Terminal Proterozoic-Cambrian sequences in India: a review with special reference to Precambrian-Cambrian Boundary

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The Terminal Proterozoic marine sequences, grading into Cambrian, are present in the Krol Basin (Lesser Himalaya), the Kashmir, Spiti-Zanskar and Kumaun Basins (Higher Himalaya) and in Marwar Basin (western India). These sequences post-date a major tectono-thermal event associated with Cadomian Orogeny and rest on eroded older successions which include well dated Malani Igneous Suite (Malani Rhyolite 745 ±10 Ma; Siwana Granite 731± 14 Ma) in western India and over the Salkhala Group with granites (745 ± 50 Ma) or the Simla Group in the Himalaya. This cycle of sedimentation terminated with Pan-African Orogeny in Late Cambrian. These sequences are dominantly siliciclastic in basins in Higher Himalaya while those in Krol Basin and Marwar Basin show development of thick carbonate-evaporite facies with or without phosphorite. From the Upper Vindhyan and Bhima Groups in central and south India, respectively a *Chuaria-Tawuia* Assemblage along with sphaeromorphida Acritarch of Early Neoproterozoic age has been recorded. The $\delta^{13}C$ values range from +1.3 to +4.0 ‰ PDB and that of $\delta^{18}O$ from -5 to -9 ‰ PDB. These are, thus, not considered part of this sequence. In absence of age-determinating biota and radiometric dates from the basal part of the succession, the lower boundary of the Terminal Proterozoic can not be delineated and dated. However, a significant depletion in $\delta^{13}C$ values may be taken to mark the lower boundary.

The upper boundary of the Terminal Proterozoic (Precambrian-Cambrian Boundary) can not be demarcated in terms of GSSP due to absence of trace fossils of Zone-I (*Harlaneilla podolika* Zone) and Zone-II (*Phycodes pedum* Zone) in carbonate facies in Krol Basin and poor documentation of siliciclastic facies in Kashmir and Spiti-Zanskar Basins. The trace fossils correlative with ichnozone-III occur in all the sections in Himalaya and are useful for regional and global correlations. However, a significant depletion in $\delta^{13}C$ values has been recorded in the carbonate facies of Krol Basin between the horizons yielding Ediacaran and small shelly fossils of Meishucunian Zone-I. This has also been recorded in the Marwar Basin below the Phosphorite Bed. This depletion may be correlated with that recorded from the Precambrian-Cambrian transition in Siberian Platform, Anti Atlas Mountains, Morocco, China, etc. It may be taken into consideration to define and mark the boundary in the absence of trace fossils.

Key-words — Terminal Proterozoic, Cambrian Sequences, Precambrian-Cambrian Boundary, India.

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साराँश

भारत में अंतिम प्रोटीरोजोइक-कॅम्ब्रियन अनुक्रम : कॅम्ब्रियनपूर्व-कॅम्ब्रियन सीमा पर विशेष सन्दर्भ सहित एक समीक्षा

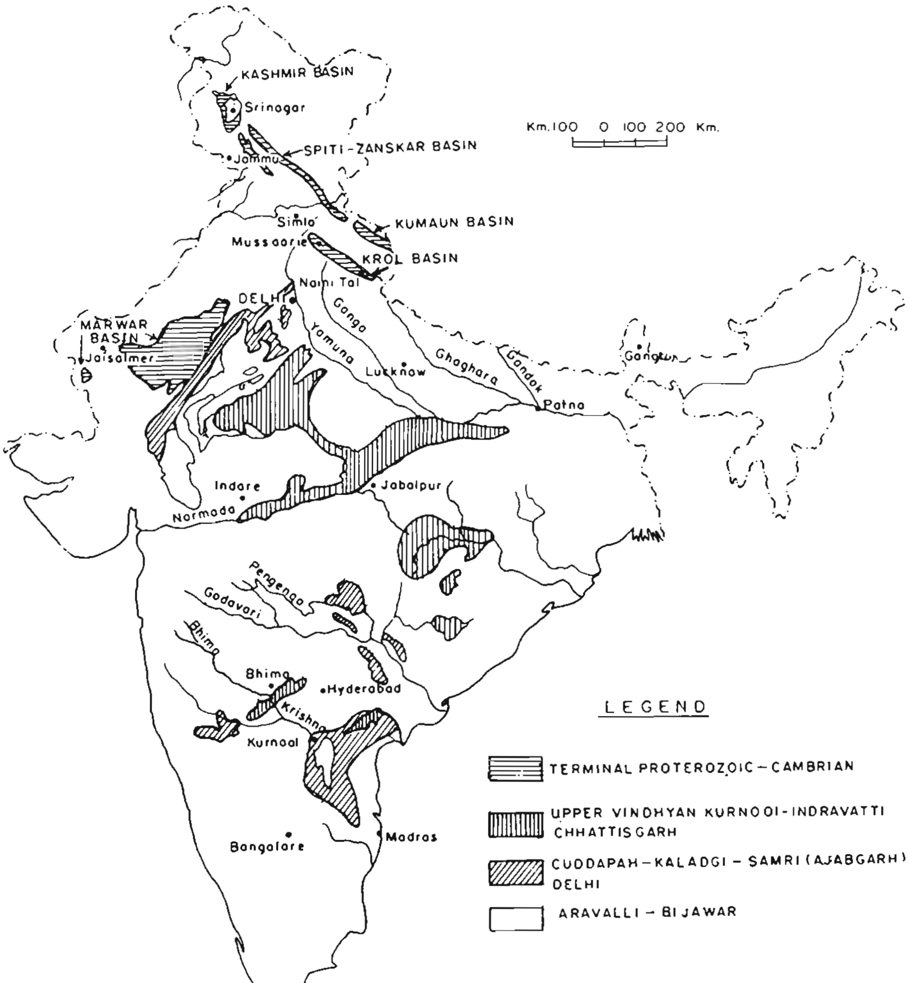
गोपेन्द्र कुमार, रविशंकर, प्रभात कुमार माइती, वी.के. माथुर, एस. के. भट्टाचार्य एवं आर. ए. जानी

