CHAPTER VI

T R A P P E A N   R O C K S

GENERAL

The metabasics occupy a fairly large portion of the total study area, and as already mentioned, mostly lie in the core of the much distorted Bhowali-Bhimtal anticline. These trappean rocks have been traced further north and north-west to extend along the Khairna stream and seen to taper out in the hills to the west of the Garampani Bazar. Shah C.P. (1973) has mapped the Garampani area and has adequately recorded the hinge area of the anticline, that plunges due NW (Fig. 3.2).

The basic rocks occurring within the study area, are quite extensive and comprise several varieties. In fact, these rocks are so strikingly exposed in the Bhimtal area, that several authors in the past have taken special note of them and conducted some investigations. It is difficult to understand how such an interesting suite of basic rocks occurring in an easily accessible area, could remain uninvestigated till now. In the past, mention has been made of these rocks by Ball (1878), Middlemiss (1890), Rode et al. (1941, 1942), Heim and Gansser (1939), Gansser (1964), Thomas (1952), Pande I.C. (1963), Pande P.C. (1964), Mathur (1965), Powar et al. (1968), Raina and Dungrakoti (1973) and Varadarajan (1973). Of these, the description of Heim and Gansser (1939) and Gansser (1964) though brief, are most appropriate and partly correct. Recent work of Varadarajan (1973) however is the most detailed one. The present author has collected more details and his conclusions for the first time reveal the true nature of these trappean rocks. He has collected ample evidences to show that these feebly metamorphosed basic rocks of spilitic affinity formed an integral part of the volcanism associated with the geosynclinal history in this part of the Himalaya.

PROBLEM OF NOMENCLATURE

The trappean rocks of Bhimtal have been variously named by the previous workers. Heim and Gansser (1939, p.52) who encountered these rocks at Bhowali have called them as 'epidotic diabase'. Pande P.C. (1964) has designated them as 'mugearite basalts'. A rather adequate and appropriate reference is made by Gansser (1964,p.92) who described the metabasics as tuffaceous greenstones and altered diabasic rocks. Elsewhere, in a general statement the same author (Gansser, Op.cit.,p.236) has said that "Locally and mostly associated with the quartzites, there are thick sections of tuffaceous beds, altered into chloritic schists with some epidioritic intercalations representing actual flows. Tuffs and flows were most likely submarine". It is obvious that Gansser was already aware of the true nature of the metabasics of Bhowali and Bhimtal to a certain extent, and his thinking is quite close to that of the present author who has preferred to assign spilitic affinity to these basic rocks.

According to the present author, the texture, mineralogy, chemistry and mode of occurrence of these rocks, definitely point to their comprising a spilitic suite. Though the author is fully aware of the complexity of the spilite problem, yet he has taken into consideration the different opinions of the various workers, and ventured to call these rocks as spilites. As will be seen in the following pages the basic rocks of the study area, consist of coarse grained and fine grained varieties, and all are invariably altered. Considering their alteration and metamorphism the word 'diabase' has been used by some, while others have preferred to distinguish between coarse and fine varities by calling them meta-basalts and metadolerites. The present author, has collected adequate samples of different textural types and thus he is in a position to distinguish between the coarser dolerites from the fine grained basalts. All these exhibit many of the typical characteristics of spilites.

THE SPILITE PROBLEM

Generally a special variety of altered basalts and dolerites, which is usually high in soda is known as spilite, and this sodic variety typically represents geosynclinal volcanism.

According to Turner and Verhoogen (1961, p.258), "Most eroded geosynclines show evidences of igneous activity approximately synchronous with at least the later part of the filling and sinking of the trough. Prominent among the products of such activity, and almost confined to the geosynclinal environment, are submarine lavas, tuffs and equivalent intrusives of sodic composition. These constitute the spilite keratophyre association. The most characteristic rocks of the spilite keratophyre association are spilites - basic lavas consisting principally of highly sodic plagioclase (albite or oligoclase) and augite or its altered equivalent (actinolite, chlorite-epidote, chlorite-hematite etc). Olivine is typically absent or is represented sparingly by serpentine pseudomorphs. Evidence of hydrothermal activity (e.g. alteration of pyroxene, infilling of vesicles with epidote, calcite and so on) is usually conspicuous, while persistence of relict patches of labradorite or andesine within crystals of albite shows conclusively that in some cases the present condition of the felspar is a result of albitization of initially more calcic plagioclase. Many spilites are pillow lavas. Common associates of spilitic lavas are intrusive chemically equivalent albite diabases, as well as flows, minor intrusions, and tuffs of highly sodic keratophyre and quartz keratophyre. Chemical features characteristic of the whole rock association are a high content of Na_2O, low K_2O and rather low Al_2O_3. But not uncommonly a typically spilitic suite of rocks is intimately associated with, and indeed includes, basalts and diabases of normal composition with labradorite as the constituent felspar, as well as basaltic rocks which clearly have been affected by lime metasomatism involving replacement of plagioclase and infilling of vesicles by hydrous lime, aluminium silicates, notably epidote, prehnite and various zeolites. It is agreed by most writers that the late magmatic metasomatism plays an important role in the evolution of spilitic rocks in general.

