SCHOOL OF EARTH, OCEAN AND ATMOSPHERIC SCIENCES

GOA UNIVERSITY

Exam:

Roll No: 21P045011

LABORATORY CERTIFICATE

This is to certify that Mr. ~~/Ms.~~ Toufiq Malgundkar

has satisfactorily completed the course of practical for M.Sc in Applied Geology.

Experiments conducted are pertaining to paper GLC-122

Practicals prescribed by the University for Msc Part II class, during the academic year 2022 - 2023

DEAN

SEOAS

Faculty member in-charge

Dr. Anthony Viegas
Vice Dean (Academic),
School of Earth, Ocean
& Atmospheric Sciences,
Goa University,
Goa - 403 206.

GUJARAT AND RAJASTHAN FIELD REPORT 2023

Toufiq Malgundkar

Msc Part 2

School of Earth, Ocean and Atmospheric Sciences, Applied Geology

21P045011

Acknowledgement

I take this opportunity to thank the Goa University for allowing the students to go for a field trip for the fulfilment of the course MSc Applied Geology. Thank you for providing financial and allowing us to engage in field activities. I want to pass my regards to the entire part-2 class of geology for their support and participation of the trip. My humble appreciation goes to the dean of department of 'School of Earth, Ocean, and Atmospheric Sciences' Professor Chandrashekar U. Rivonkar, and special thanks go to the vice-dean Professor Anthony Arthur A. Viegas for not only making prior arrangement for the trip but also for accompanying us and providing guidance, moral support and proper understanding of what we were taught by explaining further.

I also want to thank Dr. Niyati Kalangutkar, program director for school applied geology, and Dr. Pooja Ghadi and Dr. Mahesh Mayekar for accompanying us, providing moral support, guidance and expressing concern to us. The trip became successful and knowledgeable because of your company.

I thank all the people that we met at different institutes like ONGC, Physical Research Lab (PRL), and Jhamarkotra Mine among others for giving us detailed information about the firms. I personally learnt a lot about phosphate/open cast mines. I extend my appreciation to my classmates and friends for their cooperation in discipline and adhering to the instructions. All this made the trip the most successful one.

Finally, I would like to thank my parents for their allowing me to the field trip and as well as for their support throughout the journey

CONTENT

Stratigraphy Of India

The geology of India is diverse. Different regions of India contain rocks belonging to different geologic periods, dating as far back as the Eo archean Era. Some of the rocks are very deformed and altered. Other deposits include recently deposited alluvium that has yet to undergo diagenesis. Mineral deposits of great variety are found in the Indian subcontinent in huge quantity. Even India's fossil record is impressive in which stromatolites, invertebrates, vertebrates and plant fossils are included. India's geographical land area can be classified into the Deccan Traps, Gondwana and Vindhyan. The Deccan Traps covers almost all of Maharashtra, a part of Gujarat, Karnataka, Madhya Pradesh and Andhra Pradesh marginally. During its journey northward after breaking off from the rest of Gondwana, the Indian Plate passed over a geologic hotspot, the Réunion hotspot, which caused extensive melting underneath the Indian Craton. The melting broke through the surface of the craton in a massive flood basalt event, creating the Deccan Traps. It is also thought that the Reunion hotspot caused the separation of Madagascar and India. The Gondwana and Vindhyan include within its fold parts of Madhya Pradesh, Chhattisgarh, Odisha, Bihar, Jharkhand, West Bengal, Andhra Pradesh, Maharashtra, Jammu and Kashmir, Punjab, Himachal Pradesh, Rajasthan and Uttarakhand. The Gondwana sediments form a unique sequence of fluviatile rocks deposited in PermoCarboniferous time. The Damodar and Sone River valleys and Rajmahal hills in eastern India Contain a record of the Gondwana rocks.

The Indian Craton was once part of the super continent of Pangaea. At that time, what is now India's south west coast was attached to Madagascar and southern Africa, and what is now its east coast was Attached to Australia. During the Jurassic Period about 160Ma, rifting caused Pangaea to break apart into two super continents, Namely Gondwana (To the south) and Laurasia (to the north). The Indian Craton remained attached to Gondwana, until the super continent began to rift apart about in the early Cretaceous, about 125 million 5 years ago (ICS2004). The Indian Plate then drifted northward towards the Eurasian Plate, at a pace that is the fastest known movement of any plate. It is generally believed that the Indian Plate separated from Madagascar About 90 million years ago (ICS2004), however some biogeographical and geological evidence suggests that the connection between Madagascar and Africa was retained at the time when the Indian Plate collided with the Eurasian Plate about 50 million years ago (ICS2004). This orogeny, which is continuing today, is related to closure of the Tethys Ocean. The closure of this ocean which created the Alpsin Europe and the Caucasus range in western Asia, created the Himalaya Mountains and the Tibetan Plateau in South Asia.