अन्तिम प्रोटीरोजोइक समुद्री अनुक्रम क्रोल द्रोणी (लघु हिमालय), काश्मीर स्पिति-जन्सकार एवं कुमायुं द्रोणी (उच्च हिमालय) तथा पश्चिमी भारत में मारवाड़ द्रोणी में विद्यमान हैं। ये अनुक्रम कोडोमियन उत्पत्ति से सहयुक्त एक प्रधान विवर्तनिक-तापीय घटना के समकालीन हैं तथा अन्य शेष अनुक्रम पुरानी अनुक्रमों के ऊपर स्थित हैं। अवसादन का यह चक्र अनंतिम कॅम्ब्रियनकाल में पैन-अफ्रीकी उत्पत्ति के साथ-साथ समाप्त हो गया। उच्चतर हिमालय में ये अनुक्रम द्रोणीयों में सिलिसिक्लास्टिक से प्रभावी हैं तथा क्रोल एवं मारवाड़ द्रोणीयों में फोस्फोराइट युक्त अथवा फोस्फोराइट विहीन मोटे कार्बोनेट-इवेपोराइट संलक्षणीयों का धीमा विकास प्रदर्शित करते हैं। केन्द्रीय एवं दक्षिण भारत में क्रमशः उपरि विन्ध्य एवं भीमा समूहों से प्रारम्भिक निओप्रोटीरोजोइक आयु के एक्रीटार्को सहित एक *चुआरिया-तवुइया* समुच्चय अभिलिखित की गई है। डेल्टा कार्बन[13] आँकड़े +1.3 से +4.0 प्रति हजार पी.डी.बी. तथा डेल्टा ऑक्सीजन[18] के आँकड़े -5 से -9 प्रति हजार की दर से आँके गये हैं जिसके कारण ये इस अनुक्रम में सम्मिलित नहीं किये गये हैं। इस अनुक्रम के आधारी भाग की आयु संबन्धी एवं रेडियोमितीय आँकड़ों की अनुपस्थिति के कारण अंतिम प्रोटीरोजोइक की सीमा सुनिश्चित नहीं की जा सकी है। तथापि डेल्टा कार्बन[13] के आँकड़ों के आधार पर इसे निचली सीमा माना जा सकता है।

काश्मीर एवं स्पिती-जन्सकार द्रोणीयों में सिलिसिक्लास्टिक संलक्षणी की अल्प संख्या तथा क्रोल द्रोणी में कार्बोनेट संलक्षणी में मंडल-1 (*हार्लेनियॅल्ला पेडोलिका* मंडल) एवं मंडल-2 (*फाइकोड्स पीडम* मंडल) की अनुपस्थिति के कारण अंतिम प्रोटीरोजोइक (कॅम्ब्रियनपूर्व-कॅम्ब्रियन सीमा) की ऊपरी सीमा सुनिश्चित नहीं की जा सकती। इक्नोजोन-3 के समतुल्य ट्रेस जीवाश्म हिमालय में सभी खंडों में मिलते है तथा क्षेत्रीय एवं भूमण्डलीय तुलनाओं की दृष्टि से बहुत महत्वपूर्ण हैं। तथापि मीशुक्वान मंडल-1 के एडियाकरन एवं छोटे शैली जीवाश्म धारक संस्तरों के मध्य क्रोल द्रोणी की कार्बोनेट संलक्षणी में डेल्टा कार्बन^{13} के आँकड़ों में महत्वपूर्ण ह्रास देखा गया है। मारवाड़ द्रोणी में फोस्फोराइट संस्तर के नीचे भी ऐसा ही प्रेक्षित किया गया है। इस ह्रास की तुलना साइबेरियन प्लेटफार्म, एन्टी एटलस पर्वत, मोरक्को, चीन आदि में कॅम्ब्रियन पूर्व-कॅम्ब्रियन परिवर्तन से भी की जा सकती है। ट्रेस जीवाश्मों की अनुपस्थिति में सीमांकन करने में भी इसका सदुपयोग किया जा सकता है।

OF LATE, the marine sequences, referred variously as the Sinian, Vendian or Ediacaran, forming the latest Precambrian or Terminal Proterozoic and grading into Cambrian, are receiving an international cooperation in connection with defining the lower and upper age limits and identification of events for regional and global correlation. The question of placing the boundaries became the topic of international discussions which led to the formation of two working groups (WG), one under the aegis of IUGS-IGCP Project 29 for the Demarcation of the Precambrian-Cambrian Boundary in 1976 with the objective to recommend criteria for and identify a global stratotype section and point (GSSP) for the boundary. The other one under IUGS to study the Terminal Proterozoic System in 1988 with the aim to define the chronostratigraphic base of the period.

The section in Canada was ultimately chosen as the GSSP by the WG of IGCP 29 which was subsequently ratified by the Executive Committee



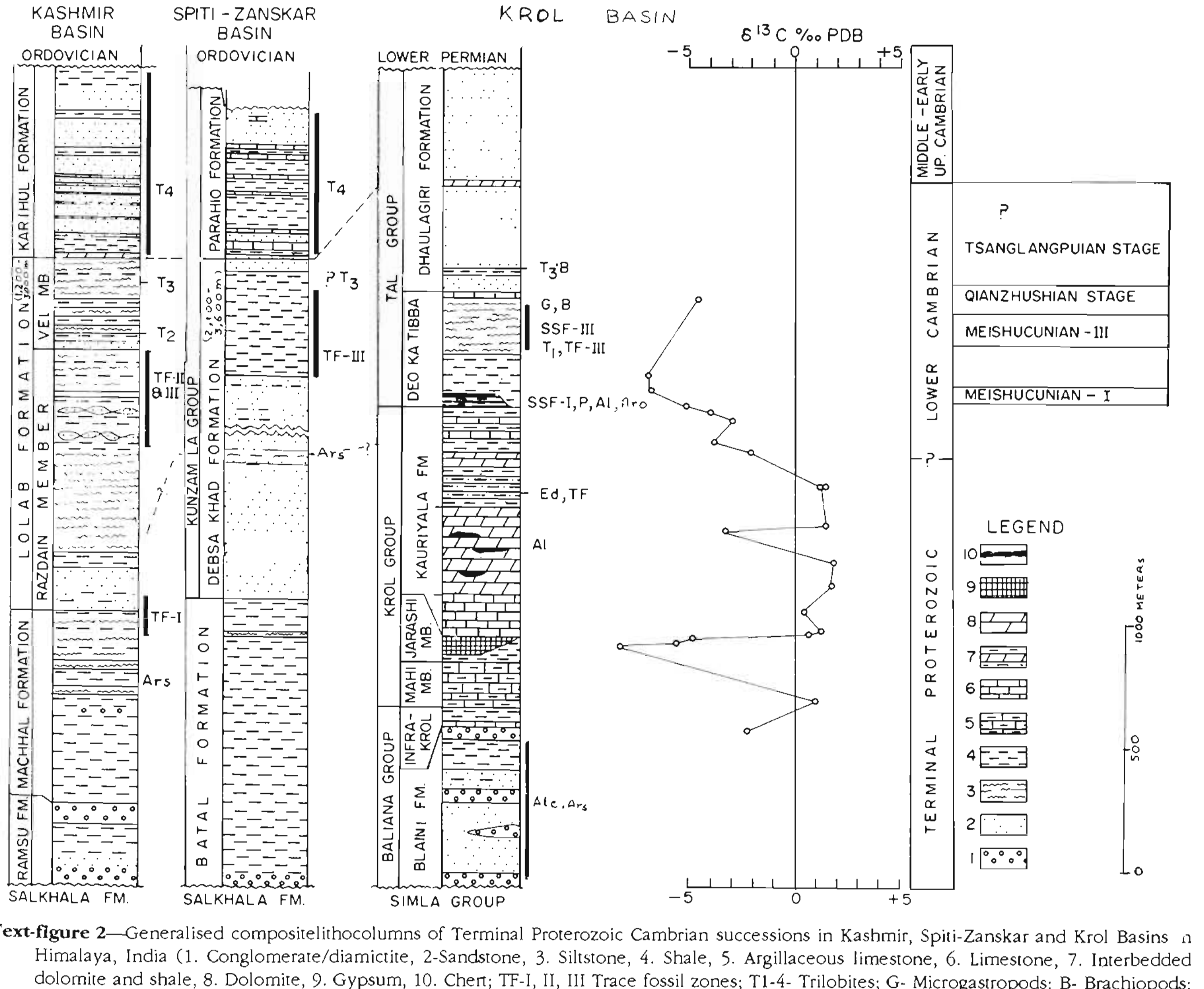
Text-figure 1—Map of India showing location of different basins of Terminal Proterozoic-Cambrian successions.

