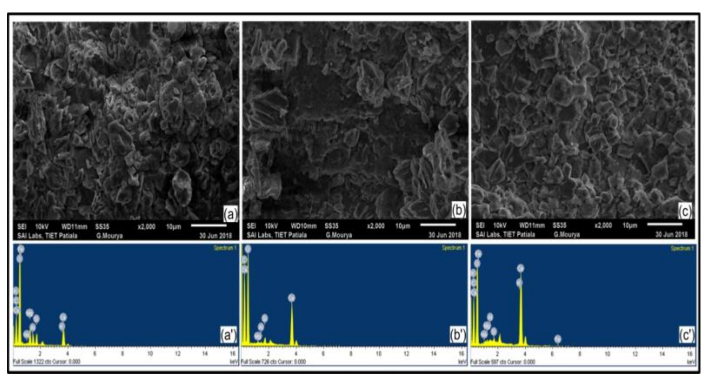

Fig.6. Scanning electron microscope images of the sample from (a) Khalsi (Narula) (b) Kargil (c) Drass. EDX plots of the same samples showing different elemental peaks (a') Khalsi (Narula) (b') Kargil (c') Drass.

Table 1. showing atomic and weight percentage of elements present in the samples.

Drass			Kargil			Narula		
Element	Weight%	Atomic%	Element	Weight%	Atomic%	Element	Weight%	Atomic%
C K	5.24	8.61	C K	20.60	30.70	C K	8.39	15.01
O K	57.95	71.51	O K	49.91	55.83	O K	44.56	59.87
Na K	0.31	0.26	Mg K	0.01	0.01	Na K	0.10	0.10
Mg K	4.32	3.51	Al K	0.32	0.21	Mg K	0.29	0.26
Al K	2.82	2.06	Si K	1.19	0.76	Al K	0.17	0.14
Si K	3.35	2.35	Ca K	27.98	12.49	Si K	0.63	0.48
K K	0.07	0.03	------	------	------	K K	0.15	0.08
Ca K	17.81	8.78	------	------	------	Ca K	42.69	22.90
Fe L	8.14	2.88	------	------	------	Fe L	3.02	1.16

IV. DISCUSSION AND CONCLUSION

The faunal assemblage recovered during this study i.e. rudist, gastropods and corals suggest shallow marine carbonate environment of tropical to sub-tropical region. The restriction of *Orbitolina* bearing limestone to the basal part of the group i.e. the Khalsi Formation is remarkable as this suggests that the earliest phase of sedimentation was platformal in nature. The presence of rudists in colonized morphology represent non-turbulent typical reef like micro-environment whereas, the presence of pyrite crystals suggest reducing conditions during the sedimentation. Similar collection of rudists fossils have been made from the cretaceous Langshan Formation of Lhasa block which along with the Orbitolinid record suggest the rock Formation not older than late-Albian. The presence of rudists, foraminifera, corals, bivalves, bryozoans colony suggest the shallow warm water environment of deposition due to the subduction of Neo Tethys sea and later uplifting of ocean floor in this region after the completion of subduction between the Indian and Eurasian. Rudists, corals, forams (Orbitulina), crinoids and bryozoans are widely distributed as reefal framework along tropical and sub-tropical Tethyan ocean margin. Based on the collection of megafossils, field relationship and the earlier research the fossils have close affinity with the south Asian-Pacific faunal province. Based on the field relation of subduction related volcanic rocks, megafossils and thin section studies the present study suggest shallow marine, platform/open shelf and reef build-ups with significant distribution on volcanic ridges or seamounts.

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