# CHAPTER VII

## SPILITIC ROCKS OF THE KUSMA-PHALEBAS AREA

### GENERAL

The basic volcanics occur in the close association with the rocks of Kusma Quartzites and Balewa Formation north of the Phalebas Thrust. They form lensoid bodies consistently concordant with the country rocks, varying in thickness from few metres to as much as 30 to 40 metres.

These basic rocks have been variously described by the previous workers. Nadgir & Nanda (1966) named them as epidiorites, and attributed them much stratigraphic significance in their Suparitar series. Dealing with the nature of the epidiorites, these authors have written

(1966, pp. 11), "No intrusive relation seems to exist, and the occurrence of the quartzite-basic rock association over vast area points to the basic rocks being lava flows. It is difficult to say whether the flows are sub-marine or sub-aerial. No pillow structures are seen but the frequent occurrence of green chlorite-quartzite and cryptocrystalline limestone bands as interbands in the basics may indicate mixing of terrigenous sand with tuff and the flows may be partly marine and partly sub-aerial".

On the other hand, Fuchs (1967), Fuchs & Frank (1970) and Frank & Fuchs (1970), described these basic rocks as metadiabases and postulated that the presence of basics in the quartzite facies is the characteristic of Chail series in Central and Western Nepal. According to the above authors, these metadiabases were poured under sub-volcanic to volcanic conditions.

Though these basic rocks were recognised as an important stratigraphic marker horizon (Nadgir & Nanda, 1966, and Fuchs & Frank, 1970), in the rocks of Central and Western Nepal, little emphasis was given to their exclusive studies. None of the previous workers worked out the nature, mineralogy and chemistry of these rocks and as such different terminologies were applied to describe these rocks. The present author, after a detailed field investigation and laboratory studies (viz. mineralogy, textural relationship and the chemistry) has come to the conclusion that the basic rocks of the study area show striking similarity with spilites.

The spilitic rocks of the study area, though considerably sheared and incipiently metamorphosed, exhibit igneous congruent fabric, both in texture and mineralogy. The author collected and studied a number of representative samples from the study area, and thus is in a position to distinguish between the spilites of coarser diabasic type and finegrained aphanitic basaltic type. Mineralogically, these spilitic rocks are characterised by minerals like chlorite, uralite, epidote and calcite. The feldspar, which forms the major constituent is invariably albitic - fresh and unaltered, exhibiting a primary nature. Texturally, less sheared spilitic rocks reveal ophitic to sub-ophitic and intersertal textures. Chemistry of these rocks also points to their spilitic nature.

## MODE OF OCCURRENCE

The spilitic rocks are found to occur in the quartzites and gritty quartzose phyllitic rocks, north of Phalebas Thrust, as concordant lenses ranging in extension from 100 m to as much as several km, with varying thickness. The frequency of the spilitic rocks (as lenses) is high in the quartzites of Kusma Quartzites and low in the gritty quartzose phyllites of Balewa Formation. On the basis of distribution, the spilites of the area can be divided into two distinct divisions i.e. spilitic rocks of the southern belt running more or less parallel to Phalebas Thrust and of the northern belt running along Kusma Reverse Fault. Obviously these spilitic lenses occur in the same stratigraphic position, the existing distribution being due to the repetition of the same stratigraphic sequence due to the Kusma Reverse Fault.

## NATURE AND PETROGRAPHY

In the field, the volcanics show a dark green colour and somewhat foliated appearance. The sheared variety show metamorphic foliation similar to country rocks, and are quite fissile, thus resembling green chlorite schists. The quartz and epidote veins are seen invariably cutting these rocks. Along the quartz vein and also in the spilitic rocks, sulphide mineralisation is very frequently noted. Pyrite cubes are also quite conspicuous, whereas galena and chalcopyrite occur only along the quartz vein.

In general way, spilitic lenses are schistose and finegrained at the contact with the country rocks and tend to become gradually massive and coarser towards the median parts of the lenses. The lenses of tuffs in the quartzites have been highly sheared and appear as green schists. The quartzitic rocks at the contact with such tuffaceous layers are green and chloritic. The microscopic studies of such quartzites reveal the mixing of tuffaceous materials with the quartzites. In all the spilitic lenses, it is very interesting to observe numerous calcite layers of sizable thickness (1 cm to 20 cm).

The nature of the spilitic lenses - concordant relationship with the country rocks, occasional tuffaceous layers, mixing of the tuffaceous material with the country rocks etc. reveal the volcanic to sub-volcanic character of these basics. The absence of pillow structures might be due to the shallow depth of the depositional basin. Fiala (1966, pp. 25), has shown that the relative abundance of tuffs and absence of pillow structure is indicative of the eruption of basic rocks under shallow marine conditions.