The current orogenic event is causing parts of the Asian continent to deform westward and Eastward on either side of the orogen. Concurrently with this collision, The Indian Plates ruptured on to the adjacent Australian Plate, for new larger plate, the Indo-Australian Plate. The earliest phase of tectonic evolution was marked by the cooling and Solidification of the upper crust of the earth's surface in the Archaean Era (prior to 2.5 billion years) which is represented by the exposure of gneisses and granites especially on the Peninsula. These form the core of the Indian Craton.

The Aravalli Range is the remnant of an early Proterozoic orogeny called the Aravali-Delhi Orogen that joined the two older segments that make up the Indian Craton. It extends approximately 500 kilometers from its northern end to isolated hills and rocky ridges into Haryana, ending near Delhi.

Early Paleozoic rocks are found in the Himalayas and consist of southerly derived sediment eroded from the crystalline craton and deposited on the Indian platform. During the Jurassic, as Pangea began to rift apart, large grabens formed in central India filling with Upper Jurassic and Lower Cretaceous sandstones and conglomerates. By the Late Cretaceous India had separated from Australia and Africa and was moving northward towards Asia. At this time, prior to the Deccan eruptions, uplift in southern India resulted in sedimentation in the adjacent Indian Ocean. Exposures of these rocks occur along the south Indian coastal Pondicherry and in Tamil Nadu. At the close of the Mesozoic one of the greatest volcanic eruptions in earth's history occurred, the Deccan lava flows. Covering more than 500,000 square kilometers area, the sea marks the final break from Gondwana.

Geology Of Gujarat

The state of Gujarat comprises an area of approximately 1,96,000 sq.km and is enclosed within the North Latitude 20°10° to 24° 50° and East Longitude 68° 40° to 74° 40°. Geologically Gujarat provides a wide spectrum of rock types of different ages. Whereas the Aravalli in the NE is as old as 2500 million years, the unconsolidated alluvium and beach material in its Central and Western parts, date back to a few thousand years only. All the important lithological types Igneous, Sedimentary and Metamorphic occur within the state. Geomorphologically, the State can be divided into three distinct divisions, viz.:

a) Gujarat-Mainland: The well-known agriculturally rich alluvial basin of Gujarat rises from the estuarine tracts between Narmada and Tapi rivers and extends 402 km northwards merging into the desert plains of Rajasthan and the Rann of Kutch. It is roughly 121 km wide. The eastern border of the basin is bounded by Aravali, Vindhya, Satpura, and Sahyadri hill ranges. The topography of the land is obviously controlled by the geological formations. The eastern part of the south Gujarat bordering the alluvial tract has a typical Deccan trap scenery up to Narmada valley. The hills are formed by circumdenudation leaving wide plateau at top, and a step like feature because of horizontal lavaflows and their differential weathering.

b) Saurashtra-Kathiawar Peninsula: The Saurashtra is bounded by Gujarat plains in the East and NE, by gulf of Kutch and Little Rann on the north, and on the SE by the Gulf of Cambay. The Arabian Sea borders the entire southern seaboard. The Central part of the region forms an elevated table land, from where most of the rivers rise and flow radially. The terrain generally slopes gently towards the peninsular margin to merge into the coastal plains and the great alluvial tract stretches to NE and east. The sedimentary rocks along the coast form almost a low flat country.

c) Kutch Peninsula: The mainland of Kutch is isolated by the Great Rann of the north and east, Little Rann on the SE, Gulf of Kutch on the south and rest by the Arabian sea. The central portion of Kutch forms a table-land sloping on all sides, the shape of the region is like a tortoise and hence the name. In general, there are three hill ranges, trending almost east-west. North-flowing rivers disappear in the Rann; others join the sea. The Banni is formed by sediments deposited by northern border of the main land and is composed of fairly good soil. The Rann is a dry bed of the remnant of an arm of the sea, which formally connected the Narmada rift with Sind and separated Kutch from the mainland.

