SCHOOL OF EARTH, OCEAN and ATMOSPHERIC SCIENCES

Academic year: - 2022-2023
Semester IV

Class: - MSc Part 2
Seat No.: - 202100088
Roll No: - 20P045028

CERTIFICATE

This is to certify that Master Vishal Venugopal has satisfactorily completed the course of fieldwork pertaining to Paper GLC- 122: Geological Field Training for MSc in applied Geology as prescribed by Goa university for MSc part II class, during the academic year 2021-2022.

Faculty member in-charge **Program officer SEOAS**

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Fieldwork in and around Gujarat and Rajasthan

Report submitted in partial fulfilment of the requirements of the degree of Bachelor of Science

By

Vishal Venugopal

Roll No: - 20P045028

SCHOOL OF EARTH, OCEAN and ATMOSPHERIC SCIENCES

Goa University

2023

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GEOLOGY 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 quantities. Even India's fossil record is impressive in that stromatolites, invertebrates, vertebrates and plant fossils are included. India's geographical land area can be classified into the DeccanTraps, Gondwana and Vindhyan. The Deccan Traps covers almost all of Maharashtra, apart from 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 Permo-Carboniferous 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 supercontinent of Pangaea. At that time, what is now India's southwest 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(ICS 2004), rifting caused Pangaea to break apart into two supercontinents, Namely Gondwana (to the south) and Laurasia (to the north). The Indian Craton remained attached to Gondwana until the supercontinent began to rift apart in the early Cretaceous, about 125 million 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 the closure of the Tethys Ocean. The closure of this ocean which created the Alps in Europe and the Caucasus range in western Asia created the Himalayan 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 sutured onto the adjacent Australian Plate, forming a 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 (before 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 kilometres (311 mi) 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 sediments 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, before the Deccan eruptions, an 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 kilometres (193,051 sq. mi) area, the sea marks the final break from Gondwana.

After the close of the Proterozoic Era, a great hiatus in t geological record from Cambrian to Triassic is recorded in Gujarat. The Mesozoic sequence ranging from Middle Jurassic to Lower Cretaceous is represented by fossiliferous sediments that occur in parts of Kachchh, Sabarkantha, Panchmahals, Surendranagar, Kheda, Vadodarà and Rajkot districts. The close of the Mesozoic Era witnessed a major volcanic activity in the form of the widespread outpouring of lava in parts of Saurashtra, Kachchh, southern Gujarat and eastern parts of Pançhmahals and Vadodara districts. The Deccan Trap volcanic activity continued from the Cretaceous to the Eocene with at least four different phases of the eruption. It is of interest to mention that older volcanic basaltic composition has intersected at the base of the Dhrangadhra Sandstone at Lodhika (Banerjee, 1999). This older volcanic fall in the alkali basalt field of the TAS diagram (Banerjee, op. cit.). The occurrence of older traps below Mesozoic sediments was also indicated earlier by Kaila *et al.* (1981) at Dhanduka, 150 km NE of Lodhika. The Deccan Traps are overlain by the Tertiary rocks, which occur all along the coastal area in Saurashtra in the Khambhat (Cambay) basin and parts of Kachchh. The Khambhat basin contains Eocene and Oligocene sediments having oil/gas-producing horizons. There are more than 22 oil/gas fields in the State. The Quaternary sediments comprise alluvium, miliolite, coral reefs, calcareous sand etc.

Figure 1: - Geology of India

GEOLOGY OF GUJARAT

The Gujarat State bounded by N 20°02' and 24°42' and E 68°04' and 74°30' has an aerial extent of 1,96,024 sq km. The western and southern parts of the State are bordered by the coastal tract along the Arabian Sea. The State of Gujarat has a long coastline (approx. 1550 km) from Sir Creek in the northwest to Umargao in the southeast, which forms nearly one-third of the Indian coastline. The coastal tract borders the Kutch Peninsula, the Saurashtra Peninsula and the Central Plains of Gujarat. The southeastern part is occupied by the Deccan Plateau whereas the southwestern part forms the Saurashtra (Kathiawar) Peninsula. In the northeast, the conspicuous hill chains represent the southward continuation of the Aravalli Range. The Kutch Peninsula and the Rann of Kachchh occupy the north-western part of the State. The area extending in a north-south direction and lying between Aravalli Range and Saurashtra-Kachchh Peninsulas is covered by an alluvial tract. The State exposes a wide variety of lithological assemblages belonging to the Precambrian, Mesozoic and Cenozoic Eras and is endowed with rich mineral wealth. Extensive exploration leading to the production of oil and natural gas in Ankleshwar, Khambhat and Kalol has put Gujarat prominently on the country's oil map. Minerals of commercial significance found in the State are those of base metals, lignite, bauxite, bentonite, dolomite, fireclay, fluorite, fuller's earth, kaolin, ball, clay, limestone, chalk, calcareous sand, quartz and silica sand. Gujarat is the only State where potash is produced as a by-product in manufacturing common salt from brine.

The geology of Gujarat State is characterised by hard rock terrain represented by Precambrian metamorphites and associated intrusives; sedimentaries of Jurassic, Cretaceous and Tertiary Periods and the traps/flows of Deccan Volcanics of Cretaceous-Eocene age. The Precambrian metamorphites, viz. the rocks belonging to Aravalli Supergroup and the Delhi Supergroup occupy the NE part of Gujarat, adjacent to Rajasthan and Madhya Pradesh. The Aravallis are overlain by the Delhi Supergroup of rocks (Palaeoproterozoic-Mesoproterozoic), the two having been separated based on an unconformable relationship, structural discordance and associated volcanic activities. Rocks of these Supergroups are confined to the north-eastern part of Gujarat, in Sabarkantha and Banaskantha districts. These Supergroups are composed of metasedimentaries and are characterized by extensive magmatism. The magmatic activities recorded in the Aravalli Supergroup include an early phase represented by the rocks of Phulad Ophiolite Suite and a syn- to the late orogenic phase of magmatism represented by several granitic activities such as Sendra-Ambaji granite and gneiss, Godhra granite and gneiss, Erinpura granite and gneiss and Idar granite.