and Council IUGS in 1992 (Landing, 1994). This GSSP, however, did not meet the basic requirements of global correlation and posed certain problems as like other fossils, the trace fossils are also facies controlled being more abundant in siliciclastic facies. The stress, therefore, was given to develop an "integrated and refined global biostratigraphy, chemostratigraphy and event stratigraphy for the Precambrian-Cambrian interval" in another IGCP Project 303 formed in 1991.

In India, the Terminal Proterozoic succession grading into Cambrian, constituting the Supersequence IV (Shanker *et al.*, 1989, 1996), is represented in Krol, Kashmir, Spiti-Zanskar, Kumaun and Marwar Basins (Text-figure 1). This succession is of special significance as it contains large deposits of evaporites (gypsum and or salt), rock-phosphate, and oil and natural gas in certain sectors. Different sections in these basins were studied to identify lithostratigraphic, biostratigraphic, chemostratigraphic and event stratigraphic markers for defining the lower and upper age limits of the Terminal Proterozoic System for regional and global correlations. The studies were also extended to Bhima Basin in South India in addition to upper part of the sequence in the Vindhyan Basin of central India; as these successions were considered to grade into Cambrian.

KROL, KASHMIR, SPITI-ZANSKAR BASINS

The Terminal Proterozoic succession grading into Cambrian, forming the Supersequence IV (Shanker *et al.*, 1989, 1996), is exposed in the Krol

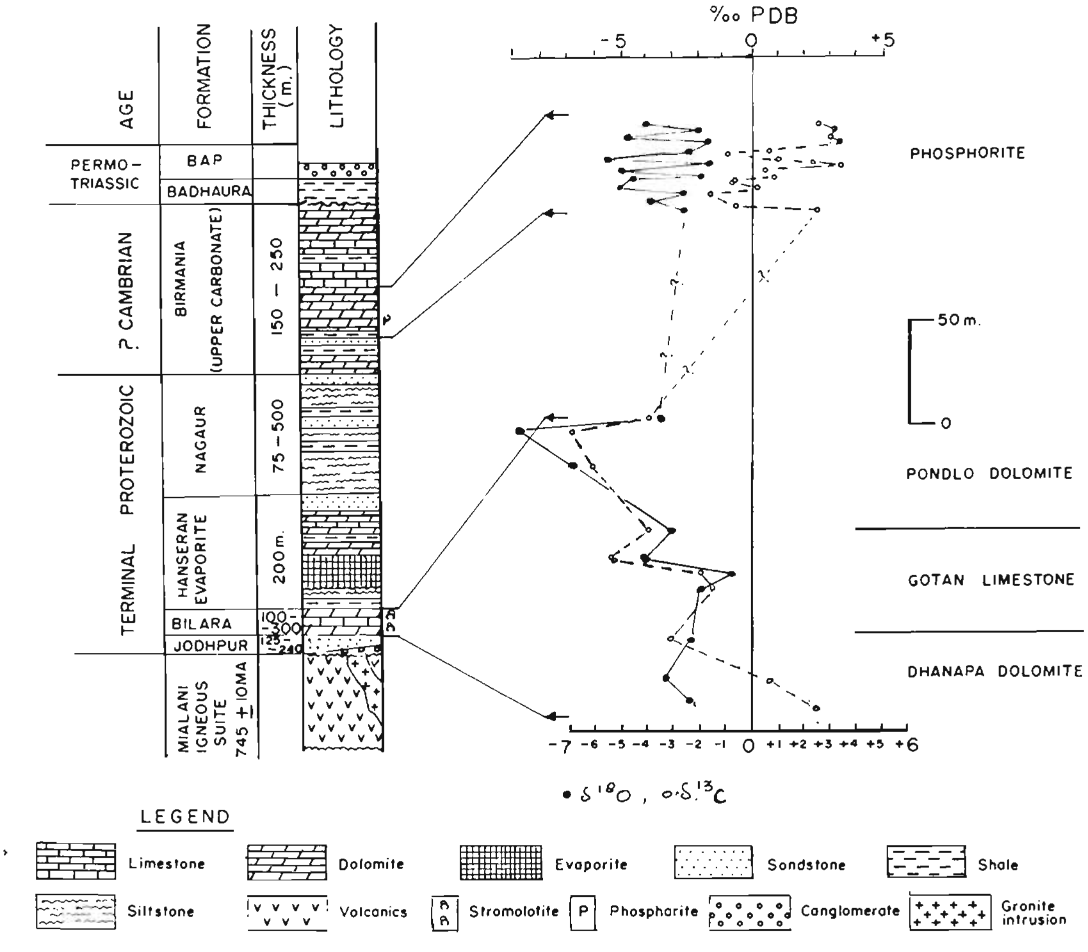


Text-figure 2—Generalised compositelithocolumns of Terminal Proterozoic Cambrian successions in Kashmir, Spiti-Zanskar and Krol Basins in Himalaya, India (1. Conglomerate/diamictite, 2-Sandstone, 3. Siltstone, 4. Shale, 5. Argillaceous limestone, 6. Limestone, 7. Interbedded dolomite and shale, 8. Dolomite, 9. Gypsum, 10. Chert; TF-I, II, III Trace fossil zones; T1-4- Trilobites; G- Microgastropods; B- Brachiopods; SSF-I, III- Small Shelly Fossils zones; Ed- Ediacaran fossils; Al-Calcareous algae; Alc- Cyanophycean algae; Ars-Acritarchs unornamented; Aco-Acritarchs ornamented; P-Phosphorite).

