A DEVELOPMENT AND ENVIRONMENT FORTNIGHTLY

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GEOGRAPHY and YOU

GY



INDIA'S SPECTACULAR GEOHERITAGE SITES

- LADAKH: THE INDIA-EURASIA COLLISION REGION
- ERRA MATTI DIBBALU: COASTAL RED SAND DUNES OF VISAKHAPATNAM
- THE CLIFFS OF VARKALA
- LONAR: THE IMPACT CRATER
- ZAWAR: WORLD'S OLDEST ZINC MINING AND METALLURGY SITE

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A DEVELOPMENT AND
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PHOTO COURTESY: HEERA RAMESH

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Rasik Ravindra
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Sachidanand Sinha
Professor, CSRD, Jawaharlal Nehru University, New Delhi.


B Meenakumari
Former Chairperson, National Biodiversity Authority, Chennai.


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RESEARCH BY LIGHTS

COVER PHOTO
A 10 M GRANITE BOULDER AT YADGIRI, KARNATAKA.
COURTESY GAJANAN HEGDE

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Vol. 19, Issue 24 No. 135 ■ 2019: Timely and accurate data has always been the hallmark of G'nY. I read the last issue titled 'Food Imperatives' (Vol 19 Issue 24 No. 135) and every point was unbiased and clearly presented for independent interpretation by the reader. I particularly liked the article 'Climate Change Impacts on Nutrition In The Indian Context'. It wonderfully connected the dots between two seemingly unrelated fields.- ABHINAV KR YADAV—*via customer feedback.*

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THE ARTICLE ON 'Sustainability and Living Marine Resources' available online was a thorough and informed account of our aquatic resources. I believe the oceans, seas and coastal areas are critical components of our earth's ecosystem. I liked how the author, Dr V Sampath, lucidly wrote about the issue. Treatise about space expeditions and stories about northeast India interest me.—RASHI GOGIA, GURGAON, HARYANA *via customer feedback.*

THE SPECIAL ISSUE on 'Development Driven Disasters' (Vol 18, Issue 6 No. 117) and 'Landforms in India' (Vol 19, Issue 17 No. 128) was well documented. The articles are well structured and the contents are highly reliable, backed by solid academic research. G'nY magazine covers almost all current and pressing issues that are hard to find anywhere else.—RITAJ DOGRA, SHIMLA, HIMACHAL PRADESH *via customer feedback*

I THOROUGHLY ENJOY READING articles in G'nY. I find the magazine to be the best for geographical studies. Pictographic data and figures make it easier to absorb the facts. I would request to include articles related to geographical hurdles of hilly areas in India like Himachal Pradesh, Uttarakhand and more. Specifically the adverse effects on soil erosion and water mismanagement afflicting these areas is my area of interest.—Arnav Aggarwal, Dharamshala, Himachal Pradesh *via customer feedback*

THE G'NY MAGAZINE covers diverse thematic topics related to recent trends and issues. I have been a regular reader and the content of the magazine is concise and easy to read. However, I find few articles dedicated to economic aspects and would request more coverage on the current slowdown of the Indian economy.—ARUN SHARMA, SHIMLA, HIMACHAL PRADESH *via customer feedback.*

MY EXPERIENCE WITH G'nY has been excellent and I have been a devoted subscriber for the last three years. The journo-mag has been consistently delivering high quality content over the years. There is no doubt that G'nY is the best journo-mag out there as it covers all issues ranging from social sciences, Indian economy to disaster management and sustainable development. I especially liked the issue on 'India's Agri Policy Challenges', (Vol 18, Issue 11 No. 122) as it covers many important aspects and policies related to the oft neglected sector. —PRIYANSHU, PURANDAHA, HARYANA *via customer feedback.*

I REALLY LIKE THE CONTEMPORARY issues of the G'nY like the Water Ownership issue(Vol 18, Issue 2 No. 113). The magazine content is culturally diverse, the text is bright, easy to read, and the issues are substantiated. I like how readers' letters are honestly and generously featured in every issue which often raise important issues. I would want to read an issue on the Linguistic Survey of India.—ROHIT CHATE *via customer feedback.*

WRITE Editorial Office: IPP Ltd, 501, Bhikaji Cama Bhawan, R K Puram, New Delhi - 110066. Letters may be edited for clarity and length. Include name, address and telephone. **PHONE** 011-46014233, 26186350 **EMAIL** editor@geographyandyou.com
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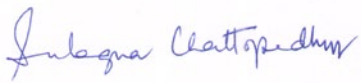
Editor's note

Sulagna Chattopadhyay
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Conserving clues to an ever changing world

During my college days we toured extensively—egged on by an inspired faculty who believed that learning resided in the outdoors. I remember the dark shafts and the stifling stillness of the Ghatshila copper mines' innards (East Singhbhum, Jharkhand); the brightly lit humongous tunnels with freshwater pooling on the floor below the massive Himalayan gneissic mountain at Rammam hydel station (Darjeeling, West Bengal); the blistering sunshine and the red desert rocks at the Akal Fossil Park in Jaisalmer (Rajasthan)—memories that have shaped my learning. My appreciation for man's unrelenting handiwork, of wringing out the proverbial 'cheese from rocks' grew by leaps and bounds. Yet I worried—was there a line between what we can do and what cannot be undone? Of course the development narrative for a nation like ours is pitched to a cacophony with multi-patriate interests looking to better lives. Amongst these however, are the soft fluted tones of a few visionaries who guide humankind to conserve that which can no longer be recreated—as it holds invaluable clues to the turmoils of our ever changing future. Dedicated to geoheritage this issue of G'nY urges all conservationists to stand together to show the world the treasures that India harbours within its verdant folds. Happy Reading.





Guest Editor's note

Satish C Tripathi
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General Secretary, The Society of Earth Scientists
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Geoheritage – A Window to the Past

The breaking away of the Gondwanaland about 180 million years ago (mya) resulted in the separation and isolation of the dynamic Indian subcontinental landmass. As Madagascar split away ~85-90 mya (Late-Cretaceous) India took a northward flight right across the equator, ultimately colliding with Eurasia to birth the magnificent Himalaya. India in fact continues to move northward at a rate of 1.5 cm per year. The myriad features fashioned out of bare rocks during India's long odyssey have fuelled the imagination of humans for centuries, driven as it were by changing climate, catastrophes and erosional agencies.

India therefore is abundant in geological diversity—yet the sense of heritage that these magnificent creations instill, is bereft of a spotlight. Our ancestors were aware of this richness, according cultural and spiritual values to geosites such as hot springs, hills and more. In fact the remnants of ancient mining and metallurgy dating back to ~2500 years indicate a great knowledge of geological processes. As early as 1970s, several geosites were declared 'National Geological Monuments' by the Geological Survey of India, much ahead of the world—marking an underlying understanding of geosite conservation. However, developing them in to a geopark could not be prioritised. As a result, geotourism never gained momentum.

Geosites have an immense potential in educating the masses about earth processes, signatures of past climatic changes and catastrophic events, evolution of life and role of palaeovegetation in making our planet livable. It can help understand sustainable environmental management within a developmental framework. Integrated with India's cultural ecosystems geosites would help reconnect with the dynamic past.

Despite several geosites being conserved—caves, hot springs, rock gardens, etc., its geoscientific component is either absent, negligible or misleading. It would be a good starting point to address these sites in priority. Geo-conservation is not only important for tourism, it is imperative for safeguarding future research activities that will service generations. The current challenge is to interpret geoheritage meaningfully in order to cater to dedicated geotourists as well as casual visitors. Geoheritage literature is meager with few and far between popular geoscientific literature, films, interactive shows, geo-guides and the like. Geoscientists therefore need to don an additional mantle of lucid writing and speaking in a language that all understand.

The Society of Earth Scientists (SES) is dedicatedly working on geoheritage conservation and global geoparks. It is also developing a suitable legislation towards it. The special 'India's spectacular geoheritage sites' issue of G'nY is therefore an attempt to build an enabling environment for future interventions.



By **Manjit Kumar Mazumdar** & **Bidisha Bayan**

CONSERVING INDIAN GEOHERITAGE: THE GEOPARK APPROACH

Through a balanced blend of science, culture, education and tourism, geopark networks across the world are successfully improving the socio-economic condition of communities, thereby contributing to sustainable development of the region. India, with numerous geosites of significance, needs to learn from experiences world over and take a leap of faith to build its first global geopark.

PHOTO: PRASAD



Marble rocks, Jabalpur is a scenic geoheritage site situated in the Indian state of Madhya Pradesh. The river Narmada has carved its way through the soft marble rocks to create a wide gorge. It is an archive of geographical changes which took millions of years to form and is a worthy spot to be on the UNESCO world geoheritage list.

The author are Associate Professor, Department of Geology, Pragjyotish College, Guwahati, Assam, janmoni2@rediffmail.com. *The article should be cited as Mazumdar M. K. & B. Bayan, 2019. Conserving Indian Geoheritage: The Geopark Approach, Geography and You, 19(25 & 26): 6-15*

Geological sites record important geological phenomena that help trace the evolutionary history of earth. These sites serve as the doorway to the planet's 4600 million year history and provide essential information about the earth's evolutionary changes and processes. Geoparks are however not only territories consisting of important geological and geomorphological sites, it often bears great archaeological, ecological and cultural significance. The conservation of the earth's geodiversity through the multi-pronged geopark initiative therefore has the potential to contribute to the sustainable development objectives of Agenda 21 adopted by the United Nations in the Conference on Environment and Development (UNCED) in 1992 and reconfirmed in the World Summit on Sustainable Development (WSSD) in 2002.

The first global protected sites came into being as National Parks in 1872, followed by accreditations such as Regional Parks (1968), Biosphere Reserves (1976), World Heritage Properties (1978), Leader Territories (1991), Cultural Parks (1997) and finally Geoparks (2000) (Xun and Ting 2003; Martini and Zouros 2008; Martini 2009). However, in 1985, several years before the Digne symposium 1991 (https://bit.ly/2qMXa8T) that mandated protection of geoheritage sites, Chinese geologists had already proposed the establishment of geoparks in territories with marked geological landscapes in an effort to boost geoscientific surveys and provide a fillip to conservation.

In 2000, geological organisations from four European nations—France, Greece, Germany and Spain—came together to discuss their common problems. The recommendations that emerged prioritised the protection of geological heritage and a structured promotion of geological tourism resulting in the creation of the European Geoparks Network (EGN) (McKeever and Zouros 2005). A few years later in 2004, representatives from the scientific board of the International Geoscience Correlation Programme (IGCP), International Geographical Union (IGU) and the International Union of Geological Sciences (IUGS), along with international experts met in Paris under the aegis of the United Nations Education, Scientific and Cultural Organisation (UNESCO). They unequivocally declared the establishment of a global network of geoparks under the auspices of UNESCO, which subsequently came to be known as the UNESCO Global Geoparks Network (Table 1). In later years, geoparks gradually evolved in America, in Africa and in the Arabian nations.

Geoparks as a Sustainable Development Model

Geoparks have proved to be successful models in showcasing geoheritage localities and promoting geotourism through a wide array of tourist activities, thereby contributing immensely to the regional economy and welfare of the people living within and near vicinity of the geoparks. Geoconservation of various geoheritage sites is ensured through both





PHOTO COURTESY: AUTHOR

outdoor and indoor modes.

Internationally, all geoparks are sustained through a geotourism mode that promotes activities and geo-events like academic meets, nature trails, excursions, cycling tours, exhibitions, concerts, photographic contests, hiking, horse-riding, kayaking, guided geo-tours, cultural events and more for sustenance of the sites. Geoparks also have good infrastructural provisions like geo-activity centres for the youth, geo-museums, hotels, cafes, geo-shops, geo-routes, geopark rangers, etc. and operate through the active involvement of local communities. The geo-shops promote various local products and a wide range of souvenirs etc. Adequate signage and interpretation panels are put up along various geo-routes for facilitating tourists.

An example of how geoparks can act as an instrument of change can be cited from the Mount Yuntaishan National Geopark in China. This geopark covering an approximate area of 240 square km, has a complex topography and terrain and a large area of virgin forests which is home to about 500 species of exotic flowers and rare herbs. Due to the picturesque landscape, the geopark has earned the reputation of being a 'Long Art Gallery'. In 2001, when this geopark was established in China's Henan province, there were 380,000 visitors earning a revenue of around 6 million yuans. In two years, the number of visitors soared to 950,000, generating revenue of 48 million yuans (Xun and Ting, 2003). A survey carried out in TERRA vita Geopark of Germany showed that during the main tourist season in 2007 (1 April–31 October) approximately 12.3 million Euro gross revenue was generated (Hartling and Meier 2010). These instances exemplify the quantum of impact that geoparks can have on the regional economy.

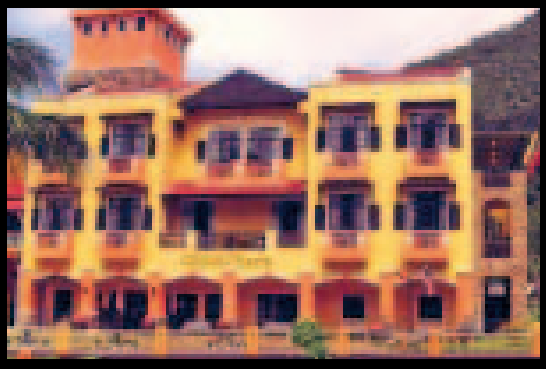
There are various geoparks in a number of countries which are assisted through governmental and non-governmental agencies that contribute actively towards global geoheritage conservation and promotion (Table 2).

UNESCO Global Geoparks

Currently, there are 147 UNESCO Global Geoparks in 41 countries (Fig. 1). While China tops the list with 39 UNESCO geoparks, India is yet to commence the building of its first geopark. Interestingly, geoparks in many European and Asian countries are affiliated to regional networks—European Geoparks Network (EGN), Asia-Pacific Geoparks Network (APGN), etc. Continued deliberations spanning the period 1999-2000 of the EGN resulted in the building of regional operational guidelines. The APGN was established under Article 18 of the Global Geoparks Network (GGN) Statutes with the

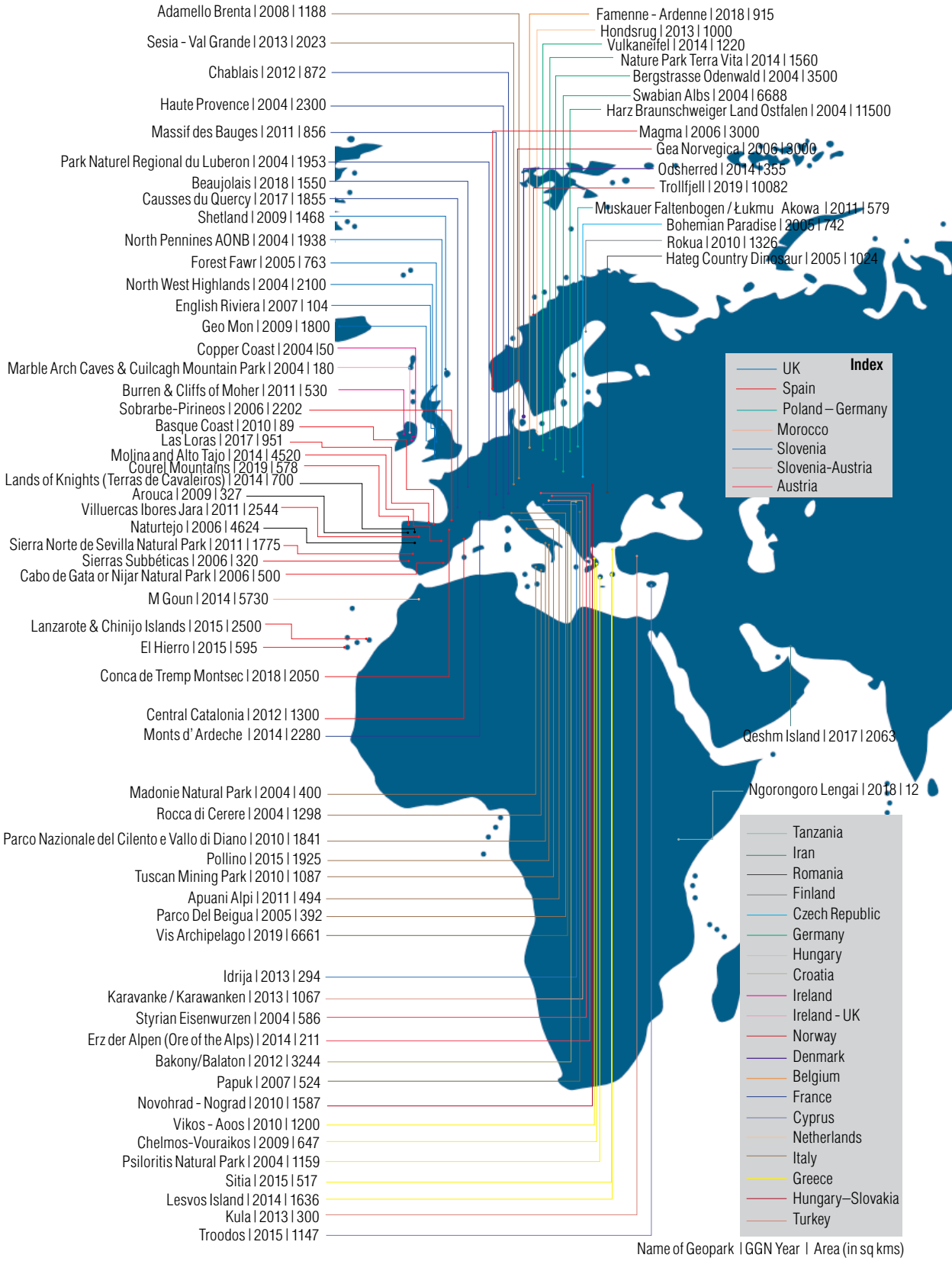
Left to Right: Idrija is a UNESCO Global Geopark situated in the western part of Slovenia in Europe. It is located at the intersection of the Dinarides and Alps and is marked by exceptionally deep gorges; Lochaber Geopark, UK encompasses an area of 4,468 sq km. This geoheritage monument is a fine example of how such sites can be promoted and conserved and how authorities can provide a fillip to responsible tourism; Geoshop in Magma Geopark, Norway promotes local products. The rocks in this park are unique, formed as they are from molten magma about 930 mya; The Langkawi Geopark, Malaysia has the best-exposed and most complete Palaeozoic sedimentary sequence in Malaysia.





Global Geopark Network (GGN) & UNESCO Geoparks




Adamello Brenta | 2008 | 1188
Sesia - Val Grande | 2013 | 2023
Chablais | 2012 | 872
Haute Provence | 2004 | 2300
Massif des Bauges | 2011 | 856
Park Naturel Regional du Luberon | 2004 | 1953
Beaujolais | 2018 | 1550
Causses du Quercy | 2017 | 1855
Shetland | 2009 | 1468
North Pennines AONB | 2004 | 1938
Forest Fawr | 2005 | 763
North West Highlands | 2004 | 2100
English Riviera | 2007 | 104
Geo Mon | 2009 | 1800
Copper Coast | 2004 |50
Marble Arch Caves & Cuilcagh Mountain Park | 2004 | 180
Burren & Cliffs of Moher | 2011 | 530
Sobrarbe-Pirineos | 2006 | 2202
Basque Coast | 2010 | 89
Las Loras | 2017 | 951
Molina and Alto Tajo | 2014 | 4520
Courel Mountains | 2019 | 578
Lands of Knights (Terras de Cavaleiros) | 2014 | 700
Arouca | 2009 | 327
Villuercas Ibores Jara | 2011 | 2544
Naturtejo | 2006 | 4624
Sierra Norte de Sevilla Natural Park | 2011 | 1775
Sierras Subbéticas | 2006 | 320
Cabo de Gata or Nijar Natural Park | 2006 | 500
M Goun | 2014 | 5730
Lanzarote & Chinijo Islands | 2015 | 2500
El Hierro | 2015 | 595
Conca de Tremp Montsec | 2018 | 2050
Central Catalonia | 2012 | 1300
Monts d' Ardeche | 2014 | 2280
Madonie Natural Park | 2004 | 400
Rocca di Cerere | 2004 | 1298
Parco Nazionale del Cilento e Vallo di Diano | 2010 | 1841
Pollino | 2015 | 1925
Tuscan Mining Park | 2010 | 1087
Apuani Alpi | 2011 | 494
Parco Del Beigua | 2005 | 392
Vis Archipelago | 2019 | 6661
Idrija | 2013 | 294
Karavanke / Karawanken | 2013 | 1067
Styrian Eisenwurzen | 2004 | 586
Erz der Alpen (Ore of the Alps) | 2014 | 211
Bakony/Balaton | 2012 | 3244
Papuk | 2007 | 524
Novohrad - Nograd | 2010 | 1587
Vikos - Aoos | 2010 | 1200
Chelmos-Vouraikos | 2009 | 647
Psiloritis Natural Park | 2004 | 1159
Sitia | 2015 | 517
Lesvos Island | 2014 | 1636
Kula | 2013 | 300
Troodos | 2015 | 1147
Famenne - Ardenne | 2018 | 915
Hondsrug | 2013 | 1000
Vulkaneifel | 2014 | 1220
Nature Park Terra Vita | 2014 | 1560
Bergstrasse Odenwald | 2004 | 3500
Swabian Albs | 2004 | 6688
Harz Braunschweiger Land Ostfalen | 2004 | 11500
Magma | 2006 | 3000
Gea Norvegica | 2006 | 3000
Odsherred | 2014 | 355
Trollfjell | 2019 | 10082
Muskauer Faltenbogen / Łukmu Akowa | 2011 | 579
Bohemian Paradise | 2005 | 742
Rokua | 2010 | 1326
Hateg Country Dinosaur | 2005 | 1024
Qeshm Island | 2017 | 2063
Ngorongoro Lengai | 2018 | 12
Index
UK
Spain
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Slovenia
Slovenia-Austria
Austria
Tanzania
Iran
Romania
Finland
Czech Republic
Germany
Hungary
Croatia
Ireland
Ireland - UK
Norway
Denmark
Belgium
France
Cyprus
Netherlands
Italy
Greece
Hungary–Slovakia
Turkey
Name of Geopark | GGN Year | Area (in sq kms)

