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PRECAMBRIAN OF INDIA—POSSIBLE SOURCE OF EVIDENCE FOR EARLY LIFE

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When did life begin? This question is of fundamental importance in the study of terrestrial evolution. An interdisciplinary approach to the problem has highlighted the relationship between the development of the earth and the evolution of its biosphere. The presence of molecular fossils in the ancient rocks can provide valuable information about the origin and early evolution of life. Investigations carried out in many parts of the world have provided strong evidence for morphological and chemical forms of life from the various time planes of the Precambrian period.

India provides a unique opportunity for further studies as it is easily accessible and unexplored. The presence of the very ancient rocks makes it further more exciting. There is an evident need for applying the geological, geochronological, paleobiological and organogeochemical studies to specific areas of interest. Such a programme may enable one to narrow the gap between chemical and biological evolution.

Key Words: **Precambrian; Terrestrial, Chemical and Biological Evolution; Biosphere; Molecular Fossils**

INTRODUCTION

ON the planet earth the rock record is evidenced by the oldest metasedimentary sequence of the Isua-Godthab of Western Greenland, which has been radiometrically dated at 3.8Ga. Recent paleobiological and organic geochemical studies were carried out on these rocks to ascertain the earliest evidence of life. The presence of morphological remains such as stromatolites or microfossils could not be established although the isotopic studies of the organic carbon revealed a wide variability, indicating that isotopic fractionation had occurred. Since the isotopic shifts could not all be accounted for by metamorphism, there is little doubt that biological control of the terrestrial carbon cycle had been established by Isua times.[1,2] In retrospect, the 3.5Ga sediments of the Warwoona group of Western Australia account for the presence of stromatolites and the existence of complex microbiota associated with it.[3] The microbiota indicate that biological evolution had preceded the period, probably close to the Isua period. The discovery further stimulates the search for the earliest life in the Archaean sediments and subsequent interpretation of various microbial ecosystems in the Precambrian.

Evidence for Life in Precambrian Sediments

Another significant event in the evolutionary history of the earth is the creation of the oxygenic atmosphere which resulted in a complex interplay of the various biogeochemical processes. The study of early life on earth will help the understanding of the poleobiochemistry of these organisms and the paleoenvironments prior to origin and evolution of life. In the Precambrian sediments evidence for life can be broadly categorized into two sections : (1) chemical and (2) morphological.[4]

Chemical evidence seeks to investigate the following parameters :

a. Extractable organic matter ;

b. Insoluble organic matter;

c. Stable isotope evidence; and

d. Paleoenvironmental significance of banded iron formation.

Morphological evidence includes the study of :

a. Stromatolites ;

b. Microfossils—(*i*) filamentous and (*ii*) spheroidal ; and

c. Algal megafossils.[5]

Integration of the above data provides a comprehensive knowledge of life in the entire prephanerozoic period of the earth.

Sedimentary Organic Matter

Sedimentary organic matter has been observed to be of two types: extractable and insoluble.

Extractable Organic Matter—Extractable organic matter is composed largely of a volatile geolipid fraction of the organic matter which has been preserved in the sediments with minor alteration. The organic compounds are commonly referred to as chemical, or molecular, fossil. A chemical fossil has been defined as an organic compound in the geosphere whose structure suggests an unambiguous link with a known natural product.[6] The notion of the biological marker compounds has been central to the search for chemical traces of life in the Precambrian for the last two decades.

A variety of compounds has been reported from the Precambrian sediments.[7] They include alkanes (branched and cyclic), steranes, fatty acids, porphylins, carbohydrates and amino acids. Among them, the most recent discovery of the five nitrogenous bases—adenine, cytosine, thymine, guanine and uracil from the McArthur shales, Western Australia—has demonstrated beyond doubt that the geological record bears the imprints of the primary constituents of life.[8]

Insoluble Organic Matter—The rather inert, insoluble organic matter in the sediments is termed "kerogen". This type of organic matter is formed during the

diagenesis of sediments involving condensation and polymerization reactions, which result in the formation of complex macromolecules.

In recent years studies on the Precambrian kerogens have been carried out by the analytical pyrolysis technique.[8,9] The pyrolysis products included alkanes, alkenes and alkadienes and aromatic hydrocarbons.

Stable Isotope Studies

The elements hydrogen, carbon, oxygen, nitrogen and sulphur are predominantly cycled in the atmosphere and hydrosphere by the various biogeochemical pathways of living organism. Carbon prominently figures as being one of the primary constituents of life. Biological fractionation by photosynthesis results in the enrichment of lighter isotope of carbon ^{12}C. Stable isotopic studies carried on various Precambrian rocks has shown a wide range of values of ^{13}C ranging from -20 to -320 per mill. The interpretation of the data requires the understanding of the geochemical history of the sediments.

Banded Iron Formation

The presence of banded iron formation in the Precambrian was described as an evidence of oxygenic atmosphere as a result of photosynthesis.[10] In recent years, the geological evidence has shown that terrestrial oxidation occurred prior to and synchronous with the deposition of banded iron ore formation. Therefore, the idea of direct relationship between photosynthetic oxygen and precipitated iron is at best debatable.

Stromatolites

Stromatolites are organosedimentary structures produced by sediment trapping, binding and precipitation resulting from metabolic activity and growth of organisms, primarily blue-green algae. They have been reported all over the world from the Precambrian sediments. The prominent Archaean stromatolites are from Bulawayan, Rhodesia, and the North Pole, Pilbara region of Western Australia. The presence of these structures is an indication of biological activity as evident from the modern analogous mats in the coastal environment of the Shark Bay of Australia.

Spheroidal and Filamentous Microfossils

A large number of spheroidal and filamentous microstructures has been reported from stromatolites and cherts of the Precambrian. These microfossils show morphological resemblance to the prokaryotes. In the late proterozoic period certain large megascopic algal remains and macroscopic spheroids like *Chuaria* have been reported from various parts of the world. These structures are considered to be "algal megafossils".

PRECAMBRIAN ROCKS OF INDIA

The Precambrian rocks of India occupy nearly two thirds of the Indian subcontinent, encompassing the peninsular, extrapeninsular and to some extent the basement rocks of the Indo-gangetic alluvium.

The extrapeninsular region of India comprises a polymetamorphic tectonic history imprinted by the Himalayan orogeny. The Himalayas are a result of the innumerable geological processes represented in sediments of various geological ages. The peninsular India on the other hand is dominated by the rocks of the Precambrian period which have been tectonically stable for a long period of time. The distribution of the Precambrian rocks in the Indian subcontinent is presented in Map 1.[11] Gupta[11] has reviewed the stratigraphy of the Precambrian rocks of India.

