CHAPTER 1

INTRODUCTION

Rajasthan occupies a pre-eminent place in the geology of the Indian subcontinent. For her vast geological canvas extending from 3500 Ma to the Recent, a bewildering variety of igneous and metamorphic rocks and enviably rich and diverse mineral resources, the state of Rajasthan (erstwhile Rajputana) has been one of the most sought-after destinations for the earth scientists of varied interests. Bestowed with low to moderate altitudes, thin vegetation cover, excellent rock exposures and congenial climate, this state is geologically one of the most extensively studied regions of India. Ever since Heron (1917, 1923, 1953) laid the basic foundation of the geological framework of Rajasthan, innumerable geologists from India and abroad alike have made significant contributions to our understanding of the geology of this northwestern part of the Indian Shield. Although, the major divisions of the Precambrian rocks of Rajasthan into Banded Gneissic Complex, Aravalli Supergroup, Delhi Supergroup and Vindhyan Supergroup, and the broad geological framework proposed by Heron (op. cit.) have remained unchanged, many new facets of the geology of Rajasthan have been brought to light over the last fifty years. At the same time, some lacunae still persist, and many enigmatic problems have emerged that call for focused geoscientific investigations.

The proposed work on the granitoids and associated mafic magmatic rocks of the Delhi Supergroup around Khetri is an attempt in the direction of bridging a gap that persists in our knowledge of the Proterozoic geology of the Khetri Copper Belt (KCB). Despite excellent geological mapping, structural and metamorphic petrological investigations and exploration carried out in the Khetri Copper Belt, which forms an important copper province of India and despite the well-known fact that magmatic rocks
play an important role in metallogeny, no serious attempt has so far been made to investigate the petrology and geochemistry of the felsic and mafic magmatic rocks of this belt. Realising the paucity and importance of such data in understanding the evolution of the KCB, it was felt necessary to carry out detailed petrological and geochemical investigations of some selected granitoid bodies of this belt. Three such bodies, namely, those of Jasrapura, Gorwala and Gothara that intrude the rocks of Delhi Supergroup in the vicinity of Khetri were selected for this purpose.

1.1. LOCATION OF THE AREA

The area of investigation can be traced in the 2 cm to 1 km (1:50,000) Survey of India topographic sheet nos. 44P/12, 44P/16 and 45M/13, lying between N. latitudes 27°58' and 28°05' and E. longitudes 75°41' and 75°50'. The area enclosing the three granitoid bodies covers about 180 km² to the north and east of Khetri town in the Jhunjhunu district of Rajasthan (Fig. 1.1). Khetri (75°47'E; 28°00'N) is approachable by all weather metalled road from Delhi (180 km) and from Chandigarh (400 km).

1.2. PHYSIOGRAPHY AND CLIMATE

Physiographically, the area is characterised by long and narrow ridges striking NNE-SSW parallel to the regional strike of the rocks. The average altitude of the ridges varies from about 450 m to 750 m above MSL, whereas the ground level varies from about 340 m to 380 m above MSL. On a regional basis, the altitude of the ridges gradually decreases in the NE direction, which is also the direction of the regional slope. Hard rocks, such as quartzite, form the escarpments. Streams are seasonal. At some places dune sand fills the depressions between the ridges.

The average annual rainfall is about 25 cm, most of which takes place during the monsoon season from July to September. The vegetation is scanty, of which thorny bushes are common. The overall climate of the area is arid and hot. In summers the daytime temperature may shoot up to 45°C or more. Winter and spring are pleasant and suitable for field work.
Fig. 1.1. Location map of Khetri, district Jhunjhunu, Rajasthan, India
1.3. PREVIOUS WORK

The history of mining in this area is almost two-and-a-half millennium old. Abu-
1-Fazl has referred to the early mining activity around Khetri and existence of a mint for
copper coins at Singhana in his work ‘Ain-I-Akbari’ written in 1590 A.D. during the
reign of Emperor Akbar. The occurrence of numerous copper deposits led to extensive
exploration in this area from mineralisation point of view.

