Society of Earth Scientists Series

Bandana Samant
Deepali Thakre *Editors*

Applications of Palynology in Stratigraphy and Climate Studies

The Society of Earth Scientists
2008

Springer

Society of Earth Scientists Series

Series Editor

Satish C. Tripathi, Lucknow, India

The Society of Earth Scientists Series aims to publish selected conference proceedings, monographs, edited topical books/text books by leading scientists and experts in the field of geophysics, geology, atmospheric and environmental science, meteorology and oceanography as Special Publications of The Society of Earth Scientists. The objective is to highlight recent multidisciplinary scientific research and to strengthen the scientific literature related to Earth Sciences. Quality scientific contributions from all across the Globe are invited for publication under this series. Series Editor: Dr. Satish C. Tripathi

Bandana Samant · Deepali Thakre
Editors

Applications of Palynology in Stratigraphy and Climate Studies

The Society of Earth Scientists
2008

Springer

Editors
Bandana Samant
Present Address:
Department of Geology
School of Environment and Earth Sciences
Central University of Punjab
Bathinda, India

Postgraduate Department of Geology
RTM Nagpur University
Nagpur, India

Deepali Thakre
Postgraduate Department of Geology
RTM Nagpur University
Nagpur, India

ISSN 2194-9204 ISSN 2194-9212 (electronic)
Society of Earth Scientists Series
ISBN 978-3-031-51876-8 ISBN 978-3-031-51877-5 (eBook)
https://doi.org/10.1007/978-3-031-51877-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

Dedicated to my esteemed Ph.D. supervisor Dr. N. R. Phadtare, Scientist (retd.), Wadia Institute of Himalayan Geology, Dehradun. I always admire him as a great teacher and a mentor for his unwavering inspiration and guidance all through my academic career.

With immense gratitude
Bandana Samant

Preface

Palynology, which deals with the study of organic walled microfossils has now emerged as a time-tested tool in stratigraphy, reconstruction of past vegetation, understanding depositional environments and climate. This book deliberates an overview of the role palynology plays in solving various geological problems, right from the Precambrian to Recent. Precambrian palynology is significant in understanding the origin of life on the earth, biostratigraphy, and the early atmosphere. The fluvio-lacustrine Gondwana sediments have rich coal deposits. Palynological studies of Gondwana sediments help in age determination and coal seam correlation. Palynology also plays a key role in understanding the changing climate and depositional environment of the Gondwana Supergroup. The intertrappean sediments of the Early Cretaceous Rajmahal Traps are significant in understanding *Ptillophyllum* flora and the evolution of the early angiosperm on the Indian subcontinent. Late Cretaceous-Early Palaeocene Deccan volcanic activity is an important geological event on the Indian subcontinent. This massive volcanic event is considered as one of the causes of the mass extinction of biota across the globe. The Deccan volcanic associated palynoflora rich infra and intertrappean sediments are useful in understanding floral diversity, age, depositional environments, and paleoclimate before the onset of volcanic activity as well as during volcanic activity. The palynoflora of this time is also useful in understanding the origin and evolution of many angiosperm families and tracking palynofloral changes across the Cretaceous-Palaeocene boundary. Post-Deccan Paleogene palynology has played a pivotal role in deciphering the floral change associated with the equatorial latitudinal position of India and understanding their age and depositional environments. Significantly, the palynoflora of the Palaeocene-Eocene deposits of the Indian subcontinent show similarity with the present day tropical and subtropical flora of Africa and Southeast Asia.

The role of palynology in comprehending climate change in the pre-industrial Common Era is enormous. This period has seen global climate events that have influenced socio-economic events and the ancient Indian economy. Alike, the significance of palynology in deciphering the impact of anthropogenic activity on the environment is quite remarkable. These topics have been thoroughly analysed and covered in this book. The study of modern pollen rain and its taxonomic characterization helps in knowing the climatic conditions of any region. This methodology can be effectively used to understand past climatic conditions. Another emerging aspect of palynology is its utilization in the field of archaeology. These days, archaeobotany and palynology are actively used in decoding floral biodiversity, paleoclimate, and human-plant relationships. Organic geochemistry and its use as a hydrocarbon biomarker are emerging fields in petroleum exploration. Organic matter in plants acts as a biomarker for elucidating the source of organic matter and past depositional environment interpretation. Details of organic geochemistry techniques and their role in understanding the paleo-vegetation of the Cambay Basin of western India are outlined in this book. Last but not the least, coal and petroleum resources are the backbone of energy resources and the economic development of any country and the paper highlights the role of palynology in the exploration of coal and petroleum.

Additionally, this book brings into focus the contribution of Indian palynologists in understanding the past floral diversity, climate, and depositional environments of the Indian subcontinent.

Nagpur, India

Bandana Samant
Deepali Thakre

Acknowledgements

First and foremost, my deepest gratitude to my Ph.D. supervisor, Dr. N. R. Phadtare, Scientist (retd.), Wadia Institute of Himalayan Geology, Dehra Dun for introducing me to the fascinating world of palynology. His mentorship and expertise helped in my academic journey and passion for palynology.

My deepest gratitude to Dr. D. M. Mohabey, Director General and HOD (retd.), Geological Survey of India for inspiring and encouraging me to work on Deccan palynostratigraphy. His consistent encouragement has been a driving force behind my research.

I extend my sincere appreciation to all my research students including Dr. Hemant Sonkusare, Anup Dhobale, Neha Thakre, Abhilash Sen, Akash Karande, and Dr. Apoorva Sitholey for their invaluable assistance during the compilation of this book.

I am thankful to the Head Department of Geology, RTM Nagpur University, for providing working facilities which have been important for conducting the research work.

I am deeply indebted to all the reviewers for meticulously going through the manuscript, offering valuable feedback and suggestions. Their expertise and careful examination have been invaluable in refining the papers.

I thank each and every author and contributor for submitting chapters for the book. Their valuable contributions helped significantly to the diversity of the contents presented.

Finally, my thanks are due to all my family members, for their patience and continuous encouragement during the compilation of this book.

This book would not have been possible without the support and contribution from each one of you.

Bandana Samant

Contents

Editors and Contributors

About the Editors

Prof. Bandana Samant obtained her M.Sc. degree in geology from H. N. Bahuguna Garhwal University, Uttarakhand, India. She did her Ph.D. in palynology of lignite deposits of Gujarat from the Wadia Institute of Himalayan Geology, Dehra Dun, Uttarakhand. Dr. Samant carried out postdoctoral work as a Research Associate, Senior Research Associate, and Research Scientist under the projects awarded by the Department of Science and Technology, and the Council of Scientific and Industrial Research. She has worked as a faculty at the Banaras Hindu University, Varanasi and RTM Nagpur University, Nagpur. Presently working at the Department of Geology, School of Environment and Earth Sciences, Central University of Punjab, Bathinda, Punjab, India. So far, she has completed seven research projects awarded by national funding agencies. She has published about 63 research papers, including one in 'Nature Communication'. She also worked as a collaborator in National Science Foundation, USA funded research projects. She was a member of the National Working Group of the prestigious International Geoscience programme, IGCP-609. Since last 20 years, she has been working on the palynoflora of Deccan volcanic associated sediments to understand the response of the flora to Deccan volcanic eruptions. Dr. Samant has successfully guided three research students for Ph.D.