The geochronological investigations on the various formations of India have been represented on a geological map of the country in Map 2.[12] Sarkar[13] reviewed the Precambrian stratigraphy and geochronology of peninsular India.

The Indian subcontinent provides an unique opportunity as the Precambrian rocks are generally well exposed and easily accessible. There is also evidence for the remnants of the oldest crust. Radiometric dating of eight tonalite samples of the Singhbum province of India has revealed age determinations as old as 3.8 G. yr,[14] which can be correlated with the Isua metasediments of Western Greenland.

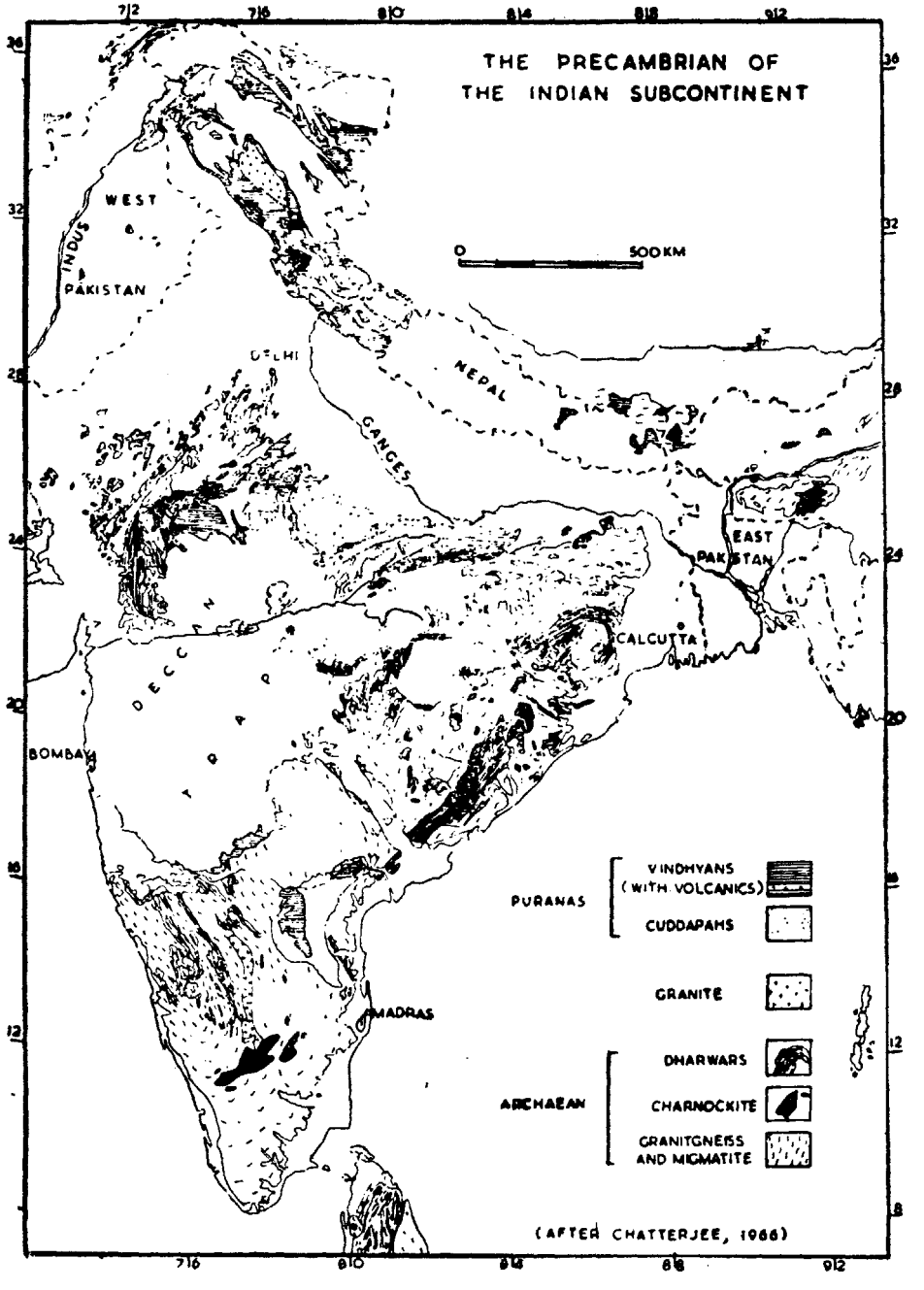
A critical appraisal of the data on the Indian Precambrian rocks highlights the lack of reliable radiometric studies for many areas. This makes selection of the area and interpretation of the data difficult. Precambrian microfossils from India have been reviewed by Prasad,[15] Sastry,[16] Raha and Sastry.[17] The reports of Archean microfossils are scarce; although there are several proterozoic microfossil reports, many of the areas need systematic investigation.[17] Certain reports of microfossils give different ages for the same stratigraphic horizon. There is an evident need for organic geochemical studies. Radhakrishna[18] has discussed the gaps in this field and has stressed the need for paleobiological and organogeochemical investigations in India.

In view of the studies in Precambrian life and paleobiology, a geochronological column is presented in Table I. The column incorporates radiometric data, lithology, biological evidence such as stromatolites and microfossils from the sediments as old as 3.5Ga. The different time planes provide a unique opportunity for detailed studies of stromatolite morphologies, the various microbial communities, and the associated geochemical fossils which reflect the nature of life in the Precambrian. The area selected for the description have been based on the following criteria :

1. rock formations which have undergone less deformational history and metamorphism;
2. undoubted stratigraphic horizons having reliable dates; and
3. fossiliferous rocks with a prospective for organogeochemical work.

Archean Rocks of India

Archean rocks are widely distributed in the eastern and southern parts of India. In eastern India the rocks are represented in Bihar and Orissa states of the Singbhum region.


