CHARACTERIZATION OF URANIUM MINERALISATION IN GERATIYON KI DHANI AREA, SIKAR DISTRICT, RAJASTHAN, INDIA

by

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SYNOPSIS

The Proterozoic North Delhi Fold Belt (NDFB) is an important province for uranium and other base metal mineralization. Uranium exploration in NDFB has resulted in discovery of numerous radioactive anomalies associated with structurally weak zones trending NNE-SSW, parallel to Kaliguman and Khetri lineaments. These structural trends fall within the broad zone of albitisation defined as 'albitite line'. The present study area of Geratiyon Ki Dhani in Sikar district, Rajasthan, is located 45km ENE of Rohil Uranium deposit. This area was taken up for uranium exploration based on encouraging results obtained during earlier surveys and gamma ray logging of extra departmental tube-wells. By detailed geological mapping over 2 sq km on 1:2000 scale, feldspathic quartzite, quartz-biotite schist, calc-silicate, albitite, granite and amphibolite of Kushalgarh Formation of Ajabgarh Group are identified as dominant rock type in the area. The NNW-SSE trending albitite ridge is highly deformed exhibiting both brittle and ductile deformational features. Albitite, which is the host rock for mineralisation has been intruded into metasediments such as quartzite and quartz biotite schist. Also younger phase of granite and amphibolite intrusion were recorded in the area. Calcite and quartz veins seals most of the fractures which possibly indicates its formation in the latest phase. Dominant alteration features in the area are calcitisation, chloritisation, ferrugenisation and silicification whereas, the minor type is sericitisation. These alteration reflect towards multiple phase of hydrothermal activity. Uranium mineralisation is hosted by brick red colour albitite, which is highly fractured and brecciated. Davidite is the main radioactive mineral present, with Brannerite and U-Ti complex. Davidite occurs as anhedral to subhedral grains of varying sizes and veins which crystallised in the vicinity or adjacent to calcite veins. Rutile mineral inclusions are common in davidite which indicating davidite crystallization later of davidite mineral paragenesis. Brannerite in the form of amorphous spots, also at places as patches. The albitite of Geratiyon ki Dhani exhibits magmatic characteristics, but it should also be noted that

albitite also comprises hydrothermal minerals like calcite and quartz. This indicates that uranium mineralization in Geratiyon ki Dhani area is magmatic-hydrothermal. There is a remarkable evidence for contribution of post magmatic hydrothermal processes in albitites as indicated by the overprint of hydrothermal minerals in albitite. The hydrothermal minerals, dominated by calcite is spatially restricted within the albitite, suggesting a genetic link between magmatic and hydrothermal stage and a possible magmatic source for the hydrothermal fluids.

Davidite and brannerite contains significant REE, as observed by positive correlation of U with TiO2, CaO, Y and Ce. The Uranium mineralization in Geratiyon ki Dhani area is magmatic-hydrothermal type associated with magmatic albitite rarely reported from world. Granites in and around Geratiyon Ki Dhani area have indicated their affinity towards A-type, anorogenic granite that were emplaced in an extensional non-compressive tectonic regime during a phase of cooling.

Thus, as per its scope, the present study has shed light on the genetic aspects of mineralization and provided the local controls of mineralization at Geratiyon Ki Dhani area. This study has helped in identification of guides for establishing further extension of mineralized body in the study area and also in the adjacent areas in the NDFB. To establish regional controls of mineralisation, more areas of the NDFB need to be taken up for such studies.

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CHAPTER 1 INTRODUCTION

Proterozoic Khetri sub-basin of North Delhi Fold Belt (NDFB) is known for uranium and base metal mineralisation. Delhi Fold Belt (Sinha-Roy, 1984) or the Main Delhi Synclinorium (Heron, 1953), is a narrow, linear belt extending from Gujarat in the southwest to Haryana in the northeast. Delhi fold belt comprising mostly Delhi Supergroup of rocks is sub divided into two parts, North Delhi Fold Belt (NDFB), an older segment to the north of Ajmer extending into Harayana and South Delhi Fold Belt (SDFB), relatively younger terrain to the south of Ajmer (Sinha-Roy et al., 1998; GSI, 2011). The NDFB is characterized by several fossil grabens and horsts, distributed laterally in three sub-basins viz. Khetri, Alwar and Lalsot- Bayana (Gupta et al. 1998; Singh, 1984). Four phases of folding were reported in the Khetri Sub-Basin (KSB) (Naha et al. 1988). The first generation of folding (DF1) is recumbent or gently plunging reclined folds with plunge towards N to NNE, the secondgeneration folds (DF2) are coaxial with DF1 while third generation folds (DF3) are conjugate folds with sub horizontal to gently dipping axial planes. NE-SW and NW-SE trending conjugate and upright folds constitute fourth generation folds (DF4).

Uranium exploration by AMD in NDFB over seven decades resulted in discovery of more than three hundred radioactivity anomalies, sizeable uranium deposits at Rohil and Jahaz, and several prospects with possibility of sizeable uranium mineralisation. Radioactivity anomalies are associated with various litho units and confined to structurally weak zones, mostly trending parallel to Kaliguman and Khetri lineaments (NNE-SSW). Uranium mineralization in the Khetri sub-basin is considered as metasomatite type and found to be spatially associated with axial region of F2 folds along structurally weak zones (Padhi et al., 2016: Jain et al., 2016; Bhatt et al., 2013; Khandelwal et al., 2011; Narayan et al., 1980; Yadav et al., 2002).

Geratiyon ki Dhani area in the eastern part of Khetri sub-basin (Toposheet No. 45M/14), about 45 km ENE of Rohil uranium deposit, is taken up for the present study (Figure 1.1). The area presents an undulating topography represented by highly resistant quartzite as ridges and least resistant calc-silicate, quartz biotite schist exposed along nalas and depressions (Ramanamurthy et al., 1994). Geratiyon ki Dhani area was taken up for subsurface exploration by AMD to establish strike and dip continuity of uranium mineralisation, after encouraging results obtained during earlier surveys and gamma ray logging of extra departmental tube-wells. Sub-surface exploration resulted in establishing uranium mineralization over a strike length of 1200 m with vertical depth of upto 300 m.



Figure 1.1 Geological map of Rajasthan showing the location of the study area

As active exploration is in progress in Geratiyon ki Dhani, it is imperative to understand the nature and controls of uranium mineralization, to guide AMDs uranium exploration in the area and similar geological environments in the surrounding areas. In addition, study of mineralized and non-mineralized rock samples will help in understanding the nature of uranium mineralisation and its geological controls, so that these guides can be used in NDFB especially in the lesser worked and lesser known areas of KSB.

1.1 LOCATION AND ACCESSIBILITY

The study area is bound by latitudes N27⁰39"50'- N27⁰41"05' and longitudes E75⁰56"20' - E75⁰57"15' in Toposheet No. 45M/14 (Figure 1.2). It is located about 130 km northeast of Jaipur, in the eastern part of Sikar district and northern part of Jaipur. The area is connected by road via Kotputli-Hasampur-Ladi ka Bas and Neem Ka Thana-Raipur mod-Ladi ka Bas road.



LOCATION MAP OF JAHAZ AREA Figure 1.2 Location Map of study area.

The interiors are approachable by fair jeepable roads. Nearest railway station is located at Neem Ka Thana (Figure 1.2). The area is situated 35 km NNW of Buchara area which is on the same albitite line as shown in the LANDSAT eTM satellite imagery (Figure 1.3). Other radioactive areas in the albitite lines are Rela, Ghasipura, Kalakota, Sirsori Ki Dhani, Ramsinghpura, Mina Ka Nangal, Mothuka, Hasampur.



Figure 1.3 LANDSAT eTM imagenery, Geratiyon ki Dhani - Buchara area of South Khetri sub-basin

1.2 CLIMATE

The area lies 429 m above sea level and climate here is considered to be a local steppe climate, which comes under arid to semi-arid climatic region with a very sparse rainfall. Average rainfall reported is 440 mm. The driest month is April, with 2 mm of rain. Most precipitation falls in July with an average of 157 mm. June is the warmest month of the year. The temperature in June averages 33.8 °C. January has the lowest average temperature (13.9 °C) of the year. There is a difference of 155 mm of precipitation between the driest and wettest months. The average temperatures vary during the year by 19.9 °C (https: //en.climate-data.org, 2019).

1.3 GEOMORPHOLOGY, DRAINAGE AND FLORA - FAUNA

Regionally, two distinct physiographic units, viz. sandy plains and hill ranges are recognized. The study area is mostly covered by linear isolated hillocks except for a small patch of agricultural land and a small village. Geomorphology of the area is characterised by NW-SE to NNW-SSE trending moderate to high linear ridges as well as isolated hillocks and peneplain area. The highest peak is 540 m above MSL with and average elevation of 430 m above MSL. The relief is around 130 m. The drainage pattern in and around the area is dendritic in pattern. The area is having two dams in Ladi ka Bas and Raipur areas, which store water from seasonal rains.

The study area is semi-desertic with very thin vegetation and mostly covered with barren hillocks. The Regional soil types are sandy loam, brown soil and desert soil. The vegetation includes trees like babool (*Acacia nilotica*), ronjh (*Acacia leucophloea*), khair (*Acaia catechu*), keekar (*Prosopis juliflora*), neem (*Azadirachta indica*), pipal (*Ficus religiosa*), ber (*Ziziphus mauritiana*), banyan (*Ficus benghalensis*) etc. and others which grows mainly along the hill slope and valley portion as thorny scrubs and dry deciduous forests. Scrubs like hingot (*Balanites roxburghii*), arusha (*Justicia adhatoda*) are also very common. These forest areas are the natural habitat of numerous carnivores including leopard, wild dog, camel, other wild animals like rabbit, neelgai, jackal, snake, wild lizard, scorpion etc and a variety of birds.

1.4 PREVIOUS WORK

Ladi ka Bas - Geratiyon ki Dhani - Kalatopri areas were under active exploration for uranium by AMD during 1987-94, including 7578.25 m of drilling over a strike length of 1765 m to prove sub surface uranium mineralization. Four inclined bore holes with a depth range of 164.75 m – 200 m and with cumulative total of 720.50 m were drilled in Geratiyon ki Dhani area to prove depth continuity of three NW-SE trending surface uraniferous anomalies hosted by albitites (100 m x 20 m, 175 - 200 x 3-6 m, 60 m x 1-5 m) of 3 - 20 xBg. Grab samples (n=17) have assayed 0.013 % to 0.250 % U_3O_8 with <0.010 % ThO₂. Drilling in the area was discontinued during 1994 - 95. Assay of core samples indicated disequilibrium strongly in favour of parent. Reconnaissance radiometric survey and geological mapping carried out in Geratiyon ki Dhani-Ladi ka Bas area during 2015-16, indicated continuation of radioactive anomaly with depth as observed from different quarry sections. Geophysical surveys carried out in Geratiyon ki Dhani area indicated presence of Low magnetic anomalies is due to absence of magnetic minerals and low gravity is due to metasediments are quartzite, albite and quartz biotite schist. Detailed mapping during 2016-17 opened up a new domain for uranium exploration with sub-surface continuity of radioactivity in quarry sections showing depth persistence and significant improvement in grade and thickness of uranium mineralisation in the area. Encouraging mineralisation was intercepted in boreholes during 2017-18 in Geratiyon ki Dhani- Ladi ka Bas block with a total of 7900 m drilling. Further drilling of 10000 m was taken up to probe the results at Ladi ka Bas-Geratiyon ki Dhani area,

resulting in significant mineralized intercepts over a strike length of 1.2 km and vertical depth upto 350 m in 30 boreholes.

Geochemistry of mineralized rock revealed association intimately associated with calcitisation. The dip of mineralization appears U-Ti to vary from 60° to 75°due SE and corroborates with the surface foliation data. The host rock of mineralization is predominantly albitite with minor biotite bearing albitite and quartz biotite schist. Uranium mineralization is associated with calcitisation along the fracture zone. Davidite was identified from the mineralised zone.

The study area, Geratiyon ki Dhani is 500 m SSW of Ladi ka Bas uranium mineralisation with known radioactive anomalies. Thus, the Geratiyon ki Dhani Block has emerged as a potential target for further subsurface exploration.

1.5 PRESENT STUDY

Principal Objectives:

- To delineate various rock types by detailed geological mapping.
- To study geochemical and petro-mineralogical characteristics and alteration features, and identify the paragenetic sequence of ore and gangue minerals.
- To recognize the nature and controls of uranium mineralization and develop a model to infer role of soda metasomatsim and genesis of uranium mineralization.

Research plan/ methodology:

- Detailed litho-structural mapping and radiometric survey over 2 sq km area (1: 2000) to delineate Lithounits, identifying structures and radioactive zones.
- Systematic sampling of mineralized and non-mineralized zones for radiometric assay and geochemical characterization using chemical and XRF analysis.

- Petro-mineralogical study to characterize different rock types, micro-structures and identification of radioactive, associated mineral phases, XRD study and paragenetic sequence.
- Study of fluid inclusions to understand the nature of fluids and their physico-chemical characteristics responsible for uranium mineralization and mineral-chemical study of selected samples by EPMA.
- Interpretation of lithological and structural data for understanding geological controls of mineralization and geochemical data of the host-rock in terms of soda metasomatism and other alterations.
- Integration of all the data for comprehensive understanding of the genetic model of uranium mineralization in study area.

Deliverables:

After completion of the study following deliverables are expected:

- Detailed lithological and structural map (1:2000) and sections of the study area in order to interpret the geological history.
- Development of local litho-stratigraphic succession.
- Geochemical characterisation of host rock and role of soda metasomatism and related alterations in uranium mineralisation.
- Genetic model for uranium mineralization of study area.

The Integrated studies involving geological observations, sampling and data collection in the field coupled with various analytical studies will help in understanding the Petromineralogical and geochemical characteristics of the host rock. This study is expected to help in understanding the characteristics of uranium mineralisation in the study area and shall guide AMDs uranium exploration in the similar geological environs of NDFB.

CHAPTER 2 GEOLOGY

2.1 REGIONAL GEOLOGY

Rajasthan covers an area of 3,42,239 sq km (GSI, 2011) and provides significant clues to the geology and tectonic development of the north-western continental segment of the Indian Peninsula. North-western Indian Craton (NWIC) represents an important segment and contains a documentation of varied geological and tectonic process of over 3500 million years. The NE-SW trending Aravalli Mobile Belt in north-western India characterized by the Aravalli mountain ranges encompasses the entire state of Rajasthan, parts of Gujarat and Madhya Pradesh and fringes of Delhi and Haryana. The intricacies in the architecture of this craton are the result of a number of episodes of crustal accretion, rifting, sedimentary basin developments, magmatic rock emplacement, crustal deformations and ore-deposit formation. The NWIC is bounded by Great Boundary Fault (GBF) in the east and Thar Desert in the west. It abuts in the south against Son-Narmada-Tapti (SONATA) lineament and Indo-Gangetic alluvium in the north (Ramakrishnan and Vaidyanadhan 2010). The Precambrian geological setting and crustal evolution of Rajasthan has significant bearing on metallogeny (Sinha-Roy et al., 1998).

The Aravalli- Delhi mobile belts of north-western India depicts a juxtaposition of Aravalli, Hindoli-Jahajpur, Sandmata-Mangalwar, Delhi and Sirohi terranes along NE-SW trending shear zones represented as lineaments on the map (Figure 2.1). Each domain comprises thick sequences of Proterozoic metasedimentary and meta-igneous rocks unconformably overlying the basement gneisses and are characterized by distinct depositional history, deformation and metamorphism. These formations include rocks of Aravalli Supergroup, Delhi Supergroup, Upper Precambrian Vindhyan Supergroup and are overlained by those of Cambrian to Jurassic, Cretaceous, and Tertiary ages. The southeastern part is exposes a pile of basaltic flows of Deccan Traps of Cretaceous age. The basement Banded Gnessic Complex overlained by the cover sequences of Proterozoic linear supracrustal rocks of Aravalli and Delhi fold belts forms the basic geological structure for the Precambrian terrane of Rajasthan (Heron, 1953; Gupta et al., 1980; Sinha-Roy, 1998; Roy and Jakhar, 2002). The Aravalli craton is characterized by repeated phases of crustal rifting and basin development and generation of oceanic troughs along which of various sedimentary rocks were deposited. Emplacement of various acid and basic igneous rocks also took place during the process. These events led to multiple deformation and polyphase metamorphism of the rock sequences. The composite Aravalli craton is flanked by the Mewar and Marwar cratons in the east and west, separated by the Phulad lineament that marks the western boundary of Delhi fold belt. The Mewar craton comprises of Mesoarchaean tonalite-trondhjemitegranodiorite (TTG) gneisses and sporadic greenstone belts. The age of Mewar gneisses is reported to be 2.45-3.50 Ga (Sivaraman and Odom, 1982; Macdougall et al., 1984; Wiedenbeck and Goswami, 1994; Roy and Kröner, 1996). The Marwar craton is extensively intruded by Erinpura and Malani granites, and at several places has been covered by younger volcano-sedimentary sequences belonging to the Sindreth, Punagarh, and Marwar groups. Isolated outcrops of the basement rocks are exposed at few places (Heron, 1953). Several mineral deposits viz. Pb-Zn-Cu, uranium, REE, tungsten, phosphorites, marble, lignite, mica, oil and gas have been reported in these fold belts.

Based on lithological, structural, metamorphic as well as geochronology, the West Indian Shield can be subdivided into Trans-Aravalli, Aravalli-Delhi and BGC (Banded Gneissic Complex) provinces from west to east bounded by shear/ fault zones. The Bhilwara Supergroup forms basement of the Aravalli mountain belt and consists of Banded Gneissic Complex (BGC). It has been classified into Sandmata Complex, Mangalwar Complex and Hindoli group; Rajpura Dariba, Pur-Banera, Jahazpur, Sawar and Ranthambor groups (Table 2.1). The Banded Gneissic Complex (BGC) is the oldest and lithologically diverse unit of the Aravalli Craton. It is predominantly a polymetamorphosed, multideformed rocksuite of tonalite-trondhjemite (TT) gneiss, migmatite, granitoids and amphibolite.



Figure 2.1 Simplified geological map of India showing Aravalli-Bundelkhand Craton (Modified after Ramakrishnan & Vaidyanadhan, 2008 and Sharma, 2009).

Deccan Trap							
PROTEROZOIC	Marwar Supergroup		Malani Volcanic	Malani plutonic Suit (~740-771 Ma) Erinpura Granite (~750 Ma) Godhra Granite (~995 Ma)			
	Vindhyan Supergroup		Ur Lov	oper Vindhyan (~1000-650Ma) wer Vindhyan (~1750-1500Ma)			
	Delhi Supergroup (2000-800Ma)	Punagarh Group Sindreth Group Sirohi Group Kumbhalgarh Group Ajabgarh Group Gogunda Group Alwar Group	Sendra-Ambaji Granite (800-1550Ma) Kishangarh Syenites (1475-1910 Ma) Granulite (Phulad Ophiolite Suit)				
	Aravalli Supergroup (2500-1600 Ma)	Champaner Group Lunavada Group Jharol Group Dovda Group Nathdwara Group Bari Lake Group Kankorli Group Udaipur Group Debari Group	Ţ	Udaipur Granites (~2275 Ma) Serpentinites, Talc Schist (Rakhabdev Ultramafic Suit)			
ARCHEAN	Bhilwara Supergroup (>2500 Ma)	Ranthambor Group Rajpura-Dariba Group Pur-Banera Group Jahazpur Group Sawar Group Hindoli Group Mangalwar Complex Sandmata Comlex	Berach	Granite/Jahazpur Granite (2585 Ma) Dolerite Sill and Dykes Untala, Gingla Granite (~2960 Ma) Mafic and Ultramafic body Acidic bodies			

Table 2.1 Lithostratigraphic classification of Rajasthan and Northern Gujrat (after Gupta etal., 1980).

Besides the complex TT-amphibolite association, the BGC of Rajasthan also shows minor metasediments, mainly quartzite, frequently fuchsite bearing, low-Mg marble, mica schists and metabasic rocks (as amphibolite or greenschist) and minor ultrabasic rocks (as hornblende schist/hornblendite) indicating a possible greenstone remnant in the BGC terrain (Sharma, 2009). These represent the early Precambrian crust formed through the process of granite-granulite greenstone accretion. Mangalwar Complex and Hindoli Group forms basins and result of the deformation in oldest, elongated sedimentary basins formed in rifted ensialic crusts. Emplacement of large scale acidic and intermediate magmatic rocks such as granite, granodiorite and tonalite plutons took place due to tectonic activity about 2900 million years ago. Sandmata Complex contains high grade metamorphic rocks up to granulite facies. The Archaean-Proterozoic boundary in Rajasthan is marked by a prominent phase of acid igneous activity and emplacement of Berach Granite and equivalent granite plutons at about 2500 million years ago. However, according to Sinha Roy et. al., 1998, the Sandmata Complex constitutes only the Ductile Shear Zone (DSZ) bounded high pressure granulite facies rocks which occur within the amphibolite facies rocks belonging to the Mangalwar Complex. The amphibolite facies rocks enclosing the granulite facies rocks represent granite-greenstone sequences intruded by tonalite-granodiorite plutons and are extensively granitised or migmatised. These granite-greenstone sequences are discernible in the form of ghost stratigraphic and dismembered units in the vast ocean of gneisses. While restricting the term Sandmata Complex to the DSZ bounded granulite facies rocks, Guha and Bhattacharya, 1995 also recognised the host amphibolite facies rocks as belonging to the Mangalwar Complex. The Mangalwar complex, Sandmata complex and Hindoli Group represent the early Precambrian crust formed through the process of granite-granulite-greenstone accretion. Large scale acidic and intermediate magmatic emplacements such as granite, granodiorite and tonalite plutons took place due to tectonic activity at about 2900 m.a. Number of major lineaments separate the stratigraphic units. Great Boundary fault separates Vindhyan basin to the east and Hindoli group in the west. Banas lineament or Jahazpur thrust separates Hindoli group from Mangalwar complex.

Era	Super Group	Group/Complex	Lithounits
	Berach/ Jahazpur Granite (2.5 Ga)		
	Untala/Gingala and Annasagar Granites (2.8 Ga)	Hindoli	Phyllite and greywacke with metavolcanics
Archaean	BGC (Banded Gniessic Complex)	Mangalwar Complex	Norite dykes, augen gneiss and tonalite/granodiorite gneiss
		Sandmata Complex	Amphibolites, greywacke, quartzite, marble, Amphibolite, carbon phyllite, two pyroxene granulite, leptinite, charnockite-enderbite, politic granulite

Table 2.2 Archaean stratigraphy of Rajasthan (After Sinha-Roy et al., 1998)

Delwara lineament marks boundary between Sandmata and Mangalwar complex. Kaliguman lineament separates Delhi fold belt from Sandmata complex in north and Aravalli fold belt in the south (Sinha Roy et al., 1998).

2.1.1 Trans-Aravalli province

The Trans-Aravalli province encompases the area west of Aravalli Mountains. It is essentially a volcanic province (Malani Igneous Suite), with Neoproterozoic cover sequences (Marwar Supergroup) and Mesozoic- Cenozoic sedimentary basins (Ramakrishnan and Vaidyanadhan, 2008; GSI, 2011).

The emplacement of the Malani Igneous Suite (MIS) is the widest spread igneous event covering large parts of western Rajasthan. The MIS exposes a great variety of igneous rocks comprising acid, intermediate, basic, ultra basic and alkaline intrusives and extrusives. These are spread over parts of west Rajasthan covering Jodhpur, Pali, Sirohi, Jalore, Jaisalmer and barmer districts and a few outcrops of rhyolites are also present in Churu and Jhunjhunu districts. Geologically the Malani rhyolites are towards the west of the Aravalli-Delhi fold belt and are spread over an area of about 51,000 km² in the Thar Desert. The MIS has been divided into three phases of igneous activity. The first phase comprises the eruption of mafic and felsic volcanics. The second phase witnessed large scale plutonic activity with the intrusion of Jalore granite, Siwana granite and Malani granites into the first phase rocks. The igneous activity culminated with the injection of mafic and felsic dyke swarms. The acid lava flows of MIS comprises rhyolites, rhyodacite, dacite, trachyte, agglomerate, volcanic breccias, ignimbrite and pyroclastics. Multiple flows have been identified in different sectors on the basis of change in colour and presence of agglomerate between them. Pareek has demarcated a total of 52 flows within the rhyolites. A total thickness of 3.5km of Malanirhyolites and rhyodacites is estimated by S.K. Bhusan (2000). Felsic volcanism has also been reported from parts of North Delhi Fold Belt associated with meta-sediments. Tertiary Alkaline Suite of rocks have been reported from Mundwara and Sarnu-Dandali areas.

