Chapter 5
Geochemistry : Major Elements

In the present chapter the geochemical characteristics of the alkali granites and the associated acid volcanics have been described. For this purpose, 20 representative samples (10 alkali granites, 4 rhyolites, 4 trachytes and 2 basalts) were analysed for major and trace elements by X-ray fluorescence. The aims of the present chapter are:

1. To establish comagmatic relationship between the alkali granites and the associated acid volcanics. The comagmatic relationship between the two has been indicated by the field, petrographic and mineral chemical studies.

2. To throw light on the nature of igneous suite to which these rocks belong.

3. To study the variations in the chemistry of these rocks.

4. To comment on the tectonic environment and post magmatic processes.

5. To deduce the pressure and temperature conditions of the formation and their bearing on the emplacement of the alkali granite and the associated volcanics.
5.1 NORMS

Overall compositional range can be seen from Table.

5.1. The normative composition are calculated. The D.I and A.I are also calculated.

As seen from the norm calculations, there is excess Na₂O₃ over Al₂O₃ for provisional albite, hence acmite and in some cases sodium metasilicate occurs in the norm.

The norms give us an idea of the silica saturation in the rocks. The rocks can be grouped as silica-oversaturated (Q+Hy in the norm), silica-saturated (Ol+Hy in the norm) and silica-understurated (Ol+Ne in the norm). Accordingly, the alkali granites, rhyolites and trachytes are silica oversaturated and the bāsalts are silica saturated.

5.2 PRESENTATION OF CHEMICAL DATA

In spite of various discussions on data appraisal and presentation, there is little agreement among petrologists as to the best method of graphically portraying chemical data for igneous rocks, hence the author follows the modern trend while discussing the chemical data and related parameters. Variation diagrams provide a useful way of synthesizing a large volume of analytical data which is clearly difficult to compare in tabular form. There are two main reasons for graphically portraying chemical data for igneous rocks:

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### Table 5.1 Chemical analyses and normative composition

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as a means of rock classification and naming
- as a means of portraying petrogenetic relations among rocks of different composition.

There are two ways of using the raw data of chemical analyses:

- either to use them as they are in binary diagrams. These diagrams portray best absolute concentrations, but in order to represent 'n' constituents in a rock n-1 plots are required.
- to transform them before using them in binary, ternary or more complicated diagrams. The ternary diagram presents one more constituent than can be represented in one Cartesian graph but ignores the absolute concentrations of the three variables and shows only the ratio of the constituents.

Since in the recent years there has been a prolific growth in the use of variation diagrams, the author has chosen and designed variation diagram with specific objectives.

a) Classification

As recommended by the IUGS subcommission summarized by Streckeisen (1976) the plutonic rocks of the area under study were classified according to the modal contents and are alkali feldspar granite (Fig. 3.1). Whereas in the case of volcanic rocks, the modal contents cannot be accurately determined in many cases because of the fine grain size or
the presence of glassy material. Hence, Le Bas et al. (1986) proposed a non-genetic classification using the total alkali-silica (TAS) diagram, and this is as nearly consistent as possible with the QAPF modal classification. The Goliya-Bhaylan acid volcanic rocks when plotted on the total alkali silica diagram (TAS) fall in the field of rhyolite and trachyte. The basic rocks fall in the field of basalt (Fig. 5.1).

b) Magma evolution

One of the most commonly used types of variation diagrams in igneous petrology is the Harker diagrams (Harker, 1909), in which the wt% of a constituent oxide is plotted against wt% SiO$_2$ as abscissa. SiO$_2$ has been chosen as abscissa as it has a reasonably wide range of values in the suite of rocks being studied, it is easier to visualise the differentiation trends, and it has a non-overlapping range of values in each fractionating mineral, though any other element or oxide which satisfies the above conditions can be chosen.

As the chemical parameters do not vary independent of each other, from these diagrams we come to know of geochemical 'coherence', that is to say, how many pairs of elements show strong correlation coefficient, either positive or negative.