Dr. Deepali Thakre completed her Postgraduate degree in geology from the Postgraduate Department of RTM Nagpur University. She did Ph.D. work on the palynological study of Deccan volcanic associated sediments of Chhindwara district, MP, for assessing the effect of volcanism on contemporary flora towards the K-Pg boundary, from RTM Nagpur University. She worked as a Junior Geologist in the Directorate of Geology and Mining (DGM). Prior to her appointment in DGM, she was a Junior Research fellow at the Space Application Centre-ISRO, Ahmedabad, Gujarat and in SERB-DST sponsored project at RTM Nagpur University, Nagpur. Her research work is focused on understanding the environmental and climate perturbation brought by the Deccan volcanic eruption, its effect on flora, and the dynamics of palynofloral turnover close to the Cretaceous-Paleogene boundary, especially in terrestrial environments.

Contributors

Subir Bera Centre of Advanced Study, Palaeobotany-Palynology Laboratory, Department of Botany, University of Calcutta, Kolkata, India

Oindrila Biswas Centre of Advanced Study, Palaeobotany-Palynology Laboratory, Department of Botany, University of Calcutta, Kolkata, India;
Department of Botany, School of Basic Sciences, SRM University Sikkim, Gangtok, India

Neelam Das Birbal Sahni Institute of Palaeosciences, Lucknow, India

Suryendu Dutta Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India

Suyash Gupta Birbal Sahni Institute of Palaeosciences, Lucknow, India

Ratan Kar Birbal Sahni Institute of Palaeosciences, Lucknow, Uttar Pradesh, India

Suraj Kumar Birbal Sahni Institute of Palaeosciences, Lucknow, India;
Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, India

Krishna Kali Mandal Dakshin Chobbish Pargana Protna Itihas Gobeshona Kendra, Dhopagachi, Baruipur, West Bengal, India

Nivedita Mehrotra Birbal Sahni Institute of Palaeosciences, Lucknow, Uttar Pradesh, India

D. M. Mohabey Postgraduate Department of Geology, RTM Nagpur University, Nagpur, Maharashtra, India

Srikanta Murthy Birbal Sahni Institute of Palaeosciences, Lucknow, India

Deepti Niyolia Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India

Dipak Kumar Paruya Centre of Advanced Study, Palaeobotany-Palynology Laboratory, Department of Botany, University of Calcutta, Kolkata, India

Sankar Suresh Kumar Pillai Birbal Sahni Institute of Palaeosciences, Lucknow, India;
Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, India

Mohammad Firoze Quamar Birbal Sahni Institute of Palaeosciences, Lucknow, Uttar Pradesh, India

Rajeev Ranjan Birbal Sahni Institute of Palaeosciences (BSIP), Uttar Pradesh, Lucknow, India;
Babasaheb Bhimrao Ambedkar University (A Central University) (BBAU), Uttar Pradesh, Lucknow, India

Mrutyunjaya Sahoo Department of Geology, Ravenshaw University, Cuttack, Odisha, India

Sumit Kumar Sahu Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India

Bandana Samant *Present Address:* Department of Geology, School of Environment and Earth Sciences, Central University of Punjab, Bathinda, Punjab, India;
Postgraduate Department of Geology, RTM Nagpur University, Nagpur, Maharashtra, India

Binod Saradar Centre of Advanced Study, Palaeobotany-Palynology Laboratory, Department of Botany, University of Calcutta, Kolkata, India

Anju Saxena Birbal Sahni Institute of Palaeosciences, Lucknow, India

Abhilash Sen Postgraduate Department of Geology, RTM Nagpur University, Nagpur, Maharashtra, India

Santosh K. Shah Birbal Sahni Institute of Palaeosciences, Lucknow, Uttar Pradesh, India

Yogesh Pal Singh Birbal Sahni Institute of Palaeosciences, Lucknow, India;
Centre of Advanced Studies in Geology, University of Lucknow, Lucknow, India

Deepali Thakre Postgraduate Department of Geology, RTM Nagpur University, Nagpur, Maharashtra, India

Neha Thakre Postgraduate Department of Geology, RTM Nagpur University, Nagpur, Maharashtra, India

Swati Tripathi Birbal Sahni Institute of Palaeosciences (BSIP), Uttar Pradesh, Lucknow, India

Poonam Verma Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, India

Precambrian Microfossils: Indicators of Early Life and Environments on the Earth

Bandana Samant

Abstract Precambrian biota, which primarily includes bacteria, prokaryotes, protists, algal-stromatolites, organic- walled microfossils (micro and macrofossils) and trace fossils, plays a significant role in understanding early life as well as their diversification on the Earth. In addition, they are also used in biostratigraphy, to understand the depositional environment, early biosphere, and atmosphere. A review of Precambrian biota, recovered from the Archean, and Proterozoic sedimentary rocks of India, reveals the presence of diverse assemblages of organic remains. These remains play a significant role in understanding Indian Precambrian biostratigraphy and early life.

Keywords Precambrian · Microfossils · Organic walled microfossils · Evolution · Biostratigraphy

1 Introduction

The Precambrian Era, which is broadly divided into the Archean (4000–2500 Ma) and Proterozoic (2500-541 Ma), is the period when simple life forms evolved on the earth. Over billions of years of the evolutionary cycle, simple life evolved into complex forms (Woese et al. 1990). Previously, records of microscopic life from the Precambrian sediments were viewed with doubt and scepticism. However, current studies and records of numerous biotic remains of the Precambrian viz, bacteria, protists, stromatolites, organic walled microfossils, and biomarkers, are now considered an important tool in biostratigraphy and understanding the early evolution of life and depositional environments (Sharma et al. 2021).

Present Address:
B. Samant (✉)
Department of Geology, School of Environment and Earth Sciences, Central University of Punjab, Bathinda 151401, Punjab, India
e-mail: bandanabhu@gmail.com

Postgraduate Department of Geology, RTM Nagpur University, Nagpur 440010, Maharashtra, India

B. Samant and D. Thakre (eds.), *Applications of Palynology in Stratigraphy and Climate Studies*, Society of Earth Scientists Series, https://doi.org/10.1007/978-3-031-51877-5_1

Stromatolites are the oldest Precambrian organo-sedimentary structures and they are thought to be an indicator of life in Precambrian sediments. Stromatolites found in the North Port Chert Member of the Dresser Formation are the best preserved, and probably the oldest biogenic structures (Djokic et al. 2017; Baumgartner et al. 2019). The oldest accepted fossilized microorganisms have been reported from the 3770/4280 Ma Nuvvuagittuq Belt of Quebec, Canada (Dodd et al. 2017). Another significant microbial sedimentary structures from the Precambrian rocks are Microbially Induced Sedimentary Structures (MISS), recorded by Noffke (2000; Noffke et al. 2001a, b). So far, 17 different types of MISS have been reported. These forms are widely known from Australia (Noffke et al. 2013), Africa (Noffke et al. 2006; 2013) and Greenland (Retallack and Noffke 2018). Holland (2006) proposed the significance of these microfossils in assessing the oxygen level of the primitive atmosphere. Overall, the Precambrian biota plays an important role in understanding evolution and diversification of life in the present-day earth's biosphere. This chapter discusses the Indian Archeozoic and Proterozoic micro- and macrofossil records, as well as their biostratigraphic significance and the role they play in deciphering the depositional environments.

2 Indian Archeozoic Microfossils

The record of microfossils from the Archeozoic cratonic rocks is scarce. Archean microbial mats, filamentous microfossils, and stromatolites are recorded from the Dharwar and Singhbhum Cratons (summarised in Sharma et al. 2021). Recently, stromatolite like structures called "Egg Craton" were recorded from the Dharwar Craton (Shukla and Sharma 2020a), it is the second occurrence of such structures in the world (Allwood et al. 2006).