The Marwar Supergroup forms small hillocks in a desertic setting and was earlier referred to as the Trans-Aravalli Vindhyans. The Marwar Supergroup has been subdivided into three groups. In stratigraphic order these are the (a) Jodhpur Group, (b) Bilara Group and (c) Nagaur Group. The Jodhpur Group has been further subdivided into the Pokaran Boulder Bed and the Jodhpur Sandstone. Microfossils indicate intertidal/foreshore depositional environment for Jodhpur and Nagaur groups (Prasad et al., 2010). In Jodhpur, Bilara areas, siliciclastic sediments have been mainly deposited in shallow water both in marine and non-marine environments (GSI, 2011). The youngest of the Marwar Supergroup, the Nagaur Group, has yielded well-preserved trilobite trace fossils and therefore a Lower Cambrian age has been assigned to the Nagaur Sandstone. The underlying Bilara Group, which represents primarily calcareous facies, has been indicated to contain the Precambrian/ Cambrian boundary on the basis of carbon isotope data. Thus the Jodhpur Sandstone (which unconformably overlies the Malani Igneous Suite with radiometric age 779–681 Ma) can be referred to as Ediacaran with age between 630 and 542 Ma.

2.1.3 Aravalli-Delhi province

The Aravalli-Delhi province is occupied by rocks of Proterozoic fold belt, viz., the Aravalli Supergroup (Aravalli Fold Belt, Early Proterozoic) and Delhi Supergroup (Early-Middle Proterozoic). Southern and south-eastern parts of Rajasthan exposes mainly the Aravalli Supergroup, and extensive tract in south western, central and north-eastern Rajasthan is occupied by Delhi Super group. The Aravalli mountain range is mainly constituted by rocks of the Delhi Supergroup. Delhi Supergroup occurs in the form of two separate fold belts (Sinha-Roy, 1998), viz., the North Delhi Fold Belt (NDFB) and the South Delhi Fold Belt (SDFB). NDFB and SDFB are separated by migmatitic gneisses around Ajmer (Bose, 1989; Sinha-Roy et al., 1998). According to Gupta et al. (1980), in the northeast, the Delhi Supergroup rocks deposited under fluvial conditions in a number of fault-bounded basins while in the central and southern parts; sedimentation was mostly under oceanic conditions.

The Mesoproterozoic Delhi fold Belt (DFB) is a 450 km long belt with variable width. The DFB spreads out in the north, becomes narrow in the middle and flares in the south (Ramakrishnan and Vaidyanadhan, 2008). In the NE, it contains rock sequences disposed in three main nearly isolated and independent fault-bound sub-basins viz. Khetri, Alwar and Lalsot-Bayana. In the central part, i.e. south of Ajmer, the lithounits show a fair degree of continuity, although these are truncated at many places by shear zones. The DFB intruded by number of granite plutons. Available geochronological data shows that the age of these plutons in the northern part ranging from ca. 1.6 Ga (Bairat, Dadikar, Harsora) to 1.4 Ga (Saladipura, Udaipurwati, Seoli). The granite plutons occurring to the south of Ajmer (Sendra, Erinpura, Godhra, Balda) have yielded younger Rb/Sr ages ranging from ca. 0.96 Ga to 0.73 Ga (Sinha Roy et al., 1998). Based on the contrasting set of geochronological data on intrusive granites, Sinha Roy et al., (1998) divided the orogen into two principal divisions of
NDFB and SDFB. The dividing line separating them is called Bithur-Pisangan line near Ajmer that denotes an E-W fault or folded unconformity (Ramakrishnan and Vaidyanadhan, 2008).

2.1.2.1 North Delhi Fold Belt (NDFB)

The North Delhi Fold Belt exposes Proterozoic Delhi Supergroup of rocks comprising sand-shale-carbonate facies. These rocks are believed to be deposited in graben and halfgraben structures (Singh, 1988; Sinha-Roy, et al., 1998). Felsic volcanic rocks and tuffs are commonly reported from the northern part of the Delhi Fold Belt (Golani et al., 1992; Khan et al., 2014). Polyphase deformation and varied grades of metamorphism have affected these volcano-sedimentary rocks which are further intruded by granites. These granite indicate the culmination of Delhi orogenic cycle. Many younger acidic and basic dykes alongwith related pegmatites, aplites and albitites have been emplaced in these rocks.

North Delhi Fold Belt is characterized by several fossil grabens and horsts. These are distributed broadly in three main sedimentary sub-basins, namely from east to west as the Laslot- Bayana, the Alwar and the Khetri sub-basins (Figure 2.2) (Singh, 1984 and 1988). The Laslot- Bayana and the Alwar sub basins taper in the south, whereas the southern continuation of the Khetri sub-basin is uncertain because of scarcity of continuous outcrops. The Laslot-Bayana sub-basin forms the eastern limit of the outcrops of the NDFB and represents an asymmetric graben bounded by two near parallel faults. A number of other faults have also been recognized. The first generation of faults parallel to the pre-Delhi fold axial traces is responsible for the formation of embryonic grabens with a southeasterly palaeoslope. The second generation of faults served as channel-ways for the Jahaj volcanics. The third generation of faults caused a slight northerly tilt of the basin and marked the onset of Alwar sedimentation. At the end phase of sedimentation, a major transgression removed barriers

between Lalsot-Bayana and Alwar sub-basins. It resulted in the formation of a wide basin in which the Ajabgarh Group sediments were deposited. Singh (1984) suggested a tidal flat environment under prograding beach conditions for the deposition Delhi Supergroup rocks. Sinha-Roy (1994) suggested that the southern margin of the North Delhi Fold Belt is defined by an E-W trending fault and almost N-S trending basin boundary faults.

2.1.2.2 Khetri Sub-basin (KSB)

The NE-SW oriented Khetri Belt (KB), a part of the NDFB, is located in the northern most part of the Aravalli-Delhi mountain range extending for about 100 km from Pacheri (Jhunjhunu district) in the northeast to Sangarva (Sikar district) in the southwest.



Figure 2.2 Regional Geological Map of NDFB showing the area under investigation (Modified after GSI)

Supergroup	Group	Formation	Lithology
Post Delhi Intrusive		Acid intrusive	Granite (1470Ma), aplite, pegmatite, quartz
			vein and albitite (847 <u>+</u> 8Ma)
		Basic intrusives	Amphibolites and metadolerite
Delhi Supergroup (NDFB) (Mesoproterozoic)	Ajabgarh Group	Arauli-Mandhan	Quartzite, staurolite-garnet schist, carbon
		Fm	phyllite
		Bharkol Fm	Quartzite with phyllite and carbon phyllite
		Thana-Ghazi Fm	Carbon phyllite, tuffaceous phyllite, sericite
			schist, quartzite and marble
		Seriska Fm	Quartzite, chert, breccias, carbon phyllite
			and marble
		Kushalgarh Fm	Marble with phosphorite, basic flows, tuff
	Alwar Group	Pratabgarh Fm	Quartzite, quartz sericite schist
			(conglomerate)
		Kankwarhi Fm	Quartz sericite schist, quartzite with lenses
			of marble and conglomerate
		Rajgarh Fm	Quartzite ,marble and conglomerate
	Raialo Group	Tehla Fm	Pillow lava, agglomerate, tuff with
			conglomerate, quartzite, phyllite and
			marble
		Nithar Fm	Quartzite with conglomerate
		Dogeta Fm	Marble, quartzite, phyllite, schist with bands
			of conglomerate
Bhilwara Supergroup (Archean)	Mangalw		
	ar		Mica schist, Calc-silicate marble,
	Complex		Paragneiss Quartzite.
(Archean)			

Table 2.3 Geological succession of North Delhi Fold Belt (Modified after Banerjee, 1980;GSI, 2011 and Roy and Jakhar, 2002)

The basin is also known as Khetri Copper Belt (KCB) because of known copper deposits. The rocks exposed in the Khetri belt are represented mainly by metamorphosed arenites and pelites belonging respectively to Ajabgarh and Alwar Group (Dasgupta, 1968; Sarkar and Dasgupta, 1980). The Alwar Group comprises pelites, quartzite-arkose and amphibole quartzite along with marble in the stratigraphic order. The Ajabgarh Group can be sub-divided in to pelites of various types, marble, calc-gneisses and quartzite.

To the east, the sub-basin is bounded by the BGC/ Delhi Supergroup in the Alwar-Jaipur zone, while sand dunes form the western part. Heron (1923) correlated the rocks of Khetri sub-basin with the psammitic Alwar and pelitic Ajabgarh 'Series' of Alwar-Jaipur Fold Belt on the basis of lithological similarities. 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' (GSI, 2011). The stratigraphic sequence of the Khetri Copper Belt after Das Gupta, 1968 is in Table 2.3. The metasedimentary rocks in the eastern part of the North Khetri belt (NKB) are inferred to have been deposited under shallow marine conditions while those in the western side are of relatively deep marine origin (Dasgupta, 1968; Sarkar and Dasgupta, 1980). The metasedimentary units in the NKB are intruded by calc-alkaline and A-type granitic rocks.

Chakrabarti and Gupta (1992) considered the low to high grade migmatised rocks in the southern part of the Khetri Fold Belt as unclassified pre-Delhis (GSI, 2011) and correlated the high grade migmatised 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 Sub-basin with those of the Alwar and Ajabgarh sequences of the respective type areas forms a controversial aspect. According to Sinha Roy et al. (1998), the so-called Ajabgarh and a part of the so-called Alwar of the Khetri area are in fact equivalent to the pre-Delhi Raialo Group (GSI, 2011). Gupta et al., (1988) divided the Khetri Fold Belt into two parts viz. North Khetri Belt and South Khetri Belt, separated by the Kantli tranverse fault and according to them, these belts 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 viz. the Chapoli Fault (GSI, 2011). It has been demonstrated that the cover sequences on either side of the Kantli Fault differ significantly from each other in lithological characteristics, especially

in the content of felsic volcanics (1832 \pm 3 Ma) as present in the South Khetri Belt (GSI, 2011).

		Younger amphibolites, chert, ankerite and quartz	
		veins	
Delhi Supergroup		Basemental mineralization and Fe-Mg	
		metasomatism	
		Granites	
	Ajabgarh Group	Older amphibolites	
		Unit 8- Phyllite, schist etc.	
		Unit 7- Quartzite, phyllite etc.	
		Unit 6- Phyllite, schist	
		Unit 5- Marble, calc-gniess	
		Unit 4- Various types of schist and phyllite	
		Unit 3- Amphibole quartzite, amphibole gneiss,	
		marble.	
		Unit 2- Quartzite, arkose	
	Alwar Group	Unit 1- Phyllite, Schist	

Table 2.3 Stratigraphy of the Khetri Copper Belt (after Das Gupta, 1968)

A widespread zone of albitisation, extending over approximately 170 km from north of Sior-Siswali to south of Kishangarh, along a NNE-SSW trending prominent lineament has been designated as 'Albitite Line' by Ray (1987, 1990) and as 'zone of albitisation' by Khandelwal et. al., (2008, 2010). This zone follows Khetri lineament in northeast and Kaliguman lineament in southwest. Along this zone, a new rock, albitite has formed. The albitites occur all along this zone with associated fluorite-ilmenite-magnetite-uraninitesulphide mineralization. Envisaging a purely magmatic origin for these rocks, Ray (1990) considered this magmatism to be intraplate and anorogenic.

2.2 Structure

The rocks of the North Khetri copper belt (NKCB) have undergone multiphase

deformation and polyphase metamorphism (Das Gupta, 1968; Lal and Shukla, 1975; Lal and Ackermand, 1981; Naha et al., 1988; Gupta et al., 1998). The structural history of the rocks of Khetri Belt became complicated due to multiple phases of folding and faulting. The metasediments of the Alwar and Ajabgarh Groups show structures of similar style and orientation. Four generations (DF₁-DF₄) have been recognised in the KCB rocks by Naha et al. (1988). The first generation folds are gently plunging reclined folds with an axial planar cleavage while the second generation folds are upright. The third set of folds are represented by kinks and conjugate folds with sub-horizontal to gently dipping axial planes. Upright conjugate folds with axial plane striking NE-SW and NW-SE and upright chevron folds with axial planes striking E-W are the fourth generation of folds. A sub horizontal NW-SE shear couple acting on horizontal beds gave rise to isoclinal, recumbent to gently plunging reclined DF1 folds with NE-SW axial trend in the first stage of deformation. This rotational strain was replaced by a pure shear in a horizontal NW-SE direction, resulting in upright DF2 folds which are coaxial with the DF1 folds. Locally, DF3 folds on subhorizontal axial planes have developed in zones of isoclinal upright folding in thinly cleaved rocks, because of sagging of early folds by their own weight. Thus they are accommodation structures, developed to release strain, accumulated by the DF2 compression. The folding of the last phase is due to compression along NS direction at low angles to the strike of S1 cleavage. This would thus signify a longitudinal shortening in the final phase of deformation (Naha et al, 1988).

According to Ray (1974), isoclinal first generation folds with steep axial planes striking NE and with moderate to high plunge towards NE or SW have been co-axially folded with the second axial plane also striking NE. The folds of third set are generally open with sub-vertical axial planes striking NW.

2.3 Metamorphism

The Khetri Belt (KB) is characterised by polyphase regional metamorphism (andalusite-sillimanite facies in the north and kyanite-sillimanite facies in the south. A progressive regional metamorphism with increasing temperature in the rocks of the Khetri Belt has been suggested to reach up to quartz-albite-epidote-almandine subfacies of the greenschist facies and grade upto higher grade amphibolite facies. The pressure- temperature conditions during M1 and M2 have been inferred to be 550 ± 50 °C and 550-650 °C with pressure range of 3-5 Kb during the M1 and M2 phases, respectively (e.g. Lal and Shukla, 1975; Sarkar and Dasgupta, 1980; Lal and Ackermand, 1981). The last metamorphic event has been dated at 950-910 Ma through chemical dating of monazite (Kaur et al., 2006; Pant et al., 2008). According to Roy Chowdhury and Das Gupta (1965), metamorphism is accompanied and followed by metasomatism resulting in the felspathization of schists in Jasrapura, Babai and Kotri, and scapolitization of amphibolites (Das Gupta and Chakravorty, 1962) in the area. The predominating iron magnesia metasomatism of quartzites and schists is represented by anthophyllite cummingtonite and chlorite in the northern part of the belt. These processes are connected with the wall rock alteration and superimpose the products of regional and thermal metamorphism.

The belt underwent prograde metamorphism related to granite intrusion and feldspathisation which was followed by retrogression, Fe-Mg-K metasomatism, associated alteration and albitisation (Sinha Roy et al., 1998). Metamorphism prior to basic rock intrusions was of low grade producing only sericite-biotite assemblages. The grade of metamorphism increases towards the eastern part of the KCB, where, strong deformation is accompanied with granite intrusions (Sinha Roy et al., 1998).

2.4 Alteration and associated Uranium mineralization:

Albitisation is the most prominent alteration phenomenon reported (Ray, 1987) in the southern part of Khetri Copper Belt. About 200 km long and 6 km wide NE-SW trending linear zone traverses the metasediments of Delhi Supergroup along the lineament joining Kishangarh in the south and Khetri in the north. The linear albitite zone shows a parallelism with the dominant structural trend of the Delhi orogeny indicating existence of a deep crustal fracture controlling the emplacement of albitites and associated cogenetic rocks such as magnetite-albitite and pyroxenite (Ray, 1990). Mineralisation of U, Cu and Mo are associated with this alteration phenomenon (Sinha Roy et al., 1998.).

2.5 LOCAL GEOLOGY

Geratiyon ki Dhani area is located in the eastern part of Khetri sub-basin in toposheet 45M/14 and is about 45 km ENE of Rohil uranium deposit. The area presents an undulating topography represented by highly resistant quartzite and albitite as ridges and least resistant calc-schists, biotite schist exposed along nalas and depressions (Ramanamurthy et al., 1994). Albitite and granite occurs as intrusions. Mineralisation is hosted predominantly by pink to brick red coloured albitite and to some extends by biotite bearing albitite and quartz biotite schist. Albitite is highly fractured and brecciated in the mineralized part and appears brick red in colour due to Fe. Intense calcitisation as fracture filling calcite veins was observed. Sub-surface exploration resulted in establishing uranium mineralization over a strike length of 1200 m along NNW-SSE trend.

Major lithounits exposed in the area are grey albitite, quartzite inter-bedded with quartz biotite schist, calc-silicate and amphibolite belonging to Ajabgarh Group. The albitite is consisting of numerous veins of quartz, calcite, rutile and hematite. Hematisation, chloritisation, silicification and calcitisation are the alteration features observed in this block. The formations in general are trending NNW-SSE to NW-SE with moderate to steep dips towards WSW. The whole sequence is affected NE-SW trending brecciation and calcitisation. The NW-SE trending albitite ridge exposed near Geratiyon ki Dhani village is highly deformed exhibiting both brittle and ductile deformation. Uranium mineralization in the Khetri sub-basin is metasomatite type spatially associated with axial region of F2 folds along structurally weak zones (Padhi et al., 2016: Jain et al., 2016; Khandelwal et al., 2011; Narayan et al., 1980; Yadav et al., 2002). Davidite, Brannerite and U-Ti complexes are the main radioactive phases identified.

CHAPTER 3 GEOLOGICAL MAPPING

Geological mapping of 2 sq km area on 1:2000 scale around Geratiyon ki Dhani area was carried out using total station, GPS and Brunton compass. This area falls under toposheet No. 45M/14 and 30 km E of Jahaz uranium deposit. Quartzite, quartz-biotite-schist, calcsilicates are the main lithiunits of Ajabgarh metasediments exposed in the study area along with intrusive granites and later phases of albitites. The area is characterized by an undulating topography represented by highly resistant quartzite occuring as ridges while least resistant schistose rocks exposed in depressions. The general strike of the rocks of the area is NNW-SSE. Geological traverses were taken along and across the strike of the litho-units. The surface investigations comprises the detailed study of topography, litho-units, fractures, foliation plane and joint pattern present in the area and radiometric checking. Some of these components are varying along the strike and some are varying along the dip. Radiometric checking of the lithounits resulted in delineating various radioactive anomalies in Geratiyon ki Dhani area. Detailed geological map generated by plotting/integrating of all data collected during the geological traverses. Subsurface data collected from boreholes drilled during ongoing investigations as well as previously drilled bore holes has been integrated with the geological map prepared from surface investigations. Lithological characterisation, systematic collection of the foliation data, alteration pattern and small scale structural features present in the borehole cores were studies as part of the work.

A geological cross section along X-Y line on the map (Figure 3.1b) has been prepared to understand relative disposition of different Lithounits with depth.

Finally, similarities and variability between surface and subsurface data analysed, correlated and the geology of the area has been interpreted. The details are given below:

3.1 Surface Observations:

- The dominant rock types are feldspathic quartzite, quartz-biotite schist and calc-silicate, intruded by albitite, granite and amphibolite.
- Feldspathic quartzite is fine to medium-grained, white to grey in colour. It is compact, massive and highly fractured and jointed. The feldspathic quartzite consists of quartz and feldspar with minor biotite and chlorite.
- Quartz biotite schist is medium to coarse grained, well foliated by the presence of orientation of flaky minerals.
- Calc silicate rock is fine to medium grained, massive, grey to green coloured, hard and compact. These rocks are composed principally of quartz, calcite, diopside, actinolite / tremolite with subordinate but occasionally fairly high amount of plagioclase and biotite
- The albitite have intruded into metasediments such as quartz biotite schist and quartzite.
- Sharp contact between albitite and quartz biotite schist has been observed in NW of study area indicating its magmatic origin. (Figure 3.3a)
- The Albitite in hand specimen is fine to medium grained, leucocratic, heterogeneous, very hard and compact in nature. It exhibits brick red to pink colour, granular texture, Quartz and feldspar were identified by naked eye. It is highly deformed, fractured, brecciated with calcite veins, veinlets and quartz veins at places
- Younger phase of granite and amphibolite intrusion were recorded.
- NNW-SSE trending quartzite ridge, spreading over a strike length of about 2 km was mapped and primary sedimentary structures such as bedding and cross bedding observed.
- NNW-SSE albitite hill host radioactive anomalies for 1.2 km intermittently in the study area.
- Secondary uranium mineral in brick red coloured albitite is observed (Figure 3.4 D).

- The albitite is brecciated with angular rock fragments of quartz and feldspar varying in size from few mm to 20 cm.
- Relict of quartz biotite schist in albitite indicate its magmatic nature (Figure 3.5a).
- The NNW-SSE trending albitite ridge (Figure 3.4 A) is highly deformed exhibiting both brittle and ductile deformational features. Brittle deformation is represented by brecciation and fracturing. Several asymmetric folds observed in the area viz. Z, M and S types, indicate ductile deformation (Figure 3.4 F,G,H)
- The lithounits exposed having overall trend of foliation N25-30⁰W-S25-30⁰E, dipping vertical to sub-vertical towards SW (Figure 3.2a).
- Two prominent conjugate sets of joint planes have been recorded- one set along E-W direction and another set along NE-SW direction. Acute bisectrix of these conjugate joints indicate probable compression direction (Sigma-1), accordingly perpendicular to this direction there was maximum extension. As a result we are getting foliation planes with a strike of N28°W, parallel to the direction of maximum extension (Figure 3.2b).
- Intense brecciation is conspicuous with un-oriented detached parts that appear to be the result of fluid / hydrodynamic activity.
- Calcite and quartz veins seal most of the fractures which possibly indicates its formation in the latest phase (Figure 3.4 E).
- Calcite shows two modes of occurrence viz. (1) as veins, cutting across the country rock and (2) as patches, filling interstitial spaces between grains.
- Local stratigraphic succession based on mapping and borehole drilling from older to younger is quartzite, quartz biotite schist, calc silicate, amphibolite, albitite and granite.

3.2 Subsurface observations:

- Lithounits intercepted in boreholes are Albitite, quartz-biotite schist, calc silicate, quartzite with several vein and veinlets of quartz and calcite along with oxides (rutile, hematite and magnetite) and minor sulphides (pyrite, pyrrhotite, chalcopyrite)
- Major alterations are calcitisation, chloritisation, silicification, sericitisation and ferruginisation along with quartzo-feldspathic injection.
- Foliation data also recorded in the core and S₁ w.r.to CA varies from sub-parallel to 75°.
 This variation in foliation data indicate folded nature of the rock types.
- Micro folding and faulting in albitite is common.
- Asymmetric folding in the foliation planes and slip along the axial planes of these foliations gives evidence of tectonic movement and crushing.
- Foliation data obtained from the borehole core show an overall strike of N20W-S20E dipping 60-75 towards SW, which is parallel to the foliation planes present in most of the surface litho-units
- Contact of albitite and quartz biotite schist is observed in borehole core (Figure 3.3b).
- In borehole core we also observed relict of quartz biotite schist in albitite (Figure 3.5b).
- Remnants of quartz biotite schist and biotite rich albitite are intercepted in borehole which shows brecciation.
- Albitite, the host rock of mineralisation, is highly fractured and brecciated in the mineralized part and appears brick red in colour.
- Average number of fracture per meter calculated for the entire borehole is 8 fractures per meter. Whereas it is found to be doubled to 16-18 fractures per meter in mineralised zones.





Figure 3.1a) Geological Map of the Geratiyon ki Dhani area b) Geological cross section along X-Y line



Figure 3.1 c&d) Geological transverse section along Geratiyon ki Dhani area



Figure 3.2 a) Rose diagram showing trend of foliation, dominantly N20°W-S20°E. b) Rose diagram of the joint planes show two major trend of E-W and N45°E-S45°W



Figure 3.3 a,b) Sharp contact between albitite and quartz biotite schist, indicating its magmatic origin



Figure 3.4 A) Panoramic view of albitite hill in Geratiyon ki Dhani. B). Brick red colour albitite showing depth persistence in quarry section. C) Intercalation of albitite and Quartz biotite schist, near QBS contact. D) Secondary uranium mineral (Uranophane) in albitite.