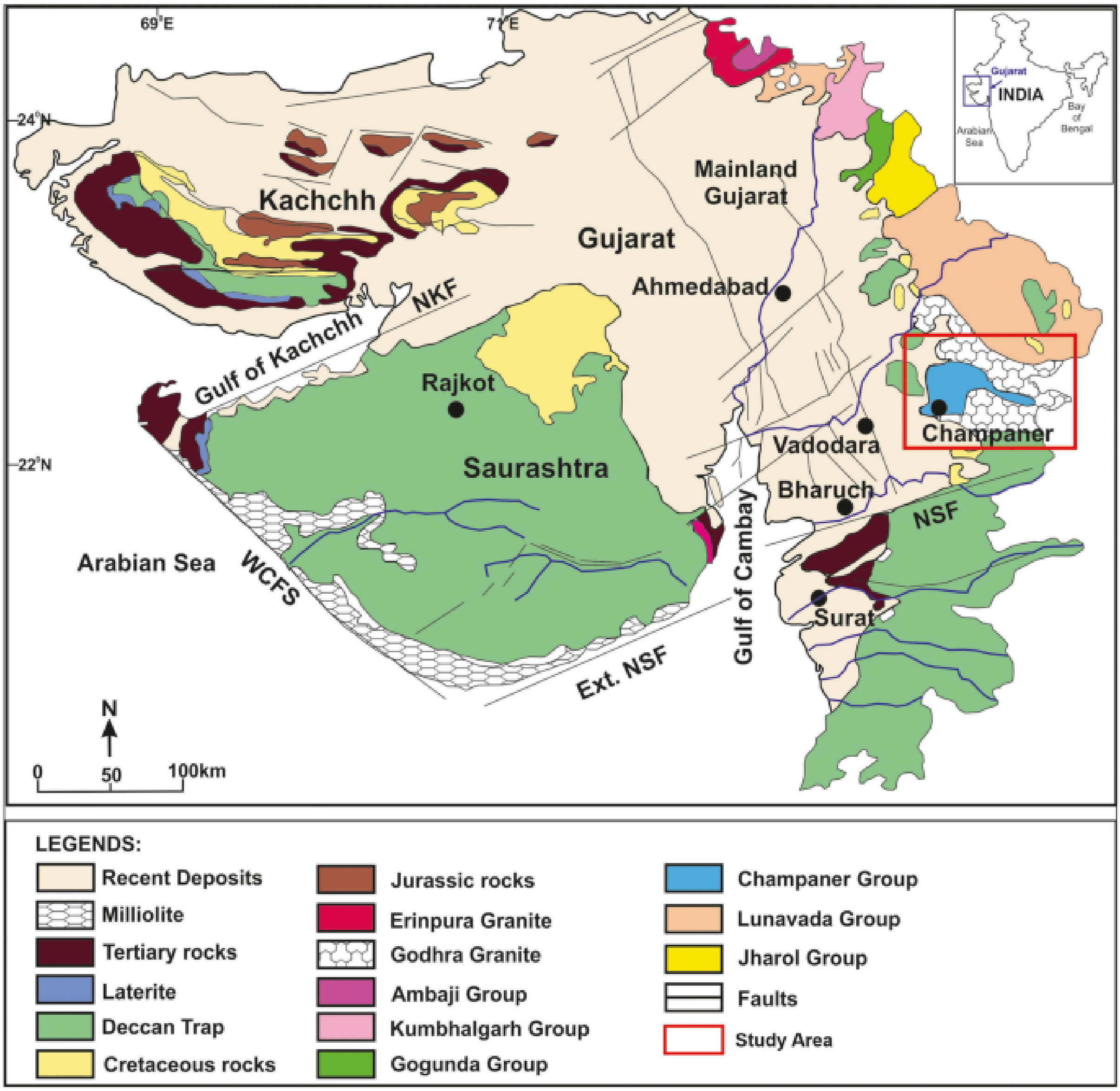

Figure 2: Geology of Rajasthan

GEOLOGY OF RAJASTHAN

The State is located within 23 03'-30 12'N and 69 29'-78 17'E and bounded on the west and northwest by Pakistan, on the north and northeast by Haryana and Uttar Pradesh and the south-southeast and southwest by Madhya Pradesh and Gujarat States respectively. The northwestern part of the State is occupied by the Thar DesDesert covering% area of the total area. The Aravalli hill range extending from Delhi in the northeast to the plains of north Gujarat in the southwest, divides the State into two unequal parts. The area to the east of the hills is covered by the eastern plains and the Vindhyan plateau. Rajasthan forms the northwestern part of the Indian Shield. The rock sequences of the region cover a period of about 3500 to 0.5 Ma. The State exposes a variety of lithological and tectonic units ranging in age from Archaean to Recent times. The basement rocks - the Sandmata Complex, Mangalwar Complex and Hindoli Group of Bhilwara Supergroup - occupy central and south-eastern plains.
They are Archaean in age and comprise in general, granulite-gneiss; amphibolite, metapelite, paragneiss, calc-silicate rocks and greywacke (the older granite-greenstone belt) and metavolcanic, metagreywacke (the younger granite-greenstone belt) respectively. The Lower Proterozoic supracrustal rocks of the Jahazpur, Rajpura-Dariba, Pur-Banera and Sawar Groups of the Bhilwara Supergroup rest on the basement rocks of the Mangalwar Complex and host several lead, zinc and copper deposits. The Bhilwara Supergroup of rocks is intruded by the Untala-Gingla Granite, Berach Granite, basic and ultramafic bodies. The Proterozoic fold belts, viz., the Aravalli fold belt (the Aravalli Supergroup) and the Delhi fold belt (the Delhi Supergroup) occupy the southern and southeastern, and south-western and north-eastern Rajasthan respectively. The Aravalli Supergroup is represented by metamorphosed and complexly folded clastic sediments with minor chemogenic and organogenic assemblages with interlayered basic volcanic, whereas the Delhi Supergroup comprises mainly carbonates, metavolcanic, metasomites and metapelites, intruded by the magmatic rock of Phulad Ophiolite Suite and syn-orogenic granites of Sendra- Ambaji, Bairath, Dadikar, Harsora, etc. Several 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 Vindhyans, 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 Supergroup which are overlain by sedimentary rocks of different ages of the Palaeozoic and Mesozoic Era. Many industrial mineral deposits are found in these rocks. The Deccan Traps are restricted to the southeastern part of the State in Chittaurgarh-Banswara area. The Cenozoic rocks are manifested in Barmer and Jaisalmer basins in the west and the Ganganagar-Palana shelf in the north. The Quaternary sediments of aeolian and fluvial origin constitute the Thar Desert of Rajasthan. The geological investigations have been continuing in the state for more than a century. However, there are some problems which need to be resolved. Scientific efforts are on to unravel such geological complexities. Recent investigations have brought out important mineral deposits in the State. To list, a few are the lead-zinc deposits of Agucha and Pur-Banera in Bhilwara district, Kayar-Gugra deposit in Ajmer district, Dariba- Rajpura-Bethumbi deposit in Rajsamand district; gold in Jagpura-Bhukia belt in Banswara district; limestone in Jaisalmer and Chittaurgarh districts; potash in Ganganagar-Nagaur basin etc.