On the basis of petrographic characters, the spilitic rock has been classified into following three types:

1. Spilitic diabase
2. Spilitic basalt
3. Spilitic tuffs

Megascopically, the diabase is somewhat difficult to distinguish from the basalt. The tuffs, however, are recognised by their intimate mixing up with clastics near their contacts with the overlying sediments.

<u>Spilitic diabase</u>

Megascopically, these are coarse grained, dark green to greyish green coloured, massive and compact rocks. The sheared variety is cleaved. In hand specimen, only green coloured chlorite and needles of uralite with occasional phenocrystic feldspar can be identified. Pistachio green coloured grains and veins of epidote are the other megascopically recognisable components of the rock. Vesicles and vesicular infillings are rare.

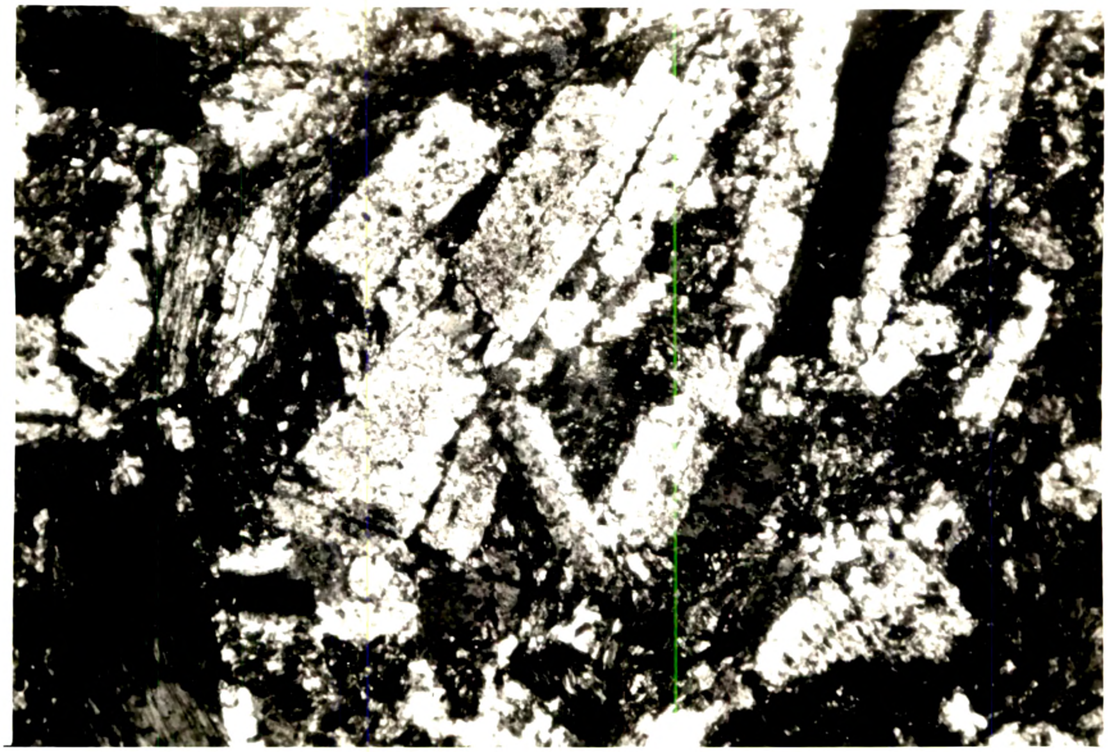
In thin section, the diabase shows (i) ophitic to sub-ophitic (Plate No. VII.1) and (ii) intersertal textures (Plate No. VII.2). Laths of plagioclase are seen embedded in a groundmass that consists of chlorite, uralite, and epidote, sphene, leucoxene and skeletal ilmenite are the usual accessory minerals. Deformed samples show bending

The texture should be described as blasto-ophitic

PLATE VII.1

Photomicrograph of spilitic diabase showing ophitic to sub-ophitic texture (crossed nicols X 60).

PLATE VII.2



Photomicrograph of spilitic diabase showing intersertal texture (crossed nicols X 60).

and breaking of feldspars and development of a cleavage marked by chloritic streaks.