LITHOSTRATIGHRAPHIC TABLE

Group	System	Rock Type	Localities	Age in millions of years
Quaternary	Recent and subrecent	Alluvium, Blown sand, Silts of Rann and Banni, Tidal flats and raised beaches.	Alluvial plains of Gujarat, Rann, Banni & Coastal deposits.	0.01
	Pleistocene	Miliolites	(i) Saurashtra coast from Gopnath northwards extending beyond Porbandar. (ii) Kutch area.	1
Tertiary or Kainozoic	Pliocene	Dwarka beds, Manchhar beds, Gypsiferous clays and sandy foraminiferal limestones.	Dwarka, Okha, Piram Island, Kutch.	12
	Miocene	Gaj beds-Highly fossiliferous clays and limestones. Agate Bearing conglomerates. Kand formations.	Saurashtra coast, Kutch	25
	Oligocene	Tarkeshwar clays.	Tarkeshwar (District:Surat) and Kutch.	40
	Eocene	Nummulitic limestones and clays.	Tarkeshwar area and Kutch.	60
Secondary or Mesozoic.	Cretaceous Eocene	Deccan traps with inter trappeans.	Parts of Sabarkantha, Panchmahals, Baroda, Broach, Surat and major part of Bulsar and Dangs Districts. Major part of Saurashtra and small part of Kutch.	
	Cretaceous	Himatnagar sandstones, Lameta (limestones). Bagh beds. Songir sandstones, Nimar sandstones, Wadhavan sandstone (Infratrappeans), Bhuj and Umia series sandstones	Himatnagar, Kapadvanj, Balasinor, Parabia, Dohad, Gabat, Narmada valley, Songir.Near pavagadh. Wadhavan, Dhrangadhra, Bhuj etc.	110
	Jurassic	Katrol series, Chari series, Patcham series (sand-stones, shales and limestones).	Kutch.	150
	Purana (Algonkian & Part of Cambrian)	Erinpura granite (Post-Delhi).	Palanpur, Danta, Idar, Modasa, Taranga, Dharoi, Virpur, Wanakbori, Godhra, etc.	1500
		Delhi System-Alwar quartzites, schists, and calc-gneisses, calcschists of Ajabgarh series.	Parts of Sabarkantha and Banaskantha, and Mehsana Districts.	
Archaean or Azoic		Aravali System-Micaschists, Phyllites, quartzites, etc.	Sabarkantha, Panchmahals, Baroda, Banaskantha.	4000
		Banded gneissic complex.	Baroda District.	

Geology Of Rajasthan

Rajasthan is endowed with a continuous geological sequence of rocks from the oldest Archaean Metamorphic, represented by Bhilwara Super-group (>2500 m. y.) to sub-recent alluvium & windblown sand. The geological sequence of the state is highly varied and complex, revealing the co-existence of the most ancient rocks of the Pre-Cambrian age and the most recent alluvium as well as windblown sand.

Rajasthan forms north-western part of the Indian Shield. The State exposes a variety of lithological and tectonic units ranging in age from Archaean to Recent times. Before going into details of Geology of Rajasthan, let us first see, geology time in general to make sense of terms in geology.

The basement rocks – the Sandmata Complex, Mangalwar Complex and Hindoli Group of Bhilwara Super group – occupy central and south-eastern plains. They are Archaean in age and comprise in general, granulite-gneiss; amphibolites, metapelite, paragneiss, calc-silicate rocks and greywacke (the older granite-greenstone belt) and metavolcanic, met greywacke (the younger granite-greenstone belt) respectively.

The Lower Proterozoic supracrustal rocks of the Jahajpur, Rajpura-Dariba, Pur-Banera and Sawar Groups of Bhilwara Super-group rest on the basement rocks of the Mangalwar Complex and host a number of lead, zinc and copper deposits.

The Proterozoic fold belts, viz., the Aravalli fold belt (the Aravalli Super-group) and the Delhi fold belt (the Delhi Super-group) occupies the southern and south- eastern, and south-western and north-eastern Rajasthan respectively. The Aravalli Super-group is represented by metamorphosed and complexly folded clastic sediments with minor chemogenic and organogenic assemblages with interlay red basic volcanic, whereas the Delhi Super group comprises mainly carbonates, metavolcanics, metasammites and metapelite, intruded by magmatic rock of Phulad Ophiolite Suite and syn-orogenic granites of Sendra- Ambaji, Baraith, Dadikar, Harsora, etc.