However, it was Hacket (1877, 1881) who first provided a broad geological
frame-work for this region. Hacket (1877) originally ascribed the rocks of the area to
Aravalli ‘Series’, which he subdivided into Alwar, Ajabgarh and Mandan ‘Groups’, but
subsequently, Hacket (1881) changed the nomenclature of Aravalli ‘Series’ to Delhi
‘Series’. Heron (1917, 1923, 1935) followed this revised nomenclature and divided
Delhi ‘System’ into Raialo, Alwar and Ajabgarh ‘Series’, but later on Heron (1953)
separated Raialo ‘Series’ from the Delhi ‘System’.

Das Gupta (1968) carried out detailed geological and structural mapping of the
Khetri Copper Belt (KCB) which he divided into North Khetri Copper Belt (NKCB)
and South Khetri Copper Belt (SKCB) to the north and south of Kantli river,
respectively. He divided the rocks of Delhi ‘System’ (now Supergroup) of the KCB into
an older, arenaceous, Alwar ‘Series’ and a younger, argillo-calcareous, Ajabgarh
‘Series’ (both now Groups). Recently, Gupta et al. (1998) proposed a new stratigraphic
frame-work for the KCB. They identified an Archaean (?) basement (Chakraborti and
Gupta, 1992) over which the Proterozoic cover sequences of the KCB, were
unconformably laid down.

Heron (1923) described the structure of the Khetri region as a series of elongated
and compressed anticlines and synclines trending NE-SW. Das Gupta (1968) described
two types of folds, the earlier two of which define the NE-SW trend and the last, cross-
folds, produce axial culminations and depressions. On the basis of detailed structural
analysis, Naha et al. (1988) recognised four phases of deformation in the NKCB,
producing NNE-SSW trending-isoclinal and reclined F₁ folds, open to overturned,
coaxial F₂ folds, chevron and conjugate F₃ folds and ENE/ESE-WSW/WNW trending
open, large wave length, subvertical F₄ folds giving rise to dome and basin structures. In
difference to the above, Gupta et al. (1998) suggested two main phases of deformation in NKCB and SKCB.

Aspects of metamorphism, related to the various phases of deformation during the Delhi Orogeny, have been discussed at length by Das Gupta (1961, 1962, 1968), Lal and Shukla (1975, 1978), Lal and Ackermand (1981), Basu (1982) and Gupta et al. (1998). The grade of metamorphism corresponds to amphibolite facies and hornblende-hornfels facies, which have been ascribed to kyanite-sillimanite type facies series in the SKCB and andalusite-sillimanite type facies series in the NKCB. According to Das Gupta (1968) and Basu (1982), thermal metamorphism induced by basic intrusions was followed by regional metamorphism related to deformation and syn-kinematic granitic intrusions which, in turn, were followed by retrogression. On the other hand, Sarkar (1973) and Sharma (1988) suggested that an earlier regional metamorphism related to D1 deformation was followed by thermal metamorphism related to D2 deformation and syn-kinematic granitic intrusions, while retrogression marked the end phase.

Das Gupta (1968) mapped and described the field relationships and broad petrographic characters of several granitoids of the KCB. These granitoids are structurally controlled, having been emplaced along the cores of anticlines or parallel to the foliation and occasionally along fault planes (Das Gupta, 1968; Bhattacharyya and Das Gupta, 1981; Bose, 1984; Gangopadhyay, 1987).

Felsic volcanic rocks comprising of fine laminated grey tuff, crystal tuff and pumice of dacitic to rhyolitic composition have also been reported from the KCB (Gathania and Golani, 1988, Golani et al., 1992). Several occurrences of albitites, intruding the Delhi metasediments and granitoids of the KCB, have been recorded in the recent years (Ray, 1987, 1990; Sinha-Roy et al., 1998; Jain et al., 1999; Sharma et al., 2000; Sinha et al., 2000; Yadav et al., 2000) all along the ‘albitite line’, which extends for ca. 170 km from Kishangarh to Khetri and further north. Unconfirmed occurrences of chloritised pyroxenites, hornblendites, nepheline syenites, carbonatites and fenites have also been reported from this zone (Basu and Narsayya, 1983; Ray, 1987, 1990).