Figure 3.4 E) Calcite veins along fracture of albitite. F) F2 folds with axial plane striking N20°W dipping steeply WSW. G) Set of minor faults observed in folded structure in quarry section. H) E-W trending fault



Figure 3.5 Relict of quartz biotite schist within albitite a) NW of Geratiyon ki Dhani b) Borehole core of Geratiyon ki Dhani are

CHAPTER 4 METHODOLOGY

Field data was collected systematically and documented for integration with laboratory data and interpretation. A total of 80 representative grab and sub-surface samples were generated from various locations within the study area for Petromineralogical (XRD) and geochemical (WDXRF, ICP-OES, whole-rock chemistry) studies. Interpretation of lithological and geochemical data of the host-rocks in terms of its alteration studies, understanding geological controls of mineralization is needed.

4.1 PETROLOGY LABORATORY AND FLUID INCLUSION

4.1.1 Thin section preparation

Rock samples including borehole core and grab samples from outcrops, require processing before they can be used for mineral analysis by either Polarizing Light Microscope (PLM), Microprobe or Scanning Electron Microscope/X-ray Microanalysis. The sample has to be thin enough for light to pass through in a transmitted light microscope and have a polished surface for electron microprobe studies. Grab samples and borehole core sample were 20 samples collected from the field for petro-mineralogical studies. For section preparation, the sample is sliced to 24 mm thick pieces (Figure 4.1). Frail or crumbly specimens were hardened first by adding a resin. A suitable size slab of sample for mounting on a slide was cut in with hacksaw or with a diamond saw. The edges are smoothened and slab is labelled. Surface is ground with -400 mesh carborandum powder then washed and dried. The procedure is repeated with 600 and 800 size silicon carbide powder afterwards. The section is mounted on a glass slide on which molten lakeside cement/epoxy resin + hardener has been smeared. The mounting is done in such a way that the ground side is in contact with the cement. The slide is kept for hardening of mount. The thickness of sample is further decreased by hand grinding until attaining a thickness of 0.03 mm. The prepared section is washed in water and placed in a holder and spun on a machine for polishing using nylon cloth and diamond paste.



Figure 4.1 Process of making thin section from rock sample

4.1.2 Method of Petrographic observation

The prepared thin sections are studied using petrographic microscope (Model: OLYMPUS BX50, Lecia DM2700P) with 2X, 5X, 10X, 20X and 50X magnification. Different optical properties of the constituting minerals were studied. Color, pleochroism, relief, mineral habit, texture and alterations, cleavage properties are observed under plane polarized light. Isotropism, birefringence, interference colors, interference Figures, extinction angle, twinning, zoning and dispersion are observed under crossed polars.

Petrographically the samples which were connected spatially to the uranium mineralisation were selected for fluid inclusion studies. Petrographic observation is done on the samples from the study area to locate fluids which were present in rock.

4.2 WAVELENGTH DISPERSIVE X-RAYS FLUORESCENCE (WDXRF)

Wavelength dispersive X-ray fluorescence spectrometry is widely used analytical technique for rapid determination of elemental composition of a sample, and used for both

qualitative and quantitative determination. WDXRF analysis is based on the principle of sample excitation by X-rays and the detection of X-ray photons of characteristic wavelength. The X-ray source, the tube, creates the X-ray beam (Figure 4.2). Before the X-ray beam penetrates the sample. The X-ray beam from the tube is referred to as primary radiation and the X-rays emitted by the sample as secondary X-rays. The secondary X-rays are collected by the collimator and directed to the analysing crystal which together determine the spectral resolution in WDXRF. After analysing crystal the X-rays go to the detector and to the pulse height analyser to be measured.



Figure 4.2 The optical path in WDXRF

XRF brings advantages such as minimal sample preparation, non-destructive analysis platform, relatively short analysis runtime, wide elemental analysis ranging from Be to U and linearity in analytical range of concentration from ppm to 100 %.

4.2.1 Preparation of sample

The rock sample from field containing larger chips and coarse powder ground to fine powder with a grinding vessel small grain size gives higher intensities and more stable results. The powdered sample is pressed in to pellets as pressed samples give higher intensities than loose powdered samples. From each sample, a fraction of 3 g is pressed with 100 kN force as a pellet for analysis. 3, 4 and 5g of blank sample on top of 10ml of Borax in aluminium cup pressed with 100kN. Borax is organic material which is highly stable under X-rays and is used to prevent X-rays from reaching the aluminium cup.

4.2.2 Target material

Target material of the X-ray tube determines the characteristics of X-rays produced. Most common target materials are rhodium (Rh), chromium (Cr) and tungsten (W). Rhodium is the widely used target material and is effective for analysis of all XRF measurable elements (Be - U), Cr as target is effective for Ti - Cl (~light elements) and tungsten as target for analysis for rare-earth elements (heavy elements). Method development is done in three steps (i) preparation of the reliable calibration samples, (ii) founding the best measuring conditions with qualitative analysis and (iii) creation of the quantitative method. ARL PERFORM'X model of Thermo Fisher Scientific WDXRF instrument is used during the study.

4.3 ICP-OPTICAL EMISSION SPECTROMETRY

ICP-OES (Inductively coupled plasma - optical emission spectrometry) is a technique in which the composition of elements (dissolved in solution) in samples can be determined using plasma and a spectrometer. Refractory elements like REEs, Th, U, Zr, Hf, Ti, Sn, W, Mo, V etc can be analysed down to ppb level. It is a simultaneous / sequential and multielemental (40-50 elements) technique with large linear dynamic range with high sensitivity. The calibration curve is linear up to 4-5 orders of magnitude (ppb-100 ppm) and no dilution is required for samples with higher concentrations.

In this technique sample solution is atomised and introduced in to hot plasma for ionization and excitation; Atoms or ions on de-excitation emit light characteristic of the element. The intensity (photons per unit area per unit time) of the light is proportional to the difference in energy levels of ground and excited atoms; giving concentration of the element.

Ι α ΔΕ. Ο



Figure 4.3 Schematic diagram of ICP-OES

4.3.1 Sample preparation technique for ICP-OES

Sample dissolution is to mix a solid or non-aqueous sample quantitatively with water or mineral acids to produce a homogeneous aqueous solution, so that subsequent separation and analyses can be performed. Solid samples must be dissolved in solution for analysis for ICPOES. There are four main techniques for sample decomposition i) fusion ii) wet ashing, iii) acid leaching, or acid dissolution iv) microwave digestion. Acidified sample solutions with appropriate dilutions are aspirated into the plasma in order to keep metals in solution. The content of salts in samples should be kept below 3 %, preferably below 2 % (= 20 g/l). Solid material should be destructed, preferably with nitric acid only (concentration HNO3below 10 %, ideally 1 %), or if necessary, with HNO3/H2O.

4.4 X-RAY POWDER DIFFRACTION (XRD)

X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. Sample analysis were done at XRD, Laboratory, Hyderabad with GE-XRD 3003 TT. The analysed material is finely ground, homogenized, and average bulk composition is determined. It is used for characterization of crystalline materials, radioactive phases, identification of fine-grained minerals such as clays and mixed layer clays that are difficult to determine optically, determination of unit cell dimensions and measurement of sample purity.

4.4.1 Sample preparation technique for XRD

The Geological samples are first observed under ultra violet light to see for the presence of any secondary uranium minerals, they are separated carefully using a fine needle and mounted for diffraction studies. The remaining sample is divided into two parts, one part is crushed between 85 to 100 micron size fractions. The sieved grain sample and the powder sample are separated using heavy liquid (Bromoform and Methylene Iodide) separately. The heavies fraction containing the radioactive minerals of interest is subjected to magnetic separation on the isodynamic magnetic separator. Thus ilmenite separates at 0.2 amps, garnet at 0.35 amps, xenotime at 0.45 amps, monazite at 0.8 amps, uraninite at 0.95 amps and zircon in the non- magnetic fraction. The minerals are now separated and nearly pure mineral fractions are obtained based on their magnetic susceptibilities. Each of the separated fractions is powdered to about 45 micron sized particles in agate mortar and diffracted separately. The remaining powder is centrifuged in bromoform and methylene iodide media and the different separates are also diffracted for identification of the constituent minerals.

4.5 CORE ORIENTATION TEST (COT)

Core orientation is the process by which the orientation of a core cylinder is determined. Typically, a mark, groove, or line is placed on the surface of the core and the in situ azimuth of the marking is determined with respect to geographic north. Most routinely, orientation is used to measure large scale features such as bedding, cross-bedding, fractures, flow textures, and stylolites. The slots for indicating the position of the core within the sampling tube, a test tube with etch mark to indicate the top point or position of the etch mark within the test tube and a connector for relating the said top point on the test tube to the longitudinal slots on the sampling tube sidewall permit determination of the in situ position of the core sample.

CHAPTER 5 PETROMINEROLOGY & FLUID INCLUSION STUDIES

To characterise different rock types present in the study area, systematic surface and sub-surface sampling has been carried out in and around Geratiyon ki Dhani area for petromineralogical studies under microscope. Samples have been studied megascopically as well as microscopically and are characterised based on mineral assemblages, texture, grain size, mutual grain relationship, alteration features, radioactive mineral phases etc. Based on these studies dominant rock types identified are Albitite, biotite bearing albitite, quartz-biotite schist, calc silicate and quartzite.

Both surface and sub-surface sampling has been carried out. Borehole core was sampled from previously drilled as well as on going drilling in the study area. Majority of boreholes were of shallow series and being drilled during November 2019- February 2020. These boreholes are along the strike line of the study area and are 100 m apart from each other. For surface sampling, traverses were taken in and around study area and samples from different litho units were collected for further study.

5.1. Albitite

Megascopic Description:

Megascopically the samples are fine to medium grained, leucocratic, heterogeneous, very hard and compact in nature. They show brick red to pink colour, granular texture, and mostly quartz and feldspar were identified by naked eye. The albitite has intruded into the metasediments such as quartz biotite schist and quartzite. It is highly deformed, fractured, brecciated with multiple quartz vein, veinlets and calcite veins at places (Figure 5.1.1 b,c,d). Brecciation observed where big crystals of quartz and feldspar upto size of 10mm-2cm are seen. Specks of magnetite are seen all along the run as disseminated crystals. Other

constituents present in these rocks are biotite, chlorite and calcite. At places, core of the whole run shows network of fractures with random orientation and sealed with calcite and quartz (Figure 5.1.1 c,d). Mostly these veins cut across the foliation plane.



Figure 5.1.1 a) Davidite (Dv) crystal with rutile (Rt) in albitite (Alb). b) Calcite (Cal) thick vein with davidite crystal. c) Numerous quartz(Qtz) vein sealing fracture. d) Network of fracture sealed with calcite vein. e) Thick quartz vein

Brick red colour is due to presence of iron, present along the grain contact. Bedding and foliation is totally distorted in this zone due to intense deformation. Calcitisation and silicification are major alteration features. Calcitisation has taken place in interstitial spaces which were created by fracturing. Chloritisation along fracture planes are common. Minor sericitisation, ferrugenisation are also observed. Davidite crystal is noted in association with rutile (Figure 5.1.2 a). Vugs and cavities were filled with secondary quartz (Figure 5.1.2 d,e).



Figure 5.1.2 a) Davidite (Dv) crystal within calcite (Cal) vein in albitite. b) Track density of davidite. c) Thin section with big crystal of davidite. d) Rutile (Rt) vein sealed with calcite (Cal) vein in albitite. e) Secondary quartz recrystallize in vug of albitite.

Microscopic Description:

In general, under microscope, this rock displays fine to medium grained, granoblastic texture with occasional porphyroclastic texture. Albite and Quartz are the major minerals while biotite and microcline are important accessory minerals. Albite content in these rocks is very high and is visually estimated to be between 60-80 % in a single section. Size of the

grain varies and large crystals range between 2 - 3 mm even in deformed grains. Albitite grains are euhedral to subhedral. Deformation in larger feldspar is exhibited by undulose extinction and twin lamellae. Perthitic textures are clearly identified. Sutured grain boundaries, bulging and stretching in quartz shows dynamic recrystallization of quartz. Finely recrystallized quartz aggregates are wrapping around larger elongated quartz grains. Red colour is due to presence of iron along the grain boundary. Chlorite and calcite are the secondary minerals developed in the rock as a result of hydrothermal alteration. The finegrained albite is mostly rounded and generally anhedral with little consistency in any given area. Within the massive albite are small, rounded grains of quartz that are hard to distinguish. Rocks are severely deformed under brittle-ductile regime. Minor alteration as hematitization, chloritization and calcitization are observed. Several thin and wide by spaced calcite veins (coarse crystalline) are randomly traversing the rock. Quartz and biotite are the other minor secondary minerals observed with calcite veins. Biotite is often chloritised. Calcite shows two modes of occurrence viz. (1) as veins, cutting across the country rock and (2) as patches, filling interstitial spaces between grains. Calcite occurs as thin veins and veinlets, crisscrossing each other at many places. They cut across structural elements (such as foliation planes) of the country rock and earlier formed albite rock. This appears to have happened as calcite represents the final stage of hydrothermal activity and is the last phase of alteration, pervasive in all the encountered rocks. Some veins show coarse grained euhedral calcite grains showing low nucleation and high growth rate due to slow cooling. At places, calcite veins incorporate euhedral tourmaline grains. Tourmaline occurs as euhedral, prismatic and elongated grains. Silicification also occurred as vugs filling. Sericitization of feldspar also observed at places.

Ore minerals: In reflected light albitite comprises oxides as the ore minerals. Sphene, Rutile, davidite, brannerite and U-Ti complex as Ti-oxides while hematite and less magnetite as Fe-oxides. Sulphide minerals are not present, while very less amount of pyrite and chalcopyrite



Figure 5.1.3 a) Albite (Alb) euhedral grain with quartz (Qtz) TL,2N. b) deformed quartz with twin albite & TL,2N. c) Stretched quartz grain with cross hatched twin TL,2N. d) Perthetic texture in albite TL,2N

is associated with albitite in cores. Presence of few REE-minerals is also noted. Monazite is very rare but where it is found, it is very small and occurs along grain boundaries, fractures, or in the cleavage of biotite. Very small zircons were also observed.

Generally rutile is anhedral, sub rounded, showing high relief, yellowish-reddish brown color in thin section which are rimming davidite or U-Ti complexes, or occurs as small grains throughout the slide. Rutile occurs as fine tabular crystals along the boundary or with in calcite. Rutile also shows intergrowth with hematite near the radioactive minerals. Rutile is exsolved within brannerite. Very rare but cubic form magnetite were also encountered in this rock. Ore minerals are undeformed and unaffected by deformation suggesting their formation subsequent to deformation.



Figure 5.1.4 a) Tourmaline (Trm) crystal with calcite (Cal) vein TL,2N. b) hematite(Hmt) present along the contact of grain & TL,1N. c) Monazite (Mz) small rounded crystal TL,1N. d) Network of fracture in albite sealed by calcite RL,2N

Davidite is identified as chief radioactive mineral, occurring within the albitite. Davidite occurs as anhedral to subhedral grains with varying sizes and in veins which crystallised in the vicinity or adjacent to calcite veins. Davidite occurs in close association of calcite and rutile. Davidite crystals under microscope exhibit reddish brown, anhedral to subhedral habit and range in size from 0.5 mm to >1.5 mm with medium density alpha tracks over CN-film. Radiation haloes were also observed around the davidite crystals. Inclusions of davidite in rutile is very common indicating crystallisation of davidite later than the rutile. Brannerite is another radioactive phase identified with opaque to translucent nature, has low reflectivity and yellow-brown internal reflection. U-Ti complex occurs as brown colour amorphous spots, and at places also as patches. They are mainly associated with rutile and brannerite.



Figure 5.1.5 a) Brown colour davidite with U-Ti complex RL,1N. b) Brannerite (Brn) and U-Ti complex with rutile (Rt) RL,2N. c) Rutile vein aligned in one direction TL,2N. d) Davidite (Dv) crystal associated within calcite(Cal) vein TL,2N



Figure 5.1.6 a) Davidite (Dv) surrounded by rutile hematite (Rt-Hmt) RL,1N. b) Secondary uranium (Sec. U) along fracture RL,2N

5.2 Biotite bearing Albitite:

Megascopic Description:

Megascopically the samples are medium grained, pink to dark grey in colour, heterogeneous, very hard and compact in nature. Colour variation in rock is directly related to the biotite content and also Fe. The albitites have intruded into the metasediments such as quartz biotite schist and quartzite. Near contact of albitite and quartz biotite schist, biotite quantity high in albitite, so rock is biotite bearing albitite which also host mineralisation. Albite, quartz and biotite are the main rock froming minerals while plagioclase, chlorite and microcline are present only in minor quantity. Biotite flakes are strongly oriented showing schistosity. Segregation of biotite at many places shows preserved foliation (Figure 5.2.1b). Biotite bearing albitite shows brecciation along with number of fractures. Brecciation observed where big crystal of quartz and feldspar upto size of 10mm-2cm were present in biotite rich zone (Figure 5.2.2 b). Foliation plane were folded to several degree and also at places fractures and faults noted in the rock (Figure 5.2.1a) Fractures are mainly sealed with secondary quartz and calcite (Figure 5.2.1c).



Figure 5.2.1a) Biotite segregation showing folding in biotite bearing albitite. b) Secondary quartz in vugs of biotite bearing albitite. c) Foliation preserved by the biotite layer in biotite bearing albitite



Figure 5.2.2 a) Minor sulphide as pyrite in biotite bearing albitite. b) Brecciation in biotite bearing albitite

At places small discrete grains of tourmaline were also observed. Specks of rutile and hematite are disseminated (Figure 5.2.2a). Calcitisation and chloritisation are prominent alterations noted. Chloritisation was observed along the fracture planes or weak zones.

Microscopic Description:

It is medium to coarse-grained, highly fractured and foliated at places. It is composed of albite, quartz, biotite as major mineral constituents and orthoclase, chlorite as minor minerals. The proportion of biotite is upto 30 % in rock which is also observed in megascopic study of rock samples. Other accessory minerals are rutile, zircon, hematite and tourmaline. The proportion of albite is higher as compared to orthoclase. Twinning is commonly seen in the larger albite grains, which also show remnants of their euhedral nature. The fine-grained albite is mostly rounded and generally anhedral with little consistency. The eudedral grain of albite contain biotite and quartz, indicating intrusion of albite in metasediments. Quartz grains are showing recrystallization, grain boundary migration and sub-grain formation whereas albite shows bending of twin lamellae.



Figure 5.2.3 a) Biotite defining foliation plane. b) Quartz grains are align parallel to foliation plane. c) Monazite inclusion in biotite. d) Quartz and biotite inclusion in albite.
The twin lamelle of albite are also deformed indicating very high degree of deformation the rocks have undergone. Quartz grains are aligned parallel to biotite showing remnants of original schistosity still preserved after the intrusion of albite (Figure 5.2.3 a&b). That's why preferred orientation is developed locally as narrow sub parallel micro-zones of finely recrystallized quartz. Remnants of biotite in albite grain revels that albite it later intrusion within quartz biotite schist (Figure 5.2.3 d).



Figure 5.2.4 a) Davidite (Dv) crystal surrounded by calcite (Cal) and biotite (Bio). b) Mineralisation along the fracture. c) Davidite associated with biotite and chlorite (Chl). d) Brannerite (Brn) crystal surrounded by rutile and biotite

Ore minerals: The ore minerals found in biotite bearing albitite are same as those found in albitite such as Ti and Fe-oxide ore minerals namely, rutile, davidite, U-Ti-Fe complex (Figure 5.2.3a). Hematite is occasionally found. Monazite and fine zircon crystal are also noted in rock (Figure 5.2.3c).

Radioactive minerals: Davidite, brannerite, U-Ti-Fe complexes and minor REE-minerals are the radioactive phases identified in the rock sample (Figure 5.2.4 a,b,c,d). Davidite as discrete grains mainly crystallised adjacent to calcite veins and was observed with radiation haloes along the boundary (Figure 5.2.4 a). Davidite crystals are reddish brown, anhedral in habit and ranging in size from 0.5 mm to >2 mm of rounded to sub rounded grain (Figure 5.2.4 c). Rutile mineral inclusions are common in davidite indicating crystallization of davidite is later in ore paragenesis.

5.3 Quartz biotite schist

Megascopic Description

In hand specimen, the rock is medium to fine grained, with well-developed schistosity. Foliation planes are defined by the parallel orientation of platy minerals, predominantly biotite. The rock comprises of feldspar, quartz and biotite in increasing order of abundance. Due to appreciable presence of biotite, the rock shows an overall dark colour. The rock, at places, contains specks of magnetite and rutile. Amphibole are also present at many places and are easily distinguishable from the biotite rich portions. Quantity of amphiboles is variable at different depths and usually very less abundant. Development of strong foliation planes has decreased the hardness of the rock. Secondary calcite veins are common. Veins of secondary silica and calcite cut across the rock. Calcite veins are present at all depths and at places show criss-cross relation. At some places brick red colour albite is present. Chloritisation is also present along the fracture planes and weak planes which are developed by retrograde metamorphism of biotite (Figure 5.3.1b). Foliation planes are crenulated i.e. crenulation of flaky minerals observed at places indicating two or more phases of deformation (Figure 5.3.1a). Secondary foliations and minor folds formed as a result of multiple deformational events that acted upon these rocks are well preserved and can be seen in the form of parallel, folded and crenulated schistosity and also at place we observed fault (Figure 5.3.1c,d). Thick quartz and calcite vein are seen with needle like and thin lenses of magnetite. Asymmetric folding and fold closure in the foliation planes and slip along the axial planes of these foliations gives evidence of tectonic movement and crushing (Figure 5.3.2 a&b). This rock is also later intruded by basic body (amphibolite) which we find in surface as well as in borehole core (Figure 5.3.2 c).

Microscopic Description

Under microscope, quartz biotite schist is medium to coarse grained and well foliated. Quartz biotite schist consists of biotite and quartz with chlorite as major minerals, albite and microcline as minor minerals (Figure 5.3.3 b). All minerals are aligned parallel to schistosity (Figure 5.3.3a). Foliation planes are defined by biotite, biotite + chlorite. Feldspars, at places, are altered to sericited but, the degree of alteration is low. Biotite flakes are narrow and strongly oriented. Quartz grains are anhedral to subhedral with size varying from 0.1 mm to 1.0 mm, and stretched parallel to the schistosity. At places quartz shows undulose extinction due to deformation. It shows straight as well as curved boundary contact with adjoining quartz grains and at places sutured grain contact is also seen. Folding in quartz biotite schist observed. Chlorite is pleochoric with change in intensity of green colour and show second order grey interference colour. Chloritisation of biotite and sericitisation of feldspars are the major alteration features observed in the rock. Minor silicification has also been observed. Grade of the rock is low as we could not find mineral assemblage quartz + biotite + chlorite +- actinolite, which shows greenschist facies.



Figure 5.3.1 a) Asymmetric folding in quartz biotite schist. b) Brecciation with intense chloritisation. c) Faulting in brecciated quartz biotite schist. d) Fold closure indicating by biotite rich layer



Figure 5.3.2 a&b) Asymmetric folding in quartz biotite schist. c) Basic intrusion (amphibole) parallel to foliation plane.