Before discussing the petrogenetic significance of these diagrams it is, however, necessary to consider the
Fig. 5.1. The total alkali-silica (TAS) diagram.
'constant sum effect' which results from the fact that the major oxides taken together make up nearly 100% of a rock. For example, since SiO\textsubscript{2} is by far the most abundant constituent and varies between 50% and 70%, the sum of all the other oxides must fall from 50% to only 30% as SiO\textsubscript{2} rises. At least some negative correlations with SiO\textsubscript{2} (though not necessarily good correlations) are therefore to be expected among other oxides irrespective of petrogenetic considerations. Chayes (1964) gives an illuminating discussion of this topic. The variations are hence more visible for low than for high levels of silica. Hence, to overcome these problems, the author has chosen to portray the diagrams by the method advocated by Bonin (1986). This method allows the variations linked directly to silica to be limited and so enhances the secondary variations. This method has been justified mathematically by Bonin (1986) and a simple procedure is given below.

i) The raw analysis must be obtained where oxides + silica = 100.

ii) A new analysis must be made so that oxides = 100 and the silica content has been eliminated.

iii) The new value from (ii) is used for the oxide but for silica the original raw value from (i) is employed. The recalculated oxides have been indicated by an asterisk to distinguish from those that are not.
Fe₂O₃, FeO, MgO and CaO decreases as silica increases and are essentially those that enter into the composition of basic rocks rather than in the acid rocks, whereas Al₂O₃, Na₂O and K₂O increases with silica; and they enter into the composition of alkali feldspars. Some oxides vary little because of their low amounts such as TiO₂, MnO and P₂O₅ though TiO₂ and P₂O₅ appear to decrease with increase in silica content. The scatter of data seen for Fe₂O₃ and Al₂O₃ seen for all rock types is probably due to subsolidus modifications. According to Bonin and Lameyre (1978) the linear but opposed patterns of CaO and Na₂O in alkaline rocks and the fact that Na₂O+CaO remain more or less constant, can be explained on the basis of an identical amount of plagioclases with basicity diminishing during the course of differentiation (Fig. 5.2).

Another commonly used variation diagram for magma evolution is the plot of differentiation index versus oxides. Thornton and Tuttle (1960) suggested to plot the oxide weight % of elements against D.I., a sum of normative quartz, albite, orthoclase, nepheline, leucite and kaliophilite. These are the minerals of the "petrogeny's residua system". Since no more than three of these normative minerals will appear in any given norm, the differentiation index is simply the sum of the percentage of three normative minerals. The D.I. is based on the simple petrogenetic idea that in all crystallization the constituents of 'petrogeny's
residua system' will become concentrated in the residual liquid, since these are the minerals which begin to crystallize in general only at low magmatic temperature.

Silica, alumina, soda, potash and iron show scatter of data, whereas CaO, MgO, TiO$_2$ and P$_2$O$_5$ define linear trend. This pattern is in agreement with non-orogenic suite in general (Martin and Piwinskii, 1972). The development of peralkaline felsic rocks in non-orogenic assemblages contributes to the scatter in Al$_2$O$_3$, Na$_2$O, K$_2$O and Fe$_2$O$_3$ at high D.I. values. At high D.I. interval 70 to 90, MgO and CaO are practically constant and are present at trace levels (Fig. 5.3.).

c) Chemical nature

i) Alkalinity

Miyashiro (1978) proposed a classification of magmatic series based on Na$_2$O+K$_2$O/SiO$_2$ content, separating an alkaline series from those that are subalkaline (tholeiitic and calc-alkaline) for the volcanic rocks, using the range of SiO$_2$ content lying between 40 and 75%. This diagram was later modified by Bonin (1986). He separated the two fields by a straight line between 45 and 80% silica content, the general equation being (Na$_2$O + K$_2$O)* = SiO$_2$-42 (asterisk indicates recalculated oxide). He suggests that the diagram may be extended to plutonic rocks as well. His arguments centres around the presence of acid and basic dykes (which excludes the existence of cumulates) and the
Fig. 5.3. D.I. vs K2O

Fig. 5.3. D.I. vs P2O5

Fig. 5.3. D.I. vs Al2O3

Fig. 5.3. D.I. vs MgO

Fig. 5.3. D.I. vs CaO
presence of plutonic rocks identical to Corsica in an oceanic realm and low Sr isotopic ratio (which indicates little or even no crustal involvement).