THE PRECAMBRIAN OF
THE INDIAN SUBCONTINENT
0
500KM
WEST
PAKISTAN
INDUS
DELHI
NEPAL
GANGES
EAST
PAKISTAN
CALCUTTA
BOMBAY
MADRAS
DECCAN
PURANAS
VINDHYANS
(WITH VOLCANICS)
CUDDAPAHS
GRANITE
ARCHAEAN
DHARWARS
CHARNOCKITE
GRANITGNEISS
AND MIGMATITE
(AFTER CHATTERJEE, 1968)

MAP 1

TABLE I

AGE × 10^9	FORMATION	LITHOLOGY	DATA Ref.
3.5	Sargur Group	Chert	Microbiota[19]
2.6	Chitradurga	Chert	Microbiota[20]
2.6	G. R. Formation	Shale	Microbiota[21]
2.5	Iron Ore Group (Singhbhum)	Chert	Stromatolite[22–24]
2.5	Bababudhan Group	Banded Iron Ore	Microbiota[25]
2.4 to 1.5	Bijawar Formation	Dolomite	Stromatolite[26,27]
2.0	Aravalli Supergroup	Phosphorites	Stromatolite[28–33]
1.4	Cuddapah	Limestone	Stromatolite[34–42]
1.4 to 0.9	Vindhyan Supergroup	Limestone	Stromatolite[43–49]
1.4	Lower Vindhyan		
0.9	Upper Vindhyan		
1.4	Kaladgi Group	Limestone	Stromatolite[49,50,61]
1.1	Pakhal Group	Silicified	Stromatolite[52,53]
	Delhi Supergroup		Stromatolite
0.9	Bhima Group	Shale	Algal Structures[54,55]
	Kurnool Group	Dolomite	Stromatolite[56]

Archaean Rocks of Eastern India

The Archean rocks of eastern India are exposed in Orissa and Bihar states and can be subdivided into the following areas from south to north :

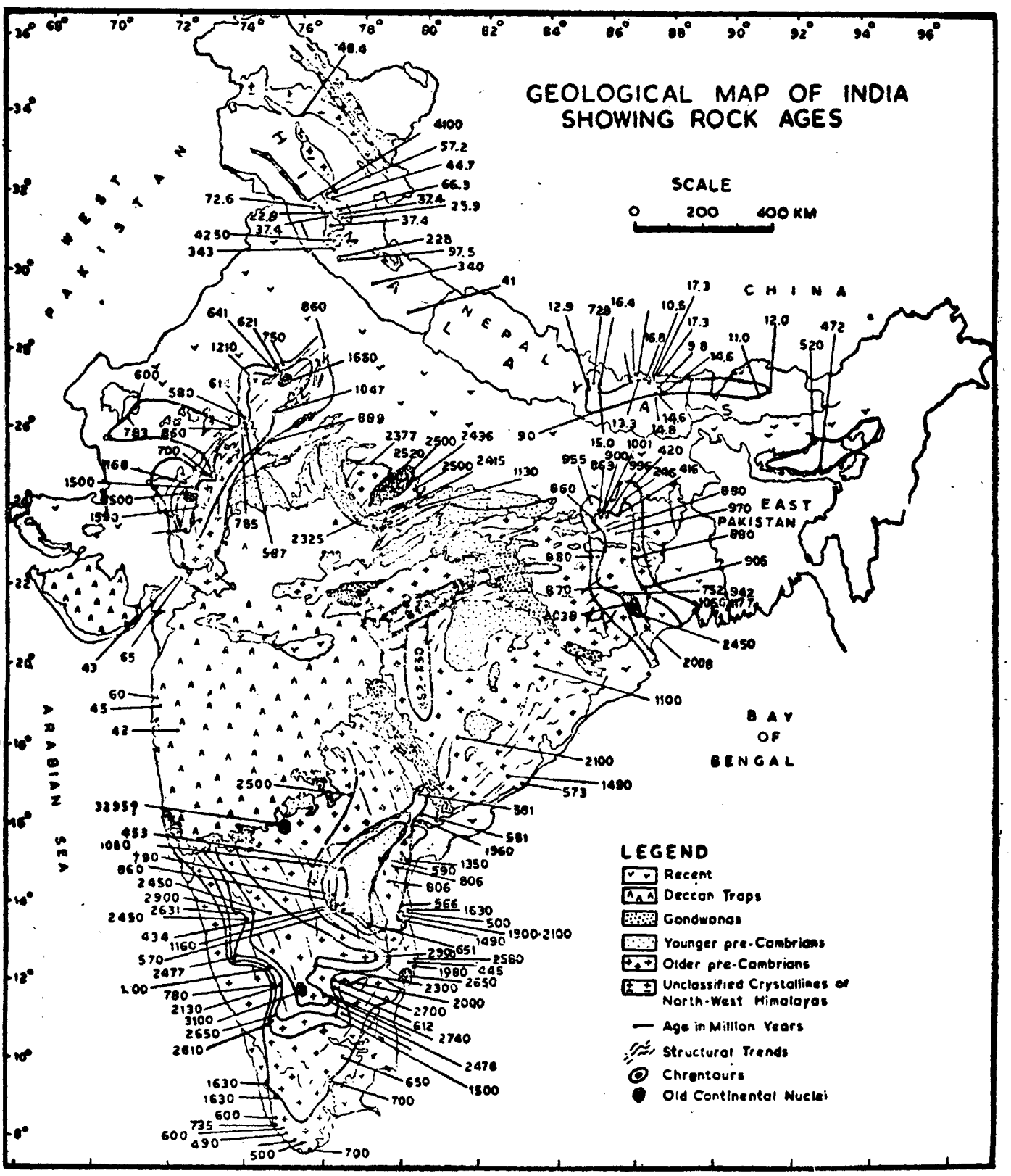
a. Singhbhum-Keonjar-Sundargarh-Bonai-Mayurbhanj;