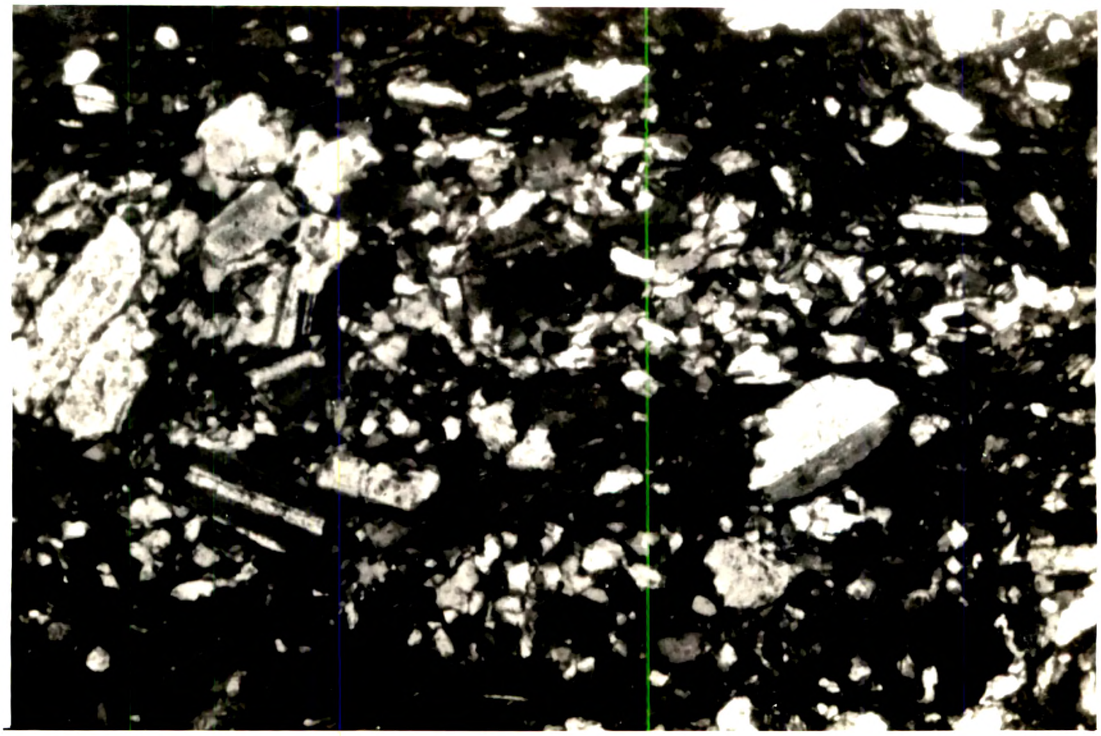
Spilitic basalt

These are obviously the finegrained equivalents; typically show a fine basaltic texture (Plate No. VII.3) - tiny laths of plagioclase (Albite) randomly embedded in a groundmass that essentially consists of calcite and chlorite. The texture can be referred to as fine intersertal (Plate No.VII.4). Calcite seems to be invariably present. Other minerals are sphene, epidote, leucoxene, skeletal ilmenite and pyrite. Amygdaloidal cavities and vesicles filled with chalcedonic silica, calcite, epidote and chlorite are quite frequent.

Spilitic tuff

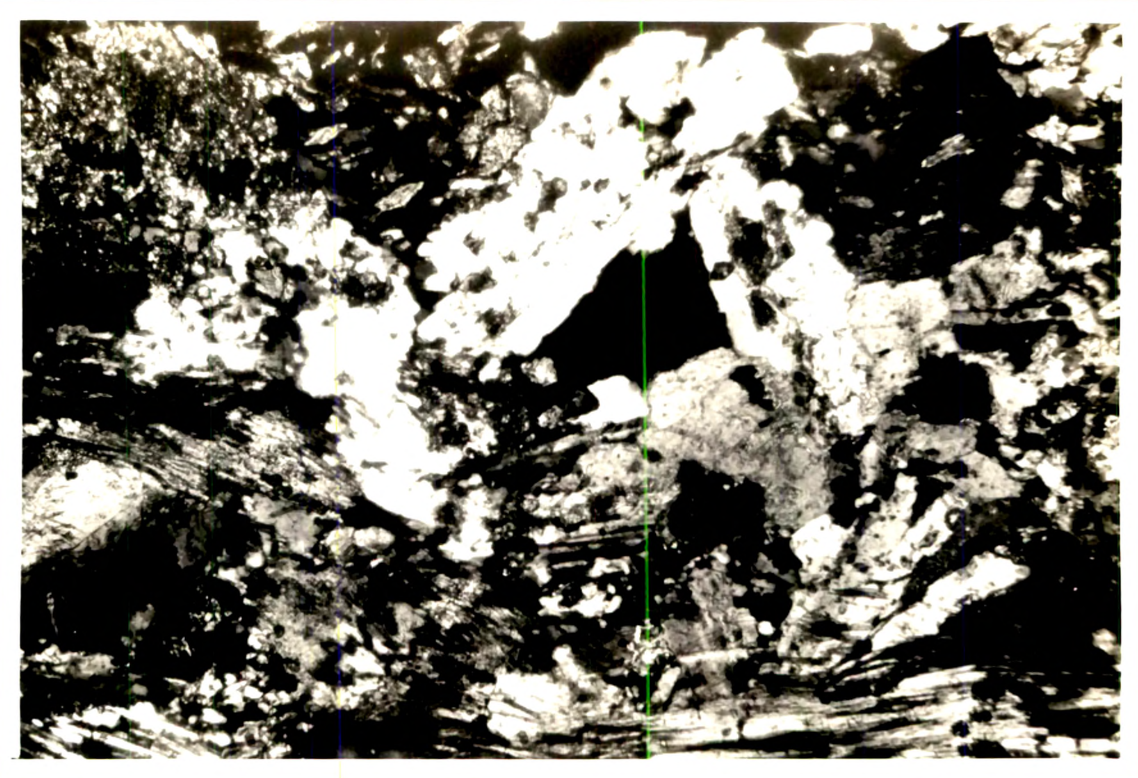
Megascopically, the tuff is a green to greyish green coloured finegrained rock. In hand specimen, chlorite is the only recognisable mineral. Pyrite cubes are invariably associated with these rocks. It is always cleaved and resembles chlorite schist in the field. Its contacts with the sedimentary cover, invariably shows a mixing up of volcanogenic and clastic material (= Tuffite).