A plot of the data reveals that they fall in the alkaline domain. This magmatic association belongs to the Coomb's line which leads from normative hypersthene basalts to alkaline rhyolites (and granites) (Coombs, 1963). Many volcanic associations genetically related to continental rifting in the Red Sea-Afar region appear to belong to the Coombs trend e.g Aden area (Cox et al., 1970) and Boina area (Barberi et al., 1972, 1975).

This magmatism belongs to alkaline series because of its alkaline content, in spite of presence of normative hypersthene in the basalts (Fig. 5.4).

A plot of CaO plus Al₂O₃ vs FeO + Fe₂O₃ shows steady increase of iron with decrease in alumina plus calcium or increasing peralkalinity (Fig. 5.5). This supported by textural relationships, which clearly indicate alkali amphiboles and pyroxenes have formed very late.

K₂O/MgO diagram

This diagram described by Ghuma and Rogers (1978) (in Rogers and Greenberg, 1981) uses the ratio of the most lithophilic major element (K) and the most mafic component (Mg) to provide maximum separation of calc-alkalic from alkali granite suite. SiO₂ contents are plotted against
\[ \log_{10} \frac{K_2O}{MgO}. \]

The \( K_2O \) and \( MgO \) values are taken as weight percent. A perusal of the diagram shows that the Goliya Bhaylan granite falls in field of alkali granite. And are greatly displaced towards high \( K_2O/MgO \) ratio (Fig. 5.6). The trend for the Sierra Nevada batholith falls in the calc-alkalic and alkali granite fields. The Sierra Nevada batholith is one only investigated assemblage that spans both fields and it shows a change of slope at the boundary.

**Alkaline-aluminium-iron diagram**

When the present data are plotted on this diagram with matching normative facies (Bonin, 1986), they fall in the facies of \( Ac+Mt \), the evolution towards peralkalinity is controlled by the proportion of \( Fe_2O_3 \) to \( Al_2O_3 \), while the alkalies remain practically constant (Fig. 5.7).

**Na-K-Al diagram**

To demonstrate the different roles played by Na and K, the data are plotted on the diagram as suggested by Bonin (1972) where one is a field where sodic feldspar dominates, the other where potassic feldspar has the role. The two fields are each further cut into two by the \( Al_{50} \) line of alumina saturation. These rocks fall in the sodic feldspar domain. The alkalinity is essentially controlled by the proposition of \( Al \) to \( K \) with a slight increase in \( Na \). This relationship is expressed by the presence of hyperalkaline coloured minerals (Fig. 5.8).
Fig. 5.4. Position of Goliya-Bhaylan rocks on modified Miyashiro's diagram (Bonin, 1986)

Fig. 5.5. CaO plus Al2O3 versus FeO plus Fe2O3

Fig. 5.6. Plot of SiO2 vs Log10 K2O/MgO
Fig. 5.7. Na+K - Fe - Al diagram (atom %).