b. Ranchi-Muri; and

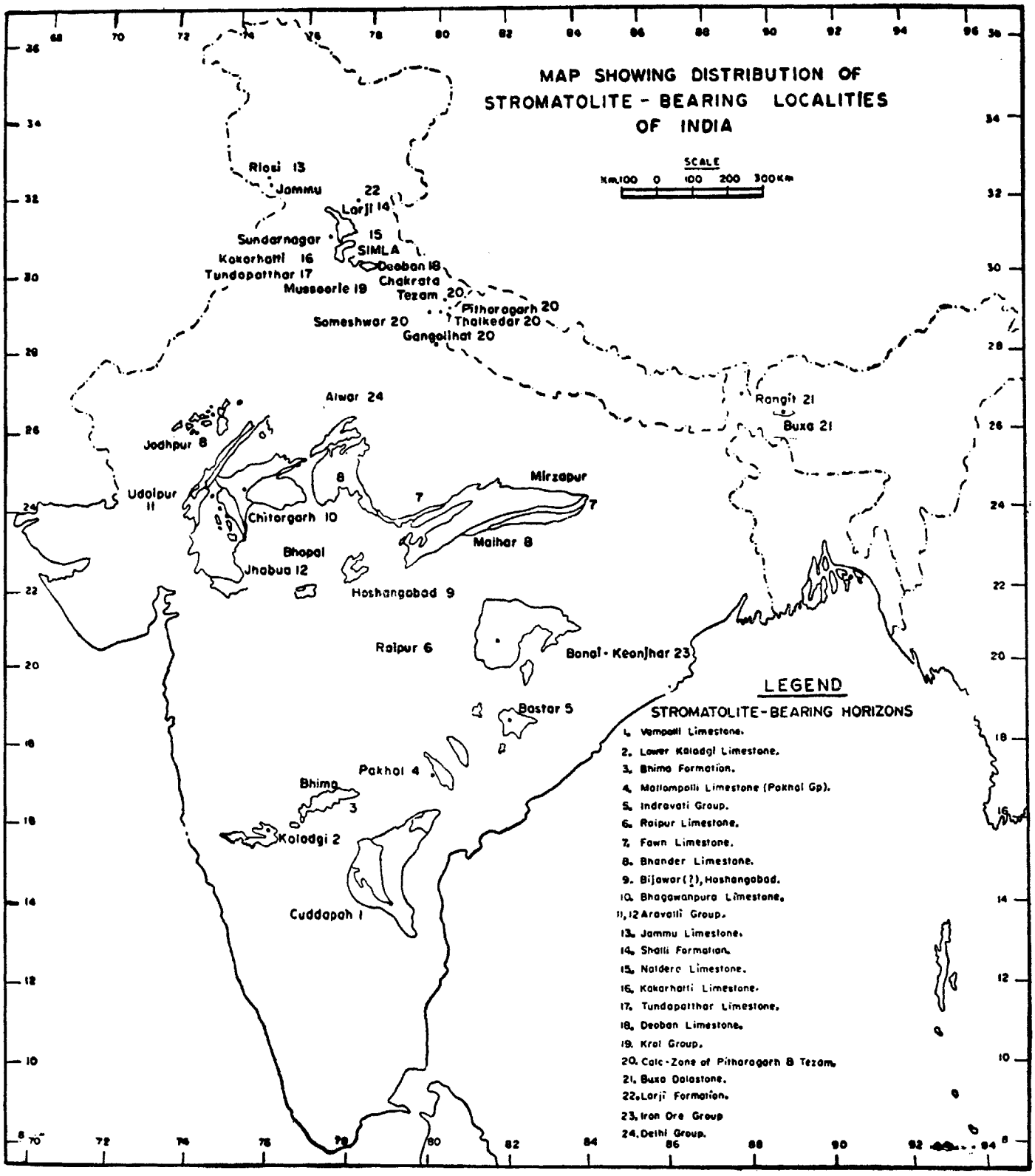
c. Hazaribagh-Gaya-Monghyr.

Three major groups of rocks—Gangpur, Iron ore and Kolhan groups are recognized with a well marked, 200km long copper belt thrust zone separating the low grade metamorphic rocks of the south from high grade metamorphic rocks to the north. On the basis of extensive structural and stratigraphic data accompanied by the various radiometric dates, Sarkar[13] proposed a revised stratigraphic succession which is as follows :

South of Copper Belt Thrust Zone in Singhbhum, N. Mayurbhanj and N. Keonjhar	North of Copper Belt Thrust Zone in Singhbhum
End of Singhbhum Orogenic Cycle (c. 0.85 *Ga*)	
Newer Dolerites (c. 1.6–0.95 Ga)	Soda Granite Granophyre Chakradharpur
Mayurbhanj Granite (c. 1.2 Ga)?	Granite Gneiss Kuilapal Granite
Gabbro-anorthosite (c. 1.47 Ga)	
Ultramafic intrusions Kalhan Group (c. 1.5–1.6 Ga)	
.....Unconformity.....	
Jagannathpur Dhanjori-Simlipal Lavas (c. 1.6–1.7 Ga)	Dalma lavas with intertrappean reworked lava conglomerates
Quartzite conglomerate	


GEOLOGICAL MAP OF INDIA
SHOWING ROCK AGES
SCALE
0 200 400 KM
CHINA
NEPAL
EAST PAKISTAN
BAY OF BENGAL
ARABIAN SEA
LEGEND
Recent
Deccan Traps
Gondwanas
Younger pre-Cambrians
Older pre-Cambrians
Unclassified Crystallines of North-West Himalayas
Age in Million Years
Structural Trends
Chrontours
Old Continental Nuclei

MAP 2


MAP SHOWING DISTRIBUTION OF
STROMATOLITE - BEARING LOCALITIES
OF INDIA
SCALE
Km.100 0 100 200 300Km
Riasi 13
Jammu 22
Larji 14
15
Sundarnagar
SIMLA
Kakarhatti 16
Deoban 18
Tundapatthar 17
Chakrata
Musseerie 19
Tezam 20
Pitharagarh 20
Someshwar 20
Thalkedar 20
Gangolihat 20
Alwar 24
Rangit 21
Buxa 21
Jodhpur 8
Udaipur 11
Chitorgarh 10
Mirzapur
Malhar 8
Bhopal
Jhabua 12
Hoshangabad 9
Raipur 6
Bonai - Keonjhar 23
Bastar 5
Pakhal 4
Bhima
Kaladgi 2
Cuddapah 1
LEGEND
STROMATOLITE-BEARING HORIZONS
1. Vempalli Limestone.
2. Lower Kaladgi Limestone.
3. Bhima Formation.
4. Mallampalli Limestone (Pakhal Gp).
5. Indravati Group.
6. Raipur Limestone.
7. Fawn Limestone.
8. Bhander Limestone.
9. Bijawar(?), Hoshangabad.
10. Bhagawanpura Limestone.
11, 12 Aravalli Group.
13. Jammu Limestone.
14. Shalli Formation.
15. Naldera Limestone.
16. Kakarhatti Limestone.
17. Tundapatthar Limestone.
18. Deoban Limestone.
19. Krol Group.
20. Calc-Zone of Pitharagarh & Tezam.
21. Buxa Dolostone.
22. Larji Formation.
23. Iron Ore Group
24. Delhi Group.

MAP 3

	Dhanjori Group
	Unconformity
Chaibasa Formation	
Unconformity	Dhalbhum Formation—Singhbhum Group
Singhbhum Granite (c. 2.95 Ga)	Chaibasa Formation (sed. 2.0–1.7 Ga)
Iron Ore Orogeny	
Iron Ore Group	
Unconformity	
Older Metamorphic Gneiss (c. 3.2 Ga)	
O.M. Orogeny	
Older Metamorphic Group	
Basement (c. 3.3 Ga)	

Older Metamorphics

The older metamorphic group is composed of calc-magnesian metasediments, argillites and arenites, tonalitic gneisses with basic intrusives. The rocks have undergone amphibolite facies of metamorphism.

Iron-ore Group

The Iron-ore group of rocks unconformably overlies the older metamorphics. The lithology of rocks is comprised of limestone, shales (often phyllitic and grading to mica schists), quartzite, sandstones hematite beds, hematite quartzites. A basal conglomerate horizon rests upon the quartzites and quartz horblende mica schists.