Global Geopark Network (GGN) & UNESCO Geopark

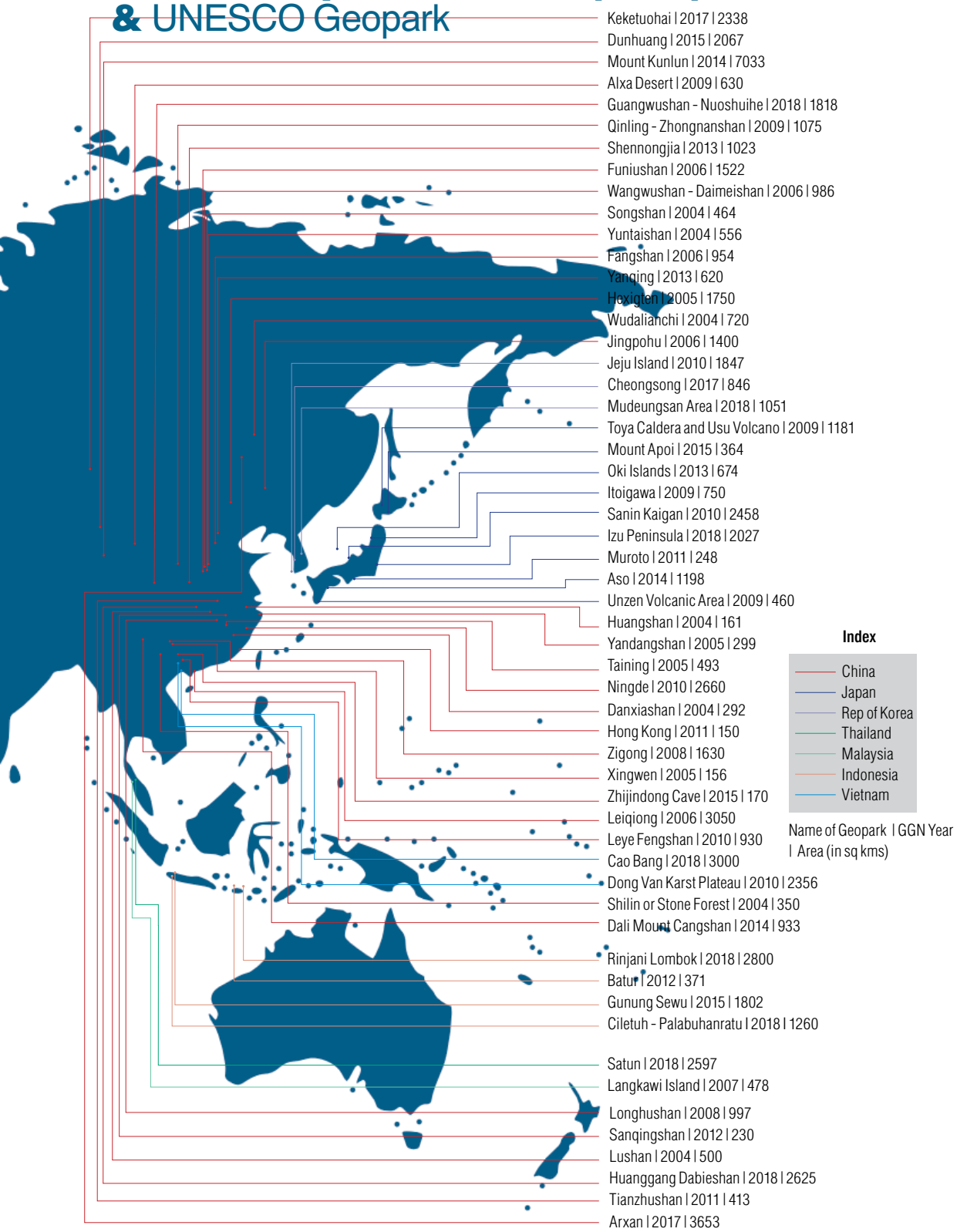


PHOTO COURTESY: AUTHOR



Natural coral bridge at Niel Island is popularly known as the 'Howrah Natural Bridge' after its historic counterpart in Kolkata, not to mention the influence of the large Bengali population in the island. It is a major draw for tourists visiting the Andaman Islands.

objective of providing a networking platform between stakeholders of established geoparks, geosites (for those without a geopark) and geoheritage sites with a view to facilitate the process of establishment of future geoparks.

Geopark Prospects in India

The Indian peninsula has a wide range of valuable geological imprints. The Geological Survey of India (GSI), as specifically stated in its Charter, is mandated to "advance the cause of geoscience by…creation and management of museums, monuments and parks…". In all 34 geosites have been declared as National Geological Monuments by GSI in 13 Indian States (Table 3). These are classified as Fossil Parks, Rock Monuments, Geological Marvels and Other Monuments based on stratigraphic and economic significance. However, this classification and nomenclature is not based on any systematic inventorisation and hence is an indicative list only. Also, there exists several other geoheritage sites all across the country that could aptly be brought within the ambit of a prospective geopark framework. However, as no geopark is functional in the country there are no assigned ministry/ government department that can fund and support its development.

Geoheritage Legislation

Strict geoconservation laws supplemented with mass awareness and protection measures have helped governments in numerous countries to conserve important geoheritage sites. In India, however there are no legislative provisions for geoheritage conservation. In 2009, there was an attempt to introduce the National Commission for Heritage Sites Bill, 2009 in the Rajya Sabha, but later in 2015, the government decided to withdraw it. Two more attempts were made in 2011 and 2013 to draft laws—Geological Locations, Features and Objects Preservation Act, 2011 and The National Geological Sites (Conservation, Protection and Maintenance) Act, 2013, but there has been no interest from the government to evaluate these. In a recent



Borra caves are located in the Ananthagiri hills of Vishakhapatnam. It is one of the largest and deepest caves in India and the Gosthani river originates here.

PHOTO COURTESY: AUTHOR

Table 2: Agencies in charge of geoheritage conservation

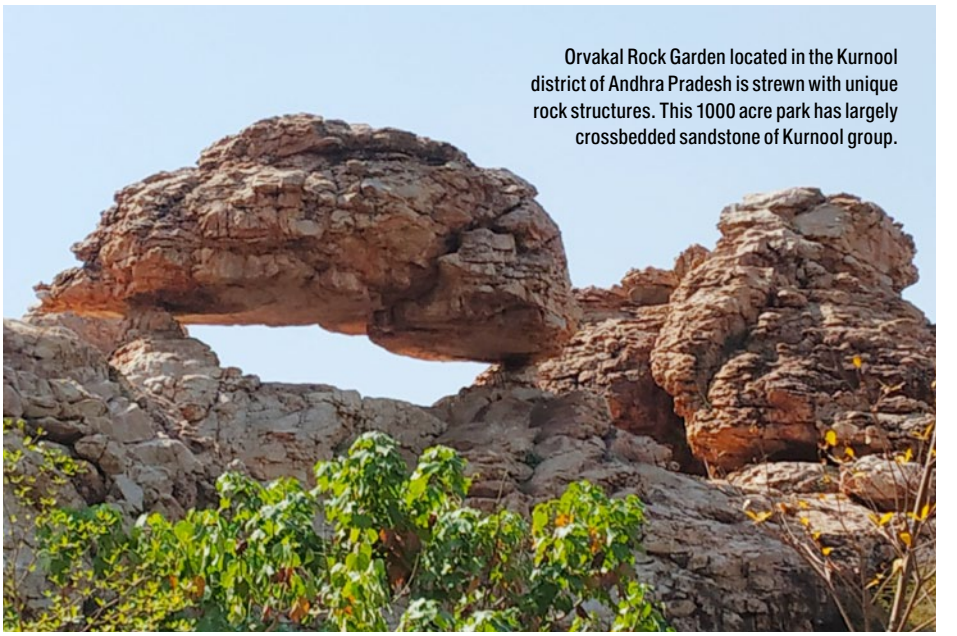
Name of agency/ body in charge of geoheritage conservation	Country
Ministry of Land and Resources	China
Ministry of Environment	Czech Republic, Iceland, Korea
Ministry of Economy, Trade and Industry	Japan
Australian Capital Territory Heritage Council	Australia
Canadian National Committee for Geoparks	Canada
Czech Environmental Inspection Agency	Czech Republic
Egyptian Environmental Affairs Agency	Egypt
The Heritage Council	Ireland
Italian National Geoparks Forum	Italy
Central Environmental Council	Japan
Directorate for Nature Management	Norway
Department of Environment and Natural Resources	Philippines
Central Environmental Protection Authority	Romania
South African Heritage Resources Agency	South Africa
ProGEO-The European Association for the Conservation of the Geological Heritage	United Kingdom
Conservation and Geotourism Committee of Geological Society of South Africa	South Africa
Commission of Geological Heritage of Geological Society	Spain
Geoconservation Commission of the Geological Society of London	United Kingdom
Commission on Geoheritage of International Geographical Union	South Africa
Joint Nature Conservation Commission	United Kingdom
Natural England	United Kingdom

development, a more elaborate and updated version of a draft geoheritage conservation legislation—the Geoheritage (Conservation and Promotion) Bill, 2019 was discussed in a brain-storming session held at the Indian National Science Academy (INSA) headquarters, initiated by the Society of Earth Scientists (SES), Indian National Committee for The International Union of Geological Sciences (IUGS)-International Union For Quaternary Research (INQUA) and INSA (SES-INSA Report 2019). This draft is scheduled to be submitted to policy makers for necessary consideration.

Challenges and Threats

The geological diversity of India is an asset that has been formed over millions of years. It preserves the natural history of the nation within it and thus mandates conservation. At a time when India's rich cultural heritage is finding legislative protection—the country's geological heritage is not being accorded due attention. The varied fossil sites are being vandalised—fossils carelessly extracted are sold to visitors for paltry sums. Many important geological sections of global significance are being sacrificed under the garb of developmental needs. The wood fossils of the dinosaurian period in the Bagh area of Dhar district in Madhya Pradesh were destroyed





Orvakal Rock Garden located in the Kurnool district of Andhra Pradesh is strewn with unique rock structures. This 1000 acre park has largely crossbedded sandstone of Kurnool group.

to such an extent that it is now difficult to find a single fossil in the locality. The Anjar section in Gujarat, preserving a unique record of the event responsible for the extinction of dinosaurs, is almost destroyed. The lignite deposits of Gujarat yield some of the internationally acclaimed vertebrate fossils and enchanting ancient amber are being mined recklessly. While it is almost impossible to stop mining activities in these areas, some of the important sections can be perhaps preserved for future research activities (SES–INSA Report 2019).

Way Forward

Geoparks can showcase our country's rich natural heritage thereby enhancing the place value of many locales—gaining international recognition. They can attract researchers, students and people from all walks of life—increasing revenue earnings for the local communities as well as state governments. It can also help in enhancing education and learning opportunities through stronger bilateral relations between partner countries. However, diligent groundwork such as putting a strong legal mechanism in place, enriched governmental budgetary support, active involvement of cross-sectoral stakeholders, awareness through various media are the current needs. Geovandalism has to be halted to accord geoheritage its rightful place. GY

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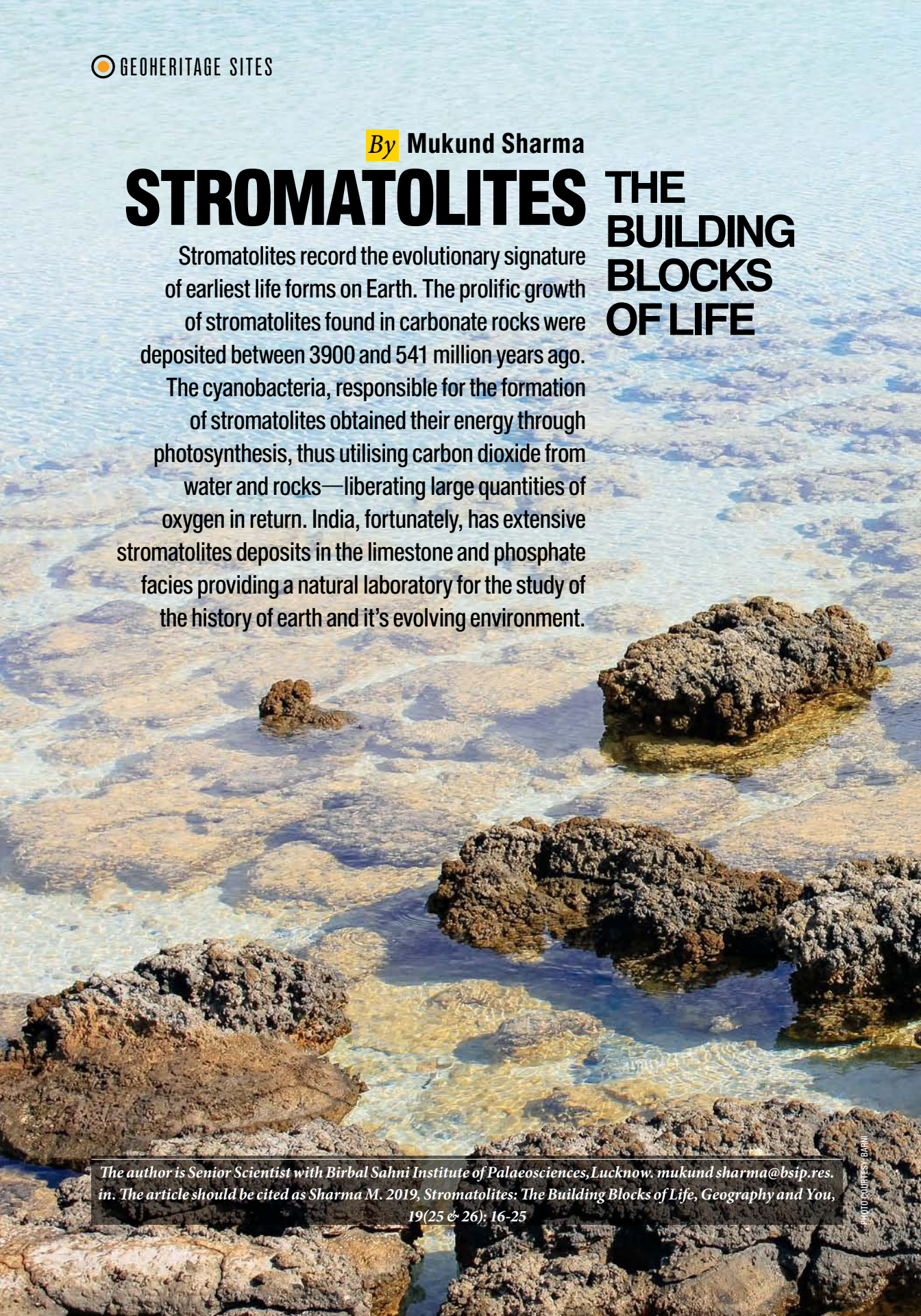
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By **Mukund Sharma**

STROMATOLITES

THE BUILDING BLOCKS OF LIFE

Stromatolites record the evolutionary signature of earliest life forms on Earth. The prolific growth of stromatolites found in carbonate rocks were deposited between 3900 and 541 million years ago. The cyanobacteria, responsible for the formation of stromatolites obtained their energy through photosynthesis, thus utilising carbon dioxide from water and rocks—liberating large quantities of oxygen in return. India, fortunately, has extensive stromatolites deposits in the limestone and phosphate facies providing a natural laboratory for the study of the history of earth and it's evolving environment.



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PHOTO COURTESY: BARNI



Living stromatalites are very rare. The only known sites are Shark Bay, Australia, the Bahamas, and the Great Salt Lake, Utah. In India , however, there are well-defined and unique fossil stromatalite structures in many locations.



The oldest sedimentary rocks on earth are about 3.9 billion years old. If one was to investigate the earliest evidences of life on the earth, these would be a place to start. Although such rocks have undergone multiple cycles of transformation through tectonism and metamorphism and no longer contain evidences of early life forms—some from the carbonate sequences deposited in tidal regions between 3900 to 541 million years ago (mya) present peculiar or bizarre natural geological structures which appear to be intricately carved and exposed to the surface of the earth. These are stromatolites.

In 1908, German scientist Ernst Kalkowsky coined two terms—stromatoid and stromatolith, to describe the laminated features in limestone but did not provide any comprehensive definition of the rocks. Stromatolites yield varied microscopic fossils, occurring abundantly and often associated with cherts. Stromatolites, mostly defined after Walter (1976), are "organo-sedimentary structures" entombing well-preserved microbial remains of one of the earliest microorganism—cyanobacteria, responsible for trapping and binding sediments hundreds of millions of years ago.

Cyanobacteria (Cyanophyta) obtain their energy through photosynthesis and are the only photosynthetic prokaryotes able to produce oxygen. The huge quantity of oxygen produced by the cyanobacteria for millions of years changed the earth's atmosphere, making it suitable for life to grow. It is the process of photosynthesis combined with the growing cyanobacteria that creates the distinctive dome-shaped, finely layered structure in rocks known as stromatolites. As the cyanobacteria grow upward, it uses carbon dioxide available in the surrounding tidal water and from the limestone/dolomite rocks upon which it grows, resulting in the precipitation of

PHOTO COURTESY: AUTHOR

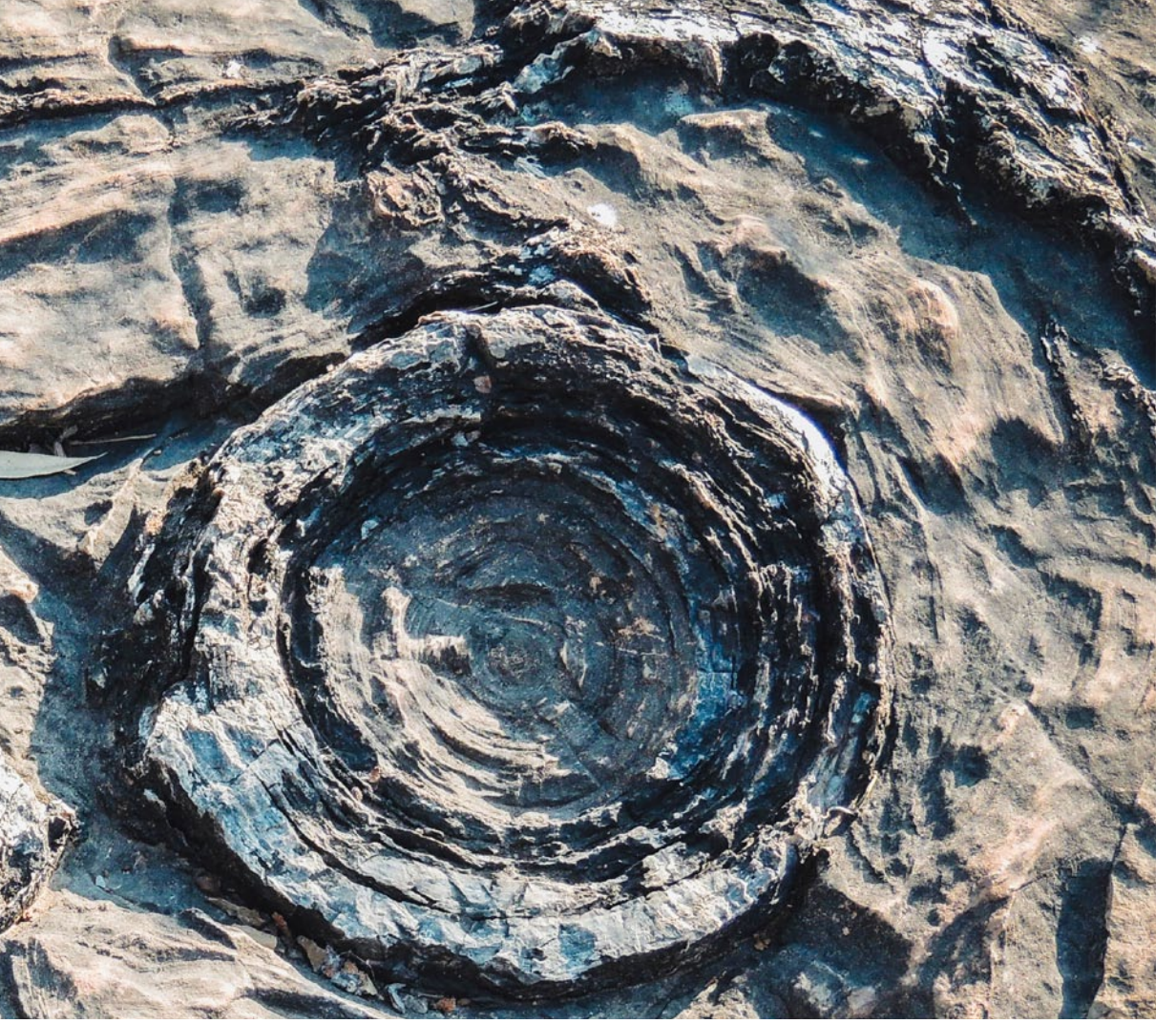


Fig. 1 Planar view of the Stromatolites of the Vindhyan Basin, Salkhan Fossils Park, Sonbhadra district, Uttar Pradesh (above); Stromatolites of the Vindhyan Basin, Chitrakoot (JankiKund), Madhya Pradesh (below).





PHOTO COURTESY: AUTHOR



Fig. 2: Columnar stromatolites of Cuddapah sedimentary basin, Tadpatri, Andhra Pradesh.

calcium carbonate. The mineral forms a crust over the cyanobacteria, which continues to grow layer after layer, acquiring various shapes.

Discovery of Stromatolites

The study of laminated spheroidal and columnar structures in stromatolites is more than a century old. Since 1908, stromatolites have been recorded in almost all the Precambrian sedimentary terrains across continents except Antarctica. These structures are also recorded from a few Phanerozoic period (rocks younger than 541 million years) sedimentary deposits. All carbonate rocks do not host stromatolites—only those deposited in shallow marine tidal environment regions developed a profusion of these structures.

Interestingly, stromatolites are being formed even today at places such as Shark Bay and Hamelin Pool in Australia; Yellowstone National Park, Salt Lake City in Western United States; Baja California in North America; Solar Lake and Ras Muhammed Pool in the Sinai desert, Egypt; Dead Sea in Jordan; and, Lake Ho in the Antarctica. Their growth is similar to that of ancient stromatolites.

The ancient stromatolites however, are found in a few locations and are therefore considered rare. In many parts of the world Precambrian stromatolites have been conserved as a testimony of the earliest life forms on earth and also developed as tourist spots. In India, these are found in the Precambrian rocks exposed in many regions of the nation—few being more than 3000 million years old.