Fig. 5.8. Na - K - Al diagram (atom %).
The evolution of a liquid toward peralkalinity depends largely on the relative proportions of Ca, Al and (Na+K), and a ternary plot of these components gives a highly simplified but instructive picture of the development of peralkalinity. As seen from the diagram, Ca remains constant and the evolution towards peralkalinity is essentially controlled by the ratio of aluminium to alkalies. The distribution of the chemical compositions of the basalts, trachytes and granites within the diagram shows that the granitic and syenitic (trachytic) fields are contiguous but the gabbro (basalt) is separated from both by a hiatus which corresponds to the Daly gap (Fig. 5.9).

ii) Iron enrichment

Though triangular AFM diagram (A=Na$_2$O+K$_2$O, F=FeO+Fe$_2$O$_3$, M=MgO) is useful for distinguishing between tholeiitic and calc-alkaline differentiation trends in the subalkalic magma series, basing petrogenetic conclusions has the following limitations (Wright, 1974):

- For most rocks the oxide combined in the AFM diagram comprise less than 50% of the rock. SiO$_2$, Al$_2$O$_3$, CaO, and TiO$_2$ are ignored and the Na$_2$O/K$_2$O ratio is obscured. These may be very important in comparing igneous rock compositions and in evaluating differentiation mechanisms.
Normalizing to 100% sums that are not all the same (e.g. A+F+M for dacite = 15%, for basalt 40%) distorts the plotted values; trend orientations do not quantitatively express specific mineral control as they do on oxide-oxide variation diagrams.

Thus, one cannot adequately interpret a genetic relation using just the AFM diagram. To be sure all rocks that are genetically related will show a "trend" on an AFM diagram but the converse is not true: rocks that are unrelated may also show a trend.

A detailed discussion of the limitations of AFM diagram with reference to alkaline rocks has been provided by Bowden et al. (1984). They have discussed that the AFM diagram suffers from a major disadvantage that in any marked alignment of points representing iron enrichment has been referred to in the literature as tholeiitic. This is not the only criterion for the recognition of tholeiitic series (c.f. Jakes and White, 1972) and has led to misconceptions. For instance, one of the characteristic features of alkaline granites and related rocks is also their enrichment in iron. Geochemically this effect has led to confusion in classification particularly when an AFM diagram is consulted. Most alkaline granites lie on so called "tholeiitic trend". In order to avoid confusion, they have suggested that the tholeiitic series of granitoid rocks should be restricted to compositions lacking K-feldspars and
biotite. Both oceanic (plagiogranites) and continental tholeiitic granitic rocks (granophyres) are known, but their volumetric proportions are small. As can be seen from the AFM diagram (Fig. 5.10), the remarkable lack of rocks intermediate between gabbros and syenites (between basalts and trachytes) has been called the "Daly gap". It appears in the statistical bimodality of rock populations that belong to anorogenic provinces (Martin and Piwinski, 1972). Recently, this has been explained by Bonin and Giret (1990). According to them, in the plutonic ring complexes emplaced at shallow levels in the crust, the common association of cumulative mafic rocks with felsic rocks derived from liquids can be explained if intermediate magmas (e.g. from monzogabbro = hawaiite to monzonite = benmoreite composition) have been trapped in crustal magma chambers (depths of about 15-25 Km), in which they have evolved by Assimilation Fractional Crystallization (AFC) processes. The probability of the existence of intermediate liquids in the mantle is high, as numerous occurrences of mantle xenoliths in intermediate (from hawaiite to benmoreite) alkaline volcanic formations have been documented. They have argued that density, not viscosity, is the major physical parameter controlling the ascent of magmas. Because of their buoyancy, moderately viscous and continuously evolving intermediate magmas can reach by diaparic ascent the ductile-brittle boundary in the crust and fill up magma chambers. Then,
Fig. 5.9. The CaO - Na2O+K2O - Al2O3 diagram (oxide wt%).

Fig. 5.10. AFM diagram (oxide wt%).
Felsic residual liquids are produced and can move up only if fractures are open in the brittle crust, mainly by fluid overpressure and/or cauldron subsidence.

The passage from gabbros (basalts) into syenites (trachytes) can be explained on the basis of a fractionation of calcic plagioclase and the more magnesian pyroxenes (Bonin and Giret, 1984). This corresponds to a sharp drop in CaO and MgO on the oxide silica diagrams. The passage from syenites to granites can be explained by a crystallization of ferriferous coloured minerals (fayalite, hedenbergite) and corresponds to decrease in Fe$_2$O$_3$ linked to an increase in Na$_2$O.