PLATE VII.3



Photomicrograph showing textural characters of spilitic basalts (crossed nicols X 200).

PLATE VII.4



Photomicrograph of spilitic basalt showing intersertal texture (crossed nicols X 200).

The term basalt can not be applied to these rocks which are metamorphosed as per description of the candidate.

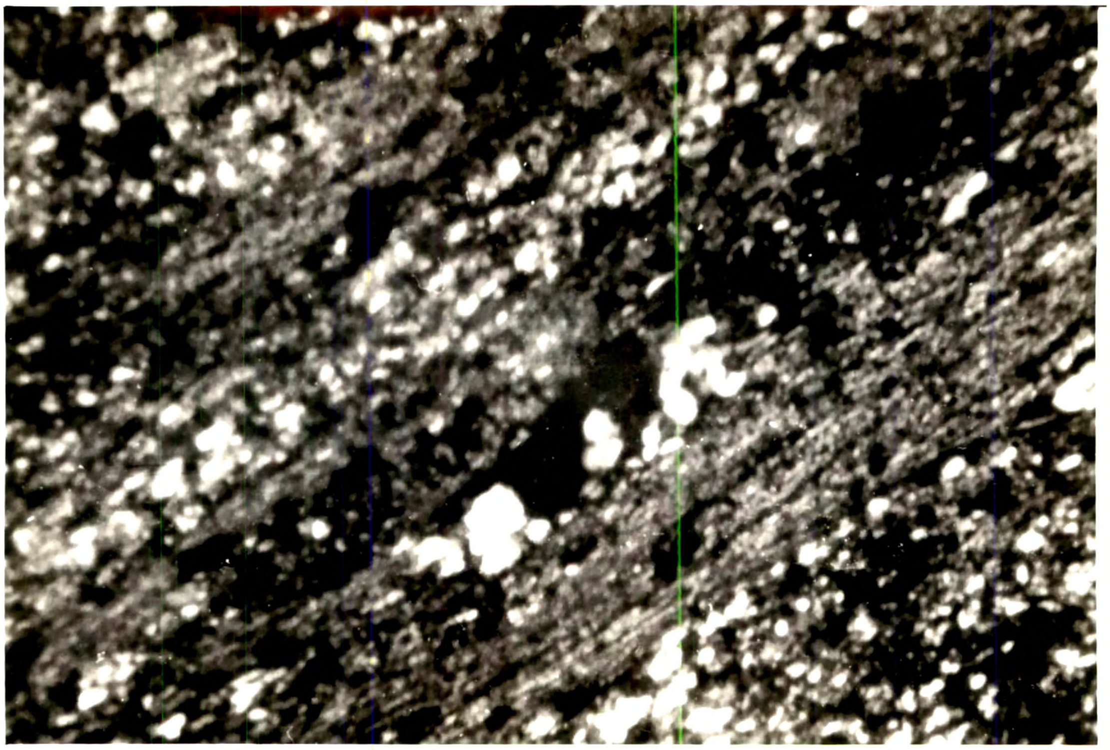
Under the microscope, the rock is seen to be made up of a confused aggregate of very finegrained foliated cryptocrystalline quartz and chlorite (Plate No.VII.5). In some of the varieties, the chlorite mass and cryptocrystalline quartz display banded structure. Quartzose layers consists of well developed interlocking fine quartz grains. Vesicles are occasionally present, they are invariably distorted and filled with the crystalline quartz. Clouded and almost isotropic portions in some of the varieties represent devitrified glassy fragment in the tuffs. Large grains of quartz occurring in the tuffaceous groundmass conspicuously represent the mixed detrital sand grains in the tuffs. Pyrite cubes, sphene, and fragmental iron ores are the accessory minerals of the tuffs.

