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NOTE ON THE C AND O STRATIGRAPHY OF THE GARBYANG FORMATION (MALLA JOHAR AREA), TETHYAN HIMALAYA, INDIA

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ABSTRACT

The carbonate rich deposits of the Garbyang Formation, Tethys Himalaya in Malla Johar area, Uttarakhand, India possibly hosts the latest Precambrian-early Cambrian sediments based on earlier studies of trace fossils. To further investigate this issue, fifty-four samples of carbonate were collected and analysed for δ^{13}C-carb and δ^{18}O-carb. The results are significant in absence of any chemostratigraphic dataset of the Garbyang Formation till date. The δ^{13}C-carb varies from -5.8‰ to 1.0‰. But, δ^{18}O-carb show anomalously low values between -10‰ and -33‰ that reflects significant meteoric water diagenesis. The influence of meteoric water diagenesis on the carbon isotopic ratios is apparently minimal as δ^{13}C-carb stratigraphy of the Garbyang Formation closely follows the established global δ^{13}C-carb curve for near Precambrian-Cambrian time frame. Signature of the probable Precambrian-Cambrian (Pc-C) boundary has been identified in the lower part of the formation (Garbyang B). Various types of burrows and trace fossils of the Cambrian affinity have been reported from succession overlying the probable Pc-C boundary.

Keywords: Tethys Himalaya, Meteoric Water, Diagenesis, Chemostratigraphy, Pc-C Boundary.

INTRODUCTION

Authigenic carbonates can play a substantial role in the carbon burial on a global scale (Schrag *et al*., 2013). Authigenesis is a post depositional process that includes early diagenesis of carbonate deposits occurring in sea water or meteoric water during deep burial (Cui *et al*., 2016). On a continental scale, present day authigenic carbonates formation can account for about 10% of the global carbonate deposition (Sun and Turchyn, 2014). It has been suggested that this process was more vigorous in the less oxygenated Precambrian ocean (Kah *et al*., 2004; Canfield *et al*., 2008; Schrag *et al*., 2013; Lyons *et al*., 2014; Planavsky *et al*., 2014; Sperling *et al*., 2015). Numerical modeling studies (Higgins *et al*., 2009) also suggest the higher rate of authigenic carbonate deposition during the Precambrian Era. Recent work on the Ediacaran carbonate deposits proposed that authigenic carbonates of the Precambrian era host the world's largest negative carbonate-carbon isotope anomaly in magnitude and duration, widely known as the Shuram Excursion (Grotzinger *et al*., 2011), which was first reported in the Shuram Formation of Oman (Burns and Matter, 1993), and later from other parts of the world such as Australia (Calvert, 2000), USA (Corsetti and Kaufman, 2003), China (McFadden *et al*., 2008) and India (Ansari *et al*., 2018).

Malla Johar area of the Tethyan Himalaya has thick carbonate sequences that were deposited between the late Neoproterozoic and Cambrian hence, constitute a fine representative of biogeochemical changes and events during this important period. Carbon and oxygen stable isotope studies in the Himalayas have been carried out earlier in the Krol-Tal succession in the Lesser Himalayas (Aharon *et al*., 1987; Banerjee *et al*., 1997; Kaufman *et al*., 2006). Secular global trends of the carbon isotope variations in Cambrian and Proterozoic rocks of India, Pakistan and Mangolia have been discussed by Banerjee (1990). Banerjee *et al*. (1986) and Mazumdar and Banerjee (2001) have studied Tal Phosphoritic chert and its implications. An extensive recent study of the Krol sequence by Kaufman *et al*. (2006) established four major negative δ^{13}C-carb excursions. One of these excursions is related to the Neoproterozoic glaciations, whereas, two others are found to be associated with the abrupt changes in the lithofacies with diagenetic imprints like karstification. The fourth excursion recorded from an open marine transgressive facies is interpreted to denote a global scale change in the carbon biogeochemical cycling.

The global carbon amount is distributed among two major reservoirs: organic carbon and carbonate carbon with very different isotope ratios. Organic carbon has extremely negative δ^{13}C (~-27 ‰) whereas carbonate carbon is near zero. Therefore, a change in their relative proportions would reflect on the carbon isotope ratio of contemporary carbonate sediments. Kaufman *et al*. (2006) also demonstrated the existence of a lateral inconsistency in the δ^{13}C-carb variation during the Pc-C period which could be due to either stratigraphic hiatus between poorly correlated beds or diagenetic alteration. More recently, Li *et al*. (2017) analyzed δ^{13}C-carb values in the Doushantuo Formation in the Yangtze Gorges area of South China to examine the spatial variability of the isotopic changes. They found highly heterogeneous δ^{13}C-carb values across the platform. According to these authors, this lateral heterogeneity in the stable isotope composition was caused by differential oxidation of organic carbon.

The oxygen isotope ratios of the carbonates from the Krol-Tal belt are mostly higher than -8‰ though many of the samples having negative δ^{13}C-carb excursion are characterized by δ^{18}O-carb values less than -8‰. Interestingly, a lower range of δ^{13}C-carb is found in strata between Krol E and overlying Tal. The

δ^{18}O-carb decrease rapidly from -5‰ to -12.7‰ which agree with the signatures reported from the Precambrian-Cambrian boundary succession in several areas across the world (Banerjee, 1990; Kaufman and Knoll, 1995; Kimura *et al*., 1997; Corsetti and Hagadorn, 2000; Shen and Schidlowski, 2000; Bartley *et al*., 2001).