Figure 5.3.3 a) Biotite showing foliation with minor folding TL,2N. b) biotite+ quartz+ plg mineral assemblage TL,2N. c) Minor rutile crystal with biotite TL,1N. d) Folding of biotite layer TL,1N

5.4 Calc silicate

Megascopic Description

In hand specimen it is fine to medium grained, massive, grey & green coloured and compact rock. These rocks are composed primarily of quartz, calcite, diopside, actinolite / tremolite with subordinate but occasionally fairly high amount of plagioclase and biotite (Figure 5.4.2a). At places Calc-silicates are well-foliated characterized by calcite-rich light coloured layers inter-banded with biotite or diopside layers (Figure 5.4.2c). Crenulation cleavage observed at places (Figure 5.4.2b). They are also highly jointed and fractured. Segregation of biotite was observed at many places. Calcite occurs as thin veins and veinlets in the borehole core (Figure 5.4.1 a,b). At places basic veins also observed (Figure 5.4.1 c)



Figure 5.4.1 a&b) Calcite vein cross cutting the foliation plane. c) Silicification of calc silicate rock. c) Thick basic vein



Figure 5.4.2 a) Diopside granular crystal. b) Crenulation cleavage/folding in calc silicate rock. c) Foliation plane showing by biotite layer

Microscopic Description

Under microscope this litho unit is medium grained with non-foliated granoblastic polygonal texture. Calcite, diopside, quartz are the major constituents while actinolite and feldspar (both plagioclase & microcline) have minor presence (Figure 5.4.3a). Calcite is the most dominant mineral with more than 50 % area in the section. Calcite has well developed crystals and also fine grained along the grain boundaries (Figure 5.4.3 b,c). It forms medium to coarse grained crystalloblastic mosaic. Diopside is very light green to blue in colour and shows faint pleochroism. Randomly oriented biotite within the groundmass of calcite exhibits decussate texture (Figure 5.4.3 e). Biotite in general is randomly oriented but at few place they show well developed foliation. Besides biotite and calcite, chlorite, an alteration product of biotite, is also found as a major constituent. Along the margin of the larger crystals of calcite (Figure 5.4.3 f), thin biotite layers were developed. A few actinolite-tremolite grains

are also present. Sphene is rarely seen. The rock underwent calcitisation in the form of veins as well as fracture filling.



Ore minerals: Rutile and magnetite are the ore minerals in minor quantities (Figure 5.4.3 e).

Figure 5.4.3 a) Feebly foliated (diopside wrapped by biotite) calc silicate rock, interstitial space filled by calcite TL, 1N. b) Interlocking texture between quartz-actinolite and dioside TL,2N. c). Calcite surrounded by biotite TL,1N. d) Rutile thin vein in calc silicate group rock RL,1N. e) Groundmass of calcite and quartz with green to blue of Hb/Act TL,2N. f). thick calcite vein

5.5 Feldspathic Quartzite

Megascopic Description

Megascopic observation of feldspathic quartzite in the study area shows occasional presence of foliation plane by biotite (Figure 5.5.1 b). The quartzite occupies major portion of the area among the metasediments. It is fine to medium-grained with white to grey colour (Figure 5.5.1 b). It is hard, compact, highly fractured and jointed. The feldspathic quartzite consists of quartz and feldspar with minor biotite and chlorite. At places it is highly feldspathised, weathered and stained with alternation of chlorite and biotite. Kaolinisation of felspar as a result of surface weathering is noticed. The low percentage of quartz in few samples of feldspathic quartzite is mainly due to the larger contributions from feldspar. Rutile and fine iron oxide were observed in the rock (Figure 5.5.1 a). Thin veins of calcite and secondary quartz are present (Figure 5.5.1 d).



Figure 5.5.1 a) Disseminated rutile (Rt) in quartzite. b) Thin lamination defining by biotite rich layer c) Fine grained feldspathic quartzite d) calcite and biotite patches in feldspathic quartzite

Microscopic Description

Under microscope it is fine to medium grained, non-foliated rock. Quartz and feldspar are the major minerals with minor biotite and chlorite. Stretched quartz grains show preferred orientation (Figure 5.5.2 b). Mostly quartz grains are monocrystalline, with few polycrystalline grains. The monocrystalline grains generally show undulose extinction. The quartz is either common quartz or polycrystalline metamorphic quartz. These quartz grains are deformed due to the impact of stress which is evident from the sutured contact between the individual mineral grains and undulose wavy extinction (Figure 5.5.2 d). Opaque minerals occur as sub rounded to sub angular grains. The common opaques are rutile and hematite (Figure 5.5.2 c). In plane polarized light hematite appears reddish coloured while rutile appear as yellowish brown.



Figure 5.5.2 a) Rounded to sub rounded quartz TL, 1N b) Quartz and feldspar stretch in one direction TL,2N c) Disseminated rutile in rock TL,2N d) Plagioclase with twin and sutured contact of quartz.

5.6 Microstructures:

Albitite rock is highly deformed exhibiting both brittle and ductile deformational features. Brittle deformation is represented by brecciation and fracturing (Figure 5.6.2 c). Several asymmetric folds observed in the area viz. Z, M and S types, indicate ductile deformation. Core orientation tests (COT) are carried out for albitite. In COT, the cores are oriented in proper direction and foliation planes are measured. While in albitite rock foliation plane are not well defined but at places foliation were measured from relict quartz biotite schist or banding. Foliation data obtained from the test shows overall strike of N25-30⁰W-S25-30⁰E, dipping vertical to sub-vertical towards SW, which is parallel to the foliation planes present in most of the surface litho-units. Asymmetric folding and fold closure are mainly observed where the foliation planes and slip along the axial planes of these foliations gives evidence of tectonic movement and crushing. Three prominent fracture trends were recorded in the study area as NW-SE, N-S and E-W (Figure 5.6.1 d&e). Network of randomly oriented fractures observed in borehole core which were later sealed by the quartz and calcite veins. These phenomenon indicate later hydrothermal activity in the area. Two prominent conjugate sets of joints have been identified- one set along E-W direction and another set along NE-SW direction. Small scale faults are present in core which indicate faulting is subsequent to brecciation (Figure 5.6.1 a,b,c; 5.6.2 a,b).

Under microscope minor folding of foliation plane is observed mainly in the curved biotite in quartz biotite schist. Coarse euhedral grains of albite and microcline exhibit twining. Displacement of twin lamelle in albite is also observed (Figure 5.6.1 g). Perthite and antiperthite textures are clearly distinguished under microscope. There are several thin and widely spaced calcite veins (coarse crystalline) randomly traversing the rock (Figure 5.6.1 f). Network of fractures holds mineralisation along with calcite veins.



Figure 5.6.1 a) Fold closure and folding in biotite bearing albitite. b) Small scale faulting c) Fold propagated fault d&e) Fracture showing cross cutting relation f) Network of randomly oriented fracture in random direction RL,1N g) Displacement of twin lamella in albite TL,2N



Figure 5.6.2 a) Step faulting in biotite bearing albitite. b) Small scale fold closure c) Brecciated core with large quartz and albite grains.

5.7 PARAGENTIC SECQUENCE

Mineral identification and textural characterization by petrological studies will help in achieving determination of the order of formation of associated minerals in time or paragenesis and estimation of the conditions under which the minerals have formed or have re-equilibrated. Paragenetic determination requires detailed examination of polished section to identify phases and diagnostic textures. On the basis of textural relationship between the grains of the rock forming and ore minerals is derived (Figure 5.7.1).

Minerals	Pre-ore stage	Ore stage	Post- ore stage
Quartz			
Biotite			
Albite		-	
Magnetite			
Rutile	_		
Sphene			
Chlorite	-		
Calcite			_
Quartz vein			
Tourmaline		_	
Hematite	-		
Davidite			
Brannerite			
U-Ti complex		-	
Secondary uranyl complex			

Figure 5.7.1 Paragenesis of rock forming and ore minerals in the study area

5.8 FLUID INCLUSIONS

A fluid inclusion is a microscopic bubble of liquid and/or gas that is trapped within a crystal. These small inclusions range in size from 0.01 to 1 mm and are usually only visible in detail by microscopic study. These inclusions preserve the physico chemical environment of the original parent fluid from which they formed. Thus, the fluid inclusions represent the volatile phases which circulated through the lithosphere during the geological history and provide a rich source of small but valuable clues for unraveling the past geological processes. They are rounded, semi rounded, facetted and irregular in shape. Some inclusions show necking which is not suitable for experiments. The following information is obtained from the heating –cooling experiments.

The crystals contain numerous two phase aqueous inclusions. The presence of coexisting gas and liquid-rich inclusions is significant because this suggests that the homogenization temperatures closely approximate the true trapping temperatures (Goldstein and Reynolds, 1994). The quartz hosted inclusions provide the best direct measure of the temperature. Primary inclusions are trapped at the time of mineral growth and secondary inclusions are trapped along healed fractures. Primary inclusions found in defect cavities in transparent mineral grains such as quartz by crack seal mechanism (Roedder, 1984) which formed during the growth of quartz crystals. Secondary inclusions found along fracture planes as linear arrays formed later to the growth of quartz. They can be further subdivided into a) Aqueous inclusions with only H₂O either in liquid, vapour or liquid positive vapour phase, b) Carbonic inclusions with CO₂ either liquid or vapour or both phases c) Inclusions with daughter minerals of halite, sylvite and in some cases tiny grains of opaque.

Thin section studies (optical exanimation) was taken up to identify fluid inclusions in the samples of Geratiyon ki Dhani area of fine to medium grained, euhedral crystals. Quartz occurring in albite rich rock are taken for examination. To understand the nature of fluid present, if any. The study reveals that the quartz contains numerous fluid inclusions which are mainly secondary and pseudo secondary in nature and less primary.

The optical examination indicates that fluids are mainly traversed along intergranular margin of quartz and hence, pseudo secondary inclusions along the growth zone of quartz grain are abundant. The secondary inclusions are fine in size and occur as trails (Figure 5.8.1b).

The primary inclusions are mainly biphase (L +V) (Figure 5.8.2a,b). They are oval to irregular in shape (Figure 5.8.1d). The average size of primary inclusions (N=12) is 6.5 microns. The size is enough to carry out thermometric studies (heating / freezing) on the sample. Pseudo secondary inclusions along the boundary of quartz also indicate the later episode of fluid activity (Figure 5.8.1c). The degree of fill of the primary inclusions on an average is 80 %.

The secondary inclusions may be another episode which will be established by temperature of homogenization and will reveal the difference in temperature and also fluid movements. The quartz grains which were examined are mostly in close proximity with biotite and albite.



Figure 5.8.1 a) Primary fluid inclusion. b) Secondary fluid present as trails c) Pseudo secondary inclusions along the contact of quartz d) Rounded to sub rounded inclusions



Figure 5.8.2 a&b) Biphase (V+L) primary fluid inclusions

CHAPTER 6 X RAY DIFFRACTION

X-ray diffraction (XRD) is a powerful non-destructive technique for characterizing crystalline materials. It provides information on crystal structures, phases, preferred crystal orientations (texture), and other structural parameters, such as average grain size, crystallinity, strain, and crystal defects. X-ray diffraction peaks are produced by constructive interference of a monochromatic beam of X-rays scattered at specific angles from each set of lattice planes in a sample. The peak intensities are determined by the distribution of atoms within the lattice. Consequently, the X-ray diffraction pattern is the fingerprint of periodic atomic arrangements in a given material.

The X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample. The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's law.

$n\lambda = 2dsin\theta$

Where n is an integer, λ is the wavelength of the X-rays, d is the interplanar spacing of the crystalline structure, and θ is the diffraction angle. This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed, and counted. By scanning the sample through a range of 2 θ angles, all possible diffraction directions of the lattice should be attained due to the random orientation of the powdered material. Conversion of the diffraction peaks to d-spacings allows identification of the compound because each compound has a set of unique d-spacings. Typically, this is achieved by comparison of dspacings with standard reference patterns. The separated samples on diffraction yield a set of inter planar spacings (d_{hkl}). The d_{hkl} for all crystalline materials both organic, and inorganic have been classified by the International Center for Diffraction Data (formerly the Joint Committee on Powder Diffraction and Standards- JCPDS) using procedures aiding in their identification. Two methods are available 1) The FINK method & 2) The Hanawalt method.

In the FINK method eight d_{hkl} values are arranged in the decreasing order of their interplanar spacings. The manual is divided into different sections .The d_{hkl} spacings in the search manual can be rotated in cyclic order to arrive at the correct mineral group or mineral.

In the Hanawalt method, three most intense important interplanar (d_{hkl}) spacings and five important d_{hkl} spacings are listed. The three d_{hkl} spacings can be altered in combination and the five important d_{hkl} spacings in different sections. Once these spacings are compared and found to be similar to the unknown, the mineral is tentatively identified. Finally, the detailed card is taken and all the d_{hkl} spacings are matched along with the integrated intensities. Once all the values match with the values given in the standard, the mineral is identified.

Four samples of Geratiyon ki Dhani area are analysed in X ray diffraction laboratory, AMD, Hyderabad. The XRD analysis results of three borehole core mineralized albitite and biotite bearing albitite samples and one grab sample containing secondary uranium mineralisation are studied.

Brannerite is the chief radioactive mineral identified from mineralised albitite (Figure.6.1 and 6.3). Xenotime, monazite and rutile are other atomic minerals found (Figure 6.2). Chlorite is Mg rich with chemical formula (Mg_{11.06} Fe_{0.94}) (Si_{5.22} Al_{2.78}) O₂₀ OH₁₆. (Figure 6.1). Other ore minerals analyzed are magnetite, hematite, anatase (Figure 6.1 and 6.2). Albite, quartz, chlorite, diopside and schorl (variety of tourmaline) and are the rock forming minerals analysed from albitite. All the rock forming and ore minerals are identified in petro-

mineralogy except diopside. Albite and quartz (Figure 6.3) are the main rock forming minerals identified in rock which is also confirmed by X-ray diffraction analysis.

Mineral Name: Brannerite												
		XCW-4831		ICDD No12-4	77							
Sl.No	hkl	d (in Angstrom)	I/I0	d (in Angstrom)	I/I0							
1	100	6.0272	18	6.04	35							
2	-2 0 1	4.7433	63	4.74	95							
3	200	4.3227	20	4.29	20							
4	110	3.4237	100	3.44	100							
5	-2 0 2	3.3231	47	3.35	100							
6	-111	3.2549	35	3.28	14							
7	0 0 2	3.0122	27	3.02	35							
8	201	2.9149	44	2.90	35							
9	111	2.7504	38	2.77	30							
10	-112	2.5080	24	2.53	30							
11	-311	2.4608	39	2.47	30							
12	-4 0 1	2.4368	15	2.41	18							
13	310	2.2794	33	2.276	12							
14	400	2.1607	7	2.144	10							
15	112	2.0745	5	2.080	8							
16	-4 0 3	2.0299	14	2.043	35							
17	003	2.0060	8	2.015	25							
18	311	1.9069	26	1.903	20							
19	0 0 2	1.8631	18	1.881	25							
20	-2 2 1	1.7338	8	1.749	8							
21	-2 0 4	1.7085	11	1.709	20							
22	-222	1.6383	6	1.642	8							
23	-513	1.6231	22	1.630	20							
24	113	1.6047	12	1.609	18							
25	022	1.5843	7	1.597	6							
26	221	1.5692	17	1.578	10							
27	-4 2 1	1.4801	8	1.486	4							
		Unit cell param	eters									
ao (in A)	9.831	.3 <u>+</u> 0.00081	ao	9.8016								
bo (in A)	3.726	52 <u>+</u> 0.00032	bo	3.762								
ao (in A)	6.850	07 <u>+</u> 0.00092	СО	6.9125								
В	11	8.45 <u>+</u> 0.5	β	118°56								
volume			volume	223.08								

Table 6.1 X-ray diffraction data of brannerite from Geratiyon ki Dhani area

	Mineral Name: Rutile												
		XCW-4831		ICDD No 21-1276									
Sl.No	hkl	d (in Angstroem)	I/I0	d (in Angstroem)	I/I0								
1	110	3.2418	3 100 3.247										
2	101	2.4842	28	2.487	50								
3	200	2.2927	6	2.297	8								
4	111	2.1861	14	2.188	25								
5	210	2.0526	9	2.054	10								
6	211	1.6868	48	1.6874	60								
7	220	1.6236	18	1.6237	20								
8	002	1.4794	3	1.4797	10								
Unit cell	parameter	S											
Ao	4.5899 <u>+</u>	0.0014	ao	4.5933									
Во	4.5899 <u>+</u>	0.0014	bo	4.5933									
Со	2.9568 <u>+</u>	0.0024	со	2.9592									
Volume	62.292 <u>+</u>	0.5	volume										

Table 6.2 X-ray diffraction data of rutile from Geratiyon ki Dhani area

Table 6.3 X-ray diffraction data of davidite from Geratiyon ki Dhani area

Mineral Name: Davidite												
		XCW-4832		ICDD No 42-5	76							
Sl.No	hkl	d (in Angstroem)	I/I0	d (in Angstroem)	I/I0							
1	202	4.1326	22	4.1270	20							
2	006	3.4812	4	3.4850	5							
3	204	3.4056	75	3.407	80							
4	211	3.3496	10	3.3520	11							
5	205	3.0566	56	3.061	60							
6	300	3.0000	37	2.995	40							
7	116	2.8885	100	2.893	100							
8	214	2.8474	58	2.848	60							
9	303	2.7524	12	2.752	13							
10	125	2.6347	37	2.636	35							
11	220	2.5985	14	2.594	12							
12	131	2.4765	51	2.474	40							
13	312	2.4257	29	2.424	25							
14	134	2.2488	56	2.249	50							
15	315	2.1404	36	2.141	30							
16	404	2.0606	3	2.064	4							
Unit cell	param	eters										
Ao	10.38	327 <u>+</u> 0.0027	Ao	10.375								
Во	10.38	327 <u>+</u> 0.0027	Во	10.375								
Со	20.86	594 <u>+</u> 0.0079	Со	20.909								
Volume	1948	3.334	volume	1949.13								

	Mineral Name: Titanite													
		XCW-483	3		ICDD No 25	-177								
Sl.No	Hkl	d (in An	gstroem)	I/I0	d (in Angstroem)	I/I0								
1	011	4.9	191	15	4.95	11								
2	200	3.2	351	100	3.24	100								
3	002	2.9	889	58	2.996	30								
4	-202	2.8	356	5	2.843	8								
5	031	2.6	069	35	2.612	30								
6	220	2.5	877	28	2.593	30								
7	211	2.3	609	3	2.366	2								
8	131	2.2	814	10	2.286	10								
9	-311	2.2	653	11	2.267	11								
10	-231	2.2	284	3	2.23	4								
11	-113	2.1	105	5	2.108	5								
12	122	2.0	823	3	2.085	2								
13	140	2.0)61	12	2.064	13								
14	-322	1.9	778	3	1.980	2								
15	013	1.9	442	5	1.949	2								
16	231	1.8	518	2	1.876	2								
17	240	1.8	028	7	1.804	6								
18	-402	1.7	442	11	1.745	13								
19	222	1.7	044	9	1.706	8								
20	033	1.6	435	14	1.647	8								
21	-251, -342	1.5	573	4	1.558	7								
Unit cell	parameters													
Ao	7.04667 <u>+</u> 0.00	01	Ao	7.066										
Во	6.53964 <u>+</u> 0.00	01	Во	8.705										
Со	8.69432 <u>+</u> 0.00	01	Со	6.561										
В	113°7880'		В	113° 5	56'									
volume	366.62		Volume											

Table 6.4 X-ray	diffraction	data of	titanite	from	Geratiyon	ki Dhani	area

Table 6.5 X-ray diffraction data of magnetite from Geratiyon ki Dhani area

	Mineral Name: Magnetite												
		XCW-4833		ICDD No 19-629									
Sl.No	hkl	d (in Angstroem)	I/I0	d (in Angstroem)	I/I0								
1	220	2.9668	34	2.967	30								
2	311	2.5322	100	2.532	100								
3	400	2.0991	26	2.0993	20								
4	511	1.6159	27	1.6158	30								
5	440	1.4843	41	1.4845	40								
Unit cell	parameter	S											
ao	ao 8.3967												



Figure 6.1 X-ray powder diffractogram of chlorite, anatase, brannerite and rutile from mineralised albitite of Geratiyon ki Dhani area



Figure 6.2 X-ray powder diffractogram of Xenotime, Anatase, quartz low, rutile and hematite from mineralised albitite of Geratiyon ki Dhani area



Figure 6.3 X-ray powder diffractogram of Albitite and quartz low from mineralised albitite of Geratiyon ki Dhani area

In biotite bearing albitite, davidite, allanite and monazite are the radioactive minerals identified. In petromineralogical studies monazite and davidite were identified as radioactive minerals. Magnetite, hematite, anatase and titanite are other ore minerals (Figure 6.4).



Figure 6.4 X-ray powder diffractogram of biotite, anatase, rutile and dolomite from mineralised biotite bearing albitite of Geratiyon ki Dhani area.

Albite, biotite, riebeckite, quartz, calcite, dolomite and plagioclase are the other rock forming minerals identified which is confirmed by petromineralogical studies. Biotite which is present in the rock is potash bearing Fe, Mg biotite. Calcite and dolomite are present in the rock as vein and fracture filling. Davidite is La rich which is also revealed in chemistry of the rock (Figure 6.5).



Figure 6.5. X-ray powder diffractogram of Davidite, albite, rutile and hematite from mineralised biotite bearing albitite of Geratiyon ki Dhani area

One albitite grab sample from the Geratiyon ki Dhani containing yellow secondary uranium mineral is analysed in the x ray diffraction laboratory (Figure 6.6). Uranophane (Ca $(UO_2))_2$ (SiO₃OH)₂ 5.H₂O) is identified as the secondary uranium mineral. Other ore minerals identified are rutile, magnetite, hematite and barite (Figure 6.7). Albite, quartz, calcite, dolomite, biotite and plagioclase are the rock forming minerals identified in biotite bearing albitite which is hosting secondary uranium mineral.



Figure 6.6 X-ray powder diffractogram of Biotite, uranophane, calcite and dolomite from mineralised biotite bearing albitite of Geratiyon ki Dhani area



Figure 6.7 X-ray powder diffractogram of uranophane, baryte and dolomite from mineralised biotite bearing albitite of Geratiyon ki Dhani area

CHAPTER 7 GEOCHEMICAL STUDIES

The mineralogical and chemical composition of meta-sedimentary and albitite rock are controlled by various factors, including the composition of their protolith, grade of metamorphism, types and degree of alteration.

Geochemistry of Albitite, biotite bearing albitite, quartzite, quartz-biotite schist, calcsilicate, granite and amphibolite rocks of the Kushalgarh Formation of Ajabgarh Group from the study area has been examined and attempts have been made to interpret various geochemical and geological aspects including source rocks, degree and grade of metamorphism and their geotectonic environment. Detailed geochemistry of each rock unit is given below.