## MINERALOGY

### Plagioclase

Plagioclase feldspar is either fresh or partly saussiritised. It is mostly an albite with An content ranging generally between 5% to 10%; exceptionally some grains show An content as high as 15% (An content was determined by the Four Axes Universal Stage by Reinhard's method; Naidu, 1958).

PLATE VII.5



Photomicrograph of tuffs showing cherty ? and chlonitic layers (crossed nicols X 60).

quartz forms clean sutured crystals

## Uralite and Hornblende

Uralite is a common mineral of the spilitic diabase. It occurs as sheaf like fibrous aggregates showing feeble pleochroism from light green to dark green or green colours. Interference colours are moderate to high order, and extinction angle below 15°. It represents the alteration product of either original pyroxene or of volcanic glass fragments.

Hornblende only occasionally occurs as stray prismatic grains showing feeble pleochroism similar to those of uralite. Prismatic sections show one set of cleavage and extinction angle higher than that of uralite.

## Chlorite

Chlorite shows various nature and modes of occurrence. Usually, it forms an important constituent of the groundmass. It also occurs within the vesicular cavities in close association with calcite and chalcedony. Showing a typical green colour, it remains isotropic under cross nicols. This variety appears to be a primary constituent of the spillite. An interesting mode of occurrence of this chlorite is as tiny inclusion in albite laths (Plate No. VII.6), and this provides an important clue to their primary origin. The

PLATE VII.6

Photomicrograph of spilitic diabase showing plagioclase with chlorite inclusions (crossed nicols X 60).

other mode of occurrence is that as streaks along the shear planes. This chlorite is cf yellowish green colour, anisotropic and shows low order (grey) polarised colours, and is obviously a product of shearing.

## Epidote

Epidote usually occurs as equant to elongated grains in close association with uralite and chlorite. It also occurs as veinlet in the spilitic rock or as inclusions in the albite grains. In the spilitic basalts, epidote is much less - the stray granular grains of epidote are found disseminated randomly in the groundmass of chlorite and calcite.

The epidote is a pistacite, which shows high relief, strong pleochroism in tones of yellowish to green colours, and high order interference colours. The elongated grains show nearly parallel extinction.

## Calcite

Calcite shows diverse modes of occurrences. In the spilitic basalts, it occurs in the groundmass with chlorite. It also forms vesicular infillings with chlorite and quartz. Besides, it also occurs as thin veinlets. In the spilitic diabase, calcite is seen in the groundmass in close association with chlorite and uralite. Calcite as inclusion in albite is invariably noted in all the varieties (Plate No. VII.7). Laths of albite in some of the spilitic basalts are found to be lying within the main mass of calcite grains (Plate No.VII.8). Such textural relationship and their inclusions in albite is suggestive of its primary nature. Calcite can be easily identified by its characteristic twinkling effect and high order interference colours.

