

GEOLOGY AND MINERAL RESOURCES OF RAJASTHAN

राजस्थान

का

भूविज्ञान

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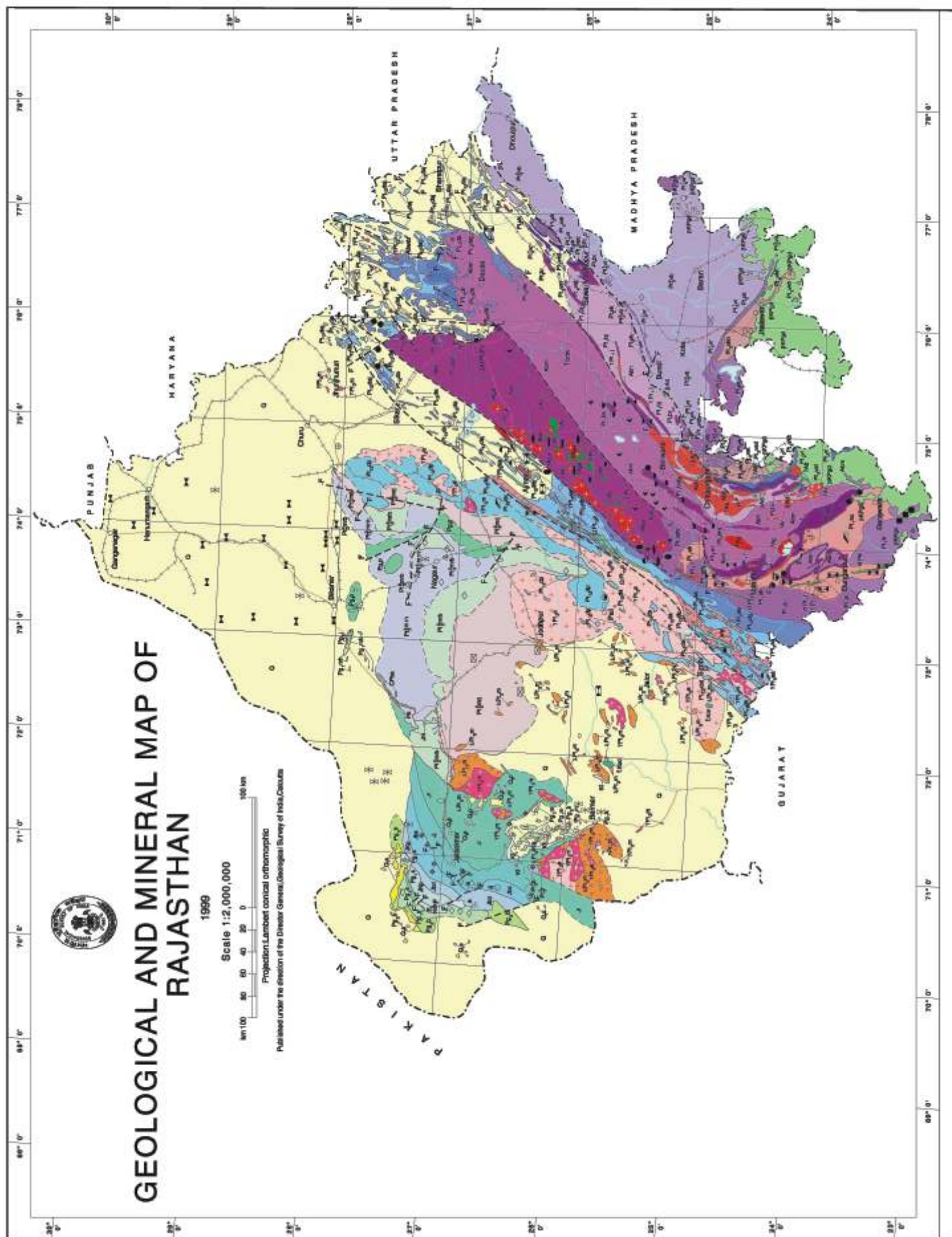
खनिज संसाधन

GEOLOGICAL SURVEY OF INDIA
Miscellaneous Publication
No. 30 Part 12 • 3rd Revised Edition

भारतीय भूविज्ञान सर्वेक्षण
भारत सरकार

160
YEARS
in the service of the nation
(1851-2011)





Detailed Geological Map is present in the folder of the book

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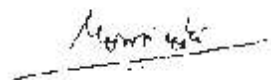
Foreword

The state of Rajasthan is endowed with a storehouse of mineral deposits of copper, lead, zinc, gold, tungsten, potash, lignite, mica, graphite and many non-metallic minerals and dimensional stones. Concerted efforts of GSI over the last few decades had resulted in augmenting the mineral resources position of Rajasthan to several folds. The knowledge on the Geology of the state of Rajasthan has undergone substantial upgradation as a result of recent works. GSI has been updating the knowledge through its publications viz. records, memoirs, bulletins and mineral atlases as well as in the form of unpublished reports. The third revised edition of Miscellaneous Publication Number 30, Part 12 covering Geology and Mineral resources of Rajasthan has been thoroughly revised incorporating the data gathered during the recent past.

The urgent need in Earth Sciences is to update the data in terms of tectono-magmatic evolution of the area. In this Publication a comprehensive evolution of the geological set up of Rajasthan has been made incorporating the latest knowledge on the tectonic and metallogenic set up of the various domains and the mineral deposits have been described.

I believe that this write up would be of much help to the scientists, students and researchers at large in the field of earth sciences.

Kolkata
December, 2010


(Jaswant Singh)
Director General
Geological Survey of India

*Rocks are records of events that took place at the time they formed.
They are books. They have a different vocabulary,
a different alphabet, but you learn how to read them.*

JOHN MCPHEE

*The primary role of the geologist is to recognise the
existence of phenomena before trying to explain it.*

B. M. KEILHAU

राजस्थान का भूविज्ञान एवं खनिज संसाधन

Geology and Mineral Resources of Rajasthan

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Introduction

The Rajasthan State, earlier known as Rajputana came into existence on March 30, 1949. It occupies 3,42,239 sq km area covering 10.74% of the Indian Territory and is the largest State of India. 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 on the south-southeast and southwest by Madhya Pradesh and Gujarat States respectively. The north-western part of the State is occupied by the Thar Desert covering 32% 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 north-western part of the Indian Shield. The rock sequences of the region cover a time span 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 Bhilwara Supergroup rest on the basement rocks of the Mangalwar Complex and host a number of 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 south-eastern, 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 volcanics, whereas the Delhi Supergroup comprises mainly carbonates, metavolcanics, metasammities and metapelites, intruded by magmatic rock of Phulad Ophiolite Suite and syn-orogenic granites of Sendra-Ambaji, Bairath, 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 Supergroup which are overlain by sedimentary rocks of different ages of Palaeozoic 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 Chittaurgarh-Banswara area. The Cenozoic rocks are manifested in Barmer and Jaisalmer basins in the west and 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.

The present write-up gives a succinct account of geology of Rajasthan and details of mineral repositories of the State. This document has been compiled from the work carried out by the officers† of Geological Survey of India for over nine decades.

†The pioneering geological work in different parts of the State in the 19th century has been of W.D. Blanford, C.A. Hackett, T.H.D. La Touche, F.R. Mallet, C.A. Mc. Mahon, H.B. Medlicott, R.D. Oldham and H. Warth. Among the notable earlier workers who mapped almost the entire State, during the period from 1914 to 1933 were A.M. Heron, A.L. Coulson, B.C. Gupta, S.K. Chatterjee, J.B. Auden, P.K. Ghosh, P.N. Mukherjee and V.P. Sondhi. After Indian Independence, mapping and assessment of mineral resources of Ajmer district were carried out mainly by C. Karunakaran, T.K. Kurien, Kedar Narain and V.R. Venkoba Rao between 1948 and 55. *The systematic mapping on modern lines and studies on tectonics and mineral resources* including detailed exploration by drilling in different districts, were carried out by a number of geologists in different areas. B. Srikantan, V.N. Sant and S.B. Sharma (1952-1966) mapped a major part of *Alwar and Jaipur districts*. S.P. Das Gupta (1953-58) completed detailed mapping of the *Khetri Copper Belt*. The adjoining areas near Neem-ka-Thana were mapped by M.L. Jhanwar, O.P. Mathur and M.L. Bhat (1964-70). The mapping in *Ajmer, Alwar, Bharatpur, Bundi, Bhilwara, Banswara, Chittaurgarh, Dungarpur, Jaipur, Jaisalmer, Kota, Pali, Sirohi, Tonk and Udaipur districts* was carried out during 1958-81 by K.K. Basu, B.S. Manjrekar, S.N. Gupta, Y.K. Arora, R.P. Srivastava, B.D. Gupta, T.N. Sahai, R.K. Mathur, L.N. Dutta, V.D. Mahajan, Balmiki Prasad, Iqbaluddin, S.C. Kapoor, K.K. Mukherjee, S. Das Gupta, G.J. Chandak, N.B. Bhattacharayya, Shiv Poojan Misra, N.P. Chaudhury, A.M. Rakshit, S.M. Banerjee, N. Chattopadhyay, K.R. Ramchandran, B. Mukerji, N. Krishnamurthy, S.S. Jain, R.P.S. Pahuja, R.L. Munshi, U.S.N. Reddy, C. Ram Mohana, S.R. Sengupta, B.J.C. Gupta, Ram Lal Garg, S.K. Sinha, S.K. Bhushan, M.R. Madhav Rao, P.C. Bakliwal, H.J. Maharaja Singh, V. Murlidharan, M.P. Muraleedharan, R. Ravindra, A.R. Das, S.P. Singh, P.K. Chaurasia, S.K. Basu, G. Ramalingam, A. Bandhopadhyay, T.K. Pyne, V.K.K. Kalluraya and B.L. Narsayya. P.C. Sogani and E.A. Khan during 1963-71 carried out the *mapping* of major part of the *Marwar Supergroup* (Trans-Aravalli Vindhya) covering Pali, Jodhpur and Nagaur districts. Besides, a large number of geologists namely S. Adhikari, A.K. Chattopadhyay, M.P. Chawade, V.P. Laul, S.M. Ramasamy, Virendra Kumar, J.N. Ray, S. Adhikari, P. Gupta, Vikram Rai, Z. Iqbal, K.S. Mishra, K. Mazumdar, N.H. Faruqui, Fareeduddin, R. Shukla, S.V. Raghupathi Rao, S.S. Ghosh, R.C. Gathania, I.V. Reddy, P.S. Bhatnagar, V. Chandrasekaran, S.K. Mitra, D.K. Rai, R. Srivastava, L.N. Mathur, G.N. Pal, I.R. Kirmani, P. Sarkar, S.S. Shrivastava, S. Ghosh, R.K. Sinha, Vimal Kumar, B.D. Thapa, S.K. Jadia, B.V. R. Reddy, M.S. Reddy, R.L. Sahu, S. Chaudhary, S.K. Mishra, P. Shrivastava, A.K. Saxena, D. B. Guha, S.A. Chore, K. Mukhopadhyay, I.

Chowdhury, A.K. Mathur, A.K. Sharma, M. Mohanty, G. Malhotra, L.S. Shekhawat, S.N. Bhattacharayya, S.K. Bohra, S.K. Wadhawan, B. Sural, R.M. Sundaram, N.K. Pal, A. Chaturvedi, K.C. Sahu, S.N. Patel, G.P. Gupta, S. Prasad, K.P. Varma, C.J. Kumanan and B.B. Sharma were engaged in mapping different parts of Rajasthan *on modern toposheets and also took up revision mapping in some of mineralized belts*. *First generation mapping* of Rajasthan was, thus, completed by 1989-90.

Workers who carried out *detailed exploration for base metals* in Rajasthan during 1952-90 includes Muktinath, C.S. Raja Rao, V.K.S. Varadan, M. Narasimhan, A.K. Banerjee, W.K. Natarajan, B.C. Poddar, R.K. Mathur, A.L. Mathur, B. Kakoti, V.D. Chande, M.K. Hore, K.R. Raghunandan, R.C. Jog, V.S. Bapna, A.S. Ramaiengar, G.H.S.V.P. Rao, G.V. Devapriyam, R.S. Jain, V. Venkatesh, K. Ganesan; B. Koti Reddy C.L. Harpavat, S.K. Roy, R.S. Jamwal, U. Samaddar, Ram Chandra, M.S. Jairam, R.N. Singh, S.P. Misra, J.L. Narang, R.S. Goyal S.C. Kaura, S.P. Ghosh, J. Bhattacharjee, Eshwara, S.M. Saxena, G.K. Pancholi, T.K. Biswal, V.K. Khullar, Binod Kumar, D. Kothiyal, R.C. Tyagi, Kashi Ram, B. Chattopadhyay, A.K. Mukhopadhyay, R.K. Singhai and T.P. Upadhyay. The work on *phosphorites* was taken up by B. Srikantan, V.N. Sant, S.N. Tarafdar, S.L. Mehra and G.P. Deshmukh (1966-1970), and B. Dayal, V.K.K. Kalluraya, A.P. Sinha and A.K. Malhotra (1970-80).

Since 1990 the GSI has been carrying out *second generation mapping, specialized thematic mapping, transect mapping and concept oriented mineral explorations* covering some parts of the State. These studies have brought out new concepts which are yet to be established on a regional basis, and therefore have not been included in the present write-up though cited in the bibliography. The officers associated with *mapping projects* were: V. Aneel Kumar, A. Rai Chowdhary, B. Chakrabarti, Kakali Jana, T.K. Jana, V.K. Chittora, R.K. Sharma, S. Mukhopadhyaya, L.M.S. Maura, S. Sanyal, Ram Jivan Singh, J.C. Dutta, S. Dutta, S.S. Sivasankaran, V.P. Sharma, K.S. Raghav, C.K. Gautam and Suresh Pareek. The officers who carried out mineral investigations were : S.S. Ameta, Ramjee, L.D. Gaikwad, R.C. Mishra, P.K. Yadav, S. Das Gupta, P.N. Sharma, Chandra Madhav, R.P. Nagar, S.S. Garhia, D.K. Bhattacharya, P.S. Gill, L.N. Singh, S.K. Singh, S.L. Singh, S. Banerji, Brij Kumar, R.A. Sharma, P.R. Golani, Shyam Narain, C.R. Saha, R.S. Rajawat, N.K. Sood, N.K. Sahiwal, D.J. Das Gupta, Shabbir Hussain, K. Nagarajan, N.N. Chaudhuri, A.K. Grover, R.G. Verma, R.K. Vishnoi, I.J. Qureshi, R.S. Garkhal, Jaya Lal, R.L. Jat, A. Cheillett, Krishan Dutt, S.S. Sarkar, A.B. Reddy and V.S. Murthy.

* established by the DGM, Rajasthan

Physiography

Physiographically, Rajasthan is divided into four regions, bearing a close relationship with the geological history of the State, viz., (i) Western desert plains, (ii) Aravalli mountain range, (iii) Eastern plains and (iv) Vindhyan plateau.

The western desert plain is a sandy desolate expanse of dune fields and rocky pavements. The plain, lying to the west of Aravalli hills, covers 1,75,000 sq km area of the Rajasthan. It is affected by scanty rainfall. The Luni and Sukri rivers, ephemerally flowing in a southwesterly direction, form the main drainage of the area. A large part of western Rajasthan is characterised by its inland drainage and carries some of the largest salt-lakes, viz., the Sambhar, Didwana, Kuchaman and Talchapar lakes.

The Aravalli hills of Rajasthan traverse the State in a NNE-SSW direction almost from end to end dividing Rajasthan in two unequal parts, three-fifth of which constitutes the western Rajasthan, two-fifth constituting the eastern Rajasthan. The Aravalli mountain range which exposes principally rocks of the Delhi Supergroup comprises alternating hill ranges and valleys extending from Delhi on the NE to the plains of north Gujarat on the SW for a distance of about 650 km. The entire hill range can broadly be divided into : (i) The north-eastern hill range to the northwest of Jaipur district with an average height of 550-650 m (Alwar hills) and intermittent wide valleys; (ii) The central Aravalli hill range comprising hills of Shekhawati and Marwar region with an average height of 400 m (Shekhawati hills); (iii) The Mewar hills covering the area of Udaipur, Dungarpur and Sirohi districts with the relief varying from a plateau between

Kumbhalgarh and Gogunda to uniformly rolling country on the south-central part and (iv) The Mt. Abu hill range, with an average 1,200 m height, constituted by the Abu batholith of the Erinpura Granite. The highest peak called Guru Shikhar, 1,727 m above MSL, is situated on the Mount Abu. The Aravalli range partly forms one of the main watersheds of India, which divides drainage to the Bay of Bengal from the Arabian Sea. Ajmer city, lying almost at the centre of the range, is in fact on a tri-junction of the watershed. The watershed passes along the centre of the range from Ajmer to the southwest up to Kumbhalgarh where it swings to the southeast for some distance to pass ultimately through Udaipur. South of Udaipur, the drainage is to the south into the Gulf of Cambay through the Sabarmati river. The streams emanating from the north and northeast of Udaipur flow into the Banas river through its tributaries. The Sahibi river drains the northern parts of the State and ultimately disappears in the plains of Haryana State. The Banganga river drains the areas in Alwar and Jaipur districts and flows through a large part of Bharatpur district, before joining the Jamuna river.

The Eastern plains occur to the northeast, east and southeast of the Aravalli range. The plains cover about 23% area of the Rajasthan. Its northern boundary meets with the Gangetic plains in Bharatpur district; whereas the south-eastern boundary lies in contact with the Vindhyan Supergroup. Three major basins viz., the Chambal basin, Banas basin and Mahi basin comprise the plains. It constitutes a vast undulating, pediplained country occupied by the gneisses and schists of the Banded Gneissic Complex as well as the phyllites

and other rocks of the Aravalli Supergroup. The terrain is covered by a thick mantle of alluvium and wind-blown sand.

The Vindhyan Supergroup in the southeast, is constituted by alternating sequences of sandstone, shale and limestone, forms the western extremity of the main Vindhyan basin. The Vindhyan in this area comprise three groups-the Bhandar Group to the northeast, followed by the Rewa Group to the south and west, and the Kaimur Group encircling the Rewa and Bhandar Group. The Deccan Traps plateau, further south, continues in Madhya Pradesh. The junction between the Vindhyan Supergroup and the Eastern plains of Rajasthan is marked by the Great Boundary Fault (GBF). The drainage in this part of Rajasthan is generally to the

north and northeast. The Berach river which drains the south-western parts of the Vindhyan, runs northwards, turns to the northeast and flows parallel to and on the northern side of the GBF. The Berach river flows into the Banas river which joins the Chambal river in Dholpur area. Elsewhere the rivers and streams flow in different directions and join the Chambal river which flows in a northeasterly direction parallel to the GBF through Kota. The Chambal river draining into the Jamuna river in Uttar Pradesh is the only perennial river in the State.

The rainfall in the Aravalli hill range and further to the east is moderate (150 cm per year). But, to the west of the Aravalli range the rainfall is scanty and sporadic.

* * * *

Indian Precambrian Shield is an assembly of more than one Archaean cratonic nuclei that amalgamated during late Archaean - early Proterozoic time. This amalgamated Indian Precambrian crust could be divided into geologically well defined geographical parts separated by some fundamental crustal dislocations and/or vast expanses of Phanerozoic rocks. One such part is the Western Indian Shield covering the states of Rajasthan and Gujarat. The Rajasthan state, encompassing an area of 3,42,239 sq km bounded by latitude 23° 03'N to 30° 12'N and longitude 69° 29'E to 78° 17'E, exposes rock sequences ranging in age from Archaean to Recent times. The Western Indian Shield can be conveniently sub-divided into Provinces on the basis of distinct lithological, structural, metamorphic, geochemical characteristics and geochronology. Shears/fault zones mark the boundaries and join the Provinces. The different provinces of the Western Indian Shield from east to west are the BGC Province, the Aravalli-Delhi Province and the Trans-Aravalli Province.

The oldest cratonic nucleus of the Western Indian Shield, familiarly known as the Banded Gneissic Complex (BGC), occupies a large tract in the Mewar plains of south and east Rajasthan and forms a major component of the BGC Province. It is skirted on the west and southwest by Proterozoic fold belts of the Aravalli and the Delhi Supergroups (forming the Aravalli-Delhi Province), and an arcuate belt of low grade metamorphosed volcano-sedimentaries (erstwhile Gwalior Series of Heron, 1953; Eastern Aravalli Belt of Gupta, 1934; and Hindoli-Jahazpur Groups of Gupta *et al.* 1980) and Vindhyan platformal sediments (Upper Proterozoic) demarcate the eastern boundary of this craton. Besides, a Deccan Trap cover delimits the southern boundary of its outcrop area. The BGC forms the basement for a number of synformal basins hosting metasedimentary/metavolcano-

sedimentary rock sequences of early Proterozoic age like those of Gangwara, Sawar, Bharak-Parasoli-Shriramnagar and Rajpura-Dariba.

The Aravalli-Delhi Province is composed of Proterozoic supracrustals sequences classified at the Aravalli Supergroups (early Proterozoic) and Delhi Supergroup (early to middle Proterozoic). Metamorphic and structural parameters backed up by geochronological data have clearly demonstrated that the BGC was a crystalline basement upon which the rocks of the Proterozoic Aravalli and Delhi Supergroups were deposited. Besides, evidences of an unconformity between the BGC and the overlying supracrustals suites have been widely proposed. The Delhi Supergroup occurs in the form of two distinct fold belts, i.e., the North Delhi Fold Belt (NDFB) in Alwar, Dausa, Jaipur, Bharatpur, Sikar and Jhunjhunu districts and the South Delhi Fold Belt (SDFB) in Ajmer, Pali, Rajsamand, Udaipur and Sirohi districts.

The Trans-Aravalli Province encompasses the area west of the Aravalli Mountains. Late Proterozoic igneous and sedimentary rock assemblages, grouped under the Malani Igneous Suite alongwith crystallines of Archaean age (equivalent of the BGC) and the Marwar Supergroup occupy a large part of the Trans-Aravalli Province. The Malani and the Marwar rocks are not deformed and, therefore, the episodes of the Precambrian magmatism/sedimentation in this part of the Western Indian shield are post-tectonic (anorogenic phenomenon).

The Late Proterozoic to Early Cambrian (?) Marwar Supergroup occupies the westernmost and northwestern parts of the State and comprises the Jodhpur Sandstone, Bilara dolomite-limestone, Hanseran evaporite sequence and the Nagaur sandstone, clay and Siltstone. These sequences overlie the basement constituted mainly by the Malani Igneous Suite. The rocks of the

Marwar Supergroup are unconformably overlain by the Bap Boulder Bed which forms the basement for the Badhaura Sandstone, the youngest Palaeozoic formation. The Mesozoic and the Cenozoic geological sequences are represented by sandstone, shale and limestone in Jaisalmer, Barmer and Palana basins and host Tertiary lignite, oil and natural gas.

The above rock sequences acted as repositories to several mineral deposits of economic importance, thereby, enlisting the state of Rajasthan as one of the leading mineral producing states in India (Table-8). Though mafic-ultramafic intrusives in shear zones or in zones of reactivation inevitably hold some promise, the high-grade rocks of the BGC are invariably devoid of important mineralisations. BGC contains vestiges of greenstone rocks engulfed in the succeeding granites and migmatites. These greenstone rocks contain copper and zinc and are bestowed with gold occurrences, the latter often in enriched forms in zones of high strain. The best known sulphide mineralisations, volcanogenic and sediment-hosted, are located in Proterozoic fold belts and in the intracratonic Proterozoic basins within the BGC and are related to extensional tectonics that led to the development of mostly abortive rift basins. Tin-tungsten mineralisations have been hosted by Proterozoic granites intruding the crystalline rocks of Archaean age (BGC equivalent rock) in the Trans-Aravalli Province and the Proterozoic SDFB. These along with the Proto-ophiolite associated basemetal sulphide deposits in the southwestern part of the SDFB reflect a process of convergent tectonics circumventing the oceanic crust.

BANDED GNEISSIC COMPLEX PROVINCE

The Precambrian rocks of Rajasthan were studied in the initial stages by Hackett (1881), Heron (1917, 1923, 1936 and 1953), Coulson (1927 and 1928) and Gupta (1934). Heron (1936, 1953) and Gupta (op.cit.) classified the Precambrian rocks of Rajasthan, "not counting the Bundelkhand Gneiss", in the order of increasing antiquity as the Vindhyan 'System', Malani 'Series', Delhi 'System', Raialo 'Series', Aravalli 'System' and Banded Gneissic Complex (pre-Aravallies) "separated from one other by five clear erosional unconformities".

Heron (1917, 1953) grouped the Aravalli 'System', the Banded Gneissic Complex and the Bundelkhand Gneiss with the Archaean. While geological information have firmly rooted the Aravalli Supergroup

in the early Proterozoic slot, the geochronological data moots that the Bundelkhand Gneiss in the Rajasthan part (renamed by Pascoe, 1950, as the Berach Granite) represents the terminal stage of magmatic activity of the Archaean orogeny in the late Archaean time.

Though controversy shrouds the BGC as a single Archaean unit, the antiquity of BGC gneisses is established beyond doubt. The Archaean basement status of the BGC is established from the existence of an unconformity between the BGC and the early Proterozoic Aravalli metasediments from southern Rajasthan, the presence of older crust in the provenance of the Aravalli metasediments (indicated from the Pb-Pb isochron age of $\sim 3.5 \pm 0.2$ Ga of Zircon-rich schists from the Aravalli Supergroup), Sm-Nd isochron age of ~ 3.5 Ga for a composite suite of gneisses and amphibolites from the BGC near Udaipur, Sm-Nd isochrones equivalent to 3.31 ± 0.07 Ga and 2.89 ± 0.05 Ga respectively from tonalite to granodiorite and amphibolite from east of Udaipur and Nathdwara respectively and Rb-Sr isochron age of 2950 ± 150 Ma of Untala and Gingla Granites which intrude the biotite gneiss, amphibolites and paragneisses of the BGC. The BGC rocks underlying the Delhi metasediments in central and north-central Rajasthan have undergone polymetamorphism, a feature recognized as characteristic of BGC rocks. This is in sharp contrast to the low grade of metamorphism and intermediate pressure metamorphism inscribed in the Aravalli and Delhi rocks respectively.

BGC represents a cratonic nucleus made up of a heterogeneous assemblage of pre-Aravalli metasediments, migmatites, granites, metabasic rocks, pegmatites and aplite. The metasediments and the igneous rocks belong to multiple cycles and phases and are blended together into composite gneiss; the original precursor rock units, representing the plutonic, volcanic and sedimentary protoliths, are scarcely preserved as xenoliths, bands, streaks and patches. The BGC rocks are intruded by a number of generations of granitic plutons, the latter ranging in age from Archaean to middle Proterozoic. Broadly, in the BGC, the northern part is dominated by meta-sedimentary supracrustals with undifferentiated greenstone sequences and the southern part is prevailed over by distinct volcanic - dominated greenstone sequences within a milieu of granite gneisses with a supposed orthogenetic basement. Inadequacy of chronometric and other data is still a major hindrance to build a distinct stratigraphic framework of the BGC.

However, a semblance of tectono-stratigraphic order was brought about in the BGC terrain of south Mewar among the different components of the BGC, which is chronometrically constrained to some extent by Sm-Nd and Rb-Sr dating. The chronology established is as follows: (1) tonalite gneiss and banded bimodal gneiss (3.3 Ga), (2) enclave suite of igneous (mafic, ultramafic and felsic ~ 2.83 Ga) and sedimentary protoliths forming greenstone-type sequences lodged as dismembered units in succeeding granites and migmatites, and (3) granites and related migmatites of Gingla and coeval rocks (2.8 to 2.9 Ga). The tonalite gneiss and the bimodal gneiss contain mafic enclaves which are apparently their protoliths.

Raja Rao (1967, 1976), Raja Rao *et al.* (1971) were the first ones to attempt a classification of BGC. They grouped the metasediments, migmatites and various gneisses of the BGC occupying an extensive tract falling east of Karera and west of the Great Boundary Fault along with the metavolcano-sedimentary sequence of the erstwhile Gwalior Series and calcareous rocks within the BGC (classified as Raialos by Heron, 1953) into a major lithostratigraphic unit designated as the Bhilwara Group. Gupta *et al.* (1980 and 1997) elevated the Bhilwara Group to the rank of Supergroup. The calcareous rocks of Darauli, Sawar and the quartzite of Rajmahal area are also included in the Bhilwara Supergroup by Gupta *et al.* (1997).

In the terrain of the Bhilwara Supergroup, there is a general increase in the grade of metamorphism from east to west. The grade increases gradually from greenschist in the east to granulite facies in the west. Rocks of amphibolite facies occur in between zones of green schist and granulite facies rocks. The rock groups belonging to the greenschist, amphibolite and granulite facies have been designated by Gupta *et al.* (1980) as Hindoli Group, Mangalwar Complex and Sandmata Complex respectively. Each of these major lithostratigraphic units has been further subdivided into several formations by Gupta *et al.* (1980, 1997). This grouping of rocks under the newly suggested nomenclature has invited criticism from some school of thoughts who believe that it may not be correct to switch over to new nomenclature from the earlier ones unless there are valid justifications.

BHILWARA SUPERGROUP

The stratigraphy of the Bhilwara Supergroup, as suggested by Gupta *et al.* (1997), is given in Table-1.

Metasediments included in the Bhilwara Supergroup consist of mica schist, quartzite, dolomite, marble, chert, fuchsite, quartzite and greywacke. Cross bedding, ripple marks and flute casts are occasionally present in the sediments. Composite gneiss/bimodal gneiss of igneous parentage, migmatite and hornblende and mica bearing schist represent a greater part of the Bhilwara Supergroup. Charnockite, granite, basic granulite and norite are also present.

Sandmata Complex

The Sandmata Complex is named by Gupta *et al.* (1980) after the Sandmata temple located south of Kekri. It forms a 200 km long and 50 km wide belt extending from Amet in the south to Kishangarh in the north. The western boundary is marked by the Delhi Supergroup which overlies the Sandmata Complex along tectonised unconformity. The eastern boundary with the Mangalwar Complex, lying to the east of Parbati and passing through Agucha and Jatan, described as a fault contact, has been rendered obscure by high-grade metamorphic effect and migmatization. The metamorphic-cum-migmatitic contact between the Sandmata Complex and the Mangalwar Complex practically coincides with the Delwara Lineament. On the southwest, the rocks of the Sandmata Complex are bounded by the rocks of the Aravalli Supergroup. The Sandmata Complex comprises migmatite, composite gneiss/bimodal gneiss, calc gneiss, garnet-sillimanite schist, biotite schist, garnet-staurolite-sillimanite schist, chlorite-biotite schist, mica schist, cordierite-garnet pelitic gneiss, enderbite-charnockite, pyroxene granulite, norite, hornblended schist, amphibolite, epidiorite, quartzite, fuchsite quartzite, conglomerate and dolomite marble. The complex is further characterized by preponderance of acid, mafic and ultramafic igneous suite. The Sandmata Complex is separated from the Mangalwar Complex on the basis that metamorphism in Sandmata Complex has reached upto the granulite facies as compared to the amphibolite facies metamorphism suffered by the Mangalwar Complex. The Sandmata Complex has been subdivided into three formations viz., the Baranch, Badnor and Shambhugarh Formations. The major intrusive phases include Giyanganarh-Asind Charnockite-enderbite, Amet Granite, Anjana Granite etc.

According to a few researchers (Sinha Roy *et al.* 1992), the Sandmata Complex constitutes only the Ductile Shear Zone's (DSZ) bounded high pressure

TABLE - 1
Classification of Bhilwara Supergroup (modified after S. N. Gupta et al., 1997)

UNCLASSIFIED GRANITES and BASIC ROCKS					
	RANTHAMBHOR GROUP	Bari Sadri Formation	Hora Formation	Mandalgarh Formation	
LOWER PROTEROZOIC	JAHAZPUR GROUP	Chuleshwarji/Jhikri/Umer Formations	Satdudhia Formation Sindesar Formation - - Dariba Formation Malikhera Formation Bhinder Formation	- Samodi Formation - Tiranga Formation Rewara Formation Pur/Pansal Formation	- Mothi Formation - - - Ghatiali Formation
			RAJPURA-DARIBA GROUP	PUR-BANERA GROUP	SAWAR GROUP
ARCHAean*	INTRUSIVES	Berach Granite and Gneiss (2585 Ma) Untala and Gingla Granites (2860 Ma), Ultramafics, Giyagarh-Asind acidic rocks, Raipur-Jalayan mafic rocks			
			Bhilwara Sector	Mando-ki-Pal Sector	Sarara Sector
	HINDOLI GROUP	Nangauli Formation Sujanpura Formation - Bhadesar Formation	Potla/Rajmahal Formations Lasaria/Suwana Formations Kekri Formation -	Sarara Formation - - -	Baranch Formation Badnor Formation - Shambhugarh Fm.
			MANGALWAR COMPLEX	Mando-ki-Pal Fm. - -	SAND MATA COMPLEX

*Also termed as Archaean

Fm. = Formation

granulite facies rocks which occur within the amphibolite facies rocks belonging to the Manglwar Complex. The amphibolite facies rocks enclosing the granulite facies rocks represent granite-greenstone sequences intruded by tonalite-granodiorite plutons and are extensively granitized or migmatized. These granite-greenstone sequences are discernible in form of ghost stratigraphic and dismembered units in the vast ocean of gneisses and also within the tonalite-granodiorite plutons.

Sandmata Granulites

One of the most characteristic features of the BGC Province is the occurrence of high grade granulite facies rocks hosted in the BGC/Sandmata Complex. The greenstone sequences of the BGC in Central Rajasthan host an ensemble of granulite facies rocks comprising garnet-sillimanite gneiss, garnet-sillimanite-cordierite gneiss, calc-silicate gneiss, enderbite-charnockite and two-pyroxene granulite. The gneiss-granulite rocks occur as isolated exposures extending from north of Kankroli in the south to north of Bhinai in the north. Supposed to be a component of the oldest rock sequences, Heron (1953) included these rocks within the Banded Gneissic Complex (BGC) forming the basement to the 'Aravalli Delhi Supergroups/Systems'. While restricting the term Sandmata Complex to the ductile shear zone bounded granulite facies rocks, Guha and Bhattacharya (1995) recognized the host amphibolite facies rocks as belonging to the Manglwar Complex.

Though constrained to a great extent by isotopic dating of charnockite-enderbite and granite from the Sandmata areas in Central Rajasthan, uncertainties still prevail concerning the age of metamorphism

and the process of exhumation of the granulite to the present level. Many of the workers believe that the granulite facies metamorphism is an Archaean event (Sinha Roy *et al.* 1992; Guha and Bhattacharya 1995), while others have assigned a late Palaeoproterozoic age to it. The only point of agreement, of course with a little departure, is the event of exhumation of the granulite to the present level as a Proterozoic one. Sinha Roy *et al.* 1992, Guha and Bhattacharya, 1995, considered the emplacement of the granulite facies rocks within the greenstone sequences by a process of thrusting. While shear bounded (incidentally shearing is a very late phenomenon) granulites are noted within amphibolite facies rocks, but they are also found to overlie the amphibolite facies rocks along normal contacts (Gupta and Rai Chaudhri, 2002). The overfolding relationship is amply demonstrated by structural relationship between the cleavages related to the first two phases of deformation. It has been worked out that the event of exhumation of the granulite facies rocks is related to the second phase of deformation (producing overfolding; some workers invoking thrusting) which is a Palaeoproterozoic tectonic event.

Mangalwar Complex

The Mangalwar Complex is named after Mangalwar village which is located about 55 km southwest of Chittaurgarh. The complex occurs to the east of the Delwara Lineament in three main stretches, the first one extending from Pipalkhunt to Mangalwar for over 350 km and showing a width of 12 to 48 km, the second one from west of Amrite to Dadala for over a distance of 50 km (Sarara ki Pal inlier), and the third one from Kunda to Pratappur for over a distance of 30 km (Mando ki Pal inlier). In the Sarara ki Pal inlier area and also around Pipalkhunt and Gangapur, the Mangalwar Complex is overlain by the Aravalli Supergroup with an erosional unconformity. The eastern boundary of the complex is marked by the Hindoli Group of rocks with an uncertain stratigraphic relationship. In the southern part, the Deccan Traps overlie the Mangalwar rocks. The complex has been subdivided into the Lasaria, Kekri, Sarara, Mando Ki Pal, Suwana, Potla and Rajmahal Formations.

The Mangalwar Complex is considered presently as representing Archaean primary granite-greenstone belt. In the northern part, migmatitic gneiss-amphibolite association of the greenstone sequence is represented by banded gneiss, amphibolite, calc silicate rock and pelitic schist. In the southern part, mafic enclaves, represented

by amphibolite, migmatized gabbroic rock and chlorite schist, are by far the most prolific of the suite. High-magnesia mafic and ultramafic enclaves include tremolite-actinolite schist, magnetite and garnet bearing chlorite-actinolite schist, chlorite schist, talc-chlorite schist and talcose serpentinites with asbestos veins. Besides, long linear bodies of felsic volcanics in the form of quartzo-feldspathic rocks are also present. Sedimentary enclaves of varying dimensions comprise fuchsite quartzite, quartzite, garnetiferous mica schist, garnet-fibrolite bearing paragneiss, chert, carbonate and BIF. These rocks have been intruded by Untala-Gingla Granites, Berach Granite, Raipur-Jalayan mafic rocks and ultramafic rocks.

Hindoli Group

The Hindoli Group, named after Hindoli village, located 20 km northwest of Bundi, comprises a low-grade (greenschist) sequence predominated by turbidite and volcanics. The arcuate belt of the nearly continuous Hindoli Group, interrupted by Berach Granite, occurs along the eastern and southeastern flank of the BGC/Mangalwar Complex. The Hindoli Group is overlain unconformably by coarse clastics, carbonate, pelite and Fe formation of the Jahazpur Group. The 10 to 50 km wide arcuate belt of the Hindoli Group extends from Gyaspur in the south to Deyi in the north and further northeastward covering a strike length of about 400 km. The trend of the Hindoli belt is NNW-SSE in the southern part, which changes to ENE-WSW in the northern part. The southern part of the Hindoli Group is enclosed within the Berach Granite, while the ENE-WSW trending northern part is confined within two DSZ running sub-parallel to the regional axial trend of the Hindolis. While the northwestern shear separates the Hindoli metasediments from the Mangalwar Complex, the southeastern shear, familiarly known as the Great Boundary Fault (GBF), demarcates its boundary with the Vindhyan Supergroup. Towards south, the Hindoli Group is covered by the Deccan Traps. Gupta *et al.* (1980) interpreted the contact between the Hindoli Group and the Mangalwar Complex as a migmatitic front. Others (Sinha Roy and Malhotra, 1989; Sinha Roy *et al.* 1998; Malhotra and Pandit, 2000) on the other hand, believe that the contact is thrust along which the Mangalwar Complex has been uplifted and juxtaposed against the Hindoli Group. The major rock types of the Hindoli Group are metavolcanics with shale, slate, phyllite, mica schist quartzite, dolomite and limestone. Three lithofacies can be recognized in the Hindoli

Group, viz. turbidite facies comprising quartzwacke and slate with interstratified volcanoclastics, stable shelf facies of quartzarenite and carbonate, and mafic and felsic volcanics including acid tuffs (Bose and Sharma, 2000). Gupta *et al.* (1997), have subdivided the Hindoli Group into three lithostratigraphic units, viz., the Bhadesar Formation, the Sujanpura Formation and the Nangauli Formation. The rocks of the Hindoli Group are metamorphosed in the greenschist facies which grades to intermediate pressure amphibolite facies near the contact with the Mangalwar Complex.

The prevailing opinions regarding the contact relationship between the Berach Granite (2585 Ma; Crawford 1970) and the Hindoli Group are somewhat divided. Gupta (1934) and Sharma and Roy (1988) considered Berach Granite as forming the basement for the Hindoli volcano-sediments (Lower Proterozoic). On other hand, Raja Rao (1967, 1970), Gupta *et al.* (1980), Sinha Roy (1985) and Sinha Roy and Malhotra (1989) considered the Hindoli Group as of Late Archaean age being intruded by the Berach Granite.

Proterozoic rocks in the Bhilwara Province

Overlying the Hindoli Group of rocks and Mangalwar Complex with an unconformity occur the next younger groups of rocks classified as the Rajpura-Dariba, Pur-Banera, Jahazpur and Sawar Groups which are exposed in a series of isolated linear belts. All these synformal metasedimentary basins/structures of Lower Proterozoic age occur in disjointed belts as outliers and they are mostly composed of dolomite, marble, calc-gneiss, calc-schist and calc-biotite schist; graphite-kyanite-staurolite schist, garnetiferous mica schist; banded chert, banded ferruginous chert and quartzite. These groups of rocks form important repositories for deposits of copper, zinc, lead, silver, iron ore, marble, kyanite, steatite, quartz, corundum and garnet.

Rajpura-Dariba Group

A metavolcano-sedimentary sequence, named Rajpura-Dariba Group after the villages Rajpura and Dariba, in the Rajsamand district, overlies unconformably gneisses and schists belonging to the Mangalwar Complex in central Rajasthan and hosts exhaustive Pb-Zn deposits. The crescent-shaped NNE-SSW belt extends from Bharak in the north to Bhinder in the south. The group is made up of interbanded metachert, carbonaceous and argillaceous schist (tuffaceous containing \pm graphite \pm garnet \pm staurolite \pm kyanite), calcareous schist, calc silicate rock, dolomite,

marble with amphibolite bands, quartzite and conglomerate. The Rajpura-Dariba Group has been further subdivided into the Bhinder, Malikhera, Dariba, Sindesar and Satdudhia Formations. The sulphides of zinc, lead, copper and iron occur as thin bands and layers exhibiting characteristic syngenetic bedded geometry and show relict sedimentary structures. Silver mineralization has been reported from the dolomitic marble stratigraphically underlying the calc silicate rocks in the Bharak area (Goyal, 1991, 1992). However, the metasediments of Bharak, according to a few workers, belong to a separate belt, namely, Bharak-Satdudhia belt, which contains metamorphosed basic and felsic volcanics.

Pur-Banera Group

The dominantly chemogenic sequence with bands of metaclastics occurs from south of Banera in the south to Samodi in the north, for over 80 km in a 3 km to 12 km wide belt. These rocks unconformably overlie the rocks of the Potla Formation of the Mangalwar Complex and have been included in the Pur-Banera Group. The unconformity is marked by a polymictic conglomerate coupled with structural break and secular change in the sedimentation pattern.

The sequence comprises conglomerate, garnetiferous mica schist, calc schist, calc silicate rock, calc silicate marble, amphibolite, dolomitic marble, magnetite quartzite (a persistent marker horizon) and banded magnetite chert. The rocks, exhibiting superposed deformation and regional metamorphism corresponding to amphibolite facies, have been classified into the Pur, Pansal, Rewara, Tiranga and Samodi Formations. The magnetite quartzite and the carbonates host strata bond zinc-lead-copper mineralization. The stratigraphic status of the metasediments of this belt is debatable. While some workers favour a Lower Proterozoic cover status, others have included it in the Archaean Bhilwara Supergroup.

Sawar Group

The chemogenic and clastic rocks exposed as isolated outcrops over 13 km long and 3 to 5 km wide area between Bajata in the north to Sawar in the south have been designated as the Sawar Group. It comprises mostly marble together with quartz-biotite schist, biotite-magnetite quartzite, amphibole quartzite and amphibolite surrounded by calc silicate rock, amphibolite, biotite gneiss and migmatites belong to the Kekri Formation of the Mangalwar Complex. The group

has been divided into the Morhi and the Ghtiali Formations. Ray (1988) ascribed a gradational relationship between the Mangalwar Complex and the Sawar Group with the present contact marking an arrested granitic front. However, an unconformable relationship can be well worked out at places along the eastern margin of the Sawar belt where a gritty quartzite grading upward into a quartz-pebble conglomerate overlies the gneissic rocks (Das Gupta, 1995). Das Gupta (op. cit.) suggested that the grit-pebble conglomerate on the eastern fringe and the garnet-magnetite rock (intersected in the borehole) on the western fringe are contemporaneous and constitute the basal units of the Sawar Group. Chalcopyrite-pyrrhotite-galena mineralization is hosted in the dolomitic marble. The age of the mineralization has been determined at 2030 Ma with 1735 Ma as the age of remobilization (Deb and Thorpe, 2001)

Jahazpur Group

A low grade (greenschist facies) lithoassemblage comprising polymictic conglomerate, gritty quartzite, orthoquartzite, arkose mica schist, chert, breccia, dolomitic marble, carbonaceous phyllite and BIF, which unconformably overlies the Hindoli Group, occurs between southeast of Nandrai in Bhilwara district to Naenwa in Tonk district. The Jahazpur rocks are contained in two linear belts, each running for about 70 km and, at their widest part, measuring 3 km across. The eastern Jahazpur belt is encompassed within a sequence of turbidite-volcanic association of the Hindoli Group, while the western Jahazpur belt, extending from Jawal in the southwest to Dhanola in the northeast, unconformably overlies the Hindoli sequence. Along the thrust zone, delineating the western margin of the western Jahazpur belt, migmatites and gneiss of Mangalwar Complex have been juxtaposed on the Jahazpur belt. In the eastern Jahazpur belt, the base of the Jahazpur sequence overlying the Jahazpur Granite (correlated with the 2.5 Ga old Berach Granite) is marked by a pebbly quartzite and arkose bed and an overlapping Jahazpur dolomite. On the strength of the unconformable relationship with the Hindoli Group and the Berach Granite, Sinha Roy et al. (1998), considered the Jahazpur group as early Proterozoic, though Gupta *et al.* (1980, 1997) included it in the Bhilwara Supergroup.

Ranthambor Group

The molasses like sediments exhibiting very low grade metamorphism (some times in diagenetic state)

occurring as isolated outcrops over a distance of 200 km from southeast of Bari Sadri to north of Hora and Mandalgarh have been included in the Ranthambor Group. It comprises quartzite, slate and phyllite intruded by concordant dolerite sills and is considered to be the youngest member of the Bhilwara Supergroup (Gupta *et al.* 1980). The group has been classified into three coeval formations viz., the Bari Sadri, Hora and Mandalgarh Formations on the basis of their spatial disposition in isolated basins of deposition.

In a recent work from Sawai Madhopur area, Guha and Rai Chowdhury (1999) considered the Ranthambor Group as forming the basal part of the Vindhyan Supergroup. Here, the Ranthambor Group comprises dominantly an alternating sequence of sandstone, shale along with a minor carbonate and basal polymictic and lenticular conglomerate beds. Guha and Rai Chowdhury correlated the Ranthambor Group with the Satola Group (Balmiki Prasad, 1984) and also concluded that the sandstone member of the Ranthambor Group is akin to the Khardeola Sandstone of the Satola Group.

Metasediments of Agucha

At Agucha, in the eastern part of the central Aravalli range, an elliptical metasedimentary sequence comprising sillimanite-graphite-garnet bearing mica schist and gneiss (much in similarity with Khondalite of south India) with bands of calc silicate rock occurs within the Mangalwar Complex. The contact relationship of the metasedimentary rocks with the Mangalwar Complex is uncertain. The Agucha sequence is interpreted to represent vestiges of strongly tectonised early Proterozoic rift sequence raised to granulite facies (Ray, 1992). The rocks at Agucha form a southerly closing synform and a very high grade Pb-Zn deposit is hosted in sillimanite-kynaites-graphite-quartz-biotite schist

ARAVALLI - DELHI PROVINCE

The Aravalli-Delhi Province is occupied by rocks of the Proterozoic fold belts viz., the Aravalli Supergroup (Aravalli-Fold Belt) and the Delhi Supergroup (the Delhi-Fold Belt). The Aravalli Supergroup occupies mainly the southern and southeastern parts of Rajasthan, while an extensive tract in southwestern, central and northeastern Rajasthan is occupied by the Delhi Supergroup.

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 Aravallis 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 NE-SW 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 (Bhattacharya and Shekhawat, 1999). 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 eugeosynclinal-miogeosynclinal couple or as 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. However, the relationships of the Aravalli rocks with other granitic bodies, namely, the Jaisamand Granite, Ahar River Granite, Udaisagar Granite, Lakapa Granite and Dudar Gneiss are debatable and are variously considered as '*basement inliers*' (Roy *et al.* 1988), '*partly basement and partly remobilized part of the same*' (Naha and Halyburton, 1977), '*partly basement and partly intrusive within the Aravalli Supergroup*' (Sinha Roy *et al.* 1993), '*intrusive into the basal Delwara sequence, but forming the basement for the middle Debari sequence of the Aravalli Supergroup*' (Shekhawat and Joshi, 1994) and '*intrusive within the Aravalli-Fold Belt*' (Guha and Garkhal, 1993).

There is no unanimity in the stratigraphic classification of the Aravalli Supergroup. According to Gupta *et al.* (1997), the Debari Group forms the basement of the Aravalli Supergroup and comprises coarser clastics of the coast line environment, syn-sedimentary basic volcanics and associated pyroclastics and shallow marine carbonate and carbonaceous sediments with local development of phosphatic and non-phosphatic algal biostromes (Table-2). 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.

TABLE - 2

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	DOVDA GROUP	Devthari Formation	NATHDWARA GROUP	Rama Formation
	Goran Formation		Dapti Formation		Kadmal Formation
BARI LAKE GROUP	Khamnor Formation				Sangat Formation
	Varla Formation				
	Sajjangarh Formation				
UDAIPUR GROUP	<i>Udaipur Sector</i>		<i>Sarada Sector</i>	KANKROLI GROUP	Puthol Formation
	Banswara Formation				
	Nimach Mata Formation		-		Rajnagar Formation
	Balicha Formation	TIRI SUB-GROUP	Zawar Formation		Morchana Formation
	Eklinggarh Formation		Baroimagra Formation		Madra Formation
	Sabina Formation		Mandli Formation		
DEBARI GROUP	<i>Debari Sector</i>	<i>Jaisamand Sector</i>	<i>Ghatol Sector</i>	<i>Sarada Sector</i>	
	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	

(after S. N. Gupta *et al.*, 1992)

The Lunavada and the Champaner Groups (exposed in Gujarat) contain thick accumulations of molasses-like sediments. However, according to Sinha Roy *et al.* (1998), Lunavada Group represents a part of Jharol Group as well as the Debari Group.

Debari Group

Clastic, chemogenic and biogenic coastal and shelf sediments deposited marginal to Mangalwar, Sarara-ki-Pal and Mando-ki-Pal cratonic masses with first order erosional unconformity and associated syn-

sedimentational shoreline basic volcanics corresponding to an early depositional and volcanic episodes of the Aravalli geological cycle, have been included in the Debari Group (Gupta *et al.* 1980, 1997). It comprises a sequence of conglomerate, meta-arkose, quartzite, phyllite, mica-schist, basic metavolcanics with associated pyroclastics, calcareous quartzite, dolomitic limestone, dolomite, calcitic marble, ferruginous chert, algal phosphatic dolomite and chert, and carbonaceous and manganiferous phyllite. The entire sequence has undergone polyphase deformation and regional metamorphism under greenschist facies.

The Debari Group forms high NW-SE trending hills west of the Mewar Plain and it can be traced between Pakhand in the north and Waori Khera in the south over a distance of 160 km. Beyond Waori Khera, the Debari Group is covered by the Deccan Traps. The Debari Group further occupies the fringes of the inliers of the BGC/Bhilwara Supergroup in Sarara-ki-Pal and Mando-ki-Pal areas. Lithostratigraphy of the Debari Group has been worked out separately in Debari, Jaisamand, Ghatol and Sarara sectors. Five formations, namely, the Gurali, the Delwara, the Jaisamand, the Berwas and the Jhamarkotra have been recognized in the Debari sector. Several other formations have been recognized in the Debari Group in the other sectors (Table-2). Sahu *et al.* (1991), have separated the Delwara Formation, comprising conglomerate, quartzite, carbonate, basic volcanics, chlorite phyllite and schist, from the rest of Debari Group and elevated status of the former to a Group. The polymictic conglomerate of the Debari Group unconformably overlies the Delwara metavolcanics. The presence of clasts of the Delwara metavolcanics within the polymictic conglomerate coupled with a structural hiatus between the Delwara Group and the Debari Group suggest the existence of a first order unconformity. The rocks of the Delwara Group occurs along the eastern margin of the Aravalli Supergroup discontinuously in an enechelon pattern between Nathdwara in the north to Phalet, Ora to Jaisamand, Salumbar to Ghatol and further beyond Talwara in the south.

Udaipur Group

A thick sequence of flysch-like, coarse to fine-grained rocks associated with minor bands of chemogenic/biogenic rocks representing the main depositional episode during the geosynclinal phase of the Aravalli geological cycle, has been included in the

Udaipur Group by Gupta *et al.* (1980, 1997).

Lithologically, the Udaipur Group comprises a thick pile of phyllite, metagreywacke, feldspathic mica schist and migmatite with intercalatory bands of greywacke, conglomeratic quartzite, dolomite, gritty dolomite, dolomitic marble, oligomictic conglomerate, phosphatic and stromatolitic dolomite, carbonaceous, manganiferous and ferruginous phyllite, chert and amphibole schists. The rocks show frequent interfingering and gradational relationships of different litho-units. The argillaceous metasediments constitute the bulk of the group. The rocks have undergone superimposed deformation and show a grade of metamorphism ranging from greenschist facies to amphibolite facies associated with syntectonic migmatization. The Udaipur Group extends from northwest of Eklingjee in the north to Santrampur in the south for a distance of more than 180 km. The average trend of the group is NNW-SSE. Near Zawar, the belt of Udaipur Group bifurcates into two parts; the eastern one extends towards southeast through Padla, Salumbar, Ashpur, Sabla, Ganora and Banswara. The western one follows N-S trend and extends southwards through Paduna, Rakhabdev, Dungarpur and Satrampur. The eastern outcrop attains a maximum width of about 50 km near Sagwas. The western outcrop attains a maximum width of about 30 km, north of Dungarpur and thins out gradually to 5 km south of Dungarpur.

The rocks of the Udaipur Group have been divided into the Sabina Formation, Eklinggarh Formation, Balicha Formation, Neemach Mata Formation and Banswara Formation in the Debari sector while Mandli, Baroi Magra and Zawar Formations are recognized in the Sarada sector.

Bari Lake Group

The rocks of the Bari Lake Group occur between Kharpena in the south to Madar in the north through the Bari Lake covering a distance of 30 km. The width of the group varies from 3 km to 5 km. The rocks of the Bari Lake Group also occur between Kharpena and Iswal and occupy a roughly triangular area around Kadmas, Khamnor, Baita and Nathdwara.

The Bari Lake Group represents a volcano-sedimentary assemblage comprising coarse to fine-grained clastic sediments, syn-sedimentational basic volcanics, pyroclastic and volcanoclastic rocks overlying the Udaipur Group. This volcano-sedimentary association marks the local upwarping and

shallowing of the trough and contemporaneous activation of a N-S trending deep seated fracture (Rakhadev Lineament) resulting in the outpouring of basic lavas. The Bari Lake group is principally composed of basic metavolcanics (actinolite-chlorite schist and chlorite schist), metamorphosed pyroclastics, quartz pebble-conglomerate, meta-arkose, quartzite, chlorite phyllite and metasiltstone with minor bands of dolomite, chert. The phyllite is, at places, carbonaceous.

The Bari Lake Group is further subdivided into several formations. The coarser clastic rocks have been included in the Sajjangarh Formation while the overlying volcano-sedimentary rocks are included in the Varla Formation. A thick sequence of phyllite and mica schist, around Khamnor, Batia, Kadmas and north of Iswal occupying area in continuity of the Bari Lake metavolcanics, and representing the metamorphosed products of fine grained pyroclastic and volcanic rocks, has been designated as the Khamnor Formation and is included in the Bari Lake Group. This formation is overlain by a persistent quartzite horizon considered to be the base of the overlying Jharol group. The rocks have undergone polyphase deformation and low grade regional metamorphism under greenschist facies condition.

Kankroli Group

The Kankroli Group occurs between Sangat in the west and Pipli in the east. It forms a hammer-head shaped arcuate outcrop. The main rock types of the Kankroli Group are garnetiferous muscovite-biotite schist, hornblende schist, hornblende biotite schist, hornblende gneiss and dolomitic marble with minor intercalations of quartzite. These rocks have undergone polyphase deformation and regional metamorphism under amphibolite facies condition.

Gupta *et al.* (1997) emphasized that the metamorphosed rocks at and around Kankroli belong to argillaceous facies and calcareous facies, which were deposited under shallow marine conditions. They classified the Kankroli Group into a number of formations, namely, Madra Formation, Morchana Formation, Rajnagar Formation, Puthol Formation and Sangat Formation. It is opined by Gupta *et al.* (op. cit.) that the Madra, Morchana and Rajnagar Formations are coeval with the Udaipur Group while the Puthol and the Sangat Formations are coeval with the Bari Lake Group. The rocks appear to have been deposited on a topographic high developed towards the northern extremity of the Udaipur-Zawar trench due to the reactivation of the Banas Lineament.

Jharol Group

The western part of the Aravalli Fold Belt comprises carbonate-free sequence of greywacke and phyllite with linear bands of quartz-arenite. This litho-sequence, which is exposed in a linear N-S trending belt, extending from Modasa in the south to Paroli in the north, over a distance of 190 kms, has been assigned as Jharol Group by Gupta *et al.* (1997). The lithosequence contains phyllite, chlorite schist, garnetiferous mica schist, quartzite, grit and conglomerate. According to Gupta *et al.* (op. cit.), the group unconformably overlies the Bari Lake Group towards east, while it is overlain by the Delhi Supergroup in the west with a plane of discontinuity in between. The Jharol Group has been subdivided into a lower Goran Formation, which is predominantly argillaceous in nature, and an upper Samlaji Formation comprising metapelites intercalated by quartzite and impure calcareous rocks. The rocks of the Jharol Group show a progressive increase in metamorphic grade from greenschist facies in the east to lower amphibolite facies in the west.

The stratigraphic position of the Jharol Group and its correlation with other groups of the Arvalli Supergroup is not convincingly established (Bose, 1989) and a part of the sequence in contact with the Delhi is construed to be southwest extension of BGC (Dev and Sarkar, 1990; Gupta *et al.* 1995; Gupta and Bose, 2000). According to Sinha Roy *et al.* (1993), the Jharol Group overlies the Debari Group in the northern part with an unconformity, the Iswal conglomerate representing the base of the Jharol Group. The Jharol Group, on this premise, represents the uppermost sequence of the Arvalli Supergroup. The western part of the Jharol Group contains conformable bands of mafic-ultramafic suite of rocks, sometimes intercalated with quartzite bands suggesting extrusive nature of the magmatic rocks. Bhattacharya and Shekhawat (1999) opined that the Jharol Group and the Debari Group were deposited in similar geological setting and hence are correlatable.