In the Koira Valley in Keonjar and Bonai, the shales are manganiferous and are associated with hematite quartzites which have alternating layers of chert, jasper and hematite. The stratigraphy of the Koira group is as follows :

	Kolhan Group
Koira group	*Mixed facies formation*—undifferentiated sequence of multicolor manganieferous shale, dolomite chert
	Upper shale formation—banded shale member-red and white Black shale member with Black pyriferous argillite
	Banded iron formation—Chert-shale member finely banded Jaspilite and coarsely banded Jaspilite member
	Volcanic formation—shaly member basic lava member Basal sandstone Quartzite formation

Singhbhum and Bonai Granites with Infolded Supracrustals

Paleobiological Investigations—Stromatolites and associated microbiota have been reported from the Iron-ore group of Singhbhum province,[22–34] Grant *et al.*[24] reported the first record of stromatolites from the Koira group (iron ore series) of Bihar-Orissa, India.

The stromatolites reported are from the mixed facies formation, within two different lithologies, chert and dolomite. There are four main types: domal, Laminar, oncolitic and clavate. The first two types are reported to be present in cherts.

The author in his discussions has indicated that the siliceous stromatolites observed are primary in nature and no replacement phenomenon is discernible; probably microfossils resembling *Eospaera* and *Hurnosporia* have been identified. Stromatolites of the area require detailed study. The absolute age of the Koira group is uncertain. It has been assigned an age between 1.6 and 2.7 G.yr.

Archaean Rocks of South India

The Dharwar Supergroup of rocks of Karnataka State, South India, form several prominent schist belts in an otherwise granitic and gneissic terrain. The central part of the craton consists of a greenstone—gneissic complex characterized by greenschist to amphibolite facies and enclosed by a mobile belt of granulites and migmatite gneisses. The Northern part of the basin is covered by upper proterozoic Kal'dagi sediments and the Deccan traps The Western side is bounded by the Arabian Sea. Gowda and Srinivasan[57] have discussed the history of concepts as applied to the rocks of Dharwar Supergroup. Srinivasan and Sreenivas,[58,59] Radhakrishna and Vasudev,[60] Ramakrishnan *et al.*,[61] Naqvi *et al.*[62] have enumerated

Closepet Granite (2.38–2.0 Ga)		
Chitradurga Granite (2.45 Ga)		
	Manganiferous phyllites Ankeritic limestones	
Ranibennur group (?)	Greywackes Chloritic phyllites	
	Agglomerate, tuffs, pillow lavas Ferruginous & manganiferous cherts	
	Dolomites and limestones Phyllites	
Chitradurga group	Orthoquartzites	
	Banded magnetite quartzites Argillites	
Bababudan group	Mafic lavas Orthoquartzites Conglomerates	
Peninsular Gneisses	II event	c. 2.6 Ga
Granites, granodiorites tonalities & granitic gneisses	I event	c. 2.95 Ga
Sargur group	Interbedded mafic and ultramafic Metalavas, Anorthosite pods Magnetite Quartzites, Graphitic Schists Kyanite-Staurolite Schists, Cordierite Graulites, Crystalline Limestones & Dolomites, Fuchsite Quartzites, etc.	
	Basement C. 3.2 Ga (?)	

schemes for stratigraphic classifications for the entire Dharwar supergroup of rocks. The table on p. 1040 by Radhakrishna and Vasudev[60] gives a succession of the sediments in the area.

Viswanathiah and Ramakrishnan[63] identified a group of sediments associated with the lava flows in the Sargur region, named "Sargur high grade schist complex." The rocks of the Sargur Group are characterized by high grade metamorphism ranging from amphibolite to lower granulite facies. Lenses of anorthosite and anorthositic gabbro are abundant. Quartzites are often fuchsitic and characteristically bedded with sedimentary baryte. Structurally, the sediments are more deformed, with tight folds, steep plunges and complicated fold interference patterns. The Sargur sediments and the peninsular complex represent the older episodes of the region.

The Bababudan Group is well developed in the arc shaped Bababudan mountains and is predominantly volcanic. The basement gneissic complex is overlain by basal orthoquartzite which is succeeded by a thick succession of mafic lava flows unconformably overlain by argillites and massive beds of banded quartz magnetite rocks. The sequence is of shallow water platformal deposition. Sedimentary structures like ripple marks and cross bedding in quartzites also suggest shallow water depositional environment. The rocks have been subjected to green schist facies to lower amphibolite facies of metamorphism.

The Chitradurga Group is geosynclinal in character with a higher proportion of sediments. It starts with a basal conglomerate, orthoquartzites, phyllites, limestones and dolomites followed by banded ferruginous and manganiferous quartzites and cherts. Pillow lavas are abundant. Greywackes and cherts are extensively developed and marked by volcanic activity. Banded pyritiferous cherts have undergone a low grade of metamorphism of green schist facies.

Ranibennur Supa-Dandeli group of rocks is exposed to the North of Chitradurga Group of rocks characterized by greywackes and chlorite phyllites. The beds are least disturbed with gentle dips and are represented in North Kanara and Dharwar districts. A horizon of ankeritic limestones, ankeritic magnetite quartzites and manganiferous phyllites are exposed from a younger manganese iron ore belt in the Supa-Dandeli region. The low grade of metamorphism and less structural deformation of the sediments from the area offers a potential site for the investigation of early evidence of life.

Radiometric Studies in the Region—Geochronological investigations have been carried out in various parts of the area. The early Precambrian sediments of South India represent a time span of 3.5 to 2.5Ga. Several radiometric dating reports in recent years support this view. Certain Conglomerates from Kaldurga in Tarikere Valley forming a part of Shimoga belt date 3.25 ± 0.15Ga.[64] The Sargur schist belt has been assigned an age older than 3.2Ga, possible remnant of the Archaean protocrust.[65] Balasubramanyan[66] advocated a minimum age of 3.2 Ga to the Archaean tonalitic gneisses and granites from South Kanara. Certain other rocks of the region are the Champion gneiss and

the peninsular gneisses. The Rb-Sr radiometric investigations of the gneisses provide age estimates of 2.95 ± 0.11 Ga with an initial Sr/Sr ratio of 0.706 ± 0.004.[64] Beckinsale *et al.*[67] dated gneisses from the Holenarasipur area giving an age of 3.36 to 3.10 Ga. Drury[68] dated metavolcanic lava flows at the base of the Kudremukh west coast belt by the Sm-Nd method, giving an age of 3.0 Ga. According to him the Kudremukh belt rests unconformably upon gneisses dated at 3.3 Ga. by an Rb-Sr method. Janardhan and Vidal[69] dated the gneisses from Gundlupet area which forms a part of the Sargur Group at an age of 2.83 Ga. They conclude that the age indicates the metamorphic event and sediments of the Sargur Group are still older. Chitradurga granites have also been dated,[70] giving an age of 2.65 Ga. The radiometric data discussed so far conclusively demonstrates that the Dharwar Supergroup is the rocks of Archaean age. The Arachean rocks of South India may provide a prospective site for evidence of early life.