Stromatolites of India

The discovery of stromatolites in India follows an enigmatic trail. During the 18th and the 19th century, English surveyors, doctors, military officers and geologists had mentioned in their memoirs, expedition notes and travelogues about the occurrence of some peculiar structures in limestone or carbonate rocks. None of them were aware what those were. Structures similar to what is presently considered stromatolites were noted by McClelland in 1834, who recorded them as ring-like features. Subsequently in 1872, William King, an English geologist from the Geological Survey of India, while mapping the Cuddapah region (Andhra Pradesh) for diamonds, reported peculiar laminated and segregated limestones in Vempalle. In 1933, James Auden, an officer of

the Geological Survey of India, while exploring and mapping coal reserves in the Vindhyachal recorded wood-section like structures. He photo-documented them and termed the structures as spheroidal bodies in limestone. These were later identified as stromatolites (Mathur 1965) (Fig. 1).

New discoveries of stromatolite occurrences also took place in the early 20th century from Karnataka—Shimoga, Dharwar, Bagalkot and Kaladgi and Andhra Pradesh—Cuddapah (Fig. 2) (Sharma et al. 2016). But the first detailed report describing sensu stric stromatolites appeared in 1964 on the Rajasthan's Marwar Supergroup (Fig. 3) (Khilnani 1964). Subsequently, a series of publications highlighted the importance of stromatolites.

The current inventory of stromatolite occurrences in India is large and comprehensive. They have been found in limestone successions of the Precambrian basins of India. Phosphorite deposits in the Aravalli group of Udaipur region are characterised by an extensive and prolific growth of stromatolites with phosphates forming an integral part of these bio-sedimentary structures. Most of the stromatolites are columnar, while many display branching with strati and compound forms, saucer-shaped structures and more. The most prominent location of the phosphatic stromatolites is at Jhamarkotra, Rajasthan, about 25 km southeast of Udaipur on the Udaipur–Jagat road linking the famous Jhamerashwar cave temple (Fig. 4a, b and c). The Geological Survey of India has declared this site as a National Geological Monument (NGM) in 1976 (GSI 2001).

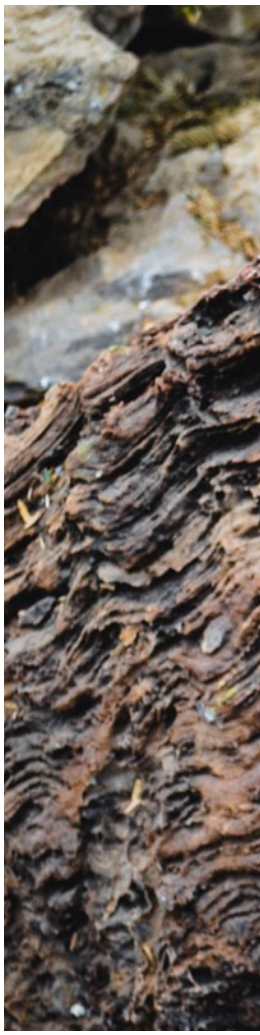


Fig. 3: Stromatolite from the Dhanapa Formation, Marwar Supergroup, Rajasthan.

Palaeoenvironment

Stromatolites hold enormous information about the ancient hydrosphere, atmosphere and biosphere of the earth and about the formation of our present biosphere. These cyanobacteria were the only organisms having the capacity to produce free oxygen on the scale needed to set off the initial oxygenation of the atmosphere and oceans (Papineau 2010) (Fig. 5). Globular structures found within the Vindhyan stromatolites (Jankikund, Chitrakoot) are interpreted as gas bubbles in cyanobacterial biomats (Sallstedt et al. 2018) (Fig. 6).

Modern stromatolites studies are also assisting in understanding the sun-earth-moon dynamics including measurement of the earth's rotation and the inclination on its axis. Undisturbed exposures



Fig. 4: Phosphatic stromatolites from the Jhamarkotra phosphate mine, Rajasthan. Visuals of freshly broken surfaces with crosscut (A) and longitudinally cut (B) columns. The visual C offers a view of the differential weathering of carbonate and apatite in columns .




B
C

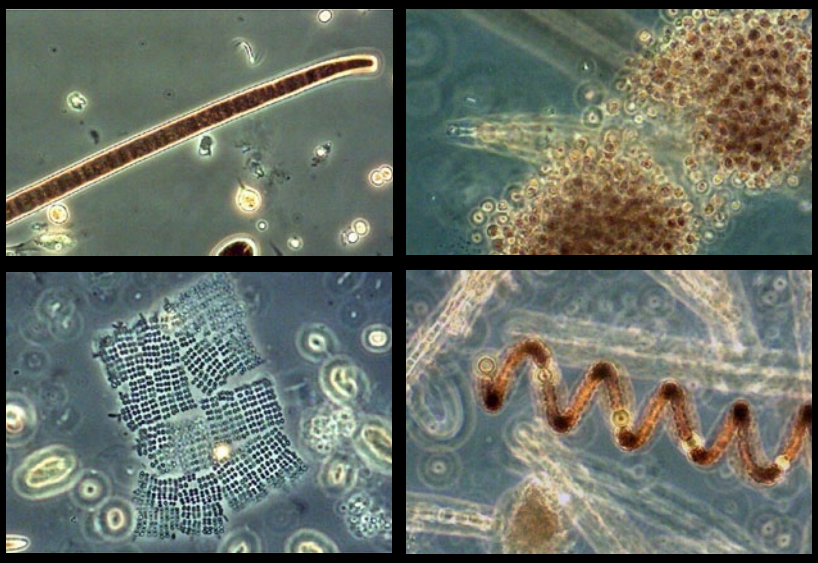


Fig. 5: Stromatolites are created by cyanobacteria, also known as blue-green algae. These microscopic life forms are not really algae but bacteria that have the ability to carry out photosynthesis. They were numerous at one point in time and were single-handedly responsible for adding oxygen into the atmosphere during prehistoric times, making earth habitable.

available in India, hence, can be used to bolster these findings.

Stromatolites also provide indirect evidence of likely life forms on other planets such as Mars. Reports of structures similar to the algal laminates on the surface of Mars encouraged astrobiologists to conduct various research experiments in a simulated environment. Global interest in Search for Extra-Terrestrial Life (SETL) has opened a new vista for stromatolites studies. In depth knowledge of stromatolites can be useful for Indian endeavours in SETL as any primitive life form on other planets are presumed to be similar to early life on earth.

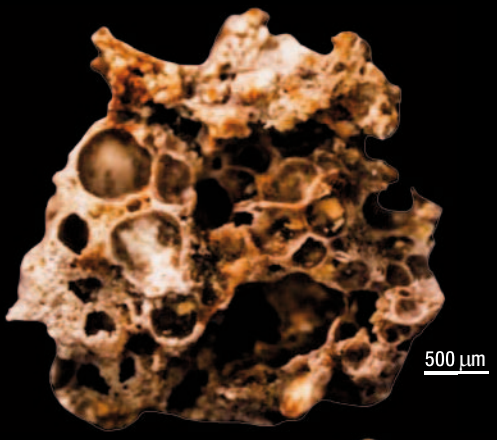
Precambrian stromatolites which have undisturbed and extensive accessible exposures in different part of India can therefore be used to test relationships and other hypothesis. In recent years in fact, experts have recorded secular and temporal variations in the stable isotopic composition of stromatolites bearing carbonate rocks while others have attempted to estimate the age of stromatolites by dating the host carbonates with the help of lead isotopes (Sarangi et al. 2004).

New geomicrobiological studies are looking to decipher the role of microbes in the enrichment of minerals like phosphorites, magnesite and uranium during the evolution of earth. These 'economic' minerals are found in abundance in stromatolites in the Indian Precambrian sequences. In some cases, the enrichment of base-metal deposits has also been attributed to stromatolites. The phosphorites occurrence in association with stromatolites is comprehensively documented in the Aravalli rocks of Rajasthan, Bijawars in central India, in rocks of Mussoorie in the Garhwal Himalaya and in Gangolihat dolomites in Uttarakhand. Magnesite deposits associated with stromatolites are recorded in the Jammu limestone and in the Gangolihat dolomites. Strata-bound uranium mineralisation in the stromatolites bearing Vempalle rocks of Cuddapah is also well known.

Conservation of Stromatolite Geosites

Carbonate rocks hosting stromatolites are being extensively used as a raw material in cement and phosphate industries. Despite extensive occurrences in India, stromatolites are currently running the risk of being wiped out due to excessive mining. The Jhamar Kotra stromatolites of Rajasthan, declared as a National Geological Monument are in a state of abject neglect. The Vindhyan exposures of the Stromatolite Park, Bhojunda, Chittorgarh district, Rajasthan, is another National Geological Monument that is awaiting recognition and conservation. The

PHOTO COURTESY: AUTHOR



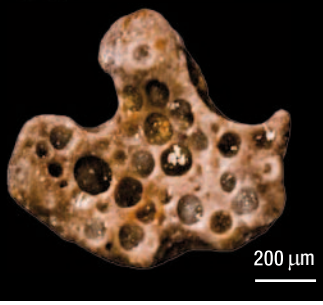
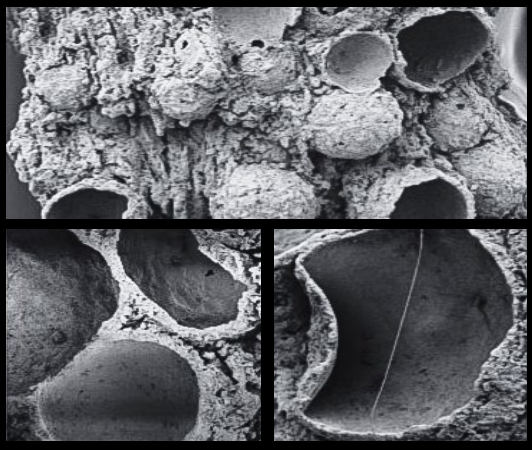


Fig. 6: Globular structures that were interpreted to be gas bubbles in cyanobacterial bio-mats from Vindhyan stromatolites, Janki Kund, Chitrakoot district, Madhya Pradesh.



A microscopic scrutiny of the globular gas bubbles in cyanobacterial bio-mats.

question is—should we leave such structures amenable to rampant destruction? Once these bio-sedimentary structures are destroyed, the wealth of information entombed in them would be lost forever. Many locations of their occurrence can be easily conserved, saved for future generations and even developed as tourist places to generate revenue for local authorities.

Way Forward

The narrative that the demands of development precedes that of preservation is flawed and short-sighted. Experts can advise which pockets of stromatolites occurrences can be held back from exploitation. Partnered by the industry working in adjoining areas, the geological treasure can be conserved for its wondrous value. In areas where dams need to be built, resulting in the consequent submergence of catchment areas, it is indeed a challenge to preserve the priceless stromatolites. India's development story has unfolded adversely for the preservation of important stromatolite occurrences, such as the building of the Bansagar Dam in Madhya Pradesh where unique stromatolites were lost forever. In such a scenario, large facies can be relocated to museums or field repositories. Sensitising policy people, the industry as well as the masses towards conserving such key geoheritage is therefore imperative. GY

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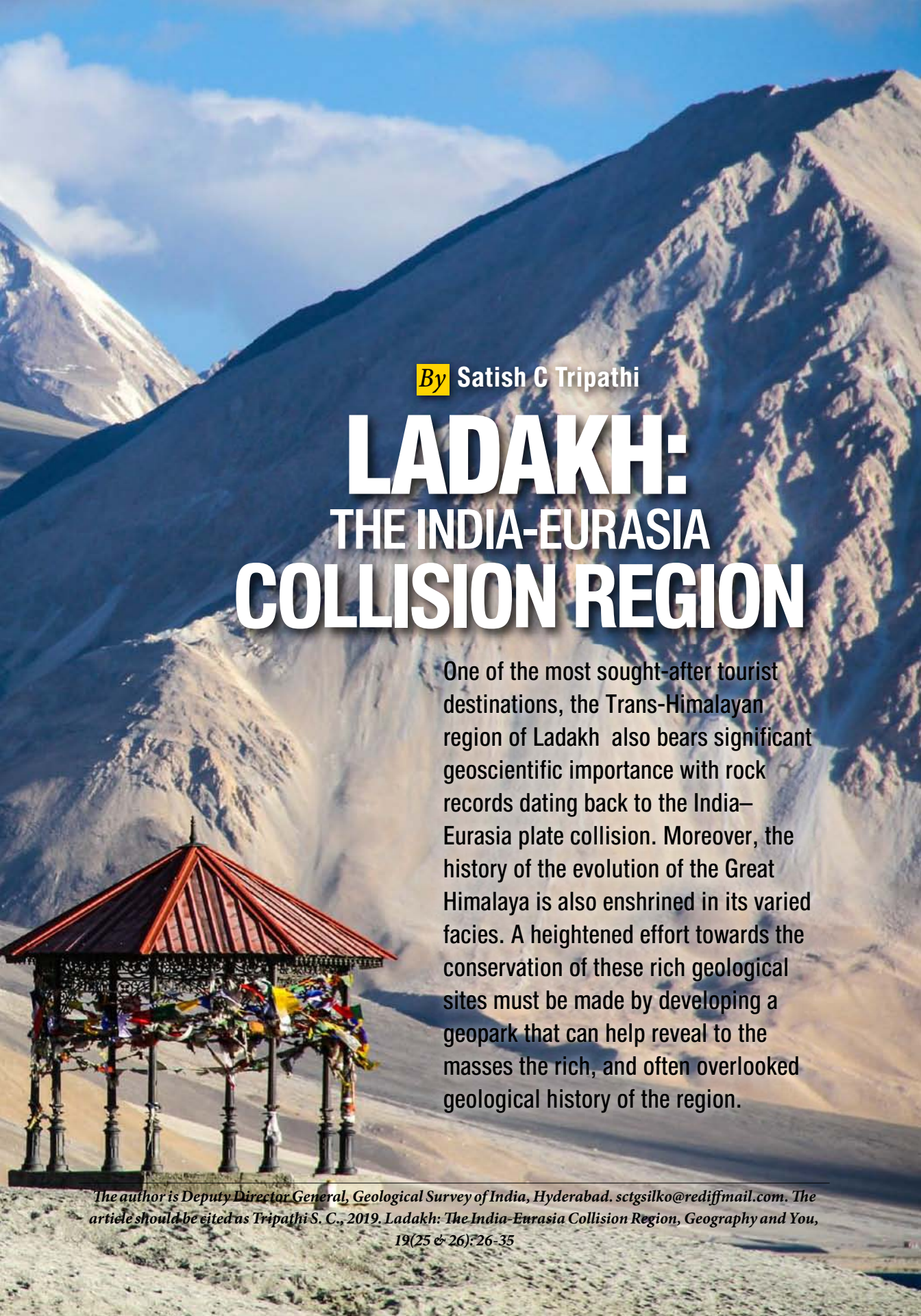
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Ladakh is one of the most scenic regions in the world with towering mountains and majestic lakes. The region, through history, has been primarily inhabited by Tibetian Buddhists.

PHOTO COURTESY: JEEVAN



By **Satish C Tripathi**

LADAKH: THE INDIA-EURASIA COLLISION REGION

One of the most sought-after tourist destinations, the Trans-Himalayan region of Ladakh also bears significant geoscientific importance with rock records dating back to the India–Eurasia plate collision. Moreover, the history of the evolution of the Great Himalaya is also enshrined in its varied facies. A heightened effort towards the conservation of these rich geological sites must be made by developing a geopark that can help reveal to the masses the rich, and often overlooked geological history of the region.

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Fig 1: The Puga hot springs is located about 180 km from Leh. It is one of India's most active geothermal regions with the potential to provide for more than 40 per cent of Ladakh's electricity requirement.

PHOTO COURTESY: RITESH ARYA



Ladakh, the Land of High Passes, has grown to be a favoured holiday destination among tourists in India, popularised famously by the 2009 blockbuster Bollywood flick, 3 Idiots. Situated at a height of over 3000 m in the north of India, these cold deserts hold within it a range of features—shifting sand dunes and sand sheets on the banks of the mighty rivers of Indus, Zanskar, Shyok and Nubra; pristine lakes such as Pangong Tso, Tso Moriri and Tso Kar; ancient hot springs of Panamik, Chumathang and Puga (Fig. 1) and the lofty Siachen glacier. At an elevation of 5,359 m, Khardung La ('la' translates as 'pass' in Tibetan) is today a strategically important gateway to the Nubra and Shyok valleys. Historically, in fact it fell on the major caravan route between Leh and Central Asia and there are documents that reveal that during the Second World War this served as a transportation route to China.

The fascinating history of the evolution of the Himalaya is well recorded in the rocks of Ladakh. Natural phenomena such as the collision of the Indian and Eurasian plates, closing of the Tethys Sea and evolution of paleo-river systems have drawn the attention of geoscientists from across the world, including geologists, biologists and atmospheric and environmental scientists. As established now, the Himalayan mountain chain was formed due to the collision of these two plates (Najman et al. 2017), an ongoing process resulting in the continued rise of the Himalaya by 5 mm annually. The Indus-Tsangpo Suture Zone

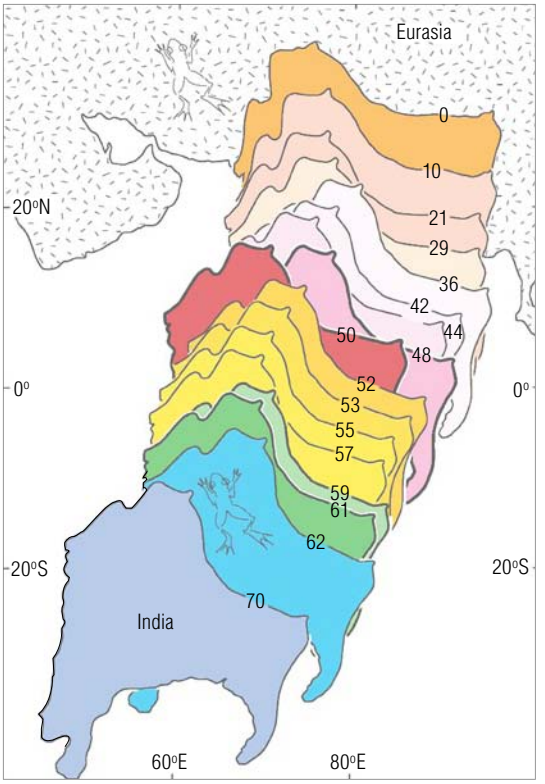


Fig 2: Illustration showing relative movement between India and Eurasia since 70 mya, when the Indian plate moved across the equator
Source: Patriat and Achache 1984

(ITSZ)— an area that separates these two plates, is the loci of deep crust–mantle activities.

The Drifting Indian Subcontinent

Fragmentation and amalgamation of continental blocks and formation of supercontinents is a process that has continued since the evolution of the earth (Dalziel and Grunow 1992). Gondwanaland was an erstwhile supercontinent which fragmented into major modern southern hemisphere landmasses—South America, Africa, Madagascar, Australia, India, New Zealand and Antarctica—bearing distinctive sedimentary facies and fossil biotas characteristic of the traditional Indian Gondwana sequence. The term 'Gondwanaland' is derived from the ancient kingdom of the Gonds that inhabited the area south of the River Narmada in central India, where the typical Gondwana rocks, or one of the earliest rock formations, were first discovered by the Geological Survey of India.

The breakup of Gondwanaland started about 180 mya in the Jurassic period. The Indian subcontinent completely separated from Madagascar about 85 to 90 mya during the Late Cretaceous period and started its northward movement as an isolated landmass and ultimately collided with Eurasian part giving birth to the Himalayan mountain chain (Fig. 2). This breakup and the subsequent opening of the Indian Ocean are thought to have been caused by tectonic plates resulting from the subduction of the Tethys Sea floor beneath Eurasia, localised along zones of weakness caused by mantle plumes—Bouvet, Marion, Kerguelen and Reunion (Chatterjee et al. 2013).

The Indian Plate travelled at a rapid pace of 20 cm each year during 67 and 50 mya, but slowed down to 5 cm per year after the collision around 50 mya. Presently, the Indian Plate moves northwards annually at a rate of 1.5 cm. During its period of travel northwards, the Indian landmass saw massive extrusion of Deccan basalt, which resulted in the extinction of dinosaurs around 65 mya, at the end of the Cretaceous period.

After the collision of the landmasses near Tibet, the Indian landmass rotated anticlockwise. This is thus the best example of an inter-continental collision and suturing. It is no wonder therefore, the fauna and flora found in the Himalayan belt is of mixed origin, having both Indian and Eurasian affinity (McLoughlin 2001).

Collision of the Indian Plate in Ladakh

Extensive research has been carried out in Ladakh to study the collision of the Indian Plate and its subsequent results. Throughout history, Ladakh has witnessed multiple collisions, evidence of which are found in various shapes and forms, with rocks emplaced or deposited as a result. Some of these formations are noted below.

Eclogite rocks: The timing of the collision can be ascertained from the age of eclogite rocks.

These rocks are formed at a temperature and pressure higher than what is found at the crust of the Earth and are emplaced due to collision within the light-coloured Puga gneisses at Sumdo, Ladakh (Fig. 3). These rocks can be identified by their red–pink garnet in a green matrix of sodium-rich pyroxene and are seen at several sections within the Puga gneisses.

Foraminiferal limestone: The collision of the Indian Plate resulted in the closing of the Tethys Sea. The age of the youngest marine rocks is another way to know the timing of the collision. Marine limestones, with planktonic foraminifera fossils, or nummulites, (55.5 mya), represent the last phase of the closing of the Tethys Sea. These nummulites are larger foraminifera and can be seen on outcrop scale (Fig. 4).

Ophiolite suite: The narrow ITSZ, separating the Indian and Eurasian Plates, contains the typical ophiolite suite of rocks (ultramafic rocks with chromite, mafic and pillow basalt) along with deep sea radiolarian chert—planktons which are common in nutrient-rich ocean waters. Figure 5 shows the ITSZ and the associated discontinuous ophiolitic mélange. The Nidar area, lying southeast of Leh, and part of the ITSZ, has preserved the best exposures of ophiolite suite of rocks, remnants of the Tethys Sea with fossil records and post-collisional river-born sediments and evolution of palaeo-drainage systems. The ultramafic rocks—serpentinite, dunite and peridotite with chromite—are mantle-derived rocks emplaced along the suture zone. The earth's mantle, 38 km thick for continents and 7–8 km thick below the ocean, is the second thickest layer below the crust. The exposure of dunite-serpentinite with layers and lenses of chromite can be seen around Nidar (Fig. 6). The pillow basalt is an important component of the ophiolite suite, which forms when basaltic lava comes in contact with sea water. These bulbous bodies are typical of ophiolite suite and have characteristic internal structures (Fig. 7). The presence of these deep-seated rocks in Ladakh indicates a high degree of crust–mantle activity along the suture zones.