Dovda Group

The Dovda Group comprises chemogenic and clastic rocks belonging to a shelf-type sequence and is exposed from Masid in the southwest to the west of Kuanthal in the northeast and further towards east upto Khandel. It overlies the Kankroli Group in the central part and the Bari Lake Group in the southern part. At Paroti, the Dovda Group shows interfingering and

gradational relationship with the Jhalor Group. In the Richer and Kuanthal areas, the Dovda Group unconformably underlies the Delhi Supergroup. According to Gupta *et al.* (1997), the contact relationship of the Dovda Group with the BGC/Bhilwara Supergroup in Amet, Koshital, Kuraj-Salera area is not clear since the junction is blurred by migmatization.

Gupta *et al.* (op. cit.) subdivided the Dovda Group into the Depti Formation and the Devthari Formation. The Depti Formation is made up of quartzite, hornblende schist, dolomitic-marble and calc-silicate rocks. The assemblage of feldspathised hornblende schist, hornblende-biotite schist, biotite schist, amphibole gneiss and migmatite has been designated as the Devthari Formation.

Heron (1953) included the migmatites, feldspathised schists and gneisses in the BGC, the dolomitic marbles and calc silicate rocks in the Raialo 'Series', the biotite schists and impure marbles in the Delhi 'System' and the quartzites, phyllites and schists in the Aravalli 'System'. Basu and Arora (1966) observed that near Sangat and Nathdwara, the quartzite and schists included in the Aravalli 'System' by Heron (op. cit.) show a gradational relationship with the gneisses and migmatites included under the BGC by Heron (op. cit.). A group of workers (Sharma 1983; Sinha Roy *et al.* 1993; Gupta *et al.* 1995) from their structural and metamorphic studies from the central Rajasthan, concluded that the pre-Delhi rocks underlying the Delhi metasediments in central and north-central Rajasthan, north of the Banas Dislocation zone, are not Aravallis or their granitized equivalents, and considered them as the BGC.

Nathdwara Group

Predominantly chemogenic rocks associated with minor clastic sediments deposited in shallow-inland basins have been assigned to the Nathdwara Group. The group is temporally correlated with the Jharol and Dovda Groups and spatially succeeds the Bari Lake Group.

The rocks of the Nathdwara Group occur in two separate areas. The eastern tract lies between Rama in the south and Berach in the north while the western tract extends from Madar in the south to Kotharia in the northwest through Iswal and Nathdwara.

The bulk of Nathdwara Group in the eastern tract comprises phyllite and calcareous phyllite with

numerous intercalatory bands of dolomite and calcitic marble. Thick bands of quartzite occur towards the base. The western tract comprises dolomitic marble, chert, quartzite and mica schist. The Nathdwara sequence has undergone polyphase deformation and regional metamorphism under greenschist facies.

The Nathdwara Group has been subdivided by Gupta *et al.* (1997) into Kadmal Formation, Rama Formation and Haldighati Formation. The Kadmal Formation comprising calcareous and arkosic quartzite with intercalatory phyllite extends from east of Jindoli in the south to Berach in the north. The Rama Formation comprises phyllite and marble and is well exposed in the area northeast of Usar and southeast of Gurach. The Haldighati Formation is exposed between Madar in the south to Kotharia in the northeast and is made up of dolomitic marble, chert, quartzite, breccia and mica schist.

Lunavada Group

An assemblage of molasses-like sediments deposited in a widespread basin in the northern parts of Gujarat and southern Rajasthan has been designated as the Lunavada Group by Gupta *et al.* (1997). Structure of early deformation, present in the flysch-like and volcano-sedimentary assemblages of the Udaipur, the Jharol and the Bari Lake Groups are absent in the Lunavada Group.

The Lunavada Group extends from Mahur in the north to Sejwada in the southeast and from Dharsua in the west to Kushagarh in the east. Towards southeast, the Lunavada Group is covered by the Deccan Traps. Towards northwest, it juxtaposes the Jharol Group. In the northeast, the rocks of the Lunavada Group are bounded by the Udaipur Group. Isolated outcrops of the Lunavada Group also occur in granitic terrain between Malu in the west and Tandwa in the east and also in the area north of Chota Udaipur.

Sinha Roy *et al.* (1998) have pointed out that the stratigraphic status of the Lunavada Group of Gupta *et al.* (1997) is not clear. As the Rakhavdeb ultramafic line in the type area separates the deep-sea Jharol facies in the west and the shelf facies Debari Group in the east, Sinha Roy *et al.* (op. cit.) opined that the Lunavada Group possibly represents a part of the Jharol as well as the Debari Group. Shekhawat and Joshi (1998), from their work in the Garhi-Partappur area, stated that the Lunavada Group of Gupta *et al.* (1997) has two distinct lithoassemblages separated by a prominent

TABLE - 3
Classification of Delhi Supergroup (Lower to Middle Proterozoic)

South-western Rajasthan and North-eastern Gujarat			Ajmer Sector		North-eastern Rajasthan	
INTRUSIVES (Post - Delhi)	MALANI IGNEOUS SUITE (Volcanic and plutonic)					
	ERINPURA GRANITE					
	GODHRA GRANITE (exposed in Gujarat)					
DELHI SUPERGROUP	PUNAGARH GROUP	Sojat, Bambolai,	SINDRETH GROUP			
		Khambal and	(Angor and			
		Sowania	Goyali			
	SIROHI GROUP	Formations	Formations)			
		Jiyapura, Reodar, Ambeshwar and Khiwandi Fms.				
	SENDRA-AMBAJI GRANITE and GNEISS				DADIKAR, BAIRATH, AJITGARH SIKAR and CHAPOLI GRANITES	
	KISHANGARH SYENITE					
PHULAD OPHIOLITE SUITE						
DELHI	KUMBHALGARH GROUP	Todgarh, Beawar, Kotra,	AJABGARH GROUP	Ajmer Formation	AJABGARH GROUP	Kushalgarh, Sariska, Thanagazi, Bhakrol and Arauli Formation
		Sendra, Ras, Barr, Basantgarh and Kalakot Formations				
	GOGUNDA GROUP	Richer, Antalia and	ALWAR GROUP	Srinagar and Naulakha Formations	ALWAR GROUP	Rajgarh, Kankwarhi, Pratapgarh; Nithar, Badalgarh and Bayana Formations
		Kelwara Formations				
					RAIALO GROUP	Dogeta and Tehla Formations

(modified after S. N. Gupta *et al.* 1992)

unconformity. Based on the observation made in the area, Shekhawat and Joshi (op. cit.) advocated for the untenability of a separate stratigraphic status of the Lunavada Group.

The predominant rock types of the Lunavada Group are phyllite, metasubgreywacke, quartz-chlorite schist and quartzite with subordinate dolomitic limestone, polymictic conglomerate, manganiferous phyllite and phosphatic algal dolomite. The rocks have been affected by at least two phases of deformation and were metamorphosed under greenschist facies condition.

The Lunavada Group has been subdivided by Gupta *et al.* (1997) into the Kalinjara, the Wagidora, the Bhawanpura, the Chandanwara, the Bhukia and the Kadana Formations.

DELHI SUPERGROUP

The Aravalli Mountain Range is mainly constituted by rocks of the Delhi Supergroup belonging to Proterozoic age. The rock sequences comprising the Delhi Fold Belt are sandwiched between the BGC/Bhilwara Group, the Aravalli Supergroup and the Palaeoproterozoic cover sequences in the east and the crystalline rocks of Archaean age (rocks equivalent to

BGC of Heron, 1953), the Malani Igneous Suite, the Marwar Supergroup (Neoproterozoic cover sequences) and Mesozoic-Cenozoic sediments in the west. The Delhi metasediments and related extrusive igneous rocks rest unconformably or with a structural discordance over the Bhilwara Supergroup in the northeastern and the central parts and the Aravalli metasediments (? BGC) in the southwestern part of Rajasthan and contiguous parts of Gujarat.

The Delhi Supergroup forming Aravalli (mountain) orographic axis extends over a strike distance of nearly 700 km from Idar in Gujarat in the southwest to Delhi in the northeast from where the Supergroup has derived its name. In central and southwestern Rajasthan, it is represented by a linear belt, which fans out from a narrow constricted part near Dewair towards northeast and southwest. According to Gupta *et al.* (1980, 1997), in the northeast, the rocks are deposited under fluvial conditions in a number of fault-bounded basins while in the central and southern parts; sedimentation is mostly under oceanic conditions.

Heron (1953) conceived the Delhi 'System' as occurring in two sectors, viz. in Alwar-Bayana-Khetri region and along a narrow linear belt (Main Delhi Synclinorium of Heron, 1953) forming the rib of the Aravalli Mountain range in Central and southwestern Rajasthan and northern Gujarat. Heron's (1917) initial concept of the Delhi stratigraphy was based on his works in the Alwar basin - a basal arenite-dominated Alwar 'Series', followed by the Kushalgarh Limestone and Hornstone Breccia, and mantled at the top by pelite-carbonate dominated Ajabgarh 'Series'. According to Heron (1917), the Alwar series rests unconformably over the limestone and quartzite of the Raialo 'Series', which was assigned a post-Aravalli and pre-Delhi status. Heron considered the Raialo 'Series' as spanning the Eparchaeon unconformity between the Delhis and the Aravallis. Drawing an analogy with the stratigraphic order established in the Alwar basin, Heron, save for the Kushalgarh Limestone and Hornstone Breccia, extended the correlation and classification of the Delhi Supergroup (Delhi 'System' of Heron, op. cit.) to embrace the rocks of the Khetri and Bayana basins of northeastern Rajasthan and even to those of the Aravalli orographic axis in central and southern Rajasthan extending into Gujarat. Arora (1968) designated the Delhi System as the Delhi Group. Recognition of several groups has led subsequently to raise its stratigraphic rank to Delhi Supergroup Gupta *et al.* (1980) (Table-3).

Varied opinions exist regarding the physical subdivisions of the Delhi Fold Belt in different parts of Rajasthan. Heron (1917, 1953) believed a single evolution of the belt, which has subsequently been supported by Singh (1988). The Khetri sub-basin in the northern sector, according to Singh (op. cit.), continues southward to northern Gujarat and constitutes the Main Delhi Synclinorium of Heron, (1953). Gupta *et al.* (1980) and Sinha Roy *et al.* (1984), on the other hand, favour the idea of diachronous development of the Delhi sub-basins. Sinha Roy, (1988) recognized three sub-basins in the Delhi Belt in the northeastern sector, namely, the Bayana sub-basin, the Alwar sub-basin and the Khetri sub-basin. Gupta *et al.* (1998), Gupta and Bose (2000) have indicated the occurrence of rocks of migmatitic basement gneissic complex intervening between the two sectors and even in the interbasinal areas in the northern sector.

It has been suggested that the northeastern sector (Alwar-Bayana-Khetri region) of the Delhi Supergroup is older than Mesoproterozoic (Sastry *et al.* 1984). In this sector, several granite bodies (e.g. Dadikar, Bairat, Ajmer, Seoli and Harsora Granites) intrusive into the Delhi Supergroup have yielded Rb/Sr isochron ages older than 1600 Ma (Chaudhary *et al.* 1984). The age of the Bairat Granite as estimated by Crawford (1970) is 1600 Ma, while the isochron ages of the Udaipurwati and Saladipura Granites which intrude the Delhi Supergroup are estimated at 1480 Ma (Gopalan *et al.* 1979). Recently, zircons from the trondhjemite phase and the alkali granite phase of the Ajiagarh Granite have yielded 1.725 ± 0.013 Ga and 1.741 ± 0.015 Ga ages respectively (EPMA studies by Biju Sekhar *et al.* 2002). However, some workers consider the Seoli, the Udaipurwati, the Saladipura and the Ajmer Granite (Anasagar Granite) to be intrusive into the basement sequences (Gupta, 1989; Gupta *et al.* 1998; Gupta and Bose, 2000; Tobisch *et al.* 1994; Mukhopadhyay *et al.* 2000). On the other hand, granites intrusive into the Delhi Supergroup occurring along the linear belt (Main Delhi Synclinorium of Heron, 1953) have yielded a much younger age of 850 Ma (Sastry *et al.* 1984). The widely separated ages could be interpreted to represent two tectono-thermal episodes within apparently similar Delhi rocks, or that the development of the Delhi rock suite took place in two independent basins that were widely separated in space and time (Naqvi and Rogers, 1987). Thus, the geochronological data on granite plutons from the different parts of the Delhi Supergroup suggest a diachronous development of the Delhi Fold

Belt, separated into the North Delhi Fold Belt (NDFB) in Alwar-Bayana-Khetri sector and the South Delhi Fold Belt (SDFB) in the areas near Ajmer and southward, the former predating the latter (Sinha Roy, 1984, 1988).

Although with many features remaining unresolved, the broad spatial division of the Delhis into two sectors, viz. the North Delhi Fold Belt (NDFB) of northeast Rajasthan and South Delhi Fold Belt (SDFB) of central and southern Rajasthan along the linear belt (Bose *et al.* 1990, Gupta *et al.* 1991a) conforms to differences between the two sectors in terms of lithofacies, structure, magmatism and metallogeny.

North Delhi Fold Belt

The North Delhi Fold Belt (NDFB) includes the Bayana-Lalsot, the Alwar-Jaipur and the Khetri basins. However, according to Gupta *et al.* (1998), Gupta and Bose, (2000), lithostratigraphy, magmatism and structural set-up of the Khetri Basin (Khetri Fold Belt - KFB) is proved to be an entity by itself.

The Bayana-Lalsot basin is located in the Bharatpur and Dausa districts of Rajasthan and falls 40 km southwest of Bharatpur. The basin constitutes the eastern-most part of the Delhi Supergroup. The Alwar-Jaipur basin extends from Jaipur in the south to beyond Rajasthan-Haryana border in the north. This basin occurs in between the Bayana-Lalsot basin in the east and the Khetri basin in the west. The Alwar-Jaipur basin is the widest amongst the three basins. In the Bayana-Lalsot and Alwar-Jaipur basins, the sedimentary sequences were deposited in fluvial and marginal marine environments and the volcanics show continental affinity (Singh, 1984). The major stratigraphic units of the Delhi Supergroup in the Bayana-Lalsot and the Alwar-Jaipur belts are the lower Raialos (mainly calcareous), the middle Alwar (mainly arenaceous) and the upper Ajabgarh (mainly argillaceous) Groups. The different groups of the Delhi Supergroup in these two belts do not show a complete development of their lithoformations throughout the fold belts. Often there is absence of formations as well as facies variations within the different groups.

The Khetri basin extends from Pacheri in the north to Sangrui in the south for a distance of about 100 km. The basin is also known as Khetri Copper Belt because of it hosting copper deposits in and around the Khetri town, situated 160 km SSW of Delhi. To the east, the basin is bounded by the BGC/rocks of the Delhi Supergroup in the Alwar-Jaipur Fold Belt, while sand

dunes occupy its western part.

Heron (1923) correlated the rocks of Khetri basin with the psammitic Alwar and pelitic Ajabgarh 'Series' of Alwar-Jaipur basin on the basis of lithological similarities. Heron (op. cit.) observed gradational contact relation between the two series. While retaining Heron's classification, Dasgupta (1968) noted the gradational nature between the Alwar and the Ajabgarh 'Series' and observed that at places the Ajabgarh 'Series' alternates with the Alwar 'Series'. Later workers followed Heron's classification while carrying out works on different aspects (Ray, 1974; Gangopadhyay, 1987). Chakrabarti & Gupta (1990) considered the low to high grade migmatized rocks in the southern part of the KFB as the unclassified pre-Delhis. They also correlated the high grade migmatized rocks intervening between the Alwar-Jaipur belt and Khetri Fold Belt with the Manglwar Complex (Gupta *et al.* 1980) or BGC (Heron, 1953) occurring to the south of the Sambhar lake.

The correlation of the lithologies of Khetri basin with those of the Alwar and Ajabgarh sequences of the respective type areas is controversial. According to Sinha Roy *et al.* (1980), the so-called Ajabgarh and a part of the so-called Alwar of the Khetri area are in fact equivalent to the Raialo Group which in turn is a pre-Delhi sequence. Gupta *et al.* (1998) divided the Khetri Fold Belt into North Khetri Belt and South Khetri Belt, separated by the Kantli tranverse fault. According to them, the North Khetri Belt and South Khetri Belt evolved independently. In the North Khetri Belt, the basement-cover interface is represented by an unconformity, while that in the South Khetri Belt is marked by a detachment fault (Chapoli Fault). It has been further demonstrated that the cover sequences on either side of the Kantli Fault differ significantly from each other in lithocharacteristics, especially in the content of felsic volcanics (1832 ± 3 Ma) present in the South Khetri Belt.

South Delhi Fold Belt

The South Delhi Fold Belt (SDFB) of the Delhi Supergroup exposed in central and southern Rajasthan and in northeastern Gujarat forms the spine of the Aravalli mountain range. This fold belt extends from near Ajmer in the northeast to Himmatnagar in Gujarat with a NNE-SSW to NE-SW trend. Further southwest of Himmatnagar, the Delhi rocks are covered by large alluvium tract. The Delhi rocks in the South Delhi Fold Belt, according to Heron (1953) are disposed in a major

synclinorium (named as the Main Delhi Synclinorium). The Synclinorium in central Rajasthan consists of two synclines separated by a tongue of pre-Delhi rocks (Pre-Delhi inlier) which tapers at either end. Heron (op. cit.) classified the Delhi 'System' of the Main Delhi Synclinorium of central and southern Rajasthan into Alwar and Ajabgarh 'Series' without establishing the younging polarity. According to Heron, the basal conglomerates (the Barr conglomerate on the western flank and the Srinagar conglomerate on the eastern flank) on either flank of the Aravalli mountain range rests on porphyritic and foliated granite (pre-Delhi) with an erosional unconformity. Sen *et al.* (1964) remarked that the unconformity below the Delhi 'System' is not apparent, as the contact is sheared or conformable.

The stratigraphy of the SDFB cannot be correlated clearly with that of the NDFB. Gupta *et al.* (1980) partially retained the classification of Heron, but coined the terms Gogunda Group and Kumbhalgarh Group for central and southern Rajasthan and correlated them with the Alwar and Ajabgarh Groups NDFB respectively. Gupta *et al.* (1997) opined that in the southern Rajasthan and in the contiguous areas in the northern Gujarat, the Delhi sedimentation took place in geosynclinal regime in contrast to beach-type and shelf-type sedimentation in North Delhi Fold Belt. In SDFB, the deposition took place on shelf-margin to shelf-interior, main trough and in post-orogenic succession basins. The dominantly arenaceous and argillaceous facies, deposited on shelf-margin, have been referred to as the Gogunda Group. The mixed calcareous and argillaceous facies of the shelf-interior has been included Kumbhalgarh Group. In the west of the Aravalli mountain range, the clastic marine sediments deposited in a deeper trough have been included in the Sirohi group and the molasses-like sediments of shallow basins have been accommodated in the Punagarh and the Sindreh Groups.

Sen (1981 and 1983) identified five tectonic zones (zone 1 to zone 5 from west to east) in the SDFB, each with an independent structural grain and with mutual tectonic contacts which often exhibit discordance to litho-boundaries. Each of these exhibits east-west trending early major fold. Sen (1981, 1983) suggested that the Barr conglomerate occurring on the western flank lies over the Barotiya sequence and not at its base. He conceived the eastern boundary of zone 2 in the south/or the continuing eastern boundary of zone 3 in the north as the palaeosuture zone. With this conception, he considered the zones 1, 2 and 3 (Pindwara-Ajmer Fold Belt) west of the palaeosuture zone as the younger

units and these together constitute the Delhi Supergroup. The zones 4 (Sayara Linear Belt) and 5 (Antalia Linear Belt) in the Gogunda-Antalia area constituting the rock sequence named as the Gogunda Group by Gupta *et al.* (1997), according to him, are older sequences spanning the gap between the Aravallis and the Delhis. A pre-Delhi status has been assigned for the Gogunda Group in the Antalia-Richer area by Gupta *et al.* (1995).

Gupta *et al.* (1988, 1991a, 1995), Gupta and Bose (2000) proposed a new stratigraphic scheme for the SDFB. According to them, the axial region in central Rajasthan comprises multiple tectonic units (cf. Sen, 1980), which retain their individuality of lithocharacters, structure, magmatism and metamorphism. They delineated five lithotectonic units, namely, Basantgarh, Barotiya, Sendra, Rajgarh and Bhim, from west to east, all of them together forming the Delhi Supergroup. Tectonic discordance in the form of early ductile shear zones and superposed brittle ductile shear zones demarcate the boundary surfaces of each unit. This is in contrast to the synclinal disposition of the lithounits as suggested by Heron (1953). A linear belt of the pre-Delhi rocks tapering at the southern end, west of Todgarh, subdivides the SDFB into two basins: western part Basantgarh-Barotiya-Sendra basin and the eastern part Bhim-Rajgarh basin, the two having no similarity in basinal deposits. Another group of rocks, namely, the Devgarh Group, occurring east of the Bhim Group, is tentatively included in the eastern basin. True stratigraphic status of the Devgarh group is uncertain. Gupta *et al.* (1995), Gupta and Bose (2000) have indicated a diachronous evolutionary history for the Delhi Supergroup of the South Delhi Fold Belt. They have indicated a time-equivalency for the Basantgarh, Barotiya, Sendra, Rajgarh and Devgarh groups and a younger status for the Bhim Group. It appears that zones 1, 2 and 3 of Sen (1980) correspond respectively to the Barotiya, Sendra and Rajgarh Groups. Zone 4 corresponds to the Bhim Group while zone 5 corresponds to part of the Aravalli Supergroup of Gupta *et al.* (1980). Also, according to Gupta *et al.* (1995), Gupta and Bose (2000), unconformity-cum-structural hiatus between the crystalline rocks of Archaean age (similar to BGC rocks) on the west of the Aravalli mountain range and the Ras Marble (Chowdhury *et al.* 1993) along with the involvement of the former in the folding of the Ras Marble gives a status of cover sequence for the latter.

The pre-Delhi inlier separating the two basins of the Delhi Supergroup near Ajmer is represented by mica schist, granite gneiss, quartzite, migmatites, calc silicate rocks and marble (Gupta *et al.* 1995; Gupta and Bose 2000).

Raialo Group

According to Heron (1917, 1953), the Raialos occur as a basal constituent of the Delhi Supergroup or as an independent unit spanning the Eparchaeon unconformity. Heron described the Raialos as predominantly composed of limestone with a thin impersistent band of quartzite, occasionally conglomerate, at its base. He recognized the basement rocks over which the Raialos rest at different places as the Aravallis, the Bundelkhand Gneiss or the Banded Gneissic Complex (BGC).

The small isolated outcrops of Raialos of Heron (1953) in the BGC terrain of Bhilwara Province outside NDFB were regarded by later workers (Naha *et al.* 1966a, 1966b, 1969, 1973; Naha & Mazumdar, 1971a, 1971b; Roy *et al.* 1984; Sen 1983) as parts of the gneissic rocks. According to these later workers, the marbles and the quartzites which were included in the ambit of the Raialo Series outside the NDFB and presumably deposited during the Eparchaeon interval, actually formed in different environments and belong to different stratigraphic horizons ranging from middle Archaean to Neoproterozoic.

It is now agreed to retain the term Raialos within the NDFB in the Alwar-Jaipur and Bayana-Lalsot belt only. Roy (1988) advocated renaming of Raialos in the NDFB as the Rayanhala Group (after the village name) to avoid confusion. The Raialo Group is best exposed around Dogeta, Gola-Ka-Bas, Raialo-Sankotra, Jhiri, Tilwarhi, Todi and kho-Dariba.

Mapping from Geological Survey of India over a period of two decades (Banerjee, 1980; Sant and Sharma, 1973; Singh, 1982; Singh and Sinha, 1983; Singh *et al.* 1985, 1986) suggested the following modifications of the stratigraphic succession as proposed by Heron (1917): (a) the entire Aravalli 'System' of Heron is missing from the Alwar area and re-designated the basement rocks as pre-Delhi (? Pre-Aravallis). (b) the Raialo 'Series' of Heron constitutes a part of the basal unit of the Delhis and is not a separate entity as suggested by Heron (1953), (c) the stratigraphic break between the Raialos and the overlying Alwar exist at a higher level than that

proposed by Heron including the volcanic sedimentary assemblage within the Raialos. The status of the Raialos has been raised to a group and is classified into lower Dogeta Formation (siliceous and dolomitic marble with subordinate conglomerate, quartzite and metasiltstone) and upper Tehla Formation (conglomerate, quartzite, metasiltstone and marble with mafic and felsic volcanics) in the Alwar-Jaipur basin, and into lower Nithar Formation (basal conglomerate and quartzite with interfingering lenses of conglomerate and pebbly quartzite) and an upper Jahaz-Govindpura Formation (basic and associated metasedimentary interbands) in the Lalsot-Bayana basin. Stromatolitic structures are present in the Tehla formation. The 'Serrate Quartzite' in the Alwar-Jaipur basin considered by Heron as the lowermost member of the Alwar sequence actually constitutes the basal member of the upper Raialos. However, Singh (1988) considered the Serrate Quartzite (conglomerate-sandstone, subordinate argillite) as a separate formation. According to Singh (*op. cit.*), the initiation of Delhi sedimentation was related to crustal downwarping producing isolated depo-centres. After the Dogeta sedimentation, downwarping of the existing basins and block faulting took place. This resulted in the formation of the Surer Graben in the Alwar-Jaipur basin in which the Serrate Quartzite was deposited. The end phase of the Raialo sedimentation was characterized by rejuvenation of the old faults and development of some intra basinal faults, which tapped basic to felsic volcanics of the Tehla Formation.

Alwar Group

The Alwar Group rests unconformably over the Raialos, in places, directly (overlapping) the Pre-Delhi rocks, and is predominantly composed of conglomerate and quartzite (subordinate siltstone and quartzose wacke). It is interesting to note that the unconformity between the Raialo Group and the Alwar Group represents a basin-wide break and is recognized in Alwar-Jaipur and Bayana-Lalsot basins (Gupta and Bose, 2000).

The Alwar Group is divided into Rajgarh, Kankwarhi and Pratapgarh Formations in the Alwar-Jaipur basin and Jogipura, Badalgarh, Bayana and Damdama Formations in the Bayana-Lalsot basin. At places, basic flows, meta-tuff and intercalated magnetitic quartzite are reported from the Alwar Group (Gupta, 1989).

The Rajgarh Formation is developed in the southern

part of the NDFB and contains a basal conglomerate followed upwards by feldspathic quartzite and grit. The Kankwarhi Formation is well developed in Raialo-Ajabgargh, Alwar, Lekri, Hamirpur and Bhindosi areas. The rock types in this formation are quartzite, schists, calcareous biotite quartzite and marble. The Pratapgarh Formation occurs in the southern part of the NDFB and comprises sericite quartzite and orthoquartzite. The quartzite is more mature than that in the Rajgarh Formation.

In the Lalsot-Bayana basin, the Jogipura Formation is best developed near Jogipura and Sita Kund. It comprises two members, namely, Sita conglomerate and quartzite. The Badalgarh Formation occupies the slope of hills from north of Sikandra in the east to west of Sita Kund in the west and from Bareja to south of Nagla Gothia. The formation is composed of an interlayered sequence of thinly bedded feldspathic quartzite, micaceous quartzite, shale and tuffaceous sandstone. The Bayana Formation is well exposed around the village Bayana, south of Damdama, north of Khereri, around Mahloni etc. Two members, namely, a lower Mor Talav quartzite and an upper Mahloni conglomerate have been recognized in this formation. The Damdama Formation has been classified into three members, namely, Umraind conglomerate, Kanawar quartzite and Lakhanpura sandstone in order of decreasing age (Singh, 1982). The main rock types of the Damdama Formation are conglomerate, quartzite, sandstone and shale.

The correlation of the lithologies of Khetri basin with those of the Alwar and Ajabgarh sequences of the respective type areas is controversial. However, the lithologies included within the Alwar Group in the Khetri basin are pelites, quartzite-arkose and amphibole quartzite and marble, while those in the Ajabgarh Group are pelites, marble calc gneiss and quartzite.

Ajabgarh Group

In the Lalsot-Bayana basin, the Ajabgarh Group overlies the Alwar Group with a disconformity in between. It comprises a lower Kushalgarh Formation and an upper Weir Formation. The main litho-types of the Ajabgarh Group are carbonaceous shale, phyllite and quartzite.

The Kushalgarh Formation occupies the area around Sita, Khairora, north of Hathori and east of Karwan. The rock types of Kushalgarh Formation are carbonaceous shale, phyllite and minor quartzite. The Weir Formation is

made up of quartzite, which is cherty at places.

The baryte deposit of Hathori area, Bharatpur district have earlier been reported to occur as fracture fillings in quartzite, which are closely associated with post-Delhi intrusive dolerites (Heron, 1917; Mathur, 1945; Roy 1958; Jain, 1965; Bhattacharya, 1969). Later investigation in the area has revealed that the baryte mineralization is confirmed within the basic volcanics and associated shale and quartzites of the Delhi Supergroup. Baryte veins occur as fracture fillings along well defined shear zones trending NE-SW to NNE-SSW and along bedding joints.

In the Alwar-Jaipur basin, the Ajabgarh Group, overlying the Alwar Group conformably in the central part of the basin and disconformably along the flanks, consists of five formations- Kushalgarh, Seriska, Thana Gazi, Bharkol and Arauli-Mandan Formations. The lower one is stromatolitic with phosphatic carbonate in the west grading to quartzite-siltstone in the east with ubiquitous presence of basic flows and tuffs. The upper four formations are psammopelitic with subordinate chert-breccia, tuff, argillite and carbonate. Chakrabarti and Gupta (1990) included the Seriska Formation within the Thana Gazi Formation.

The Kushalgarh Formation or the Kushalgarh Limestone comprises alternating siliceous schistose marble band and dolomite-rich band with the black calc schist marking the base of the formation in the southern part of the North Delhi Fold Belt. The Seriska Formation exclusively comprises quartzite, ferruginous quartzite, phyllite (Hornstone Breccia of Heron, 1953), carbonaceous phyllite and marble. The Thana Gazi Formation comprises carbonaceous phyllite (meta-tuff), quartzite, feldspathic calc-arenite, marble and breccia. Felsic volcanic rocks are also identified within this unit (Gupta & Sharma 1998). Overlying the Thana Gazi Formation is the Bharkol Formation represented by an interlayered sequence of phyllite (dominantly carbonaceous) and quartzite (usually gritty). A sequence of garnet±andalusite-bearing chlorite schist and quartzose phyllite exposed at places has been tentatively bracketed within the Bharkol Formation because of its stratigraphic position below the overlying Arauli Formation. The youngest litho-unit, the Arauli Formation, in the Ajabgarh Group is represented by carbonaceous phyllite (meta-tuff), garnetiferous chlorite schist and garnet-staurolite schist.

Heron (1953) considered the Kushalgarh Limestone as separate unit sandwiched between the Alwar and the Ajabgarh Groups in the Alwar-Jaipur basin. Later workers included Kushalgarh Limestone as the basal member of the Ajabgarh Group. It was also noted that Hornstone Breccia of Heron (op. cit.) does not form a definite time rock unit and occurs at different stratigraphic levels within the Ajabgarh Group in NDFB (Chakrabarti & Gupta, 1990). It occurs both as a clastic sedimentary breccia above the basal Ajabgarh and as brecciated quartzites in different rock units within Ajabgarh (Heron, 1953; Banerjee, 1980; Gupta and Sharma, 1998). Gupta and Sharma (op. cit.) favoured a volcanogenic origin of the breccia.

Gounda Group

In the South Delhi Fold Belt, the rocks, which were earlier mapped as Lower Delhi Group by Arora and Ramchandran (1971) together with the outliers of calc-schist of Ajabgarh (cf. Heron, 1953) have been grouped together under the Gounda Group by Gupta *et al.* (1980, 1997). The group comprises quartzite and interbedded schist with subordinate impure calcareous metasediments. The rocks of the Gounda Group are traceable from Kishangarh to Richer. These rocks take a sinistral shift near Antalia and then continue southwards (up to Himmatnagar) in Gujarat. The unit attains its maximum width around Gounda. The rocks of the Gounda Group have been separated into three depositionally related litho-associations which have been designated as the Richer, Antalia and Kelwara Formations in descending order.

According to Sen (1981, 1983), the rock sequences of the Gounda Group in the Antalia-Richer area spans the gap between the Aravallis and the Delhis. A pre-Delhi status has been assigned for the Gounda Group in the Antalia-Richer area by Gupta *et al.* (1995). Gupta *et al.* (1995), has renamed part of the Gounda Group extending from near Badnor in the north to Kitela in the south as the Devgarh Group and tentatively included it within the Delhi Supergroup.

Kumbhalgarh Group

The rock sequence occurring in the west of the Gounda Group in the South Delhi Fold Belt has been termed the Kumbhalgarh Group by Gupta *et al.* (1980, 1997) and is traceable as a broad, linear belt occupying the western part of almost the entire length of the main Aravalli Range. It runs NE-SW or NNE-SSW from

south of Rajgarh-Pisangan area in the north up to Khed Brahma in the south, over a distance of about 290 km. Lithologically, this group is represented by a sequence of calc-gneiss and calc-schist, pure and impure calcitic marble, muscovite-biotite schist, calc-biotite schist, migmatites and gneiss, quartzite, conglomerate and amphibolite. The sequence has a general sharp contact with the rocks of the underlying Gounda Group and at places with the overlying Sirohi Group. The rocks of the Kumbhalgarh Group have been regionally metamorphosed under amphibolite facies and the effects of contact metamorphism are well-marked towards the western side where they are intruded by acidic and basic rocks. The rocks of Kumbhalgarh Group have been divided into the Todgarh, Sendra, Basantgarh, Beawar, Kotra, Barr, Ras and Kalakot Formations which do not always indicate the order of superposition. The rocks show a general younging towards west.

In a new stratigraphic scheme proposed by Gupta *et al.* (1988, 1991 and 1995), Gupta and Bose (2000) for the SDFB, the axial region in central Rajasthan comprises multiple tectonic units (cf. Sen, 1980) which retain their individuality of lithocharacters, structure, magmatism and metamorphism. The delineated five lithotectonic units, namely, Basantgarh, Barotiya, Sendra Rajgarh and Bhim Groups, from west to east, deposited in two basins, namely, the western Basantgarh-Barotiya-Sendra basin and the eastern Bhim-Rajgarh basin. Tectonic discordance in the form of early ductile shear zones and superposed brittle ductile shear zones demarcate the boundary surfaces of each unit.

TRANS-ARAVALLI-PROVINCE

Trans Aravalli Province in the western part of the Aravalli Range is constituted by rocks of Malani Igneous Suite along with crystalline rocks of the Archaean age (equivalent to BGC), the Marwar Supergroup and the Mesozoic-Cenozoic sedimentary sequences. Heron (1953) opined that the rocks to the west of the Aravalli Mountain Range are older than the Delhis and are possibly correlatable with the Banded Gneissic Complex (BGC). Heron described it as 'ancient' gneiss of grey, fine-grained rock of rather granitic composition and texture, generally ferruginous but sometimes porphyritic and foliated. To the southwest, it is profusely intruded by post-Delhi Erinpura Granite. Gupta *et al.* (1991, 1995) also

suggested the pre-Delhi status of the rocks. According to Gupta *et al.* (op. cit.), the early deformation in these gneisses and schists and polymetamorphism in them, are absent in the overlying Delhi rocks, the latter younging easterly. The rock components include pelitic schist, garnetiferous quartzo-feldspathic gneiss, quartzite, thin marble bands and suspected metabasic flows now occurring as amphibolites. The rocks have suffered metamorphism upto sillimanite I grade and a phase of migmatization prior to the earliest deformation of the Delhis. According to Gupta (2004), the pre-Delhi migmatites and gneisses in the Trans-Aravalli region are product of granitization of the volcano-sedimentary rocks of the Sirohi Group only.

Farther west in the Trans-Aravalli region, the gneissic rocks of the migmatized pre-Delhis (Sirohi Group) are succeeded by a slate, phyllite and metatuff succession of Sojat Formation metamorphosed in the granulite facies. The Sojat Formation occurs in scattered isolated outcrops and as enclaves within the Erinpura Granite and Jalor Granite; the latter are intrusive into the former. The stratigraphic status of the Sojat Formation remains uncertain because of lack of isotopic age data.

Sirohi Group

According to Gupta *et al.* (1980, 1997), the Sirohi Group in the west of the South Delhi Fold Belt, comprised flysch-like thick deposits of fine argillaceous sediments viz. phyllite, mica schist and biotite schist alongwith intercalations of arenaceous and calcareous sediments (quartzite and marble) deposited during the peak or terminal orogenic phase of the Delhi geological cycle. The rocks occur in the form of a broad belt occupying the plains of Marwar lying to the southwest of Aravalli range. They have been traced as outcrops from Reodar-Chandrawati area in southwest to Gandoch and Kot in the northeast for a strike length of about 160 km over a width of about 30 km. The continuity of the belt is either lost under a thick soil/sand cover in the area or interrupted by the intrusive Erinpura Granite. The rocks have been deformed and have been regionally metamorphosed to greenschist facies. The metasediments of the Sirohi Group have been subdivided by Gupta *et al.* (1980, 1997), in order of antiquity, into the Jiyapura, Reodar, Ambeshwar and Khiwandi Formations. Gupta *et al.* (1997), considered the Sirohi Group and the Sindreth Group as belonging to the upper part of the Delhi

Supergroup in southern Rajasthan.

Although Gupta *et al.* (1997), considered the Sirohi Group and the Sindreth Group as belonging to upper parts of the Delhi Supergroup, mention may be made about the varied opinions existing regarding the stratigraphic status of the Sirohi/Sindreth Group. While describing the geology of the Sirohi region, Hackett (1881) included the rocks of the area into the 'Aravalli Series'. Coulson (1933) considered the deformed metasedimentary rocks (Sirohi Group of Gupta *et al.* 1997), as well as the undeformed sedimentary-volcanic ensembles (Sindreth Group of Gupta *et al.* 1997) as belonging to the 'Aravalli System' of supposedly Archaean age.

According to Mukhopadhyay (1990), Gupta and Bose (2004), Gupta (2004), the Sirohi Group is represented by deep sea facies assemblage manifested by argillaceous metasediments and migmatites (generally augen gneiss and granite gneiss) associated with carbon phyllite-bedded chert-carbonate-ultramafic-acid tuff (Gupta *et al.* 1989; Mukhopadhyay, 1989). The ultramafics are present as small lenses within bedded chert-carbonate rocks. These are intruded by a number of granitic bodies and quartz-felspar porphyry dykes. Of the granitic rocks occupying the western and eastern flanks of the Sirohi Group in the southwestern Rajasthan, considered earlier as post Delhi Erinpura Granites, a major part actually represents migmatized Sirohi sediments and volcanics while others belong to the intrusive phase (Mukhopadhyay, 1990). According to Mukhopadhyay (1990), Gupta and Bose (2004), Gupta (2004), the migmatized sequence extends northeastward occupying the entire area earlier marked as BGC by Heron. The rocks have suffered metamorphism upto sillimanite-I grade and a phase of migmatization prior to the earliest deformation of the Delhis. Gupta *et al.* 1989; Mukhopadhyay, 1990; Fareeduddin *et al.* 1991 has drawn an analogy between the Sirohi Group and the mica schist-phyllite-ultramafic-fuchsite-chert-tuff association representing the greenstone sequences of the Mangalwar Complex present to the east of Gounda on the eastern flank of the Delhi Supergroup. According to them, similar analogy also exists in their deformational pattern.

Roy and Sharma (1999) observed that the rocks in the region belong to two distinct horizons separated by a prominent unconformity. Roy and Sharma (op. cit.) considered the deformed and metamorphosed sequence

as the older succession of the Sirohi Group, being younger to the Delhi Supergroup. Roy and Kataria (1999) observed that the rocks in the region belong to distinct horizons separated by a prominent unconformity. According to Roy and Kataria (op. cit.), the field relationship in the neighbourhood of the Sirohi town suggests a transition from an orogenic succession, represented by the Sirohi Group, to stable cratonic condition leading to the development of shallow ephemeral basins and associated volcanicity represented by the Sindreth Group. The strict parallelism of the Sirohi rocks in relation to the Delhis suggests possibility of the Sirohi basin as a successor basin (Roy and Kataria, 1999).

Sindreth Group

Clastic sequence representing molasse-like sediments accompanied with basaltic volcanics, deposited in an isolated successor basin, developed during the late to post-orogenic phase of the Delhi Geological cycle in Sirohi district of Rajasthan, has been assigned into the Sindreth Group by Gupta *et al.* (1980, 1997). The rocks of the Sindreth Group are traceable on a roughly linear outcrop from northeast of Pandia in the northeast to north of Mirpur in the south and Gotali in east to Angor in the west over a distance of 20 km. The entire sequence of metasediments is enveloped by intrusive granite and migmatites. Lithologically, the group consists of sequence of conglomerate, gritty quartzite, micaceous quartzite, shale, phyllite and synsedimentational basic flows. The entire sequence appears to have been folded into a synform. The Angor and the Goyali Formations have been recognized within the group by Gupta *et al.* (1980 and 1997).

According to Chore (1990), the Sindreth Group, unconformably overlying the migmatites of the Sirohi Group and the porphyroblastic Erinpura granite gneiss, occurs in a N-S trending linear rift basin. Chore (op. cit.) divided the Sindreth Group into two formations. The lower Khambal Formation is dominated by pillowed basic flows with intertrappean volcanoclastics and polymictic conglomerate at the base. The overlying Angor Formation is represented by a repetitive sequence of volcanics and volcanoclastics with a polymictic conglomerate at the top. A westerly younging direction is indicated from the primary sedimentary structures, e.g. ripple marks, graded bedding and convolute laminations. The Sindreth rocks record the imprints of a single deformation and of

incipient metamorphism. Porphyry dykes of Malani affinity intrude into the Sindreth Group. It is suggested that the volcano-sedimentation of the Sindreth Group should represent a period in between the post-Delhi Erinpura Granite and the Malani Magmatic episode (Mukhopadhyay, 1990).

Punagarh Group

A thick clastic sequence, representing a molasse like association accompanied with basaltic volcanics, occurring in the Pali district of Rajasthan has been assigned to the Punagarh Group by Gupta *et al.* (1980 and 1997). According to them, the volcano-sedimentary sequence of the Punagarh Group has been deposited in a continental basin and developed during the late to post-orogenic phase of the Delhi geological cycle. The rocks of the Punagarh Group occur in roughly oval-shaped outcrop from Sheopura in the northeast to Bhumadra in the southwest and from Jadan in the east to Nimal in the west. Lithologically, the group consists of a sequence of shale, slate, phyllite, mica schist and quartzite, with synsedimentational basic volcanics containing pillow lava, metatuff and bedded chert. The entire sequence is folded to form doubly plunging syncline. The Sojat, Bambholai, Khambal and Sowania Formations have been recognized in the Punagarh Group by Gupta *et al.* (1980 and 1997).

In a significant departure from the earlier publication of Gupta *et al.* (1980), the Sojat Formation comprising the lower part of the Punagarh Group is separated out by Chore (1990) from the Punagarh Group on the strength of the unconformity present at the top of the Sojat Formation and also because of its lithological similarity with the Sirohi Group vis-à-vis its relation to Erinpura plutonism. According to Chore (op. cit.), the lowermost stratigraphic unit is the Bambholai Formation which shows a predominance of pillowed basic volcanics with at least three flows associated with pillow breccia, separated from one another by interflow sediments of jaspery quartzite and shale. Chemical analysis of basic volcanics indicates normal tholeiitic basalt to alkaline olivine basalt composition. Overlying the Bambholai Formation is the Khambal Formation, dominated by a thick massive quartzite at the base followed upward by interbedded welded tuff/bedded chert and amygdaloidal and vesicular dacitic flow. Chemical analysis attests a dacite composition to the basic rock. The youngest Sowania Formation contains a repetitive sequence of synsedimentational bimodal volcanics

with gritty quartzite at the base and shale at the top.

The Punagarh rocks are deformed into an early regional NNE-SSW trending doubly plunging fold, affected by late cross folds, and have suffered only incipient metamorphism. The regional doubly plunging fold represents the first generation structure with its closure near Khambal in the north and near Punagarh in the south. The axial plane strikes N20°E-S20°W with the axis plunging inward at a moderate angle, towards NNE over the southern closure and SSW over the northern closure respectively.

According to Chore (op. cit.), the cross cutting granite porphyry dykes are of Malani affinity. Chore (op. cit.) opined that the volcano-sedimentary sequences of the Punagarh and the Sindreh Groups are correlatable and interpreted that these groups were deposited in rift basins formed during the intermediate phase spanning the granitic intrusion (Erinpura Granite) and the initiation of Malani volcanism.

VINDHYAN SUPERGROUP

The western segment of the Vindhyan basin occupies an area of about 26,000 sq km in the south-eastern Rajasthan. The Vindhyan sediments overlie the metamorphites of the Bhilwara Supergroup and the Berach Granite with a sharp, angular unconformity (Great Eparchaeon Unconformity) defined by synsedimentary volcanics (The Khairmalia Andesite) and discontinuous bodies of conglomerate of the basal Khardeola Sandstone and Bhagwanpura Limestone Formations.

The Vindhyan Supergroup comprises an alternating sequence of sandstone, shale and limestone having a total thickness of about 3,200 m. They are divisible into two broad subdivisions, namely, the Lower and the Upper Vindhyan. The Lower Vindhyan is predominantly calc-argillaceous while the Upper Vindhyan is mainly arenaceous. The Vindhyan Sedimentation in Rajasthan took place in two different sub-basins, the Chittorgarh-Jhalawar sub-basin in the southwest having a full development of the Lower Vindhyan stratigraphy further classified, in an ascending order, into the Satola, Sand, Lasrawan and Khorip Groups and the Sapotra-Karauli sub-basin in the northeast, with only a partial representation of the lower horizons of the Lower Vindhyan sequence equivalent to the Satola and the Sand Groups of Chittorgarh area (Table-4). The two sub-basins which later came under one cover of the sediments were separated by a median

upland near Bundi where the Lower Vindhyan are absent.

LOWER VINDHYAN

Chittorgarh-Jhalawar sub-basin: The initial phase of the Satola Group sedimentation started with volcanic activity of andesitic affinity (Khairmalia andesite, pyroclastics and tuffs) followed by conglomerate, cross-bedded sandstone and shale of the basal Khardeola Sandstone overlying the metasediments of the Bhilwara Supergroup and the Berach Granite. This is followed by the tidal-flat deposits of the Bhagwanpura Limestone with thin, impersistent conglomerate beds at the base signifying deposition in the coastal regime. The prolific growth of stromatolites belonging to the genera *Collenia*, *Cryptozoon*, *Oncolites*, *Conophyton* and *Indophyton* in the Bhagwanpura Limestone indicate their deposition under stable platform condition. The succeeding Sand Group comprising the Sawa Sandstone and the Palri Shale with porcellanite was deposited in quiet water when there was an incursion of the sea causing overlaps.

The overlying Lasrawan Group of sediments comprising Kalmia Sandstone and Binota shale with glauconitic siltstone interbeds were deposited in deeper water under neritic conditions. The calc-argillaceous sediments of the overlying Khorip Group comprising Khorimalan Conglomerate (at the base) grading into Jiran Sandstone followed by Bari Shale, Nimbahera Limestone and Suket Shale with limestone were deposited in an unstable shelf.

Sapotra-Karauli sub-basin: Sedimentation, contemporary to the Khardeola and Bhagwanpura Formations, also commenced in this sub-basin with the basal conglomerate, glauconitic sandstone and shale followed by Tirohan Limestone with prolific algal growth of genera *Collenia*, *Conophyton* and *Cryptozoon*. The Tirohan Breccia with chert and porcellanite, deposited conformably over the Tirohan Limestone, is equated with the Palri Shale of the Sand Group.

The bouldery nature of the Basal Conglomerate suggests proximity of the source area and the rate of sedimentation exceeding subsidence of the basin. The succeeding Tirohan Limestone containing algal structures is indicative of its deposition under littoral marine environment. The overlying Tirohan Breccia and porcellanite is Autoclastic in origin. The presence of Tirohan Breccia in the vicinity of the GBF zone has been