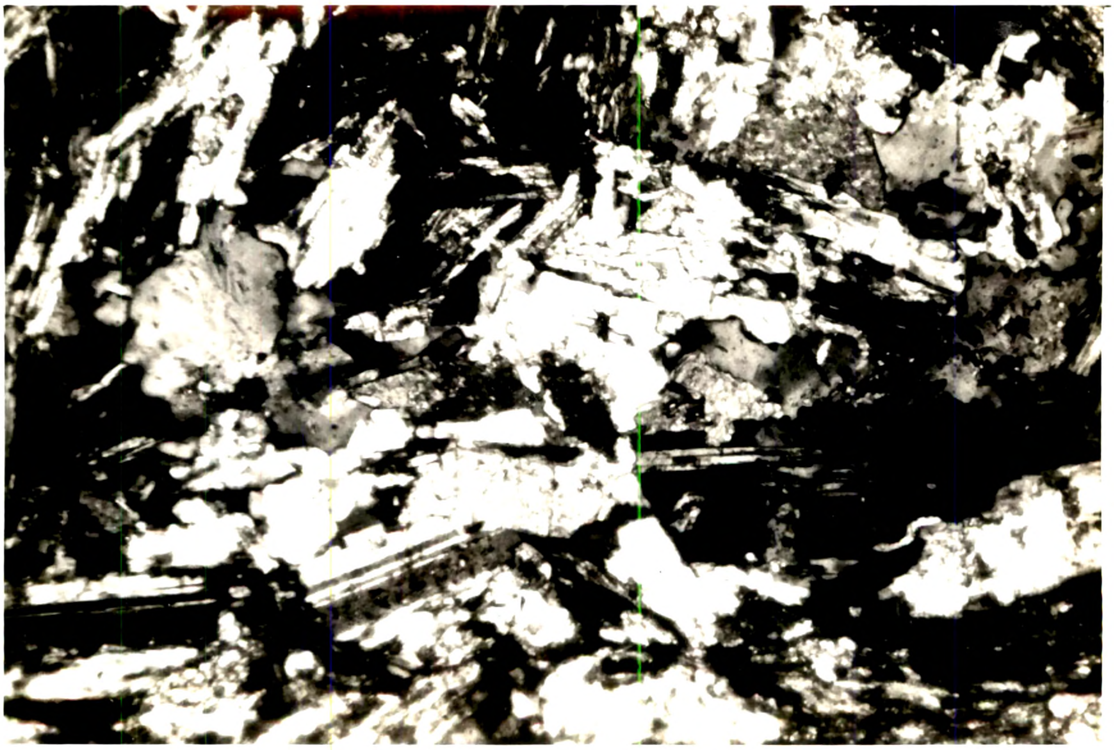
Quartz

Quartz commonly occurs as fine compact interlocked aggregate in the vesicles, and in the interspaces of highly sheared varieties. In tuffs, it forms one of the main constituent and occurs as cryptocrystalline aggregate with chlorite, displaying banding structure.

Sphene, Leucoxene, Ilmenite and Apatite

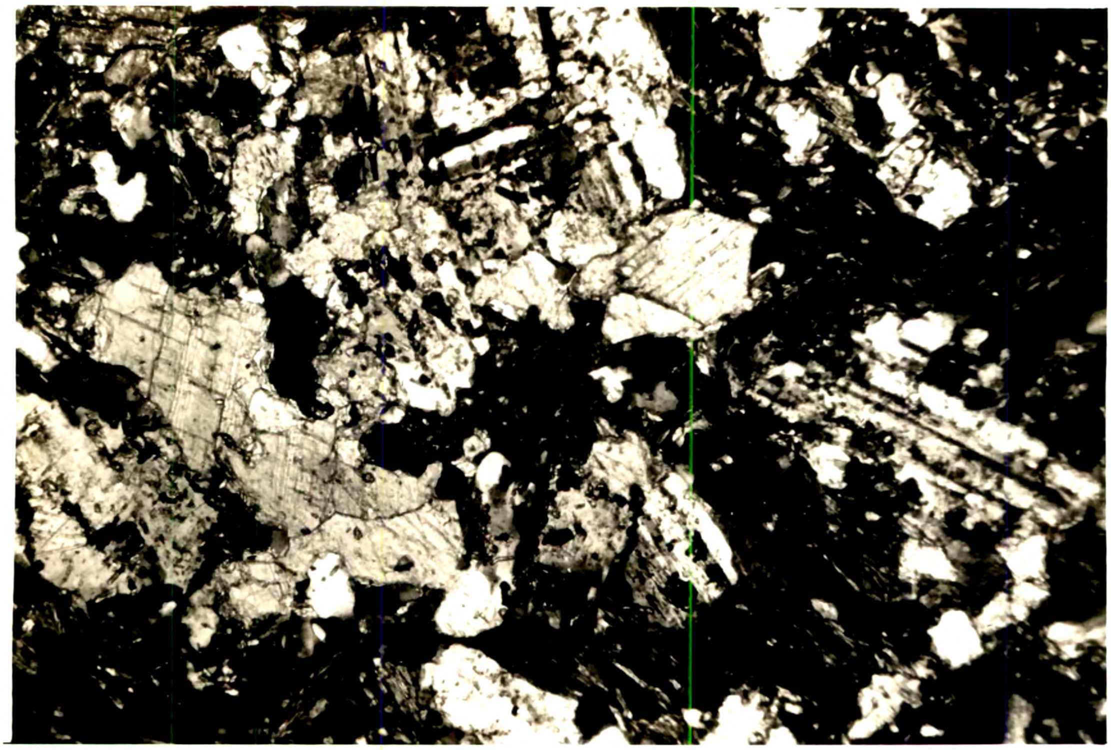
Sphene occur as tiny grains and patches in intimate association with chlorite and albite. Iron oxide and skeletal grains of ilmenite rimmed by leucoxene occur in all the varieties. Needles of apatite are very often noted as inclusions in albite of spilitic diabase.

PLATE VII.7



Photomicrograph showing inclusion of calcite in albite of spilitic basalt (crossed nicols X 200).

PLATE VII.8



Photomicrograph of spilitic basalt showing laths of albite in the main mass of calcite (crossed nicols X 200).

## PETROCHEMISTRY

The author has chemically analysed four samples of diabase, three samples of basalt and three samples of tuff, and the chemical data shows their spilitic nature. The various oxides and the cations values and Niggli values computed from the chemical data are given in the Table VII.1. The chemical data have been plotted in the appropriate diagrams.

### I. Ternary diagrams

#### (a) Triangular variation diagram, $CaO-Na_2O-K_2O$ weight percentages

Triangular diagram based on $CaO-Na_2O-K_2O$ weight percentages (Fig. VII.1), clearly reveals that some of the volcanic rocks of the study area are relatively richer in CaO content than the alkalis, but when plotted in the diagram coincide very much with the plots of the standard spilites from the other parts of the world (Table VII.2).