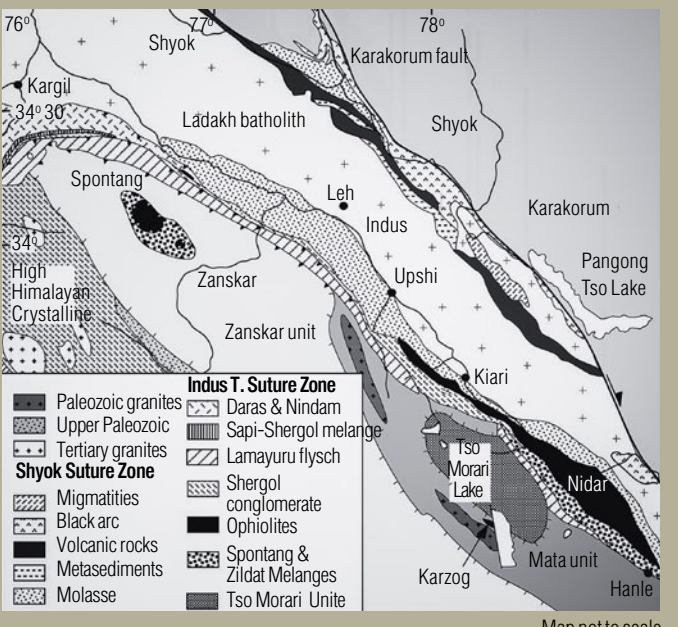


Fig 5: Regional geological map of Ladakh–Zanskar region showing disposition of Indus-Tsangpo Suture Zone (ITSZ) and associated ophiolites
Source: Mahe´o et al. 2004.



Fig 6: A spectacular belt of dark coloured chromite-band-associate in Nidar, Ladakh, stands out of the surrounding dunite—an ultramafic rock, representing earth's upper mantle.

PHOTO COURTESY: AUTHOR









Top to Bottom: High pressure mineral coesite-bearing eclogite rock occurring within the gneisses of Sumdo in Ladakh; Marine limestone with foraminifera fossils 'numulites' (eye like structures) indicating the presence of the Tethys and its subsequent closure after collision, Nidar; Basaltic lava developed pillow like structures when it came into contact with the ocean, Nidar.



Fig 8: Indus sedimentary rocks deposited by the post-collision river system exposed in the Nidar valley.

Ladakh granitoids: The rock formations that can be seen while travelling from Leh to Nubra Valley are designated as Ladakh granitoids (57–47 mya), exposed for over 600 km north of the ITSZ. Various phases of granitoids and enclaves indicate the different episodes of subduction-related magmatism during the process of the collision.

Indus group of sedimentary rocks: The Trans-Himalayan Ladakh batholith is overlain by the post-collision Indus group of sedimentary rocks. These rocks represent the youngest sediments deposited along the present-day Indus Valley, which evolved after the collision, believed to be the oldest drainage system in the world. The red, green and grey-coloured conglomerate, sandstone and shale (Fig. 8) also record the palaeoenvironmental shifts during the Miocene period (23–5 mya).

Sand dunes: The present-day cold-desert climate resulted in the formation of sand dunes and sand blankets along the Shyok, Indus and Zanskar valleys (Fig. 9). The formation of these dunes is attributed to glacial, fluvial and aeolian geomorphic processes. They are found in clusters along the river terraces adjacent to flowing river channels. Strong, and often regular, sandstorms also form a blanket of sand over the lower parts of hills.

Hot springs: The presence of hot springs in various parts of Ladakh is also indicative of high geothermal gradient. Panamik, Chumathang and Puga are some of the most favoured destinations by tourists visiting Ladakh, who believe a dip in these sulphuric waters will cure them of various ailments. Available seismic data clearly indicate that the region is still active and unstable.

Conservation of Nidar Geoheritage Sites

The characteristic ophiolite suite of rocks are spread across Ladakh's Nidar area. The nummulitic limestone found here are the remnants of the last phase of the closing of the Tethys Sea and the subsequent collision of the Indian and Eurasian Plates. The ultramafic suites with chromite, pillow lava, younger continental sedimentary rocks showing palm fossils, etc., explain the fascinating geological history of the collision of the Indian Plate and evolution of the Himalaya.

PHOTO COURTESY: AUTHOR



Fig 9: Recent migrating sand dunes developed at the banks of Shyok river at Khapalu due to arid climate prevailing at Ladakh.

Way Forward

Tourists visiting Ladakh miss these wondrous sites, favouring the more popular, and crowded, destinations of Pangong Tso or camping under the stars in Hunder. Effort needs to be put to conserve these geological sites and develop them into a geopark for interested visitors to learn more about the rich geological history of the Great Himalaya. GY

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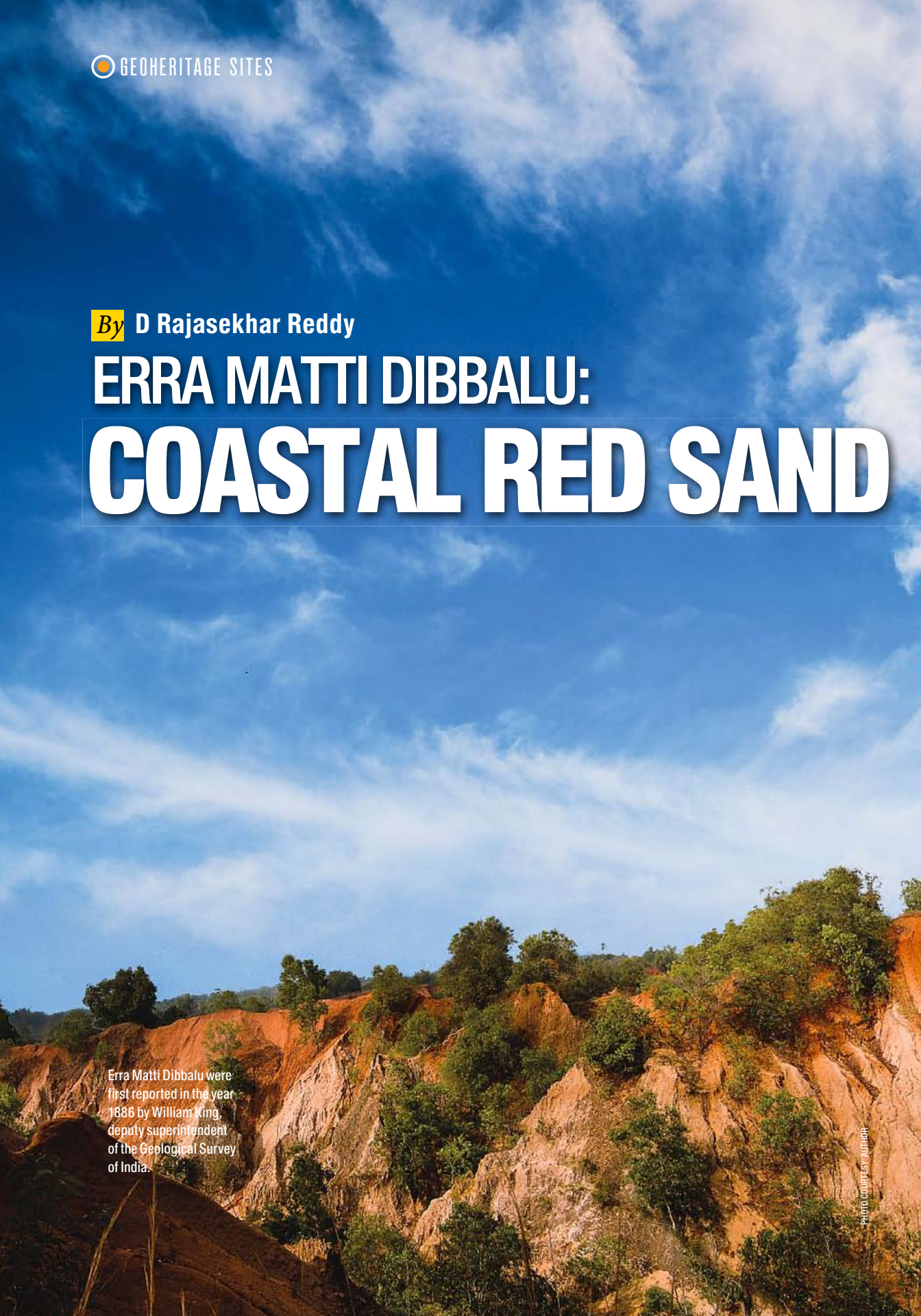
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By D Rajasekhar Reddy

ERRA MATTI DIBBALU: COASTAL RED SAND

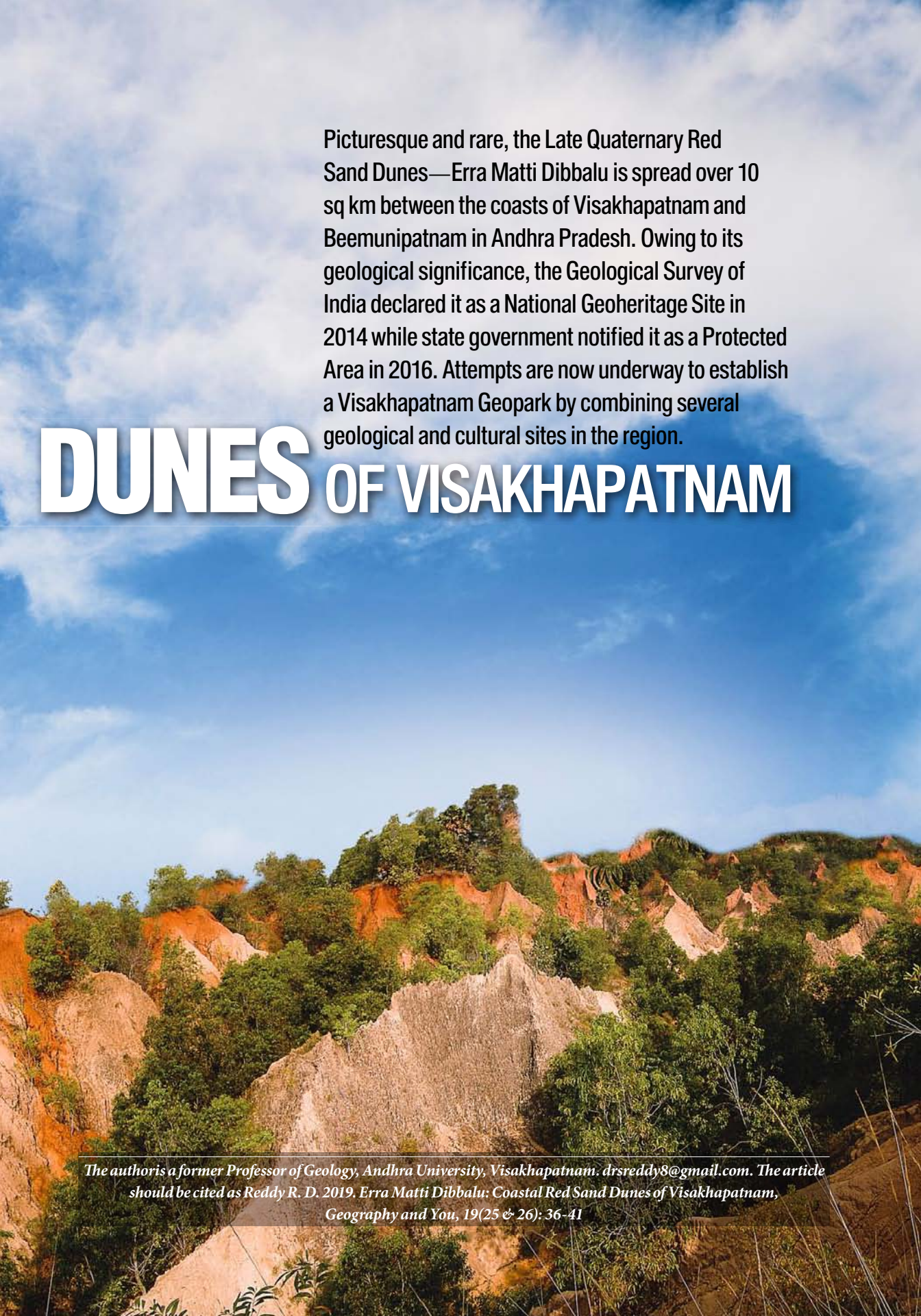


Erra Matti Dibbalu were first reported in the year 1886 by William King, deputy superintendent of the Geological Survey of India.

PHOTO COURTESY: AUTHOR

Picturesque and rare, the Late Quaternary Red Sand Dunes—Erra Matti Dibbalu is spread over 10 sq km between the coasts of Visakhapatnam and Beemunipatnam in Andhra Pradesh. Owing to its geological significance, the Geological Survey of India declared it as a National Geoheritage Site in 2014 while state government notified it as a Protected Area in 2016. Attempts are now underway to establish a Visakhapatnam Geopark by combining several geological and cultural sites in the region.

DUNES OF VISAKHAPATNAM



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The spectacular Erra Matti Dibbalu that stretches between Visakhapatnam and Bheemunipatnam along the coast is a marvelous gift of nature. The low-lying dunes with a maximum elevation of 90 m above mean sea level (msl) is located 20 km to the northeast of Visakhapatnam and 4 km southwest of Bhimunipatnam. The width of the dunes vary from 200 m to 2 km, running for 5 km along the coast in an east-west direction. Besides being unusual, the rare sand dunes have an important and interesting history of evolution. Such sand deposits have been reported only from three low latitude tropical regions in South Asia—the Teri Sands of Tamil Nadu, the Erra Matti Dibbalu in Andhra Pradesh and Red Coastal Sands of Sri Lanka. They do not occur in any other equatorial or temperate regions across the world (Gardner 1995).

Geomorphology of the Site

The gullies in the sand dunes are features that adds mystique to aesthetic appeal of the site. Erra Matti Dibbalu also showcases migrating sand dunes near the coast and parabolic (U-shaped) sand dunes extending up to 2 km landward from the shoreline indicating the intensity of wind action. The area records various landforms and features of different dimensions including gullies, buried channels, beach ridges, paired terraces, valley in valley, wave cut terraces, knick points and waterfalls which aid the understanding of geomorphic evolution of the area (Vaidyanadhan 2012).

Origin of the Red Sand Dunes

William King, a geologist from the Geological Survey of India, discovered the significance of Erra Matti Dibbalu at Bheemunipatnam for the first time, more than a century ago and described them as badlands to represent the denudational remnants of great sand banks or isolated banks formed around sunken or depressed hills. Subsequently, many researchers have contributed on various aspects of Erra Matti Dibbalu. The red sediments are deposited over the basement of khondalite rocks (garnetiferous sillimanite gneiss) and comprise of yellow sands at the bottom followed upward by reddish brown concretion bearing sand unit, brick red sand unit and light-yellow sand unit. The thickness of the sand units is not uniform throughout the area due to the variation in the basement configuration (Rao et al. 2006).

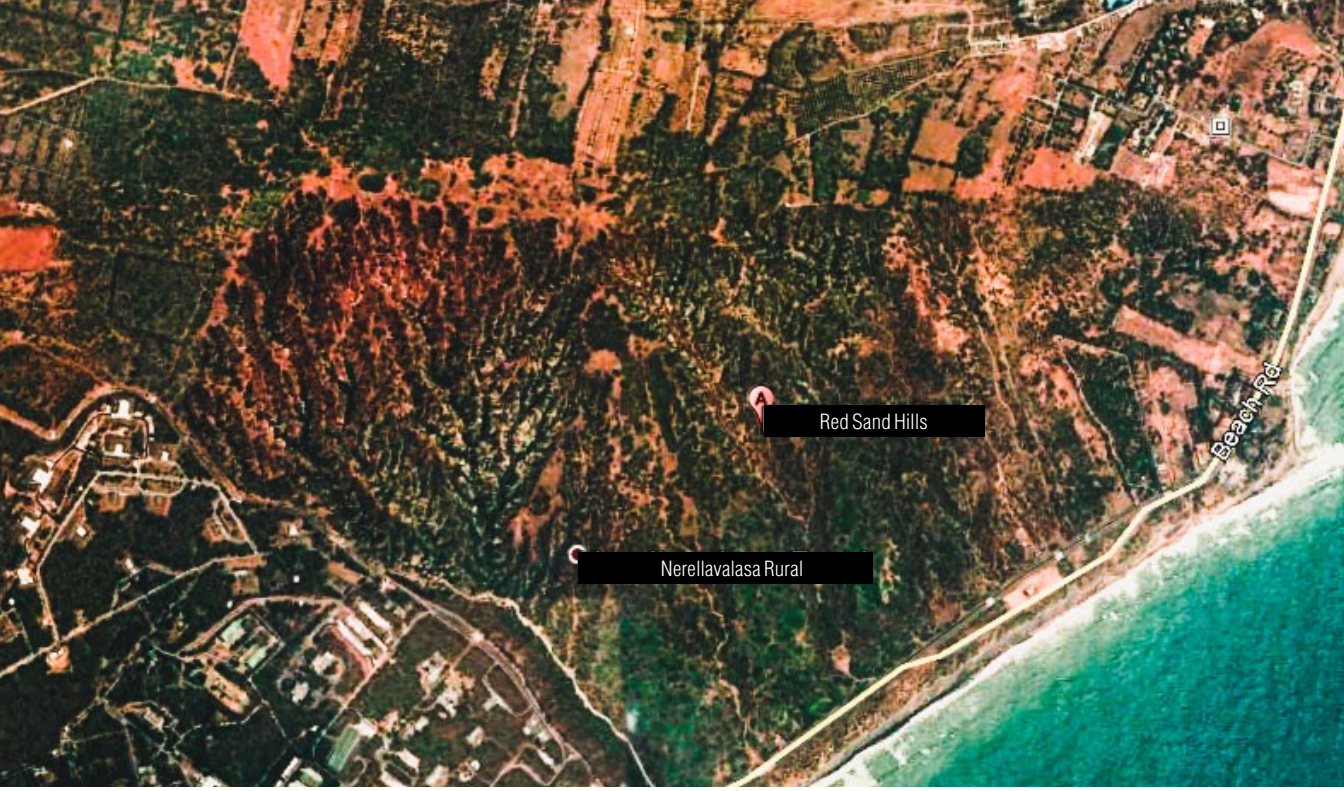
The study of the dune sediments indicate that the bottom-most yellow sand unit is fluvial (transported by rivers joining the sea) while the other overlying three units are aeolian (windblown) in origin. Geological evidence indicates that the sands of the top three units were transported during different periods by prevailing winds which was exposed due to the sea level fall during the Last Glacial Maxima (LGM), 18,500 years ago.

Subsequently, a shift in climate caused in-situ geochemical alteration of the iron bearing minerals in the sands, resulting in the reddening of the dunes. The top light-yellow sand unit however, estimated to have been deposited only around 3000 years ago, were not subjected to such a weathering and hence the sediments could not attain the red colouration. Also of significance is the calcareous concretions that are recorded in the red sediments. The age of these concretions, determined by radiometric dating ranged from 5810 ± 120 years to 5840 ±170 years ago (Rao et al. 1982). The mineralogical and geochemical studies of these sediments indicate that they are mainly derived from the khondalite suite of rocks from hinterland Eastern Ghats (Murali Krishna et al. 2016). Based on the remote sensing and field geological studies, Madabhushi (1995) revealed that the area was active tectonically between 2.5 million and 11,000 years ago.

Archaeological Signatures

Archaeological excavations of artefacts found in the compact dark yellow Erra Matti Dibbalu indicate undisputedly, an Upper Paleolithic horizon and on cross dating assigned to Late Pleistocene Epoch 20,000 BCE. Mesolithic and Neolithic cultural materials were also unearthed from the red sediments at different locales denoting their continued formation till almost recent times. These geoarchaeological evidence indicates erosion even subsequent to Neolithic period, which could be dated to 2,000 BCE. Thus, the region was also home to prehistoric man, ascertained through excavations at several places, which revealed stone tools of three distinctive

PHOTO COURTESY: AUTHOR



Satellite image of Erra Matti Dibbalu with discernible raised mounds, some as high as 90 m. The picturesque dunes were formed about 18500 years ago. Burgeoning human settlements are rapidly encroaching into the vicinity of Erra Matti Dibalu jeopardizing this unique landform. The closest one, Nerellavalasa rural, is a small hamlet just about 1 km from the site (above); Deep gullies within the Erra Matti Dibbalu act as fascinating pathways. It also however, enhances erosion during the rainy season (below).





The red sand hills of Erra matti Dibalu are composed of 50 per cent sand and 50 per cent silt and clay. Oxidation has lent them their unique red colour with the geochemical alteration of the iron bearing minerals.

periods as also pottery fragments belonging to Neolithic cultures (Reddy et al. 1999).

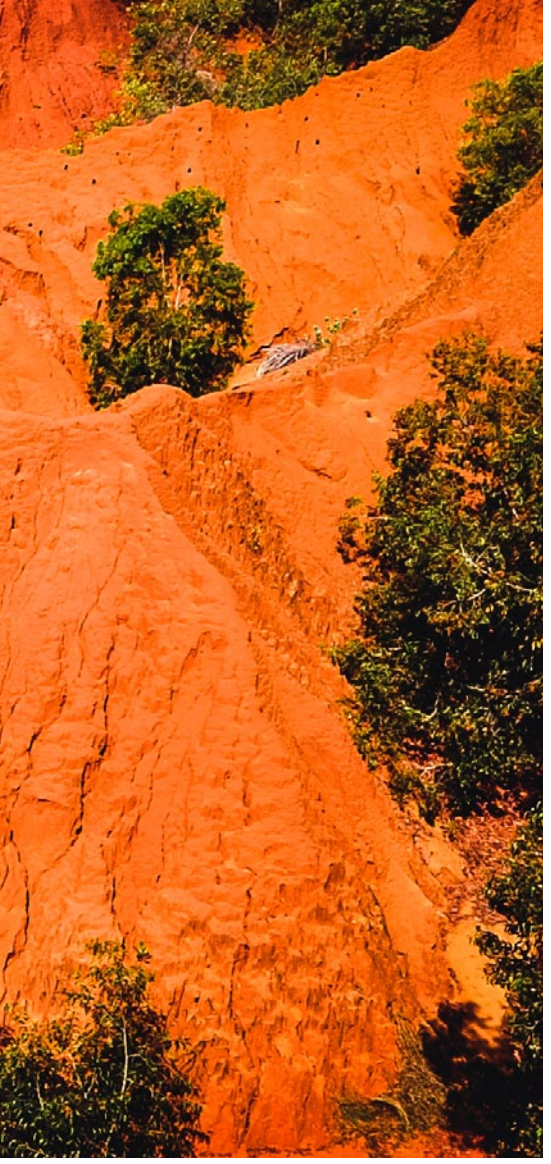
Erra Matti Dibbalu – A National Geoheritage Site

The red sand sediments of Erra Matti Dibbalu are unconsolidated and loose. Every monsoon the sediments are washed away, turning the sea a bright red. Further degradation due to human interference such as digging, climbing, littering etc. are affecting their stability and exacerbating erosion. As such, we face the danger of losing a rare and picturesque record of nature.