TABLE - 4
*Intrabasinal correlation of the **Vindhyan Supergroup** of Rajasthan*

		Chittaurgarh-Jhalawar Area (Prasad, 1981)	Bundi-Indargarh Area (Prasad, 1981)	Sapotra-Karauli Area (Banerjee and Singh, 1981)
UPPER VINDHYAN	BHANDER GROUP	-	Dholpur Shale	-
		-	Balwan Limestone	-
		-	Maihar Sandstone	Upper Bhandar Sandstone
		Sirbu Shale	sirbu Shale	Sirbu Shale
		Bundi Hill Sandstone	Bundi Hill Sandstone	Lower Bhandar Sandstone
		Samria Shale	Samria Shale	Samria Shale
		Lakheri Limestone	Lakheri Limestone	-
		Ganurgarh Shale	Ganurgarh Shale	Ganurgarh Shale
	REWA GROUP	Taragarh Fort Sandstone	Taragarh Fort Sandstone	Upper Rewa Sandstone
		Jhiri Shale	Jhiri Shale	Jhiri Shale
		Indargarh Sandstone	Indargarh Sandstone	Lower Rewa Sandstone
		Panna Shale	Panna Shale	Panna Shale
	KAIMUR GROUP	-	Akoda Mahadev Sandstone,	-
		-	Badanpur Conglomerate (also extendable to Sapotra-Karauli area)	-
		-	(Basement rocks)	-
		Chittaur Fort Sandstone		-
LOWER VINDHYAN	KHORIP GROUP	Suket Shale		-
		Nimbahera Limestone		-
		Bari Shale		-
		Jiran Sandstone (Khorimalan Conglomerate Member at the base)		-
	LASRAWAN GROUP	Binota Shale	-	-
		Kalmia Sandstone	-	-
	SAND GROUP	Palri Shale with porcelanite	-	Tirohan Breccia with porcellanite
		Ilanite Sawa Sandstone	-	-
	SATOLA GROUP	Bhagwanpura Limestone	-	Tirohan Limestone
		Khardeola Sandstone	-	Basal Conglomerate with glauconitic sandstone and shale
		Khairmalia Andesite	-	-
~~~~~ Unconformity ~~~~~				
Pre-Aravalli metamorphites and Berach Granite		Pre-Aravalli metamorphites		

attributed to syn-sedimentational tectonism. Younger units of the Lower Vindhyan (the Lasrawan and the Khorip Groups) are missing in this sub-basin.

Sedimentological studies of the Lower Vindhyan sediments indicate beach to near shore conditions. Sub-rounded to poorly-sorted arkosic sediments of the Khardeola Sandstone, Bhagwanpura Limestone and Sawa Sandstone indicate little transportation compared to rounded and well-sorted sediments of the Jiran Sandstone. The paleocurrent direction during the Lower Vindhyan time indicates an easterly transport of sediments in the Chittorgarh sub-basin, and NE to ENE in the Saporta-Karauli sub-basin. The Bhilwara, Aravalli and Delhi Supergroups acted as provenance.

### UPPER VINDHYAN

A well-marked change in the sedimentary environment from predominantly calc-argillaceous (littoral shallow-marine) to clastic (continental fluviatile) took place during the Upper Vindhyan time. During the Kaimur, Rewa and major part of Bhandar time, the two sub-basins in Rajasthan remained unconnected. In the Saporta-Karauli sub-basin, the Tirohan Breccia is unconformably overlain by the Badanpur (Kaimur) Conglomerate and Akoda Mahadev Sandstone suggesting a sharp erosional hiatus between the Lower and the Upper Vindhyan. On the contrary, deposition continued uninterruptedly in the Chittorgarh-Jhalwar sub-basin where the Chittorgarh Fort Sandstone (Lower Kaimur Sandstone) conformably overlies the Suket Formation (Khorip Group). Some more part of the basement area came under sedimentation and the strand line shifted further to the north and the Akoda Mahadev Sandstone (Upper Kaimur Sandstone) was directly deposited over the older rocks northwest of the GBF, with a distinct basal conglomerate between Akoda and Indargarh. The absence of the Lower Vindhyan in Bundi- Indargarh area is considered to be due to the basement-high known as the Bundi Upland.

The Kaimur basin was not so deep initially and it gradually subsided with sedimentation. The orthoquartzitic nature, textural maturity, good sorting and prolific development of cross-beds and ripple marks at all levels in the Kaimur Sandstone are indicative of its deposition under shallow-marine shelf regime. The presence of glauconite in the upper levels (around Rawatbhata) suggests its disposition under littoral marine condition. Restricted ferruginisation, presence

of sun cracks, rain prints and intra-formational conglomerate suggest development of local sub-aerial conditions towards the close of the Kaimur sedimentation.

The succeeding Rewa Group of sediments representing alternating argillaceous and arenaceous facies suggests periodic instability of the basin floor. The extremely fine-grained Panna shale with fine parallel laminations was locally deposited in a shore-lagoon environment. The presence of glauconitic siltstone beds at the base in Rawatbhata-Javda area indicates local reducing condition. The overlying Indargarh Sandstone (Lower Rewa Sandstone), having a restricted development, is orthoquartzitic, texturally matured, profusely cross-bedded and rippled, and was deposited in littoral to neritic zones under a shallow-marine environment. The Jhiri Shale, covering the older formations, was deposited when there was transgression of the sea. The dominant reddish, purplish colour, glauconitic siltstone intercalations and proliferation of stromatolitic colonies in the limestone member of the Jhiri Shale indicate that the depositional environments were dominated by warm-water conditions. The overlying orthoquartzitic, texturally-matured Taragarh Fort Sandstone (Upper Rewa Sandstone) showing prolific development of ripples and cross-beds, occurring in a blanket-type disposition was deposited under shallow-marine tidal-flat conditions. The presence of glauconite in sandstone and its ferruginous nature locally, suggest deposition under reducing environment. The presence of thin, discontinuous bodies of conglomerate in the upper parts indicates local high-energy conditions.

The orthoquartzite-carbonate-shale association of the Bhandar Group of sediments is broadly attributed to stable shelf regime. The reddish-purplish ferruginous Ganurgarh Shale with frequent glauconitic siltstone beds showing ripples, cross-laminations, sun cracks and intraformational conglomerate at the base, suggest a shore-lagoon tidal flat deposition whereas the argillaceous limestone and intraformational conglomerate and breccia at the top indicate supratidal conditions. The intraformational conglomerate and breccia, sun cracks and ripples in the lower beds of the Lakheri Limestone suggest their deposition under sub-aerial conditions. The rest of the formation was deposited under more or less chemogenic environment as suggested by the chert and anhydrite intercalations and almost general absence of detritus. The



corresponding limestone unit is missing in the Sapotra-Karauli sub-basin. This condition continued during the Samria Shale. The prolific growth of stromatolites in the limestone interbeds of the Samria Shale favours their deposition in open, intertidal mud flats, mainly in the protected lagoon. The orthoquartzitic nature, high maturity and good sorting together with profuse cross-beds, ripple marks and current lineations suggest deposition of the Bundi Hill Sandstone under shallow, stable shelf conditions. During the deposition of the Sirbu Shale, both the sub-basins got united into a single repository wherein the Sirbu Shale and other younger formations viz. the Maihar Sandstone, Balwan Limestone and Dholpura Shale in Bundi-Indargarh area and Upper Bhander Sandstone in Sapotra-Karauli area were deposited in shallow-marine conditions. The average palaeocurrent direction in the Maihar Sandstone in Sapotra-Karauli sub-basin is towards north. Uniformity and consistency of the direction of sediment transport signifies stable palaeoslope and general tectonic stability of the basin, especially during the Upper Bhander time. The Balwan Limestone, which is stromatolitic limestone, indicates shallow-marine condition of deposition. The youngest Dholpur shale indicates restricted condition.

Thus, it appears that throughout the Vindhyan sedimentation, the conditions of deposition were fluctuating due to subsidence and elevation of the basin and consequent transgressions and regressions of the sea. Several evidences of organic life in the form of stromatolites, trace, macro and micro fossils have been reported from the Vindhyan. The stromatolites preserved in the Vindhyan (similar to the Ripheans of the former USSR) indicate an age ranging from over 1,300 Ma to less than 600 Ma. Radiometric dating of basal Khairmalia Andesite (1,250 Ma) and the Kaimur glauconite (940-910 Ma) is in fair agreement with the results arrived at from the stromatolites.

### MALANI IGNEOUS SUITE

The Malani Igneous Suite encompasses Late Proterozoic plutonic and volcanic rocks. The suite covers an area of about 51,000 sq km in parts of Jaisalmer, Jodhpur, Barmer, Churu, Pali, Sirohi and Jalor districts of Western Rajasthan and extends further in Sind province of Pakistan.

Malani magmatism, the largest anorogenic acid volcanism in India showing little metamorphic effect, is associated with post-Erinpura granitic activity and pre-Marwar sedimentation and covers a span of 850-550

Ma. Three phases of igneous activity have been identified viz. eruption of basic flows, followed by voluminous acid rhyolite flows culminating with ash-flow deposits (first phase); intrusion of subjacent discordant granites as plutons, ring dykes, bosses and plugs (second phase) and the indiscriminate intrusion of mafic and felsic, coarse to fine-grained dykeswarms (third phase).

Malani volcanics have erupted in three stages. The volcanism commenced with eruption of basalt with occasional andesite flows (first stage) followed and covered by the voluminous outpouring of peralkaline and peraluminous rhyolite, rhyodacite and trachyte flows (second stage) and ceased with the outburst of ash-flow deposit (third stage). The dominant felsic volcanics are rhyolites and rhyo-dacites having a spread of about 31,000 sq km. The other rock types associated with rhyolites are trachytes, dacites, pitchstone, welded-tuff, vitric, lithic and crystal-ash, ignimbrite, obsidian, pyroclastic slates, agglomerate, volcanic breccia and volcanic conglomerates. The cumulative thickness of felsic volcanics exceeds 3-5 km in 95 cumulative flows (Bhushan, 2001). The final eruptive stage witnessed ash-flow deposits near Pokaran. These ash beds, 50 m in thickness, are composed essentially of light yellow and light brown lithic-crystal and vitric-ash having microscopic xenoliths of basalt and rhyolite embedded in it. The mafic-felsic volcanic suite (first phase) is intruded by post-tectonic, anorogenic Siwana and Jalor Granites during the second phase. The Siwana granite occurs as ring dykes while Jalor Granite attains batholithic dimension near Jalor and also occurs as small bosses near Salawas. The hornblende granite (Malani Granite) occurs as porphyry dykes in Barmer area. The third phase of igneous cycle experience intrusion of felsic and mafic dykes trending either NNW-SSE or NE-SW direction, the dolerite forming the predominant dyke phase. Five sub-phases in a dyke-swarm near Sankra have been recorded commencing with felsic intrusions and culminating with the basic intrusions.

The Jalor Granite plots in the granodiorite field. The main difference between the Siwana and the Jalor Granites is the presence of normative acmite and absence of normative anorthite in the former. The Jalor Granite is metaluminous. It has higher  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ . The Siwana Granite which is peralkaline has very high  $\text{TiO}_2$ , alkalis, REE and iron due to presence of alkali pyroxene and alkali amphiboles. At Siwana, the alkali

**TABLE - 5**  
*Lithostratigraphy of Marwar Supergroup (Upper Proterozoic)*

NAGAU GROUP (75 - 500 m)	Tunklian Formation	Sandstone, gritty sandstone and pebbly sandstone, containing pebbles of Malani granite, rhyolite, Bilara chert, dolomite and Delhi quartzite, specially near Gudarli.
	Nagaur Formation	Brick-red sandstone with greenish clayey blotches : siltstone, shale, evaporite <i>kick back</i> sequences. Up to 500 m thick; locally developed conglomerate at the base.
BILARA GROUP (100 - 300 m)	Pondlo Formation	Dolomite, dolomitic limestone, cherty dolomite, stromatolitic limestone and dolomite; siliceous oolites and pisolites.
	Gotan Formation	Limestone with bands of chert and dolomite.  Stromatolitic limestone dolomite, dolomitic limestone, chert and cherty dolomite.
JODHPUR GROUP (125 - 240 m)	Girbhakar Formation	Brick-red siltstone shale and sandstone, current bedded, pisolitic with pellets.
	Sonia Formation	Maroon siltstone and shale; creamish sandstone with abundant sedimentary features and pisolitic; salt pseudomorph shales; banded chert - jasper dolomite; divisible into mappable units A-G.
	Pokaran Boulder Bed	~~~~~ Unconformity ~~~~~ Bed developed along the south-western periphery comprises pebbles, cobbles, boulders and erratics of Malani granite, rhyolite in maroon/red arenaceous silty/clayey matrix.  ~~~~~ Unconformity ~~~~~
Basement rocks		

(after Pareek, 1984)

granites as well the associated rhyolites (comendites and pantellerites) and trachytes are characterized by the presence of riebeckite, aegirine and arfvedsonite indicating a co-magmatic relationship. The Malani Volcanics occur towards the western side of tightly compressed Delhi-Aravalli Fold Belts. A possible sudden release of pressure, causing rifting may have triggered the eruption. NW-SE trending fissures and

several calderas and cones were the possible mode of eruptions.

### MARWAR SUPERGROUP

The trans-Aravalli sediments, equivalent of Vindhyan deposited on the NW flank of the Aravalli hill range, occurring as numerous scattered flat-topped hills and covered under the sands of the Thar Desert

towards north, have been grouped under the Marwar Supergroup. The general resemblance to the Vindhyan sediments notwithstanding the Marwar beds having deposited in a separate basin, are considered correlatable to the Upper Bhandar Group. Laid down in continental seas, upon the Malani volcanics, at a time just before the life forms appeared in abundance, the Marwar beds are of great interest. Apart from *Chordophycous* tracks and fusiform bodies, bearing some relation to the *Cruziana furcifera*, no determinable organic remains have been found in the Marwar beds.

The rocks of the Marwar Supergroup, over 1,000 m thick, are divided into three groups, namely the Jodhpur, Bilara and Nagaur Groups (Table-5).

### **Jodhpur Group**

The Pokaran Boulder Bed, Sonia and Girbhakar Formations constitute the Jodhpur Group. The Pokaran Boulder Bed, about 3 m thick, extending southward from Pokaran in the north to Hariyoli Nadi in the south, over a distance of 42 km consists of pebbles and cobbles of granite, syenite, basic rock and quartzite in a red-brown sandy matrix (near Karewa). Cobbles of granite set in a red arenaceous matrix (near Barat-ka-Gaon.). The overlying Sonia Formation, horizontally disposed with rolling dips, commences with maroon shale with mega ripples which alternates with creamish-buff to reddish, fine to medium-grained sandstones interbedded with chert, cherty dolomite and jasper. The contact with the overlying Girbhakar Formation is marked by a short break in sedimentation indicated by the presence of pebbly horizon containing pebbles of the Sonia sandstone and chert. The Girbhakar sandstone is reddish and consists of coarse to gritty micaceous sandstone alternating with red and light green shale with pebbly and gritty layers. The Jodhpur Group of rocks shows NW to W palaeocurrent direction. The well-sorted, mature sandstones were deposited in near-shore environment. Heavy mineral analysis suggests that the materials were received from acid plutonic volcanics and low-grade contact metamorphic rocks. The beds are, for most of the part, unfossiliferous.

### **Bilara Group**

The calcareous Bilara Group which is 300 m thick comprises Dhanapa Formation - chert at the base, followed by well-bedded to laminated cherty dolomite, siliceous dolomitic limestone and stromatolitic limestone; Gotan Formation - dark grey laminated

limestone, containing bands of clay; and the Pondlo formation comprising dolomite, cherty dolomite, claystone, siltstone and reddish sandstone. It is stromatolitic towards top near Shiv Sar and contains siliceous oolites grading into pisolites near Lordiyan. Weedia, Collenia, Cryptozoon, algal nodules, ill-preserved lamellibranches and brachiopod shells are reported from the Bilaras

### **Hanseran Evaporite Group**

The Hanseran Evaporite Group (HEG) is the name given to the entire sub-surface sequence of halite bearing deposits found in the central and northern parts of Nagaur-Ganganagar basin. These dominantly halite rich deposits are time equivalent to carbonate rich sediments of Bilara Group and Birmania phosphorites. Cyclic deposits of halite containing potash minerals and separated by clay, dolomite and magnesite were noted. Potash minerals found in decreasing order of abundance are polyhalite, sylvinite, sylvite, langbeinite and carnallite. Thickness of HEG varies from 103.2m to >652.15m. Seven halite cycles have been identified (Table-5A).

### **Nagaur Group**

The Nagaur Group unconformably overlying the pondlo dolomite (the Bilara Group) commences north of Khichan with a 5 m thick conglomerate bed, containing cobbles, pebbles fragments and pieces of dolomite, chert, cherty dolomite, feldspar, quartz and sandstone cemented in a pink-brown calcareous sandy matrix. These are overlain by red, mottled, claystone, siltstone and fine-grained friable sandstone. The Nagaur sandstones have been divided into two formations - the older unit, designated as the Nagaur Formation, comprises a sequence of brick-red to red claystone, siltstone and sandstone with bands of clay and blotches of green clay and the younger unit, designated as the Tunklian Formation, comprises brick-red claystone, siltstone, calcareous clay and gritty to pebbly sandstone containing pebbles of Malani rhyolite-granite, chert, dolomite and quartzite near Gudarli.

### **Birmania Basin**

An isolated oval-shaped remnant of thick sedimentaries occupying about 100 sq km areas exists 125 km southwest of Pokaran. The rock formations are grouped as the Randha Formation and the Birmania Formation overlying the Malani Igneous Suite (basement rocks) and underlying Lathi sandstone. The

**TABLE - 5A**  
*Lithostratigraphic classification of **Hanseran Evaporite Group***

Group	Formation	Member	Lithology	Thickness (in metres)
Nagaur Group (Lower Cambrian)			Reddish to grey sandstone, siltstone with reddish to maroon clay	
			Gradational Contact	
	Lakhusar	E-16	Clay, claystone and anhydrite	1.14-70.35
	Sataiyan	E-15	Halite (H ₇ ), polyhalite, clay and anhydrite	8.12-84.35
		E-14	Clay, anhydrite/dolomite	2.13-36.5
	Harsinghpura	E-13	Halite (H ₆ ), polyhalite, clay and anhydrite	5.1-211.75
		E-12	Clay with anhydrite/dolomite	2.2-88.45
	Kupli	E-11	Halite(H ₅ ), polyhalite, clay and anhydrite/dolomite	5.3-54.6
Hanseran Evaporite Group (103.2-650.15m) Eocambrian		E-10	Dolomite, dolomitic anhydrite and clay	1.45-93.35
	Malkisar	E-9	Halite (H ₄ ), polyhalite, clay and anhydrite	1.35-86.1
		E-8	Anhydrite, dolomite and clay	1.7-87.83
	Chattargarh	E-7	Halite (H ₃ ), polyhalite, clay and anhydrite	3.5-85.88
	Kalu	E-6	Dolomite, anhydrite and clay	2.52-17.17
		E-5	Halite (H ₂ ), polyhalite, sylvinite/sylvite, langbeinite, carnallite traces with clay, anhydrite and dolomite	15.8-138.95
		E-4	Clay, dolomite and anhydrite	3.94-32.58
	Lakhasar	E-3	Halite (H ₁ ), polyhalite, sylvinite/sylvite, traces of carnallite, clay, anhydrite	16.11-60.45
		E-2	Anhydrite, dolomite and clay	0-8.83
		E-1	Clay and anhydrite	1.4-26.11
		E-0	Clay, marl, limestone, gypsum, anhydrite and dolomite with chert	0.0-90
			Gradational Contact	
Jodhpur Group (Neoproterozoic)			Grey sandstone with minor purple shale and siltstone with reddish-brown to buff and occasional dolomite bands	
			Base not seen	

contact between the Randha and the Birmania Formations is marked by an angular unconformity and the western contact with the basement rocks is faulted. The beds are unfossiliferous and considered homotaxial to the Jodhpur and the Bilara Group.

The Randha Formation is an arenaceous sequence comprising splintery maroon and grey shales at its base, ferruginous sandstone, calc-quartzitic sandstone, purple

quartzitic sandstone, whitish quartzitic sandstone and thinly-bedded sandstone with gritty layers at the top. The Birmania Formation has a sequence consisting of shales at the base, yellow cherty limestone, grey cherty limestone, dolomitic limestone, phosphorite, quartzitic sandstone and calcareous, ferruginous sandstone at the top.

#### PALAEOZOIC

After the deposition of the Nagaur Group



(Proterozoic), there was a break in sedimentation as a result of which sediments of most of Cambrian, Ordovician, Silurian, Devonian and Lower Carboniferous periods are not represented in Rajasthan.

Upper Carboniferous glaciation is represented in the Nagaur basin by the NE-SW trending remnants of the Bap Boulder Bed - an assortment of pebbles and cobbles with occasional boulders and a few erratics exhibiting well-marked glacial striations, spread over 68 sq km from Khirwa to Nokhra. The rock types include gravel/boulder (5 cm to 25 cm across in size) of rhyolite, tuff, granite, basalt and dolerite of the Malani Igneous Suite; granite, syenite, amphibolite and basic rocks, quartzite, phyllite and slate of pre-Delhi and Delhi age and limestone, dolomitic limestone and sandstone of the Marwar Group.

This is overlain by a very small remnant of the marine Badhaura sandstone of 30 m computed thickness. Extending from northwest of Badhaura upto Harbans, these marine sediments, designated as the Badhaura Formation, comprise medium to coarse-grained brownish-yellowish and ferruginous sandstone, clay, shale and siltstone containing Permian fauna and flora. The sub-surface continuation of the formation at Pugal between depths of 500 and 590m, and at Shumarwali Talai, has been established by drilling. The Permian sediments thus have thickened dipwards and represent the post-glacial sediments. The Badhaura sandstone which can be correlated with the sequence of the Indus Basin implies that the Indus Basin (Salt Range) was connected with the north and northwest Rajasthan.

## MESOZOIC AND CENOZOIC

### Deccan Traps

The Deccan Traps (Cretaceous to Eocene) covering an area of about 10,435 sq km in southeast Rajasthan have developed in two separate geographic sectors, namely, the Kota-Jhalawar sector in the southeast and the Chittorgarh-Banswara sector in the south-southeast.

**Kota-Jhalawar sector:** In this sector, the Deccan Traps overlying the Vindhyan sediments have attained a cumulative thickness of over 180 m. twelve flows, varying in thickness from 7 to 56 m are present between 280 and 481 m RL. Out of the 12 flows, five are Pahoe-hoe-type and the rest are Aa-type.

The individual flows are separated either by impersistent red bole bed or by Inter-trappean Beds comprising conglomerate, clay and chert. Both

fossiliferous and unfossiliferous clay/chert beds are present among the older flows. *Physa prinsepia* and ostracodes have been recorded near Parbati (24°23': 76°31'), Sohankheri (24°30': 76°05') and Gadiyo (24°31': 76°03'). Around Dag (23°56': 75°50') and Chaumahala (23°57': 76°36'), the flows have undergone widespread lateritisation. A gritty, sandy and cherty unfossiliferous friable Infra-trappean clay bed containing angular pieces of sandstone occurs widely in the area around Chippabarod (24°33': 76°43'), Chabra (24°40': 76°51') and Chandloi (24°30': 76°10').

**Chittorgarh-Banswara Sector:** The area is characterized by the N-S trending Deccan Traps plateau with prominent scarp on the west. The Deccan Traps overlie the Lower Vindhyan rocks in the north and northeast, but towards the west and south they rest over the rocks of the Mangalwar Complex and the Aravalli Supergroup. In all, sixteen flows varying in thickness from 11 to 55 m have been identified between 226 and 606 m RL. Out of these, four flows have Pahoe-hoe characters and the rest Aa-type characters.

Fairly widespread unfossiliferous clay bed, as Infratrappian, is present around Kushalgarh (23°12': 74°27') and Barodia whereas fossiliferous *Physa (Bullinus) prinsepia* Infra-trappean limestone bed is reported from Ram-ka-Munna in Banswara district. Unfossiliferous thin inter-trappean clay beds are noticed around Arnaud (23°53': 74°49') Dhamotar (24°06': 74°45') and Kulmipura (24°07': 74°45') whereas unfossiliferous chert bed, about 1 m in thickness is noticed near Acheri (24°26': 74°50') and Semara (24°26': 74°42').

The Deccan Traps do not show any sign of major deformation. However, columnar joints, sheet joints, pipe vesicles/amygdules are common. The flows in either sector have a gentle gradient and as such they occur at different levels. In Jhalawar-Kota sector, the contact gradient is 1:62 to 1:1050 towards NNW and NE and 1:250 to 1:500 towards NE and NW in Chittorgarh-Banswara sector. Overlapping of flows is common in both the sectors.

From the correlation of flows in two sectors it appears that in all 19 flows are present in Rajasthan.

### Tertiary Alkaline Complex

The Tertiary Magmatic event of the western Rajasthan is characterized by the mildly alkaline and hyperalkaline plutonic-volcanic suites of Sarnu-Dandali, Karara-Tavidar and Mundwara areas. The

hyperalkaline suite of rocks clearly traverses the Malani rhyolites and Cretaceous clastics and, therefore represents a major Tertiary alkaline magmatic event. The Sarnu-Dandali suite is dominantly nephelinitic in composition, various members being mafic alkaline rocks, ijolites, foidal syenites, phonolites and carbonatites belonging to a carbonatite-nephelinite association. The Mundwara suite is mostly basic comprising picrites, foidal gabbros and foidal syenite with carbonatites which intrude the Erinpura Granite.

### Sedimentaries

Triassic rocks do not outcrop anywhere in west and northwest Rajasthan but its subsurface presence, identified on pollen-spore assemblage, at Shumarwali Talai borehole, has been established. Land conditions existed during post-Permian to pre-Jurassic period and extensive erosional agencies reigned supreme leaving only traces of these Permian deposits. The Jurassic period commenced with a fluvial environment which gave rise to the Lathi sandstone.

The area north, west and south of Lathi was filled up by the sediments of the Lathi Formation, the southern continuity being checked by the Jodhpur-Pokaran-Chotan-Malani ridge. The outcrops of the Lathi sandstone are seen intermittently, separated by the desert sands. The Lathi sandstone, 360 m thick, comprises a sequence of coarse-grained sandstone, gritty sandstone, pebbly sandstone, gritty and pebbly sandstone, conglomerate, arkose, lithic-arenite, siltstone, shale ferruginous shale, ferruginous sandstone and clay.

The Lathis overlie the Malani Igneous Suite of rocks, the Pondlo dolomite, the Nagaur sandstone, the Bap Boulder Bed and the Badhaura sandstone. The contact with the Malanis is marked by a conglomerate bed, grading into pebbly sandstone and grit. A friable, weathered, dirty-white to yellowish sandstone comes in contact with the other older underlying rocks.

The Lathi sandstone has been subdivided into lower and upper members. The lower member comprises a sequence of conglomerate, arkose, lithic-arenites and coarse-grained sandstone, indicative of terrestrial deposition under stable delta in fresh water conditions. The upper member comprises bands of sandstone and siltstone, grading into limestone, indicating shallow marine shelf-sedimentation.

The abundance of fossil wood logs is so conspicuous that an area near Akal has been converted

into a Fossil Wood Park. The fossil wood is of gymnospermous origin. The Lathi sandstone has leaf impressions of *Pterophyllum* sp. *Pterophyllum acutifolium*, *Equisetites* sp. and preserves silicified wood and gastropod shells. The Lathi sandstone contains thin bands of lignite as noted in dug wells near Devikot, Nar Singh-ki-Dhani, Jhinhinyali and south of Unror.

The Mayakar Formation, which overlies the Badhaura Formation with an unconformity, has been equated with the Lower Lathis.

The deposition of Lathi/ Mayakar Formation culminated with the initiation of the marine transgressions in different basins. These include the Jaisalmer basin in the west, the Barmer basin in the south-central and the Palana-Ganganagar Shelf in the north and northwest of Rajasthan.

### Jaisalmar Basin

The Jaisalmer basin deepened towards northwest extending into Pakistan. The Jaisalmer-Mari arch, the raised platform, exposes the entire sequence.

The Mesozoics are preserved in NE-SW trending strips with their northwesterly boundaries being located near Niba, Sam, Kanoi, Mahmud-ki-dhani, Jaidesar, Sanu and Lila; the Lower Tertiaries are exposed towards northwest of these localities. The Mesozoics are represented by the Lathi sandstone, Jaisalmer limestone, Baisakhi shale, Bedesar sandstone, Parihar (Pariwar) sandstone and Abur limestone, while the Lower Tertiary includes Sanu sandstone, Khuiala limestone and Bandah limestone. Pleistocene Shumar grits overlie the Lower Tertiary sequence as capping of ferruginous grit and laterites. All these units have been assigned formational status (Table-6).

The Jaisalmer limestone has intertonguing contact with the underlying Lathis and represents the first marine transgression of the Mesozoics in Rajasthan. Subsurface thickness of this formation is ~600 m in the Jaisalmer basin. The Baisakhi shale and the Bedesar sandstone occur as mappable rock formations of 165 m and 65 m thickness respectively, but in subsurface they occur as intergrading sequences. Each of these formations has been subdivided into units A, B and C. The overlying Pariwar sandstone which represents continental deposition contains angiospermic plant remains and is 300 m thick. The overlying Abur limestone marks the end of the Mesozoic Era in the

**TABLE - 6**  
*Geological succession of Jaisalmer Basin*

Lower to Middle Eocene	Bandha Formation	Fossiliferous marls, bentonites and limestone,
Lower Eocene	Khuiala Formation	Shales, bentonite, fuller's earth and fossiliferous limestones.
Palaeocene	Sanu Formation	Variegated sandstones and shales.
~~~~~ Unconformity ~~~~~		
Lower to Middle Cretaceous	Abur Formation	Fossiliferous limestones and sandstones.
~~~~~ Unconformity ~~~~~		
Lower Cretaceous	Pariwar Formation	Feldspathic sandstones, grits and quartzites.
Upper Jurassic	Bedesar Formation	Fossiliferous grits/oolites and sandstones.
~~~~~ Unconformity ~~~~~		
Upper Jurassic	Baisakhi Formation	Shales and sandstones.
Middle Jurassic	Jaisalmer Formation	Fossiliferous limestones, marls and sandstones.
Lower Jurassic	Lathi Formation	Mainly sandstones with fossil wood.
~~~~~ Unconformity ~~~~~		
ProCambrian	Malani Igneous Suite, Marwar Supergroup and other older formations.	

Jaisalmer basin. The Abur Formation is 66 m thick and in subsurface it is divisible into the Goru Formation and the Parh Formation of younger ages showing continuity of the marine environments in the deeper parts of the Jaisalmer basin.

The Palaeogene succession is exposed in detached outcrops near Mahmud-ki-Dhani, Sanu, Shera and Lila. It commences with the Sanu sandstone which is 75 m thick and consists of fresh-water arenaceous and glauconitic sandstone, clay, shale and ferruginous shale showing current bedding. The Sanu sandstone appears to grade in subsurface into non-marine and marine bands showing fish teeth. The Khuiala limestone of a total thickness of 100 m overlies the Sanu sandstone and is overlain by the Bandha limestone of 75 m computed thickness marking the close of the sedimentary cycle in the Jaisalmer basin. The Tertiaries occur oblique to the Mesozoic strike and find representation in the Barmer basin and in the Palana-Ganganagar shelf area.

#### **Barmer Basin**

Southeast of Jaisalmer, a sequence of the Mesozoic

and Lower Tertiary rock formations occupies a N-S trending linear tract for about 100 km from Mandai and Fatehgarh in the north to Barmer in the south. This synclinal exposure having a maximum width of 50 km at Akli is known as the Barmer basin. The configuration of the basin is related to Meso-Cenozoic tectonic framework of the Cambay Graben in Gujarat. The rock formations of the Barmer basin include the Fatehgarh sandstone, Akli bentonite, Mandai sandstone and Kapurdi fuller's earth-each unit enjoying a formational status.

The Fatehgarh sandstone overlies the Lathi sandstone in the Barmer basin and represents the Cretaceous marine transgression. It occurs along the northern half of the synclinal depression of the Barmer basin and comprises conglomerate, phosphatic sandstone and clay in a 50 m thick sequence. These beds are overlain by the Akli bentonite which contains 265 m thick sequence of the bentonite, bentonite clays, and siliceous earth containing phosphatic beds. The continental Mandai sandstone (100 m) overlies the Akli and is overlain by the Kapurdi fuller's earth (30 m)

which marks the closure of Tertiary cycle in the Barmer basin.

### **Nagaur-Ganganagar Basin**

Nagaur-Ganganagar Basin covers an area of 100,000 sq km in parts of Nagaur, Churu, Jaisalmer, Pali, Jodhpur, Bikaner, Hanumangarh and Ganganagar districts of Rajasthan and parts of Bhatinda, Faridkot districts in southern Punjab and parts of Sirsa district in Haryana.

The basin is delineated by Delhi-Lahore-Sargodha sub-surface ridge in the north and northeast, Aravalli Range in the east and southeast, Jodhpur-Pokaran-Chhotan-Malani ridge in the south and Devikot-Nachana sub-surface high in the west and southwest.

The oldest sedimentary rocks in Nagaur-Ganganagar Basin belong to the Marwar Supergroup (Neoproterozoic to Cambrian). The Marwar Supergroup consists of older arenaceous rocks of the Jodhpur Group overlain by the Hanseran Evaporite Group and its calcareous (Bilara Group) and phosphorite (Birmania Formation) facies variations and younger red argillaceous rocks of the Nagaur Group. It unconformably overlies basement rocks of the Malani Igneous Suite and / or the Delhi metamorphites and in turn is occasionally overlain by sediments of Permo-Carboniferous Bap-Badhaura Formations, lower Jurassic Lathi Formation, but mostly by Tertiary sediments associated with or without lignite and Quaternary sediments.

In west and northwest Rajasthan, the nearshore, lagoonal/estuarine deposits of Paleocene to lower Eocene age are important by virtue of the occurrences of lignite seams within them. These lignite bearing deposits are confined within the Palana Formation in Nagaur-Ganganagar basin, Akli Formation in Barmer basin and Sanu Formation in Jaisalmer basin. The detailed geological, geophysical studies of these Tertiary deposits are being carried out by various organizations due to the possible occurrences of oil, lignite, phosphate, bentonite and other varieties of clays.

Lignite occurrences are found associated with the lower Tertiary (Palaeocene to Eocene) Palana Shale Formation in Palana and Nagaur sub-basins of Nagaur-Ganganagar basin. The Palana Shale Formation comprises greenish grey variegated shales and clays associated with carbonaceous shale, shaly lignite and

lignite seams. At Palana, the Palana Shale Formation is represented by sandstone, clay, fuller's earth interbedded with limestone, lignite with partings of shale, mudstone and fine sandstone. At Gurha (40 km west of Palana), the sequence changes to coarse sandstone, fuller's earth, fine to medium grained sandstone, carbonaceous shale and lignite. At Barsinghsar (2 km away from Palana), thickness of lignite seam varies from 0.1m to 41.5m. Sedimentary facies change along with lignite seam thickness variation at different localities of Nagaur-Ganganagar basin shows that the types of sediments filling up the basin kept on changing, and this, along with availability of vegetation, palaeo-slope, palaeo-drainage etc. governed the thickness of the lignite seam in different parts of the basin.

Basement topography of Nagaur-Ganganagar basin reveals the presence of several basement highs and lows which are bounded and also dissected by N-S to NNE-SSW and E-W to ENE-WSW oriented faults. The N-S to NNE-SSW oriented faults gave rise to step grabens resulting deepening and more accretion of Tertiary sediments towards northwest and northern parts where lignite seams occur at deeper levels. These tectonic activities resulted in creation of isolated smaller sub-basins of Tertiary deposits with or without lignite seams.

The Tertiary sediments in Nagaur-Ganganagar basin successively overlap rocks of the lower Jurassic Lathi Formation, the Permo-Carboniferous Bap-Badhaura Formation and Neoproterozoic-Cambrian rocks of the Marwar Supergroup. They attain an average thickness of 150m in the Palana area. However, the cumulative thickness of sediments increases towards north and northwestern parts, particularly in Pugal-Karanpur sector where the sediment thickness is more than 420 m while in Lalgah-Jattan-Maujgarh sector, the thickness is around 350 m. In the southern part of the basin, in Nagaur-Merta area, the average thickness of Tertiary sediments is 60 m.

The sub-surface data suggests that the Tertiary sea had transgressed the northwestern part of Nagaur-Ganganagar basin through two bays. The northern embayment extends in NNE direction along the Indo-Pak international border and adjoining the Nagaur basement high towards east. The southern embayment, coinciding with an E-W trending trough, which passes through Gurha, Sri Dungargarh and abuts against N-S trending Sardarshahar fault and swings southward and extends through the areas east of Nokha Mondri, west of



Merta, near Matasukh and further south through the areas around Mugdasar, Phalki, Phalka and up to Jaitaran. The absence of Tertiary rocks and near surface occurrence of rocks of Marwar Supergroup at many places along the embayment is due to later tectonic activity.

### Quaternary

The Quaternary sediments in Rajasthan are assorted deposits of aeolian, fluvial and lacustrine origin. They occur mostly in a large tract in western Rajasthan known as Thar Desert. The desert (area more than 2 lakh sq km) is delineated towards east by the NE-SW trending Aravalli Hills, towards north by the flood plains of the Ghaggar and Sutlej Rivers and in the south-west the Great Rann of Kachchh limits its further expansion. In the west comes the international India-Pakistan border, beyond which, the desert overlaps the older flood plains of the Indus River. Average elevation of the desert terrain varies from 150m to 300m MSL barring a few isolated hills rising 500 m above sea level. Outside the Thar Desert, the Quaternary sediments also occur in various fluvial basins.

The early Quaternary fluvial sediments in Thar Desert, found only at sub-surface levels, are deposited by organized drainage networks comprising major rivers of Himalayan origin (palaeo-Ghaggar-Saraswati) which were further strengthened by tributaries originating from Aravalli Uplands. These fluvial sediments were deposited initially, under high energy environment represented by polymictic conglomerates at the base, followed by repeated fining upward cycles of fluvial sediments interrupted by aeolian sediments and palaeosols. Successive onset of aridity resulted in the development of sag ponds mostly along the earlier fluvial channels and was also instrumental in subsidence of the fluvial topography and infilling by aeolian sediments.

The repeated phenomena of sand mobilization and accumulation under aeolian episodes with intermittent phases of dune stabilization were restricted to particular late Quaternary periods (Singhvi A.K. and Kar Amal, 2004). They were 200 Ka, 100-115 Ka, 75 Ka, 55 Ka and 25-30 Ka in late Pleistocene periods and 7-14 Ka, 3.5-5 Ka and 0.8-2 Ka in Holocene periods. Dune building activities had resulted in the formation of different dune forms controlled by the then prevalent wind intensity, direction, topography and vegetation. The study of dune

forms, their alignment bespeaks the control of SW monsoon wind in sand mobilization and accretion (Kar, 2004).

The onset of fluvial phase during the Holocene climatic optimum (6-7 Ka) had failed to develop drainage network in the heart of the Thar Desert, but nonetheless, the fluvial phase was responsible for the deposition of sediments along the Thar Desert fringe areas in the localized basins (graben like structures) within rocky uplands and also in areas of southern and south-eastern Rajasthan. They are Kantli-Ghaggar basin, Luni basin, Shergarh-Thob, Pokaran-Lawan, Kharotar-Kishangarh, Jaipur-Shapura areas, Banas and Chambal basins. The ubiquitous occurrences of older alluvium in the vast flood plain areas of these basins represent this second fluvial phase. The fluvial phase in Kantli-Ghaggar basin is represented by yellowish green, coarse to medium grained sand and sandy clay occurring below the calcrete/gypcrete pans. Similarly, the fluvial sediments are also occurring at the basal part of the Sambhar Lake.

During the third fluvial phase in Rajasthan, the earlier channel networks in localized basins were rejuvenated resulting deposition of younger alluvium along the river beds, banks etc. Successive remobilization of older stable dunes may be attributed to biotic interference.

Notable occurrences of minor minerals, construction materials within Quaternary deposits of Thar Desert are: fine to coarse fluvial sediments (Bajri), calcrete, gypsum and salts. Coarser fluvial sediments of grit, granule size admixed with finer fractions are used as construction material. Calcrete is used for road construction and also for lime washing village dwellings. Gypsum occurs at shallow depth, as cappings over Quaternary fluvial deposits spread over large areas in Barmer, Bikaner, Sri Ganganagar, Hanumangarh, Jaisalmer, Jalore and Nagaur districts of Rajasthan. Depending on the calcium sulphate content ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  %), gypsum is classified under four grades, namely, i) above 90%, ii) 85-90%, iii) 80-85% and iv) less than 80%. High grade gypsum including selenite (crystalline variety) are sent to cement plants and also to units making plaster of Paris. Low grade gypsum is used for reclaiming alkaline soil. Different types of salts are extracted from saline lakes, particularly from Sambhar, Didwana and Pachpadra, etc.

The regional strike of foliation in the BGC/Bhilwara and the Delhi Supergroups of rocks is dominantly NNE-SSW to NE-SW, while it is N-S and NW-SE in the Aravallis.

Large scale reworking on account of polymetamorphism and migmatization (partial melting) has greatly obliterated the sedimentary and volcanic characters of the BGC. In addition, multiphase granitic activity and tectonic dislocations in the form of ductile and brittle shear zones trampled any semblance of stratigraphic order amongst the lithological units. Besides, heterogeneous deformation patterns in this vast expanse of BGC, a feature characteristic of large gneissic massifs, resulted in progressive deformation and deformation partitioning. Such heterogeneous deformation patterns have greatly impaired structural correlations of sampled areas, worked out by different workers, to a large extent. Most of the structural works are restricted to the western fringe of the BGC in the greenstone - granulite terrain because of higher density of outcrop population and metacratonic character of the terrain on account of its proximity to the Proterozoic Delhi - Aravalli Fold Belts.

The BGC terrain exhibits multiple deformation phases and superimposed folding. The BGC bears imprints of at least three phases of folding and associated shearing (Naha, 1983; Srivastava *et al.* 1995). In some sectors/areas, four phases of folding/deformations have been reported. Structural features and deformational history of the BGC often resemble with those in the Proterozoic cover sequences in the metacratonic parts. At places, however, an early folding episode (isoclinal) and related planar and linear structures have been recorded in the BGC, which might represent deformational fabrics developed during the Archaean time. The regional foliation/schistosity is generally a transposed schistosity and appears as a composite foliation. The folds of the second phase are

isoclinal at many places. These folds are, in general, inclined to recline and are associated with axial plane crenulation cleavages, which in some sectors, have been transformed into schistosity in favorable rock types. The third phase of deformation has resulted in NNE-SSW trending folds with axial plane crenulation cleavages. The folds of the earlier phases and the planar and linear structures related to them are deformed by open cross folds of fourth and last phase of folding. These open folds and associated spaced cleavages are least pervasive. The regional amphibolite facies metamorphism and migmatization in the BGC is broadly coeval with the first phase of folding and deformation. Recrystallization is comparatively less intense during the second phase of folding whereas it is negligible during the latter phases of folding and deformation. In addition to the folding, the BGC terrain has been affected by multiple episodes of ductile and brittle shearing. As a result, occurrence of sheared-mylonitised rocks is a common feature in the BGC. In the BGC terrain, the rocks have undergone polymetamorphism, a feature recognized as characteristic of the BGC rocks (Sharma, 1983; Sinha Roy *et al.* 1993; Gupta, 2004). This is in sharp contrast to the Aravalli and Delhi Supergroup of rocks. Sharma (op. cit.) supposed that the BGC metasediments and metavolcanics have witnessed an orogeny prior to Delhi-Aravalli sedimentation. Sharma (op. cit.) and Gupta and Rai Chowdhuri (1996) also considered that the variation in the geochronological data vis-à-vis the temporal relationship between the structures and metamorphism is due to the progressive deformation and partitioning in the BGC rocks and is being explained as due to difference in tectonic levels of exposure at different places (Sharma op. cit.).

The structure of the Aravalli rocks was interpreted by Heron (1953) as controlled by upright folds on a NNE to NE trend. The Aravallis have undergone

polyphase deformation resulting in complex fold interference pattern. It has been demonstrated that the Aravalli Supergroup has been deformed by four generations of folding. Out of these four generations, three fold generations ( $F_1$  to  $F_3$ ) represent the major ones, which have affected the Aravalli rocks extending from Nathdwara in the north to Banswara in the south. In addition, Aravalli rocks also bear the imprints of a set of flat lying folds and crenulations and kinks at places. For the greater part of Aravalli Supergroup, the axial planes of the  $F_1$  and  $F_2$  folds are parallel or suparallel indicating their co-planar geometry.  $F_1$  and  $F_2$  folds are nearly co-axial and rarely Type 2 interference pattern (mirror image type) is observed, such as at Salumbar (Naha *et al.* 1988). Occasionally, the superposed folds have eyed geometry (Mukhopadhyay and Sengupta, 1979; Roy and Bejarniya, 1990). The second deformational structures indeed control the map pattern of the Aravalli-Fold Belt. Shallow dome and basin structures are formed by the interference of  $F_2$  and  $F_3$  folds.

Roy and Nagori (1990) have suggested that much of the diversity in the structural pattern of the Aravallis is caused by shearing and heterogeneous reaction of the basement (BGC) and cover sequence (Aravallis) to the deforming forces.

The first deformational episode also produced a number of ductile shear zones. These shear zones are marked by razor-sharp contacts, displacement, truncation and asymmetric repetition of lithounits (Bhattacharya and Nagrajan, 1994), intense mylonitization (Paliwal, 1988) and development of S-C fabric and stretching lineation. Though some of these shear zones record strike-slip transposition, most of them are low angle reverse faults and indicate east to southeast direction of transportation. A prominent set of shear planes on regional scale developed during the second deformation event; their stretching lineation plunges at a low angle towards north suggesting a largely strike-slip movement. These shear planes can be recognized even in satellite imageries and aerial photographs accentuated by geomorphic features. The shear planes related to third deformation are widespread in space but regional in extent. Generally, the shear planes strike NE-SW and NW-SE with steep dip and overprint the earlier structures.

Mention may be made about the zone of parallel faults bounding isolated bodies of serpentinite. This fault zone is known as Rakhabdev Lineament which

represents a much younger deformation episode in the area (Barkatiya and Gupta, 1983). The Rakhabdev and Kaliguman lineaments, according to Sinha Roy (1998), represent zones of obduction of ophiolitic mélangé within the Jharol turbidite sequence related to ensialic rifting and Aravalli trough opening which closed at Ca. 1.5 Ga.

Multiphase ductile shearing over the basement-cover interface between the BGC and the Aravalli rocks led to tectonic imbrication, e.g. near Delwara, in the Ora-Salumbar section and in the Dungarpur-Panuda section. Tectonic imbrication has caused interleaving of basement gneiss and cover sediments, close to the basement-cover interface.

The rocks of the Delhi Supergroup in the Alwar-Jaipur and Lalsot-Bayana basins exhibit folds of similar type and orientation. The regional folds are asymmetric, doubly plunging and show NE-SW striking axial planes. These doubly plunging folds have resulted in axial culminations and depressions. The earliest deformation has produced isoclines with NNE-SSW striking axial planes. Superposed on these first folds are sets of second generation folds, which are isoclinal, tight to open and have steep or vertical axial planes. These folds of the second generation control the map pattern. Folds of third generation are represented by cross folds producing culminations and depressions.

In the Khetri Fold Belt, Dasgupta (1968) recognized a number of longitudinal anticlines and synclines some of which show culminations and depressions. Gupta *et al.* (1998) have recognized two main phases of folding in the Proterozoic rocks in both the North Khetri and South Khetri Fold Belts. In the North Khetri Fold Belt, the earlier phase has produced isoclinal to tight folds with axes plunging gently towards SSE to SE with occasional reversal to NNW to NW. The later phase has produced upright to steeply inclined, close to open folds plunging gently towards SSW with occasional plunge reversal. In the South Khetri Belts, a series of steeply inclined antiforms and synforms plunging at a low to moderate angle towards NE or NNE and showing a dextral pattern belongs to the first phase. Due to the effects of ductile shearing, plunge and tightness of these folds increase as the shear zones are approached. During the second stage of deformation, open to close, upright folds have been produced showing moderate plunge towards NNE. These folds are associated with brittle shears, which run sub-parallel to their axial planes.

In the South Delhi Fold Belt, it has been opined by Gupta *et al.* (1991, 1995), Gupta and Bose (2000), Gupta (2004) and Mukhopadhyay and Bhattacharaya (2000) that SDFB is an ensemble of different tectono-stratigraphic units delimited by movement zones. These represent broadly coeval sub-basins, which were telescoped together during deformation. The dominant fold system throughout the belt has north-northwesterly striking axial planes and the plunge is in general low in the eastern segment but with gentle culminations and depressions; in the western segment the plunge is more variable. Multiple fold sets are present in both the segments.

Gupta *et al.* (1995), Gupta and Bose (2000) have recognized four phases of folding and associated shearing in the rocks of the Basantgarh, Barotiya, Sendra and Rajgarh Groups. The second and the third generation folds control the map pattern. In the Bhim Group, which lacks the earliest fold structure of Basantgarh, Barotiya, Sendra and Rajgarh Groups, the regional structure is an overturned  $F_1$  synform which shows a sinuous outcrop pattern on account of superpositions of macroscopic dextral  $F_2$  folds.

The Hindoli rocks are deformed in a series of ENE-WSW trending antiforms and synforms of isoclinal nature belonging to second phase of folding. Three phases of folding in the Jahazpur Group are correlatable across the folded unconformity with the last three phases of folding in the Hindolis; the earliest phase of folding in the Hindolis being absent in the Jahazpur Group. Though the first and second phases in the Hindolis are co-axial, the interference between the second and the third phases in the Hindolis produced crescent shaped Type-2 interference pattern of Ramsay (1967). This is in contrast to the co-axial pattern of deformation noted in the Delhis and the Aravallis. Metamorphism in the Hindoli Group has reached upto garnet-staurolite grade (middle amphibolite facies). The developments of andalusite and anthophyllite are ascribed to the thermal event associated with subterranean granite plutonism.

The rocks of the Vindhyan Supergroup are very little disturbed and have gentle dips towards south and

south-southeast. The basement rocks beyond Chittorgarh in the west, Bundi-Indargarh in the northwest, and Shivpuri in the east acted as rigid block. The Ramgarh Dome acted as a centre from which the stresses were centrifugally radiated, resulting in the formation of Bundi-Indargarh and Phalodi anticlines in the northwest; causing a series of anticlines and synclines in Sawai Madhopur, Sapotra and Karauli areas in the north-northwest; generating open rolls in Shabad area in the east; forming Jhalawar anticline in the southeast and developing a series of anticlines and synclines in Chittorgarh in the west. The rejuvenation of adjoining Aravalli Delhi mobile fold-belt in the west resulted in the Great Boundary Fault (GBF) which trends roughly NE-SW for a distance of 400 km between Chittorgarh and Agra. It started as a gravity-fault along which gradual sinking of the basin floor took place. The present reverse geometry with low-angle thrusting has brought the older basement rocks in juxtaposition with the Vindhyan sequence. The GBF is not a single plane of disruption but it evolved in stages and represented a 10-20 km wide zone (Balmiki Prasad, 1984) comprising a number of parallel and oblique faults showing horst and graben features. Recent studies along the corridor of GBF carried out in Sawai Madhopur and Chittorgarh sectors suggest that it is not a marginal basin fault, but formed during syn to post deformation  $F_1$  folds. The rocks under Marwar Supergroup of western Rajasthan are practically undisturbed except for the presence of north plunging main basinal synclinal axes trending N-S to NNW-SSE from Sojat to Bilara and Nagaur.

The Malanis were emplaced dominantly as fissure eruptions and accompanying sheet like intrusions along NW-SE and N-S faults and fissures of post-Delhi age.

The rocks of the Mesozoic and Tertiary Era in the western Rajasthan are undeformed and constitute very low-dipping strata marked, at places, by gravity faults. The area being mostly covered by desert sand, the subsurface anomalies/discontinuities, revealed by geophysical and geological exploration by GSI, ONGC and other State agencies, indicate presence of a number of faults which have shaped the present disposition of the various lithounits in the area.

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There is an established relationship between magmatism and orogenesis in the Earth's history. Each orogenic cycle has its own characteristic magmatic event also. In the geological record of Rajasthan, the following main magmatic events are recorded.

## MAGMATISM IN BGC PROVINCE

### Extrusives

In the south Mewar Plain, Bose *et al.* (1996) identified the following components in the BGC: (1) Tonalite gneiss and banded bimodal gneiss (3.3 Ga, Gopalan *et al.* 1990), (2) Enclave suite of igneous viz. mafic, ultramafic and felsic (~2.83 Ga, Gopalan *et al.* op. cit.) and sedimentary protoliths forming greenstone-type sequences lodged as dismembered units in succeeding granites and migmatites, and (3) Granites and related migmatites of Gingla and coeval rocks (2.8 to 2.9 Ga; Choudhary *et al.* 1984). The tonalite gneiss and the bimodal gneiss are assigned the oldest status on the ground, that there is no reported presence of rock formations of the enclave suite (No.2) in these gneisses except the mafics which are apparently its protoliths (Bose *et al.* op. cit.). The banded bimodal gneiss and tonalite gneiss are exposed near Rajsamand (near Kankroli) in the central Rajasthan and occur as dismembered units in the latter granites and migmatites in the area south-southeast of Udaipur respectively. The banded bimodal gneiss is conspicuous by intercalations of two distinct modal units, basic and felsic and is considered to represent metamorphosed bimodal volcanic suite. Dark coloured layers rich in ferromagnesian minerals alternating with light coloured quartz-feldspar layers have imparted the banded character to the gneisses.

The granite-greenstone sequences are generally intensely metamorphosed in the amphibolite facies and extensively granitized or migmatized in the southern and central Rajasthan. In central Rajasthan, the

greenstone sequences are divided into two stratigraphic groups (Mohanty and Guha, op. cit.): the older Sawadri Group and the younger Tanwan Group. The ultramafic rocks in the greenstone sequences are mainly represented by serpentinite, hornblendite, dunite, meta-peridotites, chlorite schist and talc-tremolite schist. Macro-spinifex texture is reported (Bhattacharya and Guha, 1988) from the ultramafic rocks where the mesostasis between the randomly oriented actinolite prisms (altered olivine?) is filled with glass. Spinifex texture is also identified in the ultramafics southeast of Udaipur (Bose *et al.* 1996). The basic volcanics represented by amphibolites contain vesicles, filled mainly with epidote and quartz, and rarely with calcite, and show sub-ophitic texture. The felsic volcanics occur as quartzo-feldspathic rocks and are conspicuous by the ubiquitous presence of pyrite in pockets and fractures.

The unaltered amphibolite samples contain 44.57 to 59.62% SiO₂ and, in the silica-alkali diagram, the majority plot in the subalkali basalt field, some in the andesite and the rest in the hawaiite field. Most of the samples contain less than 10% MgO and the rest contain 10.40 to 15% MgO. They are mostly olivine normative or are hypersthene and quartz normative. Chemical discriminants suggest them to be tholeiitic basalt. In FeO-MgO-Al₂O₃ variation diagram (Pearce *et al.* 1977), the amphibolites plot in ocean island field and close to the boundary of continental field. A few samples of amphibolites from the area near Nathdwara (Gopalan *et al.* 1990), which is the southern extension of the Sawadri Group, have low TiO₂ and relatively high silica, alumina, MgO, Ni and Cr contents. They are thus similar to basaltic andesites in many respects. The rare earth pattern suggests their derivation from basaltic parentage. The negative Eu anomaly is possibly a reflection of original source character. In the discriminant TiO₂-MnO-P₂O₅ diagram, the amphibolites plot in the transition zone of the IAT (Island Arc

Tholeiite) and CAB (Continental Alkaline Basalt) fields.

It has been observed that the older amphibolite (basic volcanics) occurring as restite in the gneisses of the Archaean crystallines have komatitic affinity. The granite gneisses show flat REE pattern and negative Sr and Eu anomalies similar to those of low alumina Archaean granites constituting a mature continental nucleus.