The alkali granites and the associated acid volcanics show an extreme enrichment in iron and the Fe/Mg ratio is extremely high (Fig. 5.10). This is supported by mineral chemical studies which confirms the presence of iron rich alkali amphiboles and pyroxenes.

iii) Alumina saturation

Shand (1927), in developing the principle of alumina saturation devised the now classic division of peralkaline (K$_2$O+Na$_2$O>Al$_2$O$_3$), metaluminous(K$_2$O+Na$_2$O< Al$_2$O$_3$< K$_2$O+Na$_2$O+CaO) and peraluminous (Al$_2$O$_3$>K$_2$O+Na$_2$O+CaO) all on molecular basis. A plot of A/CNK as a function of SiO$_2$ wt % (Fig. 5.11) shows that the granites and the associated acid volcanics rocks are metaluminous but are peralkaline according to agpaitic index (K$_2$O+Na$_2$O/Al$_2$O$_3$). There are two
samples of granites M 53 and G 98 of A.I. 0.98 and 0.95 respectively and one sample of rhyolite M 67 which has A.I. of 0.97. Although agpaitic index of 1 or more has long been considered as an index of peralkalinity, Giret, Bonin and Leger (1980) have shown that values as low as 0.9 can be appropriate for distinguishing peralkalinity. This is also indicated mineralogically by the presence of alkali amphiboles and pyroxenes and a A.I. of about 0.95 is the distinction of peralkalinity in these rocks. It may be pertinent to mention here that in those granites where the A.I exceeds 1.2, generally aenigmatite is observed.

The Goliya Bhaylan rocks when plotted on the KN/C \((K_2O+Na_2O/CaO\) versus \(SiO_2\)) diagram, the samples fall between KN/C ratio of 6.61 to 38.00 (Fig. 5.12.). The Goliya Bhaylan rocks contain only 0.09 to 1.01 % CaO. According to Clemens et al. (1986) there is a wide crystallization interval between plagioclase saturation boundaries and the solidus \((>100^\circ C)\) (Fig. 5.13). Thus, a small degree of plagioclase fractionation at elevated temperatures during early stages of crystallization would greatly deplete the melt in CaO. This effect, coupled with high Na\(_2\)O/K\(_2\)O and early crystallization of K-feldspar, means that two feldspars (plagioclase + orthoclase) would soon be replaced by a single feldspar during crystallization. The product of such processes are the hypersolvus granites of Tuttle and Bowen
Fig. 5.11. A/CNK (molecular ratio) as a function of SiO\textsubscript{2} (wt%).

Fig. 5.12. KN/C (molecular ratio) versus SiO\textsubscript{2} (wt%).
Fig. 5.13 Isobaric (1 kbar) $T$ vs. melt water content diagram showing the experimentally determined crystallization phase relations of the Watergums A-type granite. The phase-saturation boundaries are labeled with the appropriate mineral abbreviations.
(1958). It is for this reason that all these rocks have phenocrysts of only alkali feldspar and no plagioclase.

d) Tectonic environment

Batchelor and Bowden (1985) have enlarged the scope of de la Roche et al. (1980) R1-R2 multicationic diagram and have represented the whole spectrum of magmatic activity during and after orogenic cycles and have identified definite zones with known tectono-magmatic associations. The chemical data of the Goliya Bhaylan rocks, when plotted on this diagram show anorogenic trend (Fig. 5.14). Maniar and Piccoli (1989) presented various discrimination plots based on major element chemistry which sequentially discriminate the different tectonic environments. The suite under study has a bimodal distribution of SiO₂ and only Rift Related Granitoid (RRG) and Continental Epeirogenic Uplift Granitoids (CEUG) are known to have bimodal distribution whereas granitoids from other tectonic environments are known to have unimodal distribution. Discrimination between RRG and CEUG is possible using TiO₂ versus SiO₂ plot as suggested by Maniar and Piccoli (1989). RRG have higher TiO₂ value than do the CEUG, though there exists some overlap between the two fields. A plot of the data shows that they fall in the CEUG field (Fig. 5.15). These are in general agreement with the geotectonic history of the area.