Williams, Turner, and Gilbert (1965, p.58) have described spilites as rocks consisting "essentially of divergent laths of albite or oligoclase, some of which may be bent,accompanied by granular or platy ilmenite that is largely changed to leucoxene, and by abundant chlorite, calcite, and epidote. Relic granules of augite, which may be distinctly titaniferous, are not rare, but usually the original pyroxene is wholly replaced by chlorite or fibrous actinolite. Olivine is quite exceptional. Some specimens include occasional phenocrysts of andesine or labradorite, generally sheathed with more sodic felspar.

Space forbids full discussion of the origin of the characteristic soda rich felspars of spilites. Some crystals are water clear; more have a cloudy appearance or are densely charged with specks of chlorite, calcite and epidote. In some instances their sodic nature appears to be a primary feature, in others it is apparent that originally more calcic felspars have been albitized, either after the rocks solidified or during the final stages of solidification, the requisite soda being derived from sea water, from connate water trapped in the associated sediments, or from emanations given off by underlying bodies of magma. The prevalence of chlorite, calcite and actinolite suggests the pervasive effects of deuteric solutions. But since the mineral assemblage of spilites closely resembles that of many weakly metamorphosed basic rocks found in the Greenschist Facies, some spilites may be at least in part, of metamorphic origin".

Poldervaart (1968, p.739) has enumerated following facts which should also be borne in mind by those who investigate spilites:

(1) Na content above "Normal"; Na and K content above 'normal';

(2) All diagenetically or metamorphically altered; only partly altered and sometimes fresh;

(3) Only geosynclinal; not exclusively geosynclinal;

(4) Only old (atleast Mesozoic); not necessarily old;

(5) Only with pillows and consequently only submarine; neither necessarily with pillows nor always submarine.

He further states (Op. cit. p.741) that spilite also occurs in continental and very shallow water sediments.

Fiala (1966) has described the paleovolcanites of the Barrandian and Zelezne hory areas of the Bohemian Massif. He found the spilitic rocks of the area to comprise many textural types (p.26) viz.,"very fine grained aphanitic, finely, intersertal textures prevail; their interstitial mass, originally glassy, is now chloritised or more frequently actinolitized with laths of acid plagioclase (albite, albite-oligoclase, oligoclase). Ti-magnetite and leucoxenized ilmenite are abundant, sporadically apatite occurs. Micro-variolitic types in which divergently radial to arborescent (Vuagnat 1946) texture is perceptible under the microscope only, appear parallelly with sub-variolitic types, macroscopically compact, in which very minute spheroidal and sheaf like forms are mostly replaced by actinolite. Intergranular texture exhibits minute crystals and microlites of augite and ores together with chlorite and actinolite between small laths of felspar.

"Doleritic types are abundant, they correspond to feeding bodies or central parts of big extrusions which under the protecting insulating solidified margin of granulate envelope had sometimes the possibility and time to crystallize more slowly and more distinctly. Their texture is subophitic (diabasic), having the interstices between the relatively long laths of plagioclase mostly filled with one grain of augite, or ophitic, in which large uniformly oriented augite grains are intergrown by felspar laths; when the latter in the form of small phenocrysts grow completely within the augite, the texture is poikilo-ophitic."

"According to mineral composition, the dolerites are either of spilitic nature with acid plagioclase, locally upto albite, green chlorite or green amphibole (uralite) or actinolite or they are diabase dolerite with basic plagioclases, occasionally partly albitized, with pigeonite-augite upto pigeonite, showing an ophitic texture."

"The spilite porphyrites contain phenocrysts of albite, or albite-oligoclase in the intersertal groundmass with laths of felspar and actinolitized interstitial filling with abundant leucoxene (Litice near Plzeň, Dolanky, N of Prague). In the Roupov and Birkov areas porphyrites with phenocrysts of quite altered, kaolinized or saussuritized felspars are found; locally, albite phenocrysts occur even here. The groundmass contains laths of oligoclase or albite-oligoclase and strongly actinolitized mesostasis with clots of magnetite and ilmenite, in places with abundant zoisite and titanite; quartz occurs sporadically."