The Hindoli Group comprising an assemblage of mafic and felsic volcanics, altered tuffs with or without lapillis, forming in a repetitive sequence and interbanded with quartz arenite and chert, extends over a strike length of 30 km occupying low ridges from Kachola (25° 24' : 75° 07') in the southwest to Baripriyap (25° 46' : 75° 52') in the northeast; the thickness varies from 250 to 500m, the maximum being in the north of Ronija village (25° 42' : 75° 40'). At places, the volcanics are vesicular with infillings of quartz, calcite and pyrites. Presence of graded bedding and flute clasts in tuffaceous bands are indicative of its subaqueous condition of deposition.

The mafic volcanics, which are of basaltic andesite composition, include laths and rosettes of plagioclase ( $Ab_{60}-Ab_{70}$ ), clinopyroxene, quartz, glass, K-feldspar, actinolite and zoisite. Ranging in composition from dacite to rhyodacite, the felsic volcanics contain long prismatic grains of sanidine and resorbed quartz embedded in an altered glassy groundmass. The glass is altered to quartz, sericite, chlorite etc. Flow bands swirl around the phenocrysts. Often lithic fragments, mostly of quartz, are aligned parallel to the flow bands. The fine to very fine-grained tuff contains glass fragments, plagioclase and ellipsoidal clasts of polycrystalline quartz, chlorite and a few grains of altered pyroxene. Sericite needles, likely to be an alteration product of glass, define the flow banding. The lapilli-bearing tuffs contain accretionary and armoured lapillis. The former types, 0.5 to 2 mm in diameter, are ellipsoidal or pancake-shaped, and are made up of altered glass. In the armoured lapillis, the kernels of the lithic fragments are rimmed by glass. These are of 2 to 10 mm in diameter.

Bose and Sharma (op. cit.), on the basis of the  $SiO_2$  content and differentiation index (D.I.), categorized the volcanics into (1) basalts of 47-51.6 wt %  $SiO_2$  range with 20-32 D.I. values, (2) Basaltic andesites of 53.68-55.53 wt %  $SiO_2$  range with 44-46 D.I. values (3) dacites and rhyodacites of 61.2-67.15 wt %  $SiO_2$  range with

57.73 D.I. values. However, the overall  $SiO_2$  ranges of 47-55.53 wt % and 61.2-67.15 wt % ascribe a bimodal character to the Hindoli volcanics. According to Bose and Sharma (1992), high values of normative corundum in the felsic volcanics and the anomalous high values of  $Al_2O_3$  (upto 24%) and  $K_2O$  (6.2%) and low values of CaO and  $Na_2O$  (20.1%) are due to subaqueous chemical weathering.

Discriminant plotting in  $Al_2O_3$  vs. normative plagioclase (Irvine and Baragar, 1971) and FeO vs. FeO/MgO diagrams (Miyashiro, 1974) suggests tholeiitic nature to the mafic volcanics, which are largely quartz-normative with a few having olivine in the norm. A generally easterly increase in the content of  $SiO_2$ , alkalis and  $TiO_2$  suggest a more differentiated nature of the volcanics in the eastern part. MgO content varies erratically and is ascribed to crustal contamination of the ascending magma. In the  $TiO_2$  vs. FeO/MgO (Glassley, 1974) and Ni vs. FeO/MgO (Miyashiro, 1974) tectonic discriminant diagrams, the samples plot in the Island Arc Tholeiite (IAT) field or island arc and continental margin field respectively, the samples with very high FeO/MgO ratio being exceptions.

### Intrusives

During the tectonism in the BGC in Archaean period, a number of granite, granodiorite and tonalite plutons were emplaced. The granite bodies occurring at Untala, Gingla, Berach etc. represent such distinct granite plutons of Archaean age. Besides these Archaean granites, a number of granite bodies of younger age have been recorded viz. Anjana Granite, Gyangarh-Asind Charnockite-Enderbite, Banagarh Granite, Patan Granite, Jahazpur Granite, Garwar Granite, Dedulia Granite, Daulatgarh Granite, Ojagarh Granite, etc. Apart from the granites, the BGC terrain is also characterized by intrusives of carbonatites, acid granulites and mafic rocks belonging to different ages. In the following paragraphs, some of these major intrusives are described.

### Untala and Gingla Granites

The Untala Granite is a lensoid body, which is about 30 km long and 10 km wide. It occurs between Wani in the north and Arinda in the south and is well exposed near Untala (renamed as Vallabh Nagar) located 6 km north of Bhatewar on Udaipur-Chittaurgarh Highway, 35 km from Udaipur city. The granite shows a composite nature and consists of grey diorite-tonalite-trondhjemite gneiss and late pink/grey granite (Chattopadhyay *et al.*

1987). The gneiss is medium to coarse grained, foliated and composed of quartz, plagioclase, K-feldspar and biotite with minor/accessory chlorite, sericite, muscovite, sphene, zircon, apatite, epidote, zoisite and opaques. It shows hypidiomorphic granular texture, whereas at places, it is gneissic. The K-feldspar is represented by microcline or string-type perthite and orthoclase. The plagioclase shows lamellar twinning and is of oligoclase-andesine in composition. The late granite is medium grained, composed of quartz, plagioclase and K-feldspar with minor accessory biotite, muscovite, apatite, carbonates, sphene and opaques. It exhibits hypidiomorphic granular texture. The gneiss has low Rb and high Sr and low K/Rb ratio compared to late granite.

Crawford (1970) reported a Rb/Sr whole rock, muscovite and biotite isochron for the Untala Granite corresponding to an age of  $955 \pm 50$  Ma and an initial ratio  $^{87}\text{Sr}/^{86}\text{Sr}$  of  $0.7094 \pm 37$ . Choudhary *et al.* (1984) on the basis of whole rock Rb/Sr isochron of nine samples of Untala Granite, suggested the age to be  $2920 \pm 100$  Ma. Gopalan (1986) suggested that there was an isotopic equilibrium around 900 Ma. According to Chattopadhyay *et al.* (1987), the grey gneiss represents the early Archaean tonalite-trondjemite crust, i.e. the orthogenetic nuclei; and the younger phase has probably intruded around 2300 Ma and is correlatable with the Berach Granite (dated  $2445 \pm 100$  Ma; Choudhary, 1984). Roy and Kroner (1996) obtained an age of  $2866 \pm 6$  Ma for trondjemite gneiss, while Wiedenberk *et al.* (1996) obtained an age of  $2025 \pm 5$  Ma for the pink granite.

The Gingla Granite occurs around Jai Samand Lake (Dhebar Lake), which falls nearly 100 km southwest of Udaipur city. The Gingla Granite shows migmatitic and granitic components. The migmatite and granite components show gradational relationship. The leucosome in the migmatite consists of quartz and plagioclase with subordinate K-feldspar. Quartz, biotite, plagioclase and hornblende with accessory zircon, apatite and sphene constitute the melanosome. The component of granite in the Gingla body is mostly massive, hypidiomorphic granular. It shows phenocrysts of quartz and plagioclase set in a groundmass composed of quartz, plagioclase, biotite and hornblende with apatite, sphene and rutile as accessories. Bose *et al.* (1996) opined that the Gingla Granite is chemically comparable with orogenic granites.

### Gyangarh-Asind Charnockite-Enderbite

The  $1723 \pm 14/-7$  Ma (Sarkar *et al.* 1989) old enderbite-charnockite forms a major pluton in the Sandmata area. Besides, it occurs in the Bhinai area and as centimeter to metrescale bands in leptynite in the Sandmata area. Enderbite and Charnockite are intermingled with each other. Massive Enderbite-Charnockite forms the major part of the pluton. At places, banded granodiorite is present as thin to thick bands within the pluton. A breakdown of charnockite to granodiorite is noted across the diffused and graded boundary and is amply demonstrated from the omnipresence of relict enderbite-charnockite within granodiorite. Enderbite is rarely foliated, and in the massive part, occasionally oriented prisms of pyroxene and feldspar define primary foliation of the igneous mass. Granodiorite is well banded and foliated, but its boundary with enderbite-charnockite part is not always parallel to the banding in granodiorite. The enderbite-charnockite contains quartz, plagioclase, K-feldspar, hypersthene, diopside, biotite garnet and hornblende. Apatite and tourmaline occur as accessories. The contact of enderbite-charnockite with different lithologies is marked by high strain zones. Still intrusive relationship is preserved at several places. The field relationship has established that the enderbite-charnockite body has intruded the garnet-sillimanite gneiss as sheet-like body in the Sandmata area (Gupta and Rai Chowdhuri, 2002).

### Raipur-Jalayan mafic rocks

Swarms of ortho-amphibolite, gabbro and norite with associated pyroxene-granulite intruding the rocks of the Sandmata Complex, and occurring in Akeran-Shokla Jalayan-Jodhpur, Karelia-Raipur-Rajgarh areas for over 136 km distance have been included in this suite.

In the Gyangarh, Rajgarh and Bhinai areas where these are associated with acid suite of rocks, they appear to be intimately related by virtue of common parentage. They have been grouped in the Sandmata Complex considering their relation with the syn to late tectonic activity (Gupta *et al.* 1980, 1999).

### Berach Granite and Gneiss

The Late Archaean Berach Granite and Gneiss ( $2585$  Ma, Crawford, 1970;  $2445 \pm 100$  Ma, Chaudhary *et al.* 1984), which has been referred as "Chittor Gneiss" by Crawford (1970), "Bundelkhand Gneiss" by Heron (1936) and Gupta (1934) and "Berach Granite" by



Pascoe (1968, 1973) and occurring from east of Pirana in the south to northeast of Kanti in the north, over a distance of 140 km with a maximum width of about 25 km in the middle, constitute the main outcrop of the Berach Granite and Gneiss. There are five more occurrences of these rocks in Achalpur-Nikum (22 km x 0.6 km); Bhaunja-Rajpura (10 km x 0.6 km); Chainpura-Karju (7 km x 0.4 km); west of Satola (0.6 km x 0.2 km) and Dholpuni-Nalwa (17 km x 9 km) areas. The best exposures of the Berach Granite are seen along the course of the Berach River.

Heron (1936) and Gupta (1934) correlated the Berach Granite with the BGC. The prevailing opinions regarding the contact relationship between the Berach Granite and the Hindoli Group (Gwalior Series of Heron, 1917) is somewhat divided. Heron (op. cit.), Gupta (1934), Sharma and Roy (1986) considered Berach Granite as forming the basement for the Hindoli Volcano-sediments. On the other hand, according to Balmiki Prasad (1987), the Berach Granite is a late tectonic, mesozonal emplacement into the adjoining meta-pelitic and associated semi-pelitic rocks of the BGC. Balmiki Prasad (op. cit.) has also identified syntectonic granite, named as Pipla-Jolar Granite, within the crescent-shaped outcrop, intruded during the regional metamorphism of the BGC rocks. Raja Rao (1967, 1970), Gupta *et al.* (1980), Sinha Roy (1985) and Sinha Roy and Malhotra (1989) also considered Hindoli Group as of Archaean age being intruded by the Berach Granite.

The western part of the granite in the main occurrence is gneissic. It is generally pink, non-foliated, medium-grained, and consists of opalescent quartz, potash feldspar, plagioclase and chlorite, exhibiting hypidiomorphic texture in thin sections. Berach Granite from north of Chittorgarh has been dated 2,585 Ma by Crawford (1970). It is now widely accepted that the Berach Granite represents the terminal stage of magmatic activity of the Archaean orogeny in the Late Archaean period. Sinha Roy (1985) opined that the Berach Granite belongs to the climactic phase of the processes of development of granite-greenstone sequence during the end of Archaean cratonisation event.

Balmiki Prasad (op. cit.) noted a compositional variation across the granite body, in which pink-coloured, non-foliated, medium-grained granite in the eastern part grades into gneissic granite towards the west. However, no such gradations are noted by Sharma

*et al.* (op. cit.) and instead have recognized two granite phases. The older foliated granodiorite is hypidiomorphic granular, medium to coarse grained and contains quartz (generally 15 to 20%), orthoclase (less than 10%), microcline, plagioclase ( $An_{50}-An_{60}$ , 37 to 60%), biotite, muscovite and occasionally hornblende as main mineral modes. Sphene, apatite, magnetite, zircon and epidote occur as accessories. On the quartz-alkali feldspar-plagioclase diagram, the samples plot in the granodiorite, tonalite and sometimes quartz-monzogranodiorite field.

The younger phase of the Berach Granite is *sensu stricto*, granitic in composition and occurs mostly on the eastern part of the massif. The younger phase is more alkali feldspar rich, medium to coarse grained, hypidiomorphic granular. Quartz (20-25%), K-feldspar (20-40%), plagioclase ( $An_{20}-An_{30}$ ) and biotite are the chief constituents, while sphene and apatite are the accessories.

### Jahazpur Granite

The Jahazpur Granite occurs between north of Tola and north of Umat over a length of about 22 km with width of about 3 km. The Jahazpur Granite is a composite granitoid body composed of older grey granite and younger pink granite. Quartz, soda feldspar and biotite together with varying amount of potash feldspar constitute the grey granite phase which has a distinct gneissic foliation. Hornblende, actinolite and opaque minerals along with zircon and apatite form the accessory constituents. The composition is close to tonalite with plagioclase dominating over quartz. The younger pink granite, intrusive into the grey granite, is mineralogically of alkali granite composition and includes quartz, perthite and orthoclase, and minor biotite, apatite and opaques. The rock shows hypidiomorphic granular texture. According to Gupta *et al.* (1980, 1997), the Jahazpur Granite is intrusive into the rocks of the Umar Formation of the Jahazpur Group. However, Sinha Roy (1984, 1985) considered the Jahazpur Granite as forming the basement over which the Jahazpur Group of rocks was deposited. Malhotra and Pandit (2000) correlated the pink granite phase of the Jahazpur Granite with the Berach Granite (~2.6 Ga).

### Kishangarh Syenite

A unique occurrence of an interesting suite of nepheline syenite bearing alkaline suite, without any counterpart in the east of the Aravalli mountain range, is



recorded in the area around Kishangarh-Patan-Harmara, ENE of Ajmer, close to the ductile shear zone marking the boundary of the BGC with the Delhi Supergroup of the South Delhi Fold Belt. The syenite suite consists of one large intrusion and seven small sill-like bodies. Kurien (1951) considered it post-Aravalli intrusive. Basu (1961) considered the Kishangarh syenites as post-Delhi intrusives. The syenite at Harmara consists of nepheline, K-feldspar, plagioclase and hornblende with a little sphene and apatite. The outcrops of syenite occurring north and south of Ajmer-Jaipur road show a central, massive body passing through banded-type to foliated variety near the margin of the body. The isolated hill, northwest of Tilonia, is made up of syenite consisting of garnet, biotite and hornblende in addition to other essential minerals. Near Mandoria, the rock suite also includes theralite and comptonite (Basu, op. cit.). The theralite occurs as xenoliths within the nepheline syenite whereas the comptonite occurs as dykes in the nepheline syenites. Theralite is composed of clinopyroxene, amphibole, biotite, K-feldspar, plagioclase and nepheline. Sphene occurs as accessory. The principal clinopyroxene is titaniferous augite.

The alkaline rocks at Kishangarh are generally associated with gabbro (Niyogi, 1965). In general, the syenites contain equal proportions of nepheline and plagioclase (andesine) with subordinate amount of magnesian amphibole (magnesio-riebeckite), biotite and sodic pyroxene. Niyogi (op. cit.) opined that syn to late tectonic alkali metasomatism of gabbro has generated the syenites of Kishangarh area.

Roy and Dutt (op. cit.) interpreted the nepheline syenite body as diapirically emplaced katazonal pluton. The emplacement presumably took place during the opening of the Delhi rift-basins in the west.

Crawford (1970) has given a three-point Rb/Sr isochrone age of nepheline syenite at  $1490 \pm 15$  Ma, which is correlatable with the metamorphism of the nepheline syenite. The model age of 1910 Ma (Roy and Dutt, 1995) of single sample of nepheline syenite was interpreted as the emplacement of the nepheline syenite pluton (Roy and Dutt, op. cit.).

#### **Newania Carbonatite**

A large elliptical body of carbonatite (3 km in length and 50 m to 1.2 km width) along with a number of carbonate dykes and veins within Untala Granite occurs 1 km northeast of Newania, Udaipur district. It is light-

grey, medium to coarse-grained and consist predominately of calcite and biotite with minor tremolite and actinolite. It varies in composition and is represented by rauhaugite, beforeite, minor sovite and lapilli carbonatite. Distinct zone of fenitisation has developed around the pluton. Chattopadhyay *et al.* (1988) considered it as a funnel shaped intrusion along E-W axial traces of low-plunging folds.

According to Golani and Pandit (1999), the ankeritic (1551 Ma Pb/Pb age; Schleicher *et al.* 1997) and veins of calcite carbonatites are hydrothermally emplaced into the magnesian carbonatite (2.27 Ga age: Schleicher *et al.* 1997) variety in an epithermal environment. These radiometric ages are in contradiction to the earlier determined age of  $959 \pm 24$  Ma (Deans and Powell, 1968).

Rock similar to the carbonatite (5x2 m to 10x5 m) also occur 0.8 km west and 1.2 km N 35° W of Vallabhnagar railway station amidst the Untala Granite. It is dark-brown in colour, fine to medium-grained, laminated and consists of calcite, apatite, phlogopite and biotite with minor amounts of hornblende, muscovite, limonite, goethite and haematite.

#### **Dolerites and Ultramafics**

Dolerities occurring at several places as sills within the Bhadesar Formation and as dykes in the Hindoli Group of rocks are referred to as Hindoli Dolerites. These are melanocratic, medium-grained rocks. Xenoliths of these dolerites are reported from the Berach Granite and Gneiss.

Altered ultramafic intrusives occur as talc-chlorite schist in an isolated thin zone between northeast of Pipalkhunt and northwest of Jolar for over 28 km within the Manglwar Complex, besides small isolated outcrops near Barana, Nawalia within the Sand Mata Complex.

Dark-green, medium-grained, jointed dolerites exposed around Bari Sadri, Hora and Mandalgarh are younger than the Hindoli dolerites and occur as sills and dykes intruding the rocks of Ranthambhor Group. The stratigraphic position of these dolerites is uncertain.

### **MAGMATISM IN ARAVALLI-DELHI PROVINCE**

#### **Aravalli - Fold Belt**

The Aravalli - Fold Belt witnessed three main events of magmatism. These were an extensive syn-sedimental basic volcanism named as Delwara-

Siri Volcanics, emplacement of Rakhabdev Ultramafic Suite of rocks and emplacement/intrusion of Darwal, Udaipur (Ahar River), Titri, Udaisagar and Salumber granites.

### Extrusives

#### *Delwar-Siri Volcanics*

These comprise a thick pile of synsedimentary basic meta-volcanic flows of varying thickness with 1 m to 100 m thick inter-trappean beds of quartzite and ferruginous cherts. The volcanics are exposed from Untrol in the north to south of Phalet over a tract of 50 km in Debari sector between Umra and Chanda in Jaisamand sector and further south of Jaisamand lake area in the Boraj, Anjani, Gagari, siri, Parsola, Rohina Manik and Waori Khera areas over a distance of 70 km. These rocks have attained greenschist facies of regional metamorphism. The mineralogical assemblages noted are actinolite + plagioclase (oligoclase) + epidote, actinolite + oligoclase + epidote + chlorite + opaque  $\pm$  sphene  $\pm$  rutile, and hornblende + oligoclase + chlorite + biotite + opaques. The rock shows glomeroporphyritic and subophitic textures. Vesicles are filled with secondary cryptocrystalline silica, carbonate and epidote. In the chemical discriminant diagrams, the volcanics plot across basalt, basaltic andesite, andesite and trachyandesite fields, although they are mostly concentrated in the basalt field. According to Gupta *et al.* (1980), spatial distribution of these volcanics at the base of the Aravalli Supergroup (Delwara formation) along a NW-SE linear belt suggests that their eruption was controlled by a deep seated, mantle tapping and fundamental fracture now designated as the Delwara Lineament.

#### **Rakhabdev Ultramafic Suite**

The ultramafic rocks occur in Antaliya-Rakhabdev-Kherwara-Dehlana areas as large, irregular lensoid bodies of more than 5 km length within the Aravalli Supergroup of rocks in three different belts. The first belt extends from Dad in Dungarpur district in the southeast to Sero-ki-Pali in the north over a distance of 77 km, the second from Kanthria to Kaliguman over a distance of 115 km and the third from Kuanthal to Titri over a distance of 15 km. In the Antaliya area the ultramafic bodies are very small, lense or oval shaped.

The rocks are predominantly serpentinite and extensively altered by metamorphism to talc-carbonate rocks, talc and chlorite schists. According to Gupta *et al.* (1980, 1990), these are considered to have intruded

concordantly between the litho-contacts of the Jharol and the Dovda Groups, and the Lunawada Group, before and during the first phase of Aravalli folding. The occurrence of the ultramafic suite of rocks along the Rakhabdev and the Kaliguman Lineaments indicate that these deep-seated fractures might have tapped the mantle source. Patel and Mehr (1967) considered the ultramafics bodies to have been intruded during the terminal phase of the Aravalli sedimentation while Sychanthovang and Desai (1977), Sen (1981), Sinha Roy (1988) regarded these ultramafics bodies to represent obducted oceanic crust. Yet also, the ultramafics suite of rocks are considered 'cold emplacement' along a zone of rifting by Chattopadhyay and Gangopadhyay (1981) or as deeper cumulates of the basal Aravalli meta-volcanics by Srivastava (1988).

### Intrusives

#### *Darwal Granite*

Darwal Granite, emplaced in a fold-closure of Aravalli rocks, occurs over a distance of 32 km from south of Darwal to northeast of Paroli. The width varies from 200 m to over 5 km. It is grey, coarse grained, biotite-rich granite showing hypidiomorphic granular texture in general but gneissic at places. The granite is composed chiefly of quartz, K-feldspar, plagioclase and biotite. Muscovite, chlorite, sphene, calcite and allanite occur as accessories.

The Darwal Granite has been dated at  $1900 \pm 80$  Ma (Choudhary *et al.* 1981) and is considered by Gupta *et al.* (1980, 1997) as Early Proterozoic, syn-kinematically intrusive into the rocks of Aravalli Supergroup.

#### **Udaipur Granite**

The Udaipur Granite (also known as the Ahar River Granite) is exposed in a roughly triangular area northwest of Udaipur and extends from Chota Hawla in the south to Barora in the north and from Madar in the west to Bhilara in the east. It is a medium to coarse grained, pinkish to greenish-grey, porphyritic (occasionally gneissic also) granite which grades into finer aplitic forms along margins. It is composed of quartz, plagioclase-feldspar, muscovite and sericite. Magnetite, pyrite, apatite, zoisite, calcite and epidote are accessories. According to Sahu *et al.* (1991), it is two phase granite, viz. grey granite (tonalite) and pink granite (granodiorite).

The Udaipur Granite has been dated at 2026 Ma (Sarkar *et al.* 1992). Wiedenbeck *et al.* (1996) obtained

2566.2 Ma age of grey granite phase of the Udaipur Granite and interpreted this age to represent the time of crystallization of the granite.

### Titri Granite

Titri Granite occurs in an area over 3.5 km in length from Eklingpura in the north to Phanda in the south and about 1.8 km in width from Titri in the west to Bhola in the east. Although the granite is massive in greater parts, it is foliated near the contact with meta-sediments and has caused feldspathisation. It consists of pink, grey and cream coloured feldspars, translucent quartz, biotite and chlorite.

### Udaisagar and Dakan Granitoids

Udaisagar Granite occurs as isolated outcrops from north of Dakan Kotra to Udaipur and west of Jaisamand. The Udaisagar boss is about 8 km in length with an average width of about 2 km. It is white, aplitic, medium-grained and nonporphyritic granite. In the Udaisagar Granite, two phases have been identified. The pink granite represents the older phase, while the younger phase is represented by a leucocratic aplogranite. The pink granite is composed chiefly of oligoclase, K-feldspar, quartz, biotite and muscovite with sphene, apatite and opaques as accessories. The leucogranite consists of quartz, microcline and plagioclase with minor muscovite, epidote, sericite, apatite and opaques. In some outcrops, the Udaipur Granite is gneissic in nature.

### Salumber Granite

Salumber Granite occurs intermittently between north of Sanjela and east of Balawa over a distance of 70 km. It is in general a leucocratic, medium-grained, non-porphyritic granite comprising translucent quartz, orthoclase, microcline, oligoclase and muscovite, and in some cases biotite or tourmaline.

### North Delhi Fold Belt and South Delhi Fold Belt

Two main phases of magmatism are noted in the North Delhi Fold Belt and South Delhi Fold Belt. The first phase involved syn-sedimentational volcanism and second one relates to the granitic intrusions.

### North Delhi Fold Belt

#### Extrusives

Volcanics within the Raialos have rift-related tholeiitic to alkali olivine basalt affinity with signs of explosive volcanism (Banerjee & Singh, 1977). Gupta

and Sharma (1998) noted evidences of volcanism in the Ajabgarh sequence. The volcanism, which is syn-sedimentary, started with the onset of deposition of the Kushalgarh sediments and continued intermittently throughout the duration of the Ajabgarh sedimentation. Except for the middle Ajabgarh, where it is bimodal, the volcanics are unimodal in character and increase in proportion towards the top.

The chemistry of basic volcanics at Jahaj-Govindpura area in the Bayana sub-basin (Singh, 1985) reveals large variation in  $\text{SiO}_2$ ,  $\text{MgO}$  and  $\text{K}_2\text{O}$ . It is suggested by Singh (op. cit.) that the flows are transitional between tholeiitic and alkali basalts. The basic rocks show a poorly defined differentiation trend. The volcanics resemble high  $\text{K}_2\text{O}$  continental tholeiites. The tholeiites are characterized by enrichment of large ion lithophile elements (LILE) and light rare earth elements (LREE) and depletion of Nb, P and Sr (Raza *et al.* 2001). The values of  $\text{TiO}_2$  (1.06 to 2.31%), Zr (50 to 182 ppm), Ti/Y (286 to 521) and Zr/Y (2.63 to 5.70) are low, which suggest their close similarity with low-Ti continental flood basalts. Raza *et al.* (op. cit.) opined that the Bayana volcanics might have been derived from an enriched mantle source with no significant crustal contamination. It is also interpreted that the parental magma has been derived probably from a sub-continental lithospheric mafic source with Fe/Mg ratio exceeding that of model pyrolite. It is further suggested that the mantle source of these volcanics was enriched through metasomatism by progressive transport of mantle fluids and/or melts from deeper mantle. Olivine and clinopyroxene dominated the fractional crystallization and played a major role in the evolution of magma, following its derivation from shallow mantle source(s) where clinopyroxene occurred as a residual phase.

In the South Khetri Fold Belt, felsic volcanics with agglomerate, tuffs and volcanic breccias are present. Euhedral phenocrysts of plagioclase and quartz with or without orthoclase and muscovite, sometimes imparting a flow texture, are set in a fine grained matrix with glass material, biotite and muscovite. Phenocrysts of plagioclase, orthoclase and quartz show resorbed margins. The fine grained tuff is dark grey, finely laminated and often vesicular. The vesicles are 2 mm to 10 mm in diameter and are filled with soft friable or hard carbonaceous matter. In thin section, the rock is mainly composed of anhedral quartz set in a groundmass of quartz and sericite. The crystal tuff is also dark grey,



hard and porphyritic with 1-2 mm subhedral to euhedral white feldspars and cryptocrystalline quartz set against the dark grey groundmass with iron ore and possible manganese dust. Under the microscope, the rock has a well developed porphyritic texture defined by subhedral to anhedral quartz embedded in the medium grained devitrified groundmass with remnants of glass. Spherulitic texture is rarely seen (Gathania and Golani, 1988). The volcanic agglomerate and breccia are made up of lapilli and bombs of andesitic material, rectangular and squarish in shape, and welded by glassy matter with a biotite-rich groundmass. The volcanics plot in the rhyolite field in the discriminant diagrams.

### **Intrusives**

#### ***Dadikar Granite***

Dadikar Granite is exposed about 5 km northwest of Alwar town in a 4 km long and 2 km wide valley. The granite is leucocratic to mesocratic, medium to coarse grained and is two-feldspar (K-feldspar dominant) porphyroblastitic granite often showing augen texture. The mineral phases include quartz, microcline, plagioclase, biotite and muscovite. Plagioclase content generally increases towards the margin. The accessories include zoisite, apatite and zoned zircon. Two main types of granites have been recorded: (i) pink and foliated granite along the margins of the granite massif and (ii) grey or pink porphyritic type in the central portion (Banerjee, 1980). Apart from the presence of tongues and apophyses of the granite penetrating the Delhi metamorphites, the intrusive nature of the Dadikar Granite is manifested by the bulging of the strata on either side of the massif in the southern part. Occurring in the core of an antiform enveloped by the rocks of the Raialo Group, the relative status of the granite as an intrusive in the Delhis (Joshi, 1970, Gandhopadhyay, 1972) has been questioned by Chakraborti and Gupta (1990) who assigned a basement status to the Dadikar Granite. Crawford (1970) dated the age of one sample of Dadikar Granite to be 2100 Ma by whole rock isochrones. The rock has been also dated 1500-1700 Ma by Sastry (1992).

#### ***Ajitgarh Granite***

It is an intrusive body emplaced in the core of Nayai syncline and is exposed for over 2 sq km area around Ajitgarh village, Sikar district. The emplacement of Ajitgarh Granite in the Alwar-Jaipur basin is said to be syn-kinematic with second phase of deformation (Roy and Das, 1985). The Ajitgarh Granite is a minor

composite granite pluton, which includes a predominant alkali granite (grey and pink varieties), and volumetrically subordinate leucocratic trondhjemitic granite (Pandit and Kataneh, 1998). Both the phases are medium to coarse-grained and show hypidiomorphic texture. The alkali granite has predominant alkali feldspar and quartz, with minor amounts of plagioclase, biotite, hornblende and titanite. The trondjemite granite contains predominantly quartz and plagioclase with minor amounts of alkali feldspar, amphibole and titanite. Zircon and magnetite form the accessory phases in both the granites. High abundance of  $\text{SiO}_2$ , alkalis, high field strength elements (HFSE) and large ion lithophile elements (LILE) and low concentrations of MgO and CaO, high Fe/Mg and Ga/Al ratios (Pandit and Khataneh, 1998) indicate that the Ajitgarh Granite has A-type affinity. In the Ajitgarh Granite, analysis of euhedral zircons (by EPMA studies) from the trondjemite phase yielded  $1.725 \pm 0.013$  Ga age and the zircons from the pink and grey alkali granite yielded closely comparable  $1.719 \pm 0.013$  Ga and  $1.741 \pm 0.015$  Ga ages respectively (Biju Sekhar *et al.* 2002).

#### ***Bairat Granite***

The granite is exposed in a 4 km x 2.5 km area around Bairat village of Alwar district. The Granite has been dated 1500-1700 Ma. Occurring in the core of an antiform, the Bairat Granite is considered as intrusive and composite in nature (Heron, 1917; Sant and Sharma, 1973; Goswami and Ganopadhyay, 1971). Goswami and Ganopadhyay (op. cit.) delineated two types of granites: (i) foliated and lineated granite with mafic constituents and (ii) homophaneous pink granite with minor mafics. The foliated variety is white or pink, coarse to medium grained, inequigranular and porphyritic at places, consisting essentially of microcline, microcline-perthite, plagioclase (oligoclase), quartz with various proportions and combinations of biotite, hornblende, sphene, epidote, apatite, tourmaline and allanite. The non-foliated variety has similar mineralogy, but shows wide variation in texture and grain size. Goswami and Ganopadhyay, (op. cit.) grouped these granites as alkali granite and adamellite respectively. The foliated variety, according to them, is late syn-kinematic with the first phase of deformation of the Delhi rocks, while the non-foliated homophaneous pink variety is post-tectonic. One sample of the Bairat Granite has been dated at 1650 Ma by Rb/Sr whole rock isochrons (Crawford, 1970).



### Harsora granite

A cluster of granite bodies occupying 10 sq km area in and around Harsora village, Alwar district, is a syn to late kinematic emplacement of acid intrusion into the anticlinal fold closures formed by the Alwar-Raialo meta-sediments. Generally light coloured, medium to coarse grained; the hypidiomorphic Harsora granite contains large equi-dimensional grains of microcline, plates of lamellar-twined plagioclase and anhedral quartz with sutured boundary. Biotite, muscovite, zoisite, apatite and opaques form the accessories. Myrmekitic intergrowth between the plagioclase and uniformly arranged quartz grains are commonly present. Sastry (1992) has dated the granite to be of 1500-1700 Ma.

### Barodia Granite

Exposed at the tip of a box-shaped synformal fold, the Barodia Granite Pluton (3 sq km) occurs near Barodia village, Shahpura town in Jaipur district. It is light-yellow to pinkish-grey and greenish grey in colour, fine to medium-grained; I type granite, composed of quartz, K-feldspar, plagioclase, hornblende, biotite and opaques. The accessories include sphene, magnetite, chalcopyrite and pyrite. The granite shows hypidiomorphic texture in the central part of the pluton and a strong development of granophyric texture near the border. Antirapakivi texture has been observed along the border of the pluton. Compositionally, it is classified in the field of granite both mineralogically and chemically. It shows oxygen fugacity controlled differentiation from border to centre. The granite is a minor intrusion within the metamorphites of the Alwar Group of the Delhi Supergroup.

### Udaipurwati Granite

Udaipurwati Granite, the single largest massif of Khetri Copper Belt, measuring 6.5 km in length and 1.5 km in width occupies the core of the south-westerly plunging anticline southeast of Udaipurwati, north of Kandela village in Jhunjhunu district (Dasgupta 1968, and Ray 1974). The Udaipurwati Granite, besides occupying the core of the antiform as long elliptical pluton, also occurs along the Chapli Fault as small bodies. The main Udaipurwati Granite (phase-I) is a composite body whose dominant component is coarse-grained biotite augen gneiss; the augens are formed largely by K-feldspar and occasionally by plagioclase. Mineralogically, phase-I consist of biotite-orthoclase-

microcline- plagioclase-quartz as major minerals with sphene, iron ore, muscovite and zircon as accessories. A less dominant (unmappable, as veins and dykes) component of the Udaipurwati Granite (phase-II) is composed of quartz- plagioclase as major minerals with K-feldspar and biotite as minor constituents. Intrusive bodies of amphibolite are present in the granite. The massif shows a prominent primary foliation, more intensely developed near the margin, and a moderate south-westerly plunging stretching lineation defined by stretched K-feldspar augen and quartz grains and parallel orientation of biotite. Mineralogically and chemically it is granite, peraluminous in nature and showing plumbitic evolution. It shows a mixed ilmenite-magnetite series character and is classified as S-type granite. The second phase of granite within the Udaipurwati Pluton (unmappable) is represented by mafic-poor leucogranite dykes intruding the main phase. Mineralogically and chemically, these are trondjemite/tonalite character and are I-type.

According to Gupta and Guha (1998), the main phase of the Udaipurwati Granite intruded the basement rocks during the third deformation in an extensional ductile regime as an outward stretching diapir. A Rb-Sr whole rock isochron age of  $1480 \pm 40$  Ma for the Udaipurwati Granite has been reported by Gopalan *et al.* (1979).

### Seoli Granite

The Seoli Granite, re-named as Gowariyan Granite is a narrow linear body of 5 km in length and 1.5 km width exposed between Saladipura and Seoli village, Sikar district. The poorly exposed Seoli Granite ( $1494 \pm 206$  Ma whole rock Rb-Sr age, Choudhary, 1984;  $1470 \pm 90$  Ma, Sastry, 1992) is mafic-poor leucogranite containing phenocrysts of plagioclase and potash feldspar with occasional hornblende and rarely biotite. Accessories include apatite, tourmaline, magnetite and ilmenite. Chemically, these are weakly peraluminous and belong to the magnetite series. The trondjemitic phase akin to the Udaipurwati phase-II is also present in the Seoli Granite massif, though in minor amount. Primary foliation defined by biotite flakes is occasionally observed. The granite is emplaced in the core of a moderately NE plunging antiform.

### Chapoli Granite

Chapoli Granite is exposed for over 11 sq km area between northeast of Chapoli and northwest of Mandhaora villages, Sikar district. The oval-shaped

Chapoli Granite is truncated in the south by the Chapoli Fault. The granite is white to grey in colour. This coarse-grained biotite granite is augen gneissic/mylonitic towards the periphery and become homophaneous towards the core. It consists of quartz, K-feldspar, plagioclase, biotite and muscovite with minor amount of zircon, epidote, sphene and opaques. It also contains small leucogranite dykes forming the Chapoli Granite (phase II) similar to the Udaipur Granite (phase II). Mineralogically and chemically the former is granite, strongly peraluminous belonging to the S-type, magnetite series and the latter is tonalite and trondhjemite, weakly peraluminous belonging to the I-type. The granite massif occupies core of NE-SW trending antiform and is considered to be late syn-kinematic emplacement during  $F_2$  folding event. A radial expansion with tangential stretching is amply demonstrated by the stretching fabric within the granite. The whole rock age (Rb/Sr) of phase I granite is  $1313 \pm 270$  Ma (Choudhary *et al.* 1984).

### South Delhi Fold Belt

#### Extrusives

Volcanic rocks occur along the western part of the SDFB from Khed Brahma and Kui in the southwest in Gujarat through Desuri and Phulad to Pisangan, southwest of Ajmer in the northeast over 500 km length and 40 km width. Gupta *et al.* (1980, 1997) termed the volcanic sequence as Phulad Ophiolite suite. It comprises epidiorite, hornblende schist, amphibolite, pyroxene granulite, gabbro and ultramafics. These rocks have attained amphibolite grade of metamorphism and are considered by Gupta *et al.* (1980, 1997) as emplaced along Phulad Lineament perhaps representing the metamorphosed, thrust wedges of oceanic crust. The ultramafic rocks of this suite occur as small thin lenses intermittently to the northeast and west-southwest of Kirana, south of Ramawas, northeast of Lakmipura and northwest of Singor.

Gupta *et al.* (1991), Gupta and Bose (2000) considered the volcanics as synsedimentary deposited in the western Basantgarh-Barotiya-Sendra basin. According to Sinha Roy and Mohanty (1988), the Basantgarh, containing two geotectonic domains, namely, the Basantgarh Formation (ophiolite melange) and the Silva Formation (rift-filled) are characterized by contrasting geochemical signatures of their metabasalts. Generally, the Silva metabasalts are quartz normative

low K-tholeiites and have Mid Oceanic Ridge Basalt (MORB) affinities.

Metavolcanics in the Barotiya and Sendra Groups show syn-sedimentary characteristics and are associated with shallow facies sediments Gupta *et al.* (1991). Volcanism in the Barotiya and Sendra Groups is characterized by the predominance of mafic metavolcanics, which represent more than 95% of the volcanic rocks. Most of the mafic volcanics have 47 to 50%  $\text{SiO}_2$ , a few have ultrabasic or basaltic andesite compositions. Felsic volcanics with 76 to 80%  $\text{SiO}_2$  are rarely present. Intermediate compositions are generally lacking except for the sole occurrence near Narpura (Bose *et al.* 1990). The metavolcanics of the Barotiya and the Sendra Groups show sub-alkaline tholeiitic nature. The sample plots in the oceanic tholeiite field with the exception of high MgO basalt samples, the latter fall close to the boundary between tholeiitic and komatiitic basalts. Ganopadhyay and Lahiri (1984) observed that the magnesium numbers ( $\text{Mg}/\text{Mg}+\text{Fe}$ ) of the metabasalts are fairly low, indicating that these are fractionated basalts and not primitive magma. The ultramafics (intrusive into the Barotiya Group during the third phase of deformation, Gupta *et al.* (1987) associated with the metabasalts in the Phulad area may represent cumulate phases emplaced at a later date (Srivastava, 1988).

#### Intrusives

#### Sendra-Ambaji Granite and Gneiss

These rocks extend for over 360 km length from Khed Brahma-Ubrecha in the southeast to Desurti to Bijathal in the northeast with a maximum width over 40 km in south. The type sections for the Sendra-Ambaji Granite and Gneiss are seen in Ambaji, Keshavganj, Galia Damborhi and Sendra areas. Granite massifs of varying dimension occur. At Sendra, Sei and Sadri-Rankpur along Aravalli mountain range have yielded  $850 \pm 50$  Ma age (Sastri, 1992). Granite from sendra massif shows conspicuous gneiss foliation and hypidiomorphic texture, whereas granites from Sei and Sadri-Rankpur area are pink and grey in colour generally porphyritic and foliated but sometimes show prominent gneissic foliation at places.

Several phases of granitic intrusion are present in the SDFB and are grouped in three categories depending upon their relation to the Delhi deformation phases (Gupta *et al.* 1995). The earliest phase of granites occurs as small and large intrusives mostly within the Barotiya

and Sendra Groups and are Syn to post-early deformation. Petrographically and chemically, the category I granites belong to two types. The first type is represented by leucocratic coarse grained granites practically devoid of mafic minerals. The second type is represented by light grey mesocratic, coarse grained granodiorites with significant amount of biotite and occasionally muscovite.

Category II granities are pre to post-second deformation and are very common in the Barotiya-Sendra groups. The large plutons of Sendra Granite (late syn-tectonic-Gangopadhyay and Mukhopadhyay, 1987) of Heron (1953) belong to this category only. The composition ranges from granite to granodiorite and according to Gangopadhyay and Lahiri (1984) have been derived through the partial melting of crustal material. The Sendra granitoid suite comprises granites, granodiorites and tonalities. At Chang, the pluton consists of granite *sensu stricto* while those at Borwar, Chita, Jaitpura and Seliberi expose dominantly granodiorite and sub-ordinate tonalite. Chemical data of granites reveal limited variation in chemistry. The granites have high silica (71 to 76%), moderate alumina (13.5 to 14.4%) and relatively high potash (4.0 to 5.12%). Their total iron is also on the higher side in relation to silica. The granites are peraluminous in nature and have higher Rb, Ba and Li and are lower in Sr in comparison to the granodiorites and tonalities. In comparison to the granites, the granodiorites have high silica, lower alumina, lower total iron and much higher soda and lower potash. The average  $K_2O/Na_2O$  is 0.85 in comparison to 1.76 for the granites and is metaluminous to peraluminous. The Rb, Sr and Ba contents of the granodiorites are lower than that in the granites. The tonalities are characterized by low potash (below 2.0%), moderate calcium (average 2.35%) and relatively higher Sr and lower Rb, Ba and Li and are metaluminous to peraluminous. According to Aggarwal and Srivastava (1997), despite diversity in chemistry, cogenetic nature of the different plutons comprising the Sendra Granitoids is manifested from the close proximity of the plutons and similarities in their field relations, mineralogy and textural attributes; the Sendra granitoids are genetically linked to a single parental magma. Gangopadhyay and Mukhopadhyay (1987) suggested that the Chang and Borwar plutons of Sendra Group are diapirically emplaced. Roy (1988) considered these 830-730 Ma old (also 0.97 Ga Rb/Sr of Tobisch *et al.* 1994) granites to be a part of an

anorogenic magmatism post dating the Delhi orogeny and have resulted from abortive rifting 850 Ma ago. According to Tobisch *et al.* (1994) the granites in the Sendra area are not juvenile melts as their initial  $^{87}Sr/^{86}Sr$  ratio lies above the mantle evolution vector. Neither is they solely crustal melts derived by anatexis of BGC protoliths. Tobisch *et al.* (op. cit.) opined that the source was low Rb/Sr Mesoproterozoic crust (Delhi Supergroup) as well as components of the BGC.

Category III granites usually occur as thin bodies and are generally leucocratic, fine grained aplite and fine to medium grained granite and rarely granodiorite in composition (Gupta *et al.* 1995). They are ubiquitous in all the litho-units including the Bhim Group and are syn-tectonic with the third phase of deformation.

### Ajmer Granite

Ajmer Granite (Anasagar Granite) dated  $1600 \pm 90$  Ma by Sastry (1992) is located west of Ajmer in the core of an antiformal structure formed by quartzite ridges and exhibits porphyritic, coarse to medium-grained, biotite rich nature and gneissic texture. The granite body is located in the strike extension of the crystalline rocks of BGC of Central Inlier (Heron, 1953). Fareeduddin *et al.* (1995) described the Anasagar Gneiss as a migmatite unit in which biotite rich paragneiss forms a major part. These are extensively migmatized by polyphase potash feldspathic neosomes. Gupta (1989) and Fareeduddin *et al.* (op. cit.) have reported the presence of a late phase granite pluton exposed near Ajesar within the migmatitic unit. The Ajesar Granite, which is intrusive into the Anasagar Gneiss, is medium-grained porphyritic granite (Gupta 1989). Phenocrysts of feldspar in the Ajesar Granite are sometimes stretched into augen. In a recent study, Mukhopadhyay *et al.* (2000) have found several petrographic types within the Anasagar Gneiss and described the Anasagar Gneiss in totality as a plutonic body. They interpreted the Anasagar Gneiss as a sill-like body of concordant sheet intruding between an overlying psammitic and an underlying pelitic/semi pelitic unit during the late stage of the early deformation and prior to the second deformation. Fareeduddin *et al.* (op. cit.) considered the Anasagar Gneiss and its enveloping quartzite-pelitic schist/gneiss-calc silicate rocks to be older than the tectonostratigraphic units of the Delhi Supergroup in the Central Rajasthan. Mukhopadhyay *et al.* (op. cit.) determined the crystallization age of the Anasagar

Gneiss as  $1849 \pm 8$  Ma (U-Pb). According to them, the Anasagar Gneiss with its supracrustals envelope is likely to be a part of the pre-Delhi sequence.

### MAGMATISM IN TRANS-ARAVALLI DELHI PROVINCE

#### Extrusives

Basic volcanics are noted in the Sirohi, Sindreth and Punagarh Groups. In the Sindreth Group the basic volcanics show intersertal texture, the interspaces between the plagioclase (andesine) laths being occupied by pale green chalcophaeite. Some chalcophaeite forms pseudomorphs with carbonate core after (?) olivine/pyroxene. The rock is dusted with numerous euhedral crystals of opaque oxides with glass shards. At places, flow texture is deciphered defined by plagioclase microlites arranged in a parallel fashion along with euhedral opaque oxides and elliptical masses of altered glass. Alteration of glass shards commonly results in the formation of biotite. Some of the basic volcanics contain perlitic cracks and carbonate amygdules.

In the Punagarh Group, basic volcanics are generally aphanitic to fine-grained with numerous hyaloclastic bands. Pillows occur in isolation, usually enclosed in a breccia matrix. In this section, the basalt shows hyalo-ophitic, acicular to glomeroporphritic textures. Large slender plagioclase laths, often imparting a flow texture, are embedded in an altered glassy matrix which, beside, also contains fine plagioclase microlites. Relict serpentinised olivine crystals are enclosed in a rim of red iddingsite. Underformed amygdules of calcite, quartz and suspected zeolite are also noted. Chemical analysis of basic volcanics indicates normal tholeiitic basalt to alkaline olivine basalt composition.

#### Intrusives

##### *Erinpura Granite and Gneiss*

The Erinpura Granite and Gneiss dated  $830 \pm 30$  Ma by Choudhary *et al.* (1981) and Metamorphism. Abu Granite dated  $735 \pm 15$  Ma by Crawford (1975)

represent the late to post-Delhi acid intrusives. The rocks occur between Rampur in the northeast to Iqbalgarh in the southeast over an area 325 km long and 3 km to 15 km wide.

The Erinpura Granite shows variation in texture and mineral composition. Ferromagnesian-rich, coarse-grained porphyritic variety is a dominant type. The fine to medium-grained, non-porphyritic granite occurring as dykes contains a higher proportion of potash-feldspar while the more leucocratic coarse-grained type contains more muscovite and potash-feldspar and less of ferromagnesian minerals. The Erinpura Granite shows rapakivi texture both pyterlitic and wibogritic type. Emplacement of these granites was perhaps accompanied by injection of aplitic and pegmatitic material as veins. The abu massif granite, coarse-grained, grey feldspar bearing biotite-rich granite is the result of more than one generation of Magmatic pulses involving an earlier anatectic facies and a later intrusive facies. The earlier phase granite is heterogenous in nature from fine-grained (aplitic) to coarse-grained sometimes even up to pegmatitic dimensions. The later phase granite is pink in colour and biotite rich comprising K and Na feldspar, plagioclase, hornblende, zircon and rutile.

##### **Balda Granite**

The Balda Granite occurs as phacolithic bodies, dykes and apophyses within the Erinpura Granite. It is medium to fine-grained, non-porphyritic leucogranite composed mainly of quartz, alkali feldspar, plagioclase and muscovite as essential minerals, and biotite, tourmaline, topaz, chlorite and ilmenite as accessories. Mineralogically, it falls in the field of granite to granodiorite with average composition in the field of granite. Chemically, it is dominantly granitic, with a variation from tonalite-trondhjemite through granite to monzonite. Texturally, the rock is porphyritic and gneissic and shows intergrowth texture in the form of myrmekites. Quartz veins and pegmatites related to Balda Granite phase of Erinpura Granite hosts the tungsten mineralization as disseminated scheelite, wolframite, powellite and gadolinite.



# Mineral Resources

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Rajasthan, endowed with a rich mineral wealth, occupies a significant position on the mineral map of the country. In the area of metallic and non-metallic minerals, Rajasthan, by possessing 19% of working mines in the country, leads the country. It possesses a wide range of mineral resources and offers considerable potential for the future. The important metallic minerals with which the name of the State is intimately associated are: lead, zinc, copper and tungsten. It is also richly endowed with a variety of non-metallic minerals. Rajasthan has also enormous deposits of building stones like marble, granite, sandstone, limestone, slate etc. It is a leading producer of asbestos, soapstone/steatite, gypsum, rock phosphate, calcite, feldspar, clay etc. Presently, the State enjoys a monopoly in the production of wollastonite, emerald, jasper and semi-precious garnet. In addition, the State has good deposits of lignite in Bikaner, Nagaur and Barmer districts. The status of Rajasthan vis-a-vis India with regard to category-wise recoverable reserves of minerals and production of minerals is shown in Tables-7 and 8.

## APATITE

Apatite occurs as a primary constituent of igneous rocks, but only as accessory mineral. It also occurs as a vein mineral. It is a natural phosphate-bearing mineral having a definite chemical composition. Apatite is mainly of two types. One is chlorapatite  $3\text{Ca}_3(\text{PO}_4)_2\text{CaCl}_2$  and the other is fluorapatite  $3\text{Ca}_3(\text{PO}_4)_2\text{CaF}_2$ . Its main use is as fertilizer.

In Rajasthan, occurrences of apatite have been reported from Sikar and Udaipur districts.

### Sikar district

**Salwari deposit:** Apatite deposits are located in Karpura and Salwari areas ( $27^{\circ}45'$ :  $75^{\circ}50'$ ). Apatite occurs as pockets and thin veins varying in thickness

from a few cm to about 1 m. Near Kali Bankhari in Salwari area, the apatite veins extend over a strike length of 760 m. The samples analysed indicated 41%  $\text{P}_2\text{O}_3$ . Apatite content is reported to be meagre.

### Udaipur district

**Newania deposit:** Apatite deposit has been located by the Department of Mines and Geology, Government of Rajasthan (DMGR) near Newania ( $24^{\circ}40'$ :  $74^{\circ}05'$ ), about 60 km east of Udaipur. The mineral occurs as thin veins and stringers criss-crossing a large mass of crystalline limestone overlying granitic rock with mineralization spread over an area of 1.5 sq km. The possible reserves of apatite up to a depth of 4 m have been estimated to be about 30,000 tonnes containing 32-35%  $\text{P}_2\text{O}_3$ . The low-grade material appears to continue down to a depth of 27 m.

## ASBESTOS

Rajasthan accounts for about 96% of the country's total production of asbestos, whereas Andhra Pradesh and Karnataka, the other producing States contribute the remaining 4%. The Table-9 shows production of asbestos in Rajasthan as well as in the country during 2004-05 and 2005-06.

The asbestos deposits are mainly located in the southern parts of the State, confined to the altered ultramafic intrusives within the rocks of the Bhilwara, Aravalli and Delhi Supergroups. Rajasthan possesses chrysotile and amphibole varieties of asbestos.

The deposits of amphibole variety (tremolite-anthophyllite) are more predominant with an estimated reserves of about 2,10,000 tonnes whereas the deposits of chrysotile variety have estimated reserves of only about 500 tonnes. The main deposits of asbestos are located in Ajmer, Alwar, Bhilwara, Dungarpur, Pali, Sirohi and Udaipur districts.

TABLE-7

Category-wise recoverable reserves of minerals in million tonnes: India vs Rajasthan (as on 01.04.2005)

Minerals	India				Rajasthan			
	Proved	Probable	Remaining Resources	Total	Proved	Probable	Remaining Resources	Total
Apatite	6.125	0.0196	0.0184	6.163	0	0	0	0
Asbestos	2.973	3.066	15.695	21.734	2.961	3.022	7.208	13.191
Baryte	31.639	2.672	39.89	74.201	0.174	0.107	2.739	3.02
Bauxite	538.945	360.439	2390.432	3289.816	0	0	0.528	0.528
Bentonite	0	25.0605	505.512	530.572	0	11.99	411.526	423.516
Buiding Stones:								
a. Granite	23.01	1107.014	36295.977	37426.001	0	4.5	8520.708	8525.208
b. Marble	0	4.7	1787.938	1792.638	0	4.377	1118.058	1122.435
Calcite	3.218	3.523	15.831	22.572	2.985	3.155	5.886	12.026
Copper:								
a. Ore	135.461	234.032	1024.934	1394.427	27.535	25.407	615.515	668.457
b. Metal	1.643	2.74	7.033	11.416	0.247	0.267	3.466	3.98
China Clay	101.52	120.601	2373.54	2595.661	23.05	19.242	329.418	371.71
Dolomite	407.794	577.363	6547.952	7533.109	57.862	43.471	398.97	500.303
Feldspar	19.22	18.82	52.731	90.771	12.197	14.807	29.178	56.182
Fire Clay	26.897	32.404	645.462	704.763	9.013	6.386	45.789	61.188
Fluorite	8.585	0.628	10.951	20.164	0.633	0.364	4.245	5.242
Fuller's Earth	0	0.058	256.593	256.651	0	0	190.059	190.059
Garnet	6.719	14.255	36.68	57.654	0.0129	0.029	0.115	0.156
Graphite	5.164	5.587	158.025	168.776	0.047	0.165	1.7	1.912
Gypsum	40.803	27.855	1168.218	1236.876	34.381	19.812	952.608	1006.801
Iron	4959.668	2103.003	18187.197	25249.868	9.848	5.19	541.687	556.725
Kyanite & Sillimanite	1.378	11.418	164.154	176.95	0.0133	0.0055	0.005	0.0238
Pb + Zn (Ore)	62.86	62.894	396.826	522.58	61.213	56.37	350.925	468.508
Limestone	7492	5223	162630	175345	1121.846	585.485	17778.922	19486.253
Magnesite	20.863	55.27	261.749	337.882	1.081	2.202	50.521	53.804
Manganese	76.844	61.507	240.418	378.769	1.154	0.647	3.02	4.821
Nickel (Ore)	0	0	188.71	188.71	0	0	0	0
Ochre	25.747	22.12	45.573	93.44	21.383	2.797	31.272	55.452
Pyrites	27.129	29.597	1617.675	1674.401	13.667	22.917	54.292	90.876
Rock phosphate	33.09	19.633	252.585	305.308	22.42	2.797	70.709	95.926
Silver (Ore)	55.752	60.16	128.72	244.632	46.897	59.367	98.061	204.325
Quartz/Silica Sand	271.614	499.894	2466.703	3238.211	103.741	77.404	78.89	260.035
Soapstone	65.012	50.514	196.81	312.336	22.631	21.114	113.445	157.19
Tin:								
a. Ore	0.2008	0.0486	86.302	86.551	0	0	0	0
b. Metal	0.000107	0.000026	101.103	101.103	0	0	0	0
Tungsten	0	0	87.387	87.387	0	0	23.928	23.928
WO ₃	0	0	0.142	0.142	0	0	0.093	0.093
Vermiculite	1.5566	0.2069	0.674	2.437	0.0206	0.0044	0.018	0.043
Wollastonite	7.423	1.109	11.708	20.24	7.423	1.109	9.714	18.246

Source: Indian Minerals Yearbook, 2006

**TABLE-8**  
*Mineral production in 2004-05 and 2005-06: India vs Rajasthan; (Value in Rs '000)*

Minerals	Unit	India				Rajasthan			
		2004-05		2005-06		2004-05		2005-06	
		Qty	Value	Qty	Value	Qty	Value	Qty	Value
All Minerals	-	-	813757978	-	839386162	-	33375407	-	34210945
Fuel Minerals	-	-	605115751	-	614847844	-	-	-	-
Natural Gas	mcm	30820	89401200	31223	90407400	211	633000	238	714000
Metallic Minerals	-	-	99403852	-	114860798	-	-	-	-
Copper Ore	t	2929074	-	2642706	-	871632	-	931508	-
Iron Ore (Total)	X10 ³ t	145942	74029029	154436	86905259	28	4839	18	1445
Lead Concentrate	t	81675	652733	97572	708169	81647	652698	97572	708169
Silver	Kg	10955	84311	27950	227870	10570	80289	24261	182808
Zinc Concentrate	t	666424	3998845	893287	4956091	666424	3998845	893287	4956091
Non-Metallic Minerals	-	-	-	26844833	-	27283978	-	-	-
Phosphorite	t	1722983	2928350	1372951	2212353	1621020	2882893	1194013	2142227
Asbestos	t	6392	19022	2366	21830	5594	890	1726	300
Ball Clay	t	637022	117872	351049	49441	442196	63994	148547	12695
Barytes	t	1159031	505194	1189839	447658	3784	3526	6199	2458
Calcite	t	66984	21730	73332	21794	66294	21661	72892	21750
Chalk	t	129571	33274	146351	36992	-	-	-	-
Dolomite	t	4339306	915714	4428119	1076320	108128	16351	153247	20256
Feldspar	t	379055	61032	322929	53329	84647	10005	63737	7443
Fire Clay	t	662633	90734	485755	76763	162657	26835	77760	3920
Fluorite (Graded)	t	6291	16360	1774	5470	1002	3029	665	2605
Garnet (Abrasive)	t	642329	153279	679700	195826	3	8	-	-
Garnet (Gem)	kg	90	122	-	-	90	122	-	-
Graphite (R.O.M)	t	108150	39908	120322	43347	-	-	-	-
Gypsum	t	3684758	502000	3137095	389709	3641136	478204	3104350	372698
Jasper	t	1265	386	580	174	1265	386	580	174
Kaolin (Natural)	t	933654	1091332	1096564	1341425	152699	15006	165214	17415
Kyanite	t	8208	6778	7341	6579	-	-	-	-
Sillimanite	t	30711	115306	32278	170546	-	-	-	-
Limestone	X10 ³	165753	17942008	170378	19019764	25007	2971177	26666	3265553
Magnesite	t	383953	363971	351495	488552	342	529	-	-
Mica Crude	t	1276	26104	1259	32248	154	1493	30	308
Mica waste & Scrap	t	2497	-	3384	-	476	-	518	-
Ochre	t	919018	56944	920600	59253	860672	50544	878956	54487
Pyrophyllite	t	271225	42376	181328	28958	-	-	-	-
Quartz	t	319004	44349	250719	29511	53040	6686	46557	5179
Quartzite	t	97036	75939	107975	55273	7321	1098	7420	742
Silica sand	t	1962029	244699	2344793	269090	337762	51696	352610	50910