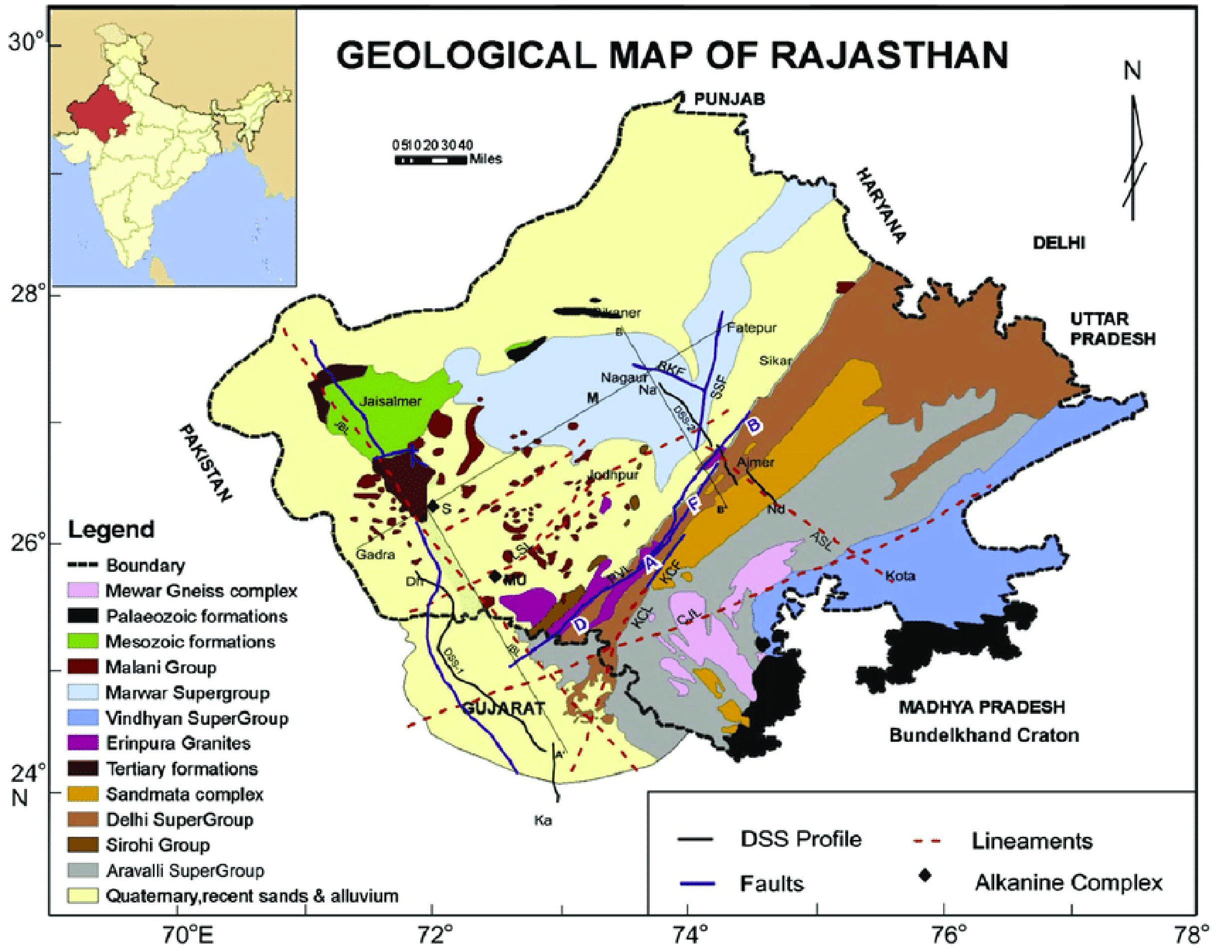

Figure 3: - Geology of Rajasthan

REGIONAL GEOLOGY

Aravalli Supergroup

A thick pile, chiefly comprising metamorphosed and complexly folded Palaeoproterozoic clastogenic sediments with minor chemogenic and organogenic assemblages and interlayered basic volcanics, overlying the Manglwar Complex and the Sandmata Complex with an erosional unconformity, has been assigned to the Aravalli Supergroup. This assemblage of stratified metasediments and interlayered extrusives, together with synorogenic and late to post-orogenic acidic, basic and ultrabasic intrusives, covers a time span from 2500 Ma to 2000 Ma. The rocks of the Supergroup show an inverted V-shaped map pattern with an arcuate disposition where the apex of the V is located near Nathdwara. The width of the belt in the north is about 40 km gradually fanning out to 150 km in the south. To the east, the Aravalli's are bounded by the Bhilwara Supergroup and to the west these are overlain by the rocks of the Delhi Supergroup. Towards southeast, the Aravalli Supergroup is covered either by the Deccan Traps or alluvium. The average trend changes from NW-SE in the southern part to NESW in the northern part. Controversy exists about the nature of contact and the stratigraphic status of the rocks on the west of the Aravalli Supergroup. Gupta and Bose (2000) have indicated that the Aravalli and Delhi Supergroups are separated by the older basement rocks, which forms the southern extension of the greenstone sequence of the BGC/Bhilwara Supergroup. Dev and Sarkar (1990) considered the older basement rocks as an attenuated block of the separated BGC continent between the two supergroups. The western contact of the Aravalli Supergroup is envisaged as a tectonic contact. Similarly, though evidences of unconformity are present along the eastern contact of the Aravalli Supergroup, ductile shearing along the BGC/Bhilwara Supergroup-Aravalli contact has led to imbrication at places.

The rocks of the Aravalli Supergroup have undergone polyphase deformation and attained progressively higher grade of regional metamorphism reaching upto amphibolite facies. The rocks also show migmatization in the vicinity of the synorogenic plutonic activity. The Aravalli Supergroup shows two distinct 'facies sequence' indicating deep-sea and near-shore shelf environments interpreted by many as geosynclinal miogeosynclinal couple or as a foreland-hinterland duplex. The eastern part of the supergroup is occupied by carbonate, conglomerate, quartzite, phyllite and proximal greywacke representing shelf facies, whereas the western part of the supergroup has a totally carbonate free distal facies, with thin bands of arenite, representing deep water facies. Metabasic volcanics occur near the base of Aravalli Supergroup. The ultramafic rocks, represented mainly by serpentinite and its metasomatic alteration products, occur in the Aravalli Supergroup in the Rakhadev-Dungarpur area and in the area between Jharol and Gogunda. There is no unanimity on the tectonic significance and stratigraphic position of these ultramafic rocks. A number of granitic and gneissic bodies are enclosed by the Aravalli Supergroup. The unconformable relation between the gneisses of Sarara inlier and the Aravalli Supergroup is unequivocal.

There is no unanimity in the stratigraphic classification of the Aravalli Supergroup. The Debari Group forms the basement of the Aravalli Supergroup and comprises coarser clastics of the coastline environment, synsedimentary basic volcanic and associated pyroclastics and shallow marine carbonate and carbonaceous sediments with local development of phosphatic and non-phosphatic algal biostromes. The Udaipur Group comprises coarse flysch-like sediments deposited in a proximal trough. The Bari Lake Group includes a volcano-sedimentary succession marking the second phase of volcanicity and upwarping, following the filling up of the proximal trough. The Jharol Group includes thick shaly flysch-like accumulation in a distal trough. The Kankroli and the Dovda Groups, extending across the Banas Lineament in the northern part, are composed of clastic and chemogenic sediments deposited under shallow marine conditions on topographic highs developed along the strike continuity of the Udaipur and Jharol troughs. The Nathdwara Group, exposed near Nathdwara, contains chemogenic rocks formed in a rectilinear shallow basin developed successor to the first phase of the Aravalli deformation.

Classification of Aravalli Supergroup (Lower Proterozoic) of South Western Rajasthan and North Eastern Gujarat

CHAMPANER GROUP (exposed in Gujarat)	Rajgarh Formation Shivrajpur Formation Jaban Formation Narukot Formation Khandia Formation Lambia Formation
LUNAVADA GROUP	Kadana Formation Bhukia Formation Chandanwara Formation Bhawanpura Formation Wagidora Formation Kalinjara Formation

SYNOROGENIC GRANITE and GNEISS

RAKHABDEV ULTRAMAFIC SUITE

JHAROL GROUP	Samlaji Formation Goran Formation	DOVDA GROUP	Devthari Formation Dapti Formation	NATHDWARA GROUP	Rama Formation Kadmal Formation

BARI LAKE GROUP	Khamnor Formation Varla Formation SajjangarhFormation
KANKROLI GROUP	Sangat Formation Puthol Formation Rajnagar Formation Morchana Formation Madra Formation

UDAIPUR GROUP	*Udaipur Sector*	*Sarada Sector*
	Banswara Formation	
	Nimach Mata Formation	-
	Balicha Formation	TIRI SUB-GROUP: Zawar Formation
	Eklinggarh Formation	Baroimagra Formation
	Sabina Formation	Mandli Formation

DEBARI GROUP	*Debari Sector*	*Jaisamand Sector*	*Ghatol Sector*	*Sarada Sector*
MATON SUB-GROUP	Jhamar Kotra Formation	Babarmal Formation	Jagpura Formation	Kathalia Formation
	Berwas Formation	Dakan Kotra Fm.	Mukandpura Kotra Fm.	Sisamagra Formation
	Jaisamand Formation	Jaisamand Formation	Jaisamand Formation	Natharia-ki-Pal Formation
	Delwara Formation	Delwara Formation	Delwara Formation	-
	Gurali Formation	-	Gurali Formation	Basal Formation

Figure 4:- Stratigraphy of Aravalli Supergroup

Vindhyan Supergroup

The Vindhyan Supergroup is a thick sequence of sedimentary rocks that is widely distributed in central India, covering an area of approximately 400,000 square kilometers. It is one of the most significant sedimentary basins in India, with a thickness that ranges from 600 meters to more than 8,000 meters in some places. The Vindhyan Supergroup is divided into two main subdivisions: the Lower Vindhyans and the Upper Vindhyans. The Lower Vindhyans are composed mainly of shale, limestone, and sandstone, while the Upper Vindhyans consist mostly of sandstone. The boundary between the Lower and Upper Vindhyans is marked by a prominent unconformity.

The sedimentary rocks of the Vindhyan Supergroup were deposited during the Proterozoic era, between 1.7 and 1.0 billion years ago. The sedimentation was influenced by the tectonic and magmatic activities of the time, which caused periodic uplift and subsidence of the basin. The Lower Vindhyans are further divided into several groups, including the Bhander, Rewa, Kaimur, and Rohtas Groups. The Bhander Group is composed of shale, limestone, and sandstone, while the Rewa Group is dominated by sandstone. The Kaimur and Rohtas Groups are characterized by shale and limestone. The Upper Vindhyans are also subdivided into several groups, including the Bhander, Rewa, Kaimur, and Semri Groups. The Bhander and Rewa Groups are similar to their counterparts in the Lower Vindhyans, while the Kaimur Group is composed mainly of sandstone. The Semri Group is characterized by shale and limestone.