3 Indian Proterozoic Microfossils

Proterozoic sedimentary basins of the Indian shield are mainly the Bijawar, Sonrai, Gwalior, Abujhmar, Bhima, Chhattisgarh, Cuddapah, Khariar, Ampani, Indravati, Sukma, Pranhita-Godavari, Kaladgi, Bhima, and Vindhyan (Ramakrishnan and Vaidyanathan 2008). A variety of MISS have been recorded from the Proterozoic rocks of northern India (Banerjee and Jeevankumar 2005; Banerjee et al. 2006, 2010; Raghav et al. 2005; Kumar and Pandey 2009; Kumar and Ahmad 2014 etc.). These structures have also been recorded from the Cuddapah Basin, suggesting a shallow marine, reducing depositional environment (Goswami et al. 2017). The oldest record of Palaeoproterozoic stromatolites is from the carbonate sedimentary rocks of the Cuddapah Supergroup (King 1872). Later on, Loon and Mazumder (2013) recorded Palaeoproterozoic stromatolites from the Iron Ore Series rocks of Singhbhum craton.

Many workers have reported various forms of stromatolite from the Cuddapah Supergroup (summarised by Sharma et al. 2021). According to Khelen et al. (2017), the various shapes of stromatolites are related to the interaction between mat growth, current structures, and sediment supply. They (op. cit.) also used them to reconstruct marine depositional environments, such as shallow shelf (marginal, inner and outer), open ocean, and anoxic conditions. The carbon and oxygen isotope studies of stromatolites have been used for understanding the paleotemperature of the Vampalli Formation of the Cuddapah Group (Chakrabarti et al. 2011). It is noteworthy that the Indian Proterozoic sedimentary rocks show a large amount of phosphatic deposition, and this phosphatic concentration is attributed to the scavenging of the microbial carpets from the sea water (Banerjee et al. 1986). Salujha et al. (1972a, b) reported the various species of *Leiosphaeridia* and *Kildinosphaera.* Shukla (2011) described Neoproterozoic biofils from Bhima Formation. Shukla and Sharma 2020b proposed that the biofilms facilitate precipitation of phosphorous and iron rich mineral forming bands. Carbonaceous shales associated with stromatolites have yielded a good number of organic walled microfossils (Jankauskas et al. 1989) that have helped in understanding the evolution and diversification of Precambrian life (Knoll 1996; Sergeev et al. 2008, 2012) (Fig. 1).

Organic walled microfossils (OWM) include cyanobacterial and eukaryotic fossil remains. The Great Oxidation Event (GOE) of 2.45–2.32 GA is an important period in the earth's history as it changed the pace of life on the earth (Schirrmeister et al. 2013) and caused the diversification of cyanobacteria. On the Indian subcontinent, diversification of Organic walled microfossils is also observed in the Mesoroterozoic and Neoproterozoic sediments. A good number of OWM have been recorded from the Vindhyan, Chhattisgarh, Kurnool, Bhima, Kaladgi and Krol Belt of Lesser Himalaya (Kumar and Srivastava 1995; Moitra 1999; Prasad et al. 2005; Sharma 2006; Sharma et al. 2009; 2016; Singh and Sharma 2014, 2016, 2019; Singh et al. 2011; Sharma and Shukla 2012a, b; Pandey and Kumar 2013; Shukla and Tiwari 2014).

Acritarchs, an important tool for the biostratigraphy of Proterozoic rocks, especially *Tappania* and *Valeria*, from Australia, (Javaux et al. 2001; Lamb et al. 2009; Knoll 2014; Adam et al. 2017) and China (Yin 1997), are also recorded from India. Various species of *Tappania* have been documented from the Bahraich Group in Ganga Basin (Prasad and Asher 2001), the Semri Group (Lower Vindhyan) from Vindhyan Basin (Prasad et al. 2005, 2007) and the Saraipali Formation (Singhora Group), Chhattisgarh Basin (Singh et al. 2019c). Acritarchs are also recorded from the Chhattisgarh Supergroup (Singh et al. 2019a, b, c), Vindhyan Supergroup (Maithy 1992; Venkatachala et al. 1996; Prasad et al. 2005, 2007; Prasad 2007), and subsurface sediments of the Marwar Supergroup, Bikaner-Nagaur Basin (Prasad et al. 2010) and Ganga Basin (Prasad and Asher 2001). *Tappania planta*, a eukaryotic fossil, and the botuliform microfossil *Jacutianema solubila* have been recovered from the Chhattisgarh Basin (Singh et al. 2016, 2019c), Ganga Basin (Prasad and Asher 2001) and the Vindhyan Basin (Prasad et al. 2005, 2007; Singh and Sharma 2016; Asher et al. 2017; Singh et al. 2019a). Tonian age marker acritarchs, *Trachyhystrichopshaera* have also been recorded from the subsurface sediments of the Ganga Basin (Prasad and Asher 2001; Asher et al. 2017; Tang et al. 2017).

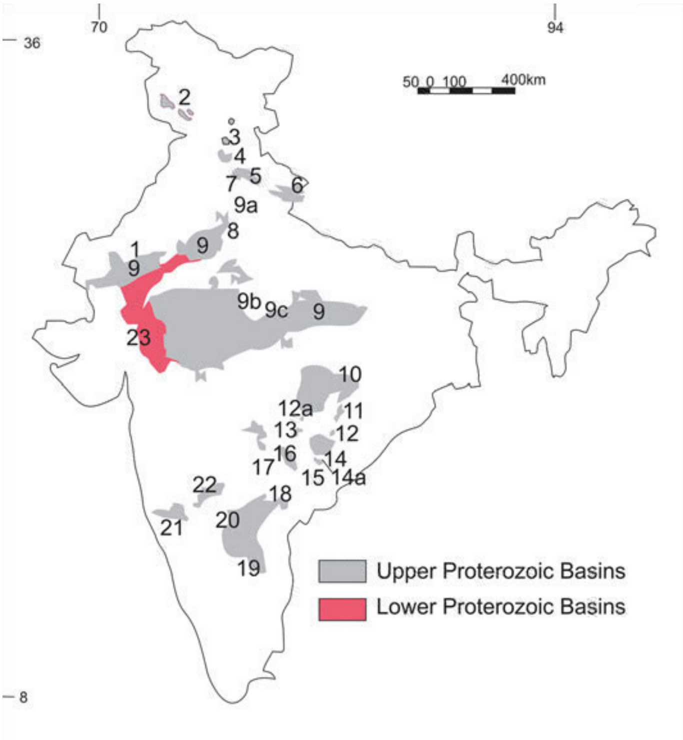

Fig. 1 Map showing Proterozoic basins of India, 1. Marwar Supergroup, 2. Jammu Lst, 3. Larji Fm., 4. Shali Fm., 5. Deoban Fm., 6. Pittoragarh Fm., 7. Sataun Lst., 8. Delhi Supergroup, 9. Vindhyan Supergroup, 9a. Gwalior Basin, 9b. Bijawar Basin, 9c. Sonrai Basin, 10. Chhattisgarh Basin, 11. Khariar Basin, 12. Ampani Basin, 12a. Keskal and Singanpur outliers, 13. Abujmar Basin, 14. Indravati Basin, 14a. Chedrapal outlier, 15. Sabari/Sukma Basin, 16. Pranhita Godavari Basin, 17. Pakhal Basin, 18. Palnad Basin, 19. Cuddapah Basin, 20. Kurnool Basin, 21. Kaladgi Basin, 22. Bhima Basin, 23. Aravalli Supergroup (modified after Sharma et al. 2020; Kale 1991)

Cyanobacterial microfossils are recorded from the Aravalli Group (Banerjee 1974), Cuddapah, and Karnool basins (Salujha et al. 1972a, b; Schopf and Prasad 1978; Gururaja et al. 1979; Gururaja and Rao 1980; Sharma and Shukla 2012a, 2012b, 2016; Shukla and Sharma 2020a). A very large size coccoidal microfossils have also been recorded from the Vindhyan Supergroup (Shukla and Sharma 2016; Sharma and Shukla 2019a). Heterocysts and akinetes are known from many Paleoproterozoic and Mesoproterozoic rocks of India (Sergeev et al. 2012; Sharma and Shukla 2019a). The oldest recorded eukaryotic fossil from India, *Shuiyousphaeridium echinulatum*, is from the Semri Group in Vindhyan (Kumar and Srivastava 1991; Anbarasu 2001; Singh and Sharma 2014). Rhodophytes are recorded from the Son valley of Chitrakoot (Bengtson et al. 2017; Sallstedt et al. 2018). Remains of *Grypania,* an oldest eucaryotes which evolved around 1.9–1.8 Ga (Han and Runnegar 1992) have also been recorded from the Rohtas Group of Vindhyan Supergroup (Sharma and Shukla 2009).