Following a national workshop jointly organised by the Geology Department of Andhra University and INTACH in 2012 the site was declared a National Geoheritage Monument in 2014 by the Geological Survey of India (Reddy and Sarma 2012). The state government of Andhra Pradesh notified the site as a Protected Area two year later, in 2016.

However, the Erra Matti Dibbalu is a valuable asset and its importance needs to transcend national borders. The scope of its study for understanding past environmental indicators is significant, enabling further research into past climate, sea level oscillations, monsoon variability etc. This needs to be utilised by the global scientific communities. If these red sand dunes are disturbed and eroded, valuable natural scientific documents will be erased forever, rendering further work impossible. Hence, there is an urgent need to protect and preserve the Erra Matti Dibbalu from any potential threat including unregulated tourism and construction activities.

PHOTO COURTESY: AUTHOR



Way Forward

The Visakhapatnam region is replete with many exquisite geological features. Study of ancient natural arch of Shilathoranam formed 1500 million years ago atop the Tirumala Hills; or that of the magnificent limestone caves with stalactites and stalagmites at Borra; and research about the volcanic ash deposit in Patal valley at Araku which is said to have originated from the volcanic eruption of Toba in Indonesia 73,000 years ago—are all indeed magnificent repositories of the earth's history. It is therefore important to establish a Visakhapatnam Geopark Circuit by combining the myriad geological, cultural and archaeological sites such as Thotlakonda, Bavikonda, Pavurallagutta etc. Geoparks can significantly help promote scientific knowledge apart from encouraging tourism, thereby, contributing to the economy of the region.

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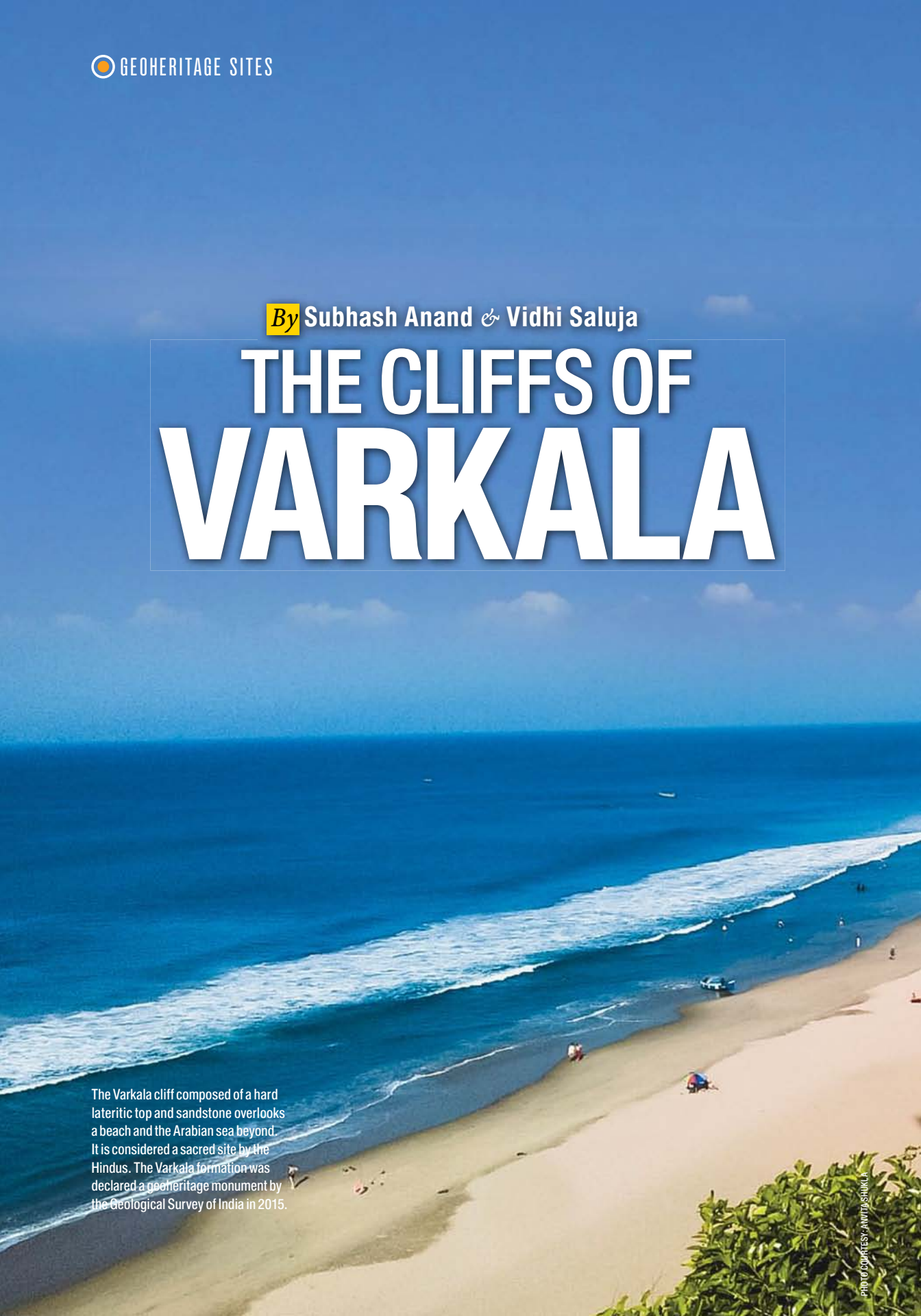
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By Subhash Anand & Vidhi Saluja

THE CLIFFS OF VARKALA



The Varkala cliff composed of a hard lateritic top and sandstone overlooks a beach and the Arabian sea beyond. It is considered a sacred site by the Hindus. The Varkala formation was declared a geoheritage monument by the Geological Survey of India in 2015.

PHOTO COURTESY: ANVITA SHUKLA

The only cliff geoheritage site recognised as a National Geological Monument—the Varkala lies about 55 km northwest of Thiruvananthapuram in Kerala. The linear wave-cut cliffs and beaches have a vibrant cultural heritage and serve as a major tourist attraction. However, unmanaged anthropogenic activity and intense erosion are pushing the cliffs landwards.



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The Thiruvambady beach, near the north cliff is also known as the 'Black Sand Beach'. The black colour is due to heavy minerals, mainly ilmenite lending it its name.

PHOTO COURTESY: RAKTIMRAY



Varkala is a linear cliff in Kerala between the Western Ghats and the Arabian Sea. Running 6 km north to south in an elevation of about 40 m, Varkala bears three prominent cliff formations—Edava, North and South. A cliff as long as this along the western sea coast is a rare feature in the coastal geomorphology of India. Varkala was declared a National Geological Monument by the Geological Survey of India in 2016 and is a fit candidate to be listed as a global geopark. Situated about 55 km northwest of Thiruvananthapuram, Varkala has been a popular destination for the last decade or so, due to its unique topography, tranquil beaches and laterite cliffs. Tourism has been primarily developed around the North cliff, along a 1.6 km length between Papanasham and the Black Beach.

The History of Varkala

The ancient Vishnu or Janardana Swamy Temple and the Papanasam beach located in Varkala, marks it as an important Hindu pilgrimage site. Also known as the Dakshina Kasi, Varkala in mythology is where sage Narada threw his Valkalom (garb made out of tree bark). He then asked his disciples to perform a penance here to redeem themselves from Brahma's curse and build a temple dedicated to Vishnu. Papanasam is therefore, considered sacred by Hindus, a place where



The Janardana Swami is a 2000 year old temple situated in the vicinity of the cliff. Varkala is often referred to as the 'Dakshina Kasi' due to the religious significance it holds. It is also a major Ayurveda centre.

one can wash away all their sins. On the auspicious day of Karkidakavavu in July, millions of pilgrims come to the beach to give offerings to their ancestors.

In 1762, in an effort to usher in learning and accord importance to Varkala, the Dalawa, or minister of the Kingdom of Travancore built an Agraharam near the temple—abode of the Brahmins, a socially revered caste group in those times. This now forms the heritage core of the town. Later in 1877, the Thiruvananthapuram–Shoranur canal was built that serves as a major transport network connecting the north and south of Kerala. The canal passed through Varkala enhancing its connectivity and consequent trade and commerce. The Vallakadavu or the boat yard then emerged as a commercial hub of the town (Lakshmi and Shaji 2016).

Geology, Geomorphology and Hydrogeology of Varkala Coastal Cliffs

The cliffs of Varkala expose various lithological units formed 15 to 20 million years ago recording past climates, sea level changes and tectonic evolution. The region is a part of the Kerala-Khondalite Belt (KKB) of the Southern Granulite Terrain (SGT) of India. The Precambrian rocks are overlain by sedimentary ones belonging to the Warkalli Formation of the Mio-Pliocene age. The cliffs of Varkala interestingly exposes all the litho-units of this formation—unconsolidated sands, variegated and white plastic clays along with carbonaceous sandy clays, enclosing impersistent seams and lenses of lignite from top to bottom (King 1882). Amazingly, these beds are almost horizontal in nature. The Warkalli Formation is capped by hard

PHOTO COURTESY: FANNNA



Cracks develop within the surface of the cliff and ultimately lead to landslides and landward migration of the cliff.

laterites which were formed during the second lateritisation cycle witnessed in Kerala (Soman 2002). On the basis of lithology and spatial distribution, Rao (1968) suggested that the Warkalli Formation were perhaps shallow water shoreline littoral deposits.

Varkala, carved out by a combination of fluvial and marine processes was consequently elevated due to tectonic forces (Sajinkumar and Muraleedharan 2014). The straight west coast of India as compared to the east coast, witnessed several episodes of tectonism. One of the most prominent of the tectonic activities is the two-stage formation of West Coast Fault (WCF) (Chandrasekharam 1985)—initially as a narrow fracture along the northern part of the margin during the late Jurassic-early Cretaceous period and then extending further south during the Tertiary period (Owen 1976). Vertical movements of the block adjacent to the WCF during the late Tertiary promoted deposition of marine and continental sediments (Raha and Roy et al. 1983).

The beach sand of Varkala and its adjacent areas have a rich concentration of heavy minerals—ilmenite, rutile, zircon, monazite, sillimanite and garnet. The Black Beach, which marks the northern limit of Varkala, derived its name from the abundance of these placers, particularly, ilmenite. The narrow confined beaches are however, submerged during high tides. Numerous springs and rivulets emerge from the cliff to join the Arabian Sea—the Warkalli Formation together with laterite in fact constitute the major aquifer system. Groundwater occurs under confined conditions in the Warkalli Formation whereas it is in phreatic condition in the overlying laterite. A

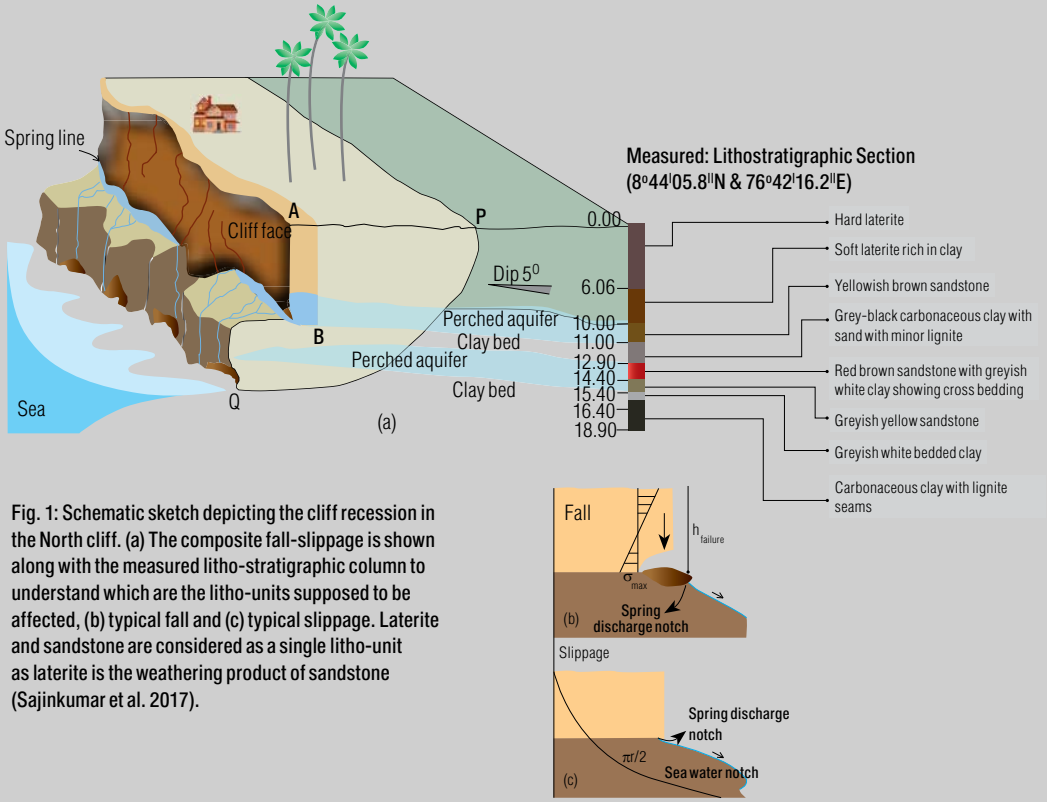


Fig. 1: Schematic sketch depicting the cliff recession in the North cliff. (a) The composite fall-slippage is shown along with the measured litho-stratigraphic column to understand which are the litho-units supposed to be affected, (b) typical fall and (c) typical slippage. Laterite and sandstone are considered as a single litho-unit as laterite is the weathering product of sandstone (Sajinkumar et al. 2017).

few stretches of marshy land are also found in the southwest of the North Cliff.

Erosion of the Varkala cliff

The cliffs of Varkala is exposed to continuous wave action. The soft and friable sandstones are easily eroded by seawater, forming wave-cut notches at the foot of the cliff, destabilising the laterite layer atop. Consequently tension cracks develop at the surface, inevitably leading to a landslide especially during the monsoon. Sajinkumar et al. has explained this process of landward recession of the cliff in Fig. 1. Since 1967, the shoreline adjacent to the cliffs of weak laterite rocks have retreated by nearly 25 to 50 m (Brilliant and Varghese et al. 2013).

The rapid increase of anthropogenic activities in the area has exacerbated this rate of retreat. There is an unprecedented rise in construction along the edges—well within the 50 m 'no construction zone' on top of the cliff. Coupled with an increase in vehicular traffic, the health of the cliffs of Varkala is under jeopardy.

Way Forward

The conservation efforts at Varkala can be significantly bolstered if it is declared a National Geopark. It will help generate new sources of revenue from geotourism and geoproducts and stimulate the creation of innovative local enterprises, small businesses, cottage industries and offer new jobs to the local community. It will create a multi-activity geopark, encouraging scientific learning, national and international tourism, profitable socio-economic activities and promote an environment of holistic sustainable development (Anand and Saluja et al. 2014).

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PHOTO COURTESY: MMOHAN2



Encroachment and commercial settlements on the cliff are a threat. The district administration is taking steps in recent years to protect the cliff from illegal construction.

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Dinosaur remains from the Mesozoic Era have been found in various states of India. Reptilian fossils were first discovered in Central India by Captain William Sleeman of the Bengal Army in 1828. Post-Independence explorations revealed fossils of Jurassic, Triassic and Cretaceous period. Such fossiliferous finds are valuable and rare and areas where they are found need to be conserved as India's geoheritage sites.

PHOTO COURTESY: AUTHOR



Skull of carnivorous *Rajasaurus narmadensis* reconstructed from the fossil remains collected from Lameta formation, Gujarat, Western India and displayed at the Indian Museum, Kolkata.

By **Saswati Bandyopadhyay**

WHEN DINOSAURS RULED THE INDIAN SUBCONTINENT



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The article should be cited as Bandyopadhyay S., 2019. When Dinosaurs Ruled the Indian Subcontinent, Geography and You, 19(25 & 26): 50-59

Dinosaurs were the largest terrestrial tetrapods that existed in the Mesozoic, an Era that is divided into Triassic, Jurrasic and Cretaceous. These reptiles appeared during the Late Triassic (ca. 247-240 million years ago (mya) and gradually became more dominant during the Jurassic (208-144 mya) and Cretaceous (144-65 mya) Periods. The dinosaurs ruled the earth for about 175 mya until the end of the Cretaceous Period (ca. 65 mya), when the entire species, sans the avians, was wiped out. Plant life during the Mesozoic had a significant bearing on the evolution of dinosaurs—the Triassic being dominated by gymnosperms such as ginkgos, conifers, cycads, etc; the Jurassic witnessing the expansion of angiosperms (flowering plants) over gymnosperms; and the Cretaceous replacing gymnosperms with willow, oak, palm and fig trees.

Discovery of Dinosaurs in India

Fossil remains of dinosaurs have been found across continents and the Indian peninsula is no exception. In 1828, Captain William Sleeman of the Bengal Army first found isolated caudal vertebrae fossils from the Lameta Formation of Jabalpur (Mohabey 2011). These were later identified as belonging to a new species of sauropod (herbivorous) dinosaur group, *Titanosaurus indicus*. Subsequently, as the Central Province of India (presently, Madhya Pradesh) was further explored by several British amateur naturalists, geologists and even soldiers and a large number of Late Cretaceous dinosaur fossils were unearthed from Bara and Chhota Simla hills in Jabalpur and Pisdura.



Mounted skeleton of *Barapasaurus tagorei* at the Indian Statistical Institute, Kolkata.

PHOTO COURTESY: AUTHOR



Mounted skeleton of *Kotasaurus yamanpalliensis* at the Birla Museum, Hyderabad.

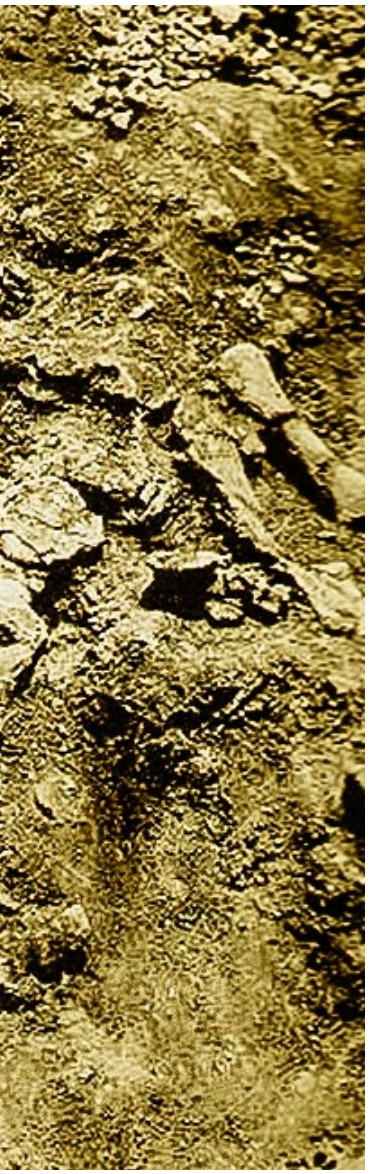


Bone distribution of *Kotasaurus yamanapalliensis* in the field. The fossil remains were first discovered in the late 1970s in the present day village of Yamanpalli in Telangana. The excavation over a 2400 sq m area revealed 840 dinosaur skeletal parts.

PHOTO COURTESY: AUTHOR

Unfortunately, a large number of specimens from these collections were lost during their transportation to the British Museum of Natural History (BMNH). Later, paleontologists Richard Lydekker, Charles Alfred Matley and Friedrich von Huene spearheaded the study of dinosaurs in India. In 1922, Barnum Brown of the American Museum of Natural History (AMNH) also collected fossil remains of reptiles from Jabalpur, which are now exhibited at the AMNH (Chatterjee et al. 2017).