Basin (Lesser Himalaya), Kashmir Basin (Higher Himalaya) and Spiti-Zanskar and Kumaun Basins (Tethys Himalaya). These rest transgressively over the Early Neoproterozoic Simla Group or over the Salkhala Group with granites dating 745 ± 50 Ma or their equivalents (Text-figure 2). The successions in basins in Higher and Tethys Himalaya are unconformably overlain by Lower Ordovician sediments of Supersequence V (Shanker *et al.*, 1989, 1996), while in Krol Basin, the Lower Permian succession forming part of the Supersequence VI (Shanker *et al.*, 1996) rests unconformably over it.

The sedimentation in the Himalayan basins starts with a conglomerate or diamictite at the base but higher up, it is areno-argillaceous with bands of limestone/dolomite appearing in the upper part. The sequence is subdivisible into Ramsu, Machhal, Lolab and Karihul Formations in Kashmir Basin and Batal, Kunzam La and Parahio Formations in Spiti-Zanskar Basin. In the Krol Basin, the sequence comprises the Baliana, Krol and Tal Groups, in ascending order. The Krol Group is essentially a carbonate-evaporite deposit. The basal part of the Tal Group contains, at places, phosphorite beds with small shelly fauna of Meishucunian Zone-I.

The presence of Middle to early Upper Cambrian trilobites in the Karihul and Parahio Formations indicates the upper age limit of the succession being early Upper Cambrian. This cycle of sedimentation terminated with Pan-African Orogeny when the sea receded and the area was uplifted. The earliest trilobites recorded from the succession belong to the Tsanglangpuian Stage of Lower Cambrian and include *Paokannia magna* correlatable to *Drepanuroides* zone of Hongjingshao substage of China from Kashmir (Kumar & Verma, 1987) and *Redlichia noetlingi* of Wulnjing substage (upper part of Tsanglangpuian) of China from Lolab Formation (Shah *et al.*, 1980), in Kashmir and Kunzam La Formation, Spiti (Reed, 1910) and Tal Group, Krol



Text-figure 3—Generalised composite lithocolumn of the Marwar Group, western India showing stable carbon and oxygen isotope variations.

Basin (Kumar *et al.*, 1987). Some poorly preserved Redlichiid Trilobites in association with Meishucunian Zone-III small shelly fauna, have also been recorded from underlying beds of the Tal Group (Joshi *et al.*, 1989).

The record of various fossils occurring below trilobite bearing horizon (early Tsanglangpuian Stage) from different successions has been reviewed by Kumar (1995) and discussed by Mathur *et al.* (1997). Among these, records of trace fossils, small shelly fossils and Ediacaran fauna are of special interest for regional and global correlations. The trace fossils are diverse and abundant in silicilastic facies of Higher Himalayan ranges. These have been grouped in three assemblages, which in ascending order are: I-*Planolites beverleyensis-Planolites reticulatus*, II-*Arenicolites-Gordia-Phycodes*, and III-*Monomorphichnus-Dilichnites-Astropolichnus* (*Astropolithon*)-*Rusophycus* Kumar 1987. The assemblages I and II are known from Kashmir only and occur in the basal part of the Lolab Formation (Razdain Member).

Assemblage I also contains *Skolithos* and *Bergauria* and has yielded Late Precambrian microbiota (Maithy *et al.*, 1988). Assemblage III is ubiquitous and is recorded from the upper part of Razdain Member of the Lolab Formation (Raina *et al.*, 1989; Shah & Sudan, 1983; Bhargava & Srikantia, 1982) and Kunzam La Formation (Debsa Khad Member, Kumar *et al.*, 1984; Bhargava *et al.*, 1982; Bhargava & Srikantia, 1985). The other characteristic ichnofossils are *Dimorphichnus, Tapherhelminthopsis circularis, Gyrochorte, Planolites corrugatus, Phycodes palmatum, Kupwaria fusiformis, Bifasciculus, Bifungites*, etc. In Spiti, this zone can further be sudivided into *Rusophycus didymus-Isopodichnus* Subassemblage appearing at a higher level. This assemblage in Krol Basin occurs in association with small shelly fossils of assemblage II (Kumar *et al.*, 1987) considered equivalent to Meishucunian Zone-III of China.

STABLE ISOTOPE STUDIES

Stable isotopic studies in the Krol Basin, Garhwal Syncline, reveal four depletions in $\delta^{13}C$ values (Bhattacharya *et al.*, 1996) with corresponding increase in $\delta^{18}O$ values (see Mathur *et al.*, 1997). The first and the fourth depletion in $\delta^{13}C$ values are of

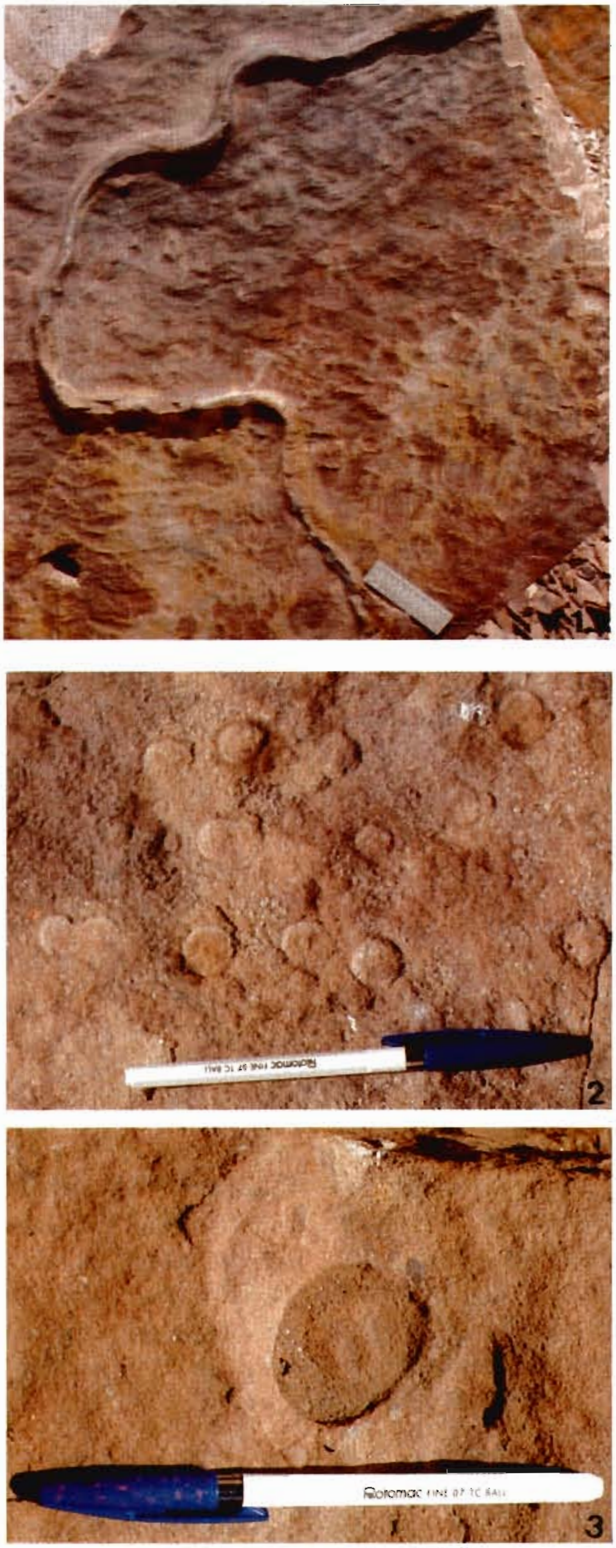


PLATE 1

1. Secondary filling resembling trace fossil in sandstone, Jodhpur Formation, Jodhpur, Rajasthan.

2, 3. Calcareous concretion in sandstone, Jodhpur Formation, Jodhpur, Rajasthan.