The CEUG rocks are associated with continental areas which have experienced epeirogenic crustal uplift with
no subsequent development into a rift. This uplift is possibly due to hot-spot activity or an aborted rifting event. No associated orogeny is recognized during this time period and the only tectonic disturbance is the epeirogenic uplift of the crust.

e) Nature of Igneous suite

Na$_2$O vs K$_2$O diagram

In the Na$_2$O-K$_2$O plot, for granitoids (Hine et al. 1978), the Goliya Bhaylan granites neither plot in the S-field nor in the I-field (Fig. 5.16). These samples have chemical characteristics distinct from the I and S type granites designated by Chappel and White (1974) or the 'magnetite series' and 'ilmenite series' proposed by Ishihara (1977). These granites have chemical characteristics typical of A-type granites (Loiselle and Wones, 1979). Compared with typical I-type granitoids of similar silica content, the A-type granites contain lower abundance of MgO, CaO, TiO$_2$ and P$_2$O$_5$ but high K$_2$O and Na$_2$O. The most significant chemical feature is that slight differences in the molecular ratios of Na + K to Al can produce striking changes in the mineralogical composition of the suite. According to apatitic index Goliya Bhaylan granites are classified as alkaline.

A comparison of the various types of granitoids and the chemistry of the major elements and the related parameters are given in the tabular form (Barbarin, 1990) (Table 5.2).
Fig. 5.14. Position of Goliya-Bhaylan granites on the R1-R2 diagram (Batchelor and Bowden, 1985).

Fig. 5.15. TiO₂ versus SiO₂ plot of Maniar and Piccoli showing the fields of RRG and CEUG (1989).

Fig. 5.16. Na₂O-K₂O diagram showing the fields of I-type and S-type granites.
Chemistry

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(x: low; xx: medium; xxx: high).

'C<sub>ST</sub>' (Crustal Shearing and Thrusting) groups: intrusive two-mica leucogranites associated with major crustal movement occurring during a collisional event.

'C<sub>CA</sub>' and 'C<sub>I</sub>' (Crustal Collisional - Autochthonous or Intrusive) group: peraluminous, either autochthonous or intrusive, biotite-rich and alumina-silicate-bearing granitoids formed during a collisional event.

'H<sub>LO</sub>' (Hybrid Late Orogenic) groups: calc-alkaline, potassic and often K-feldspar-porphritic monozogranites emplaced during post-collisional uplift.

'HA<sub>CA</sub>' (Hybrid Continental Arc) groups: hornblende-rich, calc-alkaline granodiorites and tonalites emplaced in a continental margin above an active subduction zone.
'TIA' and 'TOR' (Tholeiitic Island Arc and Tholeiitic Oceanic Ridge) group: tholeiitic granitoids associated with island arc or oceanic ridge volcanics.

'A' (Alkaline) group: anorogenic, alkaline (and exceptionally peralkaline), perthite-rich and frequently alkaline amphibole and pyroxene bearing granitoids associated with enclastic up-doming or rifting. On the basis of the above parameters the granites of the Goliya Bhaylan area are classified as alkaline type.

f) **Post magmatic processes**

The oxidation ratio (molecular ratio \(\frac{2Fe_2O_3}{2Fe_2O_3+FeO} \times 100\)) is plotted as a function of D.I., it varies in alkali granites from 44.00 to 96.94, in rhyolites from 91.08 to 96.95, in trachytes from 21.09 to 89.06. At the D.I. interval of 70-90, it shows scatter of data (Fig. 5.17). This is mainly due to the presence of oxidized mineral species like aegirine, magnetite where most of the iron is in the \(Fe^{3+}\) state (i.e. \(Fe_2O_3\)) (as shown by mineral chemical data). The variation in \(P_{O_2}\) is being regarded due to the hydrothermal fluids which accompanied crystallization of the magma.