The Vindhyan Supergroup is known for its unique fossil assemblages, which include stromatolites, algae, and cyanobacteria. These fossils provide important information about the evolution of life on Earth and the environmental conditions that existed during the Proterozoic era. Overall, the geology of the Vindhyan Supergroup is complex and varied, reflecting the diverse sedimentary environments that existed in the basin during its formation. It is an important area for geological research and provides valuable insights into the geological history of India and the wider Earth.

Supergroup	Group	Fm.	Eastern part of Son valley sector (existing)	Western part of Son valley sector (existing)	Proposed stratigraphy of Son valley sector	Age (Ma)
VINDHYAN SUPERGROUP	UPPER VINDHYAN GROUP	BHENDER	Upper Bhander Sandstone	Upper Bhander Sandstone	Upper Bhander Sandstone	
			Sirbu Shale	Sirbu Shale	Sirbu Shale	625±25[F-T]Srivastava and Rajagopalan, (1988)
			Lower Bhander Sandstone	Lower Bhander Sandstone	Lower Bhander Sandstone	
			Bhander Limestone	Bhander Limestone	Bhander Limestone	908±72[Pb-Pb] Ray et al. (2002) 1075-900[Pb-Pb] Gopalan et al. (2013)
			Ganurgarh Shale	Ganurgarh Shale	Ganurgarh Shale	
		REWA	Rewa Sandstone	Rewa Sandstone	Rewa Sandstone	
			Rewa Shale	Rewa Shale	Rewa Shale	1100-700[Chauria-Tawuia] Rai et al. (1997)
		KAIMUR	Dhandraul Sandstone	Dhandraul Sandstone	Dhandraul Sandstone	
			Scarp Sandstone/ Mangeswar Sandstone	Scarp Sandstone/ Mangeswar Sandstone	Scarp Sst./ Mangeswar Sst.	
			Bijaigarh Sh.		Bhagwar Shale/Silicified Shale	1210±52[Re-Os] Tripathy and Singh (2015)
			Ghaghar Sandstone Upper Sandstone/Quartzite			
			Susunia Breccia			
			Silicified Shale			
			Sasaram Sandstone (Lower Quartzite)		Sasaram Sandstone (Lower Quartzite)	
		UN				
	LOWER VINDHYAN / SEMRI GROUP	ROHTAS	Rohtas Limestone	Bhagwar Shale	Rohtas Limestone	1514±120[Pb-Pb] Chakraborti et al. (2007) 1599±48[Pb-Pb] Sarangi et al. (2004) 1601±130[Pb-Pb] Ray et al. (2003)
				Rohtas Limestone		
			Rampur Shale	Rampur Shale	Rampur Shale	1599±8[SHRIMP] Rasmussen et al.(2002) 1602±10[SHRIMP] Rasmussen et al.(2002)
		KHEINJUA	Chorhat Sandstone	Chorhat Sandstone	Chorhat Sandstone	
			Koldaha Shale	Koldaha Shale	Koldaha Shale	
			PORCELLANITE			1628±8[SHRIMP] Rasmussen et al.(2002) 1630.7±0.4[U-Pb] Ray et al.(2002) 1631.7±5.4[SHRIMP] Ray et al.(2002) 1640±4[^{206}Pb/^{207}Pb] Bickford et al.(2017)
		KAJRAHAT	Kajrahat Limestone	Kajrahat Limestone	Kajrahat Limestone	1721±90 [Pb-Pb] Sarangi et al.(2004)
			Arangi Shale	Arangi Shale	Arangi Shale	
UN			DEOLAND			
			MAHAKOSHAL GROUP			

UN-Unconformity; Fm.-Formation

Figure 5:- Stratigraphy of Vindhyan Supergroup

GUJARAT

Day- 1 (22/01/2023)

Spot - 1

Latitude: - 22º31’17” N
Longitude: - 72º14’58” E

Location: - Lothal, Saragwala

Lothal was first discovered by S.R. Rao, in 1957. It is the southernmost outlier of the Harappan Civilization to have been thoroughly excavated, thus clearly demonstrating the vast extent of this civilization, but the claim that Lothal was a port settlement with direct trade relations with Mesopotamia has wide implications. Nearly half a century of research has unfortunately brought only rather scanty information on the nature of the Harappan economy and, particularly, its commerce. Until the excavation of Lothal, the direct evidence for Harappan maritime activity was limited to two depictions of boats (one on a pottery sherd, the other on a seal) from Mohenjo-daro, and likely as not these represent river craft rather than seaworthy vessels. It has reasonably been thought that shipping did play a part in Harappan commerce, even if doubt remains whether the Harappans themselves went to sea, or rather left the water transport of their merchandise to others. Lothal (from the Gujerati *loth* = dead, hence meaning the same as Mohenjo-Daro) is situated near Saragwala village, about fifty miles southwest of Ahmedabad. It lies in a level plain between the Bhogava and Sabarmati Rivers and at present is some twelve miles distant from the Gulf of Cambay coast. The siltation rate of the Sabarmati delta is known to be rapid, so that in former times the site may actually have been nearer the sea. Lothal today is not linked with the Gulf by a waterway, but to the west had a depression which, we may suppose, formerly provided such a connection. The settlement area according to the published plan is about 600 by 850 feet.

It may be remarked that most of the sealings from Lothal indicate usage on packages wrapped in rush or bamboo-mats and secured by strings. In some cases impressions of twisted cords tied into knots are also observed. Of the Indian exports carried in this trade there is less evidence, but they certainly included ivory and shell objects and beads of gemstones, and probably cotton or cotton goods. The raw material for beads came from Mehhgam and Bhagatrav, the two Harappan sites on the Narmada and Kim rivers respectively. A bead-factory with a kiln has been found at Lothal, and a large quantity of beads of gemstones in various stages of manufacture, three bronze drills and other accessories of the lapidaries have also been recovered there. Ivory-working was another Lothal industry, as is evident from the ivory tusk and ivory objects found in the excavations. It is further suggested that elephants lived around Lothal, not only because a leg-bone of an elephant has been recovered at Lothal itself but also because Kautilya refers to the short stature of the elephants of Saurashtra. A terracotta sealing from Lothal bears on the back the impression of a piece of cloth of plain weave and how extensive was the trade in cloth is indicated by the discovery at Umma near Lagash. of the imprint of an Indus seal from a bale of cloth. Shell was probably another commodity exported from Lothal. The rocky coast near Porbandar and Jamnagar is one of the sources of Indian chank-shell. Other varieties were imported into Lothal from South India and processed for export purposes. Two workshops of shell-workers in the bazaar street of Lothal, as also the large quantity of finished and unfinished objects of shell including bangles, inlay, etc., found here, suggest that Lothal was an important shell-working centre. Dentalium beads and shell inlays found at various sites in the Euphrates-Tigris valley may be supposed to have come from Lothal and the Indus valley cities. Copper and copper alloys had to be imported into Lothal from West Asia in the form of ingots for making tools required by carpenters, smiths, bead-makers, shell-workers and fishermen. Neither the alluvial plains around Lothal nor the hills of central Saurashtra produce any copper ore or tin.