Dinosaurs of the Early Jurassic Period (201-174 mya) were first discovered from the Pranhita-Godavari Gondwana Basin (P-G Basin) in south-central India (Jain et al. 1962). About 300 bones of a sauropod dinosaur were found in the mudstone unit of the Early Jurassic Kota Formation. Later, with further exploration of the Triassic-Jurassic sediments of this Gondwana Basin vertebrate fossils were unearthed and the oldest dinosaur from the Triassic Period (251-201 mya) and several





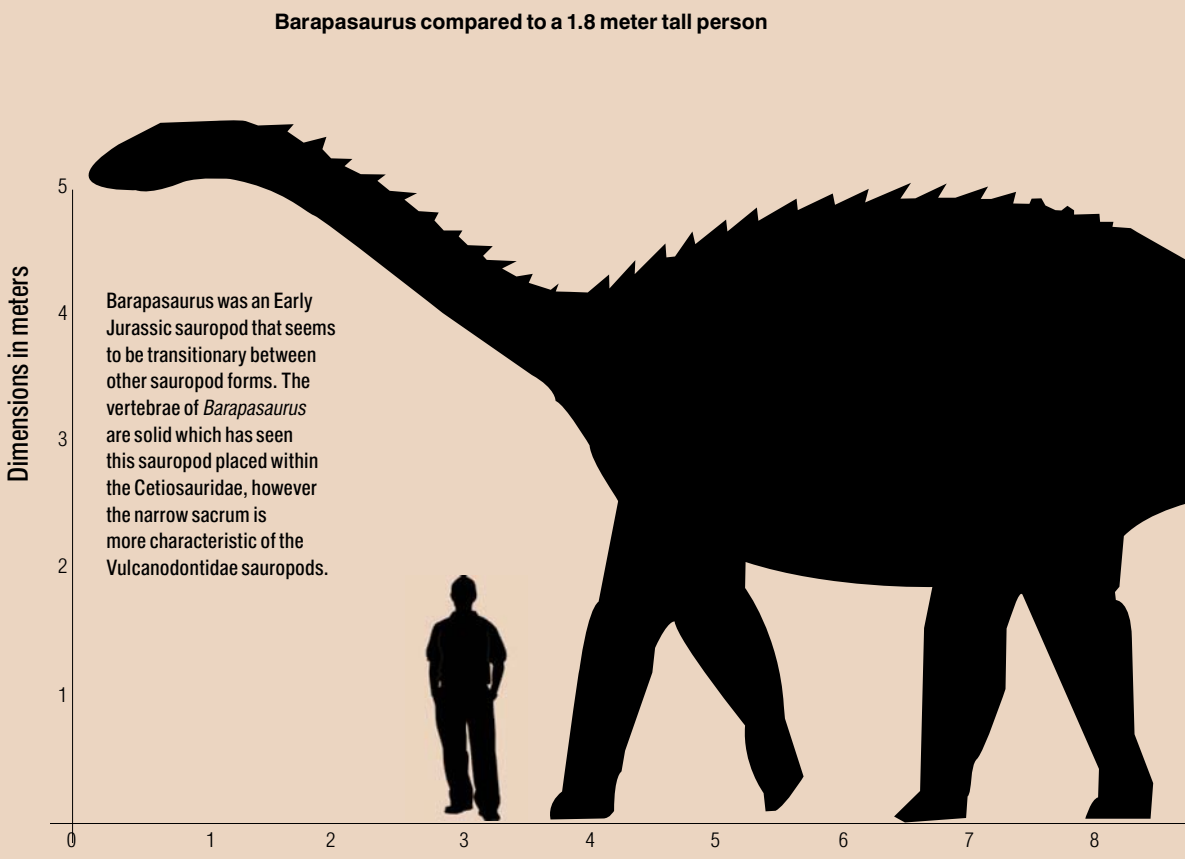
Barapasaurus tagorei was discovered in 1961 by the Geological Studies Unit of the Indian Statistical Institute, Kolkata. The dinosaur was named after Rabindranath Tagore since the discovery coincided with centenary year of the Nobel Laureate.

other Jurassic dinosaurs came to be seen. Also, a significant number of theropod (beast-footed) dinosaurs were unearthed mainly from the Late Cretaceous (100.5–66 mya) sediments of Gujarat and Madhya Pradesh in the 1980s by the Geological Survey of India (GSI). These collections are presently housed at the GSI, the Indian Statistical Institute (ISI), Kolkata, and Birla Museum, Hyderabad, indicating that a good number of varied dinosaurs wandered the Indian subcontinent during the Mesozoic Era.

This paper offers a brief account of the history of Indian dinosaurs from the Triassic to Cretaceous (251-65 mya).

Indian Triassic Dinosaurs

The first mention of the Triassic dinosaur in India was made by Sankar Chatterjee in 1987 who excavated the oldest Indian dinosaur from the Late Carnian (237-227 mya) Lower Maleri Formation of the P-G Basin in Telangana's Adilabad district. This dinosaur was identified



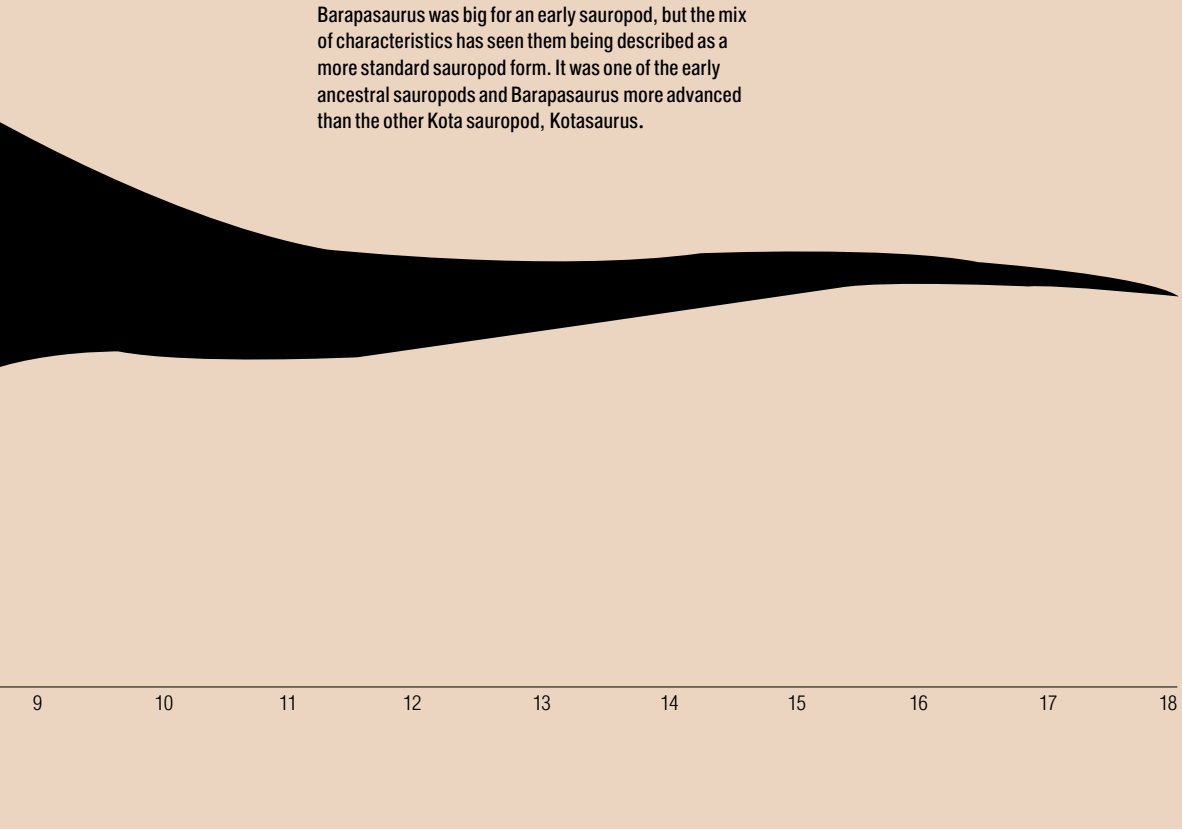
as a basal or primitive theropod and named *Alwalkeria maleriensis* (Chatterjee and Creisler 1994). Later, much controversy arose regarding the identity of this dinosaur, and finally Novas et al. (2011) and Chatterjee et al. (2017) concluded it to be a valid basal saurischian dinosaur (bipedal omnivore) species.

From the Norian (~227-208.5 mya) Upper Maleri Formation, five dinosauriformes, including two new dinosauromorph species, *Nambalia roychowdhurii* and *Jaklapallisaurus asymmetrica*, a guaibasaurid and two basal dinosauriformes were found (Novas et al. 2011). Later, two more different dinosaur taxa of saurpodomorphs and a neotheropod were unearthed from the Rhaetian (~208.5-201 mya) Lower Dharmaram Formation (Novas et al. 2011) in the P-G Basin in Andhra Pradesh.

Indian Jurassic Dinosaurs

The Jurassic dinosaurs in India find mention in only two horizons, the Kota Formation and the underlying upper part of the Dharmaram Formation in the P-G Basin. The Hettangian (201-199 mya) Upper Dharmaram Formation has yielded two sauropodomorphs or 'lizard-footed forms', an extinct clade of long-necked, herbivorous dinosaur; a stem sauropod—*Lamplughsaura dharmarensis*; a small massospondylid prosauropod—Pradhaniagracilis; and a theropod similar to Dilophosaurus (Kutty et al. 2007). Lamplughsaura is considered a sister taxon of Kotasaurus from the Kota Formation and may be considered as the earliest known herbivorous dinosaur in India (Chatterjee et al. 2017). The overlying Early Jurassic Kota Formation of

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Barapasaurus was big for an early sauropod, but the mix of characteristics has seen them being described as a more standard sauropod form. It was one of the early ancestral sauropods and Barapasaurus more advanced than the other Kota sauropod, Kotasaurus.

Source: Some characteristics of Barapasaurus tagorei, a sauropod dinosaur from the Lower Jurassic of Deccan, India - S. L. Jain, T. S. Kutty, T. Roy-Chowdhury & S. Chatterjee - 1979.

the P-G Basin has two units. From the lower-unit mudstone (Sinemurian to Pliensbachian; 199-182 mya) sauropod dinosaur bones associated with large fossilised tree trunks were unearthed (Fig. 1 and 2) (Jain et al. 1962). After the initial discovery, further excavations unearthed a large number of bones including at least six partially associated skeletons. A new sauropod dinosaur, *Barapasaurus tagorei* (Fig. 1 and 2), was discovered and further studies suggested that the Barapasaurus was more advanced than the other Kota sauropod, Kotasaurus (Bandyopadhyay et al. 2010).

Indian Cretaceous dinosaurs

The historical background of all the Late Cretaceous dinosaur collections, has been meticulously recorded by Carrano et al. (2010) and Mohabey (2011). From 1917 to 1924, Charles Matley carried out systematic excavation in Jabalpur, Pisdura and Dongargaon in central India. Later, Matley and F. von Huene published their monumental work on the Late Cretaceous Indian dinosaurs in 1933. They described three genera and four species of sauropods. However, with later discoveries of new sauropod dinosaurs from different parts of the world and improved phylogenetic analyses the identity of these collections were revised. The four main sauropod species of Huene and Matley's 1933 collection includes *Titanosaurus indicus, T. blanfordi, Antarctosaurus septentrionalis,* and *Laplatasaurus madagascariensis*. Few bones and several narrow-crowned teeth were found from the Lameta Formation near Rahioli village in Gujarat, which were identified as *Titanosaurus*

rahioliensis (Mathur and Srivastava 1987). Later, dinosaur egg clutches were also found in a nearby locality (Fig. 5). Another well-preserved, partially articulated skeletal material of a new titanosaur species was excavated from the Lameta Formation of Dongargaon, Madhya Pradesh. Jain and Bandyopadhyay (1997) described these materials and established a new taxon, *Titanosaurus colberti*. While re-evaluating all the known Titanosaurus species of the world, Wilson and Upchurch (2003) invalidated *Titanosaurus indicus* and *Laplatasaurus madagascariensis* and abandoned the genus Titanosaurus. They renamed *Titanosaurus colberti* as *Isisaurus colberti*, and also changed Antarctosaurus to *Jainosaurus septentrionalis* (Hunt et al. 1994) as a valid diagnostic taxon. Hence, *Jainosaurus septentrionalis* and *Isisaurus colberti* are the only two valid Indian Late Cretaceous sauropod dinosaur fossils.

Later, Wilson and Upchurch (2003) described an associated skeleton of a single individual from a new abelisaurid theropod, *Rajasaurus narmadensis* (Fig. 6) from the Late Cretaceous Lameta Formation near Rahioli village. Seven specimens at different ontogenic stages of A belisauridae—*Rahiolisaurus gujaratensis*, were excavated from a single quarry near Rahioli village (Novas et al. 2010). Wilson and Upchurch (2003) considered that only three large-bodied theropods (Rajasaurus, Indosuchus and Indosaurus) and a fourth, small-bodied theropod (Laevisuchus), represented the definite abelisaurid theropods of India. Subsequently, Novas et al. (2004) reviewed the Cretaceous theropod collection from Bara Simla available at the GSI, Kolkata, and concluded that all the theropod elements belonged to a single theropod clade, the Abelisauridae, a carnivorous ceratosaurian theropod found in the Gondwana supercontinent.

Hence, five valid theropod taxa dominated the Indian Late Cretaceous scenario: *Indosuchus raptorius, Indosaurus matleyi, Rajasaurus narmadaensis, Rahiolisaurus gujaratensis* and *Laevisuchus indicus.*



Dinosaur egg clutch exposed within Lameta formation at Rahioli village, Kheda district, Gujarat.

PHOTO COURTESY: AUTHOR

Way Forward

Telangana, Maharashtra, Madhya Pradesh, Gujarat and Tamil Nadu are the states where dinosaur fossils are found in India. Of these, the Maleri and Kota Formations in Telangana and Maharashtra, respectively, have yielded the most important earliest discoveries of the Triassic and Jurassic basal sauropod dinosaurs, while the best known Late Cretaceous dinosaurs have been found in the Lameta Formation of Madhya Pradesh

and Gujarat. However, all the areas where such discoveries have been made are in a state of neglect. Several of these sites, especially those with eggs and nests, have been vandalised and a good number of bones and eggs have been pilfered. Some fossiliferous sites are also gradually getting destroyed due to deforestation, large-scale mining, agricultural expansion and urbanisation. These excavation sites require utmost protection. Additionally, there are many more dinosaur sites in India hitherto undiscovered and laws for systematic excavation of fossils from these areas should be implemented as early as possible. GY

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By Debahuti Mukherjee, Basisha Iangrai & Sabyasachi Shome

MEGHALAYAN

The preserved record of a 4200-year-old event within the stalagmites of Mawmluh limestone cave in Meghalaya has resulted in the cave and state gaining international recognition. The study of these stalagmites suggests a major climatic event which might have impacted human civilization during the time. The current geological age, starting 4200 years ago, is now called the Meghalayan Age, the youngest time division of the Holocene Epoch.

PHOTO COURTESY: MUSIC4LIFE



Mineralised water seeping through the roof of the Mawmluh cave. The water helps build stalagmites and stalactites over thousands of years. These peculiar structures—speleothems, document the changes in global climatic conditions over geological time scales.

AGE THE YOUNGEST AGE INTERVAL IN EARTH'S HISTORY

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The entrance of the Mawmluh cave—one of the longest and deepest caves in India. Mawmluh is 7.2 km in length and is located at an elevation of 1290 m. It is about 500 m from the Cherrapunjee-Mawmluh road.

PHOTO COURTESY: AUTHOR



"Time, geologic time, looks out at us from the rocks as from no other objects in the landscape. The youth of the earth is in the soil and in the trees and verdure that springs from it; its age is in the rocks."

With these words, John Burroughs, a 19th century American naturalist, expressed an important aspect of geodiversity. Earth's history, with all the variability and richness of different abiotic and biotic processes, is recorded in the geological formations. Studying these helps us understand how the environment which supports natural life, evolved and sustained global changes through various geological periods. Therefore, it is important to recognise geologically important sites as part of a country's geoheritage and conserve them accordingly. India has several such geoheritage sites of international significance. One of these, which gained international recognition in 2018, is the Mawmluh limestone cave in Meghalaya. The findings from this cave point to a major climatic event that occurred 4200 years ago which marks the beginning of the youngest geological age—the Meghalayan Age.



The Holocene Epoch

The Earth was formed nearly 4.6 billion years ago. Geologists divide this long period of existence into slices of time. Each slice corresponds with some major event such as the break up of continents, climatic shifts, emergence or extinction of particular biotic group etc. The Geologic Time Scale (GTS) is a system of chronological dating that relates geological strata to time. Earth scientists use this scale to describe the timing and relationship of events during the earth's history. Time is primarily divided into eons. Eons are further divided into eras, which are in turn divided into periods, epochs and ages. We currently live in the Holocene Epoch which is the most recent stratigraphic unit within the geologic record and covers the time interval from 11,700 years before present till the present day.

The term Holocene was first used by Paul Gervais in 1867 to denote the warm episode that began after the end of the Last Glacial Period and was formally adopted by the International Geological Congress (IGC) in 1885. Holocene stratigraphy provides records of sea-level change, climate change, vegetation dynamics, faunal migration, archaeological information and above all the interaction between man and environment. As this Epoch encompasses varied events, it mandates further subdivision in the light of developments in the Quaternary subdivision. The Subcommission on Quaternary Stratigraphy (SQS) invited INTegration of Ice-core, Marine, and TErrestrial records (INTIMATE), a core project of the International Union For Quaternary Research (INQUA) Palaeoclimate Commission, to form

PHOTO COURTESY: AUTHOR



Samples of stalagmites were taken from the 'Hanging garden' of the Mawmluh limestone cave for study by different research groups. The Geological Survey of India is planning to construct a structure to control the discharge of water from a nearby small stream into the cave and in order to make the cave accessible for scientific study round the year.

a joint working group to study the need for subdividing the Holocene Epoch. The working group recommended a three-fold classification where Early Holocene starts from 11.7 kilo annum (ka), Middle Holocene Boundary starts at 8.2 ka and the Late Holocene Boundary at 4.2 ka. The Holocene Epoch, thus, represents three ages—Greenlandian (11.7–8.2 ka), Northgrippian (8.2–4.2 ka) and Meghalayan (4.2 ka–today) (Fig. 1).

Record of Holocene Climatic Changes

Changes in climate in recent times are mainly studied from ice cores in the polar regions or stalagmites from limestone caves. A stalagmite is formed as a secondary mineral deposit that slowly rises from the floor of a limestone cave. It is created by water seeping through cracks from a cave's bedrock, dissolving compounds such as calcium carbonate or calcium sulphate. Given the right acidity, the minerals start to precipitate from the water as it drips to the floor. The precipitate solidifies, giving rise to a stalagmite. Such cave formations grow very slowly—a large stalagmite can take tens of thousands of years to develop. Each layer of a stalagmite can be precisely dated and can yield information about the composition of water from which the fragment was formed. High resolution stable isotopic studies of stalagmites from the limestone cave of Mawmluh, Meghalaya have revealed that a major climatic event occurred about 4,200 years ago. A significant weakening of the monsoon is recorded followed by a mega-drought which had a strong effect on the human civilisations that existed at the time. This event marks the beginning of the Meghalayan Age. The 4.2 ka aridity event is also visible in a range of geomorphological, stratigraphical and

Period	Epoch	Age	Age (Ma)	
Quaternary	Holocene	Mehalayan	0	0.0042
		Northgrippian	0.0042	0.0082
		Green Indian	0.0082	0.0117
	Pleiscene	Tarantian	0.0117	0.126
		Chibanian	0.126	0.781
		Calabrain	0.781	1.80
		Gelasian	1.80	2.58



Fig. 1: Quaternary subdivision and cross section of the stalagmite sample from where the boundary at 4.2 Ka was described.

archaeological records in many parts of the world (Weiss 2014). The stalagmites in the Mawmluh cave has now been tagged a Global Boundary Stratotype Section and Points (GSSP)—the first formally ratified marker in India of a geological time period (Walker et al. 2018).

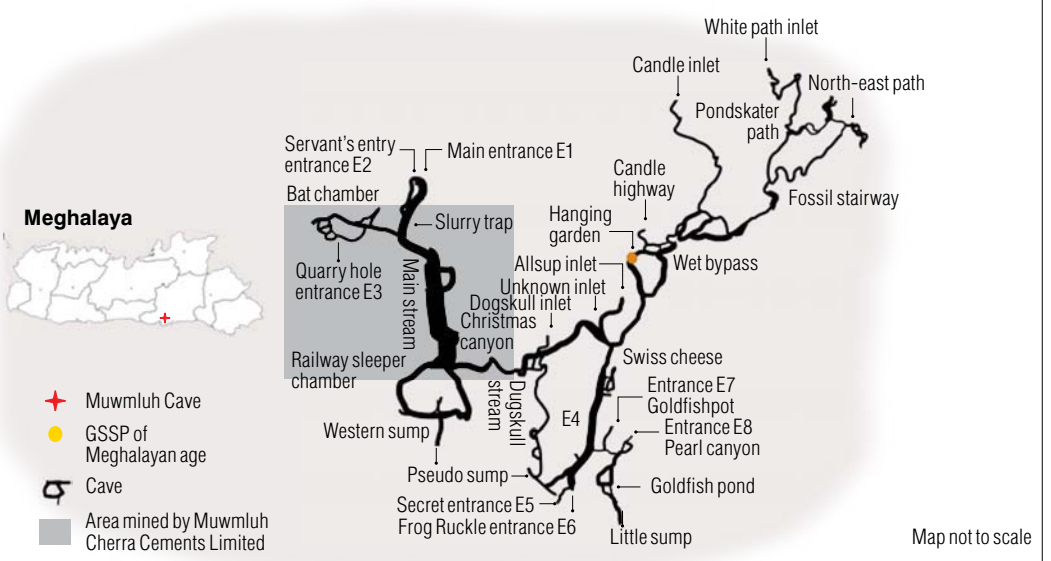
The Climatic Signatures of the 4200-Year-Old Event

The Late Holocene event which occurred at 4.2 ka was circum-global and was marked by widespread drier, warmer and arid climate. Despite being primarily a middle and low latitude phenomenon, it could also be witnessed in the middle and higher latitudes of the Northern hemispher. This pronounced climatic event affected human communities across North Africa, Middle East and Asia. The Akkadian Empire of Mesopotamia collapsed around 4.2 ka due to sudden aridity—while in the Indus valley, the society transitioned from a rural to a post-urban one due to drought conditions that prevailed around 4.0 ka. There was considerable weakening in the flow of the mighty Indus and the now lost river Saraswati. Abandonment of human settlement and increasing nomadism at this time is also documented in rain-fed agricultural areas of Iraq, Syria and Palestine.

Being predominantly a middle and lower latitude phenomenon, the GSSP was chosen from the speleothem (cave formations) record of the Mawmluh cave in Meghalaya. High relative humidity, minimum temperature fluctuation, relatively steady drip rate and location of the sampling site provide optimum conditions for calcite crystallisation from the percolating water. The ratio of oxygen isotope in the sample section reflects the ups and downs of rainfall. Oxygen isotope ratio are cyclical variations that studies the abundance of oxygen with an atomic mass of 18—more rainfall results in less $\delta^{18}O$ in the sample. The isotope ratio in the sample around the 4.2 ka event comprised a two-step sequence, with an initial enrichment at 4.3 ka and a shift to more positive value at 4.1ka. This was well

PHOTO COURTESY: AUTHOR

Fig. 2 : Plan map of the Mawmluh Cave



Source: Modified after Huguet et al. 2018

within the range of the ages of other climatic proxies for the 4.2 ka event. The age of 4.2 ka effectively split the difference between the two abrupt shifts in the isotopic signal at 4.3 and at 4.1 ka. The studies helped the International Union of Geological Sciences (IUGS) recognise the GSSP of the Meghalayan age in the speleothem sample of Mawmluh cave.

Mawmluh Cave

The Khasi Hills are believed to be the uplifted northeastern extension of the Indian Peninsular shield with a basement similar to the Chhotanagpur Gneissic Complex. The geology of the area is represented by Upper Cretaceous-Palaeogene sedimentary sequence resting over the Precambrian crystalline basement. The Mawmluh Cave is developed along the contact between the Lower Sylhet Limestone layer and the Lower Sylhet Sandstone of the Shella Formation.