Steatite	t	684440	334961	627216	291057	496818	266537	441663	227231
Vermiculite	t	3377	5183	4774	4657	536	43	929	93
Wollastonite	t	170292	129097	128582	98740	170292	129097	128582	98740
Laterite	t	949973	90887	931297	97663	2200	57	-	-

Source: Indian Minerals Yearbook, 2006

**TABLE-9**  
*Production of asbestos: (Qty in tonnes, value in Rs '000)*

State/ District	2004-05					2005-06				
	No of Mines	Grade		Total	Value Mines	No of	Grade		Total	Value
		Chrysotile	Amphibole				Chrysotile	Amphibole		
India	21	798	5594	6392	19022	10	640	1726	2366	21830
Rajasthan	18	0	5594	5594	890	7	0	1726	1726	300
Ajmer	3	0	0	0	0	1	0	0	0	0
Pali	3	0	1468	1468	212	3	0	153	153	15
Rajsamand	6	0	540	540	164	1	0	371	371	80
Udaipur	6	0	3586	3586	514	2	0	1202	1202	205

Source: Indian Minerals Yearbook, 2006

### Ajmer district

The asbestos deposits are located near Kanwali (25°30': 74°30') in Kotra Reserve Forest area, about 3 km southwest of Kotra, Arjanpura, Kotri and Nai-Khurd. Smaller occurrences of asbestos have been reported from Manpura (26°50': 74°45'), Bhubani (23°30': 74°45'), Rajgarh (26°45': 74°35') and Gudas (26°29': 74°46').

**Kanwali (Kaolai) deposit:** The chrysotile asbestos occurs in the serpentinised zones found within dolomitic marble. The serpentinisation is prominent near fractures and joints in the rock. The asbestos, creamish-yellow in colour with pearly lustre has hard and somewhat brittle fibres.

**Kotra Reserve Forest deposit (26°02': 74°13'):** Asbestos of tremolite variety occurs in the altered ultrabasic bodies varying in width from 570 cm. The slip-fibre veins thin down at a depth of 5.6 m. The reserves up to a depth of 5 m have been estimated at 2,050 tonnes.

**Arjanpura deposit (26°17': 74°32'):** At places tremolite admixed with anthophyllite occurs as slip-fibre varying in thickness from 5 to 30 cm. The mineralization is sporadic but appears to continue to a depth of about 1015 m. Besides mining asbestos from the veins, the host rock containing disseminated fibres is also quarried in this deposit which is estimated at 60 tonnes per month.

**Kotri deposit (26°04': 74°12'):** Tremolite veins occurring as slip and cross-fibres are being worked from an altered ultrabasic rock. The reserves have been estimated at 121 tonnes up to a depth of 25 m while that of the mass-fibre zone has been estimated at 720 tonnes up to a depth of 5 m.

**Nai-Khurd deposit (25°49': 74°10'):** Both chrysotile and tremolite varieties of asbestos are found in this area. The chrysotile variety is generally poor. The tremolite variety behaves erratically as the veins pinch out abruptly in the pits. The total reserves of tremolite variety have been estimated at about 625 tonnes, while that of chrysotile variety at 1,125 tonnes.

### Alwar district

Asbestos has been reported from Palpur (27°11': 76°24'), Dhalawas (27°33': 76°33') and Ghazi-ka-Thana (27°24': 76°19') and from a number of other localities. The occurrences are, however, too small to be of any commercial importance.

### Bhilwara district

**Barana deposit :** Workable deposits of tremolite variety of asbestos occur as cross-fibre veins varying in thickness from 25 cm to 1.10 m in altered ultrabasic rocks near Barana (24°41': 74°23'). There are a number of thin veins along minor slips parallel to the three main slip zones. The total reserves of the deposits up to 25 m depth (ground water level) have been estimated at about 2,405 tonnes. The workable reserves are likely to exceed 10,000 tonnes if mined below ground water level.

### Dungarpur district

Asbestos deposits are located near Dewal (23°55': 73°35'), Sarkand and Mundwara (23°59': 73°50'), Jakol (23°50': 73°45'), Khemaru (23°50': 73°45'), Matugamra (23°50': 73°40'), Gugra (23°50': 73°35') and Nalwa (23°50': 73°35').

**Dewal deposit:** Tremolite variety of asbestos occurs here as slip-fibre veins varying in thickness from 7.6 to 9 cm. Cross-fibre vein of 25 cm thickness has also been



recorded. The reserves have been estimated at about 436 tonnes.

**Mundwara deposit:** Though very small, the deposit may yield about 8-10 tonnes of asbestos.

#### Sirohi district

Only one occurrence of asbestos near Bori-ki-Bhuj (24°30': 72°59') has been recorded.

#### Udaipur district

Asbestos is known to occur near Kagdar-ki-Pal, Rakhabdeo, Jogi-ka-Gudha, Antalia, Bhauva, Dhelana, Odwas, Sarai, Salumber (24°05': 74°00'), Kunthal (25°20': 73°50'), Molera (24°55': 73°30'), Shapol (25°50': 73°45') Makarjaba, Serro-ki-Pal, Masara-ki-Obri, Khan, Khakhar, Telera, Baroli (24°40': 74°50') and Tikki. Of these areas, first four occurrences were prospected by the Hyderabad Asbestos Cement Products Ltd.

**Kagdar-ki-Pal deposit (24°02': 73°40'):** Exploratory drilling in the area has indicated five zones of asbestos fibres up to a depth of 612 m. The reserves have been estimated at 60,000 tonnes of ore with an average grade of 0.75% i.e. 450 tonnes of asbestos.

**Rakhabdeo deposit (24°02': 73°41'):** Marked concentration of chrysotile fibres exhibiting typical stock-work pattern is seen in the serpentinite along the fractures which are at right angle to the strike of the phyllites.

**Jogi-ka-Gudha deposit (24°01': 73°41'):** Tremolite variety of asbestos occur as slip-fibres varying in width up to 25 cm. These are erratic veins of variable thickness and often pinching out abruptly. The reserves have been estimated at about 900 tonnes.

**Antalia deposit (25°13': 73°46'):** The deposit is small with reserves of about 19.30 tonnes.

**Bhauva deposit:** The estimated reserves of this small deposit, 15 m in length and 10 m in depth, are about

36.58 tonnes.

**Dhelana deposit (23°50' : 73°35'):** Veins of tremolite asbestos varying in width from 15 to 23 cm have been worked up to a depth of 9 m in three zones. The reserves over a length of 30 m are estimated at about 401.35 tonnes.

**Odwas deposit (24°00': 73°45'):** Cross-fibre veins of tremolite asbestos of pinch-and-swell type with thickness varying from 1 to 40 cm have been recorded. The reserves have been estimated at 133.10 tonnes.

**Sarai deposit:** The deposit has been estimated to contain about 49.79 tonnes of asbestos.

#### Pali district

The asbestos occurrences are located near Kanotiya (26°05' : 74°13'), Ramgarh (26°04' : 74°08'), Gorla (25°56' : 74°20'), Dhal (25°35' : 73°45'), Mala-ka-Gudha (25°40' : 73°50') and Sendra (26°05' : 74°10').

**Kanotiya-Ramgarh deposit (26°15' : 74°45') :** The asbestos occurs as thin cross-fibre veins, 23 cm thick, in large number (1520) over a strike length of 1 m. The reserves of tremolite asbestos for two cross-fibre veins each 25 cm thick have been estimated at 1,15,440 tonnes.

### BARYTE

Baryte, Barite or the 'Heavy Spar' are different names of the same mineral having the composition BaSO₄. The mineral is very important and vital to the petroleum industry which consumes more than 80% of the world's baryte production. Baryte finds its principal utility in drilling mud for exploration of oil because of its high specific gravity, inertness to acids, insolubility in water and above all its lower cost compared to many other available heavy materials.

India occupies a very prominent position in the world map of baryte, ranking third in reserves (Table-10) and second in production.

**TABLE-10**  
*Reserves of Baryte in India: (Qty in tonnes)*

State	Reserves		Remaining resources	Total
	Proved	Probable		
India	31639934	2672846	39890567	74203347
Rajasthan	174741	107109	2739285	3021135
Andhra pradesh	31438494	2550264	35907692	69896450
Himachal pradesh	26699	11001	101356	139056

Source: Indian Minerals Yearbook, 2006

**TABLE-11**  
*District-wise, category-wise production of Baryte in Rajasthan: (Qty in tonnes)*

State/ District	2004-05				2005-06			
	No of Mines	Grade		Quantity	No of Mines	Grade		Quantity
		Snow White	Off-Colour			Snow White	Off-Colour	
India	17	5640	1153391	1159031	13	43951	1145888	1189839
Rajasthan	2	117	3667	3784	2	945	5484	6429
Alwar	1	0	97	97	1	230	244	474
Udaipur	1	117	3570	3687	1	715	5240	5955

Source: Indian Minerals Yearbook, 2006

India is endowed with the world's largest single baryte deposit at Mangampet in Andhra Pradesh containing as high as 61 million tonnes of recoverable reserves. With such huge reserves, India is in a comfortable position not only to meet the domestic requirement but also to export it as per demands. In 1993-94, India exported baryte worth Rs. 4.83 crore.

In Rajasthan, baryte mineralization is associated with igneous, metamorphic and sedimentary rocks. It occurs as veins, cavity-fillings, bedded and residual deposits. Occurrences of baryte are known in the districts of Alwar, Bharatpur, Bhilwara, Bundi, Chittaurgarh, Jalor, Pali, Sikar, Sirohi and Udaipur (Table-11), whereas important deposits are limited to Alwar, Bharatpur, Pali and Udaipur districts.

#### **Alwar district**

The baryte deposits of this district, contributing 90% production of the State, fall in two distinct zones known as the Rajgarh belt and the Alwar belt passing from Bhagat-ka-Bas and the other from Sainpuri to Akbarpur, respectively. The geological setting in both the zones is identical.

##### *Rajgarh belt*

In this belt the baryte deposits/occurrences are located at number of places in quartzite and at the contact with granite. Baryte occurs as veins and veinlets in quartzite along the shear planes and fold closures. The localization of baryte mineralization is guided by structural control. In Rajgarh belt baryte occurs at Jamrauli (27°07': 76°40'), Khera (27°10': 76°55'), Ferozpur (27°19': 76°40'), Ramsinghpura (76°31': 27°11'), Tetra (27°12': 76°43') Dholera (27°11': 76°42'), Bhagat-ka-Bas (27°13': 76°42'), Khora-Makora (27°13': 76°44'), Guara Gijar (27°07': 76°38'), Nangal (27°07': 76°39'), Mundia (27°12': 76°48') and Pharaoti (27°08':

76°49'). Occurrences of barytes have also been reported from Ladia Gujarat (27°10': 76°36'), Balapur (27°07': 76°40'), Santhas (27°05': 76°40'), Berli (27°10': 76°25'), Palpur (27°12': 76°30'), Ajabgarh (27°11': 76°20') and Khurd (27°10': 76°30').

##### *Alwar belt*

In this belt baryte deposits have been located at Jhamdoli (27°40': 76°35'), Bhankhera (27°31': 76°35'), Bhurasidh (27°31': 76°35'), Dholi Ddhoop (27°37': 76°36'), Sainpuri (27°43': 76°38'), Umran (27°30': 76°34'), Rawan Dera (27°34': 76°34'), Karoli (27°41': 76°38'), Zahir-ka-Kheda (27°39': 76°37'), Sham-ki-Baori (27°33': 76°32'), Gatri (27°10': 77°05') and Bas (27°20': 76°30').

Occurrences of baryte have also been reported from Jaggas (27° 20': 76°20'), Local (27°15': 76°30') Ringaspura (27°30': 76°30'), Tatarpur (27°10': 76°30'), Bhurari (27°44': 76°38'), Ruta (26°42': 76°38'), Naurangabad (27°39': 76°37'), Behal (27°48': 76°33') and Kalikhol (27°28': 76°30').

#### **Bharatpur district**

Baryte mineralization occurs over a length of 5.5 km from west of Hathori to 2 km WNW of Ghatri (26°59': 77°09'). The area has been divided into three blocks on the basis of occurrences and control of mineralization. These are from east to west Hathori, Karwan and Ghatri blocks.

#### **Bhilwara district**

*Barliyas deposit* (25°12': 74°53'): Baryte, grey and buff in colour is found associated with quartz and calcite veins within the altered granite-gneiss of pre-Aravalli age. Thickness of the quartz-baryte-calcite veins varies from 2 cm to 2 m and extends about 15 m in N80°W-S80°E direction. Malachite and small cubes of galena are also seen.

The deposit has been worked to a depth of 11 m by putting two shafts of 2m × 2m connected with a 10 m long drive. The width of the baryte veins in the upper part of the shaft is 0.5-1.5 m and increases with depth up to 2.5 m in the lower part of the shaft, thus indicating the swelling of the baryte vein at depth. Besides, calcite vein has also been worked to a depth of 6 m in the southern part of the vein, where the width of the vein is only 0.8 m. The recovery of the baryte from these veins is about 70%. The mining has been suspended due to its low recovery. The reserves, indicated by DMGR, are about 1,600 tonnes with 80-90% BaSO₄.

### Bundi district

*Umar deposit (25°40': 75°30')*: The baryte occurs in the form of veins associated with quartz veins intruding the dolomitic limestone or at the contact of limestone and phyllites. Generally it follows the fissures and fracture planes. In the Pagara area, baryte veins are located in the prominent quartz veins, running along a fault, S30°W of village. There are two baryte veins one of which is about 1.5 m wide and 8 m long. These baryte veins do not persist beyond 13 m in depth. White and greyish baryte is found associated with galena, cerrusite, malachite and azurite. This association indicates its hydrothermal origin. Twenty-nine trenches and four pits were excavated and eight bore holes were drilled making total drilling 435.5 m. The grade varies from 56 to 98%, averaging 78.6% BaSO₄. This low-grade baryte requires beneficiation. Proved reserves for vein 1 and inferred reserves for veins 1 and 2 of the order of 1,000, 500 and 150 tonnes respectively have been estimated.

### Chittaurgarh district

Occurrences of bedded baryte have been recorded from the Vindhyan sediments. It is located at Jaurakalan near Rawatbhata (24°56': 75°35'). It occurs as small veins, stringers, vug filling and laminations in the Panna Shales of the Rewa Group. A prominent N60°E-S60°W trending vein of about 30 cm in width and 80 m in length is exposed towards the northwest slope of the Butte hill. A few very thin veins and veinlets are also seen. Whitish to pinkish baryte contains BaO (62-71%) and SO₃ (32.84%). The baryte in the thin laminations is ubiquitous.

### Pali district

*Punagarh hill (25°48': 73°27')*: About 9 km west of

Pali on the western slopes of Punagarh hill brecciated quartz-baryte-haematite rock occurs as irregular lenses and veins in the variegated slate. There are 16 lenses of brecciated quartz-baryte-haematite rocks and these vary in size from 10 to 30 cm in width and up to 450 m in length. Veins and veinlets of barytes, 5 cm to 1 m in thickness, occur in these lenses or at the contact with slates. At places, irregular veins of baryte follow the joints and the foliation planes. The veins of baryte have been worked at number of places. In the north-western working, a 2 m wide baryte vein has been exposed to a depth of 5 m. The baryte, pink-bright grey in colour, is mostly massive. Baryte mineralization marked by brecciated quartz-baryte rock appears to be co-genetic with sulphide mineralization which is confined to the shear zone and to the hinge portion of a synclinal fold in the slates. The area has been mined in the past for lead/iron ore as many old shafts, inclines are still preserved with the ore on their walls.

### Sikar district

*Kharagbingur (27°43': 75°54') and Naroda (25°45': 75°56')*: The deposits are located about 2 km NE and SSW of the village. The area lies 20 km northeast of Neem-ka-Thana on Neem-ka-Thana-Patan road. Barytes is found as fissure-filling in weak zones trending in N-S direction along bedding planes and is associated with calc-schists of the Ajabgarh Group of the Delhi Supergroup. The Baryte with 67.80-87.80% BaSO₄ occurs in two veins with a 1-2.5 m thick parting and is traceable for a strike length of about 80 m. There are two vertical shafts (4m × 4m), four inclines and five test-pits in the area.

### Jalor district

*Karara*: The baryte mineralization, south and southwest of Karara, is associated with fluorite mineralization. The baryte veins are generally present along the fractures across the fluorite veins but in places like Santoshi, Lal, Malinath and Tavidar hills, it occurs in association with the fluorite veins.

On the north-eastern flank of the Sulia hill the baryte veins occur along N-S striking fractures in the agglomerates. The baryte is fine-grained to well-crystalline and is of pale colour. The thickness of veins varies from 5-30 cm. Reserves of 808 million tonnes are indicated in this deposit assuming the depth persistence up to 20 m.

The mode of occurrence of baryte in Tavidar hill area is similar to that in Sulia hill except that the E-W fractures are also mineralized here. The fractures striking N-S contain fluorite also. The vein striking E-W is devoid of fluorite and cuts across the N-S striking veins. Mineralization of baryte is later than that of fluorite. The thickness of veins varies from 10 cm to 35 cm. Total reserves of 3,000 million tonnes are indicated for this deposit assuming a depth persistence of 20 m for the veins.

### Udaipur district

Thin streaks, lenticles, veins and bands of baryte, constituting two belts occur in association with quartz-carbonate veins within the biotite-chlorite schist, phyllite and dolomite at a number of places between Delwara (24°45': 73°40') and Nathdwara (24°53': 73°50') and in gneisses and schist near Relpataliya (24°24': 73°51').

#### *Delwara-Nathdwara belt*

In this belt baryte occurs mainly as fissures and breccia fillings or replacement in limestone. The mineralization is mostly confined to the chlorite schist and occurs as en echelon veins along foliation planes. The baryte deposits/occurrences of this belt are found in Gurli, Kioli, Junagarh (24°49' : 73°43'), Laxmi Guda (24°46' : 73°43'), Barwalia (24°48' : 73°43'), Pipalwas (24°49' : 73°44'), Nerach (24°48' : 73°42'), Khetrapal-ka-Gudah (20°48' : 73°42'), Kagmadar (24°50' : 73°43'), Nagria (24°50' : 73°45'), Ramela (24°50' : 73°46'), Ghora Ghali (24°52' : 73°46'), Karowli (24°51' : 74°45'). The individual lenses however do not exceed for more than 5 m along strike. Hard, compact, and massive baryte is fine to medium-grained and milky-white to greyish-white in colour.

### BAUXITE

Bauxite is used mainly for the extraction of aluminum metal, in the refractory and chemical industries, manufacture of emery powder, cement paint and in refining petroleum products. India is bestowed with large deposits of bauxite. The known bauxite reserves of the country are of the order of about 200 million tonnes, of which 140 million tonnes are of high-grade. Rajasthan, however, contributes very insignificant quantity of bauxite.

In Rajasthan bauxite occurrences near Baselio

(26°10': 77°19'), Majola (25°13': 77°23'), Mamoni (25°11': 76°06') and Sherol-Khera (25°09': 77°07') in Kota district have been reported by the GSI. Bauxite in these areas occurs in the form of blanket capping as a product of *in situ* alteration of the Deccan Traps. The lengths and widths of such deposits, as revealed by surface and subsurface exploration, are 1,400 m and 450 m respectively, and the total extent is likely to be much more. The average thickness of the bauxite zones is 3 m but the maximum thickness at places is more than 15 m. Exploratory mining by the GSI has so far indicated probable reserves of 0.57 million tonnes containing on an average 49.54% Al₂O₃. The deposit was handed over to the MECL for detailed exploration.

### BENTONITE

Bentonite is one of the two naturally occurring clay minerals of montmorillonite group with decolourising and absorbing properties. Almost all bentonite assume a slightly darker shade due to absorption of moisture. Two types of bentonite viz., swelling and non-swelling type, are commonly known. Sodium-bentonite is of swelling type which swells up to 15 times while calcium-bentonite is of non-swelling type. Commercial importance of bentonite depends on its swelling index, base exchange properties and setting time. The bentonite is used as grouting material in engineering constructions, in drilling muds and as carrier in insecticides, paint and pharmaceutical industries. It is also used for bleaching vegetable oils and petroleum.

Rajasthan possesses inexhaustible reserves of both swelling and non-swelling types of bentonite. Deposits of bentonite are mostly located in Barmer and Jaisalmer districts.

### Barmer district

The important localities are Harwecha (26°05': 71°09'), Sheo (26°11': 71°15'), Hathi Singh-ki-Dhani (26°12': 71°15'), Akli (26°03': 71°13'), Thumbli (26°03': 71°16') Giral (25°59': 71°18'), Sonri (25°59': 71°16') Bisala (25°54': 71°14'), Bhadres (25°42': 71°25') and Mahawar. A total of about 89.90 million tonnes of bentonite of all categories are estimated from these localities. Additional reserves of 4.45 million tonnes have been proved by GSI in Bisukala area. Chemical analysis of Barmer bentonite is given in Table-12.



**TABLE-12**  
*Chemical analysis of Barmer bentonite*

	<i>Hathi Singh ki-Dhani</i>	<i>Akli</i>	<i>Dodra Bisala</i>	<i>Bhadres</i>	<i>Barmer</i>
SiO ₂	51.4	54.9	51.4	52.4	45.23
Al ₂ O ₃	21.4	19.4	24.7	24.1	25.48
Fe ₂ O ₃ & TiO ₂	6.8	6.8	5.2	6.6	10.24
CaO	0.7	0.1	0.6	0.4	1.00
MgO	1.9	—	1.5	0.4	—
Na ₂ O	3.1	2.1	2.2	0.7	5.83
K ₂ O	8.7	10.9	7.4	8.1	12.22
Loss	6.0	5.8	7.0	8.3	—
SiO ₂ /Al ₂ O ₃ ratio	2.4	2.8	2.1	2.2	1.8

Source : GSI.

***HarwechaSheoHathi Singh-ki-Dhani areas:***

Bentonite beds associated with ferruginous sandstone are unconformably overlain by a conglomerate which is almost horizontal. The bentonite in most of the areas is covered by about 3050 cm of soil or loose sand. The bentonite is non-swelling type. Total probable reserves of 1.12 million tonnes have been estimated in these areas.

***Akli-Thumbli-Grial:*** Bentonite occurrences are covered by aeolian sands in ThumbliGrial area where bentonite is associated with conglomerate and ferruginous shale. In Akli area bentonite is usually seen underlying conglomerate band which is overlain by a thick pile of sand. The bentonite beds grade from a swelling type (as seen around Akli in the northwest) to a non-swelling type or a low-swelling type (as seen in the Grial-Thumbli area towards southeast). It is chiefly composed of about 70% montmorillonite, the rest being kaolinite, attapulgite and illite. The total probable reserves have been worked out at about 55.83 million tonnes.

***Sonri:*** A 0.6 m thick bentonite bed, unconformably overlying the Barmer sandstone (Cretaceous age), is exposed and worked. It is of high-gel and good swelling-type. The reserves are about 5.3 million tonnes.

***Bisala:*** A 5-7 m thick bentonite bed, overlain by near-horizontal conglomerate bed containing pebble and boulders of rhyolite of the Malani Igneous Suite, is exposed in a rock cutting near Dodra Tank. It is of good swelling and high-gel type. The reserves are about 0.40 million tonnes.

***Bhadres:*** Bentonite is associated with the Fatehgarh (Barmer) sandstone (Cretaceous) and the Kapurdi Formation (Eocene). Low-swelling, low-gel type bentonite is associated with streaks of gypsum and reddish clay in the southeast part of the deposit. The reserves are about 1.76 million tonnes.

***Mahawar:*** Low-swelling and low-gel type bentonite beds are associated with the Barmer sandstone and the Malani volcanics. The reserves are about 0.011 million tonnes.

***Devka-Rajral:*** The bentonite deposits occur in the the Akli Formation of Eocene age. The thickness of bentonite bed varies from 4 m to 5 m and has low-swelling index and the low-gel type has pH ranging from 7.6 to 8.4. The indicated reserves at Devka are about 9 million tonnes while at Rajral it is about 6 million tonnes. The quality of the bentonite generally compares favourably with the standard materials and may be suitable for use in oil drilling, oil refining, foundaries and as filter in paper, rubber and textile industries.

**Jaisalmer district**

Bentonite to sub-bentonitic clays associated with Upper Jurassic to Eocene formations occur at Khuiala, Tetakhan, Banda, Ganwarwali Talai, Khenya, Sam and at many other localities. The impersistent clay beds, varying in thickness from a few centimetre to 2.50 m, are interlayered with foraminiferal limestone or calcareous siltstone. These clays are non-swelling or poorly-swelling type and do not appear suitable for drilling muds or foundry sand. The tentative reserves of these sub-bentonitic clays from these areas are of the

order of 6.25 million tonnes.

Besides, the sub-bentonitic clays associated with the Baisakhi shale and Bedesar calcareous claystone are also reported from Khuiala and Khudi. It is of medium-grade. Their reserves are estimated at 3 million tonnes.

### **BERYL**

Beryl, a silicate of beryllium and aluminium, is the principal source of beryllium metal which is lighter than aluminium. When alloyed with copper and after suitable heat treatment the alloy develops high-tensile strength and ability to withstand repeated stress. Beryl has become very important in recent years because the metal is used as moderator in nuclear reactors. A small quantity of beryllium is used in the chemical industry in the manufacture of beryllium salts and in ceramic glaze. The green transparent variety of beryl is emerald which is a precious stone.

Rajasthan is the principal beryl producing State in India. Beryl occurs in association with mica pegmatites in the mica mines of Ajmer, Udaipur and Bhilwara districts.

#### **Ajmer district**

Some of the important beryl workings from pegmatites are located near Lohagal (26°32' : 74°37') and Makrera (26°15' : 74°30'). Occurrences have also been reported near Gujarwara (26°01' : 75°08'), Bisundani (25°43' : 75°10'), Barla (26°26' : 74°44'), Rajosi (26°19' : 74°39'), Kairia (26°02' : 74°54'), Tihasi (26°24' : 74°55') and Dadia (26°25' : 74°59').

#### **Udaipur district**

Beryl occurrences have been recorded at Achieawas (25°20' : 73°51'), Deoru Guda (25°21' : 73°48'), Deopura (25°23' : 73°57'), Gadachat (25°18' : 73°50') and Jaolia (25°21' : 73°49').

#### **Bhilwara district**

Occurrences have been recorded at Tiloi (25°17' : 74°23'), Bhunas (25°25' : 74°23'), Jhampura (25°17' : 74°18') and Deora (25°34' : 74°17').

### **BISMUTH**

Bismuth is principally used in medical preparations. However, it has some other important uses for making fusible alloys in combination with tin, lead, mercury and cadmium, aluminium alloys (cerrobases alloys), production of atomic bomb, in radar equipment and in

nuclear energy projects.

Bismuth occurs in nature either in native form or as sulphide, bismuthinite  $\text{Bi}_2\text{S}_3$ . This mineral is generally covered by thin film of the yellow oxide, bismuth ochre and is frequently associated with the ores of tin, tungsten and other base metal sulphides. Most of the bismuth metal is won as a by-product in the smelting of other ores.

In Rajasthan, a very localised and small lensoid occurrence of bismuth ore from an unzoned pegmatite at Narda, Neem-ka-Thana tahsil, Sikar district has been reported with anomalous bismuth (84.20%), arsenic (1.08%), gold (70 ppm with bismuthinite, 1.7 ppm in host rock), lead (0.17%) and copper (0.11%).

### **BUILDING AND ORNAMENTAL STONES**

Rajasthan is famous for varieties of ornamental building and decorative stones such as marble, limestone, sandstone, granite, slate etc. The Taj Mahal, one of the wonders of the world, and the Victorial Memorial at Calcutta are made out of the white marble of Makrana area of Rajasthan, as also the famous mosques at Agra and Delhi and many buildings in Rajasthan, U.P. and Punjab. Black marble which receives good polish had been used in constructing some of the historical buildings and monuments of Delhi and Agra and is available in the mines in Jaipur district. The red and buff-coloured Bhandar and Jodhpur sandstones have also yielded excellent stones for the monumental structures in Delhi, Agra and other cities of northern India. Yellow marble of Jaisalmer district is another ornamental stone used in many famous buildings of Rajasthan.

#### **Basalt / Rhyolite**

South-eastern parts of Rajasthan are partly occupied by the Deccan Traps which constitute the main building stone in this area. The rhyolite is mostly used for railway ballast and other construction purposes in western Rajasthan.

#### **Flaggy Stone (Kotah Stone)**

Upper Vindhyan limestone, quarried in Kota and Chittaurgarh districts, occurs in shades of yellow, green and blue. The quarries are located at Ramganj Mandi, Chechat, Suket, Manpura, Morak and Mur-ka-Kheri in Kota district. Flaggy limestone also occurs near Aroutiya, Paroliya and Kishanpura in the Jhalawar district.

## Granite

Granite and associated rocks form excellent dimensional and decorative stones. Durability, hardness, capability of taking mirror polish and fascinating colours makes the granite most distinctive stone among marble, limestone and sandstone. It is widely used as polished tiles, slabs and monumental stone all over the world.

Rajasthan has inexhaustible resources of granite, occurring within the rocks of the Precambrian age ranging from Archaean (>2,500 Ma) to Neoproterozoic (1000-570 Ma). The granites, in commercial parlance, include wide range of igneous and metamorphic rocks comprising granite, granodiorite, gneiss, enderbite-choronokite, basalt, rhyolite, dolerite, gabbro, norite etc. These rocks occur as stocks, bosses, batholiths, dykes and/or sills.

The granite occurrences in Rajasthan are distributed over wide areas in Ajmer, Alwar, Banswara, Barmer, Bhilwara, Chittaurgarh, Dungarpur, Jaipur, Jaisalmer, Jalor, Jhunjhunun, Jodhpur, Nagaur, Pali, Rajsamand, Sawai Madhopur, Sikar, Sirohi, Tonk and Udaipur districts. A district-wise brief account of important localities along with nature, colour and commercial names of the granite is given below:

### *Ajmer district*

In Ajmer district the important localities are Dang, Patan, Paranga, Masuda, Jiwana, Ramgarh, Bhinai, Dantol, Chawndiya, Harmara Buharu, Bandanwara, Fatehgarh, Devpura, Devmali, Kanpura, Udaigarkhera, Gujarwara, Ramaliya and Sikharani. Granite occurrences are also reported from Ana Sagar, Naikalan-Nai Khurd, Rail-ka-Barie, Daulatpura, Dedpura, Morazari, Sendra, Gordhanpura and Bandra-Sindri. The outcrops are widespread and occur as low to high ridges and rounded rocky hummock in an otherwise penneplained terrain. The commercial granites include mostly various types of gneisses and migmatites in this district. Dolerite dykes also occur, at a few places, as rocky boulders in the alluvium covered areas as in Kanpura. The gneisses and migmatites mostly pink and grey in colour exhibit banded, streaky or wavy pattern. Streaky gneisses, banded gneisses and augen gneisses are some of the important commercial granite varieties noticed in these areas which have been given different commercial names as Pink-Tiger Skin Granite, Pink-Zuberine Granite etc.

### *Alwar district*

The granites occur around Harsora, Khatoli, Pahari, Deosan, Samda, Lialanwas, Jaisinghpur Khera and Gowara villages. Outcrops are distributed over a large area as isolated low to high mounds separated by alluvium and blown sand. Alwar Red and Alwar Grey are the commercially known varieties.

### *Banswara district*

Occurrences of granites are reported from Narwali, Ganoda, Jupel, Mayara, Munghali Sageta, Modasel, Panthal, Piplakhunt and Thikariya villages. The granites are mostly gneisses, migmatites and amphibolites and occur as low to high ridges and boulders scattered over a small area. The colour of these commercial granites is pink and black.

### *Barmer district*

Barmer district is very rich in good quality granites. The important occurrences are Harsani, Redana, Tribniyar, Bachabhar, Chohatan, Dhorimanna, Mangata, Meli, Ludrara, Devra, Mokalsar, Siwana, Suwala, Mungeriya, Rakhi, Phulan, Piplawa, Bachharan, Viratra, Dhok etc. In general, the granites are medium-grained and uniform in texture, and have bright colours though xenoliths of mafic rocks do occur at some places. The Barmer district has contributed to some of the famous varieties of granites viz., Mokalsar-Green, Nagina-Pink, Merrigold, Barmer-Red, Desert-Classic, Mungeriya-Amethyst, Desert-Pink etc.

### *Bhilwara district*

The high-grade granitoids and gneisses and associated mafic rocks of Bhilwara Supergroup have given some very good varieties of dimensional stone. The important localities are Amet, Giyangarh, Nareli, Rampura, Kirimal, Katar, Boriya-ka-Buria, Phakoliya, Dhuala, Barjat, Patan, Daulatgarh, Janada, Pithas, Naugauwa (black), Udairamji-ka-Guda (black), Thane, Dhikola, Charan-ka-Bariya, Dori-Somani, Sabadare etc. Most of the granites include various types of gneisses, granodiorites, charnockites, pyroxene-granulites, enderbites and migmatites. Of this charnockite-enderbite of the Nareli-Giyangarh areas are very distinctive. These rocks occur as scattered large sized boulders, small mounds and sheets and are dark-brown to bronze-black in colour with blue opalescent quartz blebs. Cobra Black, Pink-Cobra, Black-Pearl, Black-Fantasy and Black-Panther are the known commercial varieties from this area.

*Chittaurgarh district*

The important localities in the district include Golia, Didiya, Gangrar, Soniana, Khuntia, Ganeshpura, Nimbahera and Chhoti Sadri. Most of these granites are the Berach Granites. A greenish-pink variety of Golie-Didiya area deserves attention.

*Dungarpur district*

The important granite occurrences in the district are Jallara, Ramgarh and Punawali-Bokarsal. At Jallara, the granite is pinkish-brown in colour and exhibits porphyritic texture. Overall the quality of granite is not very good.

*Jaipur district*

In Jaipur district granite occurrences are confined to southern part of the district. The granites are mostly granodiorite and various types of gneisses. The important localities are Sakun-Hatipura, Mal-ki-Dhani near Dudu, Mengi, Degotha, Dantri-Ladera and Bassi-ka-Bas. At Mal-ki-Dhani it is pink porphyritic granite exposed at ground level and at Bassi-ka-Bas it is highly porphyritic grey granite. In general, the outcrop density is very low. It is exposed as discontinuous low to high ridges and segregated irregular boulders in an otherwise peneplained soil covered areas. Black-Rose, Fantasia-Nero, Mid-Night Sun are some of the known commercial varieties of this area.

*Jaisalmer district*

Granites and rhyolites of Malani Igneous Suite and pre-Malani granites occurring at Randha, Lakha, Bhadli, Sankara, Sanwara, Khavario-ki-Dhani, Chandani, Luna etc. are considered to have commercial significance. The granites are medium to coarse-grained while rhyolites are porphyritic in nature. A wide range of beautiful colour shades of pink, purple, red, grey and off-white are available. Besides, basic dykes forming the black granites are also present in the area.

*Jalor district*

In Jalor district most of the area is occupied by granites and rhyolites of the Malani Igneous Suite and Erinpura Granite which occur as isolated low to high hummocks, ridges and as segregated irregular boulders with intervening soil cover and blown sand. The Jalor district has some of the very well-known granites and highly potential prospects. In general, the granites of this district are very bright in colour and are available in different shades of pink, red, orange, yellow, grey and

white. These are mostly equigranular having uniform texture. Porphyritic varieties also occur at some places. The important localities are Sanphar, Pizopura, Keshwana, Kalaghatta, Kalkaji, Tarwa, Deru, Mur, Leta Dhawla, Bhatela, Maylawas, Sakarna, Bicchawari, Khambi, Nosra, Bagra, Nann, Korana Kot, Tabab, Sangaliya Jodha, Sangaliya Sindlan, Bibalsar, Ranwara, Talwara, Kaston, Dhola, Bala, Borta etc. JalorPink, Sindoor-Red, China-Pink, Anglo-Grey, Ash-Grey, Rosy-Pink, Jalor-Red, Rani-Yellow, Imperial-Pink and Royal-Touch are some of the well-known varieties in the granite market.

*Jhunjhun district*

The important localities in Jhunjhun district are Nand, Lal Pahari, Rizani-Rasoda-Nand-Bakara, Makhar, Karpura, Hukampura, Guda, Bagora, Banglawas, Dosi, Bibasar, Kherpura, Bassi, Gumansar, Gogaji-ka-Pahar, Khetri etc. Here the granite is mostly porphyritic and is associated with rhyolites and occur as bouldery hillocks and mounds. The granite is mostly pink and grey in colour. The well-known commercial varieties of these are Steel-Grey, Jhunjhun-Red and Grey and Makhar-Red.

*Jodhpur district*

Isolated outcrops of Erinpura Granite and Malani rhyolites form small hillocks or occur as ground level exposures. The important granite localities include Desuriya, Bishunaya, Jasai, Bisala, Taralana, Nangris, Jodha-Mali, Ransigaon, Khari yona, Ramaniyana, Madlia, Pipar, Khejaralo etc.

*Nagaur district*

The granite occurs near Morad and Kinsariya village. It is mostly pink in colour and exposed as segregated boulders in an otherwise soil covered areas.

*Pali district*

In Pali district off-white, bluish-grey, pink, orange and red varieties of granites mostly belonging to the Erinpura Granite are exposed as sheets and mounds, hillocks and scattered boulders. The granite, medium to coarse-grained in general, is of gneissic variety. Porphyritic varieties also occur at a few places. The important localities are Chotila, Kerla, Khardo-ki-Dhani, Kaliwara, JakhodaMetra, Chilai, Bar, Sendra (Jhala-ki-Chowki), ManihariBala, Paldi Sumerpur, Erinpura, Nana-Beda, Saithur, Rani Nadol-Narai-Veerpura, Kota, Samariya, Kherda, Kerale, Kothar,



Javaria, Netra, Jhakh, Khindra, DaniDantiwara, Ranchalwara, Satpalia, Sadri, Desuri etc. China-Blue, Silver-Grey and Imperial-Pink, Lovely-Orange and Tomato-Red are some of the well-known established varieties of this area.

#### *Rajsamand district*

Pink granite gneisses of Lasoni, Sonora-ka-Bariya and Kalaon-ki-Anty; brownish-black, pinkish-black, varieties of Kakrod, Isarmand and Malkot and white variety of Amet are important granites and their localities in Rajsamand district. The granite forms mostly bouldery country over a peneplained terrain.

#### *Sawai Madhopur district*

The important granite localities are Bauli, Baragaon, Sarwar, Khajana Dunger, Nagal Pahar and Karwaripal. Most of the granites are gneissic granites.

#### *Sikar district*

In Sikar district granite occurrences are reported from Dabla, Jeetala, Kharbipura, Ajitgarh, Jatpura, SeoliGowarian, Siroli, Saladipura, Chapoli, and Bagora. The granite occurs as high hillocks and isolated bouldary outcrops. Most of the granite is earthy to pinkish to grey in colour with red garnet spots. The granites of Sikar district in general are not of very good quality. Ajitgarh-Grey and Ajitgarh-White are famous varieties.

#### *Sirohi district*

Erinpura Granites are spread over a large part of the district and occur in the form of isolated outcrops, low lying hummocks and ground level exposures. These are mostly biotite-bearing greyish-white granites. At some places pinkish and red varieties belonging to Jalor Granite of Malani Igneous Suite are also exposed. The important localities are Sanpur, Mirpur, Jeerawal, Sivera, Viroli, Nandia, Birwara, Idarla-Karja, TawriJaila, Jivana, Sankara, Rampura, Van, Padiv, Kesarpura, Telpura, Abu, Veerwade-Arasanaji, Mermundwara, Koleshwara, PadruKhera, Shivganj, Anapura, Jhar, Amlari etc. Platinum-White variety is well-known in commercial market.

#### *Tonk district*

The granites, granodiorites, granitic gneisses, migmatite and associated mafic rocks of the Bhilwara Supergroup occupy most of the area in Tonk district. These rocks occur as sheets, scattered boulders, small mounds and hillocks. The important localities are

Deval, Ganwar, Rajpura, Lamba, Malare, Kadila, Hataki-Bagri-Rupawati, Phulmaliya, Hisampura, Malpura, Govardhanpura etc. The granitic gneisses, granites and migmatites are mostly pink to grey in colour with alternate bands of light and dark coloured minerals. Deval-Multi-colour and GreyTiger Skin are some well-known varieties from this area.

#### *Udaipur district*

The important granite occurrences in Udaipur district include Gingla, Untala, Udaisagar, Udaipur (Ahar river), Dakan Kotra, Jaisamand, Salumber, Jhalara, SairaPadrada, Kagwas, Moanda, Modi-Bathera-Kanor, Bari Sadri etc. In general, the granites of Udaipur district are not suitable for dimensional stone purposes. However, Akola-Khurd-Gyasapur area in Bari Sadri and Makreda Magra of Udaipur granite deserve attention.

### **Marble**

In Rajasthan, marble and marble based industries are very well developed. The marble and marble products are used in house construction, statues, marble chips, marble/dolomite powder and plaster making; as tyre detergent; and in gur, sugar, and paper industries.

The marble is won from the Precambrians of Rajasthan mainly from rocks of the Delhi Supergroup. However, marble is also reported from the rocks of B.G.C. and pre-Aravallis at places. Marble is mainly mined from Makrana, Rajnagar, Rikhabdev, Ajmer, Andhi and Bhaislana areas. Abur limestone and Jaisalmer limestone take good polish and are used as decorative stones. These are marked as 'Suparistone' and 'Yellow-marble' respectively.

Morwar in Rajsamand district has a single mine (out of numerous mines) which produces 300,000 metric tonnes of blocks-slabs of white marble per year creating a world record which find a place in the *Guinness Book of World Records*.

The enormity of the Morwar mines can be gauged by the fact that it has a spread of about 71,000 m². Sky-Line, Silver-Line, Emerald-Line, Green-Line, Grey-Line etc. are commercial names given to the other special varieties of marble products of the area. Production of blocks and slabs increased to 0.30 and 0.436 million m² respectively during 1996-97.

Rajasthan possesses the largest reserves exceeding 1,100 million tonnes accounting for about 95% of the total production of marble in India. The chief deposits of marble are as follows:

*Nagaur district*

At Makrana, the marble is fine-grained crystalline and calcareous in nature containing more than 98%  $\text{CaCO}_3$ . Chemically it has higher contents of silica, alumina and magnesia as compared to that of marble from Italy and Greece. Thus it has more abrasive resistance and is easy to process. Being fine-grained and comparatively free of impurities, it takes good polish and has great demand in market.

*Jaipur district*

At Bhainsalana the marble is fine-grained, dark, greyish-black, hard, compact, massive while the marble at Raisala and Andhi is dolomitic in nature, off-white and fine-grained. The Pista-marble of Andhi has comparatively better aesthetic value due to presence of uniformly scattered greenish minerals.

*Ajmer district*

Sursuri, Narawar, Tokra, Kishangarh, Umaria, Kharwa, Daulatpur, Baktawarpura, Shyopura, Bijapur, Sardhana, Kyampura, Magra etc. are the important localities of marble occurrences in the district.

*Udaipur district*

The marble of the Rajnagar-Agsia-Amet belt of Udaipur district is white to off-white in colour and contains comparatively more MgO content, as a result of which it turns yellowish after sometime. Similar marble deposits occur at Mandaria, Maharaj-ki-Khedi, Hairo etc. At Babarmal, pink, fine-grained, hard and compact marble occurs. It contains comparatively high silica. At Keshariaji (Rikhabdev), Prasad and Kalyanpura green serpentinite is mined and marketed as green marble.

*Sirohi district*

Ghoratankri, Perwa-Serwa, Murthala, Ajari, Bhala, Bhatan, Selwara, Deri, Indli, Badechi and Khandra are important localities of marble deposits. At Selwara, the large blocks of medium to coarse-grained marble could easily be excavated.

*Banswara district*

The marble occurring in this district is dolomitic, mostly fine-grained, white, light golden-yellowish, pink and green in colour. The important localities include Vithaldev, Tripura Sundri, Khema-Talai, Bhanwaria-Talai (white), Bhim-Kund, Oda-Bassi, Chinch (pink) etc.

*Bundi district*

Marble occurring at Bundi is commercially marketed as Umar marble. It is fine-grained, greyish to white with shades of green and pink. The marble is dolomitic in nature.

*Bhilwara district*

The marble occurring in this district is black, dark, green and greyish white in colour. Important localities include Manohargarh (Jahajpur), Boleta, Goga-ki-Khera etc. The marble is dolomitic in nature.

*Dungarpur district*

In this district fine to medium-grained, off-white, pink and green marble deposits are located. Important localities include Rohanwada, Mal-Surata, Antri-Peeth (green), Sabla, Nandli, Dad (pink) etc.

*Sikar, Pali and Chittaurgarh districts*

Maonda is an important locality for marble in Sikar district, while Bar and Sendra; and Mandaleh in Pali and Chittaurgarh districts respectively are known for marble occurrences.

*Alwar district*

In this district dolomitic marble deposits occur at Jhiri, Rajgarh, Kho, Sarer and Gordhanpur.

*Jaisalmer district*

Calcilutite and calcarenite varieties of fine-grained golden yellow limestone occurring near Moolsagar.

Amarsagar, Jethwai, Pithala, Chundi, Manpra, Bhagata etc. are commercially being exploited and marketed as yellow marble.

**Sandstone**

Sandstone is mainly found in the Vindhyan and the Marwar Supergroup sequences of Bharatpur, Tonk, Sawai Madhopur, Bundi, Chittaurgarh districts and Jodhpur, Bikaner, Pali, Jaisalmer districts respectively. Rajasthan has been the main centre of export of sandstone to other parts of the country. The important occurrences of sandstone are found in Bharatpur (Bansi-Paharpur  $27^{\circ}00' : 77^{\circ}10'$ ), Bikaner (Dumera  $28^{\circ}24' : 73^{\circ}35'$ ), Bundi (Umarthuna), Jaipur (Kotri  $27^{\circ}30' : 75^{\circ}35'$ , Juger and Radhonathgarh), Jodhpur (near Jodhpur city, Sojat  $25^{\circ}55' : 73^{\circ}40'$  and Khatu), Kota (Mokundwara, Kanawas), Tonk (Amli), Sawai Madhopur (Karauli  $26^{\circ}25' : 76^{\circ}55'$ , Hindaun) districts.

### Slate/Schist

Slate finds its use as material for roofing, paving and shelves. Slate deposits are found mainly in the Delhi and Aravalli rocks in parts of Ajmer, Alwar, Bharatpur, Bundi, Pali, Sawai Madhopur, Tonk, Udaipur and Chittaurgarh districts. Quarries in Jaipur, Udaipur, Alwar, Dungarpur and Banswara are providing schists and phyllites as roofing material.

Alwar slate has acquired a reputation in the world market for its quality and has left China and Spain far behind in the international market. Alwar district has enormous reserves of slates and has monopolised the Indian export. Alwar slates are used in the preparation of school slates, as roof tiles, and table top of the Billiard table.

The slates are available around Bahrod, Maton and Neemrana in huge quantity. Mines are also situated around Jakharana, Bassai, Kalor, Adind, Bhaiyasar, Mahatavas and Khundrot villages. RSMDC is engaged in slate mining at Maton.

### CALCITE

Calcium carbonate ( $\text{CaCO}_3$ ) is an important constituent of sedimentary rocks, next to quartz and clay minerals. In the form of limestone it is extensively used in the manufacture of lime, cement, ceramic products, calcium carbide and bleaching powder. In the pulverized form, it is used in paint, rubber, textile, paper, leather and sugar industries. Limestone of high-purity is used for imparting glaze in pottery and as a flux in metallurgical operations. Pure, crystallized, transparent variety of calcium carbonate, known as "Iceland Spar" is used in optical instruments.

The total reserves of calcite in India are estimated at 10,573 thousand tonnes. Rajasthan is the leading producer of calcite in the country (Table-13 & 13-A).

**TABLE-13**

*Production of calcite in India vs Rajasthan*

Year	India (x103 tonnes)	Rajasthan (x103 tonnes)
2003-04	122.329	121.329
2004-05	66.984	66.294
2005-06	73.332	72.892

Source: Indian minerals yearbook, 2006.

In Rajasthan, occurrences of calcite have been recorded from Sikar, Pali, Udaipur, Sirohi and Jaipur districts.

**TABLE-13A**

*Production of calcite district wise in Rajasthan*

Districts	2004-05		2005-06	
	No. of mines	Quantity ( $\times 10^3$ tonnes)	No. of mines	Quantity ( $\times 10^3$ tonnes)
Sikar	3	0.488	-	-
Sirohi	(1)	30.852	(1)	23.762
Udaipur	6	34.954	4	49.13

Source: Indian minerals yearbook, 2006; figure in parenthesis indicates associated mine

### Sikar district

Important deposits are located at Maonda (27°48': 75°58'), Jhamas, Raipur (27°44': 75°58') and Balupur. The deposits occur as veins, pockets and lenses in calc-gneisses of Delhi Supergroup. Steeply dipping veins about 0.75 m to 1 m in thickness are seen criss-crossing limestone and microgranite near Maonda where Bhikajiwali and Bada Khet quarries have given good production. DMGR has proved 39,300 tonnes of calcite at Raipur by putting 25 trenches.

### Jhunjhun district

Small occurrences are found near Paparna (27°56': 75°47') in the calc-silicate rocks.

### Pali district

Calcite occurrences are found at Bara Guda (25°51': 73°54'), Budha Lelwa (25°52': 73°54'), Kalhab (24°52': 73°11'), Kapli-ka-Bhagal (25°57': 72°58') and Khera Uparla (24°45': 73°10'). The deposits occur as veins, pockets and lenses in calc-gneiss, calc-silicate and marble of the Kumbhalgarh Group of the Delhi Supergroup. A number of small pockets of calcite are being worked at Pitlan Nana, Khemal Alipur, Khoral Patan and Dayalpura falling in Raipur and Jaitaran tehsils.

### Sirohi district

Occurrences of calcite are found near Bhula (24°33': 72°57'), and Tankiya (24°50': 73°03') in the crystalline limestone of the Delhi Supergroup.

### Udaipur-Rajsamand districts

Calcite occurs at Goiphal (24°47': 73°48'), Guda (24°35': 73°51'), Morchana (25°06': 73°41'), Ranakpur (25°07': 73°28') and Sadarla (24°55': 73°22') and Rabachh in the calc-silicate rocks of the Kumbhalgarh Group. The Rabachh deposit 73 km from Udaipur is a rich deposit containing 4,03,795 tonnes of calcite. Calcite occurs as thin to moderately thick veins of

variable length in zones of decomposed limestone. Other deposits are known to occur at Siyawa, Kheterla, Binsa Singh, Sanwara and many other places. Good deposit of calcite is located in Khila and Khera about 35 km northeast of Pindwara. Calcite occurs as oval to crescent-shaped capping over the wollastonite hill. Snow-white to white, off-brown and pale-white in colour, the calcite is invariably associated with skarn, cavities filled with mud and decomposed limestone patches. The DMGR has proved 8,78,330 tonnes of calcite at Khila and 8,618 tonnes towards at Khera where six pockets of white to off-white crystalline calcite occurs close to quartz and/or pegmatite veins.

### CHINA CLAY

Extensive deposits of china clay are found in India. With the increasing demand from industries like ceramic, refractory, textile, paper, rubber and pesticides, the production of the mineral has increased to a very large extent. Almost the entire production of china clay is consumed indigenously. A small quantity of superfine variety is also imported for specialized uses.

Rajasthan contributes about 50% production of china clay, 40% of ball clay and 10% of fire clay in the country. China clay is found to occur in Bhilwara, Bundi, Chittaurgarh, Jaipur, Jhalawar, Sawai Madhopur, Sikar, Pali districts etc. Ball clay occurs in Alwar, Bikaner and Bundi districts. Chemical analysis of important clay deposits of Rajasthan is given in Table-14.

### Bikaner district

Clay deposits have been reported from Mudh (27°52' : 72°54'), Chandi (24°53' : 73°00'), Kotri (27°50' : 72°59') and Palana (27°51' : 73°18').

*Mudh* : The clay is greyish-white in colour and free from grit. It is fine-grained and consists mainly of kaolinite. The clay has good plasticity, the water of plasticity being 27.6%. It fires to cream colour. Colour of the clay is not improved by washing. The estimated reserves are about 302 million tonnes.

*Chandi* : The clay deposit is found near the surface, overlain by 1 m thick bed of *kankar*. The thickness of the deposit varies from 0.12 m to 20 m. The clay has a good degree of plasticity, the water of plasticity being 27.6%. It fires to cream colour. The estimated reserves are about 3.05 million tonnes.

*Kotri-Marh-Gura area* : The extensive clay deposits around Kotri, Marh and Gura (27°50'20" : 72°57'30") area form a continuous horizon for about 15 km in strike length and extend beyond Gura. There are at least three clay horizons within the Palaeocene rocks. The middle clay horizon is the richest one having at least five separate clay bands alternating with ferruginous sandstone, grit and white siltstone. The individual clay beds are 13 m in thickness. The lower horizon contains two clay bands of 1.52.5 m thickness, while the upper horizon has only one bed which varies in thickness from 3 to 7 m. The clay devoid of grit is white, creamy or

**TABLE-14**  
*Chemical analysis of important clay deposits in Rajasthan*

	(District) (Village) Kotri	Bikaner Marh	Gura	Nagaur Khajwana	Sawai Madhopur Raesena	Basu	Sikar Torda	Bhilwara Mangrop	Sikar Bachara
SiO ₂	59.8	1	56.90	57.02	61.41	40.28	46.28	45.86	47.1763.58
Al ₂ O ₃	26.16	24.17	27.73	23.36	34.44	38.50	37.42	33.63	25.83
Fe ₂ O ₃	1.10	2.50	< 1	1.76	0.30	0.13	1.31	1.17	0.96
TiO ₂	2.91	0.63	1.73	—	1.66	1.58	0.12	2.50	—
CaO	Trace	Trace	—	2.43	0.25	0.18	1.12	0.12	—
MgO	Trace	0.90	< 1	1.70	0.36	—	0.15	0.92	—
K ₂ O	0.98	—	—	—	—	—	—	3.06	—
Na ₂ O	0.51	—	—	—	—	—	—	0.24	—
(KNa) ₂ O	—	2.90	< 1	—	0.14	0.46	0.35	—	—
LOI	8.56	6.00	10.64	7.46	12.37	12.18	13.6	10.65	9.63
P.C.E.				1,380°F					

Source : GSI.



brownish-white, often interlayered with impure clays, sometimes with ferruginous stains. It is highly plastic and fine-grained, and composed mainly of kaolinite. The water of plasticity is about 27.6%.

The reserves of clay are expected to be about 43.67 million tonnes. The clay is being used in ceramic industry and as filter in paper and textile industries.

#### **Barmer district**

Clay deposits occur in Bolia (25°59' : 71°22'), Bhadras (25°83' : 71°19'), Gunga (26°48' : 73°30') Nagurda (26°10' : 71°23') Nimla (26°03' : 71°20') and Sonri (25°59' : 71°10').

**Bolia :** The clay occurs in six beds, interstratified with sandstone, varying in thickness from 0.75 m to 3 m. Based on an average total thickness of 7.6 m, 1,01,000 tonnes of reserves have been estimated for the deposit. The water of plasticity (25.1%) and vitrification temperature (1,450°C) make the clay suitable for pottery earthenware, paper and rubber industries.

**Gunga :** A creamish-white plastic clay bed of about 2.4 m thickness is present. The clay vitrifies at 1,320°C and is suitable for low-grade pottery. Similar type of clay also occurs at Nimla, Bhopa etc.

#### **Bundi district**

A two-metre thick kaolin band occurs along a ridge south of Manak Chowk (25°33' : 75°54'). The reserves were estimated approximately 1,01,600 tonnes. This clay is white in colour which on firing changes to cream and grey colour. Other parameters are water of plasticity (23.428.4%), air shrinkage (2.392.87%) and moderate vitrification.

#### **Pali district**

Greyish-white clay with an average thickness of 2 m occurs in Literia. Upper part of the deposit is slightly iron stained. It possesses a fair degree of plasticity (25.01%). The estimated reserves of the deposit are about 2.53 million tonnes.

#### **Nagaur district**

**Khajwana (26°55' : 73°53'):** A 1.5 m thick non-plastic clay bed within the Nagaur sandstone is exposed in a quarry. It is reported to be useful in earthenware paper and rubber industries.

Clay pockets are also reported to occur at Kuladah, Indawar, Mundwa, Nimri, Chandawatan, Saradana and Haldah.

#### **Sawai Madhopur district**

Clay has been reported from Raesena (26°41' : 76°36'), Basu (26°06' : 76°36') and Phalodi (20°51' : 76°26').

**Raesena:** The clay is whitish in colour and has fairly good plasticity. It fires to white colour. The reserves estimated are about 3.05 million tonnes.

**Basu:** The clay associated with feldspathic quartzite is white in colour and free from grit. The reserves estimated of the deposit are about 1.12 million tonnes.

**Phalodi:** The 1.52.4 m thick clay located in Phalodi, is plastic, slightly gritty, white to pale-yellow in colour. It vitrifies fairly at 1,450°C and fires to pale-grey with dark spots. The reserves estimated vary between 20,300 tonnes to 38,600 tonnes. Other clay occurrences are at Naurali (26°16' : 76°53') and Talwara (26°20' : 76°38').

#### **Sikar district**

The clay deposits are found near Buchara (27°30' : 75°55'), Torda (27°26' : 76°01'), Fatehpura (27°34' : 76°03'), Khelna (27°32' : 75°09'), Sonpura (27° 30' : 76°03'), Gol (26°37' : 76°23') and Purshotampur (27°43' : 75°52').

**Buchara :** The clay bed, about 5 m thick, derived from the kaolinised feldspar of pegmatite is located east of Buchara. The reserves estimated are about 1,12,000 tonnes. The clay is generally white in colour, fairly plastic, the water of plasticity being 33.32%. The chemical analysis of the clay is : SiO₂-63.58%, Al₂O₃-25.83%, Fe₂O₃-0.96% and L.O.I.-9.63%. Blended with high-grade clay, this clay can be used in the manufacture of stoneware, chinaware etc.

**Torda :** The average thickness of the clay band at Torda is about 5 m and the reserves estimated for the deposit are about 60,000 tonnes. The clay is white with occasional limonitic stains. The water of plasticity is 33.44% and sp.gravity is 2.5.

#### **Alwar district**

Clay is reported near Rajgarh (27°09' : 76°35'), Phargoli (27°09'30" : 76°49'), Mudali (27°19' : 76°38') and Kalgaon (27°42'30" : 76°46'). It is greyish-white in colour and slightly iron stained. The clay is moderately plastic with the water of plasticity 15.99%.

#### **Bhilwara district**

Clay deposit occurs near Mangrop (25°40' : 74°40').

The average thickness of the deposit is 2.5 m. The clay, soft and white in colour, is very plastic and fires to cream colour. The estimated reserves are about 1.01 million tonnes.

#### **Chittaurgarh district**

Good clay deposits are reported to occur near Eral (24°31': 74°40') and Sawa (24°45': 74°30').

*Eral:* Clay is greyish-white in colour, very fine-grained and fairly plastic. The estimated reserves of the deposit are about 6.1 million tonnes.

*Sawa:* The Sawa clay is generally greyish-white in colour and fires to buff colour. It is moderately plastic, the water of plasticity being 18.04%.

#### **Udaipur district**

The clay deposit is located about 7 km ESE of Udaipur near Kharbaria-ka-Gurha (24°33': 73°43'). The thickness of the clay band is likely to exceed 17 m. The inferred reserves of this deposit are about 3.99 million tonnes. The clay is fairly plastic, the water of plasticity varying between 31.24% and 44.70%. It is non-fusible when fired to 1,400°C and has a low-dry shrinkage.

#### **Jaisalmer district**

Pockets and bands of clay interstratified with the Lathi sandstone occur at Chhor, Keta and Duskot and within the Mandai sandstone at Mandai. The clay bands are 12 m in thickness. The clays have low-shrinkage and have restricted use in pottery as they develop cracks on firing.

#### **Jodhpur district**

Clay bands ranging in thickness from 3 m to 6 m occur on the Masuria hill near Jodhpur. Low-grade variety occurs at Kharadia within limestone of the Bilara Group.

### **COLUMBITE TANTALITE**

(*Niobium - Tantalum*)

Columbite and tantalite, the niobates and tantalates of iron and manganese, are the most important ores of niobium and tantalum. The nearly-pure niobate is called columbite and the nearly-pure tantalate is tantalite.

#### **Ajmer district**

Columbite and tantalite are reported to occur in pegmatites at Ugai mine, Lohagal and Makerwali, Dazipura and Nimrikhera (25°59': 74°10').

#### **Udaipur district**

At Lakola (25°10' : 74°18') large irregular crystals weighing up to 15 lbs. containing over 30% Ta₂O₅ and 45% Nb₂O₅ are reported to occur in pegmatites.

#### **Chittaurgarh district**

Columbite-tantalite mineral is reported to occur at Soniana where coarse-grained mineral is associated with veins of quartz and aplite with 35% Ta₂O₅ and over 41% Nb₂O₅.

#### **Bhilwara district**

The columbite-tantalite ores containing about 15% Ta₂O₅ and 60% Nb₂O₅ are reported to occur at Sangua. The presence of columbite and tantalite has also been recorded from the pegmatite bodies at Danta mines, Laxmi mines and Bhunas (25°13' : 74°23').

### **COPPER**

Copper is the most essential metal used by the man since the 'Bronze age'. In spite of its part substitution by aluminium, the demand of copper is ever increasing. At present the production of copper metal in the country is only 15,000 tonnes as against the annual demand of about 0.5 million tonnes. A major part of the demand for this metal is, therefore, met by imports causing heavy drain on our foreign exchange.