significance in defining/demarcation of the lower and upper boundaries of the Terminal Proterozoic System. These two depletions correspond to one recorded in the basal part of the successions deposited immediately after the Varangian glaciation, and the other above the Ediacaran horizon continuing into Cambrian (Knoll & Walter, 1992). The other two short-lived depletions may be related to basinal conditions as the lower one (second depletion) is in horizon containing evaporite deposits, and the upper (third depletion) in deeper carbonates with lenticular black chert. The development of chert may be related to Caldecote Igneous Event of English Midlands (Brasier, 1985). The record of a small-sized negative Eu-anomaly, coinciding with the fourth depletion is significant (Bhattacharya *et al.*, 1996).

MARWAR BASIN

The sediments unconformably overlying the Malani Igneous Suite (Malani Rhyolite 745±10Ma Crawford & Compston, 1970; Siwana Granite 731±14 Ma, in Kochhar & Dhar, 1993) or the older Proterozoic metasediments (Delhi & Aravalli Groups) constituting the Marwar Group (Marwar Supergroup; Pareek, 1981, 1984), are considered to be the southeastern extension of the Precambrian-Cambrian succession of the Salt Range, Pakistan. The sequence is also referred informally as the Trans-Aravalli Vindhyan though it does not form part of the Vindhyan Basin. It is unconformably overlain either by the Permian-Triassic or the Tertiary sequences in the northern and western parts. It is partially or wholly covered by the Neogene-Quaternary sediments of the Indo-Gangetic plain or the Thar Desert. Northwards it has been encountered in bore-holes (Das Gupta & Bulagauda, 1994; Peters *et al.*, 1995). These sediments are mainly exposed in Jodhpur-Nagaur area (also referred as Nagaur Basin). An outlier is also exposed around Birmania, north of Barmer which is considered to be deposited in another basin — the Birmania Basin (Pareek, 1981).

Based on surface and subsurface data (Shrivastava, 1971; Pareek, 1981, 1984; Das Gupta & Bulgauda, 1994; Peters *et al.*, 1995; Dasgupta, 1996) the Marwar Group has been divided into Jodhpur, Bilara, Nagaur and Birmania (Upper Carbonate) Formations in ascending order. The generalised lithostratigraphy is given below :

FORMATION	GENERAL LITHOLOGY
Birmania (Upper Carbonate)	Cherty limestone at base followed by calcareous ferruginous sandstone, quartzitic sandstone, phosphorite, limestone, dolomite at top.
	——Unconformity——
Nagaur (Tunklian sandstone)	Brick red claystone, siltstone, clay, gritty to pebbly sandstone with fragments and pebbles of chert, dolomite, quartz, quartzite, Malani rhyolite and granite.
	——Disconformity——
Hanseran Evaporite (Nagaur Sandstone)	Limestone, dolomite with gypsum, anhydrite, halite red to brick red sandstone, siltstone, claystone Khichan conglomerate with cobbles and pebbles and pieces of chert, dolomite, feldspars, sandstone.
	——Disconformity——
Bilara	Pondlo Dolomite : Foetid dolomite, cherty limestone with bands of claystone, siltstone and sandstone; stromatolites in upper 1.5 m.
	Gotan Limestone: Foetid laminated dark greyish dolomitic limestone and dolomite, stromatolite.
	Dhanappa Dolomite: Chert at base followed by cherty dolomite, siliceous dolomitic limestone.
Jodhpur	Girbhakar Sandstone: Purple, brick red to whitish medium grained to gritty, pebbly sandstone, with bands of shale at base.
	——Diastem——
	Sonia Sandstone: Buff to whitish, slabby, arkosic sandstone with calc. concretions, shale.
	Pokhran Boulder Bed: Conglomerate with boulders, cobbles and pebbles of Malani Rhyolite, granite.
	——Unconformity——
Malani Igneous Suite (Malani Rhyolite 745±10 Ma; Siwana Granite 731±14 Ma) and older Proterozoic metasediments of Delhi and Aravalli Groups.	

The biostratigraphic studies show that the stromatolites in the Bilara Formation are of stunted growth and include *Collenia pseudocolumnaris* Maslov, *Collenia* sp., *Concollenia* sp., *Cryptozoan accidentalis* Dawson, *Irregularia* sp. and *Stratifera* sp. with occasional oncolites (Barman, 1980). The trace fossil-like structures were also noticed in the Jodhpur Formation; they are all of inorganic origin, some are rill-marks, while others are secondary fillings (Pl. 1, fig. 1). Some rounded calcareous concretions and their impressions after leaching out of the carbonate give the impression of medusoids (Pl. 1, figs 2, 3). The specimen reported by Khan (1973) as brachiopod *Orthis* was examined by one of us (GK) and found to be a pellet.

The preliminary stable isotopic studies show that the $\delta^{13}C$ values are in the range of +0.6 to +3.6‰ PDB in the basal part of the Bilara Formation while in upper part the value shows depletion in the range of - 1.3 to -6.9‰PDB which may continue in the overlying Hanseran (Nagaur Sandstone) Evaporite. There is again a short-lived positive excursion (+.4 to 3.6‰ PDB) in the Birmania Formation (Upper Carbonate) at the level of phosphorite bed. The stable carbon isotopic values in the heavy oil recovered from bore-holes in the Birmania Formation give -32.4‰PDB (Das Gupta & Bulgauda, 1994). The oil is non-biodegraded, and thermal-maturation-dependant biomarker ratios indicate generation from source rock which is 'age diagnostic and source dependant biomarkers' indicating that 'the oil originated from algal and bacterial organic matter in Infra-Cambrian, carbonate rich source rock deposited under anoxic marine conditions' (Peters *et al.*, 1995).