The Tethys Himalaya shows a thick succession of latest Precambrian-Cambrian rocks. Rocks are clastic in nature and made up of shale, siltstone, sandstone and conglomerates with only minor carbonates. In contrast, the Garbyang Formation of the Malla Johar area (N 79º 51´; E 80º 45´) in Tethys Himalaya presents a major carbonate deposit associated with sulphate minerals. In the present study, we have analyzed carbonate samples from this formation for C and O isotope ratios. The resultant δ^{13}C-carb chemostratigraphy of this area allows one to locate Pc-C boundary and also delineate the possible role of carbonate authigenesis in alteration of global Pc-C signals.

GEOLOGICAL SETTING

The Tethyan Himalaya (Suess, 1893) is found in the northern part of the Himalaya extending from Kashmir to Nepal and beyond in the east, where successions of the latest Precambrian to Cretaceous are present (Kumar *et al*., 1977). The Tethyan successions in the north-western Himalaya are exposed in four distinct basins namely Kashmir, Zanskar, Spiti and Malla Johar in Kumaun Himalaya. Sedimentation in these basins presumably started around the Neoproterozoic (Aharon *et al*., 1987). The latest Precambrian-early Cambrian deposit comprises of clastic sedimentary succession. This succession is named differently in various basins, namely, Manchhal and Lolab formations in Kashmir Basin, Haimanta Group in Zanskar and Spiti basins. In all these basins, the basal part is represented by the clastic succession of the late Neoproterozoic. The Cambrian succession is composed of clastic sediments with minor carbonates. Attempts have been made to identify the Precambrian-Cambrian boundary using body and trace fossils in Kashmir Basin (Lolab Formation) (Raina *et al*., 1983; Shah and Sudan, 1983; Raina *et al*., 1990), in Zanskar Basin (Kunzum La Formation; Hughes and Droser, 1992; Parcha, 1998; Shah *et al*., 1998; Peng *et al*., 2009; Singh *et al*., 2014) and in the Spiti Basin (Kunzum La Formation; Parcha, 1998; Sudan *et al*., 2000; Bhargava, 2008; Parcha and Pandey, 2011; Singh, 2013; Singh *et al*., 2015; Singh *et al*., 2016; Singh *et al*., 2017; Hughes *et al*., 2019).

The Malla Johar Supergroup (Kumar *et al*., 1977) is located in the Kumaun Himalaya, where Tethyan Zone sediments overlie the metamorphic rocks of the Central Crystalline Zone (Heim and Gansser, 1939) and are overlain by the exotic blocks of Malla Johar. Geology of the Malla Johar area has been discussed by Kumar *et al*. (1977) and Sinha (1989) under different nomenclature. In the present paper, nomenclature of Kumar *et al*. (1977) has been followed. The Tethyan Zone sediments in this area are designated as Malla Johar Supergroup and have been divided into four groups, namely Malari, Sumna, Rawalibagar and Sancha Malla groups (Kumar *et al*., 1977) (Table 1). The Malari Group is made up of clastic sediments, represented by shale, siltstone, sandstone and conglomerate. They represent late Precambrian in age. The basal part of the Sumna Group is designated as the Garbyang Formation , and it is composed of carbonate, gypseous shale, sandstone and siltstone deposited essentially in a tidal flat complex (Kumar *et al*., 1977). The succession is considered to be of Cambrian age as evidenced by the presence of trace fossils and burrows made up of arthropod/trilobite (Banerjee *et al*., 1975; Tandon and Bhatia, 1978). However, so far no age diagnostic body fossils have been recovered.

Garbyang Formation

The Garbyang Formation represents calcareous deposits above the Ralam Formation of the Malari Group, which represents clastic rocks of latest Precambrian. In the Lower Garbyang Formation, phyllite is interlayered with ferruginous dolomite in type locality (Banerjee, 1974), whereas in the Malla Johar area (Garbyang A, B, C) is relatively rich in carbonate and intercalated with shales (Kumar *et al*., 1977). A characteristic aspect of the Garbyang Formation is that the lower part comprises mainly of carbonate and there are cycles of carbonate-gypseous shale on a few meter scale. While in type area of the Garbyang Formation, carbonate only dominated in the upper horizon (Banerjee, 1974). In none of the other basins of Tethyan Himalaya, namely, Kashmir, Zanskar and Spiti, such carbonate-gypseous shale succession is present. In the study area, the thickness of the Garbyang Formation is estimated to be 726 m in the Kio valley between Deepak Nagar and Sappers Lake (Kumar *et al*. 1977). The base of the Garbyang Formation A grades into the underlying Ralam Formation while top changes to crinoidal limestone of the Shiala Formation (Ordovician in age) (Kumar *et al*., 1977; Sinha, 1989). Kumar *et al*. (1977) sub-divided the Garbyang Formation into seven lithostratigraphic members as described below.

***Garbyang A* (*46 m thickness*):** Topmost unit of the Ralam Formation grades into Garbyang A. It is essentially a carbonate succession with dark shale and minor shale-sand alternations. Carbonate is often vuggy and contains pyrite. Sandy carbonates often show cross-bedding, whereas carbonate units shows small ripple and herringbone cross stratification. Deposition of the Garbyang A took place in the tidal setting.

***Garbyang B* (*110 m thickness*):** It is mainly a succession of dolomite, marl and gypseous shale, which are arranged in 1-5 m thick cycles, starting with well-bedded dolomite and culminating with gypseous shale and thinly bedded dolomite. About 30 cycles are recognized. The dolomite shows occasional cross-bedding features. The cycles represent intertidal-supratidal deposits.