In addition, carbonaceous microfossils are also recorded from the Indian Proterozoic rocks. Algal carbonaceous fossils are recorded from the Vindhyan, Chhattisgarh, Kurnool, and Bhima formations (Sharma and Singh 2019b). Late Proterozoic Chuarids (*Chuaria* and *Tawuid*) and other coccoid microfossils are recorded from the Kurnool Group (Das Sharma et al. 1992; Ashok Kumar et al. 1993; Sharma and Shukla 2012a, b, 2016). These microfossils are important age marker fossils and are significant in giving information about the transition of organisms from unicellularity to multicellularity. The largest carbonaceous fossil of *Tawuia dalensis* was recorded from the Early Neoproterozoic rocks of the Lesser Himalaya (Sharma et al. 2016). Well preserved benthic multicellular algae of the Phaeophyceae are also known from the Chhattisgarh Basin (Babu and Singh 2011; 2013) (Fig. 2).

The Ediacaran period represents the end of the Precambrian. It is represented by an assemblage of sessile soft bodied organisms that are preserved as impressions. A lot of burrowing and bioturbations are reported from the Cuddapah and Kurnool basins (Kale et al. 1997; Gururajan et al. 2000; Sharma 2008; Vijayam 1968; Arya and Rao 1979; Sharma 2008). Ediacaran disc like structures and some strange fossils are also known from Ediacaran successions (Shukla and Sharma 2020b; Kumar and Ahmad 2016; Pandey and Sharma 2017; Pandey et al. 2019a, b). A diverse Ediacaran Complex Acanthomorphs palynoflora is recovered from the Vindhyan Supergroup (Prasad and Asher 2016). *Obruchevell*, a Vendian marker, is recorded from the Owk Shale of the Kurnool Group (Sharma and Shukla 2012a).

The Krol belt in the Lesser Himalaya represents a thick, uninterrupted sequence of the Ediacaran-Lower Cambrian interval. These sequences have diverse acanthomorphic acritarch sequences. Shukla and Tiwari (2014) reported large sized acanthomorphic acritarchs from the Krol Formation in the Ediacaran horizon. Acritarchs are also recorded from the Infra Krol sequences. (Tiwari and Knoll 1994; Tiwari 1996; Tiwari and Pant 2004). Ichnofossils, which are important in understanding metazoan activity on the earth and benthic activity of organisms in marine life (Jensen et al. 2000) have been recorded from the Krol-Tal formations (Singh et al. 2019a, b, c). From the Mussoorie and Garhwal areas, trace fossils and shelly fauna were recorded by Banerjee and Narain 1976; Singh and Rai 1983; Azmi 1983; Azmi and Joshi 1983; Azmi and Pancholi 1983). Ichnofossils were also recorded from Marwar Supergroup; Kurnool and Bhima groups.

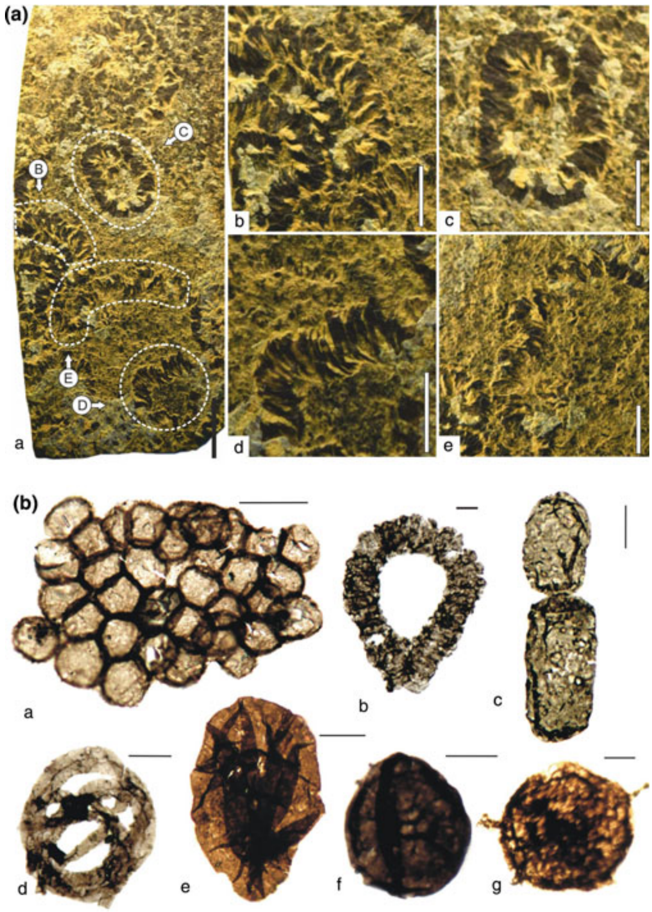

Fig. 2 **a** Organic walled tubular fossil *Shaanxilithes ningqiangensis* recorded from the very top of the Krol Group and in the basalmost Tal Group in Nigalidhar syncline of India preserved as organic compression on the bedding surface. (A) assemblage of *Shaanxilithes ningqiangensis* showing the annulations and high sinuosity; (B–E) magnified views of *S. ningqiangensis* demarcated by boxes at different levels. (A) showing the diagnostic properties; B, D–E) curved ribbon like feature showing annulations; (C) discoidal shaped *S. ningqiangensis* with poorly preserved annulations (Museum specimen no. BSIP 41,863; Scale bar A = 1 cm, for B–E = 0.5 cm). **b** Microfossils assemblage of the Owk Shale, Kurnool Basin, South India. (A) Spheroidal small vesicles tightly arranged in planar colonies *Ostiana microcystis*; (B) spirally coiled cyanobacterium *Obruchevella delicata*; (C) multicellular botuliform microfossil *Jacutianema solubila*; (D) loosely coiled filament of *Obruchevella parva*; (E) compressed, thin-walled spheroidal vesicles of *Leiosphaeridia tenuissima*; (F and G) Ediacaran complex acanthomorph, (F) *Cavaspina* aff. *C. acuminate*; (G) *Variomargosphaeridium* aff. *V. litoschum* (A: Slide no. BSIP-16351; B: Slide no. BSIP-16643; C: Slide no. BSIP-14401; D: Slide no. BSIP-16643; E: Slide no. BSIP-14405; F: Slide no. BSIP- 16,348; G: Slide no. BSIP-16346; Scale bar for B = 10 μm; for rest of the specimens = 20 μm) (A, C, E, F, G after Shukla et al. 2020a, b), (Reprinted from Sharma et al. 2021, copyright (2021), published with permission from, Springer; License Number: 5544181150056)

4 Summary

The preceding review of Indian Archean and Proterozoic rocks show the presence of well preserved and quantitatively and qualitatively diverse fossil remains, that not only played a crucial role in Precambrian biostratigraphy but also aided in comprehending the evolution and diversification of early life and the early biosphere of the earth.