The region around Mawmluh cave in the Cherrapunji area is primarily an undulating grassland with a thin soil cover supporting a smattering of shrubs and bushes. The cave located south of Cherrapunji was first reported by Oldham in 1859. Cherrapunji, being situated on an uplifted plateau receives heavy orographic rain that originate in the Bay of Bengal. The winds traversing the plains of Bangladesh rise rapidly to the upper atmosphere as it reaches the upland in the Khasi and Jaintia hills. The heavy rainfall helps a large part of the water to percolate down into the ground, seeping through the roof of the cave and dripping at constant rate. This assists the formation of a varied number of stalactites and stalagmites on the roof and floor respectively.

The cave despite being named Krem Mawkyhrdop, is more often than not referred to as Mawmluh—after the nearest village Mawmluh. It is approximately 7.2 km long and located at an elevation of 1290 m with eight openings. The stalagmite which was studied for isotope analysis and geochronology was taken from a site—the 'Hanging Garden' situated at a distance of about 5 km from the



Display board installed by the Geological Survey of India to highlight the significance of the Mawmluh Cave.

entry point 1 (Fig. 2). However, the cave is under constant and severe threat due to the limestone quarrying above the cave system by the Mawmluh Cherra Cement Limited.

Way Forward

The Geological Survey of India (GSI), North Eastern Region has initiated work on the preservation and conservation of the cave as a geoheritage site. The limestone mining in the vicinity of the cave adversely affecting its preservation potential. The GSI has been trying to impress upon the stakeholders of the mining company the importance of this cave and has been attempting to convince them that if mining activity near the cave wall is not stopped immediately, this globally important geoheritage site may as well be destroyed forever. In an effort to make the public at large aware of its importance, geoscientific display boards demonstrating the significance of the Meghalayan age have been installed in the vicinity of the area. Varied awareness programmes on the importance of the site were carried out in Mawmluh village involving locals and the school children of the area. It must be realised that geoheritage is a matter of pride for the people of the land and its proper conservation and stewardship can be done only by them.

PHOTO COURTESY: AUTHOR





The Mawmluh limestone quarry is located precariously close to the cave (marked by the black arrow). Unchecked mining is an environmental hazard in Meghalaya, threatening the repositories of earth's natural history.

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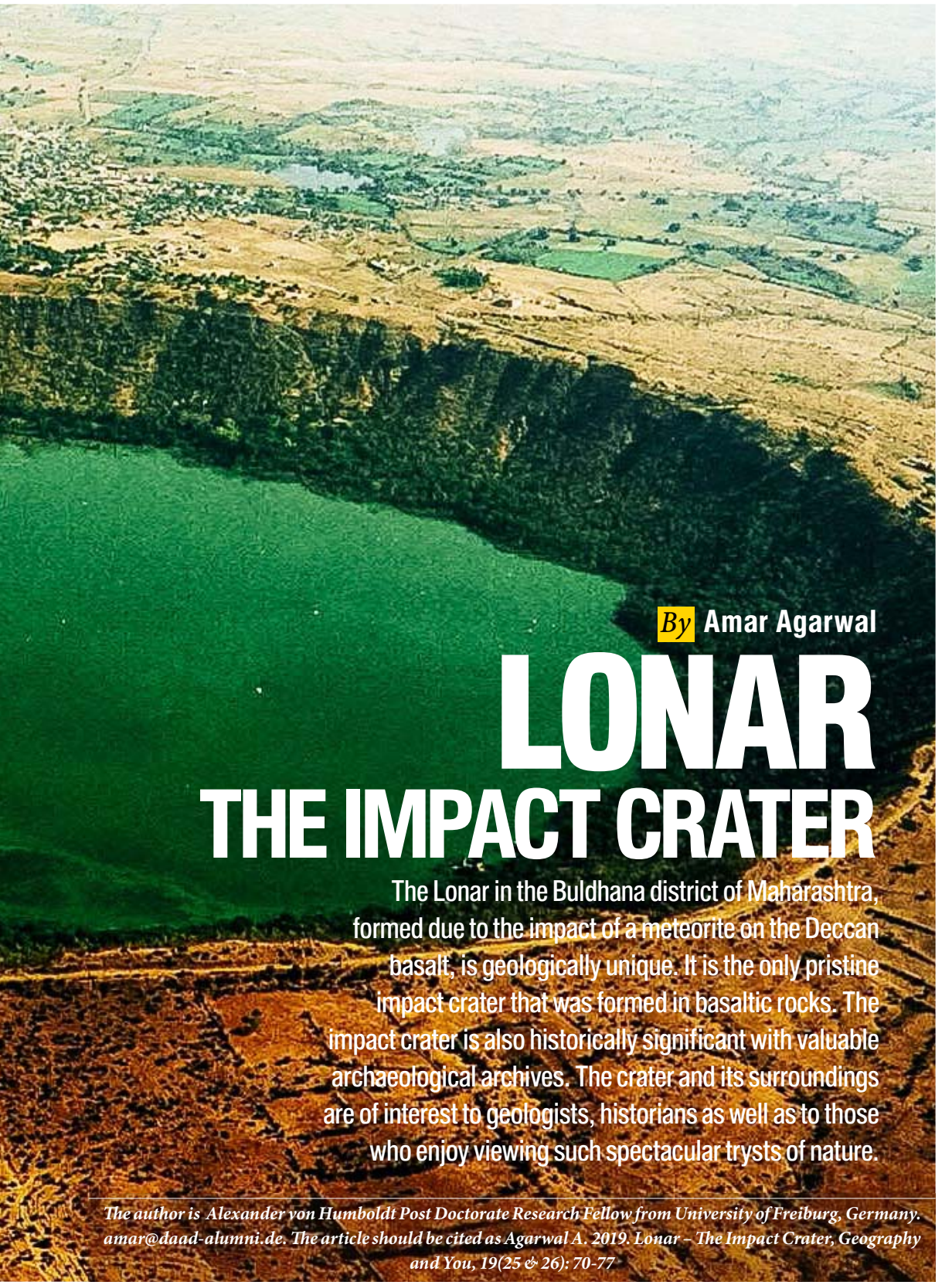
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Panoramic view of Lonar showing elevated rim developed due to asteroid impact. The brackish water lake is developed at the central depression.

PHOTO COURTESY: AUTHOR



By **Amar Agarwal**

LONAR
THE IMPACT CRATER

The Lonar in the Buldhana district of Maharashtra, formed due to the impact of a meteorite on the Deccan basalt, is geologically unique. It is the only pristine impact crater that was formed in basaltic rocks. The impact crater is also historically significant with valuable archaeological archives. The crater and its surroundings are of interest to geologists, historians as well as to those who enjoy viewing such spectacular trysts of nature.

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Ruins of a small ancient temple on the eastern part of the Lonar crater. It is one of the numerous temples surrounding the site. Most of them were built around the 12th century and are fine examples of the Hemadpanthi architectural style of the Yadava period.

PHOTO COURTESY: AUTHOR

Impact craters form when asteroids or meteoroids collide with the surface of another larger planetary body (the target) at hypervelocity speed, typically between 36,000-108,000 km per hour. Meteoritic impacts have the potential to change the landscape and environment of the surface of any planetary body such as the earth or the moon, within a blink of an eye.

Impact cratering is one of the most important geological processes that has modified terrestrial and extra-terrestrial landscapes and has been the cause of at least one mass extinction on earth. The famous meteoritic impact—the Chicxulub event (considered responsible for dinosaur extinction), took place 64 million years ago at the eastern coast of Mexico. This event decreased the biodiversity of the earth to less than 10 per cent. The energy delivered by the projectile (diameter of 11-81 km) was equivalent to 21-921 billion Hiroshima atom bombs.

Until now 205 meteor impact structures have been discovered on earth, of which three are present in India

Upon collision of a meteorite with a target, a high energy shock wave travels through the meteorite and the target and causes substantial crustal damage and heating. At the point of impact, the pressure and temperature exceed 100 gigapascal (GPa) and 2500°C respectively (Kenkmann et al. 2014). As a result, the meteorite and the target near the point of impact are subjected to evaporation, melting and solid-state deformation. A part of the target is blown away, excavating a roughly hemispherical depression called the transient crater cavity. This transient crater cavity consequently transforms into an impact crater, due to gravity.

An impact crater has a rim, wall and floor. The crater rim is usually slightly elevated from the surrounding. The crater wall is inward (steeply) sloping and is made up of intensely deformed target rocks. Within the crater wall, large scale deformational features such as thrust wedges and melted intrusive dykes are common. The crater floor is morphologically featureless in case of small craters (< 3-5 km) which are also called simple craters, such as the Lonar in India. In the case of larger craters, the crater floor is marked by a central peak made up of intensely deformed subsurface target rocks. These are complex craters—an example of which is found in Ramgarh, India. In both simple and complex craters, the crater floor is formed by impact breccia and melt, below which are the shocked target rocks. Most of the blown-away material is deposited on the crater rim and around the impact crater. This material forms the ejecta blanket. The shocked material in the ejecta blanket is a tell-tale sign of the impact process and has unique features that can be identified under a microscope, in field, or by remote sensing satellites.

Geological Significance

Until now, 205 natural impact structures have been discovered on the earth, of which three may be found in India—Dhala in Madhya Pradesh, Ramgarh in Rajasthan and Lonar in Maharashtra. The Dhala crater is about 11 km in diameter and formed 2.5 to 1.7 billion years ago (Pati et al. 2010); the Ramgarh crater is about 10 km in diameter and formed 166.1 to 163.5 million years ago (Kenkmann undated); and, the Lonar crater is the smallest and youngest of the three—1.88 km in diameter and formed 15 to 50 thousand years ago due to the impact of a chondritic meteorite on the Deccan Basalt (Agarwal et al. 2016; Nayak 1972; Misra et al. 2009). In comparison to the Chicxulub impact event (crater diameter of about 200 km), the Lonar event was quite small and



therefore did not destroy the flora and fauna in the adjoining area. Lonar is also the only terrestrial impact crater formed on a basaltic target which did not experience any post-impact deformation. The Dhala and Ramgarh craters are old and therefore have been affected by erosion, with a large parts of the crater morphology being removed. The Lonar impact structure, on the other hand, is pristine and its morphology is well preserved—owed, in part, to the semi-arid climate of the region.

The Lonar impact structure is marked by a 135 m deep near circular depression, which is the impact crater. The crater floor comprises of 30–100 m thick unconsolidated post-impact sediments, which are underlain by nearly 225 m of impact breccia. The crater is filled with a shallow brackish lake which is fed by a small stream entering the crater from the northeast at the head of the Dhar canyon. At the confluence of the stream and the lake within the crater, a delta is formed, which is used by the local farming communities. The Lonar impact structure has a slightly elevated crater rim with steep inner slope and gentle outer slope. The inner slope is made up of fractured and brecciated flows of the Deccan Basalt. Six different flows of basalt are exposed in the inner crater wall. They have a similar mineralogical composition and are separated from each other by thin paleosol layers. The basalt flows present numerous small faults and various degrees of fracturing and brecciation. The density and orientation of microfractures show a clear connection with the distance from the crater. However, the rock magnetic parameters were not affected by the impact.

The outer slope of the crater rim has a continuous blanket of ejecta extending from the rim crest outward up to a distance of 1350 m. In fact, melt rocks with shock features discovered in the ejecta blanket around the Lonar crater, confirmed its meteoritic impact origin (Nayak 1972). The Lonar crater was recognised as a National Geological Monument way back in 1979 by Geological Survey of India.

PHOTO COURTESY: AUTHOR



Lonar, viewed from the south-eastern crater rim. The raised rim and near circular lake is characteristic of meteorite impact—initially believed to be of volcanic origin. It is the world's largest and only hyper velocity impact crater in basaltic rock.

Archaeological Significance

In addition to the above described geological significance, the archaeological importance of Lonar crater is noteworthy. The lake and village near it are said to have derived the name from Lonasura—a mythological demon who was slayed by Lord Vishnu and pushed into the netherworld at the place where the lake lies. There are about 15 archaeologically valuable temples around the Lonar crater belonging to Hindu gods and deities built between 6th and 12th century CE by different dynasties (www.bl.uk). The style of architecture and wall-carvings are similar to that of the Khajurao. The temples are in various degrees of preservation. Presently they are under the protection of Archaeological Survey of India.

Way Forward

Lonar crater is an extraordinary feature with immense geological and historical importance. It is the one of the few inland brackish water lakes in India, which is also highly alkaline



1&2. The Kamalja Devi Temple overlooking the Lonar Lake is dedicated to goddess Padmavati; 3. Inside view of the well-preserved Gomukh Temple at the head of the Dhar canyon in the northeastern crater rim; 4. Google image of the Lonar marking the position of outcrops A and B. The outcrop 4A is coarse ejecta in the outer slope of the north-western segment of the crater rim while 4B is fine ejecta in the outer slope of the northern segment of the crater rim.

(Borul 2012) making it a hotspot of a wide range of fauna and flora, including numerous endemic species and microbial biodiversity. This world renowned site needs enhanced protective measures to stop solid and liquid waste being dumped in and around the crater. At present, most of tourists visiting the area belong to nearby cities. Efforts should also be made to convert it into an important tourism site for national and international tourists.

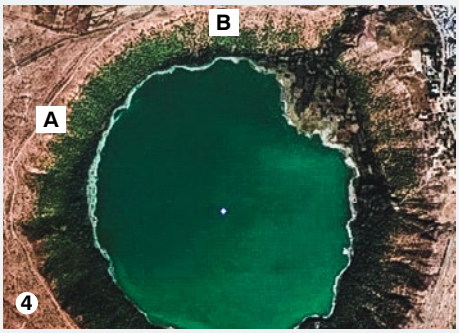
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Towards India's Geoheritage Conservation



The Society of Earth Scientists (SES) and Indian National Science Academy (INSA) have been working towards putting a legislation in place on the conservation of India's geological sites. On August 5-6, 2019 a brainstorming session on 'Conservation of Geoheritage: Current Scenario and Future Action Plan' was held at INSA in an effort to further this cause. Prominent geoscientists from all across the country deliberated on the proposed draft bill during the brainstorming session. Earlier, on July 21, 2019 a march titled 'Walk to Save our Geoheritage' was organised to sensitize and generate awareness about India's geoheritage at several locations across the country. Simultaneously held in Jodhpur, Udaipur, Chandigarh, Lucknow, Hyderabad and Visakhapatnam the march invited a lot of interest and enthusiasm among the geoscientists, students, conservationists and earth lovers alike. SES has submitted the draft bill along with a status paper to several ministerial offices for due consideration. *—Inputs from Ramesh G and Ramesh Gugloth, Hyderabad*

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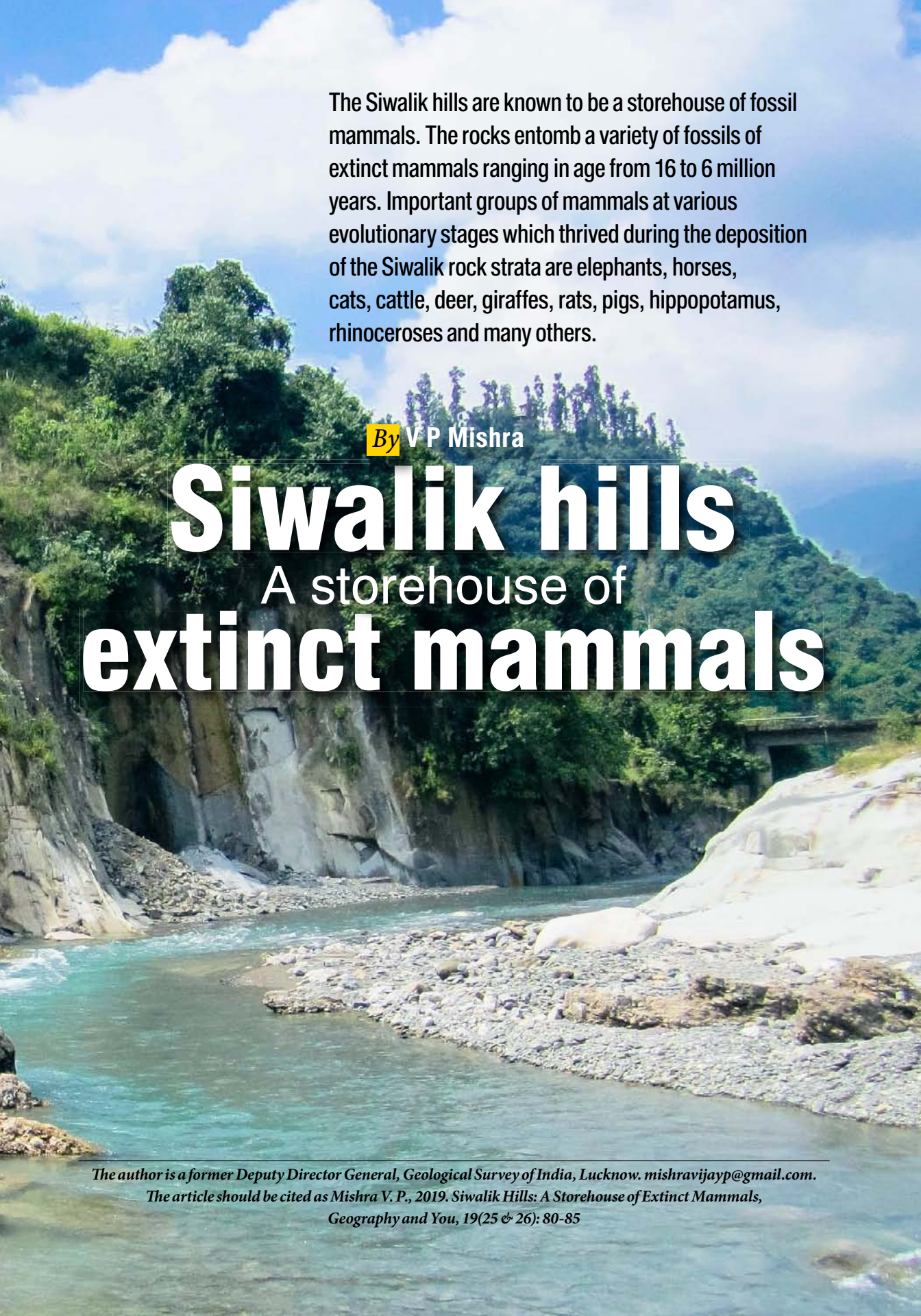
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Siwalik is the youngest Himalayan mountain belt, stretching from the river Indus in the west to the Brahmaputra in the east. The region is one the richest storehouses of antiquarian mammalian fossils in the world.



The Siwalik hills are known to be a storehouse of fossil mammals. The rocks entomb a variety of fossils of extinct mammals ranging in age from 16 to 6 million years. Important groups of mammals at various evolutionary stages which thrived during the deposition of the Siwalik rock strata are elephants, horses, cats, cattle, deer, giraffes, rats, pigs, hippopotamus, rhinoceroses and many others.

By **V P Mishra**

Siwalik hills
A storehouse of
extinct mammals

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The article should be cited as Mishra V. P., 2019. Siwalik Hills: A Storehouse of Extinct Mammals, Geography and You, 19(25 & 26): 80-85

The low hill ranges of 'Siwalik' exposed between the mighty Himalaya and the plains of the Indian subcontinent form the foothills of Himalaya. This range is about 2400 km long, from the Indus River in the west to the Brahmaputra River in the east, with a gap of 90 km between the Teesta and the Raidak rivers in West Bengal/ Assam. The width of the Siwalik hills varies from 1000 m to 5000 m with an elevation of 1500 m to 2000 m, and supports a variety of fauna and flora. The term Siwalik (or Shiwalik) is considered to have originated from the Hindi and Nepali term 'Shivalik Parvat' and derived from the hills of the same name in Haridwar, Uttarakhand. Shivalik is said to mean 'tresses of the Lord Shiva'. These hills are made up of clay, silt, sandstones and conglomerates brought down between 16 million to 6 million years ago, by numerous fast flowing rivers arising from the then rapidly rising mountain mass in the north.

The hills record the signatures of various episodes of the rise of the Himalaya. The Siwalik is composed of 5000-6000 m thick succession of sedimentary rocks of fluvial nature. Consequent to the rise of the Himalayan mountain chain, there seems to have been a progressive increase in moisture content and temperature, which helped support thick forest vegetation. These climatic conditions therefore, helped the existing Siwalik fauna multiply rapidly and numerous forms of elephants (proboscids), horses (equids), cattle (bovids), pigs (suids), giraffes, apes, rhinos, deer, rats (rodents) and cats (carnivorous animals) thrived in large numbers.

The Fossil Store House

As the region contains numerous mammalian and other vertebrate fossils, intensive explorations and research have been carried out by geoscientists from across the world. Since its inception in 1851, scientists from the Geological Survey of India (GSI) have worked on Siwalik rocks and published exhaustive memoirs on fossil mammals. This research has helped recover fossils of fish, few amphibian, snakes and birds, crocodiles, tortoises, molluscan shells, leaf impressions and fossil wood in addition to the mammalian fossils.

Complete vertebrate skeletons have not yet been found in the Siwalik rocks and their rarity can be attributed to the fact that dead animals are eaten by scavengers like vultures in terrestrial conditions before they get buried over a period of time. Also, during the deposition, various bones get disarticulated and/or preserved in isolation.

While the Siwalik strata as a whole is quite fossiliferous, certain geological sections yield more fossils than the others such as Markanda Valley and Nurpur (Himachal Pradesh), north of Chandigarh (Haryana & Punjab) and Uttarbaini and Ramnagar (Jammu & Kashmir). These geosites have earned popularity because of their easy accessibility and therefore, need to be preserved as geoheritage sites.

Vertebrate fossil collections from Siwalik rocks are innumerable, some systematically undertaken done while others have been collected done by amateurs as curios. Perhaps countless specimens have been destroyed by the local inhabitants of the region who regarded the fossils as bones of 'demons' and hence inauspicious.





Siwalik Fossil Park and its museum at Saketi, Himachal Pradesh, is a notified geoheritage monument. The park was established by the Geological Survey of India in 1974.

The ancestors of modern Indian mammals lived in the Siwalik. Fossils of their evolutionary stages have been found here in abundance.

Spectacular vertebrate collections from the region made during the 19th and 20th centuries are housed in museums across the world such as the Indian Museum, Kolkata, British Museum, London, Paris Museum, France, American Museum of Natural History, New York, Yale Peabody Museum, Connecticut, Wadia Institute of Himalayan Geology, Dehradun, Panjab University, Chandigarh, Siwalik Fossil Park, Saketi (Himachal Pradesh) and numerous other institutions and universities world over (Verma, Mishra and Gupta 2002).