According to Fiala (op. cit. p.23), the outpouring of hot thin lava under submarine conditions, need not necessarily give rise to pillow structure. Especially under the shallow water conditions, spilites may show "granulation", a phenomenon somewhat analogous to blast furnace slag outflowing into rapidly streaming water. In areas with abundant tuff development the absence of pillow lavas is striking; this fact may account for a lesser depth of the sea during volcanic activity.

SPILITES OF STUDY AREA

A perusal of the geological map (Fig. 4.1) of the area, reveals that the spilitic rocks occur in two ways:-

1. Occupy the core of the Bhowali-Bhimtal anticline, and
2. Form two prominent layers within the quartzite-slate sequence.

Of the two, the most striking exposures are those that lie in the Bhimtal area occurring within the core. The two individual layers, that occur a little higher up in the sequence, tend to taper out in the NW and become more prominent southward, outside the limits of the study area.

Based on their mineralogy and texture, the trappean rocks could be classified into the following three main types:

1. Spilitic diabase,
2. Spilitic basalt,
3. Tuffs and Tuffites.

Of the above three, the diabase and basalt are characterised by the constant presence of sodic felspars. The distinction between the two types is mainly based on the grain size and texture. The coarser rocks have been called "diabase", while the finer varieties have been taken as 'basalts'. It should however be noted that no clear cut demarcation exists between the two types, and a number of occurrences of intermediate variety could be taken both as diabase or basalt. The third type-tuffs and tuffites, are obviously derivatives from the above two, and are typically layers of volcanic ash and fragments, of course, the subsequent deformation and metamorphism has considerably altered their original tuffaceous nature. The term 'Tuffites' has been used after (Drozen, 1966, p.34) to indicate rocks comprising a mixture of volcanogenic tuffs and clastic sediments. The tuffs and tuffites are difficult to separate megascopically.

The two layers of the trap that occur in the quartzite-slate sequence, comprise mostly medium-grained diabase, with thin beds of tuffs/tuffites intervening between it and the overlying sedimentaries. As only small portions of these trappean layers occur within the study area, the author has not investigated these in much detail.

On the other hand, the most conspicuous exposures of the trappean rocks occupying the anticlinal core, are most revealing, and are seen to consist of all varieties. The coarser diabases occupy the median portion. The basaltic type comes next, and forms the two flanks to the NE and SW. The tuffs and tuffites together with a few lensoid bouldary and pebbly quartzites lie at the top of the sequence, and in the present folded anticlinal shape, occur above the basalts and below the pebbly quartzite formation. It should however be made clear that this symmetrical zonal arrangement is not uniform and on account of the (1) original irregularity of the occurrence of the three types, (2) superimposition of E-W (F_2) flexures and (3) varying effect of deformation and metamorphism, the above nature of distribution is not very obvious, and is revealed only after a careful sampling.

The spilites have been extensively cleaved, as a result of which they have developed strong foliation at many places. Wherever the deformation has brought about cleaving the resulting rocks resemble greenschists, and in such deformed spilites, it is sometimes difficult to recognise their original nature. Under the microscope, these cleaved traps reveal a somewhat parallel network of fractures along which chlorite and uralite minerals show a preferred orientation. The portions enclosed between these cleavage fractures, show the original igneous textures (Plate 6.4). The degree of cleaving is variable, and in highly cleaved samples, the rock is almost wholly consisting of foliated mass of chlorite and/or uralite and streaks of finely granulated quartz.