***Garbyang C* (*165 m thickness*):** It is made up of calcareous sandstone, shale and bedded limestone which is in contrast to underlying unit of the Garbyang B. Sandy bands show small ripple bedding, channeling, planes of discontinuity and large scale cross-bedding. The carbonates are oolitic in nature and near the top of this unit carbonate content decreases. Several horizons of this unit show prominent trace fossils, mostly in the form of tracks and trails. These features represent deposits of tidal flat complex, particularly in sand bar shoal area of shallow sea which is dominated by strong wave and current activity.

***Garbyang D* (*70 m thickness*):** It consists of a succession of meter thick sand beds alternating with sand-shale interlayered beds, and few sandy carbonate layers. The sandstone shows cross-bedding low-angle beach-bar bedding, minor channels. Mud rich units show lenticular-flaser bedding and tidal bedding. Overall unit is deposited in mixed intertidal, while part of the succession is deposited in the subtidal setting.

***Garbyang E* (*45 m thickness*):** This succession is essentially shale dominated with sandy intercalations and meter-scale thick sandstones and sandy carbonate bands. Graded bedding,

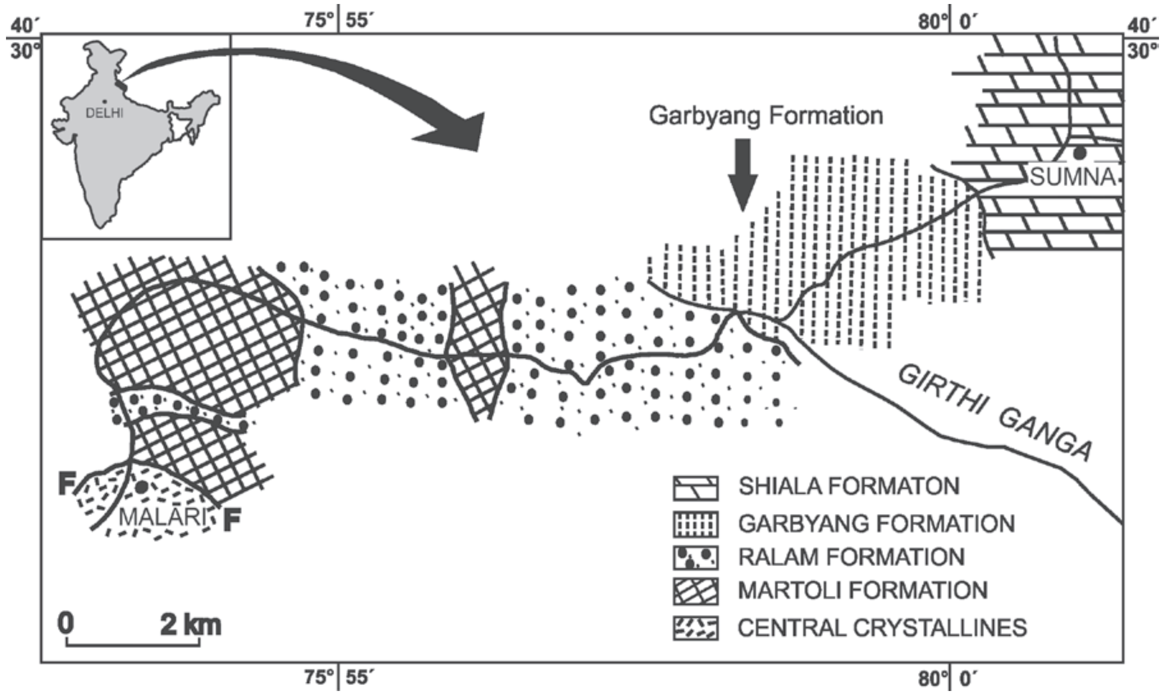

Fig. 1. Schematic geological map of the Malari-Sumna region showing position of the Garbyang Formation (After Kumar *et al*., 1977).

lenticular-flaser bedding, tidal bedding, cross-bedding, small ripple bedding are common bedding structures. Major part of this unit was deposited in the subtidal setting in an open tidal sea. Some of the horizons are witnessed with subaerial exposure, which suggest intertidal depositional environment.

***Garbyang F* (*120 m thickness*):** It is a succession of alternating horizons of oolitic carbonate, marl, and sandstone. The carbonate shows prominent cross-bedding. Marls show lenticular-flaser bedding and tidal bedding. Sand beds show cross-bedding, small ripple bedding, lenticular-flaser bedding, longitudinal cross bedding and mud pebble conglomerate. This succession also exhibits several horizons rich in various trace fossils.

***Garbyang G* (*140 m thickness*):** It is essentially a succession of sandstone, shale with a few carbonate bands. Small ripple bedding, graded rhythmite, lenticular-flaser bedding, intraformational conglomerate, graded bedding are common bedding structures. The topmost part is sandy. The succession shows several horizons of bioturbated sediments. Well-developed vertical burrows are common.

DEPOSITIONAL ENVIRONMENT

The Garbyang Formation represents deposition in a shallow sea with moderate wave activity (Kumar *et al*., 1977). Evidence of tidal activity is very prominent. Sedimentary features suggest low clastic sediment supply initially and development of carbonate platform where deposition of the dolomite - gypseous shale succession occurred in intertidal to a supratidal domain (Garbyang B). Still later, the carbonate platform changed to a tidal flat complex with the prominent supply of terrigenous (clastic) sediments. The deposition took place mostly in an intertidal setting; some parts deposited in the subtidal zone and sand shoal complex. Occasionally, horizons of sandy carbonates were formed in the intertidal zone. The topmost part of the succession was mostly deposited in a subtidal setting and shallow shelf often effected by wave activity. Thus the carbonates of the Garbyang Formation were formed in variable intertidal-supratidal settings.