Paleobiological Investigations in Dharwar—Gowda and Srinivas[21] have reported acritarchs which have been considered by others[42] as putative 'pseudofossils', mineralogical artifacts.[42] This calls for the reexamination of the rocks for the supposed microfossils in thin section as their importance lies in the fact that it would represent an early proterozic non-stromatolitic biota.

Venkatachala *et al.*,[71] reported the presence of *Leiosphaerida aglutinata, L. dhakshinii, L. insigna concentrites muricatus, Protoleiosphaeridum sp. Granomarginata sp.* and *Vavosphaendium reticulatum* from the Dharwars of Karnataka. These reports and some others were based on studies of objects detected in acid resistant residues; these are questionable as they provide no direct evidence of the relationship between the microstructures detected and the original (undissolved) rock matrix.[42]

Viswanathiah and Venkatchalapathy[25] reported the presence of microbiota from the Bababudan group. The authors have described an assemblage of microfossils present in thin sections of the cherts.

Suresh[20] and Suresh *et al.*,[72] provided additional information on the Dodguni microbiota from the Chitradurga schist belt. These fossils were examined in thin sections of the cherts.

Proterozoic Rocks of India

Proterozoic rocks representing various time planes are exposed in different parts of India (Table I and Map 3).[16] The various proterozoic basins are discussed below :

Aravalli Supergroup of Rajasthan

The Aravalli sediments of India behold many geological formations of different ages. They are broadly categorized as :

Rialo Group;

Aravalli and Gwalior Supergroups :

Banded gneissic complex; and

Bundelkhand granite and associated rocks.

Radiometric Studies of the Aravalli Supergroup

Sarkar[13] has considered the end of Aravalli orogeny between 0.95 and 1.5Ga. The Pb isotope age of Aravalli schists near Udaipur was found to be and K-Ar age of gneiss 50km South of Udaipur was found to be 1.59Ga. Crawford[73] assigned the commencements of Aravalli Orogeny between 2.5 and 2.59Ga.

Geology and Paleobiological Investigations

Banerjee[28,29] reported stromatolitic colonies in and around the Udaipur area : Kanpur, Matoon, Dhamdhar, Jhamarkotra, Sameta, Dakamkotra, Neemuch Mata, Badgaon; all them are located between 2 to 25km. Generalized stratigraphic succession established by Banerjee[28,29] is as follows :

Udaipur formation—lithic quartzite, flaggy quartzite and current bedded orthoquartzite. greywacke and phyllite, sandy phyllite, calcareous phyllite.

orthoquartzite, brecciated calcareous quartzite, marble and carbon phyllite.

impure marble, dolomitic limestone with rolled and rewashed fragmental phosphorite and biothermal phosphorite.

Matoon formation—sandy phyllite, schist, orthoquartzite, brecciated quartzite, dolomite, marble, fragmental phosphorite, locally biothermal phosphorite.

impure marble, carbon phyllite with small garnets, manganiferous dolomite, intruded by granite.

buff, reddish white and brown orthoquartzite with intercalated phyllite and chlorite schist at the top.

Debari formation—metaconglomerates and coarse arkose, meta arkose, meta conglomerate.

.....Shears.....Local faults.....

Bhilwara group (Banded gneissic complex)

The stromatolites have been reported in lower and middle part of Matoon formation. The author reported two assemblages in the lower and middle units of the Matoon.

(a) *Baicalica and Minjaria*—1.0–1.3Ga.

(b) *Collenia Columaris*—1.65–1.85Ga.

Baicalica is middle Riphean in age; *Minjaria* on the other hand is the lower part of upper Riphean. The report of the phosphorite bearing horizon is also

confined in the dolomitic limestone of the Matoon formation, which is abundant in brecciated cherty rocks and bluish gray dolomites interbedded with stromatolitic columns.

The depositional environment of the phosphorite bearing strata of Udaipur appear to be related to a facies change from argillaceous and silico-argillaceous shale and phyllite into calcareous or arenaceous. It appears to have been deposited close to an area of abrupt shallowing of the basin. Sedimentary structures such as load casts, convolutely laminated shaly horizon superimposed directly over the current bedded, pebbly orthoquartzites, followed by algal dolomitic phosphorite, have been reported.

Certain microfossils have been observed in thin sections. Banerjee[28,29] has reported the presence of filamentous bodies of *Baicalica* assemblage characteristic of middle Riphean age preserved in a phosphate carbonate chert matrix.

The area is suitable for detailed organic geochemical and paleobiological research. The association of phosphorite with stromatolites makes it more interesting and the reported environment of deposition by Banerjee[28,29] is of shallow water marginal sedimentation.

The occurrence of two different types of stromatolitic assemblage needs a detailed investigation.

Cuddaph Basin of Andhra Pradesh, South India

The Cuddapah basin represents the middle Proterozoic sequence of sediments The crescent shaped basin (Map 3) has been extensively studied. Lithologically, it comprises alternating quartzites and shales. The classification of the Cuddapah Supergroup is as follows :

	Srisailam quartzites
Krishna Group	Kolamnala shales
	Irlakonda quartzites
Nallamalai Group	Cumbum shales
	Bairenkonda quartzites
Cheyair Group	Tadpatrishales
	Pulivendla quartzites
.....Unconformity.....	
Papagni Group	Vempalle shales and limestones
	Gulcheru quartzites
.....Eparchean Unconformity.....	
Archaeans	Gneisses and Schists

Radiometric Studies of the Cuddapah Supergroup

Crawford[73] reported the ages of the lavas in the Vempalle Formation to be 1.32 ± 0.6 Ga. The Rb-Sr whole rock isochron age of these lavas gives an age of

1.25Ga whereas the intrusive dolerites are 0.98 ± 0.11Ga. According to Crawford[73] the Cuddapahs can be correlated with lower Vindhyans. Crawford and Compston[74] dated the base of the basin to be 1.7Ga and the top at 0.98 ± 0.11Ga.

Paleobiological Investigations

Rao[34] reported stromatolites *Conophyton*, *Kussiella*, *Colomnella* in the Vempalle Formation of the Cuddapah Supergroup. The latter two are reported in the Tadpatri by various workers. Prasad and Verma[38] have reported *Collenia rajurkarii* in the upper part of Vempalle strata. *Conophyton* has been reported from the Cumbum Formation.[41] A large assemblage of structurally preserved microorganisms was identified including *Archaeorestis barghoorn*, *Corymboccoccus awramik*, *Eostrion barghoorn* which were similar to the forms of the Gunflint Formation of Canada.