The various aspects pertaining to the occurrence, exploration, controls and genesis of the copper and iron sulphide mineralisation in this belt have been
investigated earlier by several geologists (Dunn, 1943; Roy Chowdhury et al., 1962; Prasad Rao, 1963; Verma and Krishnanunni, 1963) besides several unpublished reports of the Geological Survey of India. Chalcopyrite, pyrrhotite and pyrite form the dominant sulphide ores in the KCB. The stratigraphic/lithological control is indicated by copper mineralisation at the Alwar-Ajabgarh interface, and structural control is manifested in the form of fracture fillings, replacement bodies and ore-shoots along shear zones and in the fold hinges (Roy, 1958; Roy Chowdhury et al., 1962; Roy Chowdhury and Das Gupta, 1965; Muktinath et al., 1968; Das Gupta, 1970; Ray, 1974; Banerjee, 1975, Sarkar et al., 1980; Basu, 1986; Sarkar, 2000; and others). However, difference of opinion prevails regarding the genesis of sulphide mineralisation in the KCB viz. hydrothermal origin (Roy Chowdhury et al., 1962; Prasad Rao, 1963; Roy Chowdhury and Das Gupta, 1965), syn-sedimentary diagenetic origin (Ray, 1974; Chandra Chowdhary et al., 1977; Sarkar et al., 1980; Sarkar and Das Gupta, 1980; Sarkar, 2000) and a volcano-sedimentary or volcano-exhalative origin (Basu, 1986; Golani et al., 1992). Recently, Deb (1999, 2000) has classified the Khetri Copper deposit as sediment-hosted-stratiform deposit (SHS) and Saladipura Fe-sulphide deposit as (mafic) volcanic-hosted massive sulphide deposit (VMS). U-Mo-Bi-Ba-F mineralisation is reported in the albitites, breccia, albitised pyroxenites and hornblendites all along the ‘albitite line’, and has been ascribed to Na-metasomatism and albitisation (Narayan Das et al., 1980; Ray, 1987, 1990, Jain et al., 1999; Sharma et al., 2000; Sinha et al., 2000; Yadav et al., 2000).

The radiometric age data available on the KCB are meager. Amongst the earliest of these are two K-Ar dates (~600 Ma) on phyllite and schist by Sarkar et al. (1964), and an apparent Rb-Sr whole rock date on the Chapoli granite (~1000 Ma) by Crawford (1970). Subsequently, Gopalan et al. (1979) determined an Rb-Sr whole rock isochron age of 1480 ± 40 Ma for Udaipurwati and Saladipura granites with re-equilibration of biotite at ~700 Ma. Several granitoids of the North Delhi Fold Belt (NDFB), that include the Seoli and Chapoli granites of the SKCB, do not yield reliable Rb-Sr ages, but generally lie between 1500 Ma and 1700 Ma reference isochrons (Choudhary et al., 1984). Gupta et al. (1998) have cited from an unpublished BRGM report, an Rb-Sr whole rock age of 1844 ± 7 Ma for the Jasrapura granite, and 208Pb/206Pb single zircon ages of ~1700 Ma for the Gothara granite and 1832 ± 3 Ma for felsic volcanics of the
SKCB, respectively. Galena from Saladipura sulphide deposit gave a Pb/Pb model age of 1780 Ma (Deb et al., 1989). The zircon from Chapoli granite, together with those from Ajmer-Barna granites of the South Delhi Fold Belt (SDFB), gave U/Pb upper intercept age of 1680 ± 12 Ma on the Wetherill concordia with lower intercept at 70 ± 17 Ma (Sivaraman and Raval, 1995). Thus, the age data on the rocks of KCB are too scanty and highly variable for any meaningful interpretation.

1.4. AIMS OF INVESTIGATION

The prime aim of the present work is to undertake detailed petrological and geochemical investigations of the Jasrapura, Gorwala and Gothara granitoids in order to precisely characterise them and to decipher their petrogenesis and petrotectonic environments. As a first step in this direction, the three granitoid bodies have to be remapped on an enlarged scale accompanied by investigation of their field relationships with the country rocks, including the metavolcanics as well as with the mafic dykes that occur within these granitoids.

The next step involves petrographic studies which are aimed at determining the textural and mineralogical characteristics and quantitative mineralogical composition of the granitoids in order to pigeon-hole these rocks in internationally acceptable classification as per the IUGS recommendations.

In order to achieve the prime objective, the major part of this work aims at generating high quality major, trace and rare earth element data and to utilise these data for geochemical characterisation of these granitoids, besides deciphering their overall geochemical behaviour, petrogenesis, trends of magmatic evolution and tectonic setting. These data are also likely to throw light on the nature of source and physical conditions of magma generation.