VINDHYAN BASIN

The generalised lithostratigraphy based on works of Sarkar, 1981; Mathur, 1981; Soni *et al.*, 1987 is given below:

	GROUP	FORMATION	MEMBER
		Bhavpura	
		Balwan Limestone	
	Bhander	Maihar Sandstone	
		Sirbu Shale	
		Bundi Hill Sandstone	
		Nagod Limestone (Lakheri)	
		Ganurgarh Shale (Simrawal)	
Upper		Gahadra Sandstone	
Vindhyan	Rewa	Jhiri Shale	
		Itwa Sandstone	
		Panna Shale	
	Kaimur	Dhandraul Quartzite	
		Bijaigarh Shale	
		Markundi Quartzite	
		Ghurma Shale	
		Ghagar Quartzite	
		Unconformity	
		Rohtas Limestone	Suket Shale
			Nimbahera Limestone
			Bari Shale
			Jiran Sandstone
			Khori Conglomerate
Lower			
Vindhyan	Semri	Glauconite Sandstone	
		Fawn Limestone	
		Olive Shale	
		Chopan Porcellanite	
		Kajrahat Limestone	
		Arangi	
		Unconformity	
Basement of Bundelkhand Granite (Archaean) or Mahakoshal Supergroup (Paleoproterozoic) and its equivalents.			

There is absence of materials for reliable dating and radiometric dates are conflicting (Vinogradov *et al.*, 1964; Crawford & Compston, 1970; Srivastava & Rajagopalan, 1988). There, however, appears to be a broad agreement in considering lower age limit of the Semri Group to be around 1400 Ma and the upper before the intrusion of the Majhgawan pipe dating 1,140 Ma. The sedimentation of the Upper Vindhyan (Kaimur Group) on the other hand, commenced around 940 Ma and was considered to have continued well into Phanerozoic.

On the basis of presence of *Chuaria-Tawuia* assemblage from the Suket Shale of the Rohtas Limestone, Semri Group, Maithy and Shukla (1977) suggested the upper age limit of the Lower Vindhyan to be around 1,000 Ma.

Recent magnetostratigraphic studies (Poornachandra Rao & Bhalla, 1996), preliminary in nature, did not contribute much in fixing the age as correlation and interpretation are primarily based on the assumption that Upper Vindhyan is equivalent to the Marwar Supergroup; the latter post-dates Cadomian Orogeny and possibly continues into Cambrian. The Vindhyan sequence does not record imprints of major events, such as, the tectono-thermal episode associated with the Cadomian Orogeny, marine transgression related to widespread Varangian glaciation, the development of evaporite-facies and phosphogenesis, which are well recognised in the Marwar Basin and also in the Himalayan basins.

Maithy and Babu (1997) reported a rich biota from the Bhander Group. Recently, Kumar and Srivastava (1997) have reported *Chuaria circularis-Tawuia dalensis* from Sirbu Shales of the Bhander Group and suggested a probable age of 700 Ma.

Preliminary result of carbon isotopic studies indicate $\delta^{13}C$ values in the range of +2.9 to +4.0‰ PDB which is comparable to that recorded from the Bhima Basin in south India and from Precambrian sequences elsewhere in the world. In the absence of imprints of Varangian glaciation and Cadomian Orogeny from the Upper Vindhyan succession, it appears that this sedimentation terminated before the on-set of the Cadomian Orogeny in Early Neoproterozoic itself, i.e., before 650 Ma.

BHIMA BASIN

The Bhima Basin in south India is one of the several small isolated basins which expose Proterozoic successions. It received attention in view of the recent record of *Sabellitids* along with *Chuaria-Tawuia* from the Halkal Shale and its assignment to Terminal Proterozoic (Das Sarma *et al.*, 1992). Biota assigning a Late Proterozoic to Cambrian age (Saluja *et al.*, 1971; Venkatachala & Rawat, 1972; Vishwanathiah *et al.*, 1976) has also been recorded.

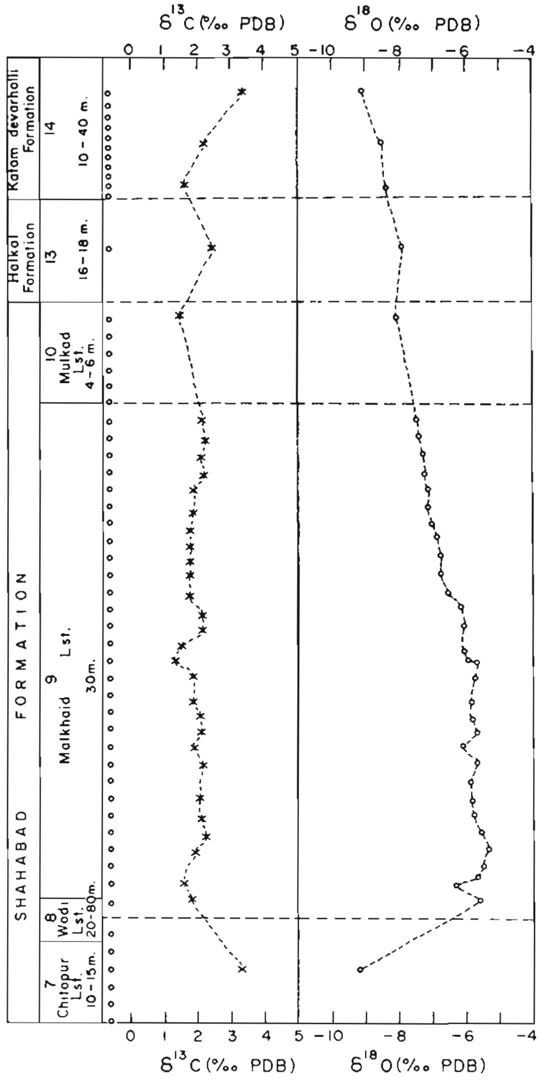
The Proterozoic sediments of the Bhima Basin constituting the Bhima Group (Bhima Series; King, 1872) rest unconformably over the Archaean basement and in turn is overlain by the Deccan Trap (Misra *et al.*, 1987; Kale *et al.*, 1990). The lithostratigraphy worked out by Misra *et al.* (1987) is given below:

SUBGROUP	FORMATION	MEMBER/LITHOLOGY	THICKNESS
	Harwal-Gogi	15 Shale	5-10 m
	Katamdevarhalli	14 Limestone	10-40 m
Andola	Halkal	13 Fissile Shale	16-20 m
(31-68 m)		12 Orthoquartzite	
		11 Chert Pebble Conglomerate	
		Para-unconformity	
		10 Flaggy	
		9 Argillaceous dark grey	
		limestone	6-4 m
		8 Massive dark grey &	
		7 Bluish grey limestone	8-20 m
	Shahabad	6 Variegated & siliceous/	
		cherty limestone	20-80 m
Sedam		Blocky, light grey to	
(62-205 m)		blush grey limestone	10-15 m
		Slabby & flaggy limestone	4-8 m
		4 Purple Shale	2-10 m
	Rabanapalli	3 Green/	
		Yellow Shale	5-15 m
		Siltstone	3- 4 m
		2 Quartzitic sandstone	5-15 m
		1 Conglomerate/grit	1-2 m

Stable Isotopic studies

A total of 49 samples of limestone were collected at one meter interval from the Shahabad and Katamdevarhalli Formations. Since the beds are horizontally disposed, continuous exposures are lacking and the sampling has to be done in different sections exposing different litho-units (Text-figure 4). Of these samples, 39 samples belong to the Shahabad Formation, in which 6 samples of the basal unit were collected from quarry near Mudbol Village, 27 of the blocky grey and variegated units from quarry faces of the Rajashri Cement Factory at Adityanagar and 6 samples of massive bluish grey limestone exposed in a quarry at Mulkod. The remaining 10 samples were collected from the Katamdevarhalli Formation exposed in a hill near Kedihalli Village. Besides, a sample of carbonaceous matter from shale of Halkal Formation was also analysed.