Schopf and Prasad[42] account a diverse assemblage of originally preserved unicellular and filamentous microorganisms from the Collenia bearing Vempalle Formation. According to them, it represents the oldest stromatolitic microbiota known in India.

Pakhal Group of Andhra Pradesh

The Pakhals represent a conspicuous stratigraphic sequence in the Pranhita Godavari Valley. The stratigraphic position of the Pakhals in the area is as follows :

Gondwana Supergroup

Purana Supergroup — Sullavai Group
Pakhal Group

Undifferentiated basement complex

Geology and Paleobiological Investigations

Chaudhuri[52] reported stromatolites from the Mallampalli Subgroup. A generalized stratigraphic succession is presented to indicate the various lithologies present.

Pandikunta shale (450′) Mallampalli Subgroup	slate with bedded limestone
Pandikunta limestone (8050′)	cherty limestone with interbedded purple limestone
Mallampalli conglomerate (100′)	Ferruginous silicerudite (local) Arkose arkosic conglomerate

——————————Non-conformity——————————

Archaean — Granite and gneisses, etc.

The upper calcareous Pandikunta Formation has stromatolites *Colonella*, *Conophyton* and *Kussiella* were assigned.[52] He assigned the stromatolites to various groups : types LLH, SH and SS depending on whether the base of the structure is attached to the substratum or not. Each of the three groups has been divided into various subgroups.

The dominant lithology of the Pandikunta Formation is limestone and dolomite. The carbonate rocks occur as well developed, fairly persistent beds. Glauconitic sandstone and few lenses of shales are found associated with it. The beds containing stromatolites are light gray, buff purple and light pink, weathered black, fine grained, massive dolomitic limestone. Sedimentary structures like small scale bedding and ripple marks characterize the different lithotypes.

The depositional sedimentary environment occurred, according to Basumallick[75] in a marine epineritic condition evidenced by the presence of glauconite, bedded chert, moderate to well sorted arenites, secondary growth of potash feldspar and high magnesia content of the carbonates. The formation has been dated 1.4 Ga based on K-Ar ratio in glauconitic sandstones.

Vindhyan Supergroup

The Vindhyan Supergroup has a wide geographical distribution encompassing the border of three states : Rajasthan, Madhya Pradesh and Uttar Pradesh : these are representatives of the Northern part of India. The area has been extensively investigated by various workers and the broad division of the stratigraphic units is as follows :

	Upper Bhander Sandstones
	Sirbu Shales
	Lower Bhander Sandstones
	Lower Bhander Limestones
	Ganurgarh Shales
Rewa Group	Upper Rewar Sandstones
150–300m	Jhiri Shales
	Lower Rewar Sandstones
	Panna Shales
Kaimur Group Upper	Kaimur Sandstones (Dhandhraul Quartzites)
150–300m	Upper Kaimur Congolmerates (Scarp Sandstones)
	Bijaigarh Shales
	Upper Quartzite
	Silicified Shales
	Lower Quartzites
Semri Group	Rohtas Formation
300–1,000m	Kheinijua Formation—Glauconite Sandstone, Fawn Limestone, Olive Shales
	Porcellanite Formation
	Basal Formation
	Kajrahat Limestone
	Conglomerates

The classic area for the study of rocks is the Semri group in the Sone Valley, Mirzapur. Lithologically, the rocks belonging to this group comprise dolomitic limestones, which at places are intercalated with bands of rhyolitic tuffs and glauconitic sand stones.

Bhargava,[76] on the basis of the studies performed in the North and West of Sidhrie, concluded that the environment of the deposition of the lower Vindhyans is a shallow marine environment ranging from intertidal to epineritic zones. The lower Vindhyans are unconformably overlain by the Kaimurs in the Mirzapur District, represented by Bijagarh shales, which comprise carbonaceous, pyritifereous, micaceous, siltstone of bleached or yellow colour representing an euxinic facies. The pyrite bearing horizon near Bijagarh is about 10m thick but it thins out eastward and westward.[77]

The Rewa group succeeds the Kaimur group, lithologically composed of red shales and sandstones. The Bhander group, which constitutes the youngest division of the Vindhyan supergroup and comprises a thick succession of shales, limestones, dolomites and sandstones. Geologically, the rocks of the Vindhyan supergroup are ideally suited for detailed organic geochemical and paleobiological work.

Radiometric studies of the Vindhyan Supergroup

The geochronological data available indicate that the base of the lower Vindhyans may have a minimum age of 1.4Ga and the base of upper Vindhyans can be demarcated at above 1.14Ga.[78]

Misra[77] gave a time span of 1.4Ga to 0.9Ga for the Vindhyans by the evidence provided by various stromatolitic horizons. The Glauconitic sandstone is dated to be 1.11 ± 0.06Ga,[79] which is thus of late or early middle Riphean age.

Paleobiological Studies of the Vindhyans

Jones[80] reported the presence of black, carbonized, wrinkled, discoidal bodies from the Suket shales exposed at Rampura in the Neemuch District of M.P. The organic remains were assigned to the genus *Obelella* and later considered resembling *Chauria circularis*. Workers were disputed on the plant or animal origin of these organic discs. Chapman[81] attributed these discs as representatives of two new genera : *Fermoria* and *Protobolella*. Sahni and Srivasthava[82] suggested evidence supporting the algal nature of *Fermoria*. Misra[83] contended that the material was of inorganic origin, a colloidal precipitation of mineral matter. Palynological investigations in the area were carried out by a number of workers, and revealed a microfloral assemblage—*Leiosphaerida, Retisphaerodium, Lacunalites, Tasmanites, Gloeocapsmorpha*, etc. However, in all probability the microfloral assemblage which indicates Cambrian and Ordovician age appears post depositional and may not represent the time period of deposition.

Kumar[48] recorded an assemblage of *Kussiella Russiensis, K. dalensis, Collenia symmetrica, Colonnella* and *Conophyton* from the Kajrahat limestone (basal members of the Semri group) and *Conophyton garganicus* and *Collonella columnaris* from

the Fawn limestone of the Vindhyan. The report suggests an early Riphean age for the lower part and middle Riphean age for the upper part of the Semri group.

The Bhander group has reports of *Collenia baicalica*,[47] *Crytozoon Occidentals*,[53] *Baicalia baicalica*, *B. Satnesis* and *Maiharia maiharensis*,[48] *Tunguissa*, *Boxonia* from different parts of the Vindhyans.