A number of base metal deposits are located in these belts as also other minerals.

The isolated hillocks of western Rajasthan constitute the Upper Proterozoic Malani Igneous Suite and the Erinpura Granite pluton. Eastern Rajasthan is characterised by the vast sedimentary stretch constituting the Vindhyan, which is juxtaposed against the rocks of the Bhilwara Supergroup along the Great Boundary Fault. The northern and north-western parts of the State exhibit Upper Proterozoic-Early Cambrian rocks of the Marwar Super group which are overlain by sedimentary rocks of different ages of Paleozoic and Mesozoic Era. Many industrial mineral deposits are found in these rocks. The Deccan Traps are restricted to the south-eastern part of the State in Chittorgarh-Banswara area.

FIELD REPORT

Day 1 –

Location- Lothal

22.4654° N, 72.2327° E.

The archaeological site of Lothal is situated in the Indian state of Gujarat. During the ancient Indus Valley Civilization, which flourished from around 2600 BCE to 1900 BCE, it was a significant port city. Archaeologists have long researched the location, but its geology and the presence of foraminifera have also yielded significant hints about its past.

Geologically, Lothal is located on the eastern side of the Saurashtra Block's Kathiawar Peninsula. The Arabian Sea to the west and the Indian subcontinent to the east encircle the tectonic block known as the Saurashtra Block, which is a portion of the Indian subcontinent. The Saurashtra Block has a diverse geology, with both sedimentary and metamorphic rocks being found there.

The local dynasty had a market where they sold beads made on the forge out of materials like chameleon, banded agate, and amethyst onyx. Micro beads of steatite were also present which was used as seals, the seals were supposed to be from traders of Arab. Skeletal remains of people were also found in this region which could be the evidence of possible cemetery in the dynasty.

There was a slope-maintained drainage system that reportedly made the water flow into the river by the inclination of the slope to the canal, which led the excess water into the sea from rivers such as the Bogavadi and Sabarmati.

The presence of foraminifera is very essential in understanding Lothal's geological history. Foraminifera are microscopic sea creatures that produce a calcareous shell and are often utilised as bioindicators in paleoenvironmental investigations. The foraminifera discovered in Lothal indicate that the area was formerly a marine environment, with the Indus River delta close.

Overall, the geology of Lothal, as well as the presence of foraminifera, give vital clues to the site's history. Scientists believe the site was originally a prosperous port city in a maritime environment that was finally drowned owing to changes in sea level. This knowledge aids our understanding of the Indus Valley Civilization's history and the manner in which humans have interacted with their environment over time.

Fig 1: local dynasty market

Fig 2: forge

Fig 3: drainage into the canal

Day 2

Physical Research Laboratory, Ahmedabad, Gujarat.

23.1688° N, 72.5451° E

Fig 4: Physical Research Laboratory

The Geosciences Division of India's Physical Research Laboratory (PRL) is a major scientific organisation devoted to the study of the earth and its different components. It is one of the country's largest and most prominent institutions dedicated to geosciences.

The PRL Geosciences Division, based in Ahmedabad, Gujarat, was founded in 1947 and has been essential in increasing our understanding of the earth's structure, composition, and motion. The division is home to a group of highly skilled and experienced researchers who study on a variety of earth scientific topics such as seismology, geodynamics, geodesy, atmospheric science, oceanography, and paleoclimate.

The Geosciences Division of PRL has a wide range of research facilities and state-of-the-art equipment that are used to conduct cutting-edge research. We were led by a group of scientists Prof. Sanjeev Kumar, Dr. Vineet Goswami and Dr. Yogita Kadlag who briefly explained us working of few instruments that utilized by them for research purposes. Which include the following:

MC-ICPMS stands for "multi-collector inductively coupled plasma mass spectrometry" and it is a powerful analytical technique used for high precision isotopic analysis of a wide range of elements. *Here's a brief explanation of how MC-ICPMS works:*

- Sample introduction: A small amount of sample material is introduced into an inductively coupled plasma (ICP) source, where it is vaporized and ionized.
- Ionization: The ions produced in the ICP are extracted and focused into a beam, which is then sent through a series of magnetic fields. The magnetic fields cause the ions to bend, and the degree of bending depends on their mass-to-charge ratio (m/z).
- Separation: The ion beam is separated into its various isotopes by a mass spectrometer. This allows the different isotopes of an element to be measured separately.