AGE OF THE GARBYANG FORMATION

Garbyang formation of of Kali river section (Banjerjee *et al*., 1974) includes both Ralam and Garbyang formations. In the Malla Johar area, these formations are separted (Kumar *et al*., 1977). The Ralam Formation (Malari Group) underlies the Garbyang Formation. No report of body or trace fossils from the Ralam Formation and the lower part of the Garbyang Formation is considered as indication of their Precambrian origin (Kumar *et al*., 1977). The presence of evaporitic succession gives an additional support for the terminal Precambrian age for the lower part of the Garbyang Formation and tentatively Cambrian age for upper part of the Garbyang Formation.

Earlier, the Garbyang Formation itself was given a Cambrian age by Heim and Gansser (1939), based on the presence of compressed gastropods from the Kali Valley. Sinha (1989) also described flat gastropod *Ecelioptis kushanensis* from the Garbyang Formation. Banerjee *et al*. (1975) and Tandon and Bhatia (1978) describe a number of trace fossils from the Garbyang Formation, namely *Isopodichnus, Rusophycus, Cruziana, Phycodes, Lavicyclus, Aulichnites, Teichichnus* and *Planolites*. These trace fossils belong to the middle part of the Garbyang Formation and based on their presence the succession is given a Cambrian age. Kumar *et al*. (1977) described trace fossil *Rouaultia* which is normally found in Cambrian rocks. Bioturbated horizons, vertical burrows and traces and tracks are recorded in the middle and upper part of the Garbyang Formation (Kumar *et al*., 1977). The biogenic activity is seen in the Garbyang C and younger sediments in the form of bioturbated features, whose numbers increase upwards towards the top of the Garbyang Formation.

Notwithstanding the absence of Cambrian body fossils in any part of the Garbyang Formation, the above data suggest that the middle to upper part of the Garbyang Formation (Garbyang C-G) may be of Cambrian age and the Precambrian-Cambrian boundary may be present in part below these horizons.

MATERIAL AND METHOD

Study Area

The study area is located in the northeastern part of the Chamoli district, Uttarakhand in North India and collection were made during the field season of July-September in 1974. The road and mule track from Malari to Sumna exposes the latest Precambrian-Ordovician succession (Malari Group and lower part of the Sumna Group). The Garbyang Formation along this track is well exposed from Deepak Nagar to Sappers Lake along the Girthi Ganga Valley (Fig. 1). Samples were collected from the fresh road cutting sections. In the Garbyang A and B, relatively close sampling were done, while in the upper part of the Garbyang Formation samples were collected at larger spacing.

Stable isotope analysis

Stable isotope analysis of the carbonate phase of the collected samples was done in Physical Research Laboratory (PRL), Ahmedabad. Big pieces of carbonate rock samples were broken into smaller fragments, and a few of these were powdered and sieved where 50 to 80 mesh (180 to 300 μm) fractions were kept in vials for analysis. Small aliquots of these powders (weighing about 5 mg) were reacted at 25^{o}C in the vacuum with 100% phosphoric acid to convert carbonate to CO_2 gas using a custom made glass reaction system. Since the samples were dolomitic in nature, the reaction was slow and had to be carried out for about 30 to 40 min for completion. Isotopic analyses were performed on the CO_2 gas using a VG Micromass 903 triple collector Isotope Ratio Mass Spectrometer (IRMS). Results are presented in the standard δ-notation as per mille (‰) deviation of the sample carbonate from the VPDB carbonate standard where $\delta = [(R_{sample}/R_{standard})-1]*1000$ and R = $^{13}C/^{12}C$ or $^{18}O/^{16}O$. Samples were analysed along with an internal laboratory standard (made from Carrara marble obtained courtesy of Roberto Gonfiantini; Z-Carrara with $\delta^{13}C$= 2.2‰, $\delta^{18}O$= -1.3‰ relative to VPDB) calibrated via international Standard NBS-19 ($\delta^{13}C$= 1.95‰, $\delta^{18}O$= -2.20‰ relative to VPDB) obtained from IAEA, Vienna. The uncertainties in $\delta^{13}C$ and $\delta^{18}O$ analysis of carbonates were estimated by repeat analysis of Z-Carrara and are about 0.1‰ (for both). Some of these samples i.e. GARB-442, 451, 459, 476 and 492 were reanalysed at Stable Isotope Laboratory of the Birbal Sahni Institute of Palaeosciences (BSIP), following the method described in Ansari *et al*., (2018). The results from the reanalysis show a difference of -0.2 to -0.9‰ in $\delta^{13}C$-carb and 02-1.5‰ in $\delta^{18}O$-carb compared to the first analysis.