Acknowledgements I am grateful to Dr. Bijai Prasad, Scientist (Retired), Oil and Natural Gas Commission Limited, Dehra Dun for going through the manuscript meticulously and providing valuable suggestions that helped in improvising the manuscript. My thanks are also to the Head, Department of Geology, RTMNU, Nagpur for providing working facility.

References

Adam ZR, Skidmore ML, Mogk DW et al (2017) A Laurentian record of the earliest fossil eukaryotes. Geology 45(5):387–390

Allwood AC, Walter MR, Kamber BS, Marshall CP, Burch IW (2006) Stromatolite reef from the Early Archaean era of Australia. Nature 441:714–718

Anbarasu K (2001) Acritarchs from Mesoproterozoic Chitrakoot Formation, Semri Group, Chitrakoot area Central India. J Geol Soc India 57:179–183

Arya BC, Rao CN (1979) Bioturbation structures from the middle Proterozoic Narji Formation, Kurnool Group Andhra Pradesh India. Sed Geol 22:127–134

Asher R, Kapoor PN, Prasad B (2017) Ediacaran-early Cambrian Acritarchs and associated organic-walled microfossils from the subsurface Vindhyan succession of Chambal valley Rajasthan India. ONGC Bull 52(1):145–158

Ashok Kumar P, Anantaram S, Patil RS et al (1993) Palaeontological and biostratigraphic studies of late PROTEROZOIC and early Paleozoic basins of Andhra Pradesh and Karnataka. Rec Geol Surv India 126(5):296

Azmi RJ (1983) Microfauna and age of the Lower Tal Phosphorite of Mussoorie Syncline, Garhwal Lesser Himalaya India. Himalayan Geol 11:198–223

Azmi RJ, Pancholi VP (1983) Early Cambrian (Tommotian conodonts and other shelly microfauna from the upper Krol of Mussoorie syncline, Garhwal Lesser Himalaya with Remarks on the Precambrian- Cambrian Boundary. Himalayan Geol 11:361–372

Azmi RJ, Joshi MN (1983) Conodonts and other biostratigraphic evidences on the age and evolution of the Krol Belt. Himalayan Geol 11:373–409

Babu R, Singh VK (2011) Record of aquatic carbonaceous metaphytic remains from the Proterozoic Singhora Group of Chhattisgarh Supergroup, India and their significance. J Evol Biol Res 3:47–66

Babu R, Singh K (2013) An evaluation of carbonaceous metaphytic remains from the Proterozoic Singhora Group of Chhattisgarh Supergroup, India. Spec Publ Geol Soc India 1:325–338

Banerjee DM (1974) Microfossils from the Late Precambrian Aravalli stromatolites of Udaipur, Rajasthan, India. Recent Res Geol 1:263–268

Banerjee DM, Narain MJ (1976) Trace fossils in the Lower Tal Formation of Mussoorie and their environmental significance. J Sediment Petrol 46:235–239

Banerjee DM, Schidlowski M, Arneth JD (1986) Genesis of upper Proterozoic-Cambrian phophorites deposits of India: isotopic inferences from carbonate flourapaptite, carbonate and organic carbon. Precambr Res 33:239–253

Banerjee S, Jeevankumar S (2005) Microbially originated wrinkle structures on sandstone and their stratigraphic context: Palaeoproterozoic Koldaha Shale, central India. Sed Geol 176:211–224

Banerjee N, Furnes H, Muehlenbachs K et al (2006) Preservation of ca. 3.4-3.5 Ga microbial biomarkers in pillow lavas and hyaloclastites from the Barberton Greenstone Belt, South Africa. Earth Planet Sci Lett 241:707–722

Banerjee S et al (2010) Microbially related structures in siliciclastic sediment resembling Ediacaran fossils: examples from India. Microbial mats: modern and ancient microorganisms in stratified systems. Springer, Dordrecht, pp 109–112

Baumgartner RJ, Van Kranendonk MJ, Wacey D et al (2019) Nano-porous pyrite and organic matter in 3.5-billion-year-old stromatolites record primordial life. Geology 47(11):1039–1043

Bengtson S, Sallstedt T, Belivanova V, et al (2017) Three-dimensional preservation of cellular and subcellular structures suggests 1.6 billion-year-old crown-group red algae. Paleos Biol 15:e2000735

Chakrabarti G, Shome D, Kumar S et al (2011) Carbon and oxygen isotopic variations in stromatolitic dolomites of Palaeoproterozoic Vempalle formation, Cuddapah Basin, India. Carbonate Evaporites 26:181–191

Das Sharma DC, Raha PK, Moitra AK et al (1992) Discovery of Precambrian-Cambrian transition fossil *Sabellitids* from India. Curr Sci 63(3):140–142

Dodd MS, Papineau D, Grenne T et al (2017) Evidence for early life in Earth's oldest hydrothermal vent precipitates. Nature 543(7643):60–64

Djokic T, van Kranendonk MJ, Campbell KA et al (2017) Earliest signs of life on land preserved in ca 3.5 Ga hot spring deposits. Nat Commun 8(1):1–9

Goswami S, Bhagat S, Zakaulla S et al (2017) Role of organic matter in uranium mineralisation in Vempalle dolostone; Cuddapah Basin, India. J Geol Soc India 89:145–154

Gururaja MN, Jagannatha Rao BR, Bhaskara Rao B (1979) Stromatolitic microbiota from black chert of Cumbum Formation, Upper Cuddapah. Andhra Pradesh J Geol Soc India 20:138–140

Gururaja MN, Ashok Kumar P, Rao CV et al (2000) Precambrian- Cambrian boundary strata in Cuddapah Basin, Andhra Pradesh. Geol Surv India Spec Publ 55:155–162

Han TM, Runnegar B (1992) Megascopic eukaryotic algae from the 2.1 billion year old Negaunne iron formation, Michigan. Science 257(5067):232–235

Holland HD (2006) The oxygenation of the atmosphere and oceans. Philos Trans R Soc Biol Sci 361:903–915. https://doi.org/10.1098/rstb.2006.1838

Jankauskas TV, Mikhailova N, Hermann TN (1989) Mikrofossilii dokembriya SSSR (Precambrian microfossils of the USSR): Leningrad, 188. Trudy Instituta GeologiiGeochronologii Dokembria SSSR Akademii Nauk. Nauka (In Russian)

Javaux EJ, Knoll AH, Walter MR (2001) Morphological and ecological complexity in earlyeukaryotic ecosystems. Nature 412(6842):66–69

Jensen SB, Saylor Z, Gehling JG et al (2000) Complex trace fossils from the terminal Proterozoic of Namibia. Geology 28:143–146

Kale VS (1991) Constraints on the evolution of Purana basins of Peninsuar India. J Geol Soc India 38:231–252

Kale VS, Patil SS, Satoskar V et al (1997) Occurrence of Planolites from the Nagarjuna Sagar Area, Northwestern Cuddapah Basin. J Geol Soc India 49:589–596

Khelen AC, Manikyamba C, Ganguly S et al (2017) Geochemical and stable isotope signatures of Proterozoic stromatolitic carbonates from the Vempalle and Tadpatri formations, Cuddapah Supergroup, India: Implications on paleoenvironment and depositional conditions. Precambr Res 298:365–384

King W (1872) On the Kadapah and Karnul formations in the Madras Presidency. Mem Geol Surv India 8:1–313

Knoll AH (1996) Archean and Proterozoic paleontology. In: Jansonius J, McGregor DC (eds) Palynology: principles and applications, vo. 1. American Association of Stratigraphic Palynologists Foundation, pp 51–80