Substantial reserves of copper ore have been established in Rajasthan, which now hold a significant place in the country in this important base metal resource. The main occurrences of copper ore are located along the prominent mineralized belts viz., Khetri Copper Belt and Alwar Copper Belt in the northeast part of the State. Besides, a number of small copper deposits associated with other base metal occurrences, which are under various stages of exploration, have been brought to light in other parts of the State.

#### **Jhunjhunu district**

##### *Khetri Copper Belt*

The Khetri Copper Belt extends over a strike length of about 80 km from Singhana in the north to Raghunathgarh in the south. The important deposits are located at Madhan-Kudhan (28°05' : 75°48'), Kolihaan (28°02' : 75°47'), Akwali (27°56' : 75°48'), Satkui (27°49' : 75°33') and Dhanota (27°45' : 75°36'). In addition a number of branching and parallel zones have also been found along the belt at Deoru (28°03' : 75°48'), Banwas (28°05' : 75°48'), Dholamala (27°59' : 75°48'), Rajotha

(28°01' : 75°49'), Usri (27°49' : 75°48'), Ajitsagar (28°03' : 75°52'), Taonda (27°58' : 75°53'), Malwali (27°57' : 75°50'), Chinchorli (27°50' : 75°45'), Bokri, Naori (27°50' : 75°38'), Ponk (27°48' : 75°38'), Gorla (27°45' : 75°51') and other places.

*Madhan-Kudhan deposit* : The deposit is situated towards the northern extremity of the Khetri Copper Belt and is 30 km by road from Nizampur railway station on Rewari-Reengus section of the Western Railway. The Cu mineralization in this area is found in the Ajabgarh and the Alwar Groups of rocks belonging to the Delhi Supergroup. The principal host rocks for mineralization are the garnetiferous chlorite-quartz-amphibole schist and quartzite. The Cu mineralization is mainly in the form of irregular net-work of impersistent stringers, disseminations, blebs and patches of metallic sulphides, mostly chalcopyrite, pyrrhotite and pyrite. Pyrrhotite is about three times as abundant as chalcopyrite. Pyrite is present in negligible quantity or may represent 5-10% of the total sulphides.

This deposit was investigated and proved by GSI/IBM during the period from March, 1957 to November, 1964. The block was handed over to the Hindustan Copper Ltd. (HCL) in 1964 for exploitation. However, further drilling in this area is being continued by the GSI/MECL on behalf of HCL in the extension areas. The total drill-indicated reserves are of the order of 92.8 million tonnes comprising 46.2 million tonnes of proved category and 46.6 million tonnes of probable category having an average grade of 1.0% Cu. The underground exploration by HCL for detailed proving has indicated so far 43.92 million tonnes of proved category of 0.91% Cu at 0.5% cutoff, most of which is localised in the Central Block.

*Kolihan deposit* : The Kolihan deposit is situated 6.5 km to the south of the Madhan-Kudhan deposit and 3 km from Khetri. The Kolihan deposit has been divided into seven blocks viz., South Block, South-Central Block, Central Block, North-Central Block, North Block, Kalapahar Block and Intervening Block. The Central Block constituting the main Kolihan deposit and the South Block, called Chandmari deposit, have been proved and recommended for production by the GSI. The distinct lodes were delineated in the Central Block (main Kolihan deposit) with copper content up to 2.5% in the mineralized lodes. Small amount of Ni, As and Ag are also found. The reserves estimated in this block are of the order of 24.43 million tonnes of ore containing an average grade of 1.4% Cu. In the South Block (Chandmari deposit), reserves of 3.50 million tonnes of

copper ore with an average grade of 0.88% Cu have been established by the GSI. Drilling in the North Block has indicated reserves of about 1.34 million tonnes of ore containing 1% Cu.

*Akwali deposit*: Akwali deposit lies in the middle of the Khetri Copper Belt and is about 6 km south of Khetri. Cu mineralization has been traced by GSI during 1962-1970 over a strike length of 1,000 m in Akwali North Block of which about 700 m is more promising. The estimated reserves are about 1.65 million tonnes of ore containing an average grade of 1.5% Cu. Some of the copper ores from Akwali area also contain rich pockets of Cu mineralization.

*Satkui deposit*: The deposit is situated at about 20 km east of Neem-ka-Thana railway station. The mineralized zone at Satkui constitutes a part of Gorla-Satkui-Dhanota section of the Khetri Copper Belt. A number of old workings and shafts spread over a strike length of 700 m are present in the western flank of the Satkui hill. Besides these, mine debris and slag dumps lie scattered over the sand dunes near the old workings. The mineralized zones are found to be localized along a major strike-slip fault developed at the contact of the massive hard quartzite and soft phyllitic quartzite of the Ajabgarh Group. Copper mineralization has been traced over a strike length of 1,000 m. The drill-indicated reserves are of the order of 3.88 million tonnes of ore containing an average grade of 1.19% Cu at 0.5% cutoff.

*Banwas (28°05' : 75°48')*: The deposit is situated north of Madankeda deposit. The area is largely under a cover of alluvium except in the southeastern part where lenticular bands of marble occur in the chlorite schist. The sulphides comprising pyrrhotite, chalcopyrite and pyrite occur as fine disseminations, stringers and veinlets along bedding, foliations and fractures in siliceous dolomite, schist and in footwall quartzite. The reserves estimated over 800 m strike length in the area are of the order of 2.64 million tonnes of ore containing an average grade of 1.9% Cu.

*Dholamala (27°59' : 75°48')*: This deposit occurs as a parallel zone about 1.5 km to the east of Khetri Copper Belt. The sulphide mineralization is mainly of massive and disseminated type. Mineralization is restricted to the sheared and silicified zone occurring at the contact of garnetiferous chlorite schist and amphibolite. The ore reserves estimated by the MECL are of the order of 1.5 million tonnes of 0.91% Cu.

Other smaller deposits of copper ore along the belt, where the ore has been proved to some extent are mainly

located at Deoru, Kalapahar, Singhana Muardpur Pacheri, Surahari, Usri, NaoriPonk, Dhanota, Taonda, Malwai, Chinchroli, Bokri etc. Occurrences of copper at Tatiya (28°04': 75°40'), Bhasawata (28°08': 75°01'), Bagor (27°58': 75°46'), Belwa (27°59': 75°40'), Fatehpur (27°48': 75°44'), Nalpura (28°01': 75°53'), Rajota (28°01': 75°48'), Mansagar (27°56': 75°48'), Babai (27°33': 75°46'), Sardarpura (28°57': 75°40'), Papurna, Rampur, Sheopuragarh, Kakrana, Nangel, Khandela have been reported.

### Sikar district

#### Neem-ka-Thana area

**Baleshwar deposit:** The copper deposit at Baleshwar (27°43': 75° 55') discovered by the GSI is located about 10 km to the east of Neem-ka-Thana railway station. The deposit consists of at least three parallel NE-SW trending sub-vertical mineralized shear zones within highly-folded calc-gneisses of the Ajabgarh Group. The sulphides occurring in the mineralized zone include chalcopyrite, pyrite, pyrrhotite and bornite. The Cu mineralization occurs as dissemination, stringers and lenticular patches. The reserves are of the order of one million tonnes of ore containing 1% Cu.

Other smaller copper deposits of worth, consideration are those of Neem-ka-Thana, Dariba, Tejawala, Ahirwala and Chiplatea areas.

### Alwar district

#### Alwar Copper Belt

**Bhagoni deposit:** A large number of old shafts and slag heaps are seen scattered about a km north of

Bhagoni (27°17': 76°21') indicating thriving mining activity in the past.

Exploratory drilling conducted so far reveals that the mineralized zones are 5-30 m (average 7 m) in width and extend over a strike length of 1,500 m. Mineralization is localized along zones of bedding shears between amphibolites and biotite-quartz schists of the Ajabgarh Group. Chalcopyrite, pyrrhotite and pyrite are the primary sulphides which occur as disseminations, coarse to medium in size and also as fracture and cleavage-fillings. Reserves of about 5.22 million tonnes of copper ore with 1% Cu are estimated down to a depth of 250 m.

**Kho-Dariba (27°10': 76°24'):** The deposit, located at a distance of about 42 km to the west of Rajhgarh (27°10': 76°35') was investigated in detail by the IBM during 1956-63. Copper mineralization in the area is found in the rocks of the Alwar Group of the Delhi Supergroup. Phyllites, to which the mineralization is essentially confined, occur as minor intercalated bands in the arkosic quartzites. The chief copper mineral is chalcopyrite associated with cubanite and pyrrhotite. The mineralization in quartzite bands and lenses is mostly of disseminated-type with occasional clusters and patches of chalcopyrite. The replacement-type mineralization is confined to the southern portion of the lodes. The total strike length of the deposit is 3.3 km consisting of two main blocks viz., Dariba mine and Dariba nala blocks. The estimated reserves (in both the blocks) are about 0.56 million tonnes of an average grade of 2.46% Cu over a width of 6.7 m.

**TABLE-15**  
*Block-wise reserves of copper in Pur-Banera-Bhinder belt*

Name of prospect	Rock type	Mineral/ Metal	Strike length	Cutoff	Grade	Reserves(million tonnes)	Category	Type
Pur-Dariba	Silicified zone calc-gneiss	Cu	250 m	—	1.03% Cu	1.173	Proved	Lenticular'pencil' shaped ore shoots
Gurla (North)	Sericite-quartzite, calc-gneiss	Cu	80 m	—	0.58% Cu	0.72	Probable	lenticular
	Quartz-magnetite-amphibolite	Cu	—	—	1.09% Cu	3.02	Possible	-do-
Manpura	Banded calc-gneiss	Cu	450 m	—	—	—	—	Lenticular discontinuous patches
Banera Forest	-do-	Chalcopyrite	1,500 m	—	0.5%	1.00	Possible	Shoots, lenticular
Devpura- Banera	Sericite-quartzite, calc-gneiss, quartz-biotite-garnet schist	Cu, Zn, Pb	2.5 km	Natural	1.08	1.73	Probable	Lenticular, discontinuous ore bodies for a strike length of 920 m
		Cu		0.67	1.00	0.94	Possible	Lenticular shoots
Malikhera	Sericite-quartzite	Cu	800 m	0.2%	0.4%	1.0	Possible	
Sanganer	Quartz-magnetite-gneiss, calc-silicate, garnet-mica schist.	Cu	3.20 km	0.2%	0.5%	20.0	Possible	

Source : GSI



Other smaller deposits of copper in Alwar and Jaipur districts, where copper ore with average grade of 0.5% have been reported, are at Baldeogarh (27°08': 76°23'), Kalighati (27°19': 76°25'), Nalladeshwar (27°25': 76°27'), Kalajoda (27°26': 76°11'), Pratapgarh (27°15': 76°09'), Matasula (27°09': 76°05'), Gol-Badshapur (27°16': 76°05'), Dhanta (27°13': 76°04'), Todi-ka-Bas and Achrol (27°08': 75°59'). Copper occurrences have also been reported from Agar (27°19': 76°12'), Deota (27°49': 76°45'), Tatarpur (27°45': 76°35'), Piplai (27°13': 76°15'), Angari (27°21': 76°35'), Sainpuri (27°44': 76°38'), Baraud (27°54': 76°23'), Jodhwas (27°20': 76°18'), Dhaula and Khan Khera.

### **Bhilwara district**

*Pur-Banera-Bhinder belt:* The Pur-Banera belt (25°18': 74°33' to 25°30': 74°41') extends over a length of 34 km having a width of about 5 km. The belt is subdivided into a prominently Pb-Zn rich eastern zone and a Cu-rich western zone in which the mineralization is associated with quartz-biotite-muscovite-garnet schist, quartz-amphibole-magnetite gneiss, sericite quartzite and calc-gneiss.

Old workings, gossans and slag heaps indicating favourable locales for Cu, Pb and Zn mineralization are scattered over a strike length of 25 km. This area has been under exploration by the GSI from time to time.

Copper deposits/occurrences of significance are located at Pur-Dariba, Gurla, Manpura, Banera forest, Devpura Banera, Malikhera, Sanganer, Rajpura, Dhulikhera and Gadan-ka-Khera (Table- 15).

*Devpura-Banera block :* The main rock types are calc-gneiss with magnetite-rich bands, sericite quartzite and quartz-biotite-muscovite-garnet schist. The rocks trend N50°-70°E - S50°-70°W dipping 45° due SE. Cu mineralization is mainly found in sericite quartzite and its contact with calc-gneiss. The mineralized zone is traced over a strike length of about 2.5 km (the main concentration being confined to one km length) with a width of 25-140 m. The main sulphide minerals are chalcopyrite and pyrite with minor cubanite, covellite and bornite. In total, 16 lodes have been delineated

within the mineralized zone. The main lode extends over a strike length of 920 m with a width of 1-6.5 m containing 0.8% copper.

### *Kaladhunda-Lakhola-Surawas belt*

The Kaladhunda-Lakhola-Surawas belt has been considered as the northeastern extension of Bethumbi-Rajpura-Dariba synform. It is a narrow belt over 25 km long and 1 to 1.75 km wide extending from Kaladhunda in the northeast to Surawas in the southwest. The Bethumbi-Dariba-Rajpura belt occurs in south-western extension of this belt.

Evidences of base metal mineralization in the belt are seen in occasional development of gossans, profuse development of malachite stains particularly in calc-silicate rocks and the presence of a few old workings. The rock types exposed in the belt are medium-grade garnetiferous mica schist, quartzite, quartz schist, amphibolite, calc-silicate rock often interbanded with dolomite and marble, marble with lenses of calc-silicate rock and carbon phyllite.

Geochemical bedrock sampling of the belt indicates higher concentration of Cu in amphibole and calc-silicate rocks while zinc shows preferential enrichment in marble and carbon phyllite. A strong Cu anomaly zone, extending over 2,000 m strike length, is located between Kaladhunda and Satdudhia. Another 1,000 m long Pb and Zn anomaly zone, near Bharak, partly coincides with high-Cu zones.

In Satdudhia (24°14' : 74°17') area which is the north-eastern continuation of Rajpura-Dariba belt, two ore bodies of 500 m and 100 m strike length, having more than 1.5% Cu have been delineated within a 1,400 m long mineralized zone. Mineralization is stratabound within garnet and staurolite bearing mica schist close to its contact with calc-silicate rock. Total reserves of 0.95 million tonnes of ore with 1.34% Cu have been estimated.

### **Chittaurgarh district**

Small copper deposits of importance are also established in Wari-Akola-Bhinder segment i.e., the southern half of the Rajpura-Dariba-Bhinder Belt.

### Wari-Akola-Bhinder segment

In the Wari Akola Bhinder segment carbonaceous schist, soda-rhyolite, garnet-mica schist, staurolite/kyanite schist, amphibolite and quartzite are tightly folded into isoclinal folds with fold axes trending NS. The host rocks for Cu mineralization are metasoda- rhyolite, garnet-mica schist and quartz amphibolite. Mainly copper mineralization has been encountered in this segment. Chalcopyrite, pyrite and pyrrhotite are the main ore minerals occurring as disseminations, stringers and veins. Mineralization is often fault/shear controlled. A list of the blocks in which reserves have been estimated is given in Table-16.

*Wari (24°53': 74°32')*: This deposit is located a km west of Wari and 5 km south-southeast of Dariba-Rajpura Pb-Zn deposit. The ground is mostly covered with scanty exposures. Garnetiferous mica schist and amphibolite with bands of calc-silicate rock are the main rock types which are intruded by quartz vein and dolerite. Cu mineralization occurs in lenticular bands showing pinch-and-swelling structures in the amphibolite-rich rock. The sulphides are chalcopyrite, pyrite and pyrrhotite. Reserves of about 1.89 million tonnes of 1.07% Cu have been estimated.

### Sirohi district

*Pipela-Ajari area*: Evidences of Cu mineralization at Pipela (24°38': 72°56') about 30 km north-northeast of Deri (24°23': 72°50') and Ajari (24°48': 73°03') have been

reported. The mineralized zone varies in width from 0.20 m to 12 m with 0.52.74% Cu and 0.50.72% Zn in Pipela while at Ajari the zone varies in width from 0.5 m to 12 m with 0.241.89% Cu and 0.573.32% Zn. The geological set-up is similar to Basantgarh and Golia deposits. The rocks belong to the Kumbhalgarh Group of the Delhi Supergroup.

*Deri area*: The DMGR has proved Cu mineralization in association with Pb-Zn mineralization near Deri (24°23': 72°50'). The presence of six parallel bands of mineralization over a total strike length of one km has been proved. The estimation of reserves indicates the presence of more than one million tonnes of ores containing Cu (1.87%), Zn (7.32%) and Pb (5.49%). In the East Block a 3 m wide zone with Cu (0.98%), Zn (12.01%) and Pb (2.64%) has also been intersected while drilling.

*Golia*: The DMGR has also proved Cu mineralization with zinc near Golia (24°41': 72°58'). Exploratory work in this area indicated reserves of about one million tonnes containing 0.8% Cu.

*Basantgarh*: This deposit, located at a distance of 10 km from Sirohi-Road railway station, lies in the Deri belt. The rock formations are limestone, garnetiferous chlorite-biotite schist, calc-gneiss, amphibolite and quartzite belonging to the Kumbhalgarh Group of the Delhi Supergroup. A prominent gossan zone is exposed in the calcareous formation on the western bank of Dharwet rivulet.

**TABLE-16**

*Block-wise reserves of copper in Wari-Akola-Bhinder segment of the Pur-Banera belt*

Name of prospect	Rock type	Mineral/Metal	Strike length	Cutoff	Grade	Reserves (million tonnes)	Category	Remarks
Wari	—	Cu	—	—	1.09%	3.02	Possible	Lenticular to shoot-type ore bodies
Pari	Soda-rich silicified gneiss/schist	Chalcopyrite	600 m	0.2%	0.9%	1.0	Possible	-do-
Rawatia Bhagal	-do- Meta-soda-rhyolite, amphibolite	-do- Chalcopyrite	140 m 1,400 m	0.2% 0.7%	1.37% Cu 1% Cu	0.43 2.8	Possible Possible	-do- -do-
Akola	Migmatized metapelite and amphibolite	Cu	1,250 m	—	0.75%	2.5	Probable	Along N-S shear zone

Source : GSI

The sulphide mineralization is mostly in the sericite-chlorite schist either as disseminations and stringers of pyrite, chalcopyrite and sphalerite or as massive ore. The maximum assay values for copper and zinc are 22% and 7.4%, respectively. The mineralization has been proved over a strike length of 1.15 km. The ore zone consists of seven vertical lenses arranged in an echelon pattern. The reserves estimated are 3.58 million tonnes containing 1.74% Cu and 1.27% Zn.

#### Dungarpur district

*Pader-ki-Pal* (24°54': 73°30'): This deposit is located at a distance of about 33 km northwest of Dungarpur on Udaipur-Ahmedabad (N.H. 8) road. The Cu mineralization over a strike length of about 900 m has been established in this area. Chalcopyrite, pyrite, bornite, covellite and azurite are the ore minerals. The host rocks of mineralization are quartzite and talc-chlorite schist. In general, two zones with average width of 2 and 5 m have been encountered. The depth persistence of the ore bodies have been established up to a vertical depth of 100 m from the surface. Reserves of about one million tonnes containing 1.12% Cu have been indicated.

Significant copper occurrences have also been reported from Amjhara (23°53': 73°32') and Bichiwara (23°45': 73°31') areas.

#### Udaipur district

The Cu mineralization in the form of irregular small narrow lenses with limited extensions have been indicated by exploratory drilling at Gopakura (24°55': 73°52'), Majera (24°47': 73°45'), Karoli (24°57': 73°45') and Umra (24°32': 73°48'). At Gopakura, reserves of about 0.03 million tonnes containing 1% Cu have been estimated by DMGR. At Majera, reserves of about 11 million tonnes with 0.6% Cu have been estimated.

#### Banswara district

Significant Cu mineralization has been reported by exploratory drilling at Jharka (23°45': 74°25'), Goj-Parla (23°57': 74°24'), Jagpura (23°54': 74°21') and Bhukia (23°32': 74°21') areas.

#### Other copper occurrences

Occurrences of Cu mineralization have also been reported from other parts of Rajasthan. The important areas are Chenpura (26°17': 74°39') in Ajmer district; Bidasar (27°48': 74°22') and Biramsar (26°02': 74°46') in

Churu district; Balia (27°12': 74°35') in Nagaur district; Hathroi (26°50': 77°06') in Bharatpur district; Rupali (26°42': 76°32') in Sawai Madhopur district; Chitar (26°07': 74°13') and Anarkhera (26°07': 74°30') in Pali district and Jhalawar districts.

### CORUNDUM

Corundum, due to its hardness, is used mainly in manufacturing abrasive material. In sintered form, it is used for special refractory crucibles. Synthetic corundum is in great demand as the production of natural corundum is insufficient to meet the demand.

Ruby and sapphire are the transparent gem varieties of corundum. Ruby is rose-red, carmine or purple. True sapphire is blue. Other colours in sapphire include white, yellow, green or pink. Reserves and production figures of corundum in India and that of Rajasthan State are given in Table-17 and Table-18.

**TABLE-17**

*Reserves of corundum as on 1.4.2005; (in tonnes)*

State/District	Proved	Probable	Remaining resources	Total
India	317	288	83190	83795
Rajasthan	--	--	11925	11925

Source: Indian minerals yearbook, 2006

**TABLE-18**

*Production of corundum; (in kg)*

State/District	1992-93	1993-94	1994-95
India	21,210	20,709	7,210
Rajasthan	475	1,610	480

Source : Indian Minerals Year Book 1996, Vol. 2, 1998, p. 311.

### DOLOMITE

Dolomite occurs in massive or bedded form. Its main industrial application is as a flux material in the iron and steel industry which accounts for 91% of the total consumption in the country. Besides, it is used in glass, ferroalloys, alloysteel, fertilizer, ceramics, chemicals, electrode, rubber, building construction etc.

The country has sizeable recoverable reserves of 4,967 million tonnes. However, requirement of low-silica dolomite is expected to rise substantially with the gradual change over from OH to LD process. The reserves of LD-grade dolomite with less than 1% SiO₂ are very small.

Though there are many occurrences of dolomite in the various geological formations of Rajasthan,

production of dolomite is very small as there are no metallurgical and other industries in the State.

The dolomite deposits occur in Ajmer, Alwar, Bhilwara, Jaipur, Jaisalmer, Jhunjhunun, Jodhpur, Nagaur, Pali, Sawai Madhopur and Udaipur districts. The total reserves in the State are placed at 1,62,644 thousand tonnes. The distribution of reserves into categories and grades is given in Table-19 and the production of dolomite in Table-20.

**TABLE-19**  
*Recoverable reserves of dolomite in Rajasthan;*  
*(In thousand tonnes)*

Grade	Proved	Probable	Possible	Total
BF	—	75,750	13,000	88,750
Refractory	—	23,496	—	23,496
Others	—	3,644	1,256	4,900
Unclassified	5,325	3,200	14,458	22,983
Not-known	—	2,821	19,694	22,515
All grades	5,325	1,08,911	48,408	1,62,644

Source : IBM

**TABLE-20**  
*Production of dolomite; (in tonnes)*

State/District	2003-04	2004-05	2005-06
India	4051409	4339306	44281193
Rajasthan	123502	108128	153247
Dausa	--	1460	--
Rajsamand	--	87998	84234
Udaipur	--	18394	69013
Sikar	--	276	--

Source: Indian minerals yearbook, 2006

### Ajmer district

Dolomite deposits occur around Kajla Kabra. The reserves are estimated to be around 13,000 thousand tonnes of BF grade. It is coarse-grained and greyish to white in colour. It contains 19.22% MgO, 4.10% SiO₂, 30.29% CaO and 0.24% R₂O₃ and has a specific gravity of 2.6.

### Alwar district

The deposits of dolomite occur around Jhiri, Dhani, Nizra and Devimata localities. The reserves are placed at 360 thousand tonnes. Dolomite has saccharoidal texture and is white to dark grey in colour. The Jhiri deposit which is 60 m wide extends over a strike length of about 360 m. This dolomite is used as marble.

### Bhilwara district

The dolomite around Kosithan is white to grey in

colour, and compact in nature. It contains 15 to 21% MgO, 30 to 34% CaO, 1 to 4.5% SiO₂ and 0.4 to 1.50% R₂O₃. The reserves are estimated at 9,269 thousand tonnes.

### Chittaurgarh district

Dolomite in Chittoria-Gorla-Chandakhedi areas is grey in colour, fine-grained, hard and compact containing MgO 18.12 to 19.53%, CaO 29.40 to 31.44%, R₂O₃ 1.12 to 2.62% and SiO₂ 6.2%. The reserves are yet to be estimated.

### Nagaur-Jodhpur-Pali districts

Dolomite occurs in a limestone belt which runs for more than 150 km from north of Sojat (Pali district) and extends towards Bilara and Borunda (Jodhpur district) through Gotan and Mundwa (Nagaur district). The total reserves of dolomite in this belt are 75,750 thousand tonnes of BF grade.

### Jaipur district

Dolomite marbles are exposed between Alwar and Jaipur at Saruara, Narwa, Tohra, Jethali, Dagob, Ajitpura, Kalajpuri, Kaled, Raganwada and Raisola. Of these, the deposits of Jethali, Dagob, Kalajpuri, Kaled and Raisola are important. These dolomite deposits belong to the Raialo Group of rocks. The estimated reserves are 31,628 thousand tonnes. These dolomites are used as marble which is famous as Andhi Marble. The broken pieces of the stones are used in making marble chips and dolomite powder.

### Jodhpur district

A small deposit of dolomite with reserves of 40 thousand tonnes of unclassified grade occurs in association with ferruginous sandstone around Teori, Bhensoi, Modyai and Nakolim *nadi* areas. It is fine-grained, hard and compact, and greyish in colour.

### Jhunjhunun district

The deposits occur at Sior and Kali Pahari. At Sior, the deposit is exposed over a strike length of 200 m and is about 60 m wide. It is of low-grade and white to pink in colour. At Kali Pahari, the dolomite deposit occurs in association with quartzite. The cumulative reserves of the district are placed at 1,020 thousand tonnes.

### Jaisalmer district

Dolomite occurs at Chicha and Chalota. Dolomite deposit at Chicha is overlain by chert and underlain by



buff-coloured crystalline dolomite. It is white, soft and fine-grained. The reserves in the district are estimated at 3,150 thousand tonnes.

#### Sikar district

Dolomite deposits occur around Makri, Machwa, Maonda and Kali Dungri. The reserves in the district are 1,951 thousand tonnes.

*Makri area:* The dolomite is white in colour, thick-bedded, crystalline and massive in nature and occurs in association with bands of calc-gneisses. In Machwa area, dolomite occurs in association with calc-gneisses.

*Maonda area:* Hard and compact dolomite of SMS and low-grade analyses CaO 31.23%, MgO 21.14%, SiO₂ 3.92%, Fe₂O₃ 0.38%, Al₂O₃ 0.12% and LOI 42.25%.

#### Sawai Madhopur district

The reserves of dolomite in the district are 23,500 thousand tonnes.

#### Udaipur district

Siliceous dolomitic limestone white in colour and saccharoidal in nature containing 2-5% SiO₂ and 18-20% MgO occurs extensively in the district. The reserves in the district have been estimated around 2,550 thousand tonnes.

### FELDSPAR

Feldspar is an alumino-silicate mineral of potassium, sodium and/or calcium. Though feldspar is among the most widely distributed rock-forming minerals and occurs as a constituent of most of the rocks, its commercial deposits are mainly confined to pegmatites. Feldspar is either quarried from the

pegmatite veins or is recovered as by-product to the mining of mica and beryl from the pegmatites. Feldspar is chiefly used in the ceramic and glass industries and in insulator making. Rajasthan is the principal feldspar producing State in the country and its reserves are about 10.13 million tonnes which constitute 72% of the total Indian reserves. Out of the total reserves of the State 2,30,827 tonnes are in proved category, 2,74,949 tonnes in probable category and the remaining 9.6 million tonnes in possible category. Out of these reserves 1.63 million tonnes are of pottery ceramic grade and rest of unclassified grade.

Rajasthan contributed 59% of the total production of feldspar in the country during the period from 2004 to 2006 (Table-21).

In Rajasthan, feldspar occurrences have been reported from Ajmer, Alwar, Jaipur, Pali and Sikar districts.

#### Alwar district

The reserves of the district are placed at 9.50 million tonnes. Out of these 1.52 million tonnes are of pottery grade, 7.96 million tonnes are of unclassified grade and 18,225 tonnes fall under not-known category. The prominent deposits are located around Mindani Tilana Sokalia; Jalia Pithawas Dhuni Kala-Khera Thuni thakiJawaja; Chawandiya; Sindari-Sandolia; Dantli Deranthu Dhal Loharwara Gangapur; Samod Usmadhal; Kabri; Dabrelia Piproli Mundot.

#### Ajmer district

Pink variety of feldspar is reported from Tatarpur (27°45': 76°35') and Khairthal. At present feldspar is mined at Tatarpur and the total reserves in the possible category are 44,603 tonnes.

**TABLE-21**  
*Production of feldspar; (Qty. in tones; value in Rs '000)*

State/ District	2004-05			2005-06		
	No. of Mines	Qty.	Value	No. of Mines	Qty.	Value
India	55(54)	379055	61032	37(38)	322929	53329
Rajasthan	35(19)	84697	10005	21(8)	63737	7443
Ajmer	18(9)	30689	3900	12(4)	30170	3290
Alwar	(1)	412	206	(1)	323	97
Bhilwara	14(5)	44465	5134	8(2)	29098	3763
Pali	(2)	3967	319	(1)	1492	134
Rajsamand	2(1)	4954	421	1	2654	159
Sikar	1	168	17	0	0	0
Tonk	(1)	42	8	0	0	0

Source: Indian minerals yearbook, 2006; figures in parentheses indicate number of associated mines.

**TABLE-22**  
*Reserves of fluorite; (in 10³ tonnes)*

State	Recoverable reserves (as on 1.4.2005)			
	Proved	Probable	Remaining resources	Total
India	8585.124	628.707	10951.838	20165.669
Rajasthan	633.309	364.447	4245.103	5242.859

Source: Indian minerals yearbook, 2006.

### Jaipur district

The white and pinkish feldspar deposit is located around Dudwa near Neem-ka-Thana. The probable reserves are 30,000 tonnes.

### Pali district

Occurrences of pink feldspar generally associated with pegmatite intrusives in gneisses and schists, have been reported from Kalalia, Khinwal, Chaondiya (26°05': 74°35') Pratapgarh, Dingor, Thandiber, Barantia-Khurd and Bera. Near Dingor, feldspar is generally iron-stained. The reserves in the district are 4,92,000 tonnes, out of which 52,947 tonnes are of pottery/ceramic grade.

### Sikar district

The deposits of pinkish-white feldspar in pegmatites are located around Dudawas and Haridas-ka-Bas. Reserves are placed at 61,783 tonnes of which 50,551 tonnes are of ceramic grade.

Feldspar in fairly large quantities is also available from the mica mines of Bhilwara, Dungarpur and Udaipur districts.

## FLUORITE

Fluorite (CaF₂) is generally colourless to white and purple in colour. The finest-grade of fluorite is used for enamelling iron, manufacture of opaque and opalescent glasses and for the production of hydro-fluoric acid. The inferior-grade fluorite is used as a flux in foundry work for the manufacture of steel. Transparent fluorite is used in the manufacture of lenses. Use of fluorite in the steel metallurgy and in the manufacture of artificial chryolite makes it an important mineral.

Rajasthan has a large number of occurrences and small deposits of fluorite and is only next to Gujarat, which has the largest deposit in India at Ambadongar. Occurrences of fluorite are reported from Ajmer, Alwar, Bhilwara, Dungarpur, Jaipur, Jalor, Jhunjhunu, Nagaur, Sikar and Sirohi districts. Workable deposits occur in Dungarpur, Jalor, Jhunjhunu, Sikar and Sirohi districts.

The total reserves of fluorite from Rajasthan (Table-22) may come to about 5.242 million tonnes of ore with an average of 12% CaF₂ except in Karara where it may be 52% CaF₂.

**TABLE-23**  
*Area-wise reserves of fluorite*

Area	Reserves (million tonnes/tonnes)	CaF ₂ %	Cutoff %
Mando-ki-Pal	0.4 mt	12.00	
Nawagaon			
Veins > 1 m	15,700 t	18.22	5
Veins < 1 m	4,625 t	18.85	5
	20,325 t	18.35	
Samota	1,78,000 t	13.89	5
	1,07,000 t	18.32	10
Kahila	0.584 mt	10.94	5
	0.303 mt	14.45	10

Source : DMG, Rajasthan.

**TABLE-24**  
*Production of fluorite (graded)*

State/District	2004-05		2005-06	
	Mines	Quantity (t)	Mines	Quantity (t)
India	5	6291	5	177
Rajasthan	4	1002	4	665
Jalore	4	1002	4	665

Source: Indian minerals yearbook, 2006.

Production of fluorite in India vs Rajasthan during 2004-05 and 2005-06 years is given in Table-24.

### Ajmer district

Fluorite is reported from a mica mine at Khairot. Mining the old deposit at Barla near Kishangarh, once prospected by the Tatas, has become cost-heavy due to inadequate quantity of the mineral.

### Alwar district

Pegmatite veins near Khairtal yield a small quantity of fluorite.

### Jaipur district

Presence of fluorite is reported from Amli.

**Bhilwara district**

Occurrences of fluorite are reported from Udaipur (25°44' : 74°16'), Bara Khera (25°43' : 74°19'), Baretpura (25°41' : 74°17') and Dantra (23°42' : 74°17'). Fluorite occurs as stringers and impersistent veins, 1-5 cm in width, along joints and fractures in biotite gneiss. The mineral is translucent and violet in colour.

**Dungarpur district**

The fluorite mineralization is associated with the rocks of Mangalwar Complex of the Bhilwara Supergroup which has been intruded by granites and pegmatites. The mineralization is controlled by structure. The ore bodies, lenticular in shape, consist of coarse fluorite with calcite, quartz and chert.

**Mando-ki-Pal-Kahila belt**

*Mando-ki-Pal (23°47' : 73°52') - Kahila:* The deposits extending from Hathai in the north to Kahila in the south, covering a distance of 15 km to 20 km are by far the largest in Rajasthan. The northern half of the belt covers the deposits of Hathai, Nawagaon, Matatiba and Samota where stringers and veins of fluorite occur as fracture fillings in the granites or in the rafts of metasediments found within the gneiss. At Bhowria-ka-Naka and Kahila which form the southern part of the belt, the fluorite veins occur along bedding planes or fractures in the Aravalli quartzites and quartz-mica schists.

In the Hathai-Nawagaon-Matatiba areas, the veins run NNE-SSW or NE-SW, whereas in the Samota area, they run in WNW to ESE direction. In Bhowria-ka-Naka area, the veins follow and occupy a NNW-SSE trending fault zone running parallel to the strike of the country rocks. In the Kahila area, the veins strike NW-SE at the NNW end of the block and have WNW-ESE trend in the central Kahila block, veering almost to EW at the eastern extremity of the vein. Area wise reserves are given in Table-23.

**Jalor district**

*Karara (Karda):* The fluorite mineralization, confined to the joints, is found in the volcanic agglomerate, trachyte and basalt assemblage. The grade is very good compared to that of Dungarpur. The reserves are placed at 0.17 million tonnes with 52% CaF₂.

**Jhunjhunu district**

*Chokri Chapoli:* Fluorspar veins are found in feldspathic quartzite, and the reserves are 1.13 million tonnes with 12% CaF₂.

**Nagaur district**

A specimen of fluorite was found at Rewat hill near Degana railway station having presence of tungsten, bismuth and uranium, the later two probably forming uranosphaerite.

**Sikar district**

Veins of fluorite occur as fracture-fillings at Salwarai (27°40' : 75°37') and reserves of 0.35 million tonnes with 12% CaF₂ have been estimated.

**Sirohi district**

Good-grade fluorite has been recently located by GSI at Balda where veins and pockets of fluorite occur as fracture and cavity-fillings in the brecciated and silicified zones and quartz veins. The mineralization is associated with the late volatile-rich magmatic phase of the Erinpura Granite. Four fluorite-bearing veins/zones ranging in length from 25 m to 350 m with widths ranging from 0.50 m to 40 m have been delineated in the area. The best vein is 150 m long and 2 m wide. The fluorite is grey to violet in colour with more than 90% CaF₂. Reserves are tentatively estimated at 50,000 tonnes. Fluorite mineralization occurs with or without wolframite. However, when wolframite is present it is very sparse and sporadic in the fluorite zones.

**FULLER'S EARTH**

Fuller's earth, also known as *Multani Mitti* is clay of sedimentary origin composed essentially of attapulgite, montmorillonite and kaolinite. It is used as cosmetic and for cleaning woolen clothes. It has absorbent properties which enable it to remove greasy and oily matter. It is also used in refining oils and animal fats.

Major production of fuller's earth in India comes from Rajasthan. Annual production is about 5,000-6,000 tonnes. Barmer is the main producing district contributing about 77% of total production of the State. The rest of the production comes from Bikaner (18%) and Jaisalmer (5%) districts. With the increase in the output of mineral oil and vegetable oil products in India, a progressive increase in demand for fuller's earth is apprehended.

**Barmer district**

The important deposits of fuller's earth are found near Kapurdi (25°54' : 71°22') and Alamsaria (25°42' : 71°27'). Other occurrences are near Joranda, Sheo, Rodhi and Bharka. At Bharka, a 3 m thick fuller's earth bed is being worked at about 15 m depth.

### Bikaner district

Fuller's earth occurs at Palana (27°51': 73°92'), Kesardasar (27°50': 73°25') and Marh (27°52': 73°53'). At Marh, it occurs in two beds which are 14 m and 1 m thick. Reserves estimated by GSI are 4.33 million tonnes of high-grade and 2.77 million tonnes of low-grade, besides inferred reserves of about 12 million tonnes. In Palana area, 1.8-2.4 m thick beds of fuller's earth occur above lignite horizon. The estimated reserves are of the order of 13 million tonnes.

### Jaisalmer district

Fuller's earth occurs at Manda (27°20': 70°50') and Mandai (26°22': 71°08'). At Manda, fuller's earth is exposed with a thickness ranging from 0.60-2.75 m and has reserves of about 30,000 tonnes. Fuller's earth is also reported from Dholi-ki-Dungri, Khumsar, Pangli, Khuiala and Bandha.

### Nagaur district

Fuller's earth, about 10 m thick, associated with ferruginous grits, gritty feldspathic sandstone, black shale and lignite has been located by GSI in a well section north of Igair. Good quality fuller's earth exposed in well sections near Arisar, Deswal and Chhappri occurs as small pockets and lenses and it is generally mixed with angular quartz grains.

## GEMSTONES

Since time immemorial gemstones, because of their unique characteristics such as colour, transparency, lustre, hardness etc., have remained an attraction for mankind. Diamond, emerald, ruby, sapphire, topaz etc. are known as precious stones, while beryl, garnet, tourmaline, zircon and other minerals come under semi-precious stone category. The raw-gemstones attain their value only after cutting and polishing. The gemstones were being mined in India even during ancient times. The famous diamonds of the world are the gift of India. Rajasthan has the main deposits of emerald and garnet in the country.

### Aquamarine

Aquamarine, a beryllium aluminium silicate, is a transparent variety of beryl. Aquamarine is mainly recorded from Toda Raising and Hanotia in the Tonk district. It occurs in association with mica and pegmatite. Aquamarine is usually cut in pendant form.

### Amethyst

Amethyst, a purple to violet-coloured transparent variety of quartz, occurs in well-crystallized form. When heated strongly it loses its colour. Under moderate heating it turns yellow and is sold as citrine. Though faceted, the steep brilliant cuts are common. It is also carved into attractive forms and shapes. Amethyst is reported to occur near the Kishangarh railway station in Ajmer district and from Bidera, Girota, Didwana and Choup in Jaipur district.

### Chrysoberyl

Chrysoberyl (oxide of beryllium and aluminium) is green in colour and differs from beryl in its composition. Chrysoberyl occurs in association with mica and aquamarine-bearing pegmatites of Ajmer and Bhilwara districts.

### Dumortierite-quartz (*blue aventurine*)

A massive opaque blue variety of crystalline quartz of semi-precious quality is reported to occur at Dewal near Shahpura, Jaipur district. The intergrown crystals of dumortierite impart blue colour to quartz.

### Emerald

Transparent variety of beryl possesses attractive colours and lustre. The colour varies from colourless to green, blue and yellow. Green coloured stones are known as emerald (*Panna*), while aquamarine has yellow colour. Emerald is a very highly-priced precious stone. In India emeralds are available mostly in Ajmer and Udaipur districts of Rajasthan. They are being mined near Rajgarh (26°15': 74°35'), Gudas (26°29': 76°46') and Bubani (26°31': 74°49') in Ajmer district and Kaliguman and Tekhi in Udaipur district.

In Ajmer and Udaipur districts, emerald-bearing zones run intermittently along a 195 km long ultramafic rock belt. Striking NNE-SSW the altered ultrabasics, which, at places are talcose, traverse phyllite, biotite schist, actinolite schist and talc schist. At Rajgarh, emerald occurs sporadically in biotite schist associated with pegmatite. At Kaliguman, emerald as sporadic crystals of varying sizes occurs with the biotite and actinolite schist. At Tekhi, good quality emerald is found sporadically in talc schist but the semi-transparent variety is commonly associated with actinolite schist. Poor quality emerald is also reported from the pegmatites in this area. At Gamgurha, good quality emerald has been reported from the talcose biotite schist.



Emerald from Ajmer-Udaipur belt is characterized by hexagonal prismatic habit. It is somewhat fragile and commonly flawed. Emerald as aggregates is also seen. The colour, except in pale and poor-grade varieties, is velvety emerald-green. The crystals are transparent to translucent. They are usually of small size but large crystal measuring a few cm in length is also known to have been found. Emerald is mined both by open-cast and underground mining methods. The main Kaliguman mine is now being worked in a series of benches.

#### **Fuchsite quartzite (green aventurine)**

Fuchsite quartzite is reported from Bhinder area Bhilwara district. It occurs in high-grade psammities of the Pur-Bunera Group. It is used in statue building.

#### **Garnet**

Garnet is used in the manufacture of coated abrasive like paper, cloth and discs for grinding and finishing glass, wood, hard rubber etc. In powder form, it is used for making lapping and buffing compounds. Garnet is generally obtained from small pits and shallow underground mines. It is also recovered as co-product in processing of beach sands. Rajasthan is the only State producing gem variety.

Total of all India recoverable reserves of garnet, as on 1.4.90 are placed at 39.5 million tonnes.

The production of garnet in India vs Rajasthan is given below in Table-25.

The garnet occurrences in Rajasthan are recorded from Ajmer, Bhilwara and Tonk districts.

#### *Tonk district*

Occurrences of garnet have been recorded near Rajmahal (25°54': 75°28'), Gaonri (25°50': 75°26') and Saroi (25°49': 75°28') from the rocks of the Aravalli and the Delhi Supergroups along pegmatites and basic dykes.

*Rajmahal:* Well-developed garnets are found to be confined to two bands about 15 cm and 1 m thick respectively. At places, small cracked pieces fit for cutting and polishing are also found.

*Gaonri:* Trapezohedral crystals or broken fragments of garnet, lilac to pink in colour, are found at Gaonri.

*Saroi:* Garnet, lilac to deep red in colour, is obtained as rounded or well-developed trapezohedral crystal but generally broken fragments of varying dimensions are common.

#### *Ajmer district*

Garnet deposits have been reported to occur near Sarwar (26°04': 75°01'). The garnet found in schist yield small transparent gem quality fragments and is generally lilac to pink in colour while those found in the vicinity of basic dykes have a deep-blue colour.

#### *Bhilwara district*

Garnet occurrences have been reported near Agucha (25°49': 74°44'). Rounded and fractured garnets varying in size from 1 mm to about 5 cm are found associated with hornblende-garnet rock.

#### **Rock Crystal**

Transparent crystal of quartz is used for necklaces and other ornaments. Associated with pegmatite it is available in Ajmer and Tonk districts.

#### **Ruby / Corundum**

Pegmatites intruding ultrabasic rocks give rise to development of corundum by desilication of feldspars. A small deposit of corundum/ruby at Jual in Tonk district and an occurrence associated with muscovite at Galwa in Bhilwara district are reported. The corundum is mainly used for manufacture of emery cloth.

**TABLE-25**  
*Production of garnet; (value in Rs '000)*

Type		2003-04		2004-05		2005-06	
		Quantity	Value	Quantity	Value	Quantity	Value
Abrasive	India	490893 t	107017	642329 t	153279	679700 t	195826
	Rajasthan	37 t	102	3 t	8	-	-
Gem	India	544 kg	149	90 kg	122	-	-
	Rajasthan	544 kg	149	90 kg	122	-	-

Source: Indian minerals yearbook, 2006.

## GOLD

Gold, the 'king of metals', has always attracted mankind for its untarnishable yellow glitter for making the brilliant ornament par excellence and its relative scarcity and physical properties render it to this day the acknowledged international measure of material values. The usages of gold are as the standard for monetary system in the form of coinage or as bullion, for ornamentation especially in jewellery, in making gold leaf, gold lace and various fabrics, gold plating and in some chemical and photographic preparations. It also has some medicinal values.

Incidences of gold in multiple environments in several part of Rajasthan are well known. The occurrences are found in the Bhilwara, Aravalli and Delhi Supergroups of rocks of Archaean to Proterozoic age. Gold mineralization is hosted by a variety of rocks types. It is invariably associated with massive to semi-massive, disseminated sulphides comprising pyrrhotite, pyrite, chalcopyrite, arsenopyrite, sphalerite, bismuthinite etc. Total reserves of gold are given in Table-26. District-wise occurrences of gold in Rajasthan are as follows:

### Banswara district

#### *Jagpura-Bhukia belt*

Numerous old workings forming parallel to sub-parallel zones occur in Jagpura-Bhukia area (3 km x 1.5 km). The area exposes amphibolite, calc-silicate marble, dolomitic marble, quartzite and keratophyre rocks. This sequence constitutes a part of regional fold closure with a prominent NNW-SSE trending shear zone. Gossans and silicified rocks with stains of malachite and azurite are seen in the old workings. The zone of old workings was earlier investigated by GSI for base metal mineralization during 1971-74.

Fine disseminations of native gold were observed within gossans occurring along the Jagpura-Bhukia old workings. Regional samples from an area over 400 km² around Jagpura and Narwali in Banswara district have shown 10 ppb to 70.2 ppm gold in gossan samples, 10 ppb to 5.2 ppm gold in quartzite samples and 10 ppb to 9 ppm gold in calc-silicate marble and amphibolite. Besides, gold values have also been recorded in BIF, sulphide-bearing chert and quartz veins. Based on the above observations four blocks, namely Bhukia-Khundli, Tartai-Jarkha, Bhuwar-Kanpura and Parsola-Mokanpura have been identified for detailed investigations.

In Jagpura-Bhukia block five parallel zones extending over a strike length of 2 km have been delineated. Groove samples taken from hanging wall as well as footwall sides have also analysed gold values from 0.76 to 1.99 ppm. The work in the area is in progress to assess the gold potential.

### Bhilwara district

*Devtalai area (25°28': 75°02'):* The area lies in the southwest part of the Jahazpur belt. It comprises greenschist to amphibolite facies of metamorphites of the Hindoli supracrustals profusely intruded by quartz reefs and forms a promising Cu-Au prospect. The reefs, varying between 2 m and 5 m in width, extend up to 500 m in length and appear to reflect a gash vein-type pattern. The reef quartz showing pyrite/pyrrhotite disseminations is generally white and greyish in colour and is often stained by iron oxides. Old workings exist in the quartz reefs.

Drilling by GSI has indicated copper and gold mineralization in the quartz reefs. A composite core sample of quartz reef over a 3 m zone between 52 m and 55 m depth, collected from Devtalai has assayed 0.2 g Au/tonne (analysis-BGML). A surface grab sample from the quartz reef about 500 m northeast along the same zone assayed 0.4 g Au/tonne (analysis-BGML). Copper investigation in the area has confirmed the incidence of gold in the area. Ore reserves of 0.83 million ton containing 0.87 ppm gold, 1.48% copper and bismuth as high as 1,000 ppm have been estimated.

*Jhikri area (25°27': 75°11'):* A fairly prominent zone of ferruginous cherty-breccia in the Banded Iron Formation (BIF) of the Jahazpur sequences is dotted with extensive old workings over a length of about a km. Bedrock sampling in the area had indicated Pb up to 1.4% and Zn up to 0.37%. Galena is also reported from the mine dumps. Huge amount of mine debris indicates considerable mining activity in the past. Slag in the area is negligible. It is very likely that BIF in Jhikri with subordinate sulphides is auriferous like the BIF in the Kolar schist belt, Karnataka.

*Mohanpura (25°15': 75°00'):* A highly-brecciated and sheared zone in the BIF in the western limb of the Jahazpur sequence, folded into a synform, in particular, has extensive old workings. The geological set-up of the area with old workings/mine debris is similar to that of the Jhikri area. The BIF is likely to be auriferous and needs to be examined.

### Dungarpur district

In Hinglaz Mata native gold was observed in gossans. Recent investigations by detailed mapping and drilling done by GSI indicated highly anomalous values of gold in jasperoid and at the contact between jasperoid and dolomite associated with disseminations of pyrite and chalcophyrite. The Hinglaz Mata-Bharkundi belt spanning over 14 km strike length has indicated incidence of gold in both the areas.

### Jaipur district

Ladera gneisses of the Bhilwara Supergroup assayed 0.1-2.6 ppm of gold. Low cupriferous horizons are found to be auriferous in this part of the district.

### Jalor district

Gold dust in the sands of the Khari river is reported from near Sangramgarh.

### Jhunjhunu district

In Khetri copper mines, gold is recovered along with copper in Kolihan and Satkui mines. Quartz-mica schist/quartzite of Delhi Supergroup hosting copper mineralization in these mines assayed 0.41.5 g/t gold and 200-300 ppm cobalt.

Occurrences of washings for gold in the *nalas* between Khetri and Singhana have been reported. Probably the quartz reef in the granite south of Singhana could be the source of this gold.

Several cupriferous areas, which are also argenti-ferous and auriferous, occurring within the rocks of the Ajabgarh and the Alwar Groups, contain old workings and gossans. These areas need further investigations.

**TABLE-26**

*Reserve of gold as on 01.04. 2005; (in 10³ tonnes )*

Type		Proved	Probable	Remaining resources
Ore (Primary)	India	15554.089	3699.862	371035.286
	Rajasthan	-	-	65589

Source: Indian minerals yearbook, 2006.

### Pali district

*Raipur:* Alluvial gold in the Luni alluvium has been reported.

*Phulad:* Cherty quartzite or silicified rhyolite covering over 2,601 sq m area around Phulad show some pyrite, and small cavities which resemble the gold bearing rocks of Nawanagar in Saurashtra. No visible

gold is seen but the assay values of 1.55 g of gold/ton are reported.

*Birantia-Khurad:* Volcanogenic massive sulphide deposit in Birantia-Khurad area recorded 0.2 ppm to 2.0 ppm gold.

*Kalabar:* In Kalabar sulphidic quartz-mica schist 0.06-0.12 ppm gold is recorded.

### Rajsamand district

Marble and amphibolites of the older supracrustals of Rajpura-Dariba Group assayed 0.5 ppm gold besides analysing high values of arsenic, antimony, mercury constituting path finders elements for gold in Rajpura-Dariba area. Impure dolomite of Rajpura, in the north-eastern continuity of Ghagri-Bedwal tract assayed 0.05 to 0.3 ppm gold.

Presence of arsenopyrite associated with sphalerite, galena, chalcopyrite, pyrrhotite hosted by calc-silicates, marbles and mica schist was observed in Bamnia area.

### Sirohi district

#### *Pindwara-Watera belt*

Pindwara-Watera belt which is 20 km long, hosts several metallogenetically similar copper-zinc prospects of Danva, Basantgarh, Goliya, Pipela and Watera. Anomalous gold values varying from 80 ppb to 3,500 ppb obtained during earlier investigation of Danva massive sulphide prompted detailed investigation for gold evaluation in this area. The area exposes rocks of the Kumbhalgarh Group comprising amphibolite (metabasic volcanics), amphibole quartz rock, layered gabbro, metapyroxenite, actinolite-chlorite schist, chlorite schist, calc-silicate rock and banded ferruginous chert intruded by granite, gabbro and lamprophyre dykes. The regional foliation trends NNE-SSW with steep dip due SE. The exploration work is in progress in three blocks mainly Pipela, Ajari and Danva blocks.

*Pipela block:* A total of 1,357.75 m drilling has been completed which has helped in establishing 450 m strike length of the ore zone. Gold content in the ore zone is estimated to range from 0.04 ppm to 0.90 ppm. The width of ore zone varies from 1.13 m to 3.60 m.

*Ajari block:* A total of 687.2 m drilling has indicated 150 m length of mineralized zone with the width ranging from 2.60 m to 3.77 m. Au content varies from 0.58 ppm to 1.37 ppm.

*Danva block:* 350 m strike length of the ore zone with an average thickness of 6.41 m has been established with a total of 1,911.8 m of drilling. Au values range from 0.18 ppm to 2.57 ppm.

### GRAPHITE

Graphite, also known as 'black lead', is a soft crystalline form of naturally occurring carbon. Graphite crucible industry and foundry units are the major consumers of natural graphite. Refractory industries consume graphite for manufacturing magnesium-carbon bricks for use in steel making in basic oxygen and electric arc furnaces.

There are numerous reported occurrences of graphite deposits in the country. The graphite mined is not of high-grade. About 50% of our requirement is met by import. Domestic graphite is mostly used in the metallurgical industry for steel foundry and graphite crucibles. The mineral occurs in lump, flaky or powdery forms which together with the total fixed carbon (F.C.) content determines the uses.

Total reserves of graphite as on April 1, 1990 are placed at 3.10 million tonnes with 0.54, 0.83 and 1.73 million tonnes falling under proved, probable and possible category (Table-27).

**TABLE-27**

*Reserve of graphite as on 01-04-2005; (Qty in 10³ tonnes)*

State	Proved	Probable	Remaining resources	Total
India	5163.505	5586.403	158025.030	168774.939
Rajasthan	47.6	165.92	1700.034	1913.554

Source: Indian minerals yearbook, 2006.

Orissa is the leading producer with 77% share while Rajasthan produces about 1%. Run of mine (r.o.m.) ranges between 10% and 60% F.C. and has to be invariably beneficiated before marketing. Production of graphite in recent years in India and also separately in Rajasthan are given below in Table-27A

**TABLE-27A**

*Production of graphite; (in tonnes)*

	1992-93	1993-94	1994-95
India	78,185	83,956	1,01,164
Rajasthan	273	N.A.	505

Source: Indian Minerals Year Book 1996, Vol. 2, 1998, p. 377.

In Rajasthan, graphite occurrences have been located in Ajmer, Alwar, Banswara and Jodhpur districts.

### Ajmer district

A thin band of graphite mixed up with clayey matter occurs in limestone/calc-gneiss near Rajori (26°00': 73°25'). A graphite band in carbonaceous schist occurs near Ajitgarh (25°47': 74°17'). A 3 m thick band of graphite/graphite schist occurs near Lotiana (25°54': 73°13') in the rocks of the Delhi Supergroup. Besides, graphite has also been reported from Amba (26°24': 74°32') and near Banota (26°22': 74°30'). The mineral is of poor quality and is associated with biotite schist interbedded with quartzite, the chief impurities being biotite and clay.

### Alwar district

A thin band of graphite with steatite occurs near Jaloli, 6-8 km southeast of Rajgarh.

### Banswara district

The graphite belt extends over a strike length of about 17 km from Khander (23°28': 74°35') in the south to Ghatol (23°45': 74°25') in the north. Occurrences of graphite were recorded at several places, mainly confined to actinolite-graphite schist. Rich concentrations are found in zones profusely traversed by pegmatite and also along shear zones. The entire belt has been subdivided into nine blocks viz., Ghatol, Bhungra, Runjari, Mahi Dam, Imlipara, Bagra, Sasakota-Kesarpura, Kotra and Khandra blocks.

*Mahi dam block:* Two bands of graphitic schist viz., Main Band 1 and 2 with strike length of 1,050 and 880 m respectively were delineated in this block. The thickness of graphite-bearing zone varies from 4 to 9 m. The reserves tentatively estimated for the Main Band 1 are of the order of 0.85 million tonnes and that of the Main Band 2 are 0.27 million tonnes. Fixed carbon content is generally poor. In the southern block of Main Band 1 the fixed carbon ranges from 10.2-18%, averaging 14.1%.

*Sasakota-Kesarpura block:* The graphite band near Sasakota extends over a strike length of one km with width varying from 0.68 to 2.74 m. The graphite band near Kesarpura extends over a strike length of about 1.5 km with thickness varying from 1 to 15 m. The ash content ranges from 69.20 to 85.14% and the fixed carbon varies from 12.41 to 18.77%.

*Khandra block:* Two bands of graphite were demarcated, the strike length of which are 350 and 650 m respectively.

*Kotra block:* Three bands of graphite extending



over strike length of 1 km, 450 m and 600 m respectively were demarcated. The thickness of the bands ranges from 3 to 16 m. Graphite in these bands is of flaky variety and the graphite content ranges from 10-20%.

**Imlipara block:** Occurrences of graphite were recorded at several places from Imlipara to Singapura, about 5 km SSE of Banswara. A band of graphite with an average thickness of 3.50 m was traced over a strike length of 800 m. In addition, two minor bands with average thickness of 4.5 m and 2.5 m were traced over strike length of 250 m and 800 m respectively.

### Jodhpur district

An irregular band of graphite occurs in association with biotite schist near Bar railway station. It has an average thickness of 50 cm.

## GYPSUM

Gypsum, a hydrous calcium sulphate containing 79%  $\text{CaSO}_4$  and 21% water, is a widely distributed mineral and is generally transparent or white in colour. It occurs either as massive type or as fibrous lumps and

transparent plates. The varieties of gypsum are selenite (finely crystalline), stainspar (fibrous with silky lustre), alabaster (fine-grained, massive and compact) and gypsite-porous gypsum of inferior quality mined with sand and grit.

Gypsum is mainly used in portland cement to retard and control the time of setting and is also used in the manufacture of ammonium sulphate for artificial fertilizer, plaster of Paris, distemper, 'burtonizing' water for beer making, potteries and as a flux in smelting nickel ores. Its uses in paper industry and as filler in insecticides are also important. Selenite is used for making gypsum plates for petrological microscopes. Alabaster is used for ornamental purpose.

Rajasthan accounts for about 90% of total production of gypsum in the country having a total reserves of 1,013.70 million tonnes as estimated by GSI. This constitutes a lions share of the total proven reserves of 1,150 million tonnes of gypsum in the country. Production of gypsum in Rajasthan during 2004-05 is given in Table-28.

**TABLE-28**  
*Production of gypsum in Rajasthan; (Qty in  $10^3$  tonnes, value in Rs '000)*

State/District	2004-05			2004-05		
	No. of Mines	Quantity	Value	No. of mines	Quantity	Value
India	33	3684.758	502000	35	3137.095	389709
Rajasthan	26	3641.136	478204	31	3104.35	372698
Barmer	3	102.926	11693	5	20.484	2458
Bikaner	9	1227.421	136631	7	1204.841	143975
Sri Ganganagar	6	728.635	87436	6	617.24	74069
Hanumangarh	3	744.021	149379	5	284.054	34086
Jaisalmer	2	789.991	88457	2	908.939	109855
Jalore	1	12.907	1226	2	68.792	8255
Nagaur	2	35.235	3382	-	--	--

Source: Indian minerals yearbook, 2006.

Reserves of gypsum have been located mainly in Bikaner, Nagaur, Barmer, Jaisalmer, Pali and Ganganagar districts (Table-29). The most important deposits occur in Nagaur district.

**TABLE-29**  
*District-wise, category-wise reserves of gypsum in Rajasthan as on 01.01.85 (Qty in  $10^3$  tonnes)*

Districts	Proved	Probable	Possible	Total