RESULTS

In the Garbyang A $\delta^{13}C$-carb ranges from -3.9‰ to 0.9‰ and $\delta^{18}O$-carb -15.5‰ to -9.1‰. In the Garbayang B $\delta^{13}C$-carb decreases upwards to -5.1‰ and slowly recovers to a less negative value of 0.8‰ and $\delta^{18}O$-carb ranges from -15.1‰ to -10‰. In the Garbayang C the $\delta^{13}C$-carb value further decreases upwards to -5.8‰ but then onwards slowly increases to 0.5‰ in the upper part. Interestingly, the $\delta^{18}O$-carb abruptly decreases down to -33.1‰ and then gradually increases up to -12.0‰. In the Garbyang D, the $\delta^{13}C$-carb decreases upwards from -0.4‰ to -2.9‰ and $\delta^{18}O$-carb decreases from -9.5‰ to -12.0‰. In the Garbyang E, $\delta^{13}C$-carb increases from -3.6‰ to -2.8‰ and respective $\delta^{18}O$-carb decreases from -13.5 to -19.2‰. In the Garbyang F the $\delta^{13}C$-carb increases from -1.7‰ to 1.0‰ and $\delta^{18}O$-carb decreases from -12.3 to -14.5‰.We do not have data from the Garbyang G succession. Overall, based on the grand mean value of about -3‰ for the $\delta^{13}C$-carb, the studied part of the Garbyang Formation shows three negative excursions. The total variation of $\delta^{13}C$-carb was ~ 6.9 ‰ (see Fig. 2 and 4 and Table 2).

DISCUSSION

The topmost part of the carbonate succession of the lower Garbyang (Garbyang B) is made up of dolomite-gypseous shale indicating evaporitic Sabkha like conditions. Likewise, the Marwar Supergroup of the western India shows prominent evaporites with cyclic development (Mazumdar and Strauss, 2006). Kumar and Pandey (2010) had already shown the possible link between three depositional realms, which are lower Cambrian of Tethys Himalaya, Tal unit of Lesser Himalaya and Nagaur Group of the Marwar Supergroup including Salt Range, Pakistan. Therefore, it appears that the Garbyang Formation of the Tethys Himalaya, the Krol-Tal succession of the Lesser Himalaya and the Marwar Supergroup of western India are part of the extensive carbonate platform which developed in North-West India and extended westwards into the Arabian Peninsula (Aharon *et al*., 1987). In these regions latest Precambrian shows development of evaporite deposit.

Carbon and oxygen isotope data from the carbonate phase of the Garbyang Formation shows prominent isotopic variations across the succession, which can be utilized to provide a chemostratigraphy based age of this succession. Like Krol- Lower Tal succession of Lesser Himalaya, the Garbyang Formation exhibits shift in marine carbon sequence of Pc-C boundary and represents sediments of Terminal Ediacaran to Cambrian age (Fig. 2). It is well-known that prominent chemical changes took place in the marine environment during the Precambrian-Cambrian transition phase. These changes are preserved in the stable isotopic composition of the deposited marine carbonate of this time (Kaufman *et al*., 2006).

Preservation of carbon isotope signature in old rock samples is an important issue as isotope ratio is often subject to alteration during burial diagenesis suffered by the sediments. However, in the case of the Garbyang Formation, we believe that the original signature of the $\delta^{13}C$-carb is preserved. This is supported by the fact that there is no correlation between the carbon and oxygen isotope values as expected in the case of alteration when extraneous carbon source/sink are also present (Fig. 3). We also note that the oxygen isotope ratios of many samples have suffered drastic changes due to meteoric water diagenesis, but these samples do not show any significant carbon isotope ratio change. Additionally, the $\delta^{13}C$-carb profile from the Garbyang Formation closely matches the one that is found in typical latest Precambrian and early Cambrian sediments. Our observations agree with the well-known fact that carbon isotope ratios are relatively resistant to post-depositional alterations, except for isotopic exchange between carbonate carbon and organic carbon