- Detection: The ion beam is then directed towards a detector system which consists of multiple collectors, each of which collects a specific isotope of interest. By measuring the isotopic ratios of the different collectors, the relative abundances of the different isotopes can be determined with high precision.

TIMS stands for "thermal ionization mass spectrometry" and it is a powerful analytical technique used for high precision isotopic analysis of a wide range of elements.
Here's a brief explanation of how TIMS works:

- Sample introduction: A small amount of sample material is loaded onto a filament, which is then heated to a high temperature. The heat causes the sample to vaporize and form ions
- Ionization: The vaporized sample is ionized by bombarding it with electrons. The ionized sample is then accelerated through a series of electric fields and sent towards a mass spectrometer.
- Separation: The ion beam is separated into its various isotopes by a mass spectrometer. This allows the different isotopes of an element to be measured separately.
- Detection: The ion beam is then directed towards a detector system which measures the number of ions hitting it. By measuring the isotopic ratios of the different ions, the relative abundances of the different isotopes can be determined with high precision.

Day 3 – Balasinoor
Spot 1
22°97’07’’ N, 73 34’ 64’’ E

Aravalli craton covers almost entire state of Rajasthan, part of Gujarat, Madhya Pradesh and fringes of Delhi and Haryana.

Classification of Aravalli Supergroup

Champaner group
Lunavada group
Jharol group
Udaipur group
Debari group
Delwara group
-----unconformity-----
Mangalwar/ sandmata complex

The Aravalli supergroup is 2.5 billion years old. The general direction of Aravalli sediment is NE-SW. The Aravalli craton's closing phase is characterised by large-scale granitic activity. The majority of Granitic masses intruded between 730 and 830 Ma, as demonstrated by a cluster of Rb- Sr ages. Godhra granite is one of the granitic intrusions that occurred during the Aravalli craton's last phase. Godhra granite has intruded the Champaner and Lunavada groups of the Aravalli supergroup, and they are 945 million years old and belong to the Neo-Proterozoic epoch.

Granitic Tors were also observed, Tors are landforms formed by rock erosion and weathering; most typically, granites, but also schists, dacites, dolerites, ignimbrites, coarse sandstones, and others. Tors are typically less than 5 metres (16 feet) tall.

Godhra granite is a porphyritic granite to granodiorite with pegmatite related. It contains minerals such as feldspar, quartz, and micas (biotite and muscovite). Muscovite and biotite are found as phenocrysts ranging in size from 0.5 to 5cm. MMEs were also in attendance. Mafic magma enclaves arise as a result of magma co-genetic mixing. Xenoliths (Mafic - biotite ± hornblende) are also present which are mafic in nature

Fig 5 Godhra Granite with Xenolith

Fig 6 Godhra Granite Hand Sample

Spot 2: Rhyoli

23 05’ 62’’ N, 73 34 35’’ E

Fig 7: Raioli dinosaur fossil park

The Raiyoli Dinosaur Fossil Park is a dinosaur museum and fossil park in the Indian town of Balasinor. The Balasinor Dinosaur Fossil Park is another name for it. The park is roughly 80 kilometres from Ahmedabad and spans an area of about 72 acres.

The Raiyoli Dinosaur Fossil Park is home to one of the world's largest dinosaur egg hatcheries as well as India's largest dinosaur fossil deposit. Dinosaurs are said to have lived in the park 65 million years ago. It houses around 10,000 dinosaur fossils discovered during excavations by the Geological Survey of India (GSI) and the Gujarat Ecological Education and Research (GEER) Foundation, including bones, eggs, and other remnants.

Fig 8L fossilized remnants of dinosaurs

The park has a museum where visitors may examine life-sized dinosaur replicas, bones, and displays about dinosaur evolution. Guests may also join a guided tour of the park to visit the real dig sites and learn about the various dinosaur species that formerly inhabited the region. The park provides guests with a one-of-a-kind opportunity to explore the prehistoric world and learn about the history of these beautiful creatures.

Fig 9 life sized Dinosaur displayed in museum

Day 4

ONGC Ahmedabad Asset GGS-Motera

23 11 31 N, 72 59 79 E.