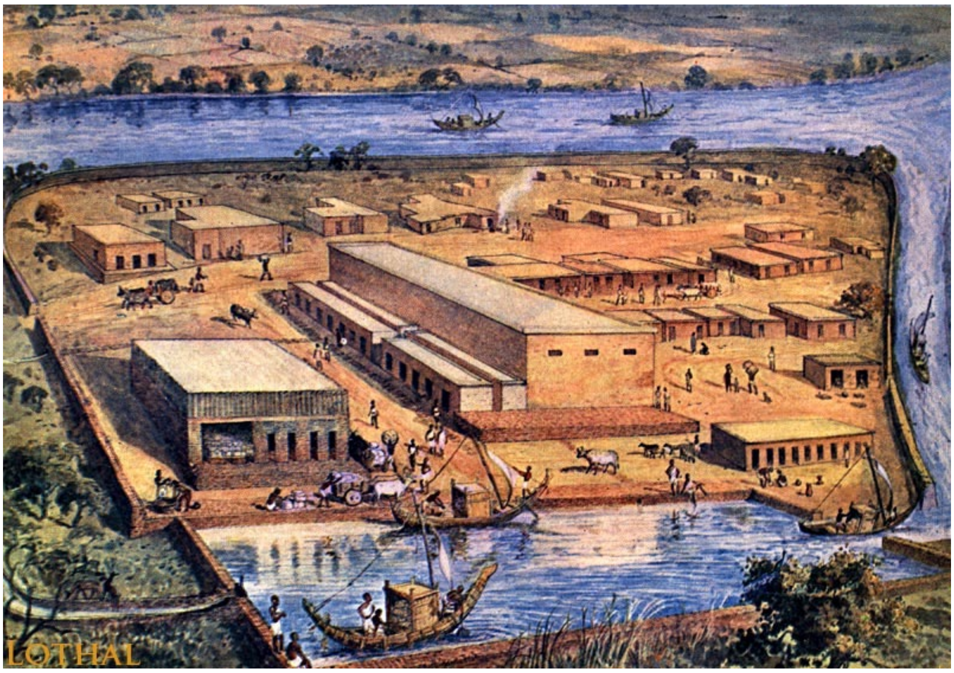

Figure 6: - Lothal Map

Figure 7: - Ware House

Figure 8 :- Drainage System

Figure 9: - Dockyard

Figure 10 : - Well

Day -2 (23/01/23)

Spot 1

Latitude: - N 23º29’11”

Longitude: - E 72º35’49”

Location: - Amritavarshini Vav

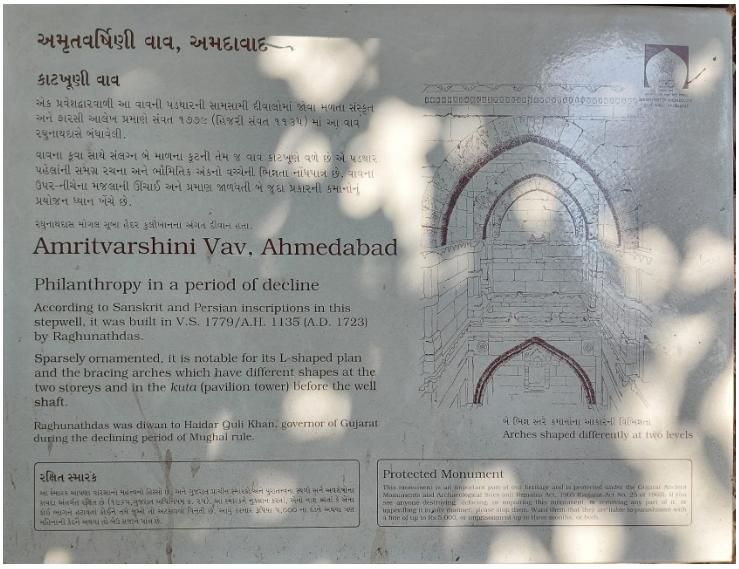

Figure 11: - The Amritvarshini Vav, Ahmedabad

The stepwell is situated 500m away from Ahmedabad railway station. It has a three storey and is more than 50ft deep. It is one of the 5 wells which was built in 1723. It is sparsely ornamented but it is notable for its L-shaped plan and the bracing arches which have different shapes at the two storeys and in the pavilion tower before the good shaft.

Figure 12: - The Well

Spot 2

Lattitude:- 23˚1’40” N

Longitude: - 73˚36’3” E

Location: – Jultah Minar

The minarets, situated north of Ahmedabad Junction railway station, are the tallest in the city. Despite significant damage at the base, the stairs inside the minarets remain functional. The minarets are composed of three levels, each adorned with intricately carved balconies. A curious phenomenon observed is that a gentle shake of one minaret causes the other to vibrate after a few seconds, while the connecting passage between them remains unaffected. Although the exact cause of this remains unknown, it is believed that the layered construction of the minarets may be a contributing factor. The English Sanskrit scholar first documented this phenomenon in the 19th century. Remarkably, these minarets can withstand fast-moving trains that pass nearby. Unfortunately, the main structure of the building was destroyed in 1753 during the Maratha-Mughal war in Gujarat. Presently, only two minarets and the arched central gateway that connects them remain.

Figure 13: - Jultah Minar

Spot 3

Latitude: - 23.0356 ° N

Longitude: - 72.5435 ° E

Location: - Physical Research Laboratory

The Physical Research Laboratory (PRL) is a national research institute located in Ahmedabad, India. It was established in 1947 by Dr. Vikram Sarabhai, who is considered to be the father of India's space program. PRL is a premier research institution for space and allied sciences in India and is affiliated with the Indian Space Research Organisation (ISRO).

The research at PRL is focused on various areas of space science, such as astronomy, astrophysics, atmospheric science, planetary science, and Earth sciences. Some of the key areas of research at PRL include studying the evolution of stars and galaxies, developing advanced telescopes and instruments for astronomical observations, studying the Earth's atmosphere and climate, and developing technologies for space exploration.

PRL also has several major facilities, including the Space Astronomy and Solar Physics Division, the Planetary Sciences Division, the Atmospheric Sciences Division, and the Electronics and Instrumentation Division. The department in question is responsible for managing various research programs, with a particular emphasis on aerosol chemistry, hydrology, palaeoclimatology, and oceanography. To support these programs, the department has several experimental facilities, such as an accelerator mass spectrometer (AMS), aethalometer, isotope ratio mass spectrometer (IRMS), Thermal Ionization Mass Spectrometer (TIMS), High-Resolution Inductively Coupled Plasma Mass Spectrometry (HRICPMS), ion chromatography and many more mass spectrometers.

The primary focus of this department is on studying the origin and evolution of Earth and its components, with an emphasis on geochronology, geochemistry, glaciology, oceanography, and palaeoclimatology. One of the most extensively researched subjects within the department is isotope geology, which involves measuring the abundances of radioactive isotopes, elements, and other components to understand various geological processes. Overall, the department aims to contribute to the advancement of knowledge in the geosciences field and to deepen our understanding of Earth and its complex systems through rigorous research and experimentation.

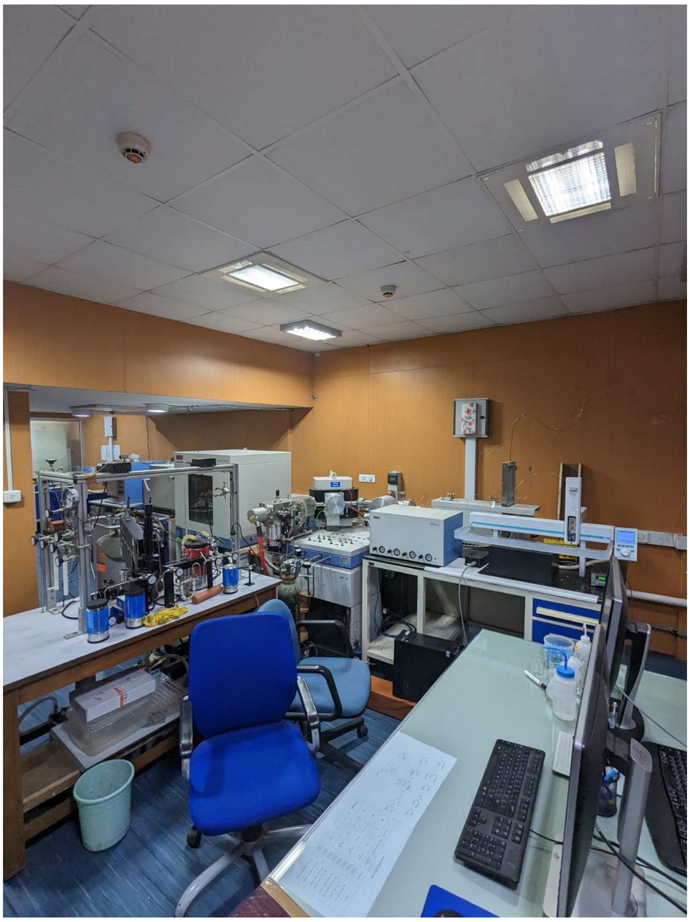

Figure 14: - ICP-AES (ICP-AES inductively coupled plasma atomic emission spectrometry)