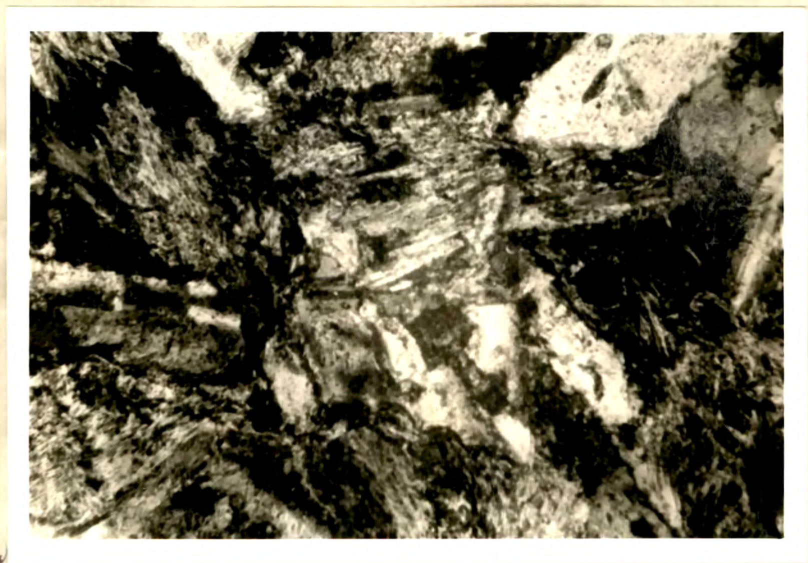
PETROGRAPHY

Spilitic Diabase

In hand specimens, these coarser equivalents of spilites, show a dark greenish grey colour. While most specimens are massive and compact, some show conspicuous cleavage and are rather foliated. Vesicular infillings are scarce, and megascopically, except chlorite, and stray grains and patches of epidote and calcite, no other minerals can be identified.

Thin sections of nonfoliated diabse, typically reveal intersertal texture. Laths of sodic felspars (0.1 x 0.15 mm to 0.2x0.55 mm) are seen randomly embedded in a chlorite and uralite groundmass (Plate 6.1). This texture is obviously a variety of ophitic relationship existing between the felspars and the original pyroxenes (now altered). In some sections, the uralitization and

PLATE 6.1



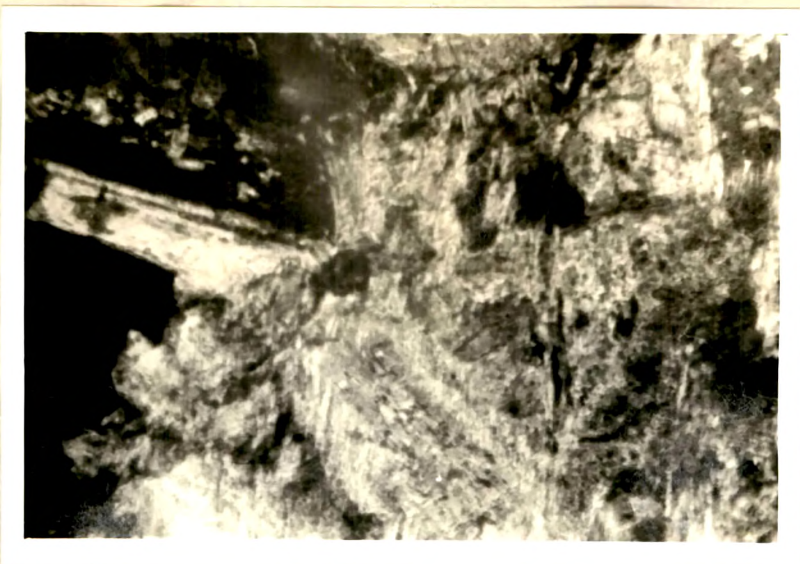
Photomicrograph of non-foliated diabase showing intersertal texture (cross nicols, X160).

chloritization of the pyroxene is partial and relict pyroxene shows distinct original ophitic to sub-ophitic texture of the diabases (Plate 6.2).

The felspar laths are rather fresh and unaltered, though in some samples they do show saussarization (Plate 6.3). Even in saussarized felspars, the alteration is never so complete as to obscure the original twinning etc. The chlorite and uralitic mass that occupies the interstitial areas, does not show any preferred orientation (or foliation). Sphene occurs as tiny granules and patches in intimate association with chlorite. In addition, occur dusty patches or iron oxide and leucoxene, skeletal crystals of ilmenite and stray grains of epidote. Occasionally, small blebs of released quartz occurs, within chlorite mass.

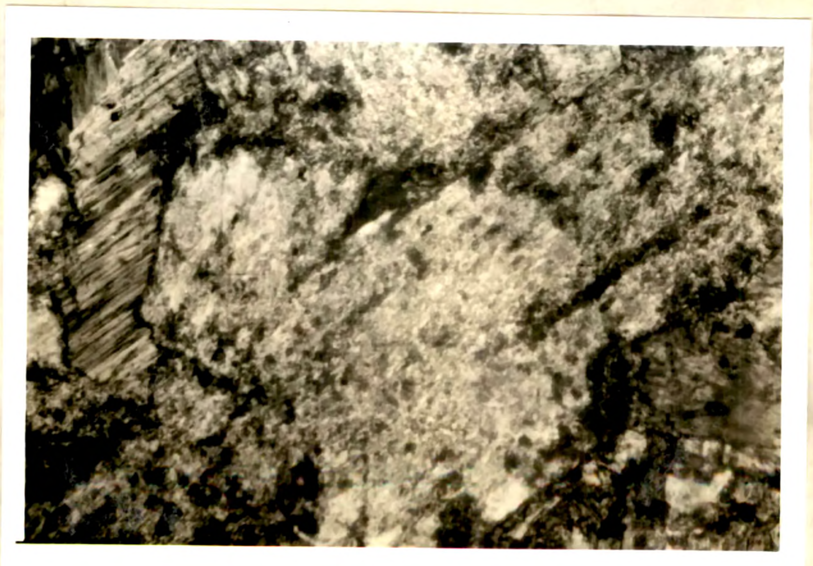
Texturally, the foliated diabase is somewhat different. In most thin sections, the chlorite-uralite aggregate shows a preferred orientation, the flakes and shreds of the two members comprising a foliated mass. Within such a mass lie laths of plagioclase. These laths also show a crude parallelism. It is observed that originally the laths were forming an ophitic texture, but which during the development of foliation have been partially bent, broken and rotated