Fig 10: ONGC, Motera

The Oil and Natural Gas Company operates the ONGC GGS Motera gas collection station in Motera, Gujarat, India (ONGC). The station's major duty is to collect and treat natural gas from adjacent oil fields before delivering it to different clients such as fertiliser companies, power plants, and municipal gas distribution networks.

The gas collection process is extracting natural gas from crude oil and water, compressing it to enhance pressure, and then transporting it to various users via pipes. To guarantee safe and effective operations, the station is outfitted with cutting-edge technology and equipment.

In addition to gas collecting, ONGC GGS Motera also does maintenance and repair work on pipelines and other equipment, as well as executing numerous environmental and safety measures to reduce the impact of its activities on the surrounding environment.

Mr. Gaurav Kumar, Safey Inspector at this facility was kind enough to show us around and explain the kind of work that they undertake.

ONGC GGS Motera uses advanced technology and equipment to ensure safe and efficient gas gathering and transmission. Some of the key technologies used at the station are:

- Gas Chromatography: Gas chromatography is used to separate and analyze the various components of the natural gas mixture. This technology helps to determine the quality and composition of the gas being processed, which is critical for maintaining the efficiency and safety of the gas gathering process.

- Compressors: Compressors are used to increase the pressure of the natural gas so that it can be transmitted through pipelines to various customers. The compressors used at ONGC GGS Motera are designed to operate at high efficiency and with minimal maintenance requirements.

- SCADA System: SCADA (Supervisory Control and Data Acquisition) system is used to monitor and control the various components of the gas gathering and transmission process. This system provides real-time data on gas flow rates, pressure levels, and equipment status, allowing operators to make adjustments and ensure safe and efficient operations.

- Pipeline Inspection: Regular inspection of pipelines is critical to ensure safe and reliable gas transmission. ONGC GGS Motera uses various inspection technologies, including smart pigs (devices that travel inside pipelines to detect defects) and remote sensing techniques, to detect and repair any pipeline damage.

- Environmental Monitoring: ONGC GGS Motera also uses advanced environmental monitoring systems to track air and water quality around the station. This helps to ensure compliance with regulatory requirements and minimize the impact of the station's operations on the environment.

Day 5 – Jhamarkotra Opencast Mine (Spot 1)

24 58 25 N, 73 51 71 E.

Fig 11: jhamarKotra mines, Rajasthan.

Rajasthan State Mines & Minerals Ltd (RSMML) is a public sector firm of the Government of Rajasthan that principally produces and markets high-grade rock phosphate, lignite, limestone, and gypsum (non-metallic minerals) from mines situated throughout Rajasthan. BGL took over operations at Jhamarkotra mines in 1969, following the discovery of rock phosphate at Jhamarkotra (Udaipur).

RSMML's primary business is the mining of rock phosphate ore. It runs one of the country's largest and most mechanised mines in Jhamarkotra, 26 kilometres from Udaipur. Jhamarkotra is noteworthy since it contributes 98% of India's rock phosphate output. Jhamarkotra is possibly India's largest open cast mine outside of the steel and coal sectors, with an annual rock handling capacity of over 20 million tonnes. Because of the geometry of the ore body, which is thin and sharply dipping, long and narrow pits with tremendous depth extension have resulted in a very high stripping ratio with high lead and lift for waste and mineral. If an entity starts falling down the 12m bench stops it from rolling further down.

The rock phosphate is found in Aravalli Supergroup metasedimentary rocks (Precambrian age). It is derived from algae. The deposit has a strike length of 16 kilometres and an average thickness of 15 metres. On the basis of 60,000 mts. of drilling in 500 boreholes, a reserve of 77 million tonnes of rock phosphate has been established. The majority of these 17 million tonnes are +30% P2O5 grade, with the remainder being 12 0 30% P2O5 grade. To enhance the low-grade phosphate ore, a 1500 TPD (Tonnes Per Day) beneficiation facility has been installed.

Extent of Jhamarkotra Deposit

Total lease area is 13sqkm2. In Jhamarkotra, the strike length of the phosphorite bed including the discontinuous outcrop extending over a linear distance of 16 km. The highest point of the phosphate bed outcrop at 600 MRL at Jhamarkotra and along the downdip direction the extension of the phosphate has been proved up to a little below 250 MRL. Ore body dips at angle of 45-55°.The phosphate bed shows an extremely variable thickness showing persistence only over a limited strike length. Thus, in Jhamarkotra, the 15 km average thickness of the phosphate bed could be traced over 6 km of continuous strike length. In some portions, ore body shows pinching and swelling structure, hence the thickness of ore body varies from 5-35m. For the sake of convenience in prospecting and mining the deposit has been divided into 12 blocks viz. A-Extension, A, B, C, D, E, F, G, H, I, J and K. The ore to overburden ratio in the Jhamarkotra Phosphate Mine is kept as 1:16.