Figure 15: - Radiometric dating of Carbon

Day-3 (24/01/23)

Spot 1

Latitude: - 22.97075 ° N
Longitude: - 73.3464 ° E
Location: - Mahadev Temple, Balasinor

The granite is named as Godhra granite after the town Godhra where massive outcrops of the rock have been reported. The intrusion of Godhra granite is the largest igneous activity in Gujarat. The age of granite is determined as 955 $\pm$ 20 Ma by the Rb-Sr technique (Gopalan et. al., 1979). The Godhra granites of Balasinor have a characteristic coarse-grained, phaneritic texture, and porphyritic appearance, with a high leucocratic colour index. The mineral composition of the Godhra granites of Balasinor includes large plagioclase grains that range in size from approximately 2.5-1.5 cm. The matrix minerals of the granite include plagioclase, quartz, orthoclase, and biotite. The biotite in the granite is observed to form large clusters due to the slow cooling rate of the rock.

Apart from the typical mineral composition of granite, the Godhra granites of Balasinor also contain enclaves with a gneissic texture. The presence of xenoliths indicates that the granite was rapidly emplaced because of which the xenoliths could not be consumed by the magma entirely. These enclaves exhibit alternating felsic and mafic bands and range in size from approximately 2.5-2 cm. It is believed that the banded gneiss is found as enclaves in the granite, which suggests that the banded gneiss is older than the Godhra Granite of Balasinor.

This granite is thus younger than the Champaner meta-sedimentary complex into which it has intruded. The presence of xenoliths with granodioritic composition imply that there have been multiple intrusions of the Godhra granite. Such activity has been referred to as prolonged granite deformation in the literature. The granite shows tor and tafoni types of weathering which are characteristic of granitic outcrops. The sizes of the plagioclase feldspar phenocryst were found to be 5 to 6cm while those of the xenoliths in the granite were 10 to 15 cm.

Figure 16: - Xenoliths in granites

Figure 17: - An outcrop of Godhra granites showing the typical tor weathering.

Figure 18: - Biotite Segregation in granites

Figure 19: - Plagioclase laths in granite

Spot 2

Latitude: - 23° 05’ 62’’ N
Longitude: - 73° 34 35’’ E
Location: - Raiyoli, Balasinor

Figure 20: - Balasinor Dinosaur Fossil Park

The location is was discovered in 1981 and found that the fossils are 65 m2llion years old. It is said to be the world’s 3rd largest Dinosaur Fossil excavation site and 2nd largest hatchery. The location is said to be the nesting site of dinosaurs in the past. The place contain bone fossils of different parts of different species.

The Balasinor region is part of the Deccan volcanic province, which is a large igneous province located in western and central India. The Deccan Traps, a thick sequence of basaltic lava flows, cover much of this region and were formed by intense volcanic activity during the Late Cretaceous period, approximately 66 million years ago. The volcanic activity that created the Deccan Traps is thought to have had a significant impact on the extinction of the dinosaurs. The massive amounts of volcanic ash and gas released into the atmosphere may have caused global cooling, leading to a decline in vegetation and a subsequent decline in dinosaur populations.

The sedimentary rocks in the Balasinor region are primarily composed of sandstones, shales, and limestones that were deposited during the Late Cretaceous period. These rocks have preserved a rich fossil record of the dinosaurs that once roamed the region. The Balasinor fossils are found in the Lameta Formation, a geological formation that is characterized by its thick beds of sandstones and shales. The Lameta Formation was deposited in a shallow marine environment, and the sedimentary rocks contain a variety of fossilized flora and fauna, including dinosaurs, crocodiles, turtles, fish, and invertebrates.

The dinosaur fossils found in the Balasinor region are typically fragmentary, consisting of isolated bones and teeth. However, some fossils are more complete, such as the Rajasaurus narmadensis skull, which has been extensively studied by paleontologists. Overall, the geology of the Balasinor region has played a crucial role in preserving the dinosaur fossils found there. The sedimentary rocks and volcanic deposits have provided a rich fossil record of the Late Cretaceous period, allowing scientists to better understand the evolution and behavior of the dinosaurs that once roamed the earth.

Several fossils of,

Dinosaur bones: The park is home to a large number of dinosaur fossils, including those of the Rajasaurus narmadensis, a theropod dinosaur with a distinctive crest on its skull, and the Titanosaur, a large herbivorous dinosaur.

Dinosaur eggs and nests: The park also contains several nests and eggs of the Titanosaur, which provide valuable information about the reproductive behavior of these prehistoric creatures.

Fish fossils: The Balasinor region was once home to a variety of fish, and their fossils can be found in the park's sedimentary rocks. These fossils provide insights into the evolution and diversity of fish during the Late Cretaceous period.

Invertebrate fossils: The park contains a variety of invertebrate fossils, such as ammonites and belemnites, which were common during the Late Cretaceous period.

Plant fossils: Fossilized plant remains, such as leaves and stems, have also been found in the park's sedimentary rocks, providing a glimpse into the flora of the region during the Late Cretaceous period.

Figure 21: - Cerapod Eggs

Figure 22: - Left Over Ribs of a Dinosaur

Figure23: - Terapod Vertebrea

Near the fossil park, an outcrop was identified where exposed outcrops of conglomerate with different sizes of clasts were observed with a size ranging from 2 – 3 cm. Fine-grained jaspers were found as clasts in Limestones. Teethes and Bones of Dinosaurs were also identified with the eggs in the limestones.

Figure 24: - Conglomerates with clast size ranging from 2-3 cm

Figure 25: - Jasper clasts in limestone

<u>DAY 4</u> (25-01-2023)

Latitude: - 23^0 31' 74" N

Longitude: - 72^0 79' 91" E

Location: - ONGC Motera GGS

ONGC Motera GGS (Gas Gathering Station) is a gas processing and compression facility located in Motera, Ahmedabad, India. It is owned and operated by the Oil and Natural Gas Corporation (ONGC), India's largest oil and gas exploration and production company. The Motera GGS plays a crucial role in the company's efforts to extract and process natural gas from the Cambay Basin in Gujarat. The Cambay Basin is a sedimentary basin located in the western part of India, covering an area of approximately 50,000 square kilometres. The basin is known for its rich reserves of oil and gas, and ONGC has been exploring and producing hydrocarbons from the basin since the 1960s. The Motera GGS is one of the major gas processing facilities operated by ONGC in the Cambay Basin. The facility has a capacity of processing 30 million cubic meters of natural gas per day, and it is equipped with state-of-the-art technologies and equipment for gas compression, processing, and transportation.

The natural gas produced from the Cambay Basin contains a mixture of gases such as methane, ethane, propane, butane, and nitrogen. The Motera GGS uses a combination of cryogenic and adsorption technologies to separate and purify these gases. The purified gas is then compressed to a high pressure of around 70 bar, making it suitable for transportation through pipelines or for use in industrial applications. Apart from gas processing and compression, the Motera GGS also has facilities for sulfur recovery and disposal. The sulfur recovery unit at the facility uses the Claus process to recover sulfur from the gas stream and convert it into elemental sulfur, which is then transported and used in various industrial applications. The facility also has a flare system for the safe disposal of excess gas, which is burnt in a controlled manner to prevent any harmful emissions into the atmosphere. In addition to its technical capabilities, the Motera GGS is also known for its commitment to environmental sustainability and safety. The facility is equipped with advanced monitoring systems and equipment to ensure compliance with environmental regulations, and it has implemented various measures to minimize its impact on the environment. The facility also follows strict safety protocols and procedures to ensure the safety of its workers and surrounding communities.