Although, this work is not aimed at detailed petrological and geochemical investigations of the mafic magmatic rocks, it is still proposed to analyse a few samples of the mafic rocks that occur within the granitoids as it can provide at least some preliminary information regarding the petrogenesis, magmatic evolution and tectonic environment of these rocks. Similarly, it is not within the scope of the present work to
go into the details of petrography and metamorphism of the country rocks. However, it is worthwhile to microscopically examine a few selected samples of the country rocks in order to obtain an overview of the nature of these rocks.

Finally, it is proposed to correlate the results obtained in the present work with those of the granitoids of the known tectonic settings in the world and to suggest a model for the petrotectonic evolution of the Khetri granitoids vis-à-vis the Delhi Orogeny.

1.5. METHODOLOGY AND APPROACH

1.5.1. Field investigations

Field work in the Khetri area was carried out during the winter and spring field seasons of 1998, 1999 and 2000. Although, the existing geological maps of Das Gupta (1968) were very helpful in the field, the granitoid bodies and their surrounding country rocks were remapped on 1:20,000 scale. The field investigations also involved regional traverses that helped in understanding the broad geology including stratigraphy and structure of the area, and the nature of country rocks. Detailed investigations were carried out to decipher the nature of the granitoids, their texture, structure and broad mineralogical composition, their relationship with the country rocks and the contact effects if any, of granitoids on these country rocks. The nature of the metavolcanics, occurring within the country rocks, and especially the mafic dykes that occur within the granitoids were also studied in detail. Fresh samples of the granitoids, approximately 5-6 kg in weight each, were collected at regular intervals to represent the spatial and compositional variations in the rocks. Samples of the mafic rocks, approximately 3 kg in weight each, were also collected for laboratory investigations. Metavolcanics and metasedimentary country rocks were also sampled for their petrographic studies.

1.5.2. Petrological investigations

The samples collected in the field were examined both megascopically and microscopically. Thin sections were prepared for petrographic studies that included deciphering the texture, structure, mineralogical composition and paragenetic
relationships amongst the various major and minor minerals present in the granitoids, mafic rocks and selected country rocks.

Forty-four thin sections of the granitoids were separately prepared and stained for modal analysis. The staining was carried out using standard staining techniques to distinguish between potash feldspar, plagioclase and quartz (Hutchison, 1974). The thin sections were etched with 48% hydrofluoric acid for about 15-20 seconds, then washed with distilled water, and finally dipped in saturated sodium cobaltinitrite solution for about 20 seconds, which imparted canary yellow stain to potash feldspar. The excess reagent was removed by rinsing the sections in distilled water. After that the thin sections were dipped in 5% barium chloride solution, rinsed with distilled water briefly, and then covered with a couple of drops of rhodizonic acid potassium salt. Consequently, the plagioclase developed brick red stain. Quartz remained unstained with both the reagents. The sections were finally rinsed in distilled water, dried and covered with cover slips.

For modal analysis of ferromagnesian and accessory minerals, unstained thin sections were also used. The modal analyses were carried out on Swift Point Counter at Geological Survey of India (GSI), Chandigarh. Approximately, 5000-6000 counts were collected for each sample. Volume per cent modal compositions of granitoids were determined from both stained and unstained thin sections of the selected samples.

1.5.3. Geochemical investigations

On the basis of careful petrographic study, a representative suite of 44 samples of the three granitoid bodies were selected for geochemical analysis, which included 13 samples from Jasrapura, 17 from Gorwala and 14 from Gothara granitoids. Likewise, 6 samples of the mafic magmatic rocks occurring within the three granitoid bodies were also analysed.

Before taking up the analytical work, it was ensured that the samples were free from contamination. To achieve this, the bulk samples collected in the field were repeatedly scrub-washed and dried. The clean and fresh samples, about 5 kg each of the granitoids and about 2 kg each of the mafic rocks, were reduced to 1 cm size with the
help of jaw-crusher and hand operated steel mortar and pestle. This was followed by grinding and powdering of the samples on the Retsch Vibratory Disc Mill using tungsten carbide and agate vessels. The magnetic impurities from the sample powders were removed by using bar magnet. In the next step, the powders were homogenised using a rotating Retsch Automatic Sample Homogeniser-cum-Divider. The process was repeated four times, remixing the octates every time. Finally, one-eighth of each homogenised powder sample was fine-ground on Retsch Vibratory Disc Mill and Retsch Centrifugal Ball Mill, with agate cup and balls. This procedure provided a representative and contamination free aliquot (about 0.3 kg-0.6 kg) suitable for whole rock geochemical analyses.