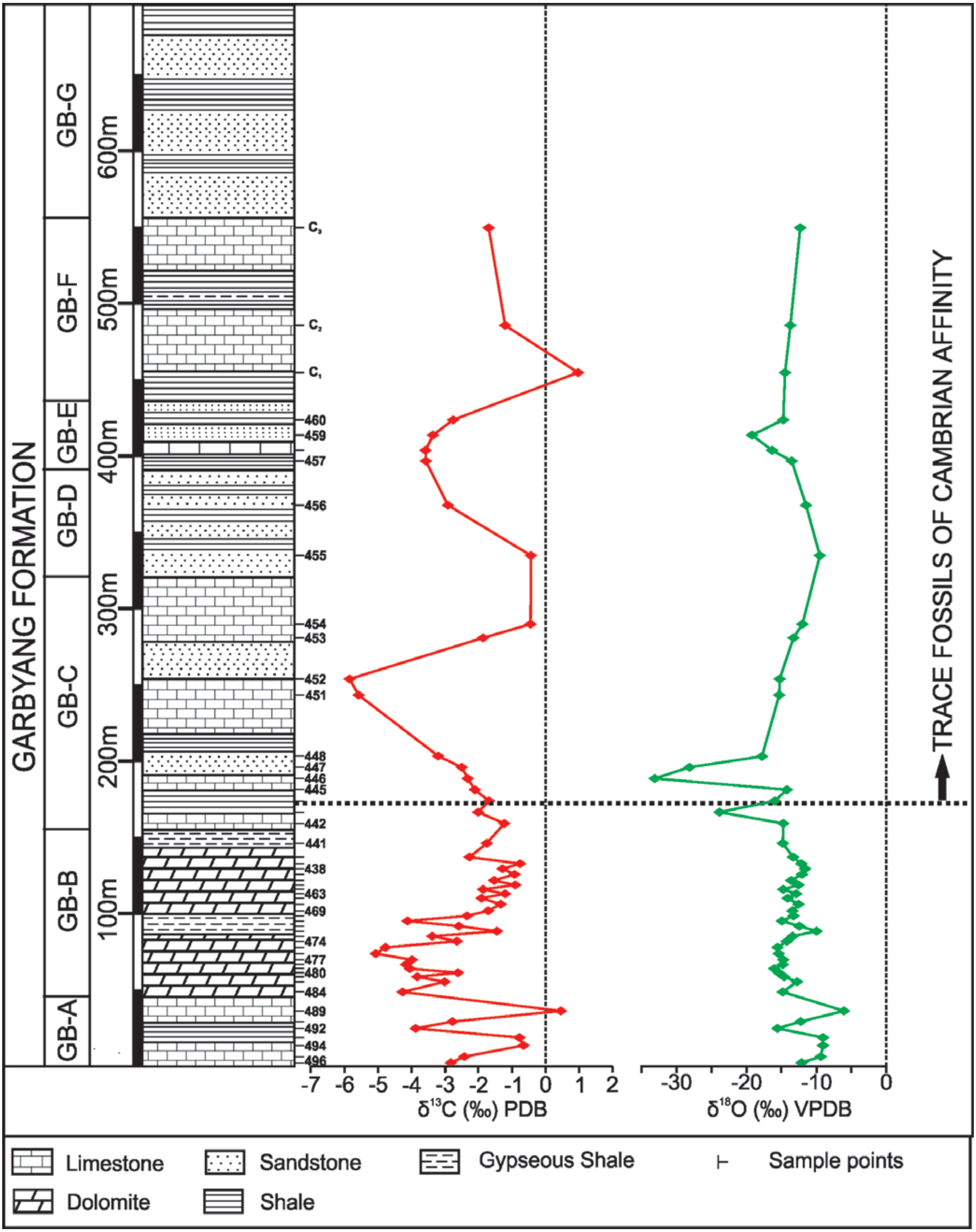

Fig. 2. Litholog of the Garbyang Formation showing major lithologies and sample points. $\delta^{13}C$-carb and $\delta^{18}O$-carb of various samples are plotted to show their depth variation. Dotted line in the lower part of the Garbyang C represents the first occurrence of the Cambrian trace fossil.

Table 1. Generalised lithostratigraphy of the Malla Johar Supergroup, Kumaun Himalaya. The Garbyang Formation is classified into seven members (Kumar *et al*., 1977).

	Group	Formation	Member	Age
Malla Johar Supergroup	Sancha Malla Group			Late Jurassic-Early Eocene
	Rawalibagar Group			Permian – Late Jurassic
	Sumna Group	Muth Formation		Devonian
		Variegated Formation		Silurian
		Shiala Formation		Ordovician
		Garbyang Formation	Garbyang G	Cambrian
			Garbyang F	
			Garbyang E	
			Garbyang D	
			Garbyang C	
			Garbyang B	Ediacaran
			Garbyang A	
	Malari Group			Latest Precambrian

or decarbonation reactions during metamorphism (Valley, 2001). The δ^{13}C-carb value in the latest Precambrian (Garbyang A and lower half of Garbyang B) that cover a thickness of around 90 m ranges from -5‰ to 0.5‰ (Fig. 2). This shift of around 5‰ probably represents the Ediacaran age corresponding to the Shuram excursion. The existence of this shift in the δ^{13}C-carb curve from different palaeogeographic locations attests to its global nature (Aharon *et al*., 1987; Kaufman *et al*., 2006; Narbonne *et al*., 2012).

In the Garbyang Formation, at the beginning δ^{13}C-carb value is -2.8‰ which stays around -1.0‰ for a short duration even after the Pc-C boundary (Fig. 2). After that, the value gradually decreases to -5.8‰. The carbon isotope value increases gradually to -0.5‰ and subsequently to ~ 0‰ for a depositional period equivalent to a thickness of 130 m (Fig. 2). Subsequently, a negative excursion up to -4‰ occurs again over 100 meter thickness. There are three such long intervals of negative carbon excursion alternating with two smaller intervals of δ^{13}C ~ 0‰ episodes. These features of the δ^{13}C-carb curve of the Garbyang Formation compare well with the typical global δ^{13}C-carb curve of time ranging between 550 Ma to 530 Ma as provided in Geological Time Scale (Saltzman and Thomas, 2012) (Fig. 2).

Based on a compilation of a large number of isotopic data of the Neoproterozoic and Phanerozoic carbonates, Knauth and Kennedy (2009) showed a plot of δ^{13}C vs. δ^{18}O where distinct zones of pristine marine carbonates, their lithification products and alteration products (by marine/meteoric water diagenesis) fall. The Garbyang samples plot in the alteration zone (mostly between -10 to -15‰ with a few samples showing values around -33‰) which suggests a very prominent role of meteoric water induced alteration (Fig. 4). However, the carbon isotope ratio is mostly more than -5‰. It seems that during the diagenesis in the Garbyang area the pore water retained the δ^{13}C composition of the dissolved inorganic carbon of the overlying water and there was no significant input of carbon from other sources. Therefore, even though carbonate authigenesis played an important role in the deposition of the Garbyang rocks, it

Table 2. Sample code of the Garbyang Formation and δ^{13}C-carb and δ^{18}O-carb values. The samples are arranged in the stratigraphic order, namely from bottom to the top.