Some of the samples are depleted in \(Na_2O\) as compared to \(K_2O\). This is mainly due to post-emplacement alkali modifications. (Kochhar et al., 1988).

Bowden et al. (1990) plotted the major element data in a modified Q-P diagram (Bowden and Kinnard, 1984). The
alkaline saturated (ALKS) and alkaline oversaturated (ALKOS) trends were transposed directly from Debon and Le Fort (1988) by them. They had superimposed on the magmatic lineage, subsolidus modifications. When our data is plotted on their diagram they show potassic hydrothermal metasomatic trend (Fig. 5.18). The presence of ferroactinolite (indicated by mineral chemical studies) has been suggested as a mineralogical criteria for potassic metasomatism in alkaline ring complexes by Bowden et al. (1987).

**g) Pressure and Temperature conditions**

Qz-Or-Ab-An-H$_2$O system: Estimates of temperature, pressure and fugacity of H$_2$O, O$_2$ and other volatiles in anorogenic granites involve a number of different approaches. One of the more classic approaches has been the comparison of normative rock compositions with the experimental work in the system qz-or-ab-an-H$_2$O, a compilation in the form of grid for all existing minimum melt points over a range of pressure and Ab/An ratio has been utilized by Anderson (1983), Anderson and Cullers (1978).

In application, the composition of undifferentiated portions of plutons that have changed little since fusion, can be utilized to estimate the depth of fusion. Likewise, extremely differentiated granites should depict a trend toward or cluster at an appropriate minimum for their level of emplacement. Such applications require a number of
Fig. 5.17. Oxidation ratio versus Differentiation index.

\[ Q = \frac{Si}{3} - \frac{(K+Na+2Ca)}{3} \]

- Alkali granite
- Rhyolite
- Trachyte
- Basalt

Fig. 5.18. Q - P cationic diagram (Bowden, 1990) (in milliequivalents).
assumptions and it is unlikely that a given granitic pluton should satisfy all these conditions.

Anorogenic granites, due to their intrinsic leucocratic composition, may be more appropriate for such an application except for their relatively dry, fluorine rich nature. The displacement of minimum melt composition for wet versus dry melting may be subparallel to the isobaric liquid melt (Luth, 1969). The shift of minima due to fluorine (Manning, 1981) which is towards the Ab corner will affect most of the differentiated granite and thus make the emplacement depth a minimum. According to Kovalenko et al. (1970) the composition of fluorine rich granites lie close to the minima for the system qz-ab-or at high PH₂O (up to 10 kb). The normative qz-ab-or components of Goliya Bhaylan granites when plotted on the diagram cluster between pressure 0.5 to 1 kb which can be regarded as approximately equivalent to rock pressure at the depth of 2 to 4 km, consistent with the clear epizonal nature of these plutons (Fig. 5.19). The presence of perthites in these granites suggest that the temperature of magma generation was higher than 660°C.

The above study establishes that Goliya Bhaylan granites and the associated acid volcanics are of A-type. When compared with I- and S- type granites of similar silica content they are low in CaO, MgO and high in SiO₂, Na₂O+K₂O, Fe/Mg. The comagmatic relationship between acid volcanics and alkali granites is further indicated by the
Fig. 5.19. Normative quartz, albite, and orthoclase of Goliya - Bhaylan granites and comparison to experimental minimum melt compositions.
major element chemistry. These rocks are peralkaline according to agpaitic index and are emplaced in an anorogenic environment and exhibit bimodal nature. The rock chemistry shows evidence of hydrothermal alteration and subsolidus modifications. The temperature of magma generation is estimated to be about 660°C at an estimated depth of 2 to 4 km (0.5 to 1 kb), consistent with the clear high level nature of these plutons.