#### (b) Triangular variation diagrams, Mg-Fe-Ca-Al cations

In the triangular variation diagrams after Green & Poldervaart (1958), first the cation values for Mg, Fe, Ca, and Al per 100 oxygen anions have been calculated. Based on this, the three diagrams representing ionic weight percentages of (i) Mg-Fe-Al, (ii) Mg-Ca-Al and (iii) Ca-Fe-Al have been

Table VII.1 : Chemical analysis of some of the spilitic diabase, spilitic basalt and spilitic tuff of the study area.

| | Spilitic diabase | | | | Spilitic basalt | | | Spilitic tuff | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $SiO_2$ | 51.51 | 50.48 | 51.28 | 47.81 | 49.35 | 49.41 | 43.35 | 53.99 | 47.36 | 43.9 |
| $Al_2O_3$ | 14.87 | 15.51 | 14.74 | 15.45 | 16.24 | 15.08 | 14.48 | 15.38 | 14.24 | 15.77 |
| Ca | 15 | 22 | 25 | 19 | 14 | 6 | 41 | | | |
| Fe | 40 | 28 | 28 | 30 | 37 | 33 | 19 | | | |
| Al | 45 | 50 | 47 | 51 | 49 | 61 | 40 | | | |
| | Niggli values | | | | | | | | | |
| si | 138 | 122 | 132 | 106 | 135 | 124 | 96 | | | |
| al | 23 | 22 | 22 | 20 | 26 | 22 | 18 | | | |
| fm | 56 | 44 | 48 | 58 | 49 | 29 | 35 | | | |
| c | 16 | 19 | 23 | 15 | 16 | 40 | 39 | | | |
| alk | 5 | 15 | 6 | 7 | 9 | 9 | 8 | | | |
| (al+fm)-(c+alk) | 58 | 32 | 41 | 56 | 50 | 2 | 6 | | | |

Table VII.2 : Chemical analysis of some of the standard spilitic rocks from different parts of the world.

| | a | b | c | d | e | f |
|---|---|---|---|---|---|---|
| $SiO_2$ | 51.22 | 48.60 | 53.15 | 49.65 | 45.28 | 50.79 |
| Ca | 31 | 29 | 31 | 31 | 28 | 28 |
| Fe | 36 | 31 | 34 | 28 | 32 | 30 |
| Al | 33 | 40 | 35 | 41 | 40 | 42 |

a Average spilite (Sundius, N., 1930, Geol. Mag. - 67, p.37).

b Somewhat potassic spilite, Wellington, New Zealand (Reed,J.F.,1957, Bull. Geol. Survey N.2. 57, p.37).

c Spilite somewhat high in potash, eastern orogen (Gilluly, J., 1935, Am. Jour. Sci. Vol. 23, p.235).

d Average spilite (Vallance T.G., 1960, Poc. Linn. Soc. N.S. Wales (LXXXV).

e-f Variolitic K-spilites (Fiala, F., 1966, p.92).

constructed (Fig. VII.2.A,B & C). The diagrams show that the spilitic rocks of the study area are richer in total Fe and CaO than the Mg and Al ratio. However the plots in the diagrams satisfy the spilitic nature of the rocks and fall in the same field as those of the standard spilites of the world.

(c) Triangular variation diagram ($Fe_2O_3$ + FeO) - ($Na_2O$ + $K_2O$) - (MgO) weight percentages

The diagram (Fig. VII.3), shows the compositional field of the spilites with respect to total Fe, Mg, and alkalis. The comparison of the plots of the study area with the standard spilites of the world, shows that the spilitic rocks of the study area are comparatively richer in total iron oxides than MgO and alkalis. It is because of this the plots of the spilitic rocks lie more towards the F component of the diagram.

II. Binary diagram

(a) $SiO_2$ vs $\frac{K_2O}{Na_2O}$ (Fig. VII.4)

The ratio of $K_2O/Na_2O$ of the weight percentages of the two alkalis, when plotted against $SiO_2$ show comparatively low values indicating relative richness of $Na^+$ against $K^+$ in the spilitic rocks of the study area. The comparison of these plots with the plots of the standard spilites from the different parts of the world (Table VII.2), shows striking similarities.

(b) $SiO_2$ vs $\frac{Na_2O}{Na_2O + K_2O}$ (Fig. VII.5)

The ratio, when plotted against the $SiO_2$, compares well with the plots of similar ratio of the spilitic rocks from the different parts of the world, thus confirming the spilitic nature of the rocks of the study area.

(c) $SiO_2$ Vs $\frac{CaO}{CaO + Na_2O + K_2O}$ (Fig. VII.6)

The plots of the ratio $CaO/CaO + Na_2O + K_2O$ are more or less comparable with the standard spilites of the different parts of the world.