Based on the recovery of isolated fossils of jaw fragments, skulls, teeth, vertebrae, scapular fragments, limb bones, ribs, etc., the important groups of mammals found here are rats (rodents), rabbits (lagomorphs), pigs (suidae), hippopotamus, Camels (camelids), ruminants (tragulids), deer (cervids), giraffes (giraffids), cattles (bovids), tapirs, rhinos (rhinoceratoids), horses (equids), elephants (proboscideans), insectivores, primates and flesh eating animals like cats, lions, bears, dogs, etc. (carnivores) (Table 1).

The recovery of a large number of fossils of several types of carnivores including sabre-toothed tiger apart from pigs, rats, deer, cattle, giraffes, rhinos and elephants indicates that they had proliferated during the deposition of Siwalik sediments. However, fossils of horses and hippopotamus though very common in Siwalik rocks—have limited varieties. The region has yielded lesser varieties of fossils of camels, rabbits, and insectivores. The fossil finds also reveal show that several cattle, buffaloes and oxen of various sizes and groups inhabited the Siwalik forests, of which many perhaps migrated westward. Present day cattle species in India form only an insignificant part of the large population and variety of the Siwalik bovids. Even though no giraffes are currently found in India, four varieties belonging to the family Giraffidae lived 10 to 1 million years ago in the Indian Siwaliks. Fossils of *Sivatherum giganteum*, the largest known giraffid and perhaps the largest ruminant of all times were commonly found in the Siwalik hills of Himachal 3 to 1 million years ago. Fossils of an extinct species of Hippopotamus, *Hexaprotodon sivalensis* (3 to 1.5 million years old) are also commonly found here. This species was almost of the same size as current living Hippopotamus but possessed six

Table 1: Mammalian groups found in fossil with their earliest occurrence in Siwalik rock strata

Mammals (Fossils)	Geologic time in million years
Rabbits (lagomorphs)	3
Hippopotamus	3
Camels (camelids)	3
Deer (cervids)	3
Apes	7.8
Horses (equids)	10.5
Carnivores	11
Rats (rodents)	15
Cattles (bovids)	15
Tapirs	15
Rhinos (rhinoceratoids)	15
Giraffes (giraffids)	15.5
Pigs (suids)	16
Ruminants (tragulids)	16
Elephants (proboscideans)	16

Source: Reference 1, and several research publications on Siwalik mammals.

Siwalik Fossil Specimens

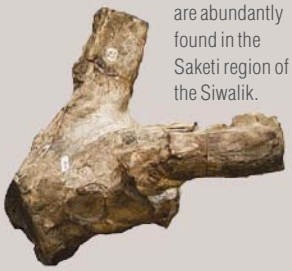


The giant elephant printed on the 1951 postal stamp is of *Stegodon ganesa*, which existed in abundance in the Siwalik region during 7 to 1 million years ago.

Commemorating the Indian geological survey centenary on January 13, 1951 a stamp was released by the Indian government.

Skull with horns of *Hemibos triquatricornis* Collected from Khera, dist. Sirmaur (H.P.)

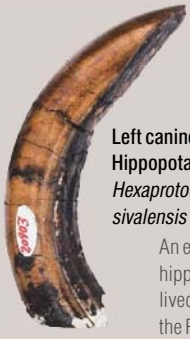
An extinct bovid, the *Hemibos triquatricornis* are abundantly found in the Saketi region of the Siwalik.



Lateral view of broken part of vertebra of *Gavialis sp.* crocodile

The gharial (*Gavialis gangeticus*), is the only living species of Gavialis. The other *Gavialis bengawanicus*, once found in abundance in the Siwalik, is now extinct.





Left canine of Hippopotamus *Hexaprotodon sivalensis*

An extinct species of hippopotamus that lived in India between the Pliocene and the Pleistocene.

Part of horn of large sized cattle. *Bovidae gen. et sp*

The Bovidae are the biological family of cloven-hoofed, ruminant mammals that includes cattle. It was represented by a reasonable number of specimens in the Siwalik during the Pleistocene.



incisor teeth, a relatively wider mouth and longer lower jaw.

Several groups of rhinoceros inhabited the Siwalik forests representing different lines of phylogenetic development. In India we now however, have only one species of rhinoceros restricted to the hilly tracts adjoining the plains of Assam and West Bengal.

Elephants present a long history of existence in the Siwalik region. Their fossil records from 16 million to 1 million years ago are profuse (over 20 types of elephants) and are morphologically diverse and phylogenetically progressive. These attained maximum anatomical development around 2.5 to 1.5 million years ago in the Siwalik hills. An extinct elephant named Stegodon had tusks over 3 m in length. The elephant group faced nearly complete annihilation due to the impact of Himalayan orogeny and augmented glacial conditions about 1.5 million years ago. The highly evolved extant *Elephas indicus* is the only surviving Indian representative of the great stock that flourished millions of years ago in the Siwalik region.

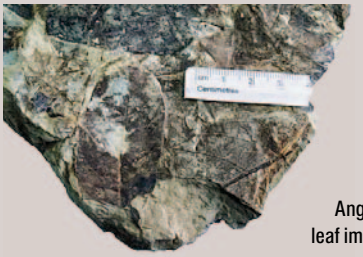
Primate fossil material is very scanty. Fossils of early primates Dryopithecus and Ramapithecus have been recovered which are 15 to 8 million years old. Fossils of stone tool using hominoids—akin to Australopithecus, have so far not been found in the Indian Siwalik strata.

The most important and remarkable aspect about the Siwalik mammals is their complete disappearance around 1.5 million years ago. Faunal extinction occurred with climatic deterioration which began with the onset of another Ice Age around 1.5 to 2 million years ago. The climate became unsuitable for highly evolved vertebrate communities and many of these mammals became extinct while some migrated to areas in the north, the Indo-Gangetic plains and also towards the Narmada valley as can be seen from the recovery of fossils of primitive elephants,



Molar tooth of extinct elephant *Stegodon sp.*

Stegodon, meaning 'roofed tooth' because of the distinctive ridges on the animal's molars, were more common than Asian elephants in this region.



Angiospermous leaf impressions in Siwalik rock

The comparable extant taxa of the present day indicates the existence of tropical to sub-tropical evergreen to semi evergreen forest with humid climate in the area during the deposition of the Siwalik sediments.



Siwalik is one of Asia's biggest fossil regions. In parks such as Saketi, outdoor displays of life sized models of extinct species adds a new dimension. Models of the sabre tooth cat, elephants, hippopotamus, giant tortoise, etc., are detailed and life like.

horses, rhinos, antelopes, bovids, hippopotamus and other mammals (about 40,000 to 100,000 years old) that have been found in the Gangetic alluvial region at Kalpi, Allahabad and Varanasi in Uttar Pradesh and Bhagalpur in Bihar. Several mammalian fossils including those of sabre-toothed tiger have been found in 200,000 year old rocks in Bankura district of West Bengal.

Siwalik Fossil Park, Saketi

A Siwalik Fossil Park has been developed by GSI, in collaboration with the Himachal government in Markanda valley of Sirmaur district. A large number of vertebrate fossils have been collected from Saketi. A museum in the park displays life-size models of extinct species of Siwalik vertebrates. It is a significant step towards preservation of prehistoric animal sites, restoration of their natural environment and its utilisation for scientific, educational and recreational purposes.

Way Forward

A large variety of modern Indian mammals had their ancestors lie in the Siwalik region. Fossils of evolutionary stages of several modern day mammals have been found here. These study of Siwalik mammalian fauna has helped to build up the evolutionary history of many mammalian groups. Presently only one geosite at Saketi (Himachal Pradesh) has been declared as National Geological Monument. Many more geosites of the Indian Siwaliks have also yielded prolific mammalian fossils which need to be conserved as geoheritage sites for future generations.

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ZAWAR
WORLD'S OLDEST

ZINC MINING AND METALLURGY SITE

By **Pushpendra Singh Ranawat**

Zawar in Rajasthan is the world's oldest mining and metallurgy site, dated to have existed around 750 BCE, marking ancient India's acumen in the sector. Zinc and lead mined from the Aravalli rocks, extracted through a unique distillation process was shipped to Europe to bolster brass instrumentation for the industrial revolution. A geo-archaeological site of this importance thus mandates a holistic conservation.

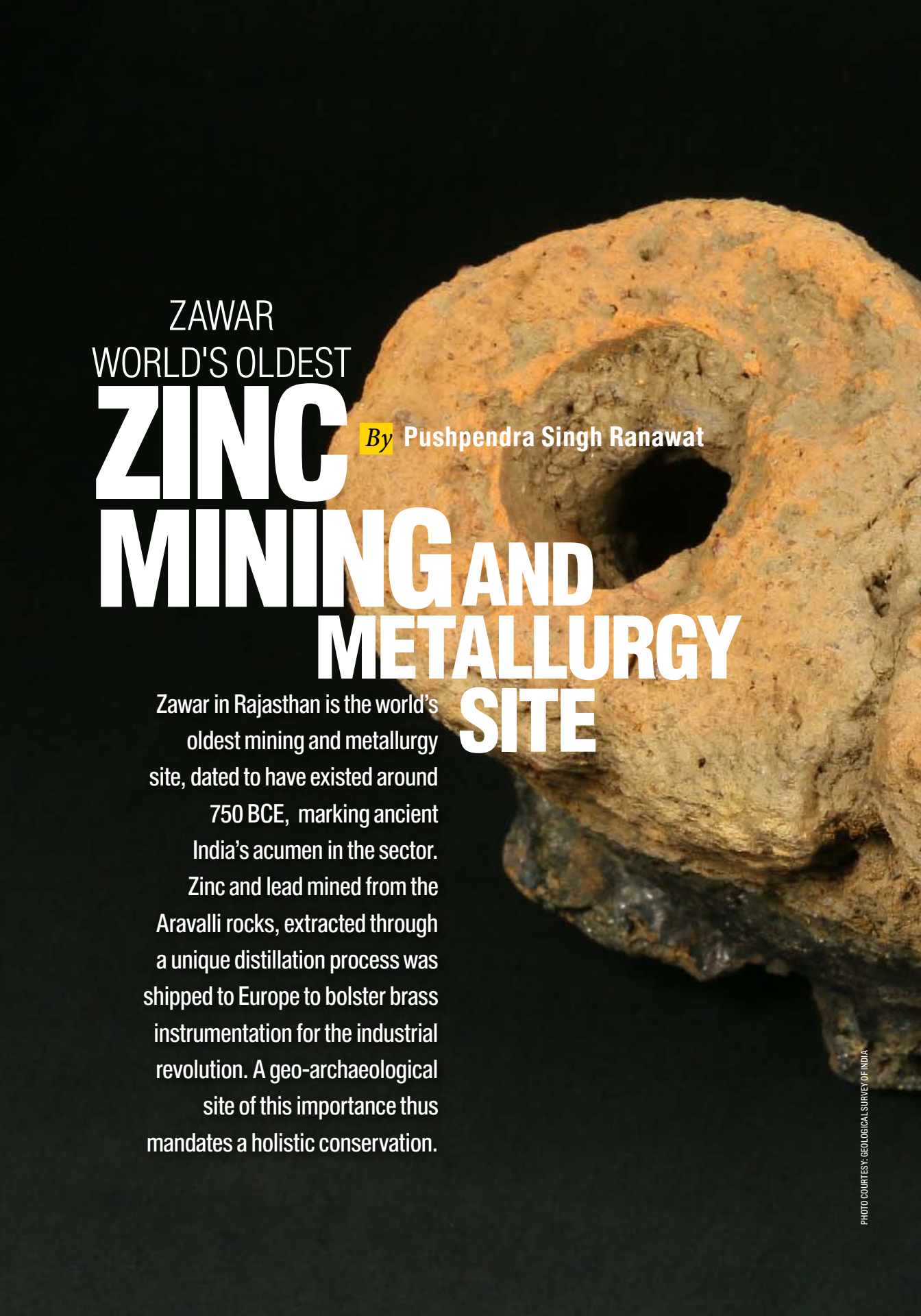


PHOTO COURTESY: GEOLOGICAL SURVEY OF INDIA



Zawar is one of the oldest mining sites in the world. Specimen of retorts used for zinc smelting are found abundantly in the area. The valley of Tiri in its vicinity is filled with heaps of slag and retorts.

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The western region of India is endowed with a rich geodiversity—a curious and unique mix of landforms and natural resources. Through centuries the resources of the region propelled a thriving global trade. Mewar in the southern part of modern day Rajasthan is one such example. Its 1800 million-year old Aravalli not only provided protection against enemy attacks but also held a precious repository of myriad metals, minerals and building materials. Of these, notable were gold, copper, lead, zinc, silver and iron, ores of which continue to be exploited at Zawar, Rajpura-Dariba, Agucha, Pur-Baneda Belt, Kayad, Khetri etc.

Zawar however, is of singular interest as it is recognised as the world's first zinc smelting site (Willies et al. 1984). The site also contains numerous natural as well as heritage elements. Zawar's zinc-lead deposit is located in a rugged and thickly forested area about 40 km south of Udaipur, Rajasthan. This approximately 20 km long mineralised belt has rich zinc-lead deposits hosted in hard, compact, siliceous dolomite (Ranawat 2016).

Zinc is a fascinating silvery white metal (pseudo-silver/mock-silver) which produces a hard golden hued alloy with copper—brass (pseudo-gold). Moreover, the significance of zinc in medicinal use has been documented in several ancient Indian texts, such as the Charaka Samhita (900-600 BCE) and Sushruta Samhita (~600 BCE). Interestingly, Kautilya's Arthshastra (3rd century BCE) chronicles prospecting guidelines for zinc ores (Biswas et al. 1996; Galib et al. 2011). Zinc-containing dateable ancient coins too attest the metal's common use in those times.

Archeological studies by the British Museum, London; M S University of Baroda; and, Hindustan Zinc Ltd. have conclusively ascertained that metallic zinc produced by distillation was undertaken for the first time at Zawar, perhaps even earlier than 765 BCE (Willies et al. 1984). The American Society of Metals recognised Zawar as an 'International Historic Landmark' in 1988 and remarked—"at this site are preserved the zinc retort distillation furnaces and remnants of related operation. The village artifacts together with temple ruins attest to the success of this metallurgical technology. This operation first supplied the zinc for making of brass instrument in Europe, a forerunner of the Industrial Revolution".



PHOTO COURTESY: M. N. MISHRA



A pair of Jain temples built between the 15th and 17th century in Zawar lies in a state of neglect. Many such temples are located in Zawar as it was a major Jain pilgrimage site during the time.









Discarded clay retorts used for smelting were reused as construction material for huts in the Zawar area indicating a thriving township back in those days. Invasions in the 18th century destabilised and finally ended a high tech industry.

The History of Zawar

Carbon dating of the timber used as support in the underground mines and the use of brass (containing >20 per cent zinc) in Ayad and other archeological sites of Mewad proved that the region used the metal fairly early in human history. Its impactful use continued at a slow but regular pace essentially because mining was undertaken by manual chiseling, as opposed to explosives usage and mechanised mining of today. Mining and smelting activities saw ups and downs with various invasions and wars. Large metal revenue was recorded from this region during the reign of Ashoka (268-232 CE) as also during the reign of Rajah Shiladitya Guhilot, through the reign of Maharana Lakha (Lakshya Singh 1382 CE) and down to Maharana Raj Singh (1653-1680 CE) in whose accounts an income of INR 17,96,944 is mentioned. However, political turmoil further on forced the closure of these mines altogether in by the 18th century.

Despite numerous remains of temples and dwellings found in Zawar being vandalised, a dozen or so stone-slab inscriptions have incredulously survived. These rock inscriptions tell us of a thriving township and its socio-economic stature. Most of them are written in Devnagari script, in Prakrit or Sanskrit—but later day Brahmi and even Mahajani scripts were present indicating a long period of continuity (Kumar 2017). The earliest recorded Sambholi inscription of 646 CE in fact proved beyond doubt the importance of this thriving industrial town with a well managed mining and smelting activity.

During the Rawal-Rana-era (646-1600s CE), mining, smelting and trading in Mewad was certainly in the hands of Jain merchants and the state provided protection and also collected tax. Inscriptions also indicate turbulent years—1540,



1554 and 1591, in Mewad's history when the area was under the control of Maharana Udai Singh (1540-1572 CE) and Maharana Pratap (1572-1597 CE). Mining activity at Zawar seems to have slowed during the reign of Maharana Pratap due to Mughal hostilities. It, however, resumed full vitality after 1615 CE following the Mewad-Mughal Treaty between Amar Singh and Mughal emperor Jahangir. Records of revenue from this mine during the reigns of his son Jagat Singh (1628-1652 CE) and his successor Raj Singh (1653-1680 CE) are also available. Thereafter, production may have ceased, first due to reemergence of hostilities, and second due to the increase in depth of ore seams that may have made commercial activity non-profitable. Modern mining and smelting however made way into the region in 1966 with the public sector undertaking Hindustan Zinc being established (www.hzlindia.com).

Mining During Ancient Times

The rocks of Zawar belong to the Proterozoic Aravalli metasediments (~1800 mya). The highly folded but low-grade metamorphosed sedimentary—phyllite, quartzite and dolomite host metal ores galena (silver bearing) and sphalerite (zinc suphide, cadmium and mercury bearing) in steeply dipping/plunging lodes, veins and ore bodies.

To mine the ores, the ancient miners dug downwards with iron club-like hammer and chisel, starting from the top of the hill. Open-cast pits for wider ore bodies can be seen, while narrow mineralisation lodes were followed underground through small openings (gophering) using wooden ladders. Flared pillars can be commonly seen in underground stopes (open mined-out hollows) that support the roof— some of which are about 100 m below the surface and can be explored to about 1100 m through 4-5 m wide tunnels. As






Stone inscriptions at the temple sites throw light on the medieval history of this ancient industrial township

the host-rock is hard-compact siliceous dolomite, no timber supports were needed for underground mining. An innovative haulage and hoisting system was evident in these old workings that is still incredibly stable. Clay oil-lamps have been recovered from intermittent alcoves in the old mines. Open dewatering drainage ducts made entirely of wood may be seen, but since most of the old workings were above the water-table, these may have been used primarily during the monsoon.

Ancient Metallurgy

The rich concentrated portion of the ore was mined. Once the rock was extracted, it was pounded in-situ within a rock depression, the ore hand-sorted and stacked separately for smelting. Lead and silver from galena were extracted through a process of smelting. Extraction of metallic zinc through smelting was, however, difficult as the boiling point of zinc (907˚C) is lower than the temperature needed to smelt its ore (1000˚C). This means that upon heating, zinc converts to vapour. This vapour needed to be condensed in order to procure metallic zinc.

The ancient smelting process commenced with the roasting of the zinc ore. This drove off the sulphur and helped convert the ore to zinc oxide. The roasted material was then mixed with reducing agents. Although the exact method used in Zawar is yet to be deciphered, recipes used to reduce ores are well chronicled in ancient Indian literature. Numerous clay retorts in three assorted sizes—elongated conical pots, wide at the open top and tapering to a small rounded end were found in the mines. It has been surmised that the ones which were 350 mm long and 120 mm in diameter were perhaps used for zinc, the ones 200 mm long and 80 mm in diameter for lead, and the really small retorts 150 mm long and 90 mm in diameter for perhaps silver. The open end of the retort is covered with a clay funnel which was attached to a long tube. The retorts were placed in an inverted position upon a clay perforated plate, 55 mm in thickness, the holes assisting air circulation. The clay plates were then placed upon a furnace for firing and smelting.

These single use clay retorts and the resultant slag can be seen strewn in abundant mounds in the area, testifying to a thriving smelting industry with not only skilled miners and smelters but also highly skilled potters who could shape these fluted and fine clay items. Myriad fused retorts with partially melted and wrinkled surface indicate that these were possibly heated to around 1500˚C . Interestingly, compound and hut walls of the locals stand testimony to the extensive use of the discarded retorts for its construction. However, metal ingots of antiquity have not yet been found during the archeo-metallurgical excavations at Zawar. This sophisticated pyro-metallurgical operation as recorded here is still basic to all high-temperature distillation operations undertaken world-over even today (Craddock 2017).



Left to Right: 1. View of the elegant Ramanath Kund (step-well) and the Ramanath (Vishnu) Temple built by Rama Devi, the daughter of Maharana Kumbha in 1497 CE (Chaitra Shukl Saptami, Sunday VS 1554); 2. Old Tidi Dam, now washed out, rebuilt during the reign of Maharana Amar Singh (most difficult days of Mewad history) by his five sons in early 1600s; 3. A timber ladder in an old mine; 4. Heaps of slag and retorts prove a thriving metal smelting industry in the past at Zawar area; 5. A stunning discovery of intact ancient zinc smelting furnaces at Zawar, which gives us an idea of ancient metallurgy; 6. Ancient underground mines at Zawar have narrow passages, though at places small stopes (mined out halls) with flared pillars are also present; 7. The three sizes of clay retorts (RtL, RtM, RtS), Funnel cap (F), tube (T), perforated plate (PP), top assembly of cap, tube over a retort (RFT), and slag (S) from Zawar smelting site, which are lying strewn in abundance in the area; 8. A historically significant hill-top fort with vaults, underground chambers and tunnel built in early 1300s CE; 9. Close-up of a vandalised Jain temple; 10. One of the four perforated plates per furnace on which the retorts sat with their condenser necks in the large holes.



Temple dedicated to local deity, 'Zawarmata' is comparatively well preserved. The temple is maintained by the Bhil tribe.

PHOTO COURTESY: M. N. MISHRA

Conservation of the Geo-Archaeological Site

There are several ancient zinc-lead-gold mining and metallurgical sites in India which are some of the oldest in the world. These ancient monuments have stored the skills and knowledge of our ancestors. Conservation of these geo-achaeological sites are of utmost importance. Zawar, therefore has the potential to develop as a global geopark showcasing not only India's rich geoscientific knowledge but also its rich architecture—ancient temples, baoris, palaces and more. The site was long neglected but of late its importance is beginning to be realised. It is hoped that concerted attempts to develop Zawar as an ancient seat of geo-achaeological learning will bear fruit. GY

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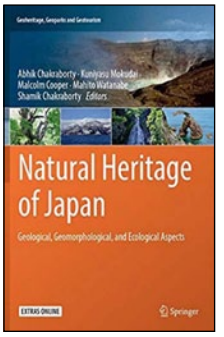
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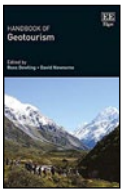
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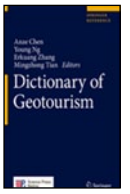
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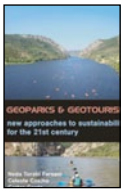
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