Barmer	4,123.000	4.000	1,767.270	5,894.270
Bikaner	1,004.000	19,487.000	16.905	37.396
Churu	—	—	3,928.000	8,928.000
Ganganagar	2,448.380	19,904.380	12,611.840	34,964.600
Jaisalmer	4,777.000	592.060	2,786.000	8,155.060
Nagaur	1,580.000	1,194.000	76,785.750	79,559.750
Pali	—	671.000	—	671.000
Rajasthan	13,932.380	41,852.440	1,19,783.860	1,75,568.680

Source : IBM 1990 GYPSUM : A Market Survey Series MS 15 : 171.

Based on the mode of occurrence, there are two main types of gypsum deposits in Rajasthan : (1) Surficial evaporite deposits of massive gypsite of Quaternary-Recent age, occurring as tabular sheets up to a few metres in thickness below an overburden (13 m) of sand, constitute the main gypsum deposits of northern and western Rajasthan and which are being mined for the past many decades and supplied all over India and (2) Associated with the carbonates and argillites of the Bilara Group of the Marwar Supergroup, syndimentary beds of gypsum, representing an older evaporite sequence, occurs at a depth range of 30-115 m or more. In addition, large quantities of anhydrite occur within the Hanseran Evaporite Group at depths between 270 and 1,000 m in Bikaner, Ganganagar and Churu districts.

### **Nagaur district**

Gypsum was located by GSI (1959-61) in two separate areas. The larger deposit covering about 58.31 km² area between Bhadwasi (27°14': 73°40') and Dhakoria (27°19': 73°44') occurs in the north where the gypsum beds occur at a depth ranging from 35.50 to 106.86 m with thickness varying from 4.70 to 13.86 m. The smaller deposit covering about 18.29 km² area occurs between Nagaur (27°52': 73°44') and Bhadwasi in the south where gypsum occurs at a deeper level between 109.72 and 115.52 m and varies in thickness from 6.85 to 9.14 m. The total reserves of gypsum from both the areas have been estimated at 953 million tonnes containing gypsum of 81% and above purity. Out of these, 227.5 million tonnes contain 81-85% gypsum and 725.5 million tonnes more than 85% gypsum.

### **Barmer district**

Large deposits of gypsum have been reported from Utlarai (25°45': 71°25') and Kavas (25°50': 71°30'). The CaSO₄.2H₂O content of gypsum varies from 60% to 80% in these deposits. Most of the gypsum produced is used by cement factories. Selenite occurrences have been reported from Chittar-Ka-Par and Thob (26°05': 72°23'). The thickness of layers varies from 10 to 40 cm. It is used for manufacturing plaster of Paris.

### **Bikaner district**

Good, workable, surficial gypsum (gypsite) deposits of Quaternary age are located at a number of places.

*Jamsar (28°16': 73°13')*: This is the largest and most extensively worked deposit in the State. It occupies an area of about 4 km² (4 km × 1 km). There are three main

gypsite beds varying in thickness from 2.4 to 3.7 m with 85-98% gypsum. The deposit is being worked by RSMML in 13 quarries. The bulk of the reserves, however, have already been mined out.

*Dhirera (28°27': 73°38')*: A gypsite bed, 2.7 m thick, occurs in an area of 0.83 km². The deposit has a reserves of approximately 0.7 million tonnes containing 85% CaSO₄.2H₂O.

*Kaoni (28°09': 73°06')*: the deposit occurs in an area of about 3 km² with an average thickness of 0.6 m (gypsite). Estimated reserves are one million tonnes with 70-85% CaSO₄.2H₂O.

*Bharu (28°12': 73°13')*: The deposit covers an area of 3-4 km² where the gypsite bed has an average thickness of 0.18-1.0 m. About 3-4 million tonnes of reserves containing 70-80% CaSO₄.2H₂O are estimated.

Minor occurrences of gypsite are also reported from Dholera, Dhirava, Akasar Dher, Juna, Akhusar, Jagdeowala, Dandla, Neushera, Seasar, Sammuwala, Dandalwala Dher, Islamwala Dher and Karamwala Dher. The reserves estimated from all these deposits are 56.89 million tonnes.

Selenite crystals varying in size from a few centimetres to 10 cm occurs near Lunkaransar. About 6% of the crystals are recoverable by washing and screening.

### **Bharatpur district**

Occurrences of gypsite have been reported from near Kathumari (27°15': 77°05') and Ghuriakhera (27°00': 77°25').

### **Jaisalmer district**

Gypsite deposits are located at Sri Mohangarh (27°17': 71°04'), Hamirwali Wadi (27°19': 71°18') Lakha (26°05': 70°55'), Nachna (27°30': 71°40'), Bhaddara (25°53': 71°18'), Phalsund (26°20': 76°25') Satta Sunde and Nokh (27°30': 72°15'). Reserves of 12.4 million tonnes are estimated in the district 50% of which contain 80% or more CaSO₄.2H₂O, while the rest are of lower grade.

### **Sri Ganganagar district**

Vast reserves of gypsite occur at Siramsar, Mahala, Pallu, Borasar, Malkasar, Karnisar, Raghunathpura, Desli, Suratgarh, Hanumangarh, Faridsar, Dhardov etc. Total reserves are about 4 million tonnes.

### Churu district

Gypsite occurs at a number of places, of which deposits near Bhallan, Bharin, Deogarh and Shethon are quite promising. These occurrences lie below the surface at depths ranging from 0.30 to 1.50 m.

### ILMENITE

Ilmenite is an ore from which titanium metal is derived. It is used in the manufacture of pigments. India possesses rich deposits of beach sands of ilmenite mainly along the coast of Kerala and at a few places along the east coast of India.

In Rajasthan, ilmenite is found to occur as scattered disseminations in the country rocks in various parts of Ajmer, Nagaur, Pali, Jodhpur and Sikar districts but these are of only academic importance.

### Ajmer district

*Kancharia* (26°32': 74°56'): A wide vein of ilmenite traversing gneiss is recorded near Kancharia. The mineral occurs as large crystals associated with quartz and calcite. The mineral is reported to have been smelted locally. However, prospecting up to a depth of 9 m did not succeed.

### Nagaur district

Presence of small quantities of ilmenite is also recorded from the wolfram mines of Degana.

### IRON ORE

Iron is extracted from its oxide ores such as haematite and magnetite which when smelted with coke and limestone yield metallic iron. Iron ores are needed to meet the demands of modern iron and steel industry. Iron deposits of Rajasthan are of minor importance to meet the demands of any large-scale iron and steel industry within the State (Table-30 & 30A). The iron ore deposits are located mainly at Morija, Rampura, Neemla-Raialo, Kotputli and Dabla in Jaipur district ; at Tonda, Sior, Zamalpur and Kali Pahari in Jhunjhunu district and at Narda, Manowas, Bagoli and Sarai in Sikar district. These occurrences are found associated with the Delhi Supergroup of rocks.

**TABLE-30**

*Reserve of iron ore as on 01-04- 2005; (in 10³ tonnes)*

State	Type	Proved	Probable	Remaining resources
India	Hematite	4945329	2058839	7626219
	Magnetite	14339	44164	10560978
Rajasthan	Hematite	6774	4039	19035
	Magnetite	3074	1151	522651

Source: Indian minerals yearbook, 2006.

**TABLE-30A**

*Reserves of iron ore in Rajasthan*

Locality	Reserves (million tonnes)	Grade
Morija	1.38 (for 15 m depth in exposed section, 15 m in unexposed section)	54-58% Fe, 1.119.5% SiO ₂ 0.22% P0.012-0.013% S
Tonda	0.15	65-70% Fe
Sior-Zamalpur	0.38	55-65% Fe
Neemla	1.0	62-68% Fe

Source: 1-3 by GSI; 4 by DMGR.

### JaipurDausa districts

*Morija area* (27°10': 75°49'): The iron ore deposits investigated by GSI extends over a strike length of 4.5 km. Bands of massive haematite occur intercalated with coarse ferruginous grits belonging to the Alwar Group of the Delhi Supergroup. The iron ore bands are intermittently exposed in soil-covered terrain at Banol, Chorgat, Banheria, Kankoria, Morija and Mayurbhunj. One to six bands with average thickness of 4 m are found exposed in these areas along 301,800 m long impersistent bands.

*Rampura area* (27°06': 75°45'): The iron ores associated with the mica schist occur as lenses, patches and thin bands. Several bands of micaceous haematite, varying in thickness from 0.6 to 2.5 m have been reported.

*Neemla* (27°04': 76°19')-*Raialo* (27°05': 76°16') *area* : The iron ore deposit comprising iron-stained marble to almost pure haematite is located within the crystalline limestone as irregular lenticular masses, measuring at times 2.12.4 m in width. The most important and extensively worked deposit about 0.6 km east of Neemla occurs as a 1.5 km long ridge. Most of the ore body is in forest area and is yet untouched.

*Kotputli area*: Iron ore is found scattered around Bagawas (27°25': 76°05'), Tateri (27°29': 75°1') and Bania-ka-Bas (27°31': 76°10') in Kotputli area.

*Dabla* (27°54': 75°56') *area*: Several scattered segregations of iron ore are located west of the Dabla railway station. Large but irregular lenticular masses and pockets of haematite and magnetite ore are found in the country rocks. A NE-SW trending hillock about 3 km west of Nizampur railway station, exposes two bands of haematite of about 3 m to 4 m in width, separated by 8 m thick band of quartzite. Other occurrences are located near Piao-ki-Khan.

### Jhunjhunun district

*Tonda area*: About 800 m east of Tonda, seven lenses of iron ore a mixture of haematite and magnetite ore being extensively quarried. Fine-grained and massive haematite is also worked near Sior and Zamalpur. Micaceous haematite is also noticed. Occurrences of iron ore are also reported between Raipur (27°44': 76°01') and Jainthpura (27°39': 76°00').

### Sawai Madhopur district

A number of minor iron ore occurrences are reported from Toda Bhim (26°55': 76°52'), Raghunathgarh (27°40': 75°24'), Jaisinghpura near Baswa (27°09': 76°38') and Karwari, about 6.5 km east of Hindaun (26°44': 77°06').

#### *Other iron occurrences*

A large tonnage of low-grade ore will also be available from all these deposits and also from Khetri Copper Belt area. The deposits located at Natharia-ki-Pal (24°14': 73°47') in Udaipur district where DMGR has estimated reserves at about 11 million tonnes with iron content ranging from 48 to 52%. The iron content of the magnetite ridge in Banera-Bhinder belt of Bhilwara-Udaipur districts ranges from 39 to 50%.

### KYANITE

Kyanite is an important high-alumina refractory mineral. Kyanite, sillimanite and andalusite are a closely related trio of aluminium silicate ( $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ ) minerals having the same chemical composition but differing slightly in physical properties.

India has been one of the world's leading producers and exporter of high-grade kyanite for many years. Production has declined in recent years due to depletion of high-grade reserves in the Lapsoburu deposit in Bihar. India is the largest producer of sillimanite in the world. The production of kyanite and sillimanite in the year 1999 was 6,068 and 12,458 tonnes, respectively.

In Rajasthan, occurrence of coarse-bladed crystals of kyanite and sillimanite in small veins and lenses are reported from Ajmer, Bhilwara, Dungarpur, Jaipur, Pali and Udaipur districts.

### Dungarpur district

Occurrences of blue-coloured kyanite have been recorded in the intensely folded biotite-garnet-kyanite schist, graphite and biotite-garnet-staurolite schists of the Aravalli Supergroup near Chhoti Padri (23°40': 74°04') and Sagwada (23°40': 74°01') near Dewal, Warela and Badia (23°42': 74°03'). The sporadic segregations (30 cm to 1 m in size) of quartz and kyanite occur along the contact of the schist.

### Ajmer district

Occurrences of kyanite have been reported to occur at Chainpura (26°35': 74°53') and Mandaoria (26°36': 74°54'). Blades of bluish-white kyanite with occasional greenish-type, associated with quartz veins, occur in

staurolite-biotite schist. The average size of the blades is about 5 cm in length and 2.5 cm in breadth.

### Pali district

Kyanite has been reported in the biotite-garnet-kyanite schist of the Delhi Supergroup near Asan (25°35': 73°35'). Where it occurs as small thin blades and lenses with quartz veins and sporadically in garnetiferous mica schist. The kyanite blades are 210 cm long.

### Jaipur district

The kyanite blades, 515 cm long, associated with quartz veins in garnetiferous mica schist of the Delhi Supergroup, have been reported to occur near Tunga (26°44': 76°09'). The segregations are sporadic in nature.

### Bhilwara district

Small occurrences of kyanite have been recorded at Pur (25°17': 74°32') and Bari Harnoi (25°19' : 74° : 39'). The kyanite blades of 0.510 cm length occur as small lenses within quartz-veins and at times in garnetiferous mica schist.

### Udaipur district

Kyanite occurrences near Kishangarh and Sansera are known.

### LEAD and ZINC

In India, Rajasthan and Gujarat have been the centres for Pb and Zn mining since centuries. At Zawar, Udaipur many mines bear ancient workings. Zawar is the place recognised as first ancient zinc smelting site in the world.

India, in recent years, has achieved near self-sufficiency in Zn, but production lags behind consumption of Pb. Identified Pb and Zn resources in the country are estimated at 416 million tonnes with 4.78% Zn and 1.47% Pb. Out of this, the economically viable category of ore reserves stands at 137 million tonnes having 2.2% Pb and 8.5% Zn. Besides, 50 million tonnes of possible resources are in the producing/developing mines and the deposits under detailed exploration. The per capita consumption in India is 138 gm of Zn and 83 gm of Pb which is among the lowest in the developing countries. Total reserves & production of Pb-Zn are given in Table-32 A & 32B.

In south-eastern Rajasthan Pb-Zn deposits occur within the Bhilwara Supergroup of Archaean to Lower Proterozoic age (e.g. Agucha, Dariba-Rajpura, Pur-Banera), Lower Proterozoic Aravalli Supergroup (e.g. Zawar) and Lower to Upper Proterozoic Delhi



TABLE-31

*District and category-wise, recoverable reserves of Pb-Zn in leasehold and freehold areas of Rajasthan*

	Proved A	Probable B	Possible A	Total 100% B	A	B	A	B
Ajmer	—	—	—	—	—	7,385.6	—	7,385.6
Alwar	—	—	—	1,446.4	—	—	—	1,446.4
Bhilwara	39,056.0	—	14,732.6	—	11,206.8	—	64,995.4	—
Chittaurgarh	—	—	161.5	—	461.9	—	623.4	—
Sirohi	—	—	793.6	—	—	—	793.6	—
Udaipur	30,325.4	538.9	11,943.1	—	20,791.6	32,067.5	63,060.0	32,606.3
Rajsamand	—	—	—	—	—	8,618.5	—	8,616.5
Total of distts.	69,381.4	538.9	27,630.8	1,446.4	31,998.4	48,531.5	1,28,849.1	50,678.3
Rajasthan		= 69,920.3 (A+B)		= 29,077.2 (A+B)		= 80,529.9 (A+B)		= 1,79,527.4 (A+B)

A = Leasehold mines B = Freehold mines

(in thousand tonnes)

Source : IBM, 1995. Lead and Zinc mining in Rajasthan. Bull. No. 29, p. 41-45.

Supergroup (e.g. Kayar-Ghugra). In terms of tonnage and grade the deposits occurring within the Archaean basement rocks far exceed those occurring in the main Aravalli and Delhi basins.

Rajasthan has the unique distinction of having the largest Pb-Zn deposits in the country (Table-31). With the total reserves of 416 million tonnes of Pb-Zn, the State, is likely to meet the country's demand. However, keeping in view the increase in consumption and consequent depletion of the known reserves, the search for more prospects is on. Efforts are being made to locate more prospects in the extensions of the known potential mineral belts in Rajasthan.

### Udaipur district

**Zawar deposit:** The Zawar (24°17': 73°41') Pb-Zn deposit is situated 40 km to the south of Udaipur. The slag heaps near the old workings in the area give a clear evidence of the ancient mining activities and used retorts of smelting that thrived in the past as far back as 14th to 18th century. Before the Zawar mines were

nationalised in 1965 and the Hindustan Zinc Ltd. was formed, the mines were worked by the Metal Corporation of India (P) Ltd.

The Zawar Pb-Zn belt extends for a distance of about 20 km from Hameta Magra to Parsad. The Pb-Zn mineralized zone extends for about 16 km from south to north before it swerves to the east. The fine-grained dolomite and gritty conglomeratic quartzite with subordinate interbedded phyllite are by far the most favourable host rocks. The sulphide mineralization in these rocks is mainly controlled by fractures and fissures. The ore is mainly stratabound and also occurs as veins, stringers and disseminations forming lenticular bodies arranged in an echelon pattern. There are five blocks in the belt, namely (from south to north) Parsad, Bara, Paduna (24°17': 73°41'), Zawar and Hameta Magra (24°22': 73°40'). Hameta Magra and Zawar blocks comprise Mochia Magra, Bawa, Balaria, Baroi Magra and Zawar Mala is the main ore-bearing hills. The estimated reserves in these blocks are shown in Table-32. Mining activity is confined to Mochia Magra, Balaria and Zawar Mala hills.

TABLE-32

*The estimated reserves in the blocks under mining and exploration by HZL (as on 01.04-1994)*

Mines/ Deposit	Developed Tonnage	%Pb	%Zn	Proved Tonnage	%Pb	%Zn	Probable Tonnage	%Pb	%Zn	Demonstrated Tonnage	%Pb	%Zn	Possible	Total
<b>ZAWAR GROUP</b>														
1. MOCHIA														
a. Central Mochia	1.742	2.25	3.97	6.758	1.61	4.21	0.469	1.84	5.26	8.969	1.75	4.22	0.509	9.478
b. West Mochia	0.572	2.56	3.54	2.405	2.34	4.57	0.813	2.20	4.12	3.790	2.34	4.32	2.641	6.431
Sub total (1)	2.314	2.33	3.86	9.163	1.80	4.30	1.282	2.07	4.54	12.759	1.92	4.25	3.150	15.909
2. BALARIA														
a. Central Balaria	2.340	1.17	6.07	8.415	1.13	5.57	1.470	1.20	6.47	12.225	1.15	5.78	2.211	14.436
b. West Balaria	—	—	—	0.672	1.37	6.40	0.356	1.34	6.78	1.028	1.36	6.53	0.756	1.784
Sub total (2)	2.340	1.17	6.07	9.087	1.15	5.63	1.826	1.28	6.58	13.253	1.16	5.83	2.967	16.220
3. ZAWAR MALA	0.775	2.60	4.09	3.789	2.21	4.80	1.798	1.55	4.77	6.362	2.07	4.71	1.407	2.769
4. BAROI (C)	0.737	3.24	0.94	2.433	4.25	1.51	1.106	3.91	1.66	4.276	3.99	1.45	2.874	7.150
5. BAROI (N & S)														
a Baroi (N)	—	—	—	—	—	—	0.340	5.45	3.18	0.340	5.45	3.18	2.180	2.520
b Baroi (S)	—	—	—	—	—	—	—	—	—	—	—	—	0.160	0.160
Sub Total (5)	—	—	—	—	—	—	0.340	5.45	3.18	0.340	5.45	3.18	2.340	2.680
HARAN MAGRA														
Sub total	6.166	2.03	4.38	24.472	1.87	4.60	0.295	2.79	3.33	0.295	2.79	3.33	1.077	1.372
							6.647	2.21	4.55	37.285	1.95	4.57	18.815	51.100

Source : IBM, 1995. Lead and Zinc mining in Rajasthan. Bull. No. 29, p. 46.

So far, investigation carried out was mainly confined to proving, in detail, the ore reserves in the selected blocks. Most of the Zawar Pb-Zn belt which extends for a total strike length of 27 km remains unexplored in detail.

### Rajsamand district

#### *Dariba-Rajpura-Bethumbi belt*

Dariba-Rajpura-Bethumbi Belt (24°57': 74°08': 25°04': 74°11') is an important source of Pb-Zn ore in the country. This multi-metal deposit is located about 16 km NNE of the Fatehnagar railway station on the Chittaurgarh-Udaipur section of the Western Railway. It is about 125 km from the Zawar mine and 88 km from Udaipur. The existence of gossan and old mines indicated the possibility of Zn-Pb mineralization extending from Dariba in the south through Rajpura and Sindesar Kalan up to Bethumbi in the north over a distance of nearly 17 km. The deposit, located in the year 1963, has since been extensively explored by the GSI. The Dariba-Rajpura mine is producing 3,000 tonnes per day (TPD) ore for the Hindustan Zinc Ltd. (HZL). Another block, Bamnia, is under development for production. North Sindesar Ridge (South) block has recently been handed over to the HZL for development.

The metasedimentary rocks of the belt occur within a narrow linear belt developed within a basement of garnet-staurolite-mica schist, feldspathic schist and gneisses (Mangalwar Complex) of Archaean age.

The principal Pb-Zn sulphide ore zone is confined to outer mica schist, metachert with lenses of dolomitic marble and outer carbonaceous schist (+staurolite, kyanite). A diagnostic gossan is developed over the ore body, particularly between Dariba and Rajpura. Old workings like pits, shafts, inclines and large slag heaps all along the gossan zones indicated widespread mining activity in the past.

The blocks investigated so far are : Dariba A and B blocks, Rajpura A, B, and C blocks, Bethumbi block, Sindesar Kalan East block, Mokaupura North and South blocks, Bamnia block and North Sindesar Ridge (South) block. The exploration in Sindesar West block and Latio-ka-Khera block is in progress. The block-wise reserves of Dariba-Rajpura-Bethumbi belt are shown in Table-33.

*Dariba-Rajpura block (Dariba A and B; Rajpura A, B and C blocks):* Extensive old workings, mine dumps, slag heap and gossan are found along a fault zone

between Dariba and Rajpura. Near Dariba, two sub-parallel ore bodies occur in graphitic mica schist and calc-silicate rock. The ore body corresponding to the gossan at the crest of Dariba hill in Dariba 'A' block is called the Dariba main lode. It is 1-47 m wide, extends for 550 m and has been proved to a depth of 380 m from the surface. The lode then pinches out and is absent for about 300 m further north when it reappears in Dariba 'B' block. The Dariba main lode extends in Dariba 'B' and Rajpura 'A', 'B' and 'C' blocks over a strike length of 3,700 m. Sulphide mineralization is seen along the contact of the calc-silicate-bearing dolomite and hanging wall graphitic schist. The chief sulphide minerals are sphalerite, galena, pyrite, pyrrhotite with subordinate minerals like chalcopryrite, tetrahedrite, tennantite, geochronite and arsenopyrite.

**TABLE-32A**

*Reserves of lead and zinc ores as on 01.04. 2005;  
(in 10³ tonnes)*

State	Type Ore	Proved 62860	Probable 62894	Remaining resources 396826
India	Lead metal	1262.98	1327.57	4617
	Zinc metal	5503.16	5589.73	13167
	Ore	61213	56370	350925
Rajasthan	Lead metal	1202.76	1188.6	56370
	Zinc metal	5503.16	5310.3	11670

Source: Indian minerals yearbook, 2006.

**TABLE-32B**

*Production of lead and zinc ores in Rajasthan;  
(Qty in 10³ tonnes)*

State	Ore Produced	2004-05 Metal content		2004-05 Metal content		
		Lead	Zinc	Ore Produced	Lead	Zinc
India	3928.5	75.128	393.036	4795.124	92.791	519.896
Rajasthan	3928.5	75.128	393.036	4795.124	92.791	519.896

Source: Indian minerals yearbook, 2006.

Chalcopryrite, tetrahedrite, tennantite with galena and minor sphalerite occur in the cherty, highly quartz veined, calc-silicate-bearing dolomite towards the footwall side as lenticular body. In the Rajpura 'A', 'B' and 'C' blocks, graphitic mica schist forms the hanging wall as well as the footwall of the lode. The mineralization is confined to the silicified calc-silicate-bearing dolomite.

**TABLE-33**  
*Block-wise reserves of Dariba-Rajpura-Bethumbi belt*

<i>Name of the prospect</i>	<i>Rock types</i>	<i>Mineral/ metal</i>	<i>Strike length</i>	<i>Cutoff</i>	<i>Grade Zn+Pb</i>	<i>Reserves million tonnes</i>	<i>Category</i>	<i>Remarks</i>
Rajpura block	Graphite-mica schist, dolomite with calc-silicate	Galena, sphalerite	500 m	2%	0.96+3.25	2.08	Probable	Stratabound (MECL)
	Amphibolite	Pyrrhotite, pyrite		3%	1.0+3.37	2.07	Probable	
	Calcareous-biotite-schist	Tennantite geochronite, arsenopyrite			1.2+4 % +.27 Cu 200 ppm Ag 500 ppm Hg	3.11 31.62	Possible	
Dariba Rajpura		Zn+Pb Cu+Cd	550 m		8.05	5.45	Proved	
					(Pb+Zn)	5.34	Probable	
						2.22	Possible	
Dariba 'A' block			550 m		6.16	2.78	Proved	
Dariba 'B' block					(Pb+Zn)	2.91	Probable	
Dariba East lode (Dariba 'A' block)			600 m		4.34	2.81	Possible	
Sindesar Kalan (East)	Graphite-mica schist, dolomite with calc-silicate, amphibolite, calcareous-biotite schist	Zn+Pb	2.5 km	2%	2.03+0.51	1.246	Proved	Stratabound
						66.65	In situ reserves (GSI)	
					3.20+0.80	34	Possible (HZL)	
Mokanpura (North)	- do -	Zn+Pb	700 m	2%	2.88	52.54	Proved	(main ore body)
Bamnia block	Carbonaceous schist, carbonate rocks.	Zn+Pb			4.24	11.64	Probable	(HW lode)
					2.71	28.59	Probable + possible	
					(Pb+Zn)			
Sindesar Kalan (W)	Calc-silicate	Zn+Pb	200 m	3%	4.22+2.24 4+2	27.53 0.74	- do - Possible	
North Sindesar Ridge (S) block	Calcareous-mica schist (tuffaceous)	Pyrrhotite	1.2 km	2%	2.81+1.48 2.77+0.78	10.46 13.00	Probable Possible	Schist hosted
	Calc-silicate-	Pyrrhotite	800 m	2%	4.96+1.99	3.80	Probable	Marble hosted
	marble.	sphalerite			5.65+1.19	8.92	Possible	
Bethumbi	Graphite-mica schist,	Galena, sphalerite			1.0+1.64	0.08	Probable	Disseminated, stringers, parallel/sub-parallel to bedding.
	dolomitewith calc-silicate rock, ferruginous quartzite				1.0+1.64	0.23	Possible	
						0.31		

Source : GSI

The Dariba East lode occurring below the large water filled pond, east of Dariba hill, has been proved over a strike length of 600 m and up to a depth of 280 m. It is 2-35 m in width. The sulphide mineralization is mainly confined to graphitic mica schist.

*Sindesar Kalan (East) block:* The host rock is graphite mica schist. Pyrrhotite is the dominant sulphide with subordinate sphalerite, galena and pyrite. Rhythmic layering of sulphide is very characteristic. The ore zone was explored over 1.9 km strike length between 470 and 176 m RL. The average thickness of the ore zone is 86 m.

*Mokanpura (North) block:* Altogether five ore bodies have been delineated in Mokanpura (North) block. Of these, four bodies are hosted in the carbonaceous schist, namely main ore body 'A', HW lode, ore bodies 'B' and 'C'. The ore body 'A' is hosted in dolomitic chert. The main ore minerals are pyrrhotite, sphalerite and galena with subordinate pyrite, arsenopyrite, chalcopyrite and greenockite. Main ore body is correlatable with the Sindesar Kalan (East) main lode. It is 850 m in strike length and 102.87 m thick in northern section.

*Bamnia block :* In the Bamnia block, boreholes intersected carbonaceous schist and interbanded mica schist and metachert with calc-magnetite-silicate-bearing dolomitic marble lenses. The rocks strike N30°E-S30°W and dip 70°-75° due E.

Carbonaceous schist, at places, is kyanite - staurolite and garnet-bearing and shows devitrified glass, sanidine etc. indicating felsic tuffaceous nature. Dolomitic marble lenses within the schist show Pb-Zn mineralization. Interbanded mica schist-metachert with lenses of calc-magnetite silicate-bearing dolomitic marble is the principal host rock to sulphide mineralization.

Pb-Zn ores are hosted by both carbonates (dolomitic marble lenses) and carbonaceous schist, but the former contains richer mineralization. Sulphide lodes are mostly concentrated along the hinges of  $F_2$  folds. Sphalerite, galena and pyrrhotite are the principal sulphide minerals.

Three major ore bodies have been delineated within the marble in mica schist-metachert. They are BM-1, BMF-1 and BMF-2. Sulphides are present as bands, stringers, fracture-fillings and as replacement bodies. The marble is highly brecciated where the mineralization is of massive type. The carbonaceous

schist hosts lode CSL-2 and 3 and the marble hosts HWM-1. Of these, the most important is BM-1 (Bamnia Main lode-1) which has a strike length of 1,300 m with average width of 12.56 m. The lode has been investigated between 200 and 450 m RL.

*North Sindesar Ridge (South) block:* In the North Sindesar Ridge (South) block, Pb and Zn ores are hosted by schist (tuffaceous) and calc-silicate marble, mostly close to their interface. The ore bodies are discontinuous, arcuate, lense-shaped in plan and the ores are better concentrated along the crests of  $F_2$  folds. Mineralization is also present along bedding and foliation. Though the richer lodes are hosted by marble and mica schist, the felsic volcanics also contain appreciable Zn and Pb sulphides. In the schist, the dominant sulphide is pyrrhotite with a little galena and sphalerite, whereas in the marble, the major sulphide minerals are pyrrhotite, sphalerite and galena with minor pyrite and arsenopyrite.

In the calc-silicate marble, the lode L-1 has a strike length of 800 m while there are two schist-hosted lodes, one each in the hanging wall and footwall of the marble-hosted lode L-1.

The lode L-1 has reserves of 7.94 million tonnes with 2.83% Pb, 7.77% Zn and 159 ppm Ag.

### **Bhilwara district**

#### *Agucha deposit*

The Agucha Zn-Pb deposit discovered by the DGM, Rajasthan in 1977, is the single most important deposit of its kind in the country. The deposit is located near Agucha (25°49': 74°44'). It is presently being worked as a 3,000 TPD opencast mine.

The Zn-Pb mineralization in Agucha occurs within an enclave of graphite-mica-sillimanite gneiss/schist within garnet-biotite-sillimanite gneiss containing bands of amphibolite, calc-silicate rock, intruded by aplite and pegmatite. The mineralised enclave forms doubly plunging synformal structure trending NE-SW with steep dip (60°-70°) to the southeast. The ore and host rocks of Agucha deposit have been subjected to higher amphibolite to granulite facies metamorphism. The deposit lies close to the ductile shear zone (DSZ) separating the high-grade granulitic rocks of the Sand Mata Complex on the west and gneiss and migmatites of the Mangalwar Complex in the east. The ore is completely recrystallised comprising coarse grains of sphalerite and some pyrite, pyrrhotite and galena.



The deposit is stratabound and appears to be of sedimentary exhalative origin. Hindustan Zinc Ltd. (HZL) has estimated its ore reserves at 61.10 million tonnes over a strike length of 104 m with 13.48% Zn, 1.93% Pb and 54 ppm Ag.

#### *Pur-Banera-Bhinder belt*

The belt is a NE-SW to N-S trending, stretching for about 130 km from Banera in the north to Bhinder in the south. The metasedimentary rocks of the belt form linear enclave within a basement of feldspathic schist, garnet-staurolite schist and gneiss (Mangalwar Complex). The presence of old workings and slag dumps throughout the belt bear testimony to widespread mining and smelting activities during ancient times. The Pur-Banera-Sankli segment of the belt, in the north, differs markedly from Wari-Akola-Bhinder segment in the south in lithology and mineralization. In the northern part, BIF is associated with the Pb-Zn-Cu mineralization. It is absent in the south where only Cu mineralization is recorded.

*Pur-Banera-Sankli segment:* In the 50 km long Pur-Banera-Sankli segment, BIF represented by magnetite quartzite, magnetite-quartz-amphibole and magnetite-carbonate are the principal host rock for base metal mineralization. Garnet-rich magnetite-bearing calc-gneiss, calc-silicate rocks are also favoured host rock for sulphides. Two parallel zones of sulphide mineralization have been recognised in this segment. The eastern zone extends from Malikhera in the north to Tiranga in the south, over 34 km strike length, through Samodi-Dedwas, east of Dhulkhera-Ranningpura-Jaliya. The western zone extends for 40 km from Manpur in the north to south of Gurla in the south through Salampura, Dariba-Suras, west of Dhulkhera and east of Devpura. In both the zones, the Pb-Zn mineralization has been observed in the upper level and copper in the lower level. The mineralization exhibits stratiform nature. The main sulphide minerals are sphalerite, galena, chalcopryrite, pyrite and pyrrhotite. The sulphides occurs as bands alternating with the host rocks parallel to the bedding, as disseminations and stringers along fractures and cleavages and fillings along slip-planes and minor fold hinges. Of the different blocks explored in this segment, reserves have been proved in Banera RF (Pb-Zn) block, Malikhera (Pb-Zn) block, Mahua Khurd East (Pb-Zn) block, Mahua Khurd West (Pb-Zn) block, Devpura (Pb-Zn) block, North Dedwas (Pb-Zn) block, South Dedwas (Pb-Zn) block, Samodi (Pb-Zn)

block, Tiranga Hill (Pb-Zn) block, Rewara (Cu-Pb-Zn) block and Bhadali Khera (Pb-Zn) block, the details of which are summarised in Table-34.

(a) *Samodi block (Pb-Zn):* The rock unit includes calc-gneiss with calc-schist and quartz-biotite schist on the eastern flank of a ridge, a magnetite formation (magnetitic calc-gneiss, magnetite quartzite, magnetite-bearing schist) along the crest of the ridge and quartzite and garnetiferous mica schist in western part of the area.

The sulphide mineralization is localised in the magnetite formation and is traced over the entire strike length of 2 km. The width of the zone ranges from 64-140 m, averaging 120 m. The ore minerals are sphalerite, galena, pyrrhotite, pyrite, arsenopyrite, chalcopryrite and marcasite. There are two to six 'shoots' of richer zones within the wide mineralized zone.

(b) *South Dedwas block (Pb-Zn):* Garnetiferous mica schist is found in the western part of the block, calc-gneisses in the eastern part while the host quartz-amphibole-magnetite rock is found in between. The rock units trend N30°E-S30°W with steep westerly dip of 70°-80°.

The ore bodies are mainly stratiform but at places branching and interlinking. There are 34 lodes of which one lode, designated Lode M, shows remarkable persistence along both the strike and dip. In a strike length of 1.7 km, the lodes have been tested at three levels at 50, 100 and 150 m depth below the surface.

#### **Sirohi district**

*Deri deposit:* A small Pb-Zn-Cu deposit in the Deri area (24°23': 72°50') has been discovered by the GSI. Four mineralized zones have been delineated which extend over a total strike length of 660 m. Mineralization, generally restricted to the quartz-chlorite-amphibolite schist and talc-chlorite schist, is controlled by prominent shear zones and strike faults. Exploration carried out have indicated the inferred reserves of 0.80 million tonnes containing 17.13% total metal content (Zn -9.12%, Pb -6.87% and Cu 1.14%).

#### **Ajmer district**

##### *Ajmer lead-zinc belt*

The Ajmer Pb-Zn belt extends over a strike length of 60 km from Kharwa (37 km southwest of Ajmer) in the southwest to Hoshiara in the northeast (13 km northwest of Kishangarh). Apart from the ancient mine working recorded at Taragarh (Shishakhan), Lohakhan and

**TABLE-34**  
*Pur Banera-Bhinder belt (Pb-Zn-Cu)*

<i>Name of the prospect</i>	<i>Rock formation</i>	<i>Mineral / Metal</i>	<i>Strike length</i>	<i>Cutoff</i>	<i>Grade (%)Zn+Pb</i>	<i>Reserves(million tonnes)</i>	<i>Category</i>	<i>Remarks</i>
Devpura (Ranningpura)	Gar.-qtz.- mica schist, Qtz.-amph.- magnetite rock calc-gneiss	Pb+Zn	400 m	Natural	1.86+0.45	12.60	Probable	Synclinal
					1.77+0.42	4.89	Possible	
						17.49*		
					2%	2.96+0.65	4.46	Probable
						2.97+0.62	1.63	Possible
							6.09	
					4%	4.83+1.20	0.91	Probable
						4.97+1.29	0.23	Possible
							1.14	
						3.2+0.88	1.92	Demonstrated
South Dedwas	Qtz.-amph. – magnetite rock; calc-gneiss and garnetiferous mica schist	Pb+Zn, Ag	1.7 km	Natural	1.37+0.84	10.02	Probable	In the 34 lodes, eastern limb of Pur syncline
					1.20+0.74	8.36	Possible	
					1.30+0.79	18.38		
					2%	2.36+1.25	4.70	Probable
					3%	2.08+1.24	3.34	Possible
						2.24+1.25	8.04	
						2.24+1.41	2.94	Probable
						2.72+1.47	1.81	Possible
						(2.79+1.43)	4.75	
						2.61+1.50	3.65	Demonstrated
North Dedwas	Magnetite amphibole rock, Gar. - mica schist, calc-silicate	Pb+Zn	150 m		0.51+1.50	–	–	Lenzoid ore in separate lenses.
Samodi	Magnetite rich rocks	Pb+Zn	2 km	Natural	1.85+1.37	1.016	Proved	Reserve estimated up to 100 m vertical depth. Disseminated stringers & layers parallel to bedding. Ore shoots in axial region of the folds.
						2.670	Possible	
						3.686		
Tiranga	Magnetite rocks calc-silicate gneiss, gar.-mica schist	Pb+Zn	900 m	2%	1.31+1.75	1.15	Probable	Ore shoots in axial region of the folds.
Bhadali khera	Qtz.-mag.-amph.- rocks, Qtz. mag.-rock	Pb+Zn+ Cu	1.4 km	2%	1.5+1.0	2.5	Possible	Stratabound ore

Source : GSI.(*total reserves)

Ghugra, a few doubtful old pits are observed at Kayar while oxidised zones/gossans are scarce and only a few scattered exposures are observed at Kayar, Madarpura and Ghugra. At Mata Dongri, slightly oxidised lead zinc ores occur in a quarry section within impure marble and calc-silicate rock. Large part of the area to the northeast of Lohakhan and Ghugra is a covered flat terrain. The ground follow up surveys to check airborne EM anomalies associated with magnetic features led to the discovery of deposits at Ghugra (Pb-Zn), Kayar (Pb-Zn) and Madarpura (Zn) in an area for about 20 km².

*Ghugra lead-zinc deposit:* The sulphide mineralization is mostly hosted by calc-silicate rocks while mineralization is also noticed in metapsammopelites and footwall quartzites. The main sulphide ores are sphalerite, galena with subordinate pyrrhotite and chalcopyrite. The ore body is emplaced within a northerly plunging synformal closure. Geophysical surveys led to the delineation of the target over a strike length of 2.0 km. Exploration by drilling resulted in delineating sulphide mineralization over a strike length of 1.10 km and down to a vertical depth of 200 m.

Mineral reserves (probable and possible) of 9.0 million tonnes with average grade of 5.7% (Pb 2.56% + Zn 3.22%) at 4% cutoff have been estimated. The associated metals include Cu, Ni, Co, Ag, Cd and Hg.

*Kayar zinc-lead deposit:* Ground evaluation of significant zones of AEM anomalies found in association with a circular magnetic signature around Kayar by GSI helped in indentifying a zone of Zn-Pb mineralization for a cumulative strike length of 1.06 km within the metasediments of the Ajmer Formation (Ajabgarh Group of the Delhi Supergroup).

Exploration has established mineral reserves (probable and possible) of 9.2 million tonnes with 12% Zn and 1.2% Pb and minor amount of copper. The associated metals include silver, cadmium and mercury. Tin and tungsten are also recorded.

The sulphide mineralization is mainly associated with graphitic quartz-mica schist, although it also occurs in quartzite and calc-silicate rock. These rocks are profusely invaded by pegmatite and quartz veins. The calc-silicate rocks show typical contact metamorphic skarn assemblages, characterised by the presence of diopside, subordinate clinozoisite and occasional wollastonite, forsterite and chondrodite. Sulphides occur as fracture-fillings along fissures, veins, cleavages and foliation planes. The dominant

sulphide ore is sphalerite with galena in subordinate amounts. Other sulphides include chalcopyrite, pyrite, pyrrhotite, cubanite and pentlandite.

*Madarpura deposit:* Exploration was carried out on an antiform complementary to the Ghugra synform. The host rock is calc-silicate rock (wollastonite-diopside-tremolite-bearing) and dolomitic limestone profusely intruded by pegmatite and quartz veins. Sulphide mineralogy is dominated by sphalerite with chalcopyrite and pyrrhotite in subordinate amounts. Other constituents in minor amounts include pyrite, marcasite, galena and molybdenite. Ore zones are confined to schistosity planes and minor fold crests.

Exploration by drilling indicated significant zones of zinc minearlization over a strike length of 1 km. Zinc content is found ranging from 0.91 to 5.51% over varying widths of 1.30-19.27 m; maximum value of lead recorded is 1.40% over a width of 1.27 m and copper content is generally low (less than 0.22%). Other associated metals include Cd, Hg and Mo. The deposit is considered to be of low-grade (2-3% Zn) and a few million tonnes of reserves have been identified.

*East Lohakhan:* On the northern outskirts of Ajmer city, this Pb-Zn prospect is located on a magnetic high and is associated with six-channel EM anomalies. The mineralization is hosted by calc-silicate rock, co-folded with quartzite and mica schist in the form of an asymmetrical southerly plunging fold. There are a number of old workings within the calc-silicate band along the axis and the limbs close to the fold closure. The available subsurface data indicates shallow ore body (40-60 m below the surface) with Pb dominating over Zn, i.e. around 2 : 1 metal ratio.

*Mata Dongri block:* Ground evaluation of aero EM anomalies associated with magnetic signature led to a find of Pb-Zn mineralization hosted within carbonate rocks, marble and calc-silicate rocks. In a quarry section, pockets of sulphide ore (slightly oxidised) containing sphalerite with galena were observed.

*Bhimyo block:* The metasedimentary rocks comprising quartzite, calc-silicate and mica schists are characterised by a distinct magnetic signature. Geochemical sampling of bed rock (oxidised zone over the calc-silicate rock) indicated Pb values up to 9,800 ppm and Zn 13,500 ppm. Soil sampling also indicated zinc anomaly over a strike length of 750 m. The prospect is under exploration.

A few more prospects/occurrences such as at Namukya-ki-Dhani, Lohagal, Makarwali, Chachiyawas, Narwar and Charanwas remain to be explored.

*Lohakhan deposit:* Geological, geophysical and geochemical investigations have indicated the possibility of Pb-Zn mineralization in Lohakhan (26°29': 74°39') at the southern outskirts of Ajmer. Presence of a sizeable Pb-Zn deposit of low-grade over a strike length of 750 m has been established by drilling. As the deposit falls within the growing township of Ajmer, further proving of the deposit to establish its mining feasibility has been suspended.

#### *Sawar belt*

The Sawar belt, is a repository for several small Pb-Zn deposits. The amphibolite-grade sediments which are essentially carbonates and pelites with volcanic detritus overlying older composite gneisses (Mangalwar Complex or BGC) cover approximately 70 km² area forming a deformed oval structure with dimensions of 12 km by 3 to 6 km. The Pb-Zn mineralization is essentially stratabound. Economic concentration of the ore is in the northern and southern closures of the Sawar belt.

The Lower Marble Member (LMM) which has discontinuous gritty quartzite at the base forms the host rock of the Pb-Zn ore. The ores are mostly remobilized and concentrated in the limb shear zones of the major fold in the northern and southern part of the belt. The block-wise reserves of Sawar belt are shown in Table 35.

*Bajta (Central) block:* In the northern part of the

Sawar belt several old workings occur along a 30-40 m wide linear zone along the contact of LMM with Lower Schist Member (LSM) in this block. Sphalerite and galena, the principal ore minerals occur in thin (less than a metre) layers and bands or irregular pockets, which are closely-spaced in the mineralized zones. Correlation of the mineralized zones brings out their stratiform nature parallel to bedding of the host (LMM) rock. Of the two lodes in the block, the footwall lode occurs in the marble of the LMM, while the hanging wall lode occur within the biotite quartzite and amphibole quartzite units of the LSM. The mineralized zone is co-folded with the country rock.

The ore zone contains irregular, patchy, coarse-grained, euhedral to subhedral aggregates of galena and sphalerite. The mode of occurrence of the ore minerals suggests remobilization during metamorphism. The host rock is very rich in magnetite and pyrrhotite, which occurs independently and not, related to sphalerite galena zones. Magnetite mainly occurs as disseminations, while pyrite mainly occurs as foliationparallel bands (less than 1cm wide) or as blebs in carbonate-rich band within calc-silicates. 1.22 million tonnes of ore has been estimated with 6.41% Pb+Zn (2.5% Pb and 3.84% Zn) at 2% (TMC) cutoff grade. These reserves are from two ore zones designated as the FW-lode (232 m strike length and 2.2 m average width) and HW-lode (391 m strike length and 2.18 m average width).

*Tikhi Extension block:* In southern part of the Sawar belt a 1.4 km long NS trending line of old workings in the LMM near the contact with LSM defines this block. Boreholes in this block intersected two or more parallel

**TABLE-35**  
*Block-wise reserves in Sawar belt*

<i>Name of prospect</i>	<i>Rock type</i>	<i>Mineral/ Metal</i>	<i>Strike length</i>	<i>Cutoff</i>	<i>Grade</i>	<i>Reserves (mt)</i>	<i>Category</i>	<i>Type</i>
Sawar	Marble, calc-silicate	Galena, sphalerite, Chalcopyrite, pyrrhotite	500 m	2% TMC	3.72% (Pb+Zn)	0.94 1.62	Probable Possible	Lense Lense
Tikhi Extension Block (South)			500 m	2% TMC	6.1% Pb 44 ppm Ag	2.27	Possible	Lense
Bajta Central			300 m	2% TMC	6.41% Pb+Zn	1.22	Probable	Lense
Ganeshpura			500 m	2% TMC	5.75% Pb+Zn	0.76	Probable	Lense
Bajta Hinge Zone Block				Natural	0.5% Cu	3.07	Possible	Lense

Source: GSI



lodes with coarse-grained galena, pyrrhotite, occasional chalcopryrite and sphalerite. The grade and width of the ore zone is better in the southern 500 m part of this block.

In the Tikhi Extension block, the host rock LMM is intensely silicified in the mineralized zone. A steeply dipping straight line disposition of the zones is suggested. The sulphide lodes occur as lenses 150 m to 200 m long and have wide variation of grade and width. In the southern part of Tikhi Extension block the grade varies from 2.52% to 17.71% Pb and width from 1.31 m to 8.77 m.

The southern 500 m part of the Tikhi Extension block has indicated a metal zonation with concentration of lead in the hanging wall side and zinc in the footwall side. There is a separation of 50-80 m between the two types of lode. Total reserves of lead-rich ore in this sector of the Tikhi Extension block is estimated at 2.27 million tonnes of 6.15% Pb and 44 ppm Ag at 2% cutoff.

#### **Sawai Madhopur district**

*Chauth-ka-Barwara deposit:* The Banjari mine at Chauth-ka-Barwara (26°03': 76°00') is a well-known old working for lead. Pb mineralization, associated with a fault zone, is exposed along an old opencast working measuring 100 m long and about 8 m (average) deep. The surface exposures are of limited extent due to covered terrain. The rock types in the area include shale, slate, quartzite and impure limestone belonging to the Hindoli Group of the Bhilwara Supergroup. The mineralization is highly-lenticular, patchy and impersistent along strike and dip and occurs as disseminations, stringers and veinlets of galena with minor pyrite and chalcopryrite. The drilling in the area has established presence of a Pb-body over a strike length of 240 m.

#### **Chittaurgarh district**

##### *Pur-Banera belt*

Pb-Zn mineralization with Cu is reported to occur at Rewara (25°06': 74°22') and Karjia Khera (25°07' : 74°23').

*Rewara block (Pb-Zn-Cu):* The area is mostly soil covered with scanty exposures. The rock units are mica schist, staurolite-garnet-mica schist, and andalusite-bearing mica schist, magnetite quartzite, quartzite, calc-gneiss, calc-schist, dolomite and calc-silicate rocks. They are folded into a northerly plunging synform.

Drilling has established Cu-Pb-Zn mineralization

on both limbs of the synform over a strike length of 1.6 km. Eight lodes on the eastern limb and four on the western limb have been defined.

Mineralization is stratabound and occurs interbanded with amphibole-quartz-carbonate gneiss and quartz-amphibole-garnet gneiss. Quartz-sericite-biotite schist carries the Pb-Zn mineralization. There is a distinct zoning with Zn-rich portions at the core, Cu-Pb-Zn in the middle and Cu towards the footwall. The sulphides present are galena, chalcopryrite, sphalerite and pyrite. Reserves of 1.2 million tonnes of possible and probable category with 0.7% Cu, 5.4% Pb and 0.4% Zn have been estimated.

*Karjia Khera:* The mineralization is recorded in the eastern limb of a syncline which is the northern continuation of the Rewara syncline. The mineralization, encountered in the boreholes over a strike length of 800 m, is poor. Sulphide disseminations include galena, sphalerite, pyrite, pyrrhotite and chalcopryrite.

Indication of galena in the form of finely crystalline disseminations is present in Bamov. Specks and stringers of galena are also noticed near Pandoli and Sopura.

#### **LIGNITE**

Lignite, a low-grade fossil fuel, represents an intermediate stage in the alteration of wood into coal. It is dark-brown to blackish-brown in colour, carries a good amount of moisture and often crumbles into powder on drying. In Rajasthan, large deposits of lignite occur in Tertiary formations of Middle Eocene age in the Barmer, Jaisalmer and Nagaur basins falling in Barmer, Jaisalmer and Bikaner-Nagaur districts, respectively. Total reserves of lignite in India and Rajasthan is given in Table-36.

#### **Bikaner-Nagaur districts**

Lignite-bearing two sub-basins are recognised, namely, the Palana-Kolayat embayment and Merta Road sub-basin.

*Palana-Kolayat sub-basin:* The lignite is associated with the Palana Formation (Middle Eocene). The lignite occurrences are disposed along this belt for about 70 km long and 30 km wide stretch. The belt is generally thicker to the south and thins out to the north. The thickness of the lignite along the axis of the fold is 7-12 m. At Palana, a seam having an average thickness of about 6.5 m has been worked till the year 1968. DMGR estimated the total reserves of

lignite available in Palana area, taking all the five blocks (Block A,B,C,D and D-1) together, to about 23.57 million tonnes after deducting the quantity already mined and destroyed by fire. The net reserves in block A and C selected for opencast mining are 11.91 and 5.56 million tonnes respectively. The reassessment of mineable reserves, assuming the lignite/overburden ratio to be 1: 15 works out as 13.65 million tonnes.

The GSI recommended drilling in the unexplored A and C blocks. The DMGR estimated the reserves of mineable lignite at about 16 million tonnes from A and C blocks. Lignite contains 37.57% carbon, 7.3% ash, 38.9% moisture, 2.89% hydrogen, 2.81% sulphur and 0.92% nitrogen. Investigation by the GSI reveals that the Palana lignite occurs as impersistent pockets. To avoid dilution due to mixing of softer top and bottom clay matter, a total reduction of 30% of the estimated reserves have to be considered.

Lignite from Palana, with calorific value ranging from 5,710 to 6,370 k cal/kg, is found to be suitable for power generation. However Palana lignite has a high-incidence of sulphur (3-3.7% on dry basis) which is a distinct disadvantage for power generation. The readily-combustible nature of the lignite due to the high-sulphur content and the soft nature of the enclosing formation causing frequent collapse of the roof during mining make lignite mining at Palana an uneconomic proposition.

**Gurha (27°55': 72°58'):** A 6.10 m thick lignite seam at a depth of 86.40 m was intersected by GSI at Gurha. The lignite, brownish-black with thin streaks of huminite and a few pyrite crystals, contains 5.8-12.41% ash, 34.67-42.20% volatile matter and 39% huminite fixed carbon. Subsequent drilling by DMG/MECL has proved 50 million tonnes of *in situ* reserves in the area with 1:15 lignite/overburden ratio. The average calorific value, at 45% *in situ* moisture, is 2,867 k cal/kg. This deposit appears to be exploitable by open-cast mining.

**Barsinghsar (27°45' : 73°10'):** Lignite seams varying in thickness from 0.10 to 41.50 m have been intersected below an overburden of 45.75-125.25 m in drilling operations by DMGR. About 70 million tonnes of lignite with average calorific value of 2,700 k cal/kg has been estimated. The lignite contains 20-24% fixed carbon, 2.4-10% ash, 23-28% volatile matter and 42-47% moisture.

Lignite seams have also been intersected near

Hadda, Narsingh-ki-Dhani, Raneri and Chak-Vijayshinghpura.

**TABLE-36**

*Reserve of lignite as on 01-01-2006; (in million tonnes)*

State	Proved	Indicated	Inferred	Total
India	4177.18	20259.4	13837.85	38274.43
Rajasthan	560.91	2620.6	1053.84	4235.35
Barmer	170.4	2177.84	911.09	3259.33
Bikaner	277.51	382.69	68.6	728.8
Nagaur	113	60.07	60.35	233.42

Source: Indian minerals yearbook, 2006.

### Barmer district

**Botiya-Bharka area:** Lignite deposits belonging to Eocene Formation at Thumbli, Hira-ki-Dhani, Akli, Sheo, Unror, Bharka, etc. were located in the year 1964 by GSI. In the Botiya-Bharka sector the presence of impersistent and lensoidal lignite seams of thickness generally varying from 0.10 to 3.0 m at depths varying between 60 and 240 m from the surface has been indicated. On the basis of depth range the lignite seams are grouped in the three zones. These zones are of 5 seams (average thickness 0.26-5.85 m), 3 seams (average thickness 0.13-4.57 m) and 4 seams (average thickness 0.72-4.03 m). The lenticular nature, splitting tendency and degenerating character are the deterring factors in proper correlation of seams. A total of 9.35 million tonnes of lignite reserves have been estimated.

**Kapurdi-Jalipa area:** In Kapurdi area, DMGR has located three distinct lignite zones below an average overburden of 60 m. Thickness of the individual seams varies from less than 1.0 to 5.60 m, the average thickness being 4.85 m. Total indicated reserves of 30.65 million tonnes down to a depth of 95 m were assessed. The reserves on mineable limits i.e. 1 : 15 lignite/overburden ratio were estimated at 21.65 million tonnes with calorific value 2,965 k cal/kg at 45% *in situ* moisture content.

About 200 million tonnes of lignite with 2,650 kcal/kg are expected to be available in prospecting area of about 7 km² and 13 km² in Kapurdi and Jalipa sectors respectively.

**Giral area:** This area lies in the western part of the Barmer basin. The exploratory drilling in this area encountered three to nine lignite seams/bands varying in thickness from 0.20 to 2.10 m within a depth range of 21.0 to 67.80 m. The cumulative thickness of lignite seams varies from 4.30 to 6.29 m.

### Nagaur district

In the Merta Road sub-basin lignite seams have been reported at an average depth of 100-120 m. The thickness of these seams varies from 0.55 to 6.05 m. The *in situ* reserves would be of the order of 11 million tonnes as postulated.

**Merta Road block:** Drilling operations by DMGR have intersected 3.19 m thick lignite seam. Total reserves are of the order of 24 million tonnes. The lignite with 45% *in situ* moisture has calorific value of 2,650 kcal/kg, 12.42% ash, 24% volatile matter and 18.25% with fixed carbon.

**Mokala-Indawar block:** Lignite seams intersected by drilling, near Mokala and Indawar are estimated to yield another 27 million tonnes. The calorific value of the lignite is 2,760 kcal/kg. The average quality of lignite (at 17.08% *in situ* moisture) is 17.63% ash, 37.65% volatile matter, 27.52% fixed carbon with 4,139 kcal/kg calorific values.

**Igair-Chhappra area:** In a dug well a lignite seam, about 5-6 m thick was observed lying at a depth of about 47 m. Drilling by DMGR has confirmed the presence of 4.30-6.00 m thick lignite seam in the area.

**Kuchera-Igair area:** Drilling in the area has indicated lignite seam of about 0.30-3.80 m in thickness under 56.70-64.75 m thick overburden. The average quality of lignite (at 45% *in situ* moisture) is 11.23% ash, 23.89% volatile matter, 19.87% fixed carbon and 2,824 kcal/kg calorific values.

### LIMESTONE

Limestone is one of the most important industrial mineral required in the manufacture of lime, cement, chemicals (soda-ash, caustic-soda, bleaching powder,

calcium carbide etc.), fertilizer (ammonium nitrate etc.) and as a flux in iron and steel, ferro-alloy and other metallurgical industries.

Limestone occurs in almost all the districts of the State, but important deposits are located in Ajmer, Bundi, Chittaurgarh, Jodhpur, Nagaur, Pali, Sirohi and Jaisalmer districts. Total production of limestone in India during 2005-06 and Rajasthan's contribution in it is given in Table-37A. Total reserve is given in Table-37.

### Ajmer district

Limestone deposits are found at Sheopura (26°01': 74°23'), Lulwa (26°04': 74°24') and Kesarpura (26°09': 74°27'). The limestone bands within calc-schists of the Delhi Supergroup extend for 13 km length with an average width of 1.5 km. The samples analyse 40.4-50.8% CaO, up to 2.3% MgO and less than 4% insolubles. Indicated and inferred reserves of 424 and 254 million tonnes respectively have been estimated with average 40% CaO content. The limestone is considered suitable for cement manufacture. Isolated occurrences of limestone have been reported from Tilona (26°39': 74°57'), Hatondi (26°16': 74°39'), Ganeshpura (25°48': 75°14'), Govindpura (25°48': 75°13'), Jaswantapura (25°47': 75°15'), Sawar (25°45': 75°13'), Ghorarel (25°51': 74°08') and Bilwas (25°53': 74°14').

**TABLE-37**

*Reserve of limestone as on 01-04-2005; (in 10³ tonnes)*

State	Reserves		Remaining resources
	Proved	Probable	
India	7491971	5223345	162629584
Rajasthan	1121846	585485	17778922

Source: Indian minerals yearbook, 2006.

**TABLE-37A**

*Production of limestone (2005-06); (in 10³ tonnes)*

State	No. of mines	Cement grade	Iron & steel grade	Chemical grade	Others	Total
India	549	162991	4364	2717	306	170378
Rajasthan	20	24895	1771	--	--	26666
Ajmer	1	1671	--	--	--	1671
Bundi	1	568	--	--	--	568
Chittaurgarh	6	9302	--	--	--	9302
Jaisalmer	2	--	1771	--	--	1771
Kota	1	1788	--	--	--	1778
Nagaur	4	412	--	--	--	412
Pali	2	4646	--	--	4646	
Sirohi	3	6508	--	--	--	6508

Source: Indian minerals yearbook, 2006

### Bundi district

Limestone deposits have been reported from Bundi (25°27': 75°38'), Lakheri (25°40': 76°11') and Satur (25°28': 75°33'). Limestone bands occur enveloped between the Ganurgarh Shales and the Lower Bhandar Sandstone of the Vindhyan Supergroup. The limestone is commonly massive, very fine-grained and breaks with conchoidal fracture. On an average, the limestone analyses 47.76% CaO, 1.5% MgO, 2.8% SiO₂, 1.1% Al₂O₃ and 0.7% Fe₂O₃. A total reserve of 850 million tonnes with 42.73% CaO has been estimated. The limestone is considered suitable for cement manufacture.

### Chittaurgarh district

Limestone deposits are found near Chittaurgarh (24°50': 74°35'), Nimbahera (24°35': 74°40'), Sirohi (25°55': 74°40') and Parsoli. The limestone horizon belongs to the Nimbahera Formation of Lower Vindhyan and is mostly of cement-grade.

Nimbahera Limestone with 42-49% CaO and low MgO content is mined at Nimbahera-Phalwa and at Bhenra-Dallakhera-Damdama to feed the cement factories at Nimbahera and Chanderi. Reserves of over 300 million tonnes have been estimated in the Bhenra-Dallakhera-Damdama areas. Total reserves of this limestone are put at 624.35 million tonnes, by IBM.

### Jodhpur-Nagaur-Pali districts

Limestone deposits are scattered over a 100 km belt between Sojat (25°55': 73°44') in Pali district, Bilara (26°11': 73°41') and Basa (26°00': 73°40') in Jodhpur district and Mundwa (27°03': 73°50') and Gotan (26°39': 73°45') in Nagaur district. The deposits include chemical and flux-grade limestone in the calcareous horizons of the Gotan Formation of the Bilara Group belonging to the Marwar Supergroup. The limestone, massive to thinly-bedded and laminated at places, is grey, dark-grey, white or pale white and light pink in colour. Fine- to medium-grained and, at places very coarsely crystalline, the limestone is associated with dolomite, cherty limestone and chert. There are more than 160 prospects in this belt, some of which are producing several thousand tonnes of chemical and flux-grade limestone. The analysis of the samples has indicated 49.38-54.02% CaO, 0.03-0.59% MgO and 2.03-7.66% insolubles. The total reserves have been estimated to the order of 54 million tonnes, of which about 29 million tonnes are of chemical grade (25 million tonnes in Bilara-Mundwa belt in Jodhpur and

Nagaur districts, 4 million tonnes in Gotan area, Nagaur district) and the remaining 25 million tonnes in Bilara-Mundwa belt is of flux-grade.

Limestone band found near Deoli Hulan (25°55': 73°54') in Pali district extends over a strike length of 9 km. The chemical analysis of the samples has indicated 45.63% CaO, 0.16% MgO and 10.56% insolubles. Reserves of 12 and 23 million tonnes with 42.03% CaO of possible and probable categories respectively have been estimated. The limestone is considered suitable for cement manufacture. The limestone near Ras (26°15': 74°10') is generally crystalline and greyish-white to blackish-grey in colour. Proved reserves of 45.37 million tonnes and possible reserves of 37.82 million tonnes in the area have been indicated by the DMGR.

### Sawai Madhopur district

An estimated reserves of 100 million tonnes have been indicated from the limestone deposits at Naraoli (26°15': 76°15'), Jhirona (25°05': 76°21') and Phalodi. The limestone horizon is of Lower Bhandar Limestone Formation of the Vindhyan Supergroup.

### Jaipur district

Limestone deposits occur near Kotputli (27°12': 76°12'). The limestone is grey to white in colour. The DMGR has estimated reserves of 586 million tonnes. In Maonda (27°49': 75°50') crystalline and grey limestone has been explored by DMGR and reserves of 101 million tonnes have been indicated. Impure limestone deposits are also found near Raori (26°57': 75°59'), Naila (26°52': 75°54'), Bandhia (26°55': 75°59'), Siroi (26°48': 75°54'), Harori (26°53': 75°58'), Raialo (27°05': 76°16'), Nimla (27°04': 76°10') and Dabla (27°54': 75°56'). The Dabla occurrence is being worked.