Albitite:

Major, minor and trace element analysis of mineralised Albitite (n=10) is given in Table 7.1. Silica (SiO₂) is the most abundant oxide with values ranging from 60.16-65.02 % with an average value of 63.06 %. TiO₂, Al₂O₃, Fe₂O₃^t, MgO, CaO and Na₂O have values ranging from 1.04-2.11 %, 17.21-19.19 %, 1.09-4.62 %, 0.82-2.60 %, 0.35-2.13 % and 7.98-9.95 % with average values of 1.36 %, 18.01 %, 2.72 %, 1.69 %, 1.05 % and 9.13 % respectively. K₂O, MnO and P₂O₅ have values ranging from 0.08-1.06 %, 0.01-0.02 % and 0.04-0.32 % with average values of 0.56 %, 0.012 % and 0.18 % respectively. The sample analysed show Cr, Ni, Ga, Rb, Sr, Ba, Y, Zr, Nb and Ce in the range of 98 - 428 ppm, 28 - 70 ppm, 19-24 ppm, 13-129 ppm, 11-222 ppm, 149-485 ppm, 19-304 ppm, 124-220 ppm, 31-114 ppm, 139-1154 with average values of 294.60, 48.20, 21.40, 91.20, 41.70, 296.90, 99.10, 177.60, 65.60, 341.60 ppm respectively. Cu is below detection limit (<10pmm) whereas Zn and Pb values range from 16-33, and 42-246 ppm with average value of 20.20 and 137.10

ppm respectively. U and Th values range from 147-942 ppm and 29-311 ppm with average value of 535.40 and 140.40 ppm respectively.

sample	XA-1	XA-2	XA-3	XA-4	XA-5	XA-6	XA-7	XA-8	XA-9	XA-10
number										
SiO ₂	63.19	64.10	60.87	63.82	64.73	62.44	62.21	65.02	60.16	64.08
TiO ₂	1.25	1.27	1.18	1.65	2.11	1.63	1.32	1.06	1.14	1.04
Al ₂ O ₃	17.59	18.16	17.99	18.40	17.21	17.26	19.19	18.38	18.38	17.54
Fe ₂ O ₃ (T)	3.17	1.37	4.62	2.51	1.09	2.62	2.52	2.66	3.89	2.75
MgO	2.60	2.52	1.81	0.82	1.07	1.31	2.34	1.70	1.75	1.02
MnO	<0.1	<0.1	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01
CaO	0.54	0.35	1.02	1.01	2.13	1.29	1.10	0.71	1.38	1.04
Na₂O	8.88	9.01	9.09	9.95	9.93	9.30	7.98	8.23	9.41	9.53
K ₂ O	0.64	0.68	0.35	<0.01	<0.01	0.19	0.77	1.06	0.72	0.08
P ₂ O ₅	0.05	0.04	<0.01	<0.01	<0.01	<0.01	0.26	0.27	0.19	0.32
Total	97.91	97.5	96.94	98.17	98.29	96.05	97.7	99.11	96.99	97.41
Cr	338	309	216	271	98	165	404	428	361	356
Ni	54	59	49	30	28	43	66	70	47	36
Cu	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zn	20	16	18	33	17	17	18	20	21	22
Ga	20	23	21	22	19	19	23	24	21	22
Rb	15	13	92	106	116	113	129	127	106	95
Sr	18	21	11	42	20	222	20	19	18	26
Y	19	45	20	304	245	126	41	27	27	137
Zr	124	210	143	220	197	175	206	163	155	183
Nb	31	60	31	112	109	114	62	39	36	62
Ce	204	209	145	1154	449	261	158	139	162	535
Ва	303	420	172	451	149	247	349	485	218	175
Pb	105	180	80	246	42	68	233	188	102	127
Th*	84	159	311	165	29	67	118	110	118	143
U*	147	174	509	804	942	686	633	504	431	524

Table 7.1 Abundance of major, minor (in %) and trace elements (in ppm) in mineralised albitite of Geratiyon ki Dhani area (n=10)

Sample	XZ/1	XZ/2	XZ/3	XZ/4	XZ/5	XZ/6
No.			-			
SiO ₂	64.41	67.56	64.81	66.1	67.81	62.3
TiO ₂	0.96	0.47	1.32	0.85	0.45	1.11
Al ₂ O ₃	16.42	16.42	16.28	16	16.39	18.9
Fe ₂ O ₃ (T)	2.84	1.14	3.23	3.46	1.18	5.11
MgO	0.03	0.59	1.06	0.20	0.69	0.01
MnO	0.01	0.01	0.01	0.01	0.01	0.01
CaO	2.11	0.77	1.09	0.33	0.67	0.88
Na₂O	9.74	10	9.57	10.62	10.27	10.27
K₂O	0.01	0.01	0.16	0.01	0.01	0.01
P ₂ O ₅	0.01	0.01	0.01	0.01	0.01	0.01
Total	96.52	96.96	97.53	97.57	97.42	98.59
Cr	116	127	110	120	115	148
Ni	30	25	31	26	31	23
Cu	<10	<10	<10	16	<10	<10
Zn	16	14	17	20	15	14
Ga	23	21	23	23	22	17
Rb	13	17	33	12	23	12
Sr	12	14	10	14	18	10
Y	10	10	50	10	35	11
Zr	202	262	234	266	231	149
Nb	17	19	26	10	24	71
Се	61	97	889	32	103	11
Ва	65	33	145	10	10	10
Pb	21	13	10	10	14	25
Th*	10	34	73	58	42	11
U*	21	38	59	85	60	20

Table 7.2 Abundance of major, minor (in %) and trace elements (in ppm) in Non-mineralised albitite of Geratiyon ki Dhani area (n=6)

The major, minor and trace element analysis result of non-mineralised Albitite (n=6) are given in Table 7.2. Silica (SiO₂) is the most abundant oxide with values ranging from 62.30-67.81 % with an average value of 65.50 %. TiO₂, Al₂O₃, Fe₂O₃t, MgO, CaO and Na₂O have values ranging from 0.45-1.32 %, 16.00-18.90 %, 1.14-5.11 %, 0.01-1.06 %, 0.33-2.11 % and 9.57-10.62 % with average values of 0.86 %, 16.74 %, 2.83 %, 0.43 %, 0.98 % and 10.08 % respectively. K₂O, MnO and P₂O₅ have values ranging from 0.01-0.16 %, 0.01 %

and 0.01 with average values of 0.04 %, 0.01 % and 0.01 % respectively. Content of Cr, Ni, Ga, Rb, Sr, Ba, Y, Zr, Nb and Ce is ranging from 110-148 ppm, 23 - 31 ppm, 17-23 ppm, 12-33 ppm, 10-18 ppm, 10-145 ppm, 10-50 ppm, 149-266 ppm, 10-71 ppm, 11-889 with average values of 122.67, 27.67, 21.50, 18.33, 13, 45.50, 21, 2224, 27.83 and 198.83 ppm respectively. Cu, Zn and Pb values ranges from <10-16, 14-20, and 10-25 ppm with average value of 11, 16 and 38 ppm respectively.

		Minerali	sed albit	ite			Non m	ineralise	d albitite	
Major oxide	Ra	nge	Mean	Std	cov	Ra	inge	Mean	Std	COV
(wt %)	Max	Min		Dev		Max	Min		Dev	
SiO ₂	65.02	60.16	63.06	1.62	2.57	67.81	62.3	65.5	2.04	3.11
TiO ₂	2.11	1.04	1.36	0.34	25.00	1.32	0.45	0.86	0.33	38.37
Al ₂ O ₃	19.19	17.21	18.01	0.62	3.44	18.9	16	16.74	1.09	6.51
Fe ₂ O ₃ ^t	4.62	1.09	2.72	1.04	38.24	5.11	1.14	2.83	1.47	51.94
MgO	2.6	0.82	1.69	0.64	37.87	1.06	0.01	0.43	0.4	93.02
MnO	0.02	0.01	0.01	0	0.00	0.01	0.01	0.01	0	0.00
CaO	2.13	0.35	1.05	0.49	46.67	2.11	0.33	0.98	0.63	64.29
Na ₂ O	9.95	7.98	9.13	0.65	7.12	10.62	9.57	10.08	0.38	3.77
K ₂ O	1.06	0.08	0.56	0.33	58.93	0.16	0.01	0.04	0.06	150.00
P ₂ O ₅	0.32	0.04	0.18	0.12	66.67	0.01	0.01	0.01	0	0.00
	Trace	element	in ppm			Т	race elen	nent in p	pm	
Cr	428	98	294.6	106.57	36.17	148	110	122.67	13.81	11.26
Ni	70	28	48.2	14.37	29.81	31	23	27.67	3.2	11.56
Cu	<10	<10	<10	<10	<10	16	<10.00	11	2.45	22.27
Zn	33	16	20.2	4.89	24.21	20	14	16	2.25	14.06
Ga	24	19	21.4	1.71	7.99	23	17	21.5	2.33	10.84
Rb	129	13	91.2	42.39	46.48	33	12	18.33	8.13	44.35
Sr	222	11	41.7	63.86	153.14	18	10	13	2.97	22.85
Y	304	19	99.1	102.63	103.56	50	10	21	16.42	78.19
Zr	220	124	177.6	31.38	17.67	266	149	224	43.12	19.25
Nb	114	31	65.6	34.02	51.86	71	10	27.83	22.37	80.38
Се	1154	139	341.6	315.81	92.45	889	11	198.83	343.44	172.73
Ва	485	149	296.9	123.87	41.72	145	10	45.5	52.62	115.65
Pb	246	42	137.1	70.66	51.54	25	10	15.5	5.85	37.74
Th*	311	29	140.4	75.78	53.97	73 10		38	23.98	63.11
U*	942	147	535.4	250.3	46.75	85	20	47.17	24.49	51.92

Table 7.3 Descriptive statistics of major, minor (in %) and trace elements (in ppm) of Mineralised albitite and Non mineralised albitite

U and Th values range from 20-85 ppm and 10-73 ppm with average value of 47.17 and 38 ppm respectively. Statistical evaluation and correlation matrix for major, minor and trace elements are given in table 7.3, 7.4 and 7.5 respectively. Bar diagram (Figure.7.1a&b and 7.2 a&b) shows the distribution of mean concentration of major, minor and trace elements for mineralised and non-mineralised albitite.

Variation diagrams have been conventionally used to simplify geochemical data in order to identify the relationships between the individual elements in the rock. Figure. 7.3 a-f shows the relationships between various major, minor and trace elements in mineralised albitite. SiO₂ shows positive correlation with Na₂O, it reflects that bulk of Na and Si is primarily contributed by albitite. Na₂O shows strong negative correlation with K₂O indicating depletion of K-feldspar on albite enrichment. CaO has positive correlation with TiO₂ whereas Fe₂O₃ shows negative correlation reflecting the presence of heavies i.e. sphene. U shows strong positive correlation with TiO₂, CaO, Y and Ce, indicating presence of uranium minerals such as brannerite and davidite. The co-variation of U with CaO and TiO₂ also reflects the association of uranium bearing minerals such as davidite and brannerite with calcite and rutile veins, which is also evident from petrographic studies. A strong positive correlation of Pb with U suggests its radiogenic origin.

	SiO ₂	TiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	Na ₂ O	K_2O	P_2O_5	Cr	Ni	Rb	Sr	Y	Nb	Се	Pb	Th	U
SiO ₂	1.00																			
TiO ₂	0.28	1.00																		
Al ₂ O ₃	-0.25	-0.40	1.00																	
Fe ₂ O ₃	-0.77	-0.58	0.18	1.00																
MgO	-0.23	-0.44	0.36	0.11	1.00															
MnO	0.40	0.35	-0.10	-0.26	-0.50	1.00														
CaO	-0.11	0.68	-0.32	-0.16	-0.60	0.58	1.00													
Na ₂ O	0.60	0.54	-0.59	-0.15	-0.70	0.03	0.49	1.00												
K ₂ O	-0.12	-0.62	0.58	0.18	0.74	-0.03	-0.53	-0.84	1.00											
P_2O_5	0.07	-0.63	0.42	0.11	0.05	0.19	-0.13	-0.49	0.45	1.00										
Cr	-0.02	-0.81	0.68	0.24	0.44	-0.19	-0.61	-0.66	0.74	0.78	1.00									
Ni	-0.07	-0.61	0.58	0.15	0.78	-0.10	-0.62	-0.95	0.94	0.41	0.69	1.00								
Rb	-0.09	0.21	0.22	0.09	-0.60	0.70	0.63	-0.02	-0.14	0.34	-0.06	-0.14	1.00							
Sr	-0.08	0.31	-0.41	-0.08	-0.28	-0.07	0.16	0.15	-0.30	-0.30	-0.42	-0.19	0.20	1.00						
Y	0.43	0.75	-0.30	-0.48	-0.80	0.30	0.51	0.74	-0.81	-0.34	-0.54	-0.82	0.30	0.19	1.00					
Nb	0.36	0.83	-0.33	-0.60	-0.65	0.23	0.52	0.55	-0.71	-0.41	-0.64	-0.64	0.33	0.57	0.86	1.00				
Ce	0.35	0.42	-0.07	-0.25	-0.69	0.03	0.16	0.66	-0.69	-0.23	-0.23	-0.70	0.15	0.03	0.89	0.64	1.00			
Pb	0.23	-0.27	0.80	-0.16	0.14	-0.15	-0.51	-0.40	0.33	0.34	0.64	0.38	0.06	-0.27	0.07	-0.01	0.35	1.00		
Th	-0.40	-0.52	0.21	0.68	0.30	-0.49	-0.53	-0.12	0.08	-0.16	0.16	0.17	-0.38	-0.36	-0.37	-0.57	-0.06	0.11	1.00	
U	0.16	0.71	-0.11	-0.26	-0.79	0.64	0.81	0.41	-0.60	-0.12	-0.53	-0.58	0.80	0.26	0.76	0.75	0.51	-0.06	-0.45	1.00

Table 7.4 Correlation of geochemical data of major, minor (in %) and trace elements (in ppm) of mineralised albitite

	SiO ₂	TiO ₂	Al_2O_3	Fe_2O_3	MgO	CaO	Na ₂ O	K_2O	Cr	Ni	Rb	Sr	Y	Zr	Ce	Pb	Th	U
SiO ₂	1.00																	
TiO ₂	-0.82	1.00																
Al ₂ O ₃	-0.73	0.31	1.00															
Fe ₂ O ₃	-0.92	0.80	0.67	1.00														
MgO	0.49	-0.03	-0.46	-0.49	1.00													
CaO	-0.40	0.33	0.01	0.06	-0.24	1.00												
Na ₂ O	0.18	-0.41	0.15	0.13	-0.44	-0.72	1.00											
K ₂ O	-0.16	0.65	-0.21	0.13	0.74	0.09	-0.64	1.00										
Cr	-0.53	0.06	0.90	0.55	-0.58	-0.20	0.39	-0.45	1.00									
Ni	0.31	0.05	-0.62	-0.44	0.55	0.39	-0.52	0.47	-0.89	1.00								
Rb	0.23	0.23	-0.34	-0.29	0.94	-0.03	-0.58	0.86	-0.59	0.67	1.00							
Sr	0.85	-0.89	-0.47	-0.76	0.16	-0.39	0.46	-0.48	-0.33	0.27	-0.03	1.00						
Y	0.15	0.28	-0.27	-0.17	0.86	-0.06	-0.46	0.82	-0.57	0.71	0.97	0.01	1.00					
Zr	0.83	-0.46	-0.88	-0.66	0.49	-0.40	0.11	0.11	-0.63	0.25	0.25	0.50	0.13	1.00				
Ce	-0.07	0.57	-0.27	0.03	0.79	0.09	-0.67	0.99	-0.51	0.53	0.90	-0.41	0.85	0.17	1.00			
Pb	-0.69	0.19	0.81	0.49	-0.71	0.49	-0.03	-0.44	0.69	-0.37	-0.54	-0.35	-0.47	-0.91	-0.48	1.00		
Th	0.40	0.14	-0.60	-0.19	0.76	-0.50	-0.03	0.68	-0.61	0.39	0.70	0.10	0.68	0.68	0.70	-0.91	1.00	
U	0.53	-0.14	-0.62	-0.21	0.42	-0.67	0.43	0.23	-0.52	0.25	0.30	0.43	0.35	0.73	0.24	-0.86	0.85	1

Table 7.5 Correlation of geochemical data of major, minor (in %) and trace elements (in ppm) of non-mineralised albitite

Geochemical characteristics of both mineralised and non-mineralised albitite shows their higher Al₂O₃, and Na₂O (and usually SiO₂) and low K₂O. These characteristics indicate that the source is soda rich in nature with very less or absence of K₂O. Na₂O/K₂O ratio varies between 7.76-1990 in mineralised and 5.60-1432 in non-mineralised albitite. CIPW norm calculation of both rocks show that albitite is composed of predominantly albite (upto 85 %) along with K-feldspar, quartz and Ca- plagioclase. The rock is mostly mono-minerallic in nature with 70-85 % albite, which is also evident from petrographic studies and XRD results. CIPW norm of mineralised albitite (table 7.6) shows rock forming minerals as albite, quartz, k-feldspar and anorthite with average content of 77.03 4.2, 2.6 and 3.5 % respectively. Whereas non-mineralised albitite (table 7.7) constitutes, albite, quartz, k-feldspar and anorthite with average content of 83.53, 5.3, 0.2 and 1.0 % respectively.



Figure 7.1 Mean concentration of a) major minor (wt %) and b) trace elements in mineralised albitite.

	Alb-1	Alb-2	Alb-3	Alb-4	Alb-5	Alb-6	Alb-7	Alb-8	Alb-9	Alb-10
Q	4.20	4.70	1.79	2.58	2.59	3.26	7.74	9.81	0.00	5.50
С	1.43	2.06	0.82	0.21	0.00	0.00	3.85	3.05	0.07	0.65
Or	3.78	4.02	2.07	0.00	0.00	1.12	4.55	6.26	4.26	0.47
Ab	75.14	76.24	76.92	84.19	84.03	78.69	67.53	69.64	77.34	80.64
An	2.35	1.48	5.03	4.98	2.39	4.79	3.76	1.76	5.61	3.07
II	0.00	0.00	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02
Ru	1.25	1.27	1.17	1.64	0.00	1.17	1.31	1.04	1.13	1.03
Ар	0.12	0.10	0.01	0.01	0.01	0.01	0.62	0.64	0.45	0.76

Table 7.6 QAPF calculation of mineralised albitite



Figure 7.2 Mean concentration of a) major, minor (in wt %) and b) trace elements in nonmineralised albitite

	ALB-1	ALB-2	ALB-3	ALB-4	ALB-5	ALB-6
Q	5.206	7.795	5.592	8.025	7.83	0.66
Or	0.059	0.059	0.946	0.059	0.059	0.059
Ab	82.417	84.403	80.979	82.242	84.248	86.902
An	1.053	0.000	0.991	0.000	0.000	4.301
Tn	2.329	1.126	3.066	1.108	1.077	0.000
Ru	0.000	0.000	0.06	0.388	0.000	1.099
Ар	0.024	0.024	0.024	0.024	0.024	0.024

Table 7.7 QAPF calculation of non-mineralised albitite



Figure 7.3(a-f) Variation diagrams between major oxide (in %) and minor elements (ppm) for mineralised albitite


Figure 7.4 (a-h) Mean concentration of major oxides (in %) and minor and trace elements (ppm) in mineralized and non-mineralized albitite.

Mean concentrations of major oxides (wt%) and trace elements (ppm) of mineralised(n=10) and non-mineralised (n=6) albitites are shown in bar diagrams (Figure 7.4 a-h). High concentration of SiO₂, Al₂O₃ and Na₂O reflect that non mineralised rock is

relatively enriched in albitite, which also reflect in norm calculation. Higher concentration of TiO₂ in mineralised rock shows rutile. Higher concentration of Ce, Ti and Y with U in mineralised rock shows radioactive minerals brannerite and Davidite. Pb content of U mineralized samples are higher than non-mineralized samples indicating its radiogenic nature.

As XRF analysis is semi-quantitative for REE, U and Th therefore selected samples (n=9) of radioactive albitite have been analysed by wet chemical methods (Table 7.8). La, Ce, Pr Nd ranges from 331-1052 ppm, 276-967 ppm, 9-50 ppm and 39-175 ppm with average values 532.89, 525, 23.44 and 84.89 ppm in albitite. Sm, Eu, Gd, Tb, Dy ranges from 6-39 ppm, 1-5 ppm,8-35 ppm,1-7 ppm, 9-52 ppm. Ho, Er, Tm, Yb and Lu ranges from 4-14 ppm,15-49 ppm, 1-8 ppm, 11-59 ppm and 1-8 ppm respectively. Y and Sc ranges from 89-334 ppm and 16-45 ppm with average values 194.89 ppm and 28 ppm respectively. U and Th values in mineralized samples ranges from 212-1060 ppm and <10-122 ppm with average values of 509.65 ppm and 45.75 ppm. Whereas Mo and Cu values are <10 ppm and <5 ppm respectively, which indicates absence or negligible sulphides in the rock. FeO and Fe₂O₃ ranges from 0.46-2.75 % and 0.15-1.4 5 % with average values of 1.27 % and 0.94 %.

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Тb	Dy	Но	Er	Tm	Yb	Lu	Y	Sc
ALB-1	431	430	17	70	11	1	13	2	24	9	27	5	39	5	168	21
ALB-2	690	897	50	115	36	5	19	3	18	4	15	3	12	4	89	16
ALB-3	355	388	18	69	16	2	13	4	35	11	38	5	32	3	303	28
ALB-4	513	362	12	39	7	1	11	3	26	6	27	4	33	5	167	29
ALB-5	373	319	9	39	6	1	8	2	17	5	19	2	25	4	123	37
ALB-6	331	276	10	44	7	1	8	3	15	6	21	2	11	3	116	28
ALB-7	336	417	21	100	21	2	20	3	27	10	19	3	44	3	150	16
ALB-8	1052	967	38	175	36	4	35	7	49	11	44	5	44	7	334	45
ALB-9	715	669	36	113	16	4	24	6	52	14	49	8	59	8	304	32

Table 7.8 Concentration of REE in mineralised albitite



Figure 7.5 (a) Chondrite normalized rare earth element patterns for albitite Boynton (1984)(b) Average Chondrite normalized rare earth element patterns for albitite

The sample analysed 736 to2474 ppm REE (avg. 1314 ppm), with LREE ranging from 669 ppm to 2272 ppm (avg. 1186 ppm) and HREE ranging from 64 to 220 ppm (Avg. 127 ppm). Chondrite normalized plot for albitite (Figure 7.5a & b) shows steeply sloping LREE and flat HREE pattern with strong negative Eu anomaly. The depletion of REEs has

been attributed to various processes including magmatic differentiation (Cuney and Friedrich, 1987), hydrothermal leaching (Cathelineau, 1987) and or a combination of both. The enrichment of LREE may be related to the presence of Davidite, Brannerite and Monazite.

The negative Eu anomaly, suggesting removal of plagioclase or its absence during fractional crystallization (Neiva, 1992; Chappel et al., 1987), flat HREE profiles indicate absence of garnet and hornblende in the source region (Chaudhri et al., 2003).

In the Ab-Or-An triangular plot of O'connor (1965) for feldspar, it is observed that mineralised and non-mineralised samples are rich in albitte and fall in trondhjemite filed of plot (Figure.7.6a). Majority of the mineralised albitite samples plot in peraluminous field except some samples plot in metaluminous, whereas non-mineralised albitite plot in peralkaline in A/CNK vs A/NK plot (Shand, 1943) (Figure.7.6b).



Figure 7.6 a) Ab-An-Or ternary diagram, feldspar triangle O'connor (1965). b) A/CNK vs A/NK plot (Shand, 1943)

SiO₂ vs K₂O plot for plutonites (Peccerillo and Taylor, 1976) shows that magma was tholeiite series (Figure.7.6c). Batcher et al.(1985) used combination of element as R1 vs R2 plot was R1=4Si-11(Na+K)-2(Fe+Ti) and R2= 6Ca+2Mg+A1 (Figure.7.6d) to see tectonic setting of the rocks. Almost all the samples of mineralised albitite plot in late orogenic field,

while non-mineralised albitite falls in anorogenic to late orogrenic i. e. albitite rock is later orogeny after the all tectonic setting. In SiO_2 vs Na_2O+K_2O plot for plutonites (Middlemost 1994 all samples fall in quartz monzonite to synite field.



Figure 7.6 c) SiO₂ vs K₂O plot for plutonites (Peccerillo and Taylor, 1976). d) Batcher et al.(1985) used combination of element as R1 and R2

Biotite bearing albitite:

Whole rock analysis major, minor and trace elements of both mineralized (n=10) and non-mineralized (n=6) biotite bearing albitite samples has been carried out (Table 7.9 and 7.10). In mineralised biotite bearing albitite silica (SiO₂) is the most abundant oxide with values ranging from 58.13-63.40 % with an average of 60.68 %. TiO₂, Al₂O₃, Fe₂O₃^t, MgO, CaO and Na₂O have values ranging from 0.83-1.62 %, 11.03-17.14 %, 2.37-3.70 %, 2.00-3.70 %, 1.40-7.24 % and 6.05-8.70 % with average values of 1.14 %, 15.66 %, 2.98 %, 2.77 %, 4.37 % and 7.04 % respectively. K₂O, MnO and P₂O₅ have values ranging from 0.42-1.10 %, 0.01-0.04 % and 0.01-0.28 % with average values of 0.81 %, 0.02 % and 0.13 % respectively. Cr, Ni, Ga, Rb, Sr, Ba, Y, Zr, Nb and Ce content varies from 115-441 ppm, 17 - 54 ppm, 15-20 ppm,119-182 ppm, 16-31 ppm, 79-442 ppm,36-190 ppm, 118-170 ppm, 59-

100 ppm, 338-471 with average values of 258.30, 35.60, 17, 148, 24, 243.30, 128.20, 143.50, 74.90 and 396.30 ppm respectively. Cu, Zn and Pb values ranges from <10, 15-24, and 79-287 ppm with average value of <10, 18.33 and 49.50 ppm respectively. U and Th values range from 214-1014 ppm and 25-122 ppm with average value of 643.10 and 49.50 ppm respectively.