Grade of the Deposit

At Jhamarkotra deposit, generally a Bi-modal grade distribution pattern viz.+30 % (37- 38%) P2O5 designated as High-Grade Ore (HGO) and 16 to 22 % P2O5 designated as Low-Grade Ore (LGO) could be deciphered. However, at places near the contacts of the above grade of phosphate bed, some transitional zones exist which are designated as Mixed / Medium Grade Ore (MGO). The marketable grade of ore is 31.5% & 30% P2O5, but a large resource of low-grade ore also occurs in the area. Looking at great demand of phosphate fertilizer and to reduce its import, the low-grade ore is being upgraded through froth flotation in beneficiation plant.

Fig 12: stromatolites

Fig 13 Mineral Apatite

Genesis of rock phosphate at Jhamarkotra

The mineral phase of apatite, which makes phosphorite, is considered to have formed by three mechanisms (i) direct inorganic precipitation, (ii) primary biogenic precipitation, and (iii) diagenetic precipitation/replacement. Diagenetic precipitation of apatite is considered as an important mechanism involved in phosphorite formation. Apatite of this origin commonly occurs as void filling and cementing material in the associated sediments. It is said that the organic matter, which collects on the shelf regions, on decay, causes very high concentration of phosphorous below the sediment water interface, leading to precipitation of apatite. During this process carbonate constituents of the sediment are also phosphatised due to the replacement

Mining Method: The open pit mining method is being followed at Jhamarkotra Mine for exploitation of the mineral. The working levels are kept dry by continuous pumping of ground water through tube-wells constructed on periphery of the pit limit. The bench height in this extent of mine is given at 7m consecutively for a couple of times with alternating 12 m heighted bench. (7m,7m,12m).

Spot 2 – Jhameshwar Mahadev Temple, Jhamarkotra

Stalactites are formations that cling to the ceilings of caves and hot springs. They sprout from dripping walls and ceilings and develop downwards. The'straw' stalactite is a monolayer crystal sheath covering a feedwater channel and developing downwards exclusively. Leakage from the canal can cause tapering (carrot-like) stalactites up to one metre in diameter and many metres in length. Accelerated deposition on protuberances can add a myriad of subsidiary forms such as crenulations, corbels, drapes and lesser stalactites. A 'column' is a stalactite–stalagmite pair grown together.

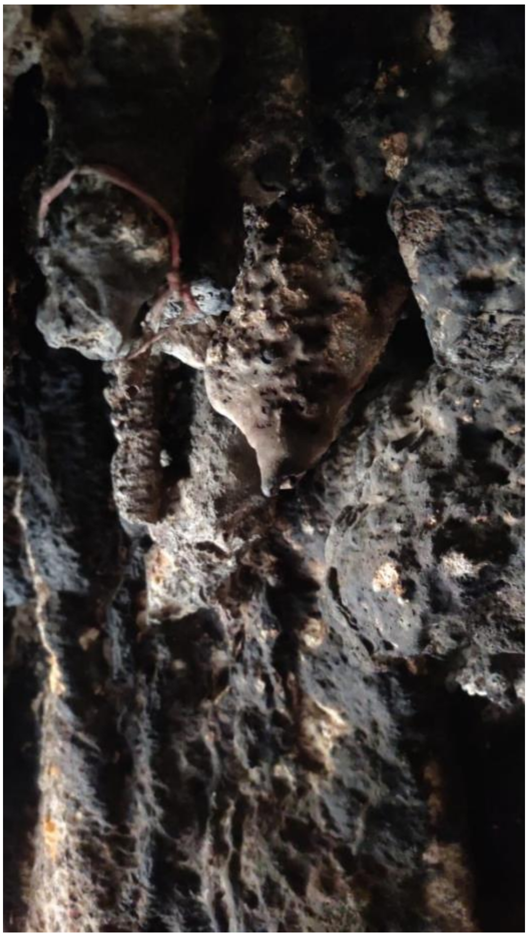

Fig 14: Stalactites

Day 6 – Chittorgarh

Rock Type – Suket Shale- Phyllite

24 47 40 N, 73 51 71 E.