Bijawar Group, Madhya Pradesh, India

The Bijawars underlie the Vindhyan supergroup and are exposed as a series of outcrops from Bundelkhand to the South of the Narmada (see Map 3). Lithologically, this group consists of 240m thick succession on horizontally or gently dipping beds of quartzites interbedded with limestones and hornstones breccia which are not uniformly distributed. In the Joga area, Hoshangabad District, the dolomites contain stromatolites *Conophyton* (cylindricus) and *Collenia columnaris* (colonnella).[27] No systematic study has been carried out. The Bundelkhand granite which underlines the Bijawars has been dated 2.37Ga by Sarkar.[84] The Bijawars has been dated by Rb-Sr isochron of whole rock at 2.41–1.51Ga.[84]

Kaladgi and Bhima Basins of Karnataka State, South India

The Kaladgis are exposed along the southern border of the Deccan trap country, extending 150km; at places they are covered by the Deccan traps (*see* Map 3). It rests unconformably on gneisses and schists with little or no metamorphism. Viswanathiah *et al.*[85] have classified the Kaladgi group.

	Badami Group	
.....Unconformity.....		
Kaladgi Group	Mudhol Formation	Machkhandi-granite
		Laksanhalli-dolerite
		Nirlasperi-breccia
		Vajramatti-quartz-arenite
		Yadhatti argillite
		Retlur limestones
		Jalikatti-argillite
		Chikshellikari limestone
	Lokapur Formation	Chitrabhanukot dolomite
		Manoli-argillite
		Makut-breccia
		Bili-quartz-arenite
	Bagalkhot Formation	Salagundi conglomerate
.....Unconformity.....		
	Dharwar Supergroup	

Paleobiological Investigations

Stromatolites belonging to *Collenia* group were identified by Viswanathiah and Gowda.[86] Raha and Sastry[17] contended that there is lack of detailed systematic studies and have recognized *Colonella-Kussiella* assemblage in the Kaladgi group.

Apart from the stromatolites, Venkatachala and Rawat[51] and Viswanathiah *et al.*[85] have recorded the occurrence of a rich assembage of acritarchs from the Chikshellikeri limestone and Chitrabhanukot dolomite of the Lokapur formation. The fossil assemblage reported includes *Microtaenia, Protoleiosphaeridium, problematicum, Spumiosa alara, Leiosphaeridia aglutinata, L. dhakshimii, Retisphaeridium dichamerum*, etc. Radiometric data are lacking from the area.

Bhima Group Karnataka

The Bhima group is well developed in the Gulbarga and Bijapur districts of Karnataka state and part of Andhra Pradesh occupying an area of about 4,200 sq. km. The group is subdivided into three units :

Upper (100m)	Black, blue, buff and purple shales with local sandstones at the bottom and flaggy limestone at the top.
Middle (165m)	Creamy, gray, bluish buff and flaggy limestones.
Lower (110m)	Sandstones, green and purple shales. The bottom beds are conglomeratic whereas the topmost beds are often calcareous.

Paleobiological Studies

The area has been studied by various workers who have reported a host of palynofossils and late proterozoic index fossil *Chauria Circularies Walcott* from the lower Bhima shales.[54]

Salujha, Rehman and Arora,[87] Venkatachala and Rawat[51] and Viswanathiah *et al.*[55] reported an assemblage of microflora. Salujha, Rehman and Arora[87] state that Bhima group may range from Cambrian to Ordovician in age. The assemblage the representing different ages conclusively does not define a time period.

Suresh and Gowda[54] upon investigations carried out on the samples collected from the Gulbarga district, Karnataka, reported a palynofossil assemblage of sphaeromorphs associated with *Leiosphaerida, Tasminites*, and *Hystrichosphene.* On the basis of characteristic index fossil *Chauria Circularis*, a late proterozoic age is suggested. There are no reports of stromatolites.

There is no record of any radiometric investigations. Schnitzer[56] on the basis of lithology and various cycles of sedimentation has considered it to be equivalent to the Kurnools in age.

Kurnool Supergroup of Andhra Pradesh, South India

The Cuddapah sediments in the parts of Kundair Valley and Palnad tract of Andhra Pradesh are conformably overlain by the rocks of the Kurnool supergroup.

Lithologically, it comprises sandstones, shales, limestones and quartzites. The best succession of this supergroup is exposed in the Kurnool area where it is subdivided into four units :

Kurnool Supergroup

Group	Formation
Kundair	Nandyal shales, Koilkunta limestone
Panaim	Pinnacled quartzites
	Plateau quartzites
Jamalmadugu	Auk shales, Narji limestone
Banganpalli	Banganpalli sandstone

Schnitzer[56] on the basis of four cycles (A, B, C, D) of sedimentation recorded various units of this supergroup. All cycles culminate in a red series (red beds, red claystone, red shales). He has reported the occurrence of stromatolitic limestones, forming large reef complexes from cycles B and C (Nargi Formation). The stromatolites are silicified, showing the presence of radiolarites in the chert bands.

It is noted that the stromatolites differ in form and character from those found in rocks of Cuddapah and Chattisgarh supergroups.

Salujha, Rehman and Arora[87] have recorded the occurrence of microplankton from different stratigraphical horizons. The forms include *Archaefavosina pellucida, Lophosphaeridium bellus, L. Kurnodi, Dictyotidium sp., etc.*

Age of the Kurnool Supergroup

Systematic radiometric studies are lacking. Sarkar[88], reported a whole rock age 0.453 Ga for the Auk shales. Palynofossil assemblage renders a late Precambrian to Cambrian age. Schnitzer[56] has considered it to be the equivalent of the Bhima group as evidenced by identical lithology, sedimentation pattern and palynological assemblage.

Chattisgarh Supergroup

The sediments are deposited in an intracratonic basin between South India and the Vindhyans. Schnitzer[56] proposed a classification scheme for this supergroup. The base of it is marked by Chandapur quartzite, which is disconformably overlain by a succession of rocks belonging to the Raipur group. Raipur succession has been assigned to five cycles of sedimentation which begin with dark limestones and extend into "red beds". Stromatolites are extensively developed and particularly larger in size in the fifth cycle of sedimentation. Jairaman and Banerjee[89] have reported stromatolites in the limestones from the Raipur area of the Chattisgarh basin. The forms described are *Gymnosolen, Inzeria, Tungussia, Cryptozoan occidentalis.* The late proterozoic Chattisgarh sediments are correlated with Kurnool supergroup.

Conclusion

The Precambrian rocks of India represent a vast area of time and space. The oldest dated sediments from the eastern part of India provide a opportunity to study the early chemical evolutionary events from this part of the earth. Although there are many reports of stromatolites from the Proterozoic basins, systematic work is needed in many areas. Reports of Archean life forms are rare. Reliable radiometric data are needed in many areas. Organogeochemical data are lacking.

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