SAMPLE CODE	ä^{13}C (‰) PDB	ä^{18}O (‰) VPDB
GARB-496	-2.8	-12.1
GARB-495	-2.4	-9.4
GARB-494	-0.7	-9.1
GARB-493	-0.8	-9.1
GARB-492	-3.9	-15.5
GARB-490	-2.8	-12.2
GARB-489	0.4	-6.1
GARB-484	-4.3	-14.8
GARB-483	-3.0	-12.7
GARB-481	-3.8	-14.6
GARB-480	-2.6	-15.4
GARB-479	-4.0	-16.0
GARB-478	-4.2	-14.9
GARB-477	-4.0	-14.8
GARB-476	-5.1	-15.4
GARB-475	-4.8	-15.6
GARB-474	-2.6	-14.2
GARB-473	-3.9	-13.4
GARB-472 A	-1.4	-10.0
GARB-472	-2.6	-12.4
GARB-471	-4.1	-14.9
GARB-470	-2.3	-13.3
GARB-469	-1.7	-13.3
GARB-467	-1.3	-12.6
GARB-465	-1.9	-14.1
GARB-463	-1.2	-12.9
GARB-462	-1.9	-14.8
GARB-461 A	-0.9	-12.6
GARB-436	-1.5	-13.6
GARB-437	-0.9	-12.1
GARB-438	-1.3	-11.6
GARB-439	-0.8	-12.1
GARB-440	-2.3	-13.3
GARB-441	-1.7	-14.8
GARB-442	-1.2	-14.7
GARB-443	-2.0	-23.8
GARB-444	-1.7	-16.0
GARB-445	-2.1	-14.2
GARB-446	-2.3	-33.1
GARB-447	-2.5	-28.1
GARB-448 B	-3.2	-17.7
GARB-451	-5.6	-15.3
GARB-452	-5.8	-15.2
GARB-453	-1.9	-13.3
GARB-454	-0.4	-12.0
GARB-455	-0.4	-9.5
GARB-456	-2.9	-11.5
GARB-457	-3.6	-13.5
GARB-458	-3.6	-16.3
GARB-459	-3.4	-19.2
GARB-460	-2.8	-14.7
GARB-C1	1.0	-14.5
GARB-C2	-1.2	-13.7
GARB-C3	-1.7	-12.3