PLATE 6.2



Photomicrograph of a diabase showing relict ophitic to subophitic texture (cross nicols, X160).

PLATE 6.3



Photomicrograph of a diabase showing partial saussarization of felspars (cross nicols,X80).

to lie along the cleavage planes (Plate 6.4). Surprisingly, though the felspars have broken they have not altered much, and are relatively fresh (Plate 6.5). Another significant feature of this foliated variety is the total absence of relict of pyroxene.

Spilitic Basalts

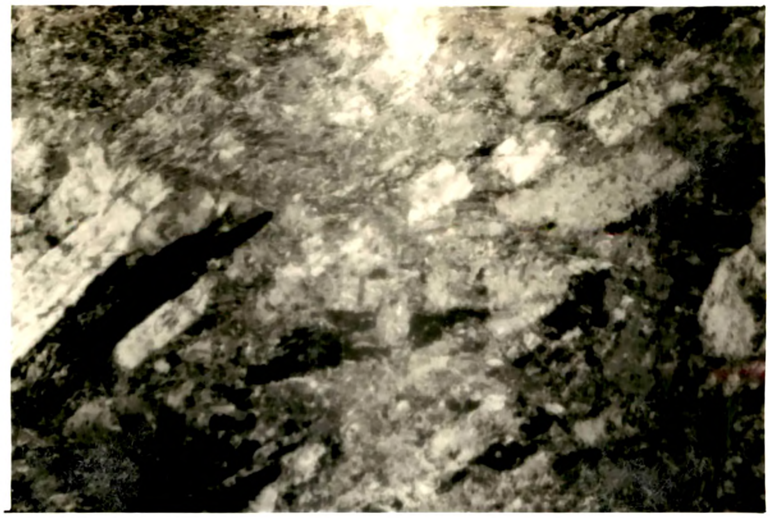
In hand specimen, this type comprises an aphanitic, greyish green rock, containing vesicles and occasional small phenocrysts of felspars. Streaks and patches of chert and crystalline quartz are abundant in some specimens.

A careful study of the megascopic and microscopic characters of the spilitic basalts from different parts of the area has established following textural varieties:

1. Glassy-amygdaloidal
2. Intersertal
3. Trachytic
4. Granulated.

1. Glassy Variety: This variety is extremely fine grained and amygdaloidal, and its hand specimen is of greyish colour. Under the microscope, it is seen to comprise an aphanitic mass, within which occur stray phenocrysts of

PLATE 6.4



Photomicrograph of diabase showing preferred orientation of felspar laths and uralite (cross nicols, X80).

PLATE 6.5

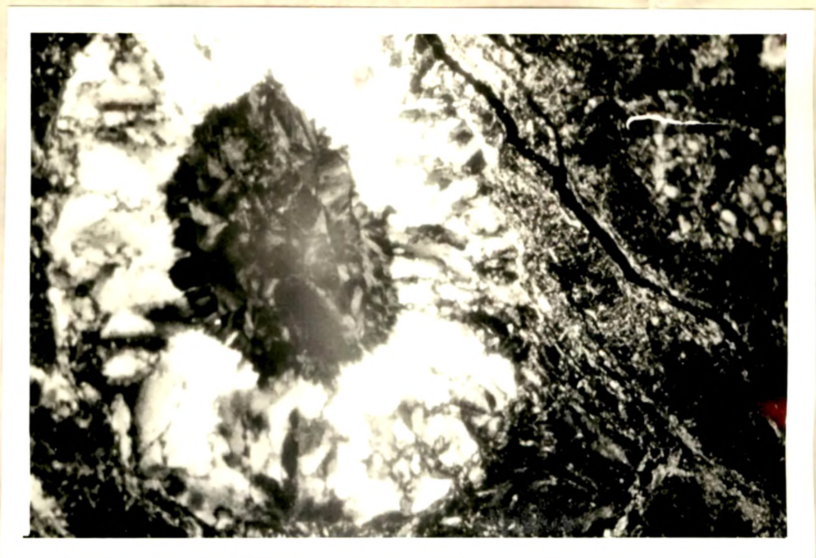
Photomicrograph of foliated diabase, with fresh sodic plagioclase laths, relict pyroxene not seen (cross nicols, X80).