The results of the stable isotopic analysis are given in Text-figure 4. The $\delta^{13}C$ and $\delta^{18}O$ values range between 0.89 to 3.59 ‰ PDB and -5.37 to -9.18 ‰ PDB, respectively. Majority of the $\delta^{13}C$ values cluster around 2 ‰ PDB excepting those in the basal unit of Shahabad Formation which have a mean value of 3.25‰ PDB. Though there are minor



Text-figure 4—Showing composite stable carbon and oxygen isotopic variations in the Bhima Group (black dots denote sample interval of 1 m).

deflections within positive $\delta^{13}C$ values, there is no negative deflection comparable to that observed at Precambrian-Cambrian transition elsewhere in the world in carbonate facies (Knoll & Walter, 1992) and also in Krol and Marwar Basins. These minor deflections may be related to changes in environment of deposition as evident by concommitant changes in $\delta^{18}O$ values.

The changes in oxygen isotopic ratios may be related to fluctuations in the basins at the time of deposition. In the basal part of the Sahabad Formation the $\delta^{18}O$ values are up to -9.18 ‰PDB which gradually decrease to -6‰ PDB as one moves upwards, to middle part which may be related to increasing influence of fresh-water due to regression of sea. In the uppermost part, the fluctuating depositional conditions with dominance of fresh water are indicated.

Biostratigraphic studies

The entire Bhima Group, excepting the basal Rabanpalli Formation was studied for microbiota and megafossils. Special efforts were made for collection of megafossils from the Halkal Formation from known localities, viz., Kolkur and Gangurti, from where *Sabellidites* was recorded by Das Sarma *et al.* (1992) and *Chuaria* (Suresh & Sundara Raju, 1983). This biota, described by Maithy and Babu (1996), includes *Chuaria circularis* Walcott 1899, *Tawuia dalensis* Hofmann 1979, *Protoarenicola baiguashanensis* Wang 1982, *Sinosabellidites huainanensis* Zheng 1980 and *Beltina danai* Walcott 1899. It has also yielded organic-walled microfossils referable to spheroidal leiosphaerids comparable to *Kildinella suketensis* Maithy & Shukla 1977, colonial spheroidal form comparable to *Myxococcoides* sp. and tubular forms assigned to *Eomycetopsis* sp. On the basis of similar macrofossil assemblage that occurs globally at 1000-900 Ma, Maithy and Babu (1996) considered the Bhima Group to be older than Varangian glaciation. It is interesting that similar biota also occurs in the Suket Shale of the Semri Group of the Lower Vindhyan sequence (Maithy & Shukla, 1977; Kumar & Srivastava, 1997).

The fossil collection of Das Sarma *et al.* (1992) was also examined. The specimen identified by them as *Sabellidites,* according to Maithy, lacks chitin, a characteristic of the form. The specimen shows more resemblance with the features of *Tawuia*.

Lower boundary of the Terminal Proterozoic System

The precise timing for initiation of sedimentation of the terminal Proterozoic-Cambrian succession is not known in absence of age diagnostic biota (which is primitive in nature) and radiometric dates. However, the distribution of sediments in northwestern and western India over different formations of older Proterozoic successions, including well dated Malani Igneous Suite (Ca 750 Ma), suggests a widespread marine transgression that followed the Cadomian Tectono-thermal event — the Malani Event. There are no evidences of Varangian glaciation (610-590 Ma) from the Indian-subcontinent. The absence of glaciogenic/glaciomarine sediments has to be reviewed in context of palaeogeographic position of the continent during this period. In the palaeogeographic reconstruction by Mekerrow *et al.*, 1992, fig. 1, India, alongwith Middle East, South China and northern part of the Siberia, occupies low latitudes (5°- 35°) in 'East Gondwana' Supercontinent (Kirschvink & Ripperdan, 1991). In this position, one can not expect glaciation due to warm-arid climate. The close lithological similarity of the Baliana-Krol-Tal Groups with that of the Yangtze Gorge succession, the Liantau-Nantau-Doushantau-Denying Formations resting unconformably over granites dating 819± 54 Ma (Kumar, 1984), is significant. The Nantau Formation is similar to Blaini Formation which was earlier considered to be glaciogenic/glaciomarine till Tangri and Singh (1982) argued for its non-glacial nature. The Nantau Formation is also considered to be glaciomarine, hence calls for its re-examination and detailed sedimentological studies in light of close lithological similarity with the Blaini and the position of the South China during Terminal Proterozoic. The development of evaporites with carbonates in the overlying succession further supports this contention. The Varangian glaciation is not as widespread as it was thought to be.

In the absence of age diagnostic biota, the lower boundary has to be defined in terms of stable isotopic curves. Knoll and Walter (1992) have shown that elsewhere in world, a substantial depletion in stable carbon isotopic values is noticed from the upper part of the 'glaciogenic' sediments 'the cap dolomite'. The preliminary chemostratigraphic data from the Marwar Basin, and detailed study in Krol

Basin have recorded two substantial depletions in $\delta^{13}C$ values, one in the pink carbonate bed occurring at top of the Blaini Formation, and basal part of the Bilara Group and the other in the overlying carbonates, which in Krol Basin lies above the horizon yielding Ediacaran biota but below the horizon contains Meishucunian Zone-I small shelly fauna. The former depletion which is globally recognised may be taken as a marker for defining the lower boundary of the Terminal Proterozoic succession in the 'East Gondwana'. Like the Precambrian-Cambrian Boundary, the stable carbon isotopic studies will be useful only in carbonate succession. The depletion is yet to be radiometrically dated.

Upper boundary of the Terminal Proterozoic System (Precambrian-Cambrian Boundary)

This boundary problem has been extensively studied in India (Kumar, 1995) and elsewhere in the world during last two decades leading to identification of GSSP in Chapal Island Formation, Fortune Head, south-east Newfoundland, Canada (Landing, 1994). The boundary has been placed between trace fossil Zone-I (*Harlaniella podolika* Zone) and Zone-II (*Phycodes pedum* Zone), 2-4 m above the base of the formation. Though the radiometric dates of the point are not available, the $^{207}Pb/^{206}Pb$ age of 530 ± 0.9 Ma of zircon from an ash bed from middle part the trace fossil Zone-III *(Rusophycus avalonsis Zone)* will place it around 545 Ma (Isachsen *et al.*, 1994). This ash bed was earlier dated as 545 Ma (Samson & Landing, 1992).