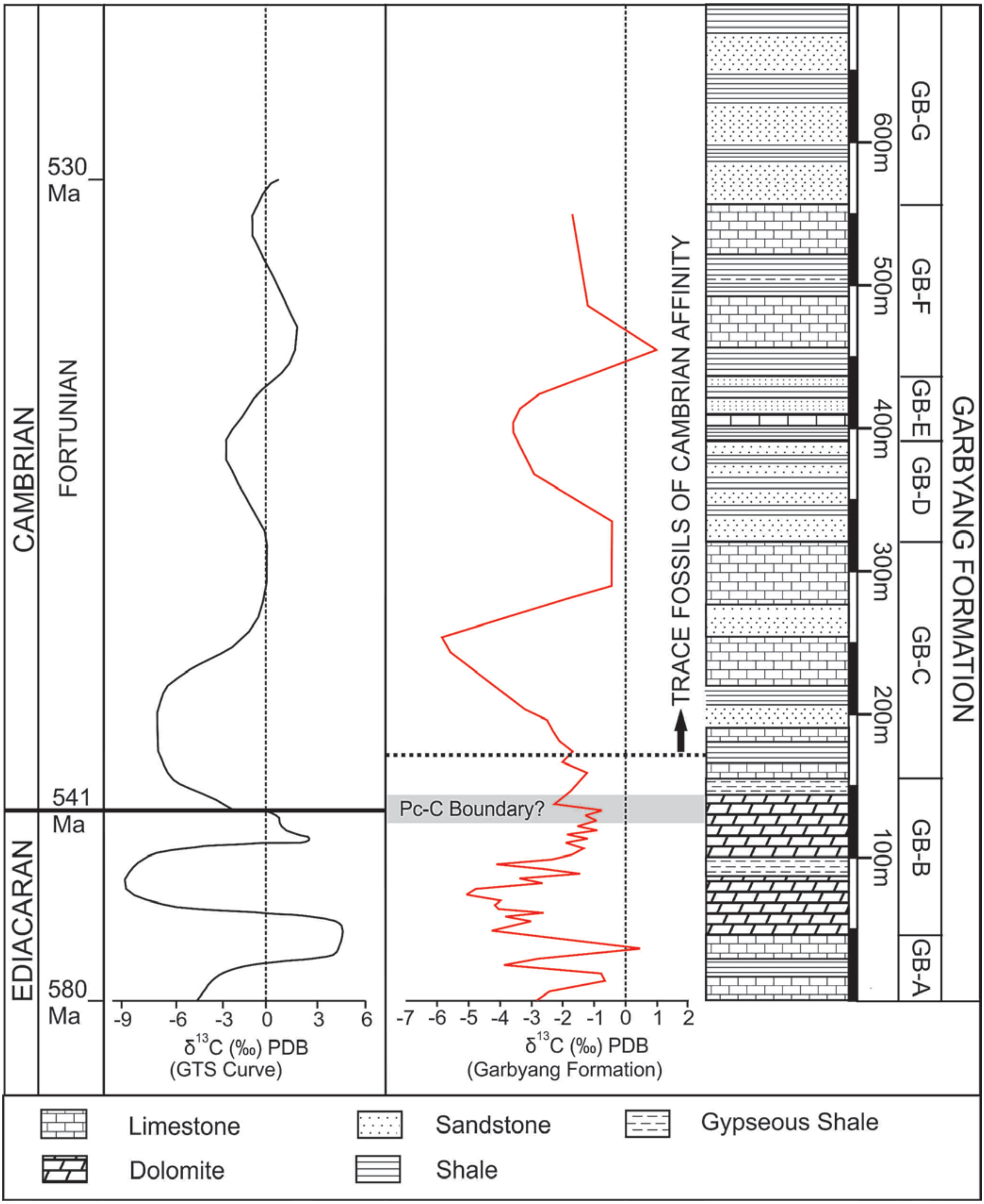

Fig. 3. The δ¹³C-carb profile of the Geological Time Scale (Saltzman and Thomas, 2012) corresponding to the isotopic changes in the Late Ediacaran and Early Cambrian also shown which compares well with that of the Garbyang Formation. The probable Precambrian-Cambrian boundary is identified in the upper part of GB-B and marked by light grey colour box.

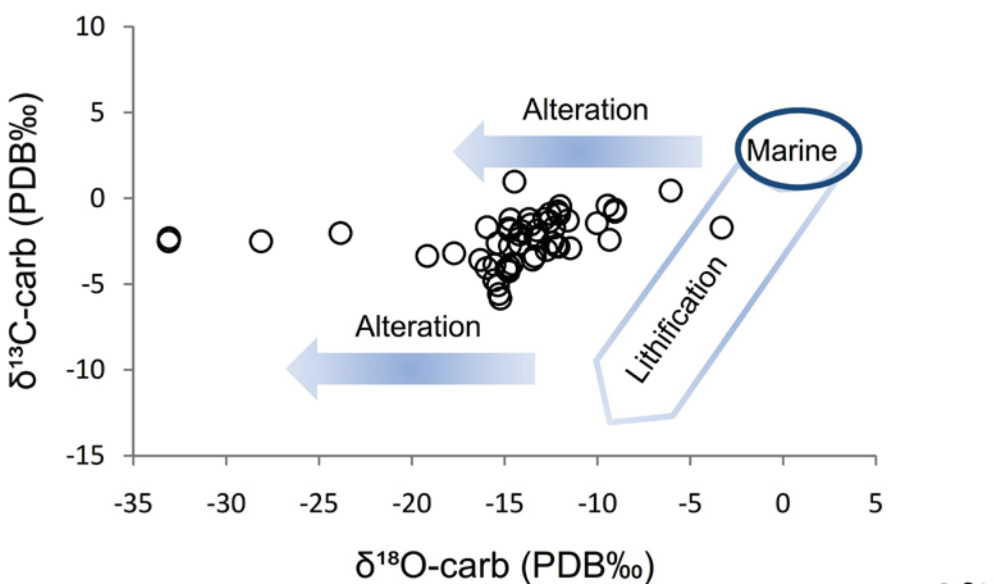

Fig. 4. Carbon-Oxygen isotope plot of the Cenozoic carbonates showing zones of marine sediments, zone of lithification and trend of alteration (after Knauth and Kennedy, 2009). The samples of the Garbyang Formation plot in the zone of alteration indicating strong meteoric water diagenesis.

hardly affected the carbon composition (Hudson, 1977; Dickson and Coleman, 1980; Morse and Mackenzie, 1990; Price *et al*., 2008; Al-Mojel *et al*., 2018). It has already been discussed that deposition of carbonates of the Garbyang Formation took place in intertidal to the supratidal setting. In the intertidal-supratidal zones, which are often sub-aerially exposed, meteoric water plays an important role in the diagenesis of carbonates (Moore, 1989; James and Jones 2015).

The noticeable excursion in the δ^{13}C-carb during late Neoproterozoic- early Cambrian transition is considered to be caused either by a change in the global organic carbon or a variation in the organic carbon at the local scale (Schidlowski *et al*., 1975). But, several studies in last few decades have demonstrated the occurrence of a prominent δ^{13}C-carb excursion just before the Pc-C boundary which is commonly known as Shuram Excursion (Grotzinger *et al*., 2011; Ansari *et al*., 2018). In the case of the Garbyang Formation, although the δ^{13}C-carb excursion do not attain the magnitude (δ^{13}C-carb < -6‰) similar to the Shuram Excursion. Nevertheless, the δ^{13}C-carb stratigraphy closely matches with the typical global δ^{13}C-carb profile for late Neoproterozoic- early Cambrian transition (Saltzman and Thomas, 2012). On this basis, the present study infers the possible presence of Pc-C boundary between the Garbyang B and Garbyang C.

In the biological context, the first record of animal activity in the form of well-defined trace fossils is considered as the initiation of the Cambrian period. As stated before, in the case of the Garbyang Formation, trace fossils of the Cambrian affinity are present in the sediments above the isotopically inferred Pc-C boundary which provides supportive evidence for the current inference.

CONCLUSION

The Garbyang Formation represents a continuous succession of carbonates deposited in the Tethys zone of the Himalaya during the terminal Precambrian-early Cambrian time. The present study was aimed to understand its depositional time frame and in particular, investigate the possible occurrence of the Pc-C boundary in this formation. Carbon and Oxygen isotope analysis demonstrates the presence of three negative carbon isotope excursions that match the features of the global curve available in GTS 2012 (Saltzman and Thomas, 2012) between 550 Ma to 530 Ma. The δ^{18}O-carb mostly below -10‰ suggests significant meteoric water interaction. Given the possibility of Pc-C boundary in the Garbyang Formation, more robust geochemical and paleontological exploration is required to further test these primary results.

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