Spot 1

The Chittorgarh district is distinguished for its undulating topography and Aravalli range highlands. The district is made mainly of rocks from the Bhilwara supergroup, the Vindhyan supergroup, and the Deccan traps. The field region is dominated by Vindhyan sedimentary conglomerates and rocks of the Bilwara supergroup, which are separated by a large boundary fault. The Berach River follows the great boundary fault. Bilwara supergroup is present at the west side of the river. The Bilwara supergroup is split into three tectono-stratigraphic units: the Hindoli group, the Mangalwar complex with separate mineralised bands, and the Sandmata complex. Greywackes and phyllites dominate the Hindoli group. These phyllites haves been folded into large- scale low plunging folds trending parallel to the GBF. Increase in the tightness and asymmetry of the folds near the fault suggests that these are fault related folds. They are highly compressed and joint sets are closely spaced than the joints present away from the river that is away from the GBF. Slicken sides are observed, which indicates the presence of fault and quartz veins are also present which may be either syngenetic or post genetic. The Suket Shale-Phyllite shows various stages of predominant folding from which possible readings were taken with respect to the hinge plane.

	Strike Direction	Dip Amount with Direction
Hinge Plane	200° N	29° N (Plunge)
Limb 1	200° N	36° E
Limb 2	125° N	54° W

Joint Sets are as follows:

	Strike Direction
Joint Set 1	145° N
Joint Set 2	100° N

Fig 15: Suket Shale-Phyllite

Fig 16: Anticlinal Plunging Hinge

Fig 17 Folding Sequence

Spot 2

24 52 59, 74 37 57

Nimbara Limestone is a type of sedimentary rock that is primarily composed of calcium carbonate. It is commonly found in the Nimbara region of Rajasthan, India, and is a popular building material due to its durability, strength, and natural beauty.

This limestone is typically light gray in color. It is formed through the accumulation of calcium carbonate-rich sediment that has been compressed over millions of years, often in marine environments. Few possible readings were taken:

	Strike Direction	Dip Amount with Direction
Spot 1	N	40° W
Spot 2	N	64° W

Day 7

Day 7 – Nathwara Limestone/Marble

25 05’ 76” N, 73 85 08” E

Nathwara Limestone is a type of limestone that is found in the state of Rajasthan, India. It is named after the town of Nathwara, which is located in the Udaipur district of Rajasthan.

This limestone is a light-colored, fine-grained rock that is composed mainly of calcium carbonate. It is quarried extensively in the Nathwara area and is used in a variety of construction and decorative applications.

Spot 1

Lithology - Marble, Schist

The marble strata were inclined with the overlying bed of schist. The schist present was heavily weathered. The marble bed which was inclined had minor crenulation folding sequence which initiated few joints present in the marble. The recrystallised silica grains in the marble suggested the following sequence have undergone contact metamorphism.

The schist present had alternate augen gneiss structure with minerals like chlorite and tremolite dominating into the rock, which suggested the name of the schist as mica schist. Elongated acicular structure is also seen in the mica schist in which the needle like structure consists of tremolite.

18 Weathered Mica Schist layer in between Marble

19 Augen Gneiss Structure

Marble	Strike Direction	Dip Amount with Direction
Spot 1	130° N	32° SW
Spot 2	360° N	26° E

References

a) Radhakrishna, B. P., & Naqvi, S. M. (1986). Precambrian continental crust of India and its evolution. The Journal of Geology, 94(2), 145-166.

b) Deb, M. (2014). Precambrian geodynamics and metallogeny of the Indian shield. Ore Geology Reviews, 57, 1-28.

c) Joshi, A.U., Gorania, P., Limaye, M.A. et al. Geoheritage Values of the ChampanerPavagadh Archaeological Park, UNESCO World Heritage Site, Gujarat, Western India.
Geoheritage 14, 88 (2022). https://doi.org/10.1007/s12371-022-00720-w

d) Roy, K.S., Sharma, J., Kumar, S. et al. Effect of coronavirus lockdowns on the ambient seismic noise levels in Gujarat, northwest India. Sci Rep 11, 7148 (2021). https://doi.org/10.1038/s41598-021-86557-9

e) Roy, A. B., & Jakhar, S. R. (2002). Geology of Rajasthan (Northwest India) precambrian to recent. Scientific Publishers.