Sample	BA-1	BA-2	BA-3	BA-4	BA-5	BA-6	BA-7	BA-8	BA-9	BA-10
no										
SiO ₂	62.72	63.4	60.19	61.33	59.82	59.5	58.42	58.13	61.98	61.35
TiO ₂	1.23	1.03	1.07	1.17	1.62	1.62	1.06	0.94	0.83	0.86
Al ₂ O ₃	17.03	16.86	16.29	16.44	16.89	17.14	16.73	16.68	11.03	11.49
Fe ₂ O ₃ ^t	2.45	2.37	3.66	3.58	2.87	3.54	2.55	3.70	2.67	2.44
MgO	2.00	2.26	2.58	2.42	2.33	3.46	2.55	3.70	3.43	2.97
MnO	0.01	0.01	0.02	0.01	0.02	0.01	0.03	0.02	0.04	0.03
CaO	3.48	1.4	5.01	3.13	4.18	2.37	5.67	4.01	7.23	7.24
Na ₂ O	8.70	8.60	6.05	6.91	6.68	7.46	6.19	6.15	6.48	7.16
K ₂ O	0.52	0.72	0.98	1.06	0.71	0.95	0.42	1.10	<0.01	<0.01
P ₂ O ₅	0.1	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.28
Total	98.24	96.65	95.85	96.05	95.12	97.05	95.09	97.42	93.7	93.82
Cr	115	127	235	343	396	441	237	241	222	226
Ni	31	40	39	48	54	34	38	32	17	23
Cu	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zn	17	21	15	16	17	<10	<10	24	<10	<10
Ga	18	18	15	19	19	20	15	16	15	15
Rb	142	144	119	143	166	182	147	141	<10	<10
Sr	18	16	21	22	25	28	24	31	28	27
Y	100	36	102	118	159	190	124	107	167	179
Zr	170	163	118	121	147	147	138	139	145	147
Nb	76	59	66	59	100	96	72	66	70	85
Ce	471	338	356	368	445	450	344	434	391	366
Ва	262	204	223	230	442	360	296	230	79	107
Pb	229	92	79	170	232	287	120	81	111	129
Th*	27	25	31	66	70	122	44	40	35	35
U*	672	458	214	429	881	773	810	313	867	1014

Table 7.9 Major, minor (oxides %) and trace elements (in ppm) of mineralised biotite bearing albitite of Geratiyon ki Dhani area (n=10)

Sample no	AR-1	AB-2	AB-3	AR-4	AB-5	AB-6
Sample no						
SiO ₂	60.59	53.17	57.8	51.48	61.16	55.75
TiO ₂	0.40	0.34	1.03	0.33	0.16	0.70
Al ₂ O ₃	17.19	14.14	16.79	13.96	17.45	17.03
Fe ₂ O ₃ (T)	3.71	17.93	7.48	19.62	1.74	7.67
MgO	4.67	4.19	2.92	4.36	1.66	6.54
MnO	0.01	<0.01	0.01	<0.01	0.01	<0.01
CaO	1.04	1.01	0.73	0.84	4.51	0.85
Na₂O	7.42	7.08	8.07	6.92	8.19	5.77
K₂O	1.75	0.96	0.84	0.93	0.43	3.02
P ₂ O ₅	<0.01	0.04	<0.01	0.03	0.31	0.05
Total	96.78	98.86	95.67	98.47	95.62	97.4
Cr	110	80	123	92	83	140
Ni	53	86	42	80	36	78
Cu	<10	<10	<10	<10	<10	<10
Zn	17	22	14	23	15	17
Ga	18	12	16	12	18	17
Rb	195	51	94	52	66	203
Sr	<10	18	<10	16	17	11
Y	19	<10	<10	<10	21	15
Zr	223	47	117	47	256	127
Nb	10	<10	16	10	<10	11
Ce	<10	23	<10	18	<10	10
Ва	96	263	35	242	25	181
Pb	<10	50	19	71	<10	11
Th*	28	13	11	17	18	12
U*	<10	<10	15	<10	19	<10

Table 7.10 Major, minor (oxides %) and trace elements (in ppm) in non-mineralised biotite bearing albitite of Geratiyon ki Dhani area (n=6)

	Minera	lised Bio	otite albi	tite		Non mineralised Biotite albitite					
Major oxide	Rai	nge	Mean	Std	cov	Rar	ige	Mean	Std	cov	
(wt%)	Max	Min				Max	Min				
SiO2	63.40	58.13	60.68	1.80	2.97	61.16	51.48	56.66	3.58	6.32	
TiO2	1.62	0.83	1.14	0.28	24.56	1.03	0.16	0.49	0.29	59.18	
AI2O3	17.14	11.03	15.66	2.35	15.01	17.45	13.96	16.09	1.46	9.07	
Fe2O3 (T)	3.70	2.37	2.98	0.54	18.12	19.62	1.74	9.69	6.76	69.76	
MgO	3.70	2.00	2.77	0.59	21.30	6.54	1.66	4.06	1.51	37.19	
MnO	0.04	0.01	0.02	0.01	50.00	0.01	0.01	0.01	0	0.00	
CaO	7.24	1.40	4.37	1.98	45.31	4.51	0.73	1.5	1.35	90.00	
Na2O	8.70	6.05	7.04	0.96	13.64	8.19	5.77	7.24	0.81	11.19	
K2O	1.10	0.42	0.81	0.25	30.86	3.02	0.43	1.32	0.85	64.39	
P2O5	0.28 0.01 0.13		0.11	84.62	0.31	0.01	0.08	0.11	137.50		
-	Trace ele	ement in	n ppm			Tra	ce eleme	ent in ppr	n		
Cr	441	115	258.3	109.1	42.24	140	80	104.67	21.8	20.83	
Ni	54	17	35.6	11.62	32.64	86	36	62.5	19.63	31.41	
cu	<10	<10	<10	<10	<10	10	10	10	0	0.00	
Zn	24	15	18.33	3.37	18.39	23	14	18	3.37	18.72	
Ga	20	15	17	1.94	11.41	18	12	15.5	2.57	16.58	
Rb	182	119	148	20.1	13.58	203	51	110.17	64.43	58.48	
Sr	31	16	24	4.94	20.58	18	10	13.67	3.4	24.87	
Y	190	36	128.2	49.35	38.49	21	10	14.17	4.52	31.90	
Zr	170	118	143.5	16.83	11.73	256	47	136.17	79.85	58.64	
Nb	100	59	74.9	14.55	19.43	16	10	11.17	2.19	19.61	
Ce	471	338	396.3	48.61	12.27	23	10	13.5	5.16	38.22	
Ва	442	79	243.3	114.52	47.07	263	25	140.33	94.34	67.23	
Pb	287	79	153	74.02	48.38	71	10	28.5	23.63	82.91	
Th*	122	25	49.5	32.37	65.39	28	11	16.5	5.74	34.79	
U*	1014	214	643.1	275.19	42.79	19	10	12.33	3.5	28.39	

Table 7.11 Descriptive statistics of major, minor (oxides %) and trace (in ppm) elements inMineralised and Non mineralised biotite bearing albitite

Major oxide analysis of non-mineralized rock (Table 7.10) revealed that silica (SiO₂) is the most abundant oxide with values ranging from 51.48-61.16 % with an average value of 56.66 %. TiO₂, Al₂O₃, Fe₂O₃^t, MgO, CaO and Na₂O have values ranging from 0.16-1.03 %, 13.96-17.45 %, 1.74-19.62 %, 1.66-6.54 %, 0.73-4.51 % and 5.77-8.19 % with average values of 0.49 %, 16.09 %, 9.69 %, 4.06 %, 1.50 % and 7.24 % respectively. K₂O, MnO and P₂O₅ have values ranging from 0.43-3.02 %, 0.01-0.31 % and <0.01 % with average values of 1.32 %, 0.08 % and <0.01 % respectively. Cr, Ni, Ga, Rb, Sr, Ba, Y, Zr, Nb and Ce revealed their values ranging from 115-441 ppm, 17 - 54 ppm, 15-20 ppm,119-182 ppm, 16-31 ppm, 79-442 ppm,36-190 ppm, 118-170 ppm, 59-100 ppm, 338-471 with average values of 258.30, 35.60, 17, 148, 24, 243.30, 128.20, 143.50, 74.90 and 396.30 ppm respectively. Cu is below detection limit whereas Zn and Pb values ranges from 15-24, and 79-287 ppm with average value of 18.33 and 49.50 ppm respectively. U and Th values range from 214-1014 ppm and 25-122 ppm with average value of 643.10 and 49.50 ppm respectively.

Variation diagrams have been conventionally used to simplify geochemical data in order to identify the relationships between the individual elements in the rock. These plots (Figure. 7.9 a-h) show relationship between various major, minor and trace elements in mineralised biotite bearing albitite. SiO₂ shows strong positive correlation with Na₂O and Al₂O₃ shows positive correlation with K₂O and negative correlation with CaO. It indicates that bulk of Si, Na, Al, K is primarily contributed by albitite and biotite. CaO has negative correlation with TiO₂ indicating absence of sphene. Positive correlation between Rb&K₂O and Zr &TiO₂ are due to their geochemical affinity (Winter, 2008). U shows positive correlation with TiO₂, CaO and Ce, Y which reflect presence of radioactive minerals Branneritte and Davidite respectively. U shows positive correlation with CaO while negative correlation with K₂O and Na₂O indicating uranium mineralisation associated with calcitisation.

	SiO ₂	TiO2	Al ₂ O ₃	<i>Fe</i> ₂ <i>O</i> ₃	MgO	MnO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Rb	Sr	Ŷ	Zr	Nb	Се	Pb	Th	U
SiO ₂	1.00																		
TiO ₂	-0.21	1.00																	
AI_2O_3	-0.28	0.61	1.00																
Fe ₂ O ₃	-0.54	0.24	0.34	1.00															
MgO	-0.47	-0.22	-0.39	0.42	1.00														
MnO	-0.19	-0.55	-0.78	-0.30	0.40	1.00													
CaO	-0.16	-0.53	-0.80	-0.24	0.30	0.92	1.00												
Na₂O	0.74	0.19	0.19	-0.50	-0.47	-0.59	-0.56	1.00											
K ₂ O	-0.35	0.44	0.80	0.79	-0.02	-0.73	-0.73	-0.09	1.00										
P_2O_5	0.26	-0.31	-0.55	-0.44	-0.03	0.22	0.46	0.24	-0.58	1.00									
Rb	-0.33	0.72	0.98	0.37	-0.30	-0.76	-0.81	0.17	0.79	-0.59	1.00								
Sr	-0.66	-0.05	-0.38	0.38	0.88	0.51	0.47	-0.63	-0.10	0.07	-0.27	1.00							
Y	-0.34	0.27	-0.47	0.11	0.51	0.44	0.52	-0.35	-0.36	0.31	-0.32	0.73	1.00						
Zr	0.49	0.11	0.01	-0.71	-0.21	-0.17	-0.25	0.80	-0.38	0.26	0.02	-0.28	-0.14	1.00					
Nb	-0.28	0.68	-0.02	-0.09	0.12	0.05	0.11	0.02	-0.18	0.25	0.12	0.38	0.73	0.26	1.00				
Ce	-0.15	0.57	0.25	0.18	0.16	-0.29	-0.21	0.22	0.18	-0.04	0.32	0.29	0.35	0.40	0.58	1.00			
Pb	0.00	0.86	0.31	0.03	-0.14	-0.44	-0.35	0.38	0.12	0.01	0.44	0.03	0.48	0.32	0.73	0.70	1.00		
Th	-0.40	0.77	0.30	0.46	0.31	-0.32	-0.34	-0.07	0.37	-0.26	0.47	0.39	0.58	-0.15	0.61	0.41	0.75	1.00	
U	0.06	0.15	-0.50	-0.62	0.06	0.48	0.48	0.11	-0.77	0.48	-0.39	0.30	0.70	0.42	0.68	0.18	0.44	0.22	1.00

Table 7.12. Correlation of geochemical data of major, minor (oxides %) and trace elements (in ppm) of mineralised biotite bearing albitite

	SiO ₂	TiO ₂	AI_2O_3	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Rb	Sr	Y	Zr	Nb	Се	Pb	Th*	U*
SiO ₂	1.00																	
TiO ₂	-0.01	1.00																
AI_2O_3	0.90	0.26	1.00															
Fe ₂ O ₃	-0.97	-0.11	-0.98	1.00														
MgO	-0.43	0.22	-0.15	0.28	1.00													
CaO	0.57	-0.57	0.41	-0.52	-0.69	1.00												
Na₂O	0.55	-0.08	0.24	-0.37	-0.94	0.52	1.00											
K ₂ O	-0.06	0.32	0.28	-0.14	0.90	-0.46	-0.84	1.00										
P_2O_5	0.49	-0.54	0.37	-0.47	-0.63	0.99	0.42	-0.40	1.00									
Rb	0.39	0.32	0.62	-0.53	0.65	-0.29	-0.48	0.86	-0.30	1.00								
Sr	-0.39	-0.74	-0.60	0.49	-0.37	0.46	0.12	-0.56	0.49	-0.79	1.00							
Y	0.83	-0.44	0.74	-0.82	-0.21	0.70	0.21	0.11	0.65	0.42	-0.10	1.00						
Zr	0.96	-0.23	0.86	-0.94	-0.38	0.69	0.44	-0.02	0.61	0.39	-0.26	0.95	1.00					
Nb	0.13	0.90	0.27	-0.17	-0.22	-0.30	0.33	-0.11	-0.30	0.00	-0.55	-0.41	-0.12	1.00				
Ce	-0.78	-0.37	-0.94	0.89	0.09	-0.28	-0.19	-0.30	-0.25	-0.62	0.71	-0.63	-0.76	-0.36	1.00			
Pb	-0.88	-0.27	-0.97	0.95	0.08	-0.35	-0.18	-0.34	-0.32	-0.65	0.58	-0.71	-0.81	-0.24	0.85	1.00		
Th*	0.48	-0.50	0.25	-0.36	-0.03	0.17	0.21	-0.01	0.05	0.34	-0.16	0.63	0.58	-0.50	-0.23	-0.20	1.00	
U*	0.62	-0.05	0.51	-0.58	-0.86	0.82	0.75	-0.58	0.80	-0.35	0.16	0.43	0.59	0.30	-0.45	-0.43	-0.12	1.00

Table 7.13. Correlation of geochemical data of major, minor (oxides %) and trace elements (in ppm) of non-mineralised biotite bearing albitite





Figure 7.7 Mean concentration of a) major, minor (oxides %) in mineralised biotite bearing albitite b) major, minor (oxides %) in non mineralised biotite bearing albitite c) trace element (ppm) in mineralised biotite bearing albitite c) d) trace element in non mineralised biotite bearing albitite

Geochemical characteristics of both mineralised and non-mineralised biotite bearing albitite shows their high SiO₂, Al₂O₃, and Na₂O and low K₂O as they are mainly composed of albite. Na₂O / K₂O ratio varies between 6.10-1432 in mineralised biotite bearing albitite and 1.90-19.40 in non-mineralised biotite bearing albitite. CIPW norm calculation of both rock shows that rock samples of biotite bearing albitite composed of albite (upto 60 %) along with biotite, K-feldspar, quartz and plagioclase. CIPW norm of mineralised biotite bearing albitite (table 7.14) shows rock forming minerals as albite, quartz, k-feldspar and anorthite with average content of 59.40, 6.6, 3.8 and 9.3 % respectively. Whereas in non-mineralised albitite (table 7.15) albite, quartz, k-feldspar and anorthite with average content of 61.28, 1.28, 7.8and 5.1 % respectively.

Table 7.14. QAPF calculation of mineralised biotite bearing albitite

S. No	BA-1	BA-2	BA-3	BA-4	BA-5	BA-6	BA-7	BA-8	BA-9	BA-10
Q	2.29	4.62	8.93	7.81	7.28	2.52	7.35	5.18	11.23	8.77
Or	3.07	4.26	5.79	6.26	4.20	5.61	2.48	6.50	0.00	0.00
Ab	73.62	72.77	51.19	58.47	56.52	63.12	52.38	52.04	54.83	59.10
An	5.88	5.27	14.40	10.71	14.00	10.48	16.62	14.66	1.01	0.00
11	0.02	0.02	0.04	0.02	0.04	0.02	0.06	0.04	0.09	0.06
Tn	2.99	1.18	2.57	2.85	3.92	0.90	2.52	2.25	1.93	2.03
Ru	0.00	0.54	0.00	0.00	0.00	1.24	0.00	0.00	0.00	0.00
Ар	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.66

Table 7.15. QAPF calculation of non-mineralised biotite bearing albitite

S. No	AB-1	AB-2	AB-3	AB-4	AB-5	AB-6
Q	1.58	0.19	1.76	0.00	2.94	0.00
Or	10.34	5.67	4.96	5.50	2.54	17.85
Ab	62.79	59.91	68.29	58.56	69.30	48.82
An	5.09	3.97	3.56	3.97	9.58	3.89
II	0.02	0.02	0.02	0.02	0.02	0.02
Tn	0.00	0.55	0.00	0.00	0.37	0.00
Ru	0.39	0.10	1.02	0.32	0.00	0.69
Ар	0.02	0.10	0.02	0.07	0.73	0.12

Mean concentrations of major oxides (wt %) and trace elements (ppm) of mineralised (n=10) and non-mineralised (n=6) biotite albite shown in bar diagram (Figure 7.8. a-l). Concentration of SiO₂, Al₂O₃, CaO and TiO₂ are much more in mineralised lithounit indicating association of uranium mineralisation with rutile and calcite within albitite. High concentration of Fe₂O₃, MgO and K₂O reflect higher biotite content more in non-mineralised biotite bearing albitite. Higher concentration of TiO₂ in mineralised unit indicate presence of rutile. Higher concentration of Ce, Ti and Y with U in mineralised rock shows radioactive minerals brannerite and Davidite. Pb content of U mineralized samples are higher than non-mineralized samples indicating its radiogenic nature.



Figure 7.8 (a-d) Mean concentration of major and minor oxides (in %), trace element (ppm) in mineralized and non-mineralized albitite.



Figure 7.8 (e-l) Mean concentration of major and minor oxides (in %), trace elements (ppm) in mineralized and non-mineralized albitite.



Figure 7.9 (a-h) Variation diagrams between major and minor oxide (in %) for mineralised biotite bearing albitite

In the Ab-Or-An triangular plot of O'connor (1965) for feldspar, it is observed that mineralised and non-mineralised samples are rich in albitte and fall in wide range of trondhjemite filed of plot (Figure.7.6a). Mineralised biotite bearing albitite samples plot in meta aluminous field, whereas non-mineralised plot in meta aluminous to per aluminous in A/CNK vs A/NK plot (Shand, 1943) (Figure.7.6b). SiO2 vs K2O plot for plutonites (Peccerillo and Taylor, 1976) shows magma of tholeiite to calc alkaline series (Figure.7.6c). Batcher et al.(1985) used combination of element as R1 vs R2 plot was R1=4Si-11(Na+K)-2(Fe+Ti) and R2= 6Ca+2Mg+A1 (Figure.7.6d) to see tectonic setting of the rocks. almost all the samples of mineralised biotite bearing albitite plot in post collision uplift to late orogenic in nature, while non-mineralised albitite falls in late orogenic i. e. albitite rock is later which intrude into metasediments. All of the samples fall in quartz monzonite field in the SiO₂ vs Na₂O+K₂O plot for plutonites (Middlemost 1994).



Figure 7.10 a) Ab-An-Or ternary diagram, feldspar triangle O'connor (1965). b) A/CNK vs A/NK plot (Shand, 1943)



Figure 7.10 c) SiO₂ vs K₂O plot for plutonites (Peccerillo and Taylor, 1976). d) Batcher et al.(1985) as R1 vs R2.

Calc-silicate:

Whole rock analysis of calc-silicates (n=6) for major, minor and trace elements (Table7.16 revealed that silica (SiO₂) is the most abundant oxide with values ranging from 47.96-57.45 % with an average value of 54.79 %. Al₂O₃, Fe₂O₃^t, MgO, CaO and Na₂O have values ranging from 4.84-9.60 %, 4.46-12.72 %, 7.72-20.21 %, 7.19-11.76 % and 0.01-4.47 % with average values of 6.53 %, 7.39 %, 13.42 %, 10.25 %, and 1.85 % respectively. TiO₂, K₂O, P₂O₅ and MnO have values ranging from 0.13-0.68 %, 0.01-0.97 %, 0.35-0.53 % and 0.04-0.08 % with average values of 0.30 %, 0.42 %, 0.06 % and 0.46 % respectively. Cr, Ni, Ga, Rb, Sr, Ba, Y, Zr, Nb and Ce revealed their values ranging from 12-124 ppm, 40-105 ppm, 10-20 ppm, 10-46 ppm, 10-11 ppm, 10-135 ppm, 26-245 ppm, 86-553 ppm, 10-42 ppm, 10-211 ppm with average values of 39.83, 67.83, 15.50, 25.17, 10.17, 35.33, 159.33, 314.67, 15.83 and 127.50 ppm respectively. Cu is below detection limit whereas Zn and Pb values ranges from <10-42, and 13-25 ppm with average value of 25.17 and 16.67 ppm respectively. U and Th values range from <10 ppm and 16-62 ppm with average value of <10 and 41.17 ppm respectively.

		1	-	-	1	1
	CS/1	CS/2	CS/3	CS/4	CS/5	CS/6
SiO ₂	55.46	57.45	55.40	55.36	57.09	47.96
TiO₂	0.68	0.14	0.13	0.13	0.14	0.57
Al ₂ O ₃	9.6	5.48	5.69	5.61	7.93	4.84
Fe ₂ O ₃ (T)	12.72	5.23	4.50	4.46	4.93	12.50
MgO	7.72	13.30	13.18	13.37	12.75	20.21
MnO	0.07	0.05	0.04	0.04	0.05	0.08
CaO	7.19	10.9	11.59	11.76	10.19	9.87
Na₂O	4.47	2.05	0.84	1.96	1.78	<0.01
K ₂ O	<0.01	0.32	0.47	0.49	0.23	0.97
P ₂ O ₅	0.35	0.46	0.47	0.47	0.45	0.53
Total	98.26	94.85	92.31	93.65	95.45	97.53
Cr	124	12	15	15	18	55
Ni	94	54	40	58	56	105
Cu	<10	<10	<10	<10	<10	<10
Zn	<10	29	21	25	25	42
Ga	20	15	15	16	17	10
Rb	<10	21	46	35	12	27
Sr	<10	<10	<10	<10	11	<10
Y	26	218	245	178	208	81
Zr	201	470	335	243	553	86
Nb	12	<10	11	<10	<10	42
Ce	<10	184	173	136	211	51
Ва	<10	<10	37	<10	<10	135
Pb	25	14	14	19	15	13
Th*	16	52	38	37	62	42
U*	<10	<10	<10	<10	<10	<10

Table 7.16 Major, minor (oxides %) and trace elements (ppm) in calc silicate (n=6)



Figure 7.11 a) Mean concentration of major and minor elements (wt %) in calc cilicate



Figure 7.11 b) trace element (in ppm) concentration in Calc silicate

Maior	Rai	nge				Traces	Ra	nge			
oxide (wt%)	Min	Max	Mean	Std	cov	ppm	Min	Max	Mean	Std	COV
SiO2	47.96	57.45	54.79	3.53	6.44	Cr	12	124	39.83	43.85	110.09
TiO2	0.13	0.68	0.3	0.23	76.67	Ni	40	105	67.83	24.53	36.16
AI2O3	4.84	9.6	6.53	1.79	27.41	cu	10	10	10	0	0.00
Fe2O3 (T)	4.46	12.72	7.39	3.63	49.12	Zn	10	42	25.33	10.84	42.80
MgO	7.72	20.21	13.42	4.18	31.15	Ga	10	20	15.5	3.4	21.94
MnO	0.04	0.08	0.06	0.02	33.33	Rb	10	46	25.17	13.4	53.24
CaO	7.19	11.76	10.25	1.68	16.39	Sr	10	11	10.17	0.41	4.03
Na2O	0.01	4.47	1.85	1.55	83.78	Y	26	245	159.33	83.18	52.21
K2O	0.01	0.97	0.42	0.33	78.57	Zr	86	553	314.67	170.22	54.09
P2O5	0.35	0.53	0.46	0.06	13.04	Nb	10	42	15.83	12.9	81.49
							Ce	127.5	211	10	76.46
							Ва	35.33	135	10	49.96
							Pb	16.67	25	13	4.54
							Th*	41.17	62	16	15.91
							U*	10	10	10	0

Table 7.17 Descriptive statistics of major, minor (wt %) elements of Calc silicate

Descriptive statistics (Table.7.17) and correlation matrices (Table.7.18) of major, minor and trace element for calc-silicate have been calculated. In calc-silicate, MgO is the second most abundant oxide followed by CaO (Figure.7.11a). High concentration of MgO and CaO indicate presence of diopside, and tremolite/actinolite.