felspars and numerous amygdaloidal cavities filled with chalcedony and chlorite (Plate 6.6). The main bulk of the rock is structureless and has a dusty appearance. When seen under the crossed nicols, it is partly isotropic and partly consisting of aggregates of sheaf like uralites and radiating microlitic felspars (Plate 6.7). This mass is traversed by numerous cracks along which occur streaky clusters of tiny shreds of chlorite and uralite (Plate 6.8). These cracks indicate a crude foliation and are obviously the fore-runners of the strong cleavage seen in the foliated varieties.

The amygdules are very interesting. They are round as well as elliptical and of variable size (2 mm to 4 mm diameter). The infilling material is generally chalcedonic silica and chlorite. In most cavites, the chalcedony occurs as lining with quartz in the centre. In several large amygdules, the central portion is occupied by fan shaped aggregates of bluish green pumpellyite (Plate 6.9).

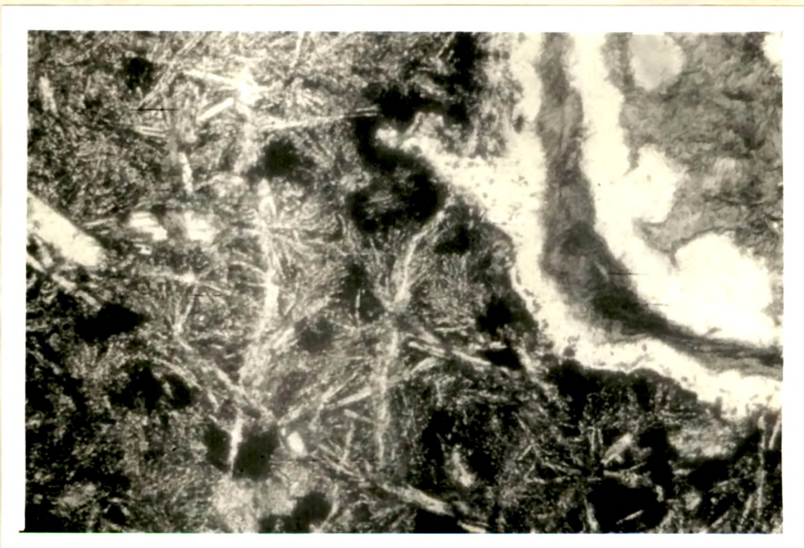
2. Intersertal Variety: This variety is the most common and shows a conspiquous grain size variation from fine to medium grain. In the fine grained varieties, the felspars

PLATE 6.6



Photomicrograph of glassy variety of spilitic basalt showing isotropic mass with amygdule containing chalcedony-chlorite (polarised light, X80).

PLATE 6.7

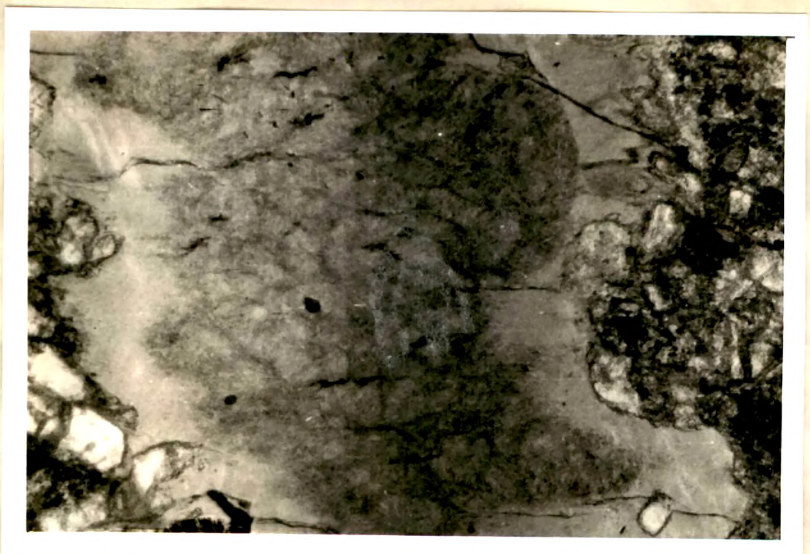


Photomicrograph of glassy spilitic baslat showing a groundmass which is partly isotropic and partly consisting of sheaf like uralites and radiating microlitic felspars and vesicular chalcedony-chlorite (cross nicols,X80).