Overall, the ONGC Motera GGS is a crucial component of India's energy infrastructure, playing a significant role in the production, processing, and transportation of natural gas from the Cambay Basin.

Figure 26: - ONGC Motera GGS

Figure 27: - ONGC Motera GGS

Rajasthan

DAY 6 (27/01/23)

Spot 1

Latitude: - 24º28’21” N

Longitude: -73º51’34” E

Location: - Jhamar Kotra Mine, Udaipur

Jhamar Kotra Mines is located in the Udaipur district of Rajasthan, India, and is a major source of rock phosphate, which is used in the production of fertilizers. The mine was started in 1968 and is an open-cast mine that operates one of the largest and fully mechanized mines in the country. The geology of the Jhamar Kotra Mines is unique and complex. The mines are located in the lower Aravalli supergroup, which is a geological formation in western India. The deposits are found below an unconformity and above the Banded Gneissic Complex of Archean age.

The host rock of the Jhamar Kotra Mines is dolomite. The horizon marker for the mines is the Jhamar deposits of 2000 million years ago (mya), which are sedimentary deposits. During the sedimentation process, there was a favorable environment for the growth of blue-green algae, which formed stromatolites. The deposits are mainly limestone, formed by the growth of blue-green algae, and are layered. The deposit was formed in a shallow basin where dissolved phosphate provided a favorable environment for algae to grow and deposit. The phosphate was being deposited in the basin from the flowing water from 500km. When the sedimentation stopped due to the water drying up, the algae process also stopped.

The ore at Jhamar Kotra Mines is thin and sharply dipping, which has resulted in long and narrow pits with great depth extension, involving very high stripping ratios with high lead and lift for waste and minerals. Despite these challenges, the Jhamar Kotra project has been able to sustain difficult periods due to its commitment towards a scientific approach for the exploitation of the deposit with the planned development of the pits. The first bench width of the mine is 10 meters, the face width is 7 meters, and the next set is also the same as this. The other bench is slightly dipping and 12 meters wide for deposition. The ore-to-overburden ratio is 1:16. The transition from low to high-grade ore might be due to meteoric rain, which dissolved dolomite, thereby increasing the grade of ore.

Groundwater has been a significant challenge for the mines, and an effective dewatering scheme was developed and implemented to keep the working levels dry. The open pit mining method is being followed at the mines for the exploitation of the mineral. Continuous pumping of groundwater through tube wells constructed on the periphery of the pit limit keeps the working area dry. The ore body is zig-zag with faults and folds. the average dip is 55 ^{o}and the thickness of 5-15km. The rock phosphate occurs in dolomitic limestone associated with stromatolites appearing in grey to bluish grey colour shades and in variable forms and shapes. The ore body is of Horseshoe shaped which is sandwiched in between the hanging wall and the footwall. Magma has got injected inside the Dolomite forming Secondary phosphate Apatite. The water flow trend is NW-SE.

Figure 28: - Jhamar Kotra Mines

Figure 29: - Apatite

Figure 30: – Possible calcite

Figure 31: - High-Grade ore

Figure 32: - Low Grade Ore

Figure 33: - Black Band – Stromatolite (algal), White Band - Dolomite

Spot 2

Latitude: - $24^{0}57'96''$

Longitude: - $73^{0}72'17''$

Location: - Jhameshwar Mahadev temple, Jhamar Kotra

Figure 34: - Stalactites of Jhameshwar Mahadev Temple

The formation of stalactites is observed inside the temple cave hanging from the top. A stalactite is an elongated structure of minerals formed and hanging from the ceilings of caves, hot springs, or man-made structures such as bridges and mines. They are deposited from a solution of minerals in the water, slowly dripping from the ceilings. Stalactites are formed by materials that are soluble and can be deposited as colloids, or in suspension and have the capacity to be melted. The stalactite can be made up of lava, minerals, mud, peat, pitch, sand, sinter, and amberat (crystallized urine of packrats). The most abundant forms of stalactites are found in limestone caves just because of sheer numbers. Thus, one may find most stalactites in stalactite and stalagmite caves.

Day 7 (28/01/23)

Spot 1

Latitude: - $24^0$90'59" N

Longitude: - $74^0$62'16" E

Location: -Berach River, Chittorgarh

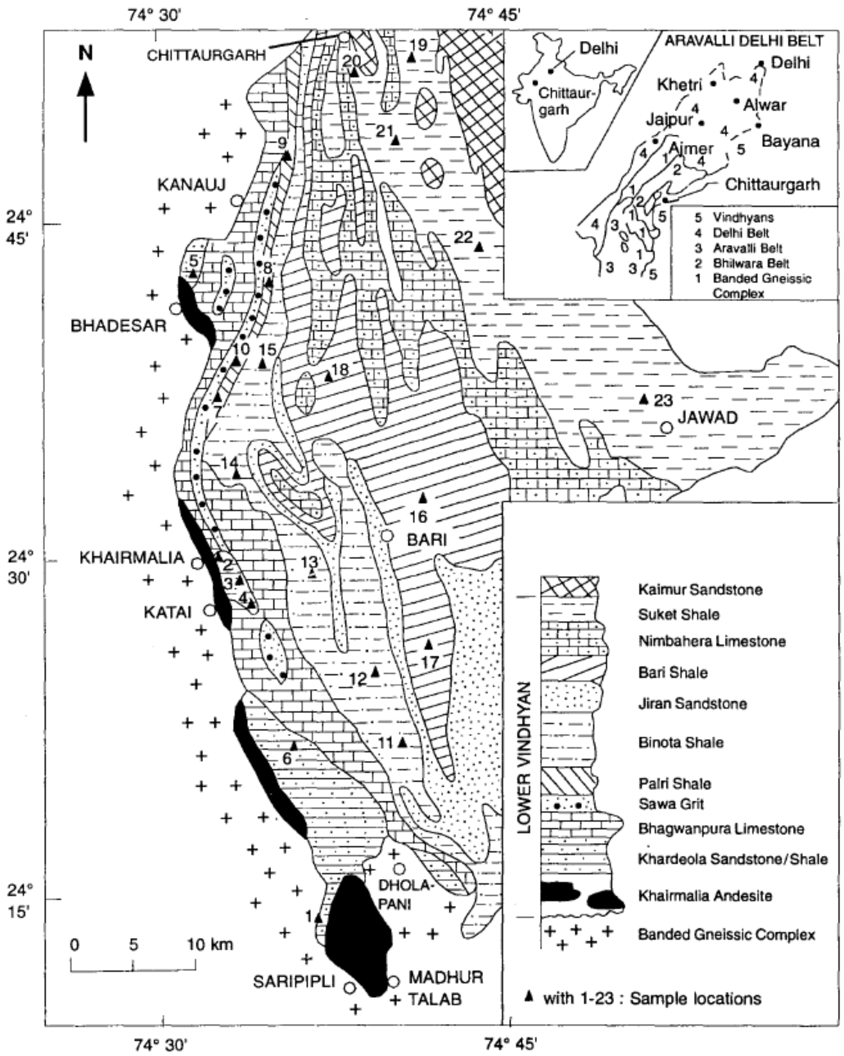

Figure 35: - Stratigraphic map of Lower Vindhyan Group in Rajasthan

The Suket Shales are part of Lower Vindhyan in the Khorip group and are correlated with the Semri group of rocks. The age is predicted to be close to 1.6 Ga. The Suket Shale which overlies Nimbahera Limestone is well exposed between Chittaurgarh and Jawad and extends further eastward. These are earthy brown, greenish, bluish grey, and purple coloured, fissile, fragile and often well-jointed shales. Sometimes, they are siliceous, micaceous and often calcareous near the base. In the upper part intercalations of greenish arenaceous bands are found at places. The rocks of this spot are exposed along the banks of the river Berach. Berach River flows parallel to the great boundary fault. This is fine-grain sedimentary rock texturally foliated and with a slaty cleavage structure. Quartz veins are concordant with the folding. The is grey coloured with red and white layers.