	SiO2	TiO2	Al2O3	Fe2O3	MgO	MnO	CaO	Na2O	К2О	P2O5	Ŷ	Zr	Nb	Се	Pb	Th*
SiO2	1.00															
TiO2	-0.58	1.00														
Al2O3	0.41	0.41	1.00													
Fe2O3	-0.66	0.99	0.31	1.00												
MgO	-0.76	-0.03	-0.81	0.09	1.00											
MnO	-0.71	0.91	0.19	0.96	0.28	1.00										
CaO	0.13	-0.86	-0.78	-0.82	0.43	-0.74	1.00									
Na2O	0.54	0.33	0.84	0.23	-0.91	0.05	-0.66	1.00								
К2О	-0.83	0.05	-0.83	0.15	0.96	0.27	0.43	-0.88	1.00							
P2O5	-0.55	-0.33	-0.91	-0.22	0.95	-0.03	0.69	-0.96	0.91	1.00						
Y	0.52	-0.97	-0.45	-0.95	0.10	-0.85	0.85	-0.43	0.01	0.38	1.00					
Zr	0.80	-0.72	0.16	-0.72	-0.31	-0.60	0.30	0.08	-0.51	-0.13	0.72	1.00				
Nb	-0.97	0.57	-0.41	0.66	0.80	0.77	-0.16	-0.57	0.82	0.59	-0.48	-0.67	1.00			
Ce	0.59	-0.95	-0.30	-0.93	0.05	-0.79	0.74	-0.34	-0.10	0.31	0.96	0.86	-0.51	1.00		
Pb	0.24	0.50	0.77	0.39	-0.77	0.16	-0.67	0.90	-0.65	-0.86	-0.63	-0.29	-0.35	-0.59	1.00	
Th*	0.18	-0.66	-0.38	-0.58	0.44	-0.32	0.55	-0.55	0.21	0.56	0.68	0.70	-0.03	0.81	-0.78	1.00

Table 7.18 Correlation of geochemical data of major, minor (in %) and trace elements (in ppm) of Calc silicate



Figure 7.12(a-f) Variation diagrams between major and minor oxide (in %) for Calc-silicate

Plot (Figure.7.12) shows correlation between major oxides. SiO_2 shows negative correlation with CaO and MgO in calc-silicate. In calc-silicate, Al_2O_3 shows positive correlation with Mgo, indicating presence of tremolite. Fe₂O₃ shows strongly positive correlation with TiO₂ which indicate presence of ilemanite.

SiO₂, CaO and MgO ternary phase diagram (Figure.7.13) shows mineral assemblages for calc-silicate group of rocks. Calc-silicate are enriched in SiO₂ than CaO and MgO dominantly composed of diopside and tremolite.



Figure 7.13 CaO-MgO-SiO₂-H₂O-CO₂ compatibility diagrams for metamorphosed siliceous carbonates, after Spear modified (1993).

Quartz biotite schist:

Whole rock analysis of quartz biotite schist (n=6) has been carried out (Table 7.19). Major oxide analysis revealed that silica (SiO₂) is the most abundant oxide with values ranging from 50.47-55.75 % with an average value of 52.83 %. Al₂O₃, Fe₂O₃^t, MgO, CaO and Na₂O have values ranging from 11.26-15.58 %, 8.23-12.13 %, 6.08-14.69 %, 0.36-2.05 % and 1.40-6.89 % with average values of 14.27 %, 10.33 %, 9.46 %, 1.15 %, and 4.16 % respectively. TiO₂, K₂O, P₂O₅ and MnO have values ranging from 0.45-0.95 %, 2.99-7.85 %,

0.09-0.54 % and <0.01-0.03 % with average values of 0.68 %, 4.48 %, 0.27 % and 0.02 % respectively. Cr, Ni, Ga, Rb, Sr, Ba, Y, Zr, Nb and Ce contnet ranges from 88-127 ppm, 30-151 ppm, 11-22 ppm, 103-390 ppm, 10-44 ppm, 175-955 ppm, 10-56 ppm, 84-172 ppm, 11-19 ppm, 10-112 ppm with average values of 103, 61.67, 15.33, 189.67, 22.67,456, 23, 112, 14.50 and 37.83 ppm respectively. Cu is below detection limit whereas Zn and Pb values ranges from <10-25, and 11-19 ppm with average value of 18.67 and 14.67 ppm respectively. U and Th values range from <10-17 ppm and 19-74 ppm with average value of 11.33 and 37.83 ppm respectively. Descriptive statistics and correlation matrices of major, minor and trace element for quartz biotite schist are shown in table 7.20 & 7.21.

Table 7.19 Major, minor (oxides %) and trace elements (in ppm) in quartz biotite schist of Geratiyon ki Dhani area (n=6)

	QBS-	QBS-2	QBS-3	QBS-4	QBS-5	QBS-6
Sample no	1					
SiO ₂	50.47	55.75	52.13	51.87	54.71	52.02
TiO ₂	0.95	0.56	0.9	0.57	0.65	0.45
Al ₂ O ₃	11.26	15.58	15.55	12.67	15.03	15.5
$Fe_2O_3(T)$	12.12	8.23	12.13	9.42	10.53	9.56
MgO	14.69	6.08	6.68	14.57	6.33	8.4
MnO	0.02	0.01	< 0.01	0.02	< 0.01	0.03
CaO	0.6	1.18	0.36	2.05	1.14	1.55
Na ₂ O	1.4	6.98	6.13	1.66	5.19	3.58
K ₂ O	5.58	2.99	3.32	6.4	3.14	7.85
P ₂ O ₅	0.54	0.39	0.27	0.21	0.12	0.09
Total	97.63	97.75	97.47	99.44	97.11	99.03
Cr	92	112	107	88	127	92
Ni	151	39	40	30	57	53
Cu	<10	<10	<10	<10	<10	<10
Zn	<10	22	17	23	15	25
Ga	22	16	15	13	15	11
Rb	390	103	198	166	143	138
Sr	<10	44	<10	32	<10	30
Y	56	<10	11	21	<10	30
Zr	84	115	172	110	107	84
Nb	16	15	19	11	11	15
Ce	<10	112	35	23	<10	37
Ba	398	582	195	431	175	955
Pb	11	19	18	13	15	12
Th*	74	30	28	19	32	44
U*	<10	<10	17	11	10	<10



Figure 7.14 Mean concentration of a) major, minor oxides (in wt %) b) trace elements (ppm) in quartz biotite schist

Table 7.20: Descriptive statistics of major, minor (wt %) and trace elements (ppm) of Quartz biotite schist

Major	Rai	nge				Major	Ra	nge			
oxide (wt %)	Min	Max	Mean	Std Dev	cov	oxide (wt %)	Min	Max	Mean	Std Dev	cov
SiO2	50.47	55.75	52.83	1.94	3.67	Cr	88	127	103	14.65	14.22
TiO2	0.45	0.95	0.68	0.19	27.94	Ni	30	151	61.67	45.55	73.86
AI2O3	11.26	15.58	14.27	1.75	12.26	Cu	10	10	10	0	0.00
Fe2O3	8.23	12.13	10.33	1.49	14.42	Zn	10	25	18.67	5.54	29.67
MgO	6.08	14.69	9.46	3.68	38.90	Ga	11	22	15.33	3.83	24.98
MnO	0.01	0.03	0.02	0.01	50.00	Rb	103	390	189.67	105.06	55.39
CaO	0.36	2.05	1.15	0.61	53.04	Sr	10	44	22.67	13.68	60.34
Na2O	1.4	6.98	4.16	2.18	52.40	Y	10	56	23	17.76	77.22
K2O	2.99	7.85	4.88	1.91	39.14	Zr	84	172	112	32.45	28.97
P2O5	0.09	0.54	0.27	0.17	62.96	Nb	11	19	14.5	2.98	20.55
						Ce	10	112	37.83	38.46	101.67
						Ва	175	955	456	286.48	62.82
						Pb	11	19	14.67	3.08	21.00
						Th*	19	74	37.83	19.78	52.29

	SiO ₂	TiO₂	AI_2O_3	Fe ₂ O ₃	MgO	MnO	CaO	Na ₂ O	K ₂ O	<i>P</i> ₂ <i>O</i> ₅	Rb	Sr	Ŷ	Zr	Се	Pb	Th*	U*
SiO ₂	1.00																	
TiO ₂	-0.45	1.00																
AI_2O_3	0.65	-0.44	1.00															
Fe ₂ O ₃	-0.63	0.89	-0.36	1.00														
MgO	-0.74	0.24	-0.94	0.22	1.00													
MnO	-0.61	-0.37	-0.28	-0.10	0.49	1.00												
CaO	0.12	-0.84	-0.05	-0.74	0.27	0.46	1.00											
Na₂O	0.79	-0.12	0.86	-0.24	-0.94	-0.67	-0.34	1.00										
K ₂ O	-0.66	-0.36	-0.36	-0.10	0.59	0.98	0.54	-0.75	1.00									
P_2O_5	-0.22	0.65	-0.57	0.29	0.39	-0.22	-0.51	-0.15	-0.23	1.00								
Rb	-0.74	0.79	-0.81	0.75	0.66	0.17	-0.51	-0.62	0.17	0.70	1.00							
Sr	0.43	-0.75	0.25	-0.93	-0.08	0.19	0.64	0.17	0.19	-0.07	-0.59	1.00						
Y	-0.76	0.38	-0.78	0.41	0.74	0.61	-0.14	-0.78	0.58	0.53	0.85	-0.26	1.00					
Zr	0.15	0.37	0.44	0.29	-0.44	-0.65	-0.45	0.59	-0.60	-0.05	-0.22	-0.21	-0.62	1.00				
Ce	0.65	-0.38	0.51	-0.68	-0.48	-0.28	0.05	0.65	-0.34	0.20	-0.53	0.78	-0.43	0.17	1.00			
Pb	0.72	0.00	0.68	-0.24	-0.75	-0.80	-0.30	0.92	-0.81	0.02	-0.55	0.24	-0.81	0.74	0.69	1.00		
Th*	-0.51	0.48	-0.55	0.49	0.40	0.37	-0.45	-0.46	0.28	0.59	0.82	-0.39	0.90	-0.55	-0.30	-0.59	1.00	
U*	-0.21	0.51	0.29	0.53	-0.25	-0.38	-0.53	0.35	-0.33	-0.03	0.02	-0.39	-0.34	0.92	-0.06	0.47	-0.32	1.00

Table 7.21: Correlation of geochemical data of major, minor (in %) and trace elements (in ppm) of Quartz biotite schist



Figure 7.15(a-h) Variation diagrams between major and minor oxide (in %) for quartz biotite schist

Variation diagram (Figure.7.15a-h) between Major, minor and trace element shows that SiO₂ has positive correlation with Na₂O, Al₂O₃ and Fe₂O₃, while negative correlation with K₂O. Al₂O₃ has positive correlation with Na₂O, indicating presence of feldspar, while negative correlation with MgO and Fe₂O₃ reflects absence of amphibole and other clay minerals.

In SiO₂- CaO- MgO ternary phase diagram (Figure.7.16a), it is observed that almost all the samples are quartz rich. Al₂O₃-Fe₂O₃-MgO ternary phase diagram (Figure. 7.16b) plotted for accessory mineral phases present in the rock shows, chlorite and amphibole as main accessory minerals in the rock.



Figure 7.16 a) CaO-MgO-SiO₂-H₂O-CO₂ compatibility diagrams for quartz biotite schist, modified after Spear (1993) b) Al₂O₃-Fe₂O₃-MgO diagram.

Feldspathic quartzite.

Whole rock analysis of feldspathic quartzite (n=6), is given in Table 7.22. SiO2 is the most abundant oxide, ranges from 81.21-50.56 % with average of 67.30 %. Other oxides ranges from 18.31-8.05 % Al2O3, 0.62-5.41 % Fe2O3,0.32-8.88 % CaO, 4.62-9.71 % Na2O and 0.04-4.49 % MgO. Trace elements concentrations in these samples are 62-148 ppm Cr, 10-46 ppmRb,12-13 ppm Sr, 129-427 ppm Zr, 10-46 ppmNb,20-119 ppm Ba, 19-186 ppm Ce. The samples have analysed upto 16.25 ppm U and 20.67 ppm Th. Two sample ranges

SiO₂ about 80 % with Na₂O 6.00 % and Al₂O₃ 8.00 % which reflect rock is feldspathic quartzite in which feldspar content is upto 15 % (also observed in petrominrelogy studies). Other sample from the area reflect biotite and magnetite present in quartzite with feldspar.

Descriptive statistics of major, minor and trace element in feldspathic quartzite are shown in table 7.20. Variation diagrams (Figure.7.18a-d) between major, minor and trace element shows that SiO₂ has negative correlation with Na₂O, Al₂O₃ and Fe₂O₃. Al₂O₃ have positive correlation with Na₂O, indicates presence of albite.

	GKDC/4/16	GKDC/5/164	GKDC/2/201	GRAB	GRAB	GRAB	
Field No	FQ/01	FQ/02	FQ/3	FQ/4	FQ/5	FQ/06	
SiO ₂	68	64.27	79.17	81.21	50.56	64.17	
TiO ₂	0.16	0.95	0.26	0.29	1.05	1.06	
Al ₂ O ₃	18.31	17.12	8.78	8.05	13.27	17.76	
Fe ₂ O ₃ (T)	0.62	1.69	1.19	1.93	5.41	2.31	
MgO	0.43	0.85	0.04	0.75	4.49	0.63	
MnO	<0.01	0.02	<0.01	<.01	0.07	0.02	
CaO	0.32	1.2	0.37	1.4	8.88	0.9	
Na₂O	9.56	9.71	7.2	4.62	7.5	9.3	
K₂O	<0.01	0.14	<0.01	0.04	0.01	0.14	
P ₂ O ₅	<0.01	<0.01	0.2	0.08	0.18	< 0.01	
Total	97.89	95.95	97.21	98.37	91.42	96.29	
Cr	80	118	62	80	148	118	
Ni	<10	10	12	<10	<10	<10	
Cu	<10	<10	<10	<10	<10	<10	
Zn	<10	<10	<10	<10	11	<10	
Ga	21	23	<10	10	15	<10	
Rb	28	46	10	20	16	42	
Sr	<10	13	<10	<10	<10	12	
Y	<10	<10	<10	<10	<10	<10	
Zr	170	154	427	339	129	173	
Nb	10	40	<10	<10	26	46	
Ce	19	41	186	69	<10	89	
Ва	25	24	87	119	20	84	
Pb	16	17	13	12	<10	<10	
Th*	<10	<10	17	23	<10	22	
U*	12	18	23	12	<10	<10	

Table 7.22 Major, minor (oxides %) and trace elements (in ppm) in feldspathic quartzite of Geratiyon ki Dhani area (n=6)



Figure.7.17 Mean concentration of a) major, minor oxides (in wt %) b) trace elements (ppm) in feldspathic quartzite

Table 7.23 Descriptive statistics of major, minor (wt %) and trace (ppm) elements in feldspathic quartzite

Major oxide Range		nge	Mean	Std		Major oxide	Range		Mean	Std	cov
(wt%)	Max	Min			(Max	Min			
SiO2	81.21	50.56	67.90	11.10	16.35	Cr	148	62	101	31.47	31.16
TiO2	1.06	0.16	0.63	0.39	61.90	Ni	12	10	11	0.89	8.09
AI2O3	18.31	8.05	13.88	4.20	30.26	cu	<10	<10	<10	0	0.00
Fe2O3	5.41	0.62	2.19	1.72	78.54	Zn	11	11	11	0	0.00
MgO	4.49	0.04	1.20	1.67	139.17	Ga	23	10	17.25	5.21	30.20
MnO	0.07	0.02	0.04	0.02	50.00	Rb	46	10	27	13.73	50.85
CaO	8.88	0.32	2.18	3.34	153.21	Sr	13	12	12.5	0.45	3.60
Na2O	9.71	4.62	7.98	1.93	24.19	Y	<10	<10	<10	0	0.00
K2O	0.14	0.01	0.08	0.06	75.00	Zr	427	129	232	116.04	50.02
P2O5	0.20	0.08	0.15	0.05	33.33	Nb	46	10	30.5	14.28	46.82
						Ce	186	19	80.8	62.58	77.45
						Ва	119	20	59.83	39.37	65.80
						Pb	17	12	14.5	2.05	14.14
						Th*	23	17	20.67	2.56	12.39
						U*	23	12	16.25	4.59	28.25



Figure 7.18(a-d) Variation diagrams between major and minor oxide (in wt %) for feldspathic quartzite

Amphibolite:

Whole rock analysis of Amphibolite (n=5), is given in Table 7.24. SiO₂ is the most abundant oxide, ranging from 51.75-59.64 % with average 53.99 %. other oxides ranging from 3.32-4.90 % Al₂O₃, 5.64-11.88 % Fe2O3, 8.50-10.14 % CaO, 0.77-1.75 % Na₂O and 13.92-19.93 % MgO. Trace elements concentrations in these samples are 62-148 ppm Cr, 10-46 ppmRb,12-13 ppm Sr, 129-427 ppm Zr, 10-46 ppmNb,20-119 ppm Ba, 19-186 ppm Ce. The samples have analysed upto 16.25 ppm U and 20.67 ppm Th.

	AMP/1	AMP/2	AMP/3	AMP/4	AMP/5
SiO ₂	53.48	52.74	51.75	52.32	59.64
TiO₂	0.5	0.67	0.52	0.49	0.17
Al ₂ O ₃	3.89	3.38	3.66	3.32	4.9
Fe ₂ O ₃ (T)	9.75	11.88	10.74	10.01	5.64
MgO	18.7	19.46	18.97	19.93	13.92
MnO	0.07	0.08	0.9	0.09	0.05
CaO	8.5	9.19	9.4	10.14	10.14
Na₂O	1.75	0.77	1.27	1.24	0.9
K₂O	0.78	0.66	0.71	0.79	0.06
P ₂ O ₅	0.04	0.05	0.05	0.05	0.03
Total	96.83	98.88	97.97	98.38	95.45
Cr	80	62	44	54	35
Ni	102	96	91	94	41
Cu	<10	10	<10	<10	<10
Zn	39	35	33	36	32
Ga	10	10	11	10	12
Rb	30	20	22	24	<10
Sr	<10	<10	<10	<10	<10
Y	71	53	65	90	146
Zr	93	99	155	106	89
Nb	28	22	25	45	16
Ce	25	28	47	28	21
Ва	70	61	91	42	<10
Pb	13	13	11	10	11
Th*	71	114	110	28	14
U*	<10	<10	<10	<10	<10

Table 7.24 Major, minor (in %) and trace elements (in ppm) in Amphibolite of Geratiyon ki Dhani area (n=5)

Statistical evaluation of major, minor and trace element for quartz biotite schist are shown in table 7.20. Variation diagram (Figure.7.15a-h) between major, minor and trace element shows that SiO2 has positive correlation with CaO and CaO has positive correlation with Al₂O₃ indicate presence of plagioclase. SiO₂ have negative correlation with MgO and Fe₂O₃.

Major oxide	Range		Moon	Std	COV	trace	race Range		Mean	Std	cov
(wt %)	Max	Min	ivicali	Dev	00	ע ppm)	Max	Min	ivieali	Dev	COV
SiO ₂	59.64	51.75	53.99	3.10	5.74	Cr	80	35	55	16.65	30.27
TiO ₂	0.67	0.17	0.47	0.18	38.30	Ni	102	41	84.8	23.95	28.24
Al ₂ O ₃	4.90	3.32	3.83	0.61	15.93	Cu	10	10	10	0	0.00
Fe ₂ O ₃	11.88	5.64	9.60	2.32	24.17	Zn	39	32	35	2.62	7.49
MgO	19.93	13.92	18.20	2.35	12.91	Ga	12	10	10.6	0.82	7.74
MnO	0.90	0.05	0.24	0.35	145.83	Rb	30	20	24	3.92	16.33
CaO	10.14	8.50	9.47	0.64	6.76	Sr	<10	<10	<10	0	0.00
Na ₂ O	1.75	0.77	1.19	0.37	31.09	Υ	146	53	85	35.37	41.61
K ₂ O	0.79	0.06	0.60	0.29	48.33	Zr	155	89	108.4	25.82	23.82
P ₂ O ₅	0.05	0.03	0.04	0.01	25.00	Nb	45	16	27.2	10.67	39.23
						Ce	47	21	29.8	9.79	32.85
						Ва	91	42	66	18.68	28.30
						Pb	13	10	11.6	1.21	10.43
						Th*	114	14	67.4	40.96	60.77
						U*	<10	<10	<10	0	0.00

Table 7.25: Descriptive statistics of major, minor (wt %) and trace elements (ppm) in amphibolite



Figure 7.19 a) Mean concentration of major, minor oxides (in wt %)



Figure 7.19 b) Mean concentration trace elements (ppm) in amphibolite



Figure 7.20 (a-d) Variation diagrams between major and minor oxide (in %) for amphibolite



Figure 7.20 (e-f) Variation diagrams between major and minor oxide (in %) for amphibolite **Granite:**

Whole rock analysis of granites (n=12), near to the study area have been carried out (Table 7.26). SiO₂ is the most abundant oxide, ranging from 67.48-75.03 %, 12.63-14.56 % Al₂O₃, 0.66-2.75 % CaO, 3.27-7.63 % Na₂O and 0.44-5.29 % K₂O. Trace elements concentrations in these samples are 53-233 ppm Rb, 24-59 ppm Sr, 35-183 ppm Y, 264-613 ppm Zr, 41-90 ppm Nb, 98-830 ppm Ba, 141-322 ppm Ce. The samples have analysed upto 62.25 ppm U and 50.83 ppm Th. Statistical evaluation and correlation matrices have been prepared to see correlation between major, minor and trace element for granite (Table 7.27 and 7.29).

CIPW norm calculation of granite revels that rock is soda rich granite with hihger albite content (42 %) along with K-feldspar, quartz and plagioclase. Rock shows (table 7.28). Albite, quartz, k-feldspar and anorthite with have an average content of 42.06, 24.82, 21.25 and 3.31 % respectively.