PLATE 6.8

Photomicrograph of glassy variety of spilite showing a crude foliation along which occur tiny shreads of uralite and chlorite, the elongated cavities contain chlorite (polarised light X80).

PLATE 6.9

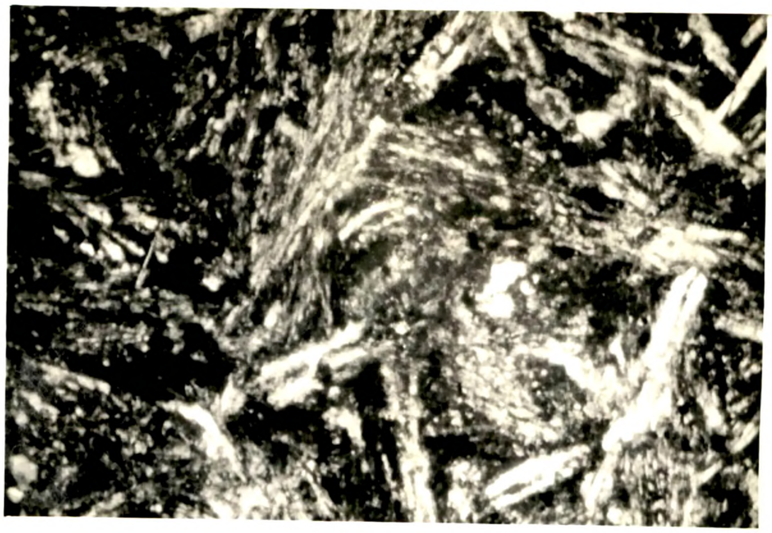


Photomicrograph of an amygdule in spilitic basalt showing a central fan shaped aggregate of bluish green pumpellyite, surrounded by a rim of chlorite (polarised light, X80).

comprise thin needles, while the coarser variety contains slightly broader laths of felspars (0.03 x 0.06 to 0.06 x 0.45 mm). The felspar needles and laths form a network, enclosed within a glassy (now altered) mass (Plate 6.10). The enclosing mass comprises either uralite and chlorite, or an indefinite dusty brownish black opaque material. The finegrained variety contins large felspar phenocrysts (Plate 6.11). The fine grained variety also quite often tends to show variolitic texture at many places (Plate 6.12). Felspars are on the whole fresh and clear, and only in one sample they were found to be saussaritized. Amygdules of chalcedony, chlorite and calcite are abundant. Stray crystals as well as veins of epidote and occasional patches and streaks of cherty silica are also common.

3. <u>Trachytic Variety</u>: This textural type is rather less common and encountered at few places only. In thin sections, it reveals flow trend. Tiny laths and needles of felspars show a distinct preferred orientation, the parallelism being due to alignment of felspars in the flow direction. In their present state, the felspars are seen embedded in an unfoliated chloritic-uralitic ground mass. The chlorite mass as well as felspars do not show any evidence of shearing effect. The relative proportions of chlorite and uralite are variable,

PLATE 6.10

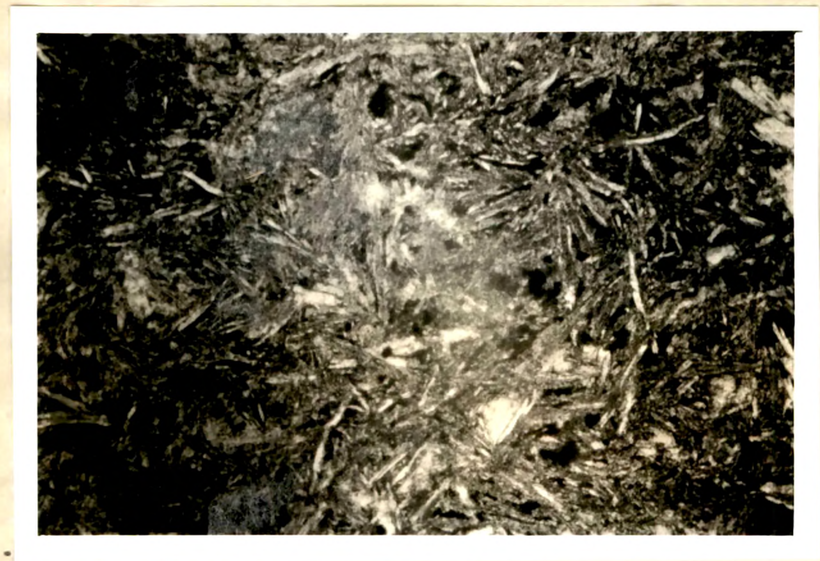


Photomicrograph of spilitic basalt showing typical intersertal texture (cross nicols,X80).