### Sikar district

The crystalline greyish-white limestone with siliceous and dolomitic bands near Patan (27°25': 74°30') has been investigated by the DMGR. Estimated reserves of 6.98 million tonnes with 46-54% CaO and 0.2-3.5% MgO and 2.22 million tonnes of possible category have been estimated. Other occurrences are also reported from Raipur (27°44': 75°58'), Jhingar (27°38': 76°01') and Saladipura (27°38': 75°31').

### Sirohi district

Occurrences of limestone are found at Abu Road (24°28': 72°47'), Dhanwan (24°31': 72°47'), Akhra (24°30': 72°50'), Pindwara (24°32': 72°52'), Murthala



(24°31': 72°49'), Kirathi (24°32': 72°50') and Mawal (24°26': 72°45'). Possible reserves of 2,036 million tonnes have been indicated for the limestone deposits at Pindwara-Abu Road belt.

#### **Dungarpur district**

The compact limestone near Sabla and Loharia with shades of pink, grey and white colour have been investigated by DMGR and reserves of 30 million tonnes with 45% CaO and low-magnesia have been proved.

#### **Banswara district**

At Talwara, the DMGR has proved 25 million tonnes of reserves with 46.28% CaO, 0.30% MgO and 24.34% SiO₂.

#### **Bikaner district**

A small occurrence of impure limestone has been recorded at Srikolayatji (27°50': 72°57').

#### **Jaisalmer district**

Khuala and Bandha limestone deposits (Lower to Middle Eocene) fall in a 100 km long curvilinear belt, from south of Sam to Bandha. The limestone beds are horizontal to sub-horizontal with low-rolling dips and are practically devoid of overburden except at a few places, where the Quaternary sedimentary cover is up to 2.0 m thick. The limestone is fine-grained, hard and compact with fossils, casts and moulds. Free quartz grains and secondary silica are noted only at a few places. Small orthoquartzite lenses are occasionally present.

Discovered and investigated by GSI, the reserves are estimated at about 560 million tonnes down to 1 m (pit depth) and an additional reserve of about 2,500 million tonnes further below. Out of 560 million tonnes, 300 million tonnes are of chemical-grade and 260 million tonnes of the rest is of flux-grade. Detailed investigations by DMGR and RSMDC have revealed the thickness of the limestone to be 4-6 m. The reserves estimated by them are 272 million tonnes with 52-54% CaO and 1.34% SiO₂ and 185 million tonnes with 52-54% CaO and 1.8% SiO₂ in Sanu block and 108.6 million tonnes with 53.4% CaO and 1.54% SiO₂ in Habur block.

Limestone from Sanu mine (RSMDC) and Habur mine is hard and remains compact after calcination at 950°C for two hours, and develops no cracks. This limestone analyses 54.20% CaO, 0.54% SiO₂ and 54.40%

CaO, 0.72% SiO₂ respectively and is of SMS grade.

### **MAGNESITE**

Magnesite, a hard white mineral, is the chief source of magnesium. Its importance lies in its property to withstand high temperature. It is extensively used in the manufacture of refractory bricks used in steel-making furnaces, in the manufacture of some special types of cement (sorel cement) and in glass and rayon industry.

Magnesite deposit near Sarupa-Chhaja in Ajmer district is known to have reserves of about 1.5 million tonnes of magnesite with an average grade of 50% MgCO₃ (24% MgO). Occurrences have also been reported from Bhimana (24°50': 73°13') in Pali district and Lewa-ka-Gurha (25°09': 73°44') area in Udaipur district.

### **MANGANESE**

Manganese finds its main use in the manufacture of pig-iron and steel, ferro-manganese (a chief ingredient for production of manganese-steel), chemicals and in dry battery cells. India possesses vast resources of manganese ores and is ranked third in the world in the production of manganese. It is second to iron ore in terms of export. In Rajasthan manganese ore deposits of significance occur in Banswara district.

#### **Banswara district**

Manganese ore deposit are confined to a belt extending from Gararia (23°19': 74°17') to Ratimaui (23°10': 74°20') for a distance of 20 km. The main deposits associated with the Aravalli phyllites are located at Sivnia (23°20': 74°16'), Khunta (23°19': 74°17'), Ghatia (23°19': 74°18'), Itala (23°30': 74°19'), Tameshra (23°18': 74°19') and Kheria (23°15': 74°21'). All along the belt manganese is exposed in numerous workings and prospecting pits. The deposits hold a possible reserves of about 3,30,000 tonnes of low-grade ore and about 32,900 tonnes of high-grade ore within a depth of 9.14 m from bottom of the existing open pits.

Manganese, in the low-grade ores, varies from 27.29 to 35.45% with Mn/Fe ratio varying between 6 and 12.2. The high-grade ores contain 46.72-52.22% Mn with a very high Mn/Fe ratio. The only promising part of the deposit appears to be the Tamesra-Kheria section which contains 97% of the reserves of high-grade ore, in addition to the reserves of the low-grade ores.

Manganese ores of Banswara district have been intermittently mined since 1945. The mining activity has been suspended due to its low-grade. The main problem for utilising the Banswara ore is its low-grade

nature with high-silica and low-iron but being amenable to beneficiations, it is possible to utilise these low-grade ores in future.

### MICA

Mica is one of the important and indispensable minerals used in electrical and electronic industry due to its excellent dielectric strength and insulating properties. India once enjoyed the status of being a leading mica exporter but with mica-substitution coming in a big way, the export-oriented mica mining industry is facing a great slump forcing many mica mines to close down.

No systematic estimates of mica reserves have been made so far because of irregular nature of mineralization. However, IBM has tentatively estimated the recoverable reserves of mica (as on 1.4.90) in the three producing States of Bihar (13,554 t), Andhra Pradesh (93,778 t) and Rajasthan (1,682 t). Production of mica in India vs Rajasthan during 2003-06 is given in Table-38.

In Rajasthan, five distinct mica-pegmatite belts have been delineated: Beawer-Ajmer belt, Bhilwara belt, Dungarpur-Banswara belt, Tonk belt and Kaunthal belt. Mica is generally of ruby variety but mostly stained and spotted due to mineral inclusions.

#### Ajmer district

*Beawer-Ajmer belt:* The pegmatite-bearing area extending for a strike length of 115 km comprises garnetiferous mica schist, calc-silicate rock, amphibolite and hornblende schist. At present, only one mica mine is in operation near Dhand. The vertical depth of mining has reached up to 40 m. The mica is of ruby variety. There is also an abandoned mica mine near Jawaja (25°56': 74°12').

#### Bhilwara district

*Bhilwara belt:* The mineralized area extends over a distance of 155 km. On the basis of the concentration

of the producing mines, the main zones delineated are: (i) Bagor (25°21': 74°23')-Lesva (25°25': 74°23') zone-which has 4 mines located at Hooja, Ganeshpura, Bhunaji and Banjan. The working depth in these mines varies from 15 to 60 m; (ii) Zorawpura (25°24': 74°25')-Bhadu (25°26': 74°28') zone-which has six mines located at Bagro-Gugara, Ghoras-Bhalawali, Bhadu-Banjani, Annapurna-Nahar, Lohariya-Banjari and Annapurna. The depth in these mines varies from 5 to 26 m and (iii) Rayara-Gundhi (25°17': 74°28')-Sainhya (25°24': 74°29') zone-which has working mines at Amargarh, Naya, Nainka, Krishna and Hari Om. The working depth in the mines varies from 4 to 23 m. Two small mines have also been reported near Jhali (25°34': 74°22') and Chapia Khera (25°51': 74°31').

#### Dungarpur-Banswara districts

*Dungarpur-Banswara belt:* Mica schist, garnetiferous mica schist and feldspathised schist are the main country rocks in the area. An abandoned mine near Chota Padri (23°40': 74°04') has been recorded.

#### Tonk district

*Tonk belt:* The mineralized area extends over a strike length of 150 m from Devran (25°34': 74°07'). Mica schist constitutes the main country rock in the area. At places, large books of mica are found though the concentration is not uniform. There are two main mines at Doli (26°21': 75°30') and Bhojpura near Phagi (26°30': 75°30'). In the first mine, a depth of 60 m has been reached, while in the second mine stoping is in progress.

#### Udaipur district

*Kaunthal belt :* The mineral-bearing zone extends from Kankroli (25°05': 73°52') in the south to Bagunda (25°32' : 74°03') in the north, over a distance of 70 km. Mica schist, calc-silicate rock, granite, pegmatites and ultrabasic rocks are the country rocks in the area. Two working mines, at Bhagwanpura and Ran near Kaunthal

**TABLE-38**  
*Production of mica; (Qty in tonnes)*

State/ District	2003-04		2004-05		2005-06	
	Crude	Scrap	Crude	Scrap	Crude	Scrap
India	1076	2928	1276	2497	1259	3384
Rajasthan	66	580	154	476	30	518
Ajmer	--	--	130	--	--	41
Bhilwara	--	--	24	476	30	477

Source: Indian minerals yearbook, 2006.

railway station and two near Sardargarh (25°14': 73°58'), are present in the area. Besides these, a number of prospecting pits are also seen. The depth attained in these mines varies from 10 to 75 m.

### MOLYBDENUM

Molybdenum is mainly used as an alloying constituent in steel industry for imparting strength, elasticity and resistance to shock and fatigue. Metal molybdenum finds application in electrical industry where it is used for contact points, thermocouples and electrodes. Molybdenum-tungsten alloy is used as filament support, in incandescent electric lamps, wireless-receivers and transmitter valves. In India the entire requirement of this metal is met by imports.

Molybdenum does not occur in nature in its free or native state. In India molybdenum is generally found associated with Pb, Zn and Cu ores and is recovered as by product concentrates. All India recoverable reserves (as on 1.4.93) are placed at 8.4 million tonnes of ore.

In Rajasthan molybdenite (the sulphide of molybdenum) is found in the sodalite-cancrinite pegmatite traversing the nepheline syenites at Manderia (26°20': 74°55') near Kishangarh in Ajmer district. Minor occurrences of academic interests are also reported from Khandela (27°35': 75°30') area of Sikar district. Molybdenum associated with the copper sulphide ores is also reported from the Khetri Copper Belt of Jhunjhun district.

### NICKEL

Nickel is an important ingredient in the production of stainless steel. It is also used as a catalyst in making alloys and coins and in the storage of batteries.

Nickel-compounds are widely used in electroplating, chemical and ceramic industry. The requirement of the country in respect of nickel is met solely by imports.

Nickel is recovered as a by-product. Conditional-resources of about 183.5 million tonnes of nickel ore containing 0.5-0.9% Ni have been estimated by IBM.

### Udaipur district

The serpentinite rocks at Rakhabdev (24°05': 73°41')-Kherwara (23°59': 73°36') area south of Udaipur indicate the possibility of getting low-grade nickel ore. Nickel is associated both with silicate structures and in the magnetic-mineral fraction of the serpentinite, but is more concentrated in the latter. Fairly good concentration of magnetic minerals are found in pale green serpentinite bands up to 10 m in width and 1 km in strike length. The magnetic minerals occur as thin veins, lenticular aggregates and patches, streaks and stringers, and as granular disseminations. Some of the bands have shown nickel concentration over 300 ppm.

Nickel-rich pyrrhotite has been found along with the copper ores in the Khetri Copper Belt in Jhunjhun district.

### OCHRE

Ochres are mineral-pigments with iron as the colouring material either in the form of haematite or limonite or both. These earth pigments are insoluble and are used directly as paint material or to give colour, body and opacity to paint, cement, linoleum, rubber, glasses, enamels, plastics etc.

In Rajasthan, occurrences of ochres are found at various places in Bikaner, Chittaurgarh, Jaisalmer, Jhunjhun, Jodhpur, Nagaur and Udaipur districts Table-39A. The reserves of ochre in India vs Rajasthan are shown in Table-39.

**TABLE-39**

*Reserve of ochre as on 01.04. 2005; (in 10³ tonnes )*

State	Proved	Probable	Remaining resources	Total
India	25747.47	22120.37	45573.43	93441.29
Rajasthan	21383.075	14032.869	31272.386	66688.33

Source: Indian minerals yearbook, 2006

**TABLE-39A**

*Production of ochre in Rajasthan; (Qty in tonnes, value in Rs '000)*

State/District	No. of Mines	2004-05 Quantity	Value	No. of Mines	2005-06 Quantity	Value
India	26(22)	919018	56944	26(14)	920600	59253
Rajasthan	8(11)	860672	50544	8(5)	878956	54487
Bhilwara	(2)	15444	975	(2)	2827	260
Bikaner	(1)	240	19	--	--	--
Chittaurgarh	6(7)	84075049261	7(3)	876129	54227	
Jhunjhun	1148	30	--	--	--	
Udaipur	1(1)	4090	259	1	----	

Source: Indian minerals yearbook, 2006; figures in parentheses indicate nos. of associated mines.

## OIL AND NATURAL GAS

The Eocambrian Hanseran Evaporite Group (HEG) of the Marwar Supergroup contains foetid dolomite and dolomitic limestone at four levels below halite beds No. 2,3,4 and 5. It is grey to dark and black carbonaceous, fine-grained, massive to vuggy dolomite. It stains paper and smells strongly of petroleum.

Foetid dolomite from Lakhasar contains 30.40 ml/kg of ethane and hydrocarbon, and is considered the source rock for the petroleum. The hydrocarbons migrated and got trapped in structural traps around DevikotNachana subsurface high separating the Jaisalmer basin from the Nagaur-Bikaner basin.

Attempts to explore hydrocarbons in Rajasthan dates back to 1956. For oil exploration the Rajasthan desert (1,20,000 sq km) has been divided into four geological basins, namely the Jaisalmer basin, Bikaner-Nagaur basin, Barmer basin and Sanchor basin. Currently both ONGC and OIL are jointly operating in Rajasthan.

In the Jaisalmer and Bikaner-Nagaur basin oil and natural gas occurrences are known but viability of commercial production is yet to be established. Nine gas fields, viz., Manhera, Tibba, Ghotaru, Bakhri Tibba, Kharaar, Bankia, Tanot, Dandewala and Ramgarh have been proved so far by ONGC and OIL within the Jaisalmer basin. A major find of heavy crude oil has recently been made at Bagewala in Bikaner-Nagaur basin. In addition to these gas fields, good hydrocarbon indications have been observed at Jalawala, Bhuana, Vikharan Nai, Shahgarh etc. The prognosticated reserves in Jaisalmer area are 180 million metric tonnes (oil + oil equivalent gas), while the discovered reserves in this basin are of the order of 8.6 billion m³ of gas.

## POTASH

Potash is one of the key elements used in fertilizers. India produces a meagre quantity of potash in Gujrat as by-product in manufacture of salt from sea water.

In Rajasthan, GSI has established by detailed geophysical investigation aided by extensive drilling, occurrences of subsurface halite-bearing evaporites over an area of 30,000 sq. km covering parts of Ganganagar, Hanumangarh, Bikaner, Churu and Nagaur districts.

Eight sub-basins/depocentres for potash mineralization containing 2% K have been identified

around Bikaner, Hanseran, Arjunsar, Gharsisar, Jaitpur, Satipura, Bharusari and Lakhasar. Out of these, the last four depocentres are considered to be prospective for sylvite/sylvinite mineralization.

Detailed exploration was conducted around Satipura, Bharusari and Lakhasar. Jaitpur, the most prospective sub-basin, could not be explored due to tough terrain conditions and non-availability of water.

Potash minerals intersected in the Nagaur-Ganganagar Evaporite basin include polyhalite (K₂MgCa₂(SO₄)₄·2H₂O), sylvinite (KCl NaCl), sylvite (KCl), langbeinite (K₂Mg₂SO₄)₃ and carnallite (KMgCl₃·6H₂O) in decreasing order of their abundance. In general, the depth of potash mineralization varies from 595 to 740 m from the surface.

The reserves estimated in Satipura, Bharusari and Lakhasar sub-basins at cutoff grade of 3% K and stoping width of 1.5 m are given in Table-40.

**TABLE-40**  
*Reserves of potash ore*

Sub-basins	Area km ²	(in millions tonnes)		Grade K%
		Probable	Possible	
Satipura	245.61	202.30	1,429.95	4.80
Bharusari	71.00	88.16	300.15	4.68
Lakhasar	29.50	113.73	342.29	4.39
Total	346.11	404.19	2,072.39	Av. 4.70

Source : GSI.

Tentative reserves of potash from a thick halite zone at 385.83-965.58 m depth around a few positive boreholes in Hanumangarh area are of the order of 6.7 million tonnes while the halite is of the order of 6 trillion tonnes (exceeding 80% NaCl).

## PYRITE - PYRRHOTITE (Sulphur)

India does not possess any significant deposit of native sulphur. The entire sulphur requirement of the country is met from imports. The uncertainty of obtaining native sulphur in the international market and its exceedingly high prices have necessitated the search for alternate indigenous sources such as pyrite (iron sulphide). The economic value of pyrite-pyrrhotite lies in its being a source of sulphur. The sulphur as well as the pyrite itself constitutes the principal raw materials for the manufacture of sulphuric acid which is used mainly in the manufacture of superphosphate fertilizer and also in several other chemical industries. Pyrite-pyrrhotite deposit near Saladipura (27°40': 75°31') in Sikar district is of paramount importance.



### Sikar district

*Saladipura pyrite-pyrrhotite deposit:* The deposit, located about 1.5 km northwest of Saladipura, is approachable by a 30 km road from Kanwat railway station.

The deposit occurs along two shear zones in the rocks of the Ajabgarh Group of the Delhi Supergroup. It extends for a strike length of 7 km with thickness varying from 5 to 100 m, the average thickness being about 25 m. The deposit occurs 36-47 m below the surface and extends for more than 350 m in depth without any sign of bottoming. Within the main ore body, there are 2-3 subzones from 1 to 20 m, separated by leaner zones.

The main minerals in the ore body are pyrite and pyrrhotite with a minor amount of sphalerite, rare galena and chalcopyrite. The source for the sulphides appears to be the basic rocks occurring in the vicinity of the ore body. While the shear zones have served as channelways for the influx of the mineralizing solution. The sulphur content of the richer zones is 30-40%, while that of the leaner zones is 10-20%. The weighted average for the entire deposit has been worked out at 22.5% S. Besides sulphur, the ore also contains about 1% Zn. The total reserves of pyrite-pyrrhotite ore in this area have been estimated at 111.62 million tonnes containing, on an average, 21.63% S.

The ore at Saladipura is amenable to beneficiation so as to obtain the required concentrates having 35-40% S with good recovery of S. This deposit will provide the pyrite concentrates needed for manufacturing sulphuric acid in the fertilizer complex being set up in Rajasthan. The area has been handed over to Messrs Pyrites, Phosphates and Chemicals Ltd., a Government of India undertaking, for exploration.

### ROCK PHOSPHATE

Rock phosphate, popularly known as phosphorite, is an essential ingredient in the manufacture of superphosphate, a fertilizer, whose paramount importance in boosting the green revolution in our country needs no emphasis.

The total reserves of rock phosphate known so far in India are about 175 million tonnes out of which 122 million tonnes are of low-grade containing 10-20%  $P_2O_5$ . Rajasthan contributes a major share in the production of rock phosphate in India (Table -41).

**TABLE-41**

*Production of rock phosphate in India vs Rajasthan*

Year	India $\times 10^3$ tonnes	Rajasthan $\times 10^3$ tonnes
1992-93	617.42	234.54
1993-94	1033.82	977.98
1994-95	1096.65	891.83
1995-96	1345.58	900.87

Source : DMGR, 1997. Bull. 18, Vol. 1

In Rajasthan, phosphorites occur in diverse lithological formations ranging in age from Lower Proterozoic to Tertiary. Of these, the discovery of the Precambrian phosphorite in the Aravalli rocks of Udaipur district, in particular, has opened up new vistas in the sphere of exploration of rock phosphate in similar metasediments in India.

The phosphorite deposits in Udaipur and Banswara districts in Rajasthan are located within the rocks of the Aravalli Supergroup of Lower Proterozoic age while those of Alwar and Jaipur districts occur in the rocks of Delhi Supergroup of Lower to Middle Proterozoic age and that of the Chittaurgarh district occur in the rocks of the Lower Vindhyan of Middle Proterozoic age. Phosphorite occurrences are also reported from the Mesozoic Formations of Jaisalmer.

### Udaipur district

The important phosphorite deposits located by the GSI are those of Maton, Kanpur, Karbaria-ka-Gurha and Dakan Kotra, all of which are located within a radius of 10-25 km from Udaipur. The largest deposit at Jhamar- Kotra discovered by DMGR is now being mined.

*Jhamar Kotra (24°40': 75°52') deposit:* This is the largest and richest phosphorite deposit proved so far in the country. The Jhamar Kotra deposit is located about 26 km southeast of Udaipur. The phosphorite horizon extends over a strike length of about 12-15 km with thickness varying from 5 to 30 m. The phosphorite is associated with algal limestone and cherty quartzite. The reserves in the entire area down to a depth of 30 m, according to the DMGR, are of the order of 40 million tonnes, of which about 10.5 million tonnes contain phosphorite having 30-37%  $P_2O_5$ . The rest of phosphorite contain about 20-30%  $P_2O_5$ . The deposit is under exploitation by the DMGR.

*Maton deposit:* The Maton (24°33': 73°47') deposit is located about 13 km east of Udaipur. The bluish grey, phosphorite horizon 0.5-20 m thick in this area,

generally follows the bedding and structural trends of the host rocks and can be traced over a strike length of 3.5 km. It is found associated with dolomitic marble in the northern part, jaspery quartzite in the central part and brecciated quartzite and sandy phyllite in the southern part. The total probable reserves estimated by GSI are of the order of 2.23 million tonnes averaging 28%  $P_2O_5$  while the possible reserves are estimated at about 3.1 million tonnes containing 21-29%  $P_2O_5$ . The deposit is now being opened by HZL.

**Kanpur deposit:** This deposit, the first to be discovered by GSI in the Udaipur area, is situated about a km south of Kanpur (24°34': 73°46'). The phosphorite horizon exposed over 1.5 sq. km stretch of flat and uneven country is mainly associated with bluish grey, fine-grained dolomitic marble.

In the eastern part, however, it occurs along the contact of brecciated jaspery quartzite and phyllite. There is only one phosphorite horizon which has been refolded into a complex pattern of folds. The thickness of phosphatic horizon varies between 4 and 6 m and the deposit is somewhat of low-grade with  $P_2O_5$  content varying from 13-25%. The total reserves indicated are of the order of 3 million tonnes containing 12-13%  $P_2O_5$ .

**Karbaria-ka-Gurha deposit:** Between the Maton and the Kanpur deposits, there occurs another discontinuous horizon of bluish-grey phosphorite which extends southwards from Karbaria-ka-Gurha (24°33': 73°47') over a distance of about 1.5 km. The phosphorite is associated with dark-grey cherty quartzite, granular and calcareous quartzite, and sandy phyllite and at places with schistose rocks. The phosphorite horizon as a whole is only 1-5 m thick with the individual bands varying in thickness from 0.15 to 3 m and traceable for a strike length of 30 m to over 400 m. The southernmost horizon appears to be most promising. The tentative reserves estimated are of the order of 0.56 million tonnes containing 22-25%  $P_2O_5$ .

**Dakan Kotra deposit:** The deposit is located about 12 km SSE of Udaipur (24°30': 73°44') near Dakon Kotra. In this area several lenticular bands of phosphatic stromatolites are found within dolomitic marble and locally in cherty and brecciated quartzites. The phosphorite horizon is about 10 m thick and extends over a strike length of over 500 m. Reserves, for a down-dip extension of 50 m, are estimated at about 0.5 million tonnes containing 15%  $P_2O_5$ .

Apart from the above phosphorite occurrences,

several other small bands and lenses of phosphatic stromatolites have also been located at various places in Udaipur district, particularly towards southwest of Lakawas (24°30': 73°45'), east of Bhila (24°30': 73°40'), south of Kanpur and east-southeast of Umra (24°30': 73°45'), Neemuch Mata (24°36': 73°42'), Badagaon (24°34': 73°40') and Sisarma (24°32' : 73°37'). Reserves of rock phosphate are given in Table-42.

TABLE-42

Reserves of rock phosphate

Place	Reserves (million tonnes)	$P_2O_5$
Sisarma	0.84	5-10%
Neemuch Mata	0.11	10%
- do -	0.22	5-10%
Badagaon	0.03	3-23%

Source : DMGR, 1997. Bull. 18 (1)

### Banswara district

Two small phosphorite deposits have been located in Sallopat and Ram-ka-Munna areas of Banswara district in identical litho-associations as those of the Udaipur district.

**Sallopat deposit:** The deposit is located about a km southwest of Sallopat (23°11': 74°08') which is 66 km southwest of Banswara. The phosphorite zones which comprise 12 detached and folded lenses occur in the central part of a 3.2 km long, NW-SE trending, dolomitic band. The individual phosphorite lenses vary in length from 24 to 150 m while the entire phosphatic zone covering all the lenses is about 1.2 km long. The preliminary reserves estimate is about 150 thousand tonnes of phosphorite having 15-20%  $P_2O_5$  content.

**Ram-ka-Munna deposit:** The deposit is located about 210 m south of Ram-ka-Munna (25°15': 74°08'). Bluish-grey phosphorite, as thin stringers and veins, occurs in dolomite and can be traced for a distance of about 120 m. The concentration of phosphorite in the veins and stringers varies widely and the  $P_2O_5$  content of the entire zone does not exceed 15%. The *in situ* reserves are about 36 thousand tonnes of phosphorite having 10-15%  $P_2O_5$  content.

### Chittaurgarh district

**Jaoda deposit:** A minor occurrence of phosphatic shale within the Nimbahera Shale Formation (Lower Vindhyan) near Jaoda has been located extending over a strike length of 10 m with an average thickness of 5 cm. The  $P_2O_5$  content varies from 5 to 8%.

### Jaisalmer district

**Birmania deposit:** It is the only phosphorite occurrence in the Palaeozoics of Rajasthan associated with highly folded and unfossiliferous Birmania Formation. The deposit is located near the abandoned village of Birmania (26°14': 70°56'), about 120 km northwest of Barmer. The phosphorite bed traceable for about 4 km in a NNE-SSW direction is underlain by calcareous quartzitic sandstone and overlain by limestone. The thickness varies from 1 to 3 m. Detailed work in the Birmania block led to estimation of probable reserves of 4.34 million tonnes of phosphorite with average 12.15%  $P_2O_5$  grade for a down-dip extension up to 100 m.

**Fatehgarh deposit:** Coarse gritty, ferruginous, phosphatic sandstone with interbedded clays occurs, near Fatehgarh, about 88 km north of Barmer. Thick phosphatic horizon, underlain by the Lathi Sandstone (Jurassic) and overlain by the Akli Formation (Palaeocene) includes phosphatic oolites, chalk-like pellets up to 3 cm in diameter and fossil shells and is traceable over a length of 50 km from Sandha (26°29': 71°18') to Bhiyar (26°19': 71°28') with thickness ranging from 0.5 to 2.5 m. The potential reserves of the area have been estimated as 12 million tonnes of low-grade iron-rich phosphatic rock with an average 8%  $P_2O_5$ .

**Rupsi and Nibh Dungar:** Phosphatic nodules were reported in Baisakhi Shales (Jurassic) from these localities. Prospecting by GSI showed that the larger nodules are devoid of phosphate while the smaller nodules have 22-27%  $P_2O_5$ . The scattered and disseminated nature of phosphatic nodules makes the occurrences uneconomical.

### Jaipur district

**Achraul:** A phosphatic area was located near Achraul in the year 1980 within the rocks of Delhi Supergroup. Exploration has indicated extension of the rock phosphate bands over 1.2 km strike length divisible into three blocks. The  $P_2O_5$  content declines sharply from 10 to 30% on the surface to 6-10% at 40 m depth. The reserves estimated at Achraul are about 1.8 million tonnes of 5-10%  $P_2O_5$ .

The chances of encountering such lenses in other sectors of the 20 km long belt, between Pirpur and Achraul, and also at Aduka-Andwan near Rajgarh in Alwar district are high.

## SALT

Salt is one of the most common substances used in

our daily life and is an essential constituent of human food. Salt is mainly prepared by evaporating sea water. Salt also occurs in nature as beds of rock salt which are in fact evaporites derived from ancient basins of highly saline seas. In dry regions like Rajasthan, salt is precipitated from saline ground water at the ground water surface in the form as efflorescences. Extraction of salt from efflorescences forms local cottage industries. Considerable quantities of common salt are prepared from the brines of saline lakes in Rajasthan. Salt lakes of Rajasthan, vary in characters (Table-43), are important sources of salt production in the country. The chief salt producing areas are in Nagaur, Barmer and Bikaner districts.

**TABLE-43**  
*Characteristics of the salt lakes of northwest Rajasthan*

Name of Lake / Playa	Area km ²	Thickness of lake sediment (in metres)	Saline or non-saline
<i>Nagaur district</i>			
Sambhar lake (also partly in Jaipur district)	243	+25	Saline, Mg/CL ratio varies from 5 to 7 against 3 for sea water
Kuchaman lake	8.5	20	Saline
Sargot lake	2.2	20	Saline
Didwana lake	10.4	20.30	Saline
<i>Jodhpur district</i>			
Bap-Phalodi area	51.0	—	Saline
Dedyan-ka-Rann	5.8	1.4	Presence of minor salt
<i>Bikaner district</i>			
Lunkaransar	4.5	—	Saline
<i>Barmer district</i>			
Pachpadra lake	82.79	—	Saline
Gudi Rann	17.3	1.4	Saline
<i>Jaisalmer district</i>			
Pokaran Rann	12.1	5	Saline
Lawan-ka-Rann	5.6	1.4	Presence of minor salt
Jhalaria-ka-Rann	7.8	1.2	Saline in deeper portion
Mertha Rann	26.0	3.3	Saline in deeper portion
Khara Rann	14.3	1.5	Saline
Kanod Rann	23.0	+3.2	Saline

Source : GSI.

### Nagaur district

The salt lakes of Nagaur district are the Sambhar lake (partly in Jaipur district), Didwana lake, Kuchaman lake and Sargot lake. Of these, the Sambhar lake and the Didwana lakes are important.

**Sambhar lake:** It is the most important lake, covering an area of 243 sq. km, annually produces about 2,00,000 tonnes of common salt. The following three types of salts (Table-44) are obtained from the Sambhar lake brine by concentrating it through solar evaporation after rainy season.

**TABLE-44**  
*Sambhar lake salts*

	NaCl%	Na ₂ SO ₄ %	Na ₂ CO ₃ %	Insoluble%
Kyar	96.36	2.39	0.40	Very little
Reshta	97.59	1.03	0.40	0.40
Pan salt	96.01	3.10	2.26	0.32

Source : GSI.

The average composition of brine is 88% NaCl, 7.5% Na₂SO₄ and 4.5% Na₂CO₃. As per rough estimates, 5-6 million tonnes of Na₂SO₄ and 2-3 million tonnes of Na₂CO₃ can be obtained from the Sambhar lake.

*Didwana lake*: It is an oval-shaped depression, 8.04 km long and 6.4 km wide, situated at a distance of 64 km from Sambhar. The salt rich in Na₂SO₄ is of very poor quality containing 80% NaCl. Extensive deposits of anhydrous crystalline Na₂SO₄ known by the name of *rohi* which is used as a raw material for heavy chemicals have been reported from Didwana. *Rohi* composed of a mineral called 'thenardite' contains 90% Na₂SO₄. The sodium sulphate deposits of Didwana are quite capable of supplying the natural chemical product to different industries for the manufacture of chemically pure sodium sulphate, sodium thiosulphate and possibly sulphur.

#### Barmer district

*Pachpadra lake*: It is a long oval-shaped depression about 12.8 km in length and 4.3-11.2 km in width covering 82.74 sq km area. Pits, about 91.41 m long and 15.23-18.28 m wide are sunk down to the depth of 3.04-3.65 m and the subsurface brine is collected into the pits through percolation. The depth of brine at the pits is about 0.9-1.67 m. The total salt production from this lake is about 1,00,000 tonnes per annum.

#### Bikaner district

*Lunkaransar lake*: The Lunkaransar lake is situated 72.4 km northeast of Bikaner covering an area of nearly 4.5 sq km. Common salt is obtained in pits/salt pans by concentration of sub-terranean brine which percolates into pits excavated for this purpose. About 8-10 thousand tonnes of common salt is collected every year from this lake. The brine contains 16% NaCl and 2.6-3% Na₂SO₄. The bitter fraction containing 9% Na₂SO₄ is being discarded without utilising it.

#### Jaisalmer district

Only a small amount of common salt for local

consumption is being produced in Khara Rann (14.3 sq m area) and Kanod Rann (23 sq m area) from the sub-surface brine. The brine is taken out from shallow dug wells and allowed to evaporate in salt pans to obtain common salt.

#### Jodhpur district

Bap and Phalodi areas covering more than 100 sq km produce salt by solar evaporation of brine pumped out from shallow dug wells.

#### SILICA SAND

(*Quartz and Glass Sand*)

Quartz is an important constituent of almost all rock-forming minerals. Free silica occurs in forms such as pure quartz (crystalline or massive), opal, agate and chalcedony. The main source for silica sand and quartz are sandstones, quartzites, pegmatites, quartz veins etc.

In Rajasthan, glass sand occurrences suitable for utilisation in glass industries are known from Jaipur, Bundi, Dausa, Sawai Madhopur, Tonk, Jaisalmer, Bikaner and Barmer districts. The other use of silica sand is in acidic Remi-mass in foundry units. The production figures of quartz and silica sand are summarised in Tables-45 and 46 respectively.

**TABLE-45**  
*Production of quartz in Rajasthan;*  
(Qty in tonnes, value in Rs '000 )

State/District	No. of Mines	2004-05		No. of Mines	2005-06	
		Quantity	Value		Quantity	Value
India	133(43)	319004	44349	89(25)	250719	29511
Rajasthan	32(33)	53040	6686	14(17)	46557	5179
Ajmer	16(17)	23077	2885	7(9)	20945	2415
Alwar	1	919	460	1	279	1395
Bhilwara	3(14)	12115	1342	1(6)	6122	702
Dausa	2	3187	349	-	-	-
Pali	(1)	876	70	(1)	148	12
Rajsamand	1(1)	674	40	(1)	2384	143
Sikar	5	5787	579	2	475	119
Tonk	4	6405	961	3	15088	1509

Source: Indian minerals yearbook, 2006; figures in parentheses indicate nos. of associated mines.



**TABLE-46**  
*Production of silica sand in Rajasthan;*  
*(Qty in tonnes, value in Rs '000)*

State/District	2004-05			2005-06		
	No. of Mines	Quantity	Value	No. of Mines	Quantity	Value
India	153(7)	1962029	244699	148(5)	2344793	269090
Rajasthan	15(4)	337762	51696	9(1)	352610	50910
Alwar	1(1)	4961	605	1	6010	661
Bharatpur	8	264880	34399	4	254415	32032
Bikaner	(1)	5070	542	(1)	1091	82
Bundi	1	36765	12794	1	40073	12022
Chattaurgarh	1(2)	1880	136	-	-	-
Dausa	1	18866	2509	1	8600	1221
Jaipur	1	4085	490	1	26597	3990
Jaisalmer	1	790	194	-	-	-
Sawai	1	465	27	-	-	-
Karauli	-	-	-	1	15824	902

Source: Indian minerals yearbook, 2006; figures in parentheses indicate nos. of associated mines.

### Jaipur-Dausa districts

**Jhir:** Silica sand is known to occur in quartzites of the Alwar Group of the Delhi Supergroup in Banskhh hill near Jhir (26°51': 71°08'). The silica sand is probably derived by leaching of feldspars from the quartzites. The sand is white, fine-grained and varies in grain size from 0.12 to 0.25 mm. The average size of the sand being mined is between 30 and 150 mesh (B.S.S.). Weathered feldspar, minute grains of tourmaline, iron-ore and mica flakes are found in small quantities. An estimated reserves of 2.8 million tonnes have been indicated.

Occurrences of glass sand are also reported from Khorī (26°51': 76°08') Nimora (26°51': 76°09'), Bhuj (26°59': 76°02'), Chitori (26°49': 76°09'), Gumanpura (26°45': 76°09'), Dhula (26°50': 76°12'), Bhankri (26°50': 76°24'), Kaloti (26°59': 76°25') and Sainod (27°17': 76°49').

### Bundi-Kota-Sawai Madhopur districts

The Taragarh Fort Sandstone contains a number of silica sand pockets which are being quarried near Manjora, Mohanpur, Patori and Guneshri. Recovered from the friable sandstone bands, the silica is milky-white to light yellowish-brown in colour. Occurrences are also reported from near Narauli (26°08': 76°22') and Jare (26°54': 76°55').

The Bundi Hill Sandstone encloses numerous lenses and pockets of silica sand in the GBF zone near Baridiya, 8 km north of Bundi. It extends over a strike length of 1.6 km with width ranging from 200 to 400 m. Average grade of sand is 99.30% SiO₂ and 0.15% Fe₂O₃. Reserves are estimated at about 1.18 million tonnes. Other occurrences of glass sand are reported from

Kundi and Kheemaj (24°42'15": 70°01'). Near Kundi, 6-10 m thick sand zones occur in the Bundi Hill Sandstone is white in colour with occasional pink and red shades, fine-to medium-grained and rarely pebbly. The estimated reserves are 5.3 million tonnes. In Kheemaj the sandstone is generally white and on an average contains 94.50% SiO₂ and 0.25% Fe₂O₃.

### Tonk district

Silica sand deposits are found near Bher (26°16': 76°06') and Siwad (26°12': 76°02'). The deposit at Bher is associated with quartzite which is sericitic at places. The estimated reserves are 6.05 million tonnes. Reserves of 2.89 million tonnes have been estimated for the deposit associated with quartzite in Siwad area. Silica sand deposit has also been reported to occur near Newai within the Aravalli quartzite.

Reserves of 36.80 million tonnes have been estimated of which 3.68 million tonnes is expected to be of friable variety capable for yielding pure silica sand.

### Jaisalmer district

**Lathi:** The pure white sandstone, occurring in an area of about 20 sq. km near Lathi was examined by DMGR. It disintegrates to workable glass sand down to at least 1.5-2.5 m depth. The sand analyses to 92.95% SiO₂, 1.2-3.99% Al₂O₃, 0.63-1.29% Fe₂O₃, 0.28% CaO and is free from MgO and TiO₂. The deposit can be utilised for manufacture of bottle glass. Reserves of 14.4 million tonnes of glass sand have been assessed. Glass sand deposits also occur at Devikot and Pthal.

### Bikaner district

**Marh:** The sand derived from a horizontally bedded sandstone assays 98.73-99.19% SiO₂ and 0.23-0.89% Fe₂O₃. The probable reserves estimated by GSI are of the order of 1.15 million tonnes.

### Barmer district

Occurrences of glass sand have also been reported from Sheo.

### Jodhpur district

In addition to glass sand, quartz occurs at Bhakarion-ki-Dhani, (Bilara tehsil) and Tinwari (Osian tehsil). Quartz exposed near Bhakarion-ki-Dhani, occurs as huge lenses and is brecciated in nature. It is white with reddish-brown stains and is being mined by a private lessee.

## SILVER

Silver is valued as a medium of exchange and also for its use in jewellery. In recent years, its application in industry has increased rapidly. In India, silver is obtained as by-product of Pb-Zn and Au mining. Reserves of silver as on 01.04.2005 and production of silver during 2003-04, 2004-05 and 2005-06 years are given in Table-47A & 48 respectively. Recoverable reserve of silver is shown in Table-47.

**TABLE-47**  
*Recoverable reserves of silver*

		Proved	Probable	Possible	Total
India	Ore (mt)	48.77	56.76	33.62	139.16
	Metal (t)	1,561.90	941.20	1,046.10	3,549.20
Rajasthan	Ore (mt)	44.35	53.27	31.41	129.05
	Metal (t)	1,517.00	914.00	958.00	3,389.00

Source : Indian Minerals Year Book 1996 Vol. 2, 1998, p. 580.

**TABLE-47A**  
*Reserve of silver as on 01-04-2005; (Ores in million tonnes)*

State		Proved	Probable	Remaining resources	Total
India	Ore	55.75	60.16	128.72	244.63
	Metal	0.0022	0.0037	0.0041	0.01
Rajasthan	Ore	46.89	59.36	98.06	204.31
	Metal	0.0022	0.0037	0.0038	0.0097

Source: Indian minerals yearbook, 2006

**TABLE-48**  
*Production of silver; (Qty in kg; value in Rs '000)*

State	2003-04		2004-05		2005-06	
	Quantity	Value	Quantity	Value	Quantity	Value
India	37870	293601	10955	84311	27950	227870
Rajasthan	34545	263924	10570	80289	24261	182808

Source: Indian minerals yearbook, 2006

In Rajasthan silver is associated with the Pb-Zn ores of Zawar, Rajpura-Dariba and Bharak areas of Udaipur, Rajsamand and Bhilwara districts respectively and is extracted during the smelting of Pb from the Pb concentrates.

### Udaipur district

**Zawar area (24°17': 73°41')**: The ore reserves estimated so far in the Mochia, Balaria and Zawarmala sections of the Zawar Pb-Zn belt are of the order of 27 million tonnes containing on an average 4% Zn and 1.5% Pb. Thus the Zawar deposit is likely to yield 4,05,000 tonnes of Pb. The average silver recovery being about 1 kg per tonne of Pb concentrate; a total of 405 tonnes of Ag is expected from the Zawar area, as per the estimates of the HZL.

### Rajsamand district

**Rajpura-Dariba area (24°57': 74°08'24"58": 74°08')**  
: Silver is often found to be associated with galena,

tetrahedrite, tennantite and pyrrargyrite in the Dariba Main and Dariba East lodes in the Rajpura-Dariba base metal area prospect. Borehole samples from this area have analysed 100-2,000 ppm of Ag. Further, the Pb-Cu concentrates containing 24.6% Cu and 63.49% Pb (with recoveries of 70.5% Cu and 92.2% Pb) were assayed and found that Cu concentrates assayed 766 gm of Ag per tonne. This indicates that silver could be recovered from the base metal ores as an important and valuable by-product. Even assuming 90 gm per tonne as the average Ag content of the ores, the Rajpura-Dariba deposit is likely to yield about 2,250 tonnes of Ag in the proved and probable reserves and additional 2,430 tonnes in the possible reserves.

### Bhilwara district

Small reserves of silver have been established at South Dedwas and Bharak (25°08': 74°16'). At Bharak, 22,579 tonnes of possible reserves of Ag, of 670 ppm grade with 150 ppm Ag cutoff, over a strike length of 200 m within siliceous dolomite, marble and metamarl have been estimated.

## SILICEOUS EARTH

Siliceous earth composed mainly of colloidal silica and other siliceous matters contains chiefly 69-81% SiO₂ and 4-12% Al₂O₃ with very little CaO, MgO and iron oxides. It is homogeneous, porous, easily breakable and light in weight. It has high absorption power. Its main use is as filters and refractory silica-bricks. Siliceous earth occurrences are known from Barmer and Jaisalmer districts.

### Barmer-Jaisalmer districts

Siliceous earth occurs as two thin beds, grading laterally and vertically into bentonite at Dharivi Khurd, Mandai, Akli and Sajeet Nimla. These beds vary in thickness from 0.15 to 1.45 m. The siliceous earth contains silica (up to 80%) and is suitable for filters and manufacture of refractory silica bricks. The total estimated reserves of siliceous earth in the area, falling partly in Jaisalmer district and partly in Barmer district, are about 10 million tonnes of which 1.2 million tonnes have been assessed in Jaisalmer area.

Siliceous earth deposits are also known from Mattika-Gol (0.33 million tonnes with 74.32% SiO₂), Bhorasar (0.66 million tonnes with 74.40% SiO₂), Jatto-ki-Dhani (0.35 million tonnes with 72.0% SiO₂) and Bariyara (0.10 million tonnes with 76.28% SiO₂).

### STEATITE

Steatite, talc and soapstone are the three terms used in trade for a hydrous silicate of magnesium. A purer variety of compact and massive talc is steatite.

Rajasthan is the prime producer of soapstone in India. Rajasthan with 6.3 million tonnes of reserves accounts for about 41% of the all India total reserves of all categories. It produces about 86% of the national output. Occurrences of soapstone have been reported from Jaipur, Bhilwara, Dausa, Sawai Madhopur, Udaipur, Dungarpur and Banswara districts.

#### Jaipur-Dausa districts

Prominent deposits are located at Dogetha-Jharna (27°07': 76°16') and Geejgarh (26°50': 76°35'). The Dogetha-Jharara deposit is associated with dolomites and basic intrusives of the Raialo Group of the Delhi Supergroup. The talc occurs as veins with concentrated pockets of massive variety in three-parallel zones and varies in thickness from 1 to 6 m. Inferred reserves of 0.25 million tonnes have been indicated in the area.

#### Bhilwara district

Prominent deposits are located at Geuria (26°26': 75°03') and Chainpura (25°28': 75°06'). Occurrences are also reported from Bhanai Khera (25°26': 75°04').

In Geuria and Chainpura, talc is confined to the dolomite of the Jahajpur Group of the Bhilwara Supergroup. The talc lenses vary in thickness from 1 to 21 m and are generally white in colour. The inferred reserves of the deposits are 0.42 million tonnes.

#### Sawai Madhopur district

Talc deposits have been reported from Dhaota (26°48': 76°44'), Dwain (26°48': 76°45'), Kamalpura (26°48': 76°46'), Rajauli (26°48': 76°48'), Garhi (26°48': 76°47'), Pura (26°48': 76°48') and Morra (26°48': 76°48'). Talc in these deposits occurs in quartzite as veins and lenses varying in thickness from 0.5 to 20 m. Talc, cleaved and foliated, is generally pale green to greenish-white in colour. Reserves of 0.01 million tonnes have been estimated from these deposits.

#### Udaipur-Dungarpur districts

Talc deposits/occurrences are associated with the Rakhabdev ultrabasic belt. The important deposits/occurrences of talc are from Undithal (24°35': 73°29'), Rathor-ka-Gurha (24°43': 73°34'), Bansra (24°44' :

73°35'), Ord (24°22': 73°47'), Deopura (24°18': 73°47'), Padla (24°19': 73°46'), Parsola (23°57': 74°23'), Bhungapat (23°56': 74°21'), Bharkhundi (23°58': 78°19'), Gurali (24°38': 73°48'), Negria (24°43': 73°48') and Nathanwas (24°55': 73°50'). Pyrophyllite is available at Naya Garhu (24°34': 73°37'), Gorach (24°48': 73°40'), Sonairo (24°44': 73°41'), Bari (24°36': 73°38'), Brahman-ka-Varla (24°39': 73°37') and Rama (24°44': 73°41').

Talc and pyrophyllite are generally pale green to greenish-white, cleaved and foliated. An indicated reserves of 0.05 million tonnes of talc have been estimated from these deposits. The reserves of pyrophyllite deposits are estimated at 0.22 million tonnes.

### TIN

Tin is recovered from its oxide cassiterite. Metal tin is widely used in alloys and in the chemical industry. Tin oxide is used as polishing material for marble and granite. India does not possess workable deposits of tin and the entire requirement is met by imports. In Rajasthan, Bhilwara district holds some promise of holding a deposit.

#### Bhilwara district

Tin ores are known to occur in Paroli (25°15': 74°55') area which has been examined by the IBM, and found to be fairly promising.

In Johna Sili area, tin-bearing lodes have been proved over a distance of 1.6 km along the strike and for 12-19 m in depth along the dip direction. The lodes, irregular in shape and size, have assayed on an average 0.25% tin metal.

### TUNGSTEN

Tungsten is a metal of strategic importance. It is used in the manufacture of high-speed alloy and special steels, and is essential for machine tools, armour plates and other military equipment. It is also used in various electrical appliances. Tungsten carbide, much harder than the hardest steel, is used in making drill bits, cutting tools etc.

In India the occurrences of tungsten ore (wolframite) are few. The best known deposit of the country is that of Degana (26°50': 74°20') in Rajasthan. The total reserves vis-a-vis production of tungsten in India and Rajasthan in recent years are summarised in Tables-49 and 50.

**TABLE-49**

*Reserve of tungsten ore as on 01-04-2005;  
(Ores in million tonnes )*

State		Proved	Probable	Remaining resources
India	Ore	-	-	87.38
	WO ₃	-	-	0.142
Rajasthan	Ore	-	-	23.92
	WO ₃	-	-	0.093

Source: Indian minerals yearbook, 2006

**TABLE-50**

*Production of tungsten concentrates; (in tonnes)*

State/ District	1992-93		1993-94	
	No. of mines	Quantity	No. of mines	Quantity
India	2	5,188	2	5,247
Rajasthan	2	5,188	2	5,247
Nagaur	1	3,434	1	5,209
Sirohi	1	1,754	1	38

Source : Indian Minerals Year Book 1996, Vol. 2, 1998, p. 604.

### Nagaur district

**Degana deposit:** The deposit located near Rewat (26°54': 76°19') is situated about 4 km northwest of the Degana railway station. Tungsten mineralization occurs as disseminations (of wolframite) in the granite and in quartz veins along the shear planes traversing the granite and phyllite, and also as gravel in the alluvial-wash around the primary ore-bearing Rewat hill. Wolframite, in the gravels, occurs in variable quantities.

Rich zones containing 0.06-0.1% WO₃ are confined to the small alluvial-fans in the immediate vicinity of wolfram-bearing veins. But subsequent dispersion has spread it out in the adjacent area also. Degana tungsten deposit has been investigated by the GSI, DMGR and IBM. Reserves of the order of 3,440 tonnes of ore from lode and gravel deposits and stock-works have been estimated with 65% WO₃ concentrates. The mines are run by the DMGR and the tungsten concentrates produced are supplied to the defence department.

### Sirohi district

**Balda deposit:** The deposit was located in 1978 at Balda (24°53': 72°54'), Sirohi district. The mineralization is confined to leucocratic Balda granite intruding quartz-mica schist of Sirohi Group (Delhi Supergroup) and Erinpura Granite/Gneiss. The tungsten mineralization also associated with fluorite mineralization is erratic in nature and occurs in the quartz veins spreading over 2.5 km × 0.5 km area as fine-stringers and discrete fine to coarse crystals. 568 tonnes of wolframite concentrate of 65% WO₃ have

been estimated from the area.

**Uduwaria deposit:** Scheelite-bearing garnet-pyroxene skarns over strike length of 2 km occur as intercalatory beds in andalusite-bearing mica schist. The length of the individual skarn varies and reaches up to 300 m and the width from a few cm to over 4 m. Mineralization persists up to 65 m depth. The zone-wise details are given in Table-51.

**TABLE-51**

*Reserves of Uduwaria tungsten deposit*

Zone	Strike length (m)	Average width (m)	WO ₃ (%)	Reserves
D	230	2.13	0.21	39 tonnes of scheelite concentrate of 65% WO ₃ up to 10 m depth.
E	300	1.25	0.05	—
C	70	3.5	0.07	—

Source : GSI.

### Ajmer-Pali districts

Scheelite (tungsten)-bearing lenses have been located in Padarla and Bar in Pali district and Sendra-Babra area in Ajmer district where exploration is in progress.

**Alniawas-Sewariya area:** Tungsten mineralization is mainly represented by wolframite with subordinate scheelite along the contact zone of Sewariya granite and meta-argillite and within the granite. Host rocks are sheared/non-sheared and greisenised.

**Pipaliya prospect:** Mineralization, hosted by quartz and pneumatolytic quartz veins, is discontinuous with impersistent strike length and narrow widths. In Pipaliya North block wolframite mineralization extends over 600 m strike length having 2.8 m width and grade 0.16% WO₃ while in South block the strike length extends over 400 m having 0.85 m width and grade 0.11% WO₃.

**Pipaliya village:** Mineralization is erratic. The visual estimated grade is 0.1-0.5% WO₃.

**Motyia prospect:** The ore body striking NNE-SSW with limited strike length and narrow width is lensoid in nature. The mineralization intersected in the boreholes indicates 0.12% WO₃ over 1.25 m and 0.18% WO₃ over 5.1 m wide zone.

## URANIUM

Uranium is a valuable metal for atomic energy and holds important place both in war and peace.



### Sikar district

Investigations carried out by the GSI in Khandela (27°35': 75°30') and Ghateswar (27°55': 76°00') areas have revealed the presence of several moderately radioactive zones in quartz-biotite schist grading to micaceous quartzite, biotite-chlorite schist, aplitic rocks, feldspathic schists and quartz-tourmaline veins. The uranium-bearing zones contain 0.0-40.11% U₃O₈. The mineralized zones also carry molybdenum and copper ores.

Occurrences of uranium ores are also known to occur at several places in Bhilwara and Udaipur districts.

### VERMICULITE

Vermiculite, yellow and brown in colour, is an alteration product of mica and retains the micaceous cleavage. When vermiculite is heated, its volume increases considerably (12 times or more). The mineral is used where some extreme lightness and low-heat conductivity are required.

### Ajmer district

Deposits of vermiculite have been recorded near Gudas (26°29': 74°46'). The width of the veins varies from a few cm to 1.22 m. It is brown in colour with soft and elastic flakes/laminae. On heating it swells up to 8-10 times its original volume. Sporadic occurrences of vermiculite are also recorded at Kaleshra (26°21': 74°25'), Rajgarh (26°18': 74°37') and Kalwar (26°59': 75°35').

### WOLLASTONITE

Wollastonite, a calcium metasilicate (CaSiO₃) is one of the latest to enter in the field of industrial minerals,

due to its fast growing industrial applications. It is used in the ceramic, enamel, glass, matches, paints, paper, plastics and plywood industries; in the preparation of artware, ceiling tiles, floor tiles, insulators, as an extender of short-fibred asbestos or as a replacement for non-fibrous materials. Rajasthan is the only wollastonite producing State in India (Table-52).

### Pali-Sirohi districts

The extensive deposit of wollastonite, located by GSI near Khera-Uparla, (24°46': 73°11') extends in parts of these two districts. The deposit occurs as a steeply dipping lenticular, elongated, skarn-like body within the Erinpura Granite massif. Striking NNE-SSW over more than 1 km in length, the deposit is 150 - 200 m in width. Wollastonite occurs *in situ* as coarsely crystalline columnar and fibrous aggregates and also as huge boulders and floats along the hill slopes and in the valleys. Possible reserves of the order of 56 million tonnes have been estimated by GSI. Significant deposits are also found in Belka Pahar near Khila in Sirohi district.

### Ajmer district

Large deposits of wollastonite have been located in GolaAlipura area, assaying 39.4% CaO, 45.5% SiO₂, 6.21% Al₂O₃, 3.33% Fe₂O₃, 0.09% MnO, 1.09% MgO, 0.23% TiO₂, 0.14% Na₂O, 0.06% K₂O and 3.26% LOI. These are estimated to contain wollastonite (47%) intimately associated with main gangue minerals like garnet (27%), epidote (13%), calcite (7%) and quartz (56%). On beneficiation, it produces a pure ceramic-grade wollastonite concentrate, assaying 46.35% CaO, 52.55% SiO₂, 0.30% Al₂O₃, 0.28% Fe₂O₃ and 0.04% MnO containing about 95% wollastonite with recovery of 59.9% (wt % yield 29.6).

**TABLE-52**

*Production of wollastonite in Rajasthan; (Qty in tonnes, value in Rs '000)*

State/District	No. of Mines	2004-05		No. of Mines	2005-06	
		Quantity	Value		Quantity	Value
India	3	170292	129097	2	128582	98740
Rajasthan	3	170292	129097	2	128582	98740
Sirohi	1	53378	43770	1	44504	38056
Udaipur	2	16914	85327	1	84078	60684

Source: Indian minerals yearbook, 2006.

## IMPORTANT MINERAL BELTS IN RAJASTHAN

### Nim ka Thana Copper Belt

Copper mineralisation in Nim ka Thana belt is mainly located in Baniwal ki Dhani and Dokan areas of Sikar district, Rajasthan. Nim ka Thana copper belt is about 20 km long starting from Nimod in the south to Mina ka Nangal in the north and further extending upto Gangutana in Haryana.

The Alwar and Ajabgarh Group of rocks belonging to the Delhi Supergroup of palaeo to meso-Proterozoic age represent the mineral belt. Quartzite, mica schist and quartz mica schist constitute the Alwar Group. The Ajabgarh Group is represented by the Kushalgarh Formation consisting of mica +/- garnet schist and quartzite. These rocks are intruded by pegmatite, quartz vein, albitite, amphibolite and granite.

The host rock for copper mineralisation is amphibole/impure marble and calcareous biotite amphibole schist of Kushalgarh Formation. The mineralisation occurs as lensoid bodies with varying width. Copper ore minerals are bornite, covellite, chalcopyrite and chalcocite occurring as fine disseminated specks, stringers and veins along foliation and fracture planes.

Total ore reserves estimated so far in this belt is about 85.26 MT containing an average grade of 0.3% Cu with minor amount of Ag.

### Dariba-Bethumbi-Surawas lead-zinc Belt

Dariba- Bethumbi-Surawas lead-zinc belt is located in Rajsamand district, Rajasthan. It contains most potential lead-zinc deposits in India. The belt is 19 km long extending from Dariba in the south to Surawas in the north where it is dislocated by a ENE-WSW cross fault and further continue in a narrow strip up to Bharak river (Bhilwara District). Famous Rajpura gossan is located in the southern part of this belt.

The area comprises cover rock sequences consisting of meta-volcano-sedimentary rocks of Rajpura-Dariba Group occurring in the gneisses of the Mangalwar Complex, a part of the Bhilwara Supergroup of Archean-Palaeoproterozoic age. The cover rocks are represented by carbonaceous schist, interbanded schist and cherty quartzite, tuffaceous schist with or without garnet, staurolite and kyanite, calcareous schist, calc silicate marble /dolomite, laminated bands of marble and schist (meta-marl), meta-psammites with quartzite and amphibolite and conglomerate. The lithounits show lateral facies variation and are intruded by quartz veins and dolerite dykes. The Mangalwar rocks comprise psammitic gneisses and quartzo-feldspathic rock. The basement of cover rock sequence is uneven showing basement highs and lows.

The area exhibits three phases of deformation. The folds of first two generation are coaxially folded with NNE-SSW fold axis. The third phase has given rise cross folds with WNW-ESE axis forming culmination and depression structures over earlier folds and produce arcuate shaped outcrop pattern of the belt. Carbonaceous schist, calcareous schist and marble/dolomite are the best rocks for lead-zinc mineralisation. Calc silicate marble/dolomite contains high grade ores. The primary host rock appears to be schist where lead-zinc ores occur as fine grained specks and thin layers and in calc silicate marble they occur as coarse grained specks, stringers, veins and pseudo-breccia. It appears that the fine grained ores were remobilized during deformation and metamorphism. The remobilized ores were concentrated at favorable locales and replaced the carbonates constituting ore zones. The main lead-zinc minerals are galena and sphalerite. Other sulphides are pyrite and pyrrhotite. Besides these, other ore minerals are tennantite, tetrahedrite, chalcopyrite and geochronite.

A total of 320 MT ore reserve has been estimated in Dariba-Bethumbi-Surawas belt containing average grade 2% to 8% Pb + Zn associated with Cd and Ag. Out of this, about 70 MT of ore reserve is established within calc silicate marble/dolomite with an average grade 6% to 8% Pb + Zn.

### Bhukia Gold Belt

Bhukia gold belt, Banswara district, Rajasthan, is located northeast of Banswara in southeastern Rajasthan. It forms a part of Proterozoic supracrustals of the Aravalli Supergroup representing a metamorphosed volcano-sedimentary sequence within the northwestern Precambrian craton and occupies an area of about 5.5 sq. km.

Muscovite-biotite-quartz schist, dolomitic marble, keratophyre, actinolite-quartzite and amphibolite/meta-pyroxenite are the major lithounits exposed in the area and together constitute a separate lithopackage which rests over the older metamorphite. These rocks have suffered three phases of deformation.

The auriferous, massive, semi-massive to disseminated sulphides present in the mineralized zones are concentrated parallel to the axial plane shears cutting through the major overturned synformal structures developed during the second phase of deformation. Auriferous sulphide mineral assemblage is represented by pyrrhotite, arsenopyrite, pyrite, chalcopyrite and lollingite. Gold is present in the native form as well as with lollingite associated with arsenopyrite.

A sizeable quantity of ore reserve is estimated containing medium grade gold.

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## PART B

### REPORTS (UNPUBLISHED) OF GEOLOGICAL SURVEY OF INDIA

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*Back Cover : Marble mining, South of Tehla, Alwar District, Rajasthan.*

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