The structural data from the tables show that the area has undergone two generations of deformation which is confirmed by the presence of two generations of the fold with the F1 fold forming syncline and anticline structure striking N50^0 which plunges towards the south and the F2 fold striking along N120. Two joint conjugate joint sets are present with trends of N 100^0 and N 140^0. An 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 more closely spaced than the joints present away from the river that is away from the Great Boundary Fault. Slicken sides are observed, which indicates the presence of fault and quartz veins are also present which may be either syngenetic or post-genetic.

Strike Direction	Dip Direction	Dip Amount
N50^0	N145^0	55^0
N55^0	N240^0	43^0
Fold Data		
Left limb – N71^0	South East	25^0
Hinge - N104^0	South	49^0
Right limb – N 150^0	South West	70^0

F2 Fold Data		
Strike Direction	Dip Direction	Dip Amount
N220^0	N40^0	45^0
N200^0	N30^0	32^0
N302^0	N210^0	43^0

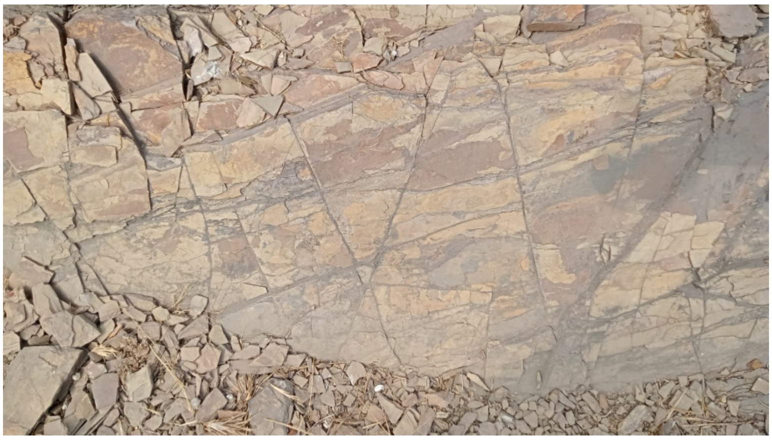

Figure 7: - Two set of Joints

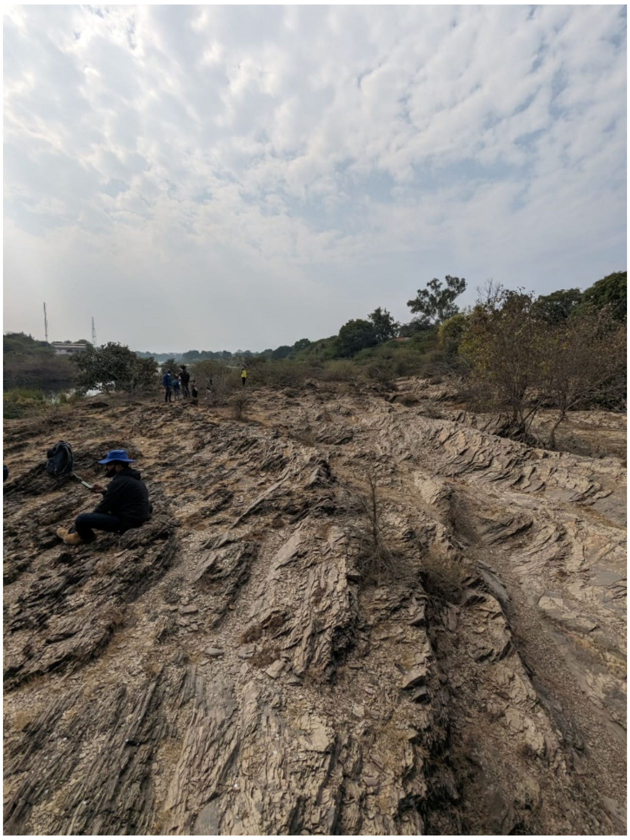

Figure 36: - Suket Shale

Figure 37: - F1 generation of Fold

Figure 38: - F2 generation of fold

Spot 2

Latitude: - 24^0 90’ 55”

Longitude: - 74^0 63’ 76”

Location: - Gambhiri River, Chittorgarh

Nimbahera Limestone is a type of limestone found in the Nimbahera region of Rajasthan, India. This limestone is part of the Lower Vindhyan formation, which is a sedimentary rock unit that was deposited during the Proterozoic era. The Nimbahera Limestone is composed primarily of calcium carbonate in the form of calcite mineral. It also contains small amounts of other minerals such as quartz, feldspar, clay minerals, and pyrite. The limestone is generally light grey to white in colour and has a fine-grained texture.

The formation of Nimbahera Limestone is attributed to the deposition of sediments in shallow marine environments. During the Proterozoic era, the Nimbahera region was covered by a shallow sea, and the accumulation of sediments over time led to the formation of the limestone deposit. The limestone has undergone a significant degree of diagenesis, which is the process by which sedimentary rocks are transformed into solid rock through compaction and cementation. Limestones of Nimbahera and Lakheri formations belonging to the Semri and Bhander. The Nimbahera Formation is separated from the Kheinjua stage by Khori Malan conglomerates, Jiran sandstone and Bari shale. The Nimbahera limestone overlies the Bari shale, which is calcareous towards the top. The assignment of 1150 Ma for the Nimbahera Limestone Formation is based on the Rb–Sr isochron age. The limestone bed strikes along N 175^0 and dips towards the west.

Day 8 (29/01/23)

Spot 1

Latitude: - 25 05’ 76” N
Longitude: - 73 85 08” E
Location: - Nathwara

The spot is close to the Nathwara limestones. The exposed rocks are in an abandoned quarry. Rocks formed are in a sequence. The weathered Mica schist layer is sandwiched between layers of marble. The marbels are deformed and the lower bed has a strike direction of 135^0 with a dip of 27^0 toward the south west and the upper marbles have a strike direction of 130^0 with a dip of 42^0 towards the southwest. The Mica schist present has a strike direction of 140^0 and a dip of 30^0 towards the southwest. There are serpentine present in the marble.

Figure 8: - Quarry

Figure 9: - Possible porphyroblast of CaCO3

Figure 10: - Mica underlined by Mica Schist

Figure 11: - Possible amphibole in Marble

Near this outcrop is another possible abandoned quarry which is composed of amphibolite schist. The schist beds have a strike direction of N 140^0 with a dip of 25^0 towards the southwest. They have the same attitude as the mica schist and marble. This outcrop is composed more of quartz than the mica shist and marble outcrop.

Figure 12: - Amphibolite Schist outcrop quarry

Figure 13: - Amphiboles of Amphibolite schist

Acknowledgement

The completion of any achievement, including this report, is not a solitary effort, but rather requires the support and contributions of many individuals. The hard work and efforts put into this report were the results of the guidance and support provided by numerous people, and I am deeply grateful to all of them for their invaluable assistance. I would like to take this opportunity to express my appreciation to everyone who contributed to the completion of this report. Without their help, it would not have been possible to achieve the level of quality and thoroughness that was required. The individuals who provided support and guidance along the way were instrumental in ensuring that the report was completed successfully.

I am particularly thankful for the assistance and guidance provided by Dr Anthony Viegas, Professor Pooja Ghadi, Dr Niyati Kalangutkar, and Professor Mahesh Mayekar as well as other faculty members of the SEOAS - Goa University who supported us throughout the fieldwork days. Their knowledge and expertise were essential in helping us to gather the necessary data and complete the report.

Lastly, I would like to extend my gratitude to my friends who provided valuable support and constant motivation during the fieldwork. Their encouragement and assistance were critical in helping me to stay focused and complete the work to the best of my ability. In conclusion, I want to reiterate that any accomplishment, including the completion of this report, is a team effort, and I am deeply grateful for the support and guidance of everyone who contributed to its success.

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