The trace fossils, like any other fossil, are also controlled by environment of deposition. They are more dominant in siliciclastic facies, and therefore, are not of much use in carbonate dominated facies. Due to this reason, the GSSP does not meet the basic requirement for global correlation. Therefore, some other criteria have to be evolved. Comparing and correlating the Himalayan sections with GSSP, it is evident that the Ediacaran and trace-fossil Zone III can be correlated but in absence or poor documentation of trace-fossils of Zones-I and II, the Precambrian-Cambrian Boundary can not be demarcated in terms of GSSP. In Krol, Kashmir and Spiti-Zanskar Basins, the trace fossils of Zone-III, which occur below the trilobites of Early Tsanglangpuian Stage of China, can be correlated with the *Rusophycus avalonsis* Zone of GSSP. The record of small shelly fossils of Meishucunian Zone III of China from the Tal Group in the Krol Basin from this level is significant in assigning its age. The trace fossils of Zones -I and II are known, so far, only from Kashmir. In the absence of diagnostic trace fossils, the Precambrian-Cambrian Boundary can not be demarcated precisely though it is located in the basal part of the Lolab Formation.

In Krol Basin, there is no record of trace fossils of Zones-I and II. However, the presence of small shelly fossils of Meishucunian Zone-I in association with phosphate from the basal part of the Tal Group is significant in view of $^{238}U/^{206}Pb$ age of 525±7 Ma and $^{207}Pb/^{206}Pb$ age of 539±34 Ma from a bentonite in unit 5 in the Meishucunian quary, China (Compston *et al.*, 1992). This bentonite has been suggested to be 'similar in age or older than 530.7 ± 0.9 Ma' of New Brunswicks ash bed (Ishachseu *et al.*, 1994). This helps in correlating the Meishucunian Zone I with basal part of *Rusophycus avalonsis* Zone (Chart 1). The Precambrian-Cambrian boundary may lie in still older underlying succession, i.e., the top part of the Krol Group (Krol E, Auden, 1934; Kauriyala Formation; Shanker *et al.*, 1993).

In absence of traces fossils in the Carbonate dominated succession, the chemostratigraphic studies may be useful for demarcation of the boundary. The studies on stable carbon isotope at this level record a substantial depletion in $\delta^{13}C$ values from positive to negative in Krol Basin (see Mathur *et al.*, 1997); from +0.6 to +3.6‰ in basal part, from - 1.3 to -6.9 ‰ PDB in upper part with a short lived positive excursion at the level of phosphorites in the Marwar Basin. Such changes in stable carbon isotopes have been recorded elsewhere in the world (Knoll & Walter, 1992) above the Ediacaran but below the Trace-fossil Zone-I. It is above this changes that rapid evolution and diversification in life has been recorded. Since the Precambrian-Cambrian Boundary has to be defined in terms of biostratigraphy, the small shelly fossils are useful in Carbonate facies.

The minor excursion at the level of phosphorite in Marwar Basin has also been recorded from China, in the Dahai Member of the Yuhucun Formation of Meishucunian Zone-II (Kirschvink *et al.*, 1991). The positive excursion has not been recorded by us in

Krol Basin, but the studies in Durmala section (D.M. Banerjee, Pers. comm.) and in Marwar Basin show a positive excursions at this level. Similar excursion have also been recorded from Morocco and Siberia, which according to Kirschvink *et al.* (1991) occur at Tommotian-Atdabanian Boundary. Such an assumption is incorrect in view that the overlying Meishucunian Zone-III in China is correlative with the *Rusophycus avalonsis* Zone of GSSP containing Trace Fossil of Zone -III (Chart 1).

CONCLUSIONS

1. In India, the Terminal Proterozoic-Cambrian succession, constituting the Supersequence IV post-dates Cadomian Tectono-thermal event (750 Ma) and terminated with Pan-African Orogeny (500 Ma). The sedimentation commenced with a wide-spread marine transgression over Supersequence III (Meso-Proterozoic) in Himalaya and Malani Igneous Suite (750 Ma) and older metasediments in western India.

2. In carbonate dominated successions, the development of evaporite and phosphate are two significant events useful for regional and global correlations.

3. The stable carbon isotope-curves are also useful for regional and global correlations in carbonate facies. The two depletions, one occurring in the basal part and the other above the horizon yielding Ediacaran Medusoids but below the beds containing Meishucunian Zone-I small shelly fauna, are related to global depletions recorded in the basal part of succession which post-dates Varangian glaciation and at or near the Precambrian-Cambrian Boundary, respectively. The other two depletions in between are related to development of evaporite in the lower level and to magmatic activity at higher level.

4. A short lived positive excursion, noticed at phosphorite level in the Birmania (Upper Carbonate) Formation, Marwar Basin, and in basal part of the Tal Group, in Krol Basin is also known from Meishucunian Zone-II level in China and Iran.

5. The successions in south India (Bhima Basin) and in central India (Vindhyan Supergroup) which contain *Chuaria-Tawuia* complex and give stable carbon isotope values in the range of +1.3 to +3.4‰ PDB in Bhima Group and +2.9 to + 4.0 ‰ PDB in Lower Bhander Limestone of

Chart 1—Correlation of Himalayan Zones (Krol Belt) with Early Cambrian chronological and biostratigraphical units (proposed by Mekerrow *et al*, 1992)

SIBERIAN SERIES	SIBERIAN STAGES	CHINESE STAGES	AVALON ZONES	LAURENTIAN ZONES	BALTIC ZONES	HIMALAYAN ZONES (KROL BELT)
Lenian	Toyonian	Maozhuangian	*Protolenus*	*Bonnia-Olenellus*	*Proampyx linnarssoni*	
		Longwangmiaoan				
	Botomian	Canglangpuan	*Strenuella*			*Redlichia-Paokannia*
		Qiongzhusian V	*Callavia*		*Holmia kjerulfi*	—
Aldanian	Atdabanian	IV		*Nevadella*	*Holmia inusitata*	*Pelagiella-Auriculatespira*
		Meishucunian III	*Camenella*	*Fallotaspis*	*Schmidtiellus*	*Allonia-Dimidia*
	Tommotian		*Sunnaginia imbricata*			
—	Nemakit-Daldynian	II	*Watsonella crosbyi*			—
		I	*Rusophycus avalonensis*	—	—	*Anabarites-Protohertzina Circotheca*
			Phycodes pedum			—

Upper Vindhyan Group, are not considered part of the Supersequence-IV and could be older.

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