The determination of major oxides SiO₂, TiO₂, Al₂O₃, Fe₂O₃ (T), MnO, MgO, CaO, Na₂O, K₂O, P₂O₅, and the trace elements Sc, V, Cr, Co, Ni, Zn, Ga, Rb, Sr, Y, Zr, Nb, Mo, Sn, Ba, Pb, Th, U, for the granitoids and the mafic rocks, was carried out by X-ray fluorescence spectrometry (XRF) at the Mineralogical Institute, University of Würzburg, Germany (Courtesy: Prof. Dr. M. Okrusch).

All elements were determined from fusion discs. Each of the finally ground sample was dried at 105°C-110°C and mixed with Spectromelt A-12 (Merk Lithium metaborate 66/34) in a ratio of 1:6, i.e. 600 mg of sample plus 3600 mg Spectromelt A-12. Since total iron was determined as Fe₂O₃, 1500 mg of ammonium nitrate was added to ensure total conversion of Fe⁺² to Fe⁺³. Melting the mixture in a platinum crucible in 4 steps ensured complete fusion. The homogeneous, bubble-free melt was poured into a platinum disc mould and cooled in an air stream to form a glass disc.

All discs were analysed on a Philips PW 1480 XRF Spectrometer with Rh target tube, using Philips X 40 software. International reference standards were used for calibration and regression. Established detection limits for trace elements are: 5 ppm for Rb, Mo, Ni, Nb, Pb, Th, U; 10 ppm for Sc, V, Cr, Co; 15 ppm for Sn and 20 ppm for Ba. The relative error is 1% for major elements, and 5%-10% for trace elements, except where the concentrations of the trace elements are close to their detection limits. There is 20% error for Sc, Co, Ga, Pb, Th and 40% for Mo, Sn and U.
Fifteen (15) samples, covering the textural and compositional range of the three granitoid bodies, were analysed for REEs. The determination of 11 REEs (La, Ce, Nd, Sm, Eu, Gd, Dy, Er, Ho, Yb, Lu) was carried out at Institute of Mineralogy and Geochemistry, University of Cologne, Germany (Courtesy: Prof Dr. H.-A. Seck). The samples were digested in HF/HNO₃ adding Tm as a spike to check the recovery rate from the exchange columns. Cation exchange resin Dowex AG50W-X8, 200-400 mesh, from Bio-Rad, was used to separate the REEs from the other elements. The REE measurements were performed on the simultaneous ICP-AES Spectroflame using internal (BBR1-6) as well as international rock standards to check the accuracy. The total standard error varies between 5% and 10%, except for Ho (~ 20%).

Six (6) samples of the mafic rocks were analysed for some additional trace elements and REEs. The determination of 14 REEs (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) and the trace elements (Li, Rb, Sr, Y, Nb, Cs, Ba, Hf, Ta, Pb, Th, U) was carried out by ICP-MS at the Institute for Mineralogy, University of Clausthal, Germany (courtesy: Prof Dr. K. Mengel). For this, 100 mg sample powder was digested in sealed Teflon vessels with HF, HClO₄ and HNO₃ (2 ml each) for 10 hours at 180°C. The samples were heated to dryness to remove the remaining acids. HNO₃ (1ml) was added three times and subsequently evaporated. The residue was made 100 ml under addition of 2% HNO₃, 200 ppb Be, and 10 ppm each of In, Rh, and Re as internal standards. The REE and trace element measurements were carried out on the ICP-MS utilising the internal standards and USGS rock standard BHVO-1 to correct for instrumental shifts and matrix effects.

The field and petrographic observations and the data accrued from geochemical investigations of the granitoids and selected mafic rocks are presented in the respective chapters that follow. These data have been discussed, graphically depicted and interpreted in the light of investigations carried out on similar rocks in India and abroad. The results obtained in this work have far reaching petrogenetic and petrotectonic implications for the Khetri granitoids.