Knoll AH (2014) Paleobiological perspectives on early eukaryotic evolution. Cold Spring Harb Perspect Biol 6(1):1–14
Kumar S, Srivastava P (1991) Microfossils from the non-stromatolitic middle Proterozoic Vindhyan Chert, Chitrakut area, Uttar Pradesh. J Geol Soc India 38:511–515
Kumar S, Srivastava P (1995) Microfossils from the Kheinjua Formation, Mesoproterozoic Semri Group, Newari area, central India. Precambr Res 74:91–117
Kumar S, Pandey SK (2009) A note on the occurrence of *Arumberiabanksi* from the Jodhpur Sandstone, Marwar Supergroup, Jodhpurarea, Rajasthan. J Palaeontol Soc India 54(2):171–178
Kumar S, Ahmad S (2014) Microbially Induced Sedimentary Structures (MISS) from the Ediacaran Jodhpur Sandstone, Marwar Supergroup, western Rajasthan. J Asian Earth Sci 91:352–361
Kumar S, Ahmad S (2016) Problematic structures from the Ediacaran Jodhpur Sandstone, Rajasthan, India and their possible affinity. J Palaeontol Soc India 60(2):21–26
Lamb DM, Awramik SM, Chapman DJ et al (2009) Evidence for eukaryotic diversification in the ~1800 million-year-old Changzhougou Formation. North China. Precambr Res 173(1–4):93–104
Maithy PK (1992) Palaeobiology of Vindhyan. Palaeobotanist 40:52–72
Moitra AK (1999) Biostratigraphic study of stromatolites and microbiota of the Chhattisgarh Basin, M.P., India. Palaeontol Indica 51:1–95
Noffke N (2000) Extensive microbial mats and their influences on the erosional and depositional dynamics of a siliciclastic cold water environment (Lower Arenigian, Montagne Noire, France). Sediment Geol 136(3–4):207–215
Noffke N, Gerdes G, Klenke T et al (2001a) Microbially induced sedimentary structures indicating climatological, hydrological and depositional conditions within recent and Pleistocene coastal facies zones (Southern Tunisia). Facies 44(1):23–30
Noffke N, Gerdes G, Klenke T et al (2001b) Microbially induced sedimentary structures: a new category within the classification of primary sedimentary structures. J Sediment Res 71(5):649–656
Noffke N, Eriksson KA, Hazen RM, et al (2006) A new window into Early Archean life: Microbial mats in Earth's oldest siliciclastic tidal deposits (3.2 Ga) Moodies Group, South Africa. Geology 34(4):253–256
Noffke N, Christian D, Wacey D, et al (2013) Microbially induced sedimentary structures recording an ancient ecosystem in the ca. 3.48 billion-year-old dresser Formation, Pilbara, Western Australia. Astrobiology 13(12):1103–1124
Pandey SK, Kumar S (2013) Organic walled microbiota from the silicified Algal clasts, Bhander Limestone, Satna Area, Madhya Pradesh. J Geol Soc India 82:499–508
Pandey SK, Sharma M (2017) Enigmatic Ediacaran Megascopic bedding plane structures on the Sonia Sandstone, the Jodhpur Group, Marwar Supergroup, India: seaweed or problematica? Geol J 52:784–807
Pandey SK, Jonathan C, Nema P et al (2019a) Ladakh: diverse, high-altitude extreme environments for off earth analogue and astrobiology research. Int J Astrobiol 19(1):78–98
Pandey SK, Bykova N, Sharma M (2019b) Current status of the Ediacaran-Cambrian Bilara Group, Marwar Supergroup. India. Estudios Geol 75(2):29–30
Prasad B (2007) *Obruchevella* and other Terminal Proterozoic (Vendian) organic-walled microfossils from the Bhander Group (Vindhyan Supergroup), Madhya Pradesh. J Geol Soc India 69:295–310
Prasad B, Asher R (2001) Acritarch biostratigraphy and lithostratigraphic classification of Proterozoic and lower Paleozoic sediments (Pre-Unconformity sequence) of Ganga Basin, India. Paleontographica Indica 5:1–151
Prasad B, Asher R (2016) Record of Ediacaran complex acanthomorphic acritarchs from the lower Vindhyan succession of the Chambal Valley (East Rajasthan), India and their biostratigraphic significance. J Palaeontol Soc India 61:29–62
Prasad B, Uniyal SN, Asher R (2005) Organic-walled microfossils from the Proterozoic Vindhyan Supergroup of Son Valley, Madhya Pradesh, India. Palaeobotanist 54(1–3):13–60

Prasad B, Uniyal SN, Asher R (2007) Organic-walled microfossils from the Proterozoic Vindhyan Supergroup of Son Valley, Madhya Pradesh, India. In: Proc. XXII Ind. Colloq. Mircopaleontol. Stratgraph, vol 1. Norosa Publishing House, New Delhi, pp 7–16

Prasad B, Asher R, Borgohai B (2010) Late Neoproterozoic (Ediacaran)– Early Paleozoic (Cambrian) acritarchs from the Marwar Supergroup, Bikaner-Nagaur Basin, Rajasthan. J Geol Soc India 75:415–431

Raghav KS, De C, Jain RL (2005) The first record of Vendian medusoids and trace fossils-bearing algal mat grounds from the basal part of the Marwar Supergroup of Rajasthan, India. Indian Miner 59:23–30

Ramakrishna M, Vaidyanadhan R (2008) Geology of India. Geological Society of India

Retallack G, Noffke N (2018) Are there ancient soils in the 3.7 Ga Isua Greenstone Belt, Greenland? Palaeoecol Palaeooceanogr Palaeoclimatol 514:18–30

Sallstedt T, Bengtson S, Broman C (2018) Evidence of oxygenic phototrophy in ancient phosphatic stromatolites from the Paleoproterozoic Vindhyan and Aravalli Supergroups. India. Geobiology 16(2):139–159

Salujha SK, Rehman K, Arora CM (1972a) Early Palaeozoic microplankton from the Kurnools, Andhra Pradesh. J Palynol 8:123–131

Salujha SK, Rehman K, Arora CM (1972b) Microplanktons from the Bhimas. J Paleontol Soc India 15:10–16

Schirrmeister BE, de Vos JM, Antonelli A et al (2013) Evolution of multicellularity coincided with increased diversification of cyanobacteria and the great oxidation event. Proc Natl Acad Sci 110:1791–1796

Schopf JW, Prasad KN (1978) Microfossils in *Collenia*-like stromatolites from the Proterozoic Vempalle Formation of the Cuddapah Basin, India. Precambr Res 6(3–4):347–366

Sergeev VN, Sharma M, Shukla Y (2008) Mesoproterozoic silicified microbiotas of Russia and India characteristics and contrasts. Palaeobotanist 57:323–358

Sergeev VN, Sharma M, Shukla Y (2012) Proterozoic fossil cyanobacteria. Palaeobotanist 61:189–358

Sharma M (2006) Small-sized akinetes from the Mesoproterozoic Salkhan Limestone, SemriGroup, Bihar, India. J Palaeontol Soc India 51:109–118

Sharma M (2008) Neoproterozoic biotic signatures in the peninsular Indian basins—an overview. Mem Geol Soc India 74:119–131

Sharma M, Mishra S, Dutta S et al (2009) On the affinity of *Chuaria-Tawuia* Complex; a multidisciplinary study. Precambr Res 173:123–136

Sharma, M Shulka Y (2009) Mesoproterozoic coiled megascopic fossil Grypania spiralis from the Rohtas Formation, Semri Group, Bihar, India. Curr Sci 96(12):1636–1639

Sharma M, Shukla Y (2012a) Occurrence of helically coiled microfossil *Obruchevella* in the Owk shale of the Kurnool Group and its significance. J Earth Syst Sci 121(3):755–768