	JTP-1	JTP-2	JTP-3	JTP-4	JTP-5	JTP-6	JTP-7	JTP-8	JTP-9	JTP-10	JTP11	JTP-12
SiO ₂	73.25	68.29	70.1	67.48	71.39	73.69	68.85	68.15	68.19	70.72	73.26	75.03
TiO ₂	0.2	0.39	0.42	0.49	0.53	0.22	0.37	0.49	0.4	0.32	0.45	0.38
Al ₂ O ₃	13.69	13.27	12.99	14.44	13.93	12.87	14.56	13.83	13.78	13.87	12.74	12.63
Fe ₂ O ₃ ^t	3.07	5.91	5.33	5.55	2.32	1.85	3.79	4.04	4.38	2.76	3.41	2.23
MgO	0.04	0.48	0.71	0.44	0.33	0.83	1.31	1.42	1.46	1.03	1.02	0.89
MnO	0.02	0.05	0.04	0.04	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.02
CaO	0.66	1.57	1.35	1.77	0.86	2.75	1.14	2.23	1.45	1.19	0.83	0.88
Na ₂ O	3.29	4.21	3.27	4.15	7.63	6.66	4.31	5.1	4.34	4.52	5.95	6.7
K ₂ O	4.96	4.64	4.64	4.75	2.01	0.44	5.13	4.16	5.29	5.01	1.62	0.49
P ₂ O ₅	0.05	0.12	0.14	0.12	0.04	0.17	0.29	0.23	0.34	0.21	0.19	0.32
Total	99.23	98.93	98.99	99.23	99.06	99.5	99.78	99.67	99.66	99.66	99.49	99.57
V	13	28	29	40	28	22	32	36	32	28	35	32
Cr	278	177	299	259	270	34	20	22	25	18	20	21
Со	8	13	14	14	7	5	10	11	11	7	9	7
Ni	12	7	10	9	16	15	10	11	10	16	15	18
Cu	5	2.5	2.5	2.5	8	9	5	11	31	6	13	27
Zn	30	40	30	31	22	22	29	24	36	37	28	25
Ga	23	21	21	21	27	27	22	21	22	25	26	27
Rb	233	154	155	141	63	53	140	114	169	219	97	61
Sr	29	41	42	42	24	41	59	41	46	36	30	37
Y	183	110	119	108	153	52	35	71	110	169	123	74
Zr	278	469	503	521	613	264	290	438	375	298	339	275
Nb	69	41	50	41	72	66	45	51	56	63	77	90
Ba	272	733	741	830	246	114	270	281	339	357	178	98
La*	155	139	139	185	45	83	87	108	133	126	232	157
Ce*	283	236	245	322	141	141	154	202	237	246	312	277
Pb	38	20	21	18	24	44	35	34	42	63	53	59
Th#	74	23	30	35	51	91	36	34	48	63	62	63
U#	45	12	17	12	33	53	29	26	35	224	147	114

Table 7.26 Major, minor (in %) and trace elements (in ppm) in Jaitpura Granite (n=12)
Table 7.27 Descriptive statistics and comparison of major, minor (wt %) and trace elements

Major	Range		Mean	Std	COV	Major	Rar	nge	Mean	Std	COV
(wt%)	Max	Min	Ivicali	Sid	00	(wt%)	Max	Min	wican	Sid	COV
SiO2	75.03	67.48	70.7	2.62	3.706	Cr	299	18	120.25	118.41	98.47
TiO2	0.53	0.2	0.39	0.11	28.205	Co	14	5	9.67	3.05	31.54
Al2O3	14.56	12.63	13.55	0.65	4.797	Ni	18	7	12.42	3.57	28.74
Fe2O3	5.91	1.85	3.72	1.38	37.097	Cu	31	2.5	10.21	9.86	96.57
MgO	1.46	0.04	0.83	0.46	55.422	Zn	40	22	29.5	6.02	20.41
MnO	0.05	0.02	0.03	0.01	33.333	Ga	27	21	23.58	2.49	10.56
CaO	2.75	0.66	1.39	0.66	47.482	Rb	233	53	133.25	60.13	45.13
Na2O	7.63	3.27	5.01	1.45	28.942	Sr	59	24	39	10.07	25.82
K2O	5.29	0.44	3.6	1.86	51.667	Y	183	35	108.92	47.37	43.49
P2O5	0.34	0.04	0.19	0.1	52.632	Zr	613	264	388.58	120.09	30.90
						Nb	90	41	60.08	16.03	26.68
						Ba	830	98	371.58	256.14	68.93
						La*	232	45	132.42	54.29	41.00
						Ce*	322	141	233	62.96	27.02
						Pb	63	18	37.58	15.5	41.25
						Th*	91	23	50.83	21.48	42.26
						U*	224	12	62.25	70.89	113.88

(in ppm) in Jaitpura granite

Table 7.28: QAPF table of Jaitpura granite

	JTP-1	JTP-2	JTP-3	JTP-4	JTP-5	JTP-6	JTP-7	JTP-8	JTP-9	JTP-10	JTP-11	JTP-12
Q	33.81	23.04	29.77	21.33	20.32	28.48	20.58	17.84	18.92	22.15	29.70	31.88
Or	29.31	27.42	27.42	28.07	11.88	2.60	30.32	24.58	31.26	29.61	9.57	2.90
Ab	27.84	35.62	27.67	35.12	60.46	56.36	36.47	43.16	36.72	38.25	50.35	56.69
An	2.95	3.61	5.78	6.74	0.00	3.92	3.76	2.56	2.49	2.76	2.88	2.28
Di	0.00	1.74	0.00	0.00	1.74	4.46	0.00	4.18	0.94	0.60	0.00	0.00
Ну	0.10	0.39	1.77	1.10	0.02	0.00	3.26	1.60	3.20	2.29	2.54	2.22
Tn	0.00	0.82	0.00	0.88	1.25	0.49	0.00	1.15	0.90	0.70	0.00	0.00
Ru	0.18	0.00	0.38	0.09	0.00	0.00	0.34	0.00	0.00	0.00	0.43	0.36

	SiO ₂	TiO₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	MnO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Rb	Sr	Zr	Ва	Pb	Th	U
SiO ₂	1.00																
TiO ₂	-0.47	1.00															
Al ₂ O ₃	-0.68	0.22	1.00														
Fe ₂ O ₃	-0.78	0.38	0.25	1.00													
MgO	-0.27	0.18	0.05	-0.02	1.00												
MnO	-0.65	0.17	0.19	0.86	-0.15	1.00											
CaO	-0.30	-0.08	-0.01	0.12	0.28	0.12	1.00										
Na ₂ O	0.51	0.23	-0.32	-0.69	0.05	-0.59	0.07	1.00									
K ₂ O	-0.76	0.03	0.67	0.66	0.07	0.57	-0.10	-0.87	1.00								
P ₂ O ₅	-0.07	0.01	-0.06	-0.08	0.87	-0.12	0.10	0.04	-0.02	1.00							
Rb	-0.35	-0.35	0.39	0.38	-0.13	0.38	-0.29	-0.85	0.85	-0.12	1.00						
Sr	-0.53	-0.06	0.35	0.40	0.58	0.41	0.38	-0.41	0.41	0.61	0.10	1.00					
Zr	-0.51	0.77	0.26	0.49	-0.31	0.40	0.03	0.05	0.17	-0.50	-0.15	-0.23	1.00				
Ва	-0.67	0.31	0.27	0.89	-0.31	0.91	0.12	-0.63	0.60	-0.34	0.39	0.22	0.60	1.00			
Pb	0.60	-0.40	-0.36	-0.67	0.41	-0.56	-0.20	0.30	-0.37	0.54	-0.01	-0.14	-0.77	-0.71	1.00		
Th	0.81	-0.66	-0.38	-0.84	-0.13	-0.71	0.01	0.43	-0.58	-0.03	-0.17	-0.41	-0.63	-0.71	0.65	1.00	
U	0.47	-0.21	-0.27	-0.50	0.21	-0.32	-0.31	0.22	-0.24	0.25	0.12	-0.32	-0.50	-0.41	0.87	0.48	1.00

Table 7.29: Correlation of geochemical data of major, minor (in %) and trace elements (in ppm) of Jaitpura Granite

Since XRF analysis is semi quantitative for REEs samples of granite (n=7) have been analysed by wet chemical method for REE analyses to determine source of granite (Table 7.30). Among REEs in the granite the LREEs La, Ce, Pr, and Nd ranges from 60-105 ppm, 125-190 ppm, 13-18 ppm, and 41-72 ppm with average values 81.42, 160.1, 14.8 and 58.28 ppm. The MREEs, Sm, Eu, Gd, Tb, Dy and Ho have values ranging 7-14 ppm, <1-2 ppm, 7-15 ppm, 2-4 ppm, 7-16 ppm and <2-4 ppm with average values 10.85,1.42, 11.14, 2.42, 11.71 and 3.28 ppm respectively. The HREEs, Er, Tm, Yb and Lu ranges from 5-9 ppm, <1 ppm, 4-7 ppm, 1-2 ppm with average values of 7.28, .62, 5.42 and 1.42 ppm respectively. Sc and Y ranges from 2-4 ppm and 36-96 ppm with average values of 3.42 ppm and 60.57 ppm respectively.

Table 7.30 REE content of Jaitpura granite

Sample No	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Но	Er	Tm	Yb	Lu	Y	Sc
JTP/C/1	65	125	13	41	7	1	8	2	10	2	6	0.5	5	1	42	3
JTP/C/2	60	125	13	44	8	1	9	2	7	3	5	0.5	4	1	36	4
JTP/C/3	73	150	15	63	12	2	12	3	10	2	7	0.5	6	1	58	4
JTP/C/4	88	175	16	69	13	2	14	2	12	4	9	1	7	2	70	3
JTP/C/5	90	186	14	65	12	1	13	4	16	4	9	1	6	2	96	2
JTP/C/6	105	190	18	72	14	2	15	2	15	4	9	0.5	6	2	86	4
JTP/C/7	89	170	15	54	10	1	7	2	12	4	6	0.5	4	1	36	3

Chonderite normalized plot for granite shows (Figure 7.21a) steeply sloping LREE and flat HREE pattern with strong negative Eu anomaly. The negative Eu anomaly, suggesting the removal of plagioclase or absence during fractional crystallization (Neiva, 1992; Chappel et al., 1987), flat HREE profiles indicate the absence of garnet and hornblende in the source region of granites (Chaudhri et al.,2003).



Figure 7.21 a) Chondrite normalized rare earth element patterns for granites after byonton (1984).

All of the samples fall in granite field in the SiO₂ vs Na₂O+K₂O plot for plutonites (Middlemost 1994) (Figure.7.21b). Samples plot in peraluminous- metaluminous field in molar Na₂O-Al₂O₃-K₂O (Figure.7.21c). Pearce et al.(1984) used combination of trace element such as Nb vs Y and Rb vs (Y+Nb) to distinguish between granitoids, almost all the samples of the area plot in WPG (with in plate granitoid) i. e. A type, anorogenic granite (Figure.7.21d&e), that were emplaced in an extensional non-compressive tectonic regime during a phase of cooling (Chaudhri, 2003). Rb-Ba-Sr ternary diagram (Figure.7.21e) for granite) are plotted. It has observed that all the granite samples followed the trend of differentiation.



Figure 7.21 b) SiO₂ vs Na₂O+K₂O plot for plutonites (Middlemost 1994) c) molar Na₂O-Al₂O₃-K₂O



Figure 7.21 d&e) Granitoid discrimination diagram by Pearce et al. (1984)



Figure 7.21 f) Rb-Ba-Sr ternary diagram, after El Bouseily and El Sokkary

CHAPTER 8 DISCUSSION

The Delhi Supergroup forms a narrow belt extending from Gujarat in the southwest to Haryana in the northeast. It is divided into the North Delhi Fold Belt (NDFB) and the South Delhi Fold Belt (SDFB) (Sinha-Roy et al., 1998). The NDFB extends from Haryana in northeast to Ajmer in southwest and has been identified as an important province for uranium, copper, iron and fluorite mineralization. Uranium exploration in NDFB extending over a time span of about fifty years has resulted in delineation of about more than three hundred radioactive anomalies associated with structurally weak zones. Majority of these weak zones trend NNE-SSW, parallel to Kaliguman and Khetri lineaments. These structural trends fall within the broad zone of albitisation defined as 'albitite line' (Ray, 1987 and 1990) which has been traced over 120 km from north of Sior to south of Sakun-Ladera near Kishangarh within NDFB (Singh et al., 1998).

Geological mapping of 2 sq km area on 1:2000 scale around Geratiyon ki Dhani area was carried out using total station, GPS and Brunton compass. Geratiyon ki Dhani area is located in the eastern part of Khetri sub-basin in toposheet 45M/14 and is about 45 km ENE of Rohil uranium deposit, which is an established uranium deposit in the NDFB. Quartzite, quartz-biotite-schist, calc-silicates are the main lithiunits of Ajabgarh metasediments exposed in the study area along with intrusive granites and later phases of albitites. Geratiyon ki Dhani area was taken up for subsurface exploration after encouraging results were recorded while mapping, gamma ray logging of extra departmental tube-wells. Uranium exploration activities have been carried out in this area to establish the dip and strike continuity of subsurface mineralization. Sub-surface exploration resulted in establishing uranium mineralization over a strike length of 1200 m and a vertical depth of upto 350 m. A total of 30 boreholes have recorded significant mineralized intercepts.

Albitite and granite occur as intrusions. Mineralisation is hosted predominantly by pink to brick red coloured albitite and to some extent by biotite bearing albitite and quartz biotite schist. Albitite is highly fractured and brecciated in the mineralized part and appears brick red in colour due to Fe. Intense calcitisation as fracture filling calcite veins was observed. The formations in general are trending NNW-SSE to NW-SE with moderate to steep dips towards WSW. The whole sequence is affected NE-SW trending brecciation and calcitisation. The NW-SE trending albitite ridge exposed near Geratiyon ki Dhani village is highly deformed exhibiting both brittle and ductile deformation. The albitite is intensively brecciated and angular rock fragments of quartz and feldspar vary in size from few mm upto 20 cm. The albitite have intruded into metasediments such as quartz biotite schist and quartzite. A younger phase of granite and amphibolite intrusion were recorded. The NNW-SSE trending albitite ridge is highly deformed exhibiting both brittle and ductile deformational features. Brittle deformation is represented by brecciation and fracturing. Several asymmetric folds observed in the area viz. Z, M and S types, indicate ductile deformation. The lithounits exposed having overall trend of foliation N25-30⁰W-S25-30⁰E, dipping vertical to sub-vertical towards SW. Two prominent conjugate sets of joint planes have been identified- one set along E-W direction and another set along NE-SW direction. Acute bisectrix of these conjugate joints indicate the probable compression direction (Sigma-1), accordingly perpendicular to this direction there was maximum extension. As a result we are getting foliation planes with a strike of N28°W, parallel to the direction of maximum extension.

Major alterations are calcitization, chloritization, silicification, sericitisation and ferrugenisation along with quartzo-feldspathic injection. Foliation data also recorded in the core and S_1Vs CA varies from sub-parallel to 75°. This variation in foliation data indicate folded nature of the rock types. Average number of fracture per meter calculated for the

entire borehole is 8 fractures per meter. Whereas it will be doubled to 16-18 fractures per meter in mineralisation intercepted in the borehole, indicating increasing channel ways favouring mineralisation.

Sharp contact between albitite and quartz biotite schist has been observed in NW of study area and also relicts of quartz biotite schist in albitite indicate its magmatic origin. Uranium mineralisation in Geratiyon ki Dhani area is hosted by magmatic albitite which is different from well-known Rohil and Jahaz uranium mineralisation where host rock were albitised metasediments.

In the study area, surface and sub-surface samples have been studied megascopically as well as microscopically and are characterised based on mineral assemblages, texture, grain size, mutual grain relationship, alteration features, radioactive mineral phases etc. Based on these studies dominant rock types identified are Albitite, biotite bearing albitite, quartz-biotite schist, calc silicate and quartzite.

The Albitite in hand specimen is fine to medium grained, leucocratic, heterogeneous, very hard and compact in nature. Brick red to pink colour, granular texture, mostly quartz and feldspar were identified by naked eye. It is highly deformed, fractured, brecciated with multiple quartz vein, veinlets and calcite veins at places. Other constituents present in these rocks are biotite, chlorite and calcite. Whole run shows the network of fracture with random orientation sealed with calcite and quartz. Calcitisation and silicification are identified as major alteration features. Davidite is identified as chief radioactive mineral, occurring within the albitite.

Ore and accessory minerals include sphene, rutile, davidite, brannerite and U-Ti complex as Ti-oxides while hematite and very less magnetite as Fe-oxides. Davidite occurs as anhedral to subhedral grains of varying sizes and veins which crystallised in the vicinity or

adjacent to calcite veins. Davidite occurs in close association of calcite and rutile. Generally rutile is anhedral, sub rounded rimming davidite or U-Ti complexes and also occurs as discrete grains. Rutile is exsolved within brannerite and also precipitated as separate phase in the surroundings. Ore minerals are found undeformed and unaffected by deformation which suggest post deformational mineralisation event. Radiation haloes were also observed around the davidite crystal. Inclusions of rutile mineral is very common in davidite indicating davidite crystallization later to that rutile.

Calcite shows two modes of occurrence viz. (1) as veins, cutting across the country rock and (2) as patches, filling interstitial spaces between grains. Calcite occurs as thin veins and veinlets, criss-crossing each other at many places. They cut across structural elements (such as foliation planes) of the country rock and earlier formed rock albite. This appears to have happened as calcite represents the final stage of hydrothermal activity and is the last phase of alteration, pervasive in all the encountered rocks. Some veins show coarse grained euhedral calcite grains showing low nucleation and high growth rate due to slow cooling. At places, calcite veins incorporate euhedral tourmaline grains. Tourmaline occurs as euhedral, prismatic and elongated grains. Silicification also occurred as vugs filling. Sericitisation of feldspar also observed at places.

Biotite bearing albitite is medium grained, pink to dark grey in colour, heterogeneous, very hard and compact in nature. Colour variation in rock is directly due to presence of the biotite content. The albitite have intruded into the metasediments such as quartz biotite schist and quartzite resulting specks and segregation of biotite content in albitite. Albite, quartz and biotite are the main minerals while plagioclase, chlorite and microcline are present only in minor quantity. Biotite flakes strongly oriented revelling the schistosity. Segregation of biotite at many places preserved foliation. Biotite bearing albitite shows brecciation along with number of fractures.

Under microscope, it is composed of albite, quartz, biotite as major mineral constituents and orthoclase, chlorite as minor minerals. The proportion of biotite is upto 20-30 % in rock which is also observed in rock sample. Other accessory minerals are rutile, zircon, hematite and tourmaline. The proportion of albite is higher as compared to orthoclase. Twinning was commonly seen in the larger albite grains, which also show remnants of their euhedral nature. The fine-grained albite is mostly rounded and generally anhedral. The eudedral grain of albite shows inclusion of biotite and quartz indicating later phase of albite.

Quartz biotite schist is medium to coarse grained, well foliated -defined by the general orientation of platy minerals. Quartz grains are anhedral to subhedral grain size varying from 0.1 mm to 1.0 mm, stretched parallel to the schistosity plane. Chloritisation of biotite and sericitisation of feldspars are the major alteration features observed in the rock. Minor silicification has also been observed. Grade of the rock is low as such we couldn't find any garnet or staurolite minerals, so these are low grade schist later intruder by basic body.

The optical examination indicates that fluids, primary inclusions are mostly biphase (L + V). They are oval to irregular in shape. The average size of primary inclusions (N=12) is 6.5 microns. The degree of fill of the primary inclusions on an average is 80 %. The size is enough to carry out thermometric studies (heating / freezing) on the sample later on. Fluids mostly came along intergranular margin of quartz hence, pseudo secondary inclusion along growth zone of quartz grain is abundant. The secondary inclusions are fine in size and occurs as trails. Pseudo secondary inclusions along the boundary of quartz will also indicate the later episode of fluids.

Geochemical studies of all lithounits recorded in the area has been carried out. Major element analysis of mineralized albitite rock revealed that silica (SiO₂) is the most abundant oxide and Al₂O₃, Na₂O, Fe₂O₃^t, MgO, TiO₂ and CaO are in decreasing order of abundance. CIPW norm calculation of mineralised and non mineralised albitite show that rock samples of albitite composed of predominantly albite (upto 85 %) along with K-feldspar, quartz and plagioclase. The rock is mostly mono-minerallic in nature with 70-85 % albite, which is also evident from petrographic studies and XRD results. Comparison between mineralised and non-mineralised rock have been carried out. High concentration of SiO₂, Al₂O₃ and Na₂O reflect that rock is relatively enriched in albite. CaO is also high in mineralised rock, due to intense calcitisation along fracture. Higher concentration of TiO₂ in mineralised rock shows rutile. Higher concentration of Ce, Ti and Y with U in mineralised rock shows radioactive minerals brannerite and Davidite.

Major element analysis of mineralized biotite bearing albitite rock indicate that silica (SiO₂) is the most abundant oxide than Al₂O₃, Na₂O, CaO, Fe₂O₃^t, MgO and TiO₂ and in decreasing order of abundance. U shows positive correlation with TiO₂, CaO and Ce, Y indicate presence of radioactive mineral Branneritte and Davidite respectively. U shows positive correlation with CaO while negative correlation with K₂O and Na₂O indicating uranium mineralisation is associated with calcitisation.

The sample analysed 736 to2474 ppm REE (avg. 1314 ppm), with LREE ranging from 669 ppm to 2272 ppm (avg. 1186 ppm) and HREE ranging from 64 to 220 ppm (Avg. 127 ppm). Chondrite normalized plot for albitite shows steeply sloping LREE and flat HREE pattern with strong negative Eu anomaly. The depletion of REEs has been attributed to various process including magmatic differentiation (Cuney and Friedrich, 1987), hydrothermal leaching (Cathelineau, 1987) and or a combination of both. The enrichment of LREE may be related to the presence of Davidite, Brannerite and Monazite. The negative Eu anomaly, suggesting removal of plagioclase or its absence during fractional crystallization (Neiva, 1992; Chappel et al., 1987), flat HREE profiles indicate absence of garnet and hornblende in the source (Chaudhri et al., 2003).

In the Ab-Or-An triangular plot of O'connor (1965) for feldspar, it is observed that mineralised and non-mineralised samples are rich in albitte and fall in trondhjemite filed of plot. Majority of the mineralised albitite samples plot in peraluminous field except some samples plot in metaluminous, whereas non-mineralised albitite plot in peralkaline in A/CNK vs A/NK plot (Shand, 1943). SiO₂ vs K₂O plot for plutonites (Peccerillo and Taylor, 1976) shows that magma was tholeiite series. (Batcher et al. (1985) used combination of elements as R1 vs R2 plot was R1=4Si-11(Na+K)-2(Fe+Ti) and R2= 6Ca+2Mg+Al to see tectonic setting of thr rocks. Almost all the samples of mineralised albitite plot in late orogenic field, while non-mineralised albitite falls in anorogenic to late orogrenic i. e. albitite rock is later orogeny setting. In SiO₂ vs Na₂O+K₂O plot for plutonites (Middlemost 1994) all samples fall in quartz monzonite to synite field.

An attempt has been made to establish relationship between granites in and around study area and albitite in the area. It has been observed that major oxide geochemistry of both are shows high Na₂O. They plot in peraluminous- metaluminous field in molar Na₂O-Al₂O₃-K₂O. Granite plot in WPG (with in plate granitoid) i. e. A type, anorogenic that were emplaced in an extensional non-compressive tectonic regime during a phase of cooling (Chaudhri et al., 2003). Rb-Ba-Sr ternary diagram shows that all the granite samples followed the trend of differentiation.

CHAPTER 9 CONCLUSION

In Geratiyon ki Dhani area, detailed geological mapping, study of surface and subsurface samples megascopically as well as microscopically and their characterisation based on mineral assemblages, grain size, texture, grain contact relationship, hydrothermal alteration, radioactive mineral phases, geochemical parameters are carried out as part of the present study. These studies resulted in the following outcomes/interpretations and conclusions.

- By detailed geological mapping over 2 sq km on 1:2000 scale and petromineralogical studies, dominant rock types identified in the area are feldspathic quartzite, quartz-biotite schist and calc-silicate, intruded by albitite, granite and amphibolite.
- Dominant alteration features in the area are calcitisation, chloritisation, ferrugenisation.
- Albitite is of igneous origin showing intrusive relationship with country rocks and lacks metasomatic textures.
- Albitite is the main host for uranium mineralisation. Davidite is the main radioactive mineral present, with Brannerite and U-Ti complex.
- Mineral paragenetic sequence indicates uranium mineralization is found to be associated with rutile and calcite. Further EPMA analysis of samples will be helpful for better understanding of genesis.
- Rutile mineral inclusions are common in davidite which indicates davidite crystallized later in ore paragenesis.
- Calcite represents the final stage of hydrothermal activity and is the last phase of alteration, pervasive in all the encountered rocks.
- The fracture density in mineralised part is about twice of that in non-mineralised part in albitite.

- Davidite and brannerite along with calcite and rutile precipitated by late phase of magma along the fracture.
- Davidite and brannerite contains significant REE, as observed by positive correlation of U with TiO₂, CaO, Y and Ce.
- The Uranium mineralization in Geratiyon ki Dhani area is magmatic-hydrothermal type associated with magmatic albitite rarely reported from world. Further fluid inclusion studies involving both heating and freezing experiments will aid in better understanding of the source and temperature of the mineralizing fluid.

Thus, as per its scope, the present study has shed light on the genetic aspects of mineralization and provided the local controls of mineralization at Geratiyon ki Dhani area. This study has helped in identification of guides for establishing further extension of mineralized body in the study area. It may be of immense help in planning of exploration adjacent areas in NDFB.

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