PLATE 6.11

Photomicrograph of spilitic basalt showing occasional pheocrysts of sodic felspars (cross nicols, X80).

PLATE 6.12



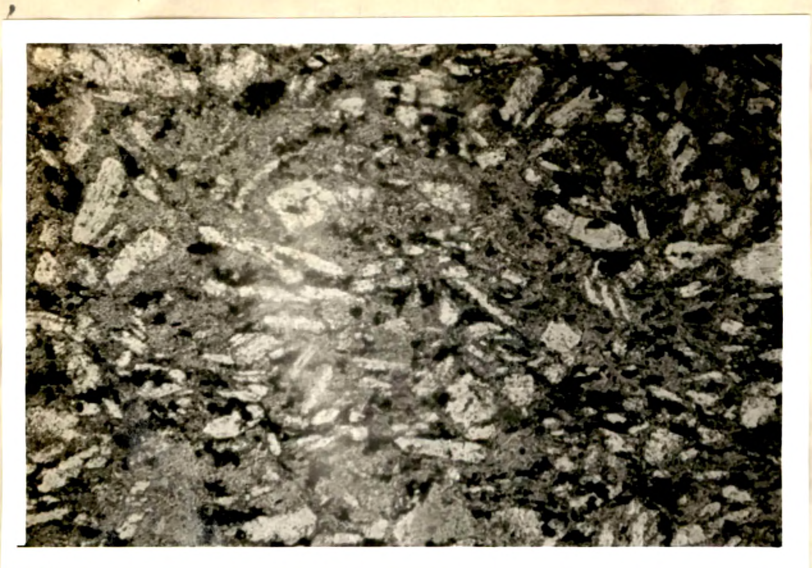
Photomicrograph of a fine grained spilitic basalt showing variolitic texture (polarised light, X80).

and the author found that in some the chlorite predominated, while in other the uralite was dominant. Stray patches and streaks of cherty quartz, and occasional grains and veins of epidote and calcite are also recorded.

This trachytic variety contains numerous vesicles filled with cryptocrystalline silica, chlorite and palagonite (Plate 6.13). These cavites show some elongation in the direction of flow (Plate 6.14). A few thin sections reveal tendency of the passage of trachytic to intersertal texture.

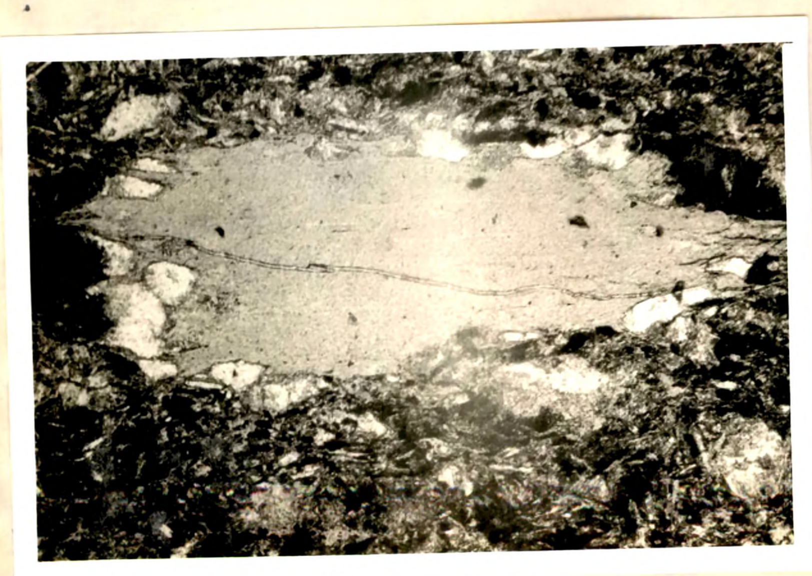
4. Granulated Variety: This rare and unusual variety is scoriaceous in appearance and resembles 'slag' to a certain extent (Plate 6.15). It is greyish black in colour and contains abundant cavities filled with calcite and zeolites. In thin section, it shows intersertal texture, felspar laths embedded in an opaque chocolate brown dusty matrix. In addition to felspars and the vesicular cavities, the matrix also encloses small fragments of green chloritic material perhaps palagonite (altered glass). The entire mass is studded with small cavities filled with zeolite and also with large elongate vesicles containing calcite (Plate 6.16).

PLATE 6.13



Photomicrograph of spilitic basalt showing trachytic structure with infilling of cavities (polarised light, X80).

PLATE 6.14