(d) $SiO_2$ Vs Total Alkalis (Kuno's diagram)

The weight percentages of almost all the analysed spilitic rocks except the tuffs lie in the alkali basalt field of Kuno (1959),(Fig. VII.7).

III. Variation diagram based on Niggli values : Si Vs (al + fm) - (c + alk)

The diagram (Fig. VII.8), shows the relationship of the

Niggli values Si Vs (al + fm) - (c + alk) for the rocks of the study area. The various plots are closely comparable with the spilites of Lahn Dill, Northern Vosges of France (Juteau and Rocci, 1974).

IV. Variation diagram based on other weight percentages (Fig. VII.9)

The variation diagram showing $SiO_2$ as abcissa and other weight percentages as ordinates reveal the trend of the distribution of major elements in the spilites, and this is correlatable with the variation of the oxide percentages of the spilitic rocks of the world.

## DISCUSSION

From the chemical data and the various plots in various appropriate diagrams, following characteristics of the spilitic rocks of the study area can be deciphered.

(1) A marked chemical heterogeneity in the spilitic rocks. This may be due to the original variation in chemical characters of spilitic rocks, and such variation in chemical characters of spilitic rocks has also been suggested by Amstutz (1968) and Patwardhan & Bhandari (1974).

(2) Comparatively low $Al_2O_3$ oxide percentages, which is also considered to be the characteristic of spilitic rocks (Turner & Verhoogen, 1960).

(3) High $Na_2O/K_2O$ ratio (Turner & Verhoogen, 1960)

(4) Occasionally high CaO weight percentages. Vozar (1974) and Fiala (1974) have also reported higher CaO weight percentages in the spilitic rocks.

The spilites of the area under study reveal many characters to indicate that their mineralogy and textures are primary. The plagioclase feldspar is mostly albite showing primary congruent fabric of Amstutz (1974), and the author is inclined to believe that the albite is neither a product of decalcification nor a product of metamorphism. The partial sericitization of the feldspars could be due to late stage hydrothermal solutions contained in the magma and a part of the evolution of the crystallising rocks, and there is no need to consider this as the result of any metamorphism. Similarly, chlorite showing ophitic relationship with albite or occurring as inclusions in albite, as vesicular infillings and as an alteration product of glass, pointedly indicates that after all it is a primary crystallisation product. Amstutz & Patwardhan (1974, pp.74) referring to the inclusions of chlorite in the albite, stated "It is much more probable that these inclusions are primary trapped interstitial "fluids" i.e. trapped portions of "rest fluids" or rather rest fluids". Yoder (1967) has also substantiated the possibility of magmatic chlorite. The chlorite that forms the streaks with preferred orientation in foliated varieties is however of later origin. The author has already stated that even the calcite occurring in the spilites is of primary origin. Patel (1978) has also reported the occurrence of possibility of primary calcite in the spilitic rocks of Ranibagh-Amritpur area, Nainital Dist. Kumaon Himalaya, U.P. Amstutz & Patwardhan (1974) has called the inclusions of calcite in the albite as the true entrapping of the magmatic fluids.

The textural characters like the ophitic and sub-ophitic relationship between albite, chlorite and even calcite suggest a primary congruent fabric of Amstutz (1974) and Patwardhan & Bhandari (1974). Further Amstutz & Patwardhan (1974) and Patwardhan & Bhandari (1974) have also mentioned that the primary crystallisation of albite or even the presence of primary chlorite and carbonates may be referred to as characteristics of spilites. Also the presence of iron ores, titanium iron-ores and apatite iron-ores are characteristic of spilites (Niggli, 1952). Thus the presence of titanite, iron-ores and apatite in the spilites of the study area supports this contention.

Amstutz & Patwardhan (1974) have categorically opined that chlorite, albite and carbonates (as seen in the present case) are stable over a wide range of conditions and can develop during hydromagmatic or hydrothermal crystallisation fractionation of the rocks.

Many examples of differentiated spilites of undoubted magmatic origin have been reported. The high $Fe_2O_3/FeO$ ratio in the spilites has been reported by Sukeshwala (1974) for Bombay spilites, by Spadea (1974) for spilites of south Italy and according to them it is indicative of differentiation in spilites. The high $Fe_2O_3/FeO$ ratio in the spilites as in the rocks of the study area indicates water rich environment and this together with heterogeneity obviously is suggestive of differentiation. The water rich environment in the magma system and the resultant high $Fe_2O_3/FeO$ ratio has a far reaching significance in the present context. The water enrichment in the magma system accelerates the removal of silica and calcium and promotes the growth of albite and chlorite with or without fresh pyroxene. The relative scarcity of the pyroxene in the spilites of the study area further supports this contention.