Sharma M, Shukla Y (2012b) Megascopic carbonaceous compression fossils from the Neoproterozoic Bhima Basin, Karnataka, South India. Geol Soc London 360:277–293

Sharma M, Shukla Y (2016) The palaeobiological remains of the Owk Shale, Kurnool Basin: a discussion on the age of the basin. J Palaeontol Soc India 61(2):175–187

Sharma M, Tiwari M, Ahmad S et al (2016) Palaeobiology of Indian Proterozoic and early Cambrian successions- recent developments. Proc Indian Natl Sci Acad 82:559–579

Sharma M, Shukla B (2019a) Akinetes from Late Palaeoproterozoic Salkhan Limestone (ca.1600 Ma) of India: a proxy for understanding life in extreme conditions. Front Microbiol 10(397)

Sharma M, Singh VK (2019b) Megascopic carbonaceous remains from Proterozoic basins of India. In: Mondal M (ed) Geological evolution of the Precambrian Indian Shield. Society of Earth Scientists Series, Springer, pp 725–749

Sharma M. Pande SK, Kumar S (2020) Vindhyan Basin, Son Valley area, Central India (Field Guide). In: 36th International Geological Congress, New Delhi. pp 1–176

Sharma M, Singh VK, Pandey SK et al (2021) Precambrian and early Cambrian paleobiology of India: *Quo Vadis*, vol 87. In: Proceedings of the Indian National Science Academy., New Delhi, pp 199–233. https://doi.org/10.1007/s43538-021-00029-2
Shukla Y (2011) Palaeobiology of terminal Proterozoic Bhima Basin, Karnataka: University of Lucknow, India. Unpublished thesis
Shukla R, Tiwari M (2014) Ediacaran acanthomorphic acritarchs from the Outer Krol Belt, Lesser Himalaya, India: Their significance for global correlation. Palaeoworld 23:209–224
Shukla B, Sharma M (2016) A new assemblage of large-sized microfossils from the Salkhan Limestone (ca 1600 Ma), Semri Group, Vindhyan Supergroup, India. J Palaeontol Soc India 61:287–299
Shukla Y, Sharma M (2020a) 'Egg-carton' shaped plausible organo-sedimentary structures from the Archaean Dharwar Craton. India Int J Earth Sci 109(3):931–932
Shukla Y, Sharma M (2020b) Ediacaran discs from the Bhima Group, Karnataka, South India. J Geol Soc India 95:483–490
Shukla,Y, Sharma M, Sergeev VN (2020a) Organic walled microfossils from the Neoproterozoic Owk Shale, Kurnool Group, South India. Palaeoworld 29:490–511
Shukla Y, Sharma M, Noffke N, Callefo F (2020b) Biofilm microfacies in phosphatic units of the Neoproterozoic Halkal Shale, Bhima Basin, South India. Precambrian Res 349:105501
Singh IB, Rai V (1983) Fauna and biogenic structures in Krol-Tal succession (Vendian–Early Cambrian), Lesser Himalaya: their biostratigraphic and palaeontological significance. J Palaeontol Soc India 28:69–80
Singh VK, Babu R, Shukla M (2011) Heterolithic prokaryotes from the coated grains bearing carbonate facies of Bhander Group, Madhya Pradesh, India. J Appl Biosci 37:80–90
Singh VK, Sharma M (2014) Morphologically complex organic-walled microfossils (OWM) from the Late Palaeoproterozoic-Early Mesoproterozoic Chitrakut Formation, Vindhyan Supergroup, Central India and their implications on the antiquity of eukaryotes. J Palaeontol Soc India 59:89–102
Singh VK, Sharma M (2016) Mesoproterozoic organic-walled microfossils from the Chaporadih-Formation, Chandarpur Group, Chhattisgarh Supergroup, Odisha, India. J Palaeontol Soc India 61:75–84
Singh BP, Virmani N, Bhargava ON et al (2016) Trilobite fauna of basal Cambrian Series 3 (Stage 5) from the Parahio Valley (Spiti), Northwest Himalaya, India and its biostratigraphic significance. Ann Paléontol 102(1):59–67
Singh BP, Bhargava ON, Mikul R et al (2019a) Integrated sedimentological, ichnological and sequence stratigraphical studies of the Koti Dhaman Formation (Tal Group), Nigali Dhar Syncline, Lesser Himalaya, India: paleoenvironmental, paleoecological, paleogeographic significance. Ichnos 27(2):1–34
Singh VK, Sharma M (2019) Morphologically complex organic-walled microfossils (OWM) from the Late Palaeoproterozoic-Early Mesoproterozoic Chitrakut Formation, Vindhyan Supergroup, Central India and their implications on the antiquity of eukaryotes. J Palaeontol Soc India 59:89–102
Singh VK, Sharma M, Sergeev VN (2019a) Helically coiled cyanobacterial microfossil *Obruchevella* from the Saradih Limestone, Raipur Group, Chhattisgarh Supergroup, India. J Palaeontol Soc India 64:304–313
Singh VK, Sharma M, Sergeev VN (2019b) A new record of acanthomorphic acritarch *Tappania* Yin from the early mesoproterozoic Saraipali Formation, Singhora Group, Chhattisgarh Supergroup, India and its biostratigraphic significance. J Geol Soc India 94(5):471–479
Tang Q, Hughes NC, McKenzie NR et al (2017) Late Mesoproterozoic–early Neoproterozoic organic-walled microfossils from the Madhubani Group of the Ganga Valley, northern India. Palaeontology 60(6):869–891
Tiwari M, Knoll AH (1994) Large acanthomorphic acritarchs from the Infra Krol Formation of the Lesser Himalaya and their stratigraphic significance. Him Geol 5:193–201

Tiwari M (1996) Precambrian Cambrian boundary microbiota from the Chert Phosphorite Member of Tal Formation in the Korgai Syncline, Lesser Himalaya, India. Curr Sci 71:559–566
Tiwari M, Pant C (2004) Neoproterozoic silicified microfossils in Infra Krol Formation, Lesser Himalaya India. Him Geol 25:1–21
van Loon AJ, Mazumder R (2013) First find of biogenic activity in the Palaeoproterozoic of the Singhbhum craton (E India). Geologos 19(3):185–192
Venkatachala BS, Sharma M, Shukla M (1996) Age and life of the Vindhyans—facts and conjectures. Mem Geol Soc India 36:137–165
Vijayam BE (1968) Worm burrows in Narji Limestone, near Govindinne, Kurnool district, Andhra Pradesh. Curr Sci 37(5):142
Woese Carl R, Kandler O, Wheelis M (1990) Towards a natural system of organisms: proposal for the domains Archaea, Bacteria, and Eucarya. In: Proc Natl Acad Sci USA 87(12):4576–4579
Yin L (1997) Acanthomorphic acritarchs from Middle-Upper Proterozoic shales of the Ruyang Group in Shanxing, China. Rev Paleobotany Palynol 98:15–25

Significance of Palynology in Understanding Age, Palaeoclimate and Correlation of Indian Gondwana Sediments

Mrutyunjaya Sahoo, Srikanta Murthy, Anju Saxena, Sankar Suresh Kumar Pillai, and Sumit Kumar Sahu

Abstract The Gondwana sedimentary deposits are spread across the Indian Peninsula. The Gondwana sequences in Peninsular India are mostly non-marine. Based on morphological features of palynoflora and megaflora, palynomorphs from different biostratigraphic sediments (Talchir to Supra Panchet) of Gondwana show a high degree of variation. Based on the microstructures of exine among spores, the primitive and younger states of the sediments are confirmed with time. The morphological characteristics of pollen spores help in their evolutionary sequence through different time scales, hence playing a vital role in biohorizon stratigraphy. Apart from this, palynomorphs also help in delineating the biostratigraphic age, First Appearance Datum (FAD), LAD (Last Appearance Datum), DOD (Dominance of Datum), assemblage zones, and palaeoclimate. The current paper provides an overview of the role of palynology in determining the biostratigraphic ages, palaeoclimatic conditions, and correlation of Indian Gondwana sediments. The data presented here is the basic framework for further refinement of chronology based on palynology. It is a compilation of published data from peninsular India.

Keywords Palynology · Indian Gondwana · Correlation · Palynostratigraphy · Palaeoclimate

M. Sahoo
Department of Geology, Ravenshaw University, Cuttack 753003, Odisha, India

S. Murthy · A. Saxena · S. S. K. Pillai (✉) · S. K. Sahu
Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow 226007, India
e-mail: sureshk_pillai@bsip.res.in

S. S. K. Pillai · S. K. Sahu
Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India

B. Samant and D. Thakre (eds.), *Applications of Palynology in Stratigraphy and Climate Studies*, Society of Earth Scientists Series, https://doi.org/10.1007/978-3-031-51877-5_2

1 Introduction

The sedimentary rock strata ranging in age from the Permo-Carboniferous to the Early Cretaceous (Asselian to Albian; 299 to 100 Ma), found in patches in different parts of India, South Africa, South America, Madagascar, Australia, and Antarctica, are referred to as Gondwana. These landmasses were joined together in the geological past, constituting the supercontinent called Gondwanaland. Some characteristic features are the presence of coal, fossilized remains of land plants, and vertebrates. The social importance of the Gondwana Supergroup is conferred by the fact that more than 99% of the total coal resource of the Indian subcontinent is hosted in the Gondwana basins. The palaeontological and stratigraphical studies of the Indian Gondwana have revealed that the accumulation of sediments occurred in several discrete inter-cratonic basins in the peninsula. The major Gondwana basins in India are in the peninsular region (Fig. 1) and are dispersed along modern-day river valleys, viz., the Godavari, Son-Mahanadi, Narmada, and Pranihta-Godavari. The Indian Gondwana basins are usually named after these rivers. The Gondwana sediments show distinct characteristics as most of its land area occupied high latitudes in the southern hemisphere (Gondwanaland), providing a unique environment (Veevers 1993; Tiwari and Kumar 2002). Under the influence of Gondwana's climate, ecology, land-sea distribution, and geotectonics, the typical flora and fauna of the Gondwana region maintained their identities during the Permo-Carboniferous to Early Cretaceous (mainly in the Permian). The palaeogeographic configuration mentioned above is supported by the strong association between the floras of Gondwanaland during the Permian (the *Glossopteris* floral province) and most of the Mesozoic.

Palaeontology plays the most important role in understanding the then geological events of the past, and among the studies of palaeontology, palynology is a high-precision tool for the process. The term was proposed by Hyde and Williams (1944). Palynology studies acid resistant organic microfossils (5–500 μm in diameter) such as spores, pollen, dinoflagellate cysts, microscopic algae, megaspores, etc. Throughout much of geologic time, these microscopic plant particles have accumulated in sediments without losing their morphological characteristics. Their recovery from residues enables the palynologist to establish a correlation based on time equivalence. The palynologist analyses the particulate samples collected from the air, from water, or deposits, including sediments of any age. The condition and identification of those particles, organic and inorganic, give the palynologist clues to the life, environment, and energetic conditions that produced them. Flora and fauna during the Permian and Mesozoic were influenced by different climates, ecology, and land-sea distribution, but they maintained their identities (Tiwari and Vijaya 1995). Hence, it is an essential tool for studying different geological and biological events.

Palynology serves as an essential tool, since it has been used worldwide for dating, correlation, palaeovegetational, and palaeoclimatic interpretation of the Gondwana sediments (Tiwari and Tripathi 1992; McLoughlin 2001; Backhouse et al. 2002; Souza and Marques-Toigo 2005; Jha 2006; Quattrocchio et al. 2006; Shi et al. 2010; Tripathi et al. 2012; Jha et al. 2012; Jha et al. 2014; Souza et al. 2015; Sahoo

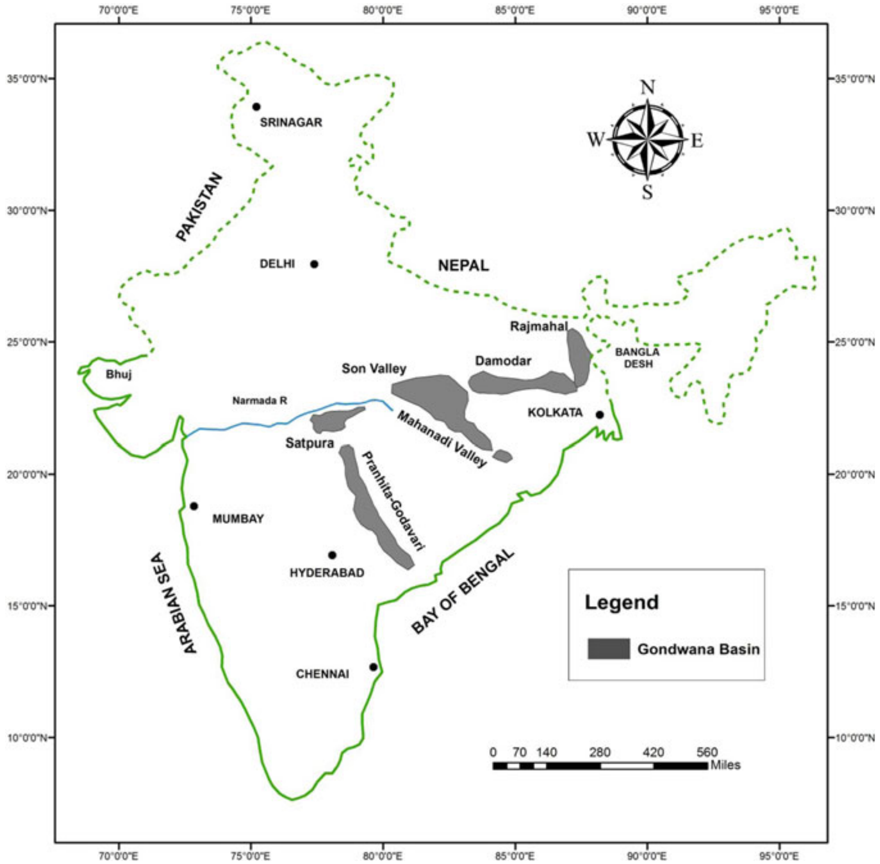

Fig. 1 Gondwana basins of peninsular India

et al. 2020a, b). The sediments and the biota in Eastern Gondwana were similar as the continents were together during the Permian and until the Lower Cretaceous (Aptian-Albian). As the landmasses were together (the last phase of Gondwanaland), uniformity prevailed in Australia and Antarctica until the Early Cenozoic.

There is always a debate between geologists and palaeontologists concerning the age of sediments. But the bioentities (megaflora or palynoflora) are imperative for determining the age of the deposits. The biological entities of the Permian are essential tools for correlating their relationships throughout the continents of Gondwanaland. It helps in delineating the relationship between the regions and calibrating the chronostratigraphy. Palaeontologists are considering the palynological tool for filling the geological gaps and prevailing problems based on the chronology of the Indian Gondwana sequences (Tiwari and Tripathi 1992 and references therein).

The palynological study of the Indian Gondwana sequence dates back to the nineteen-thirties. Since then, data on the morpho-taxonomy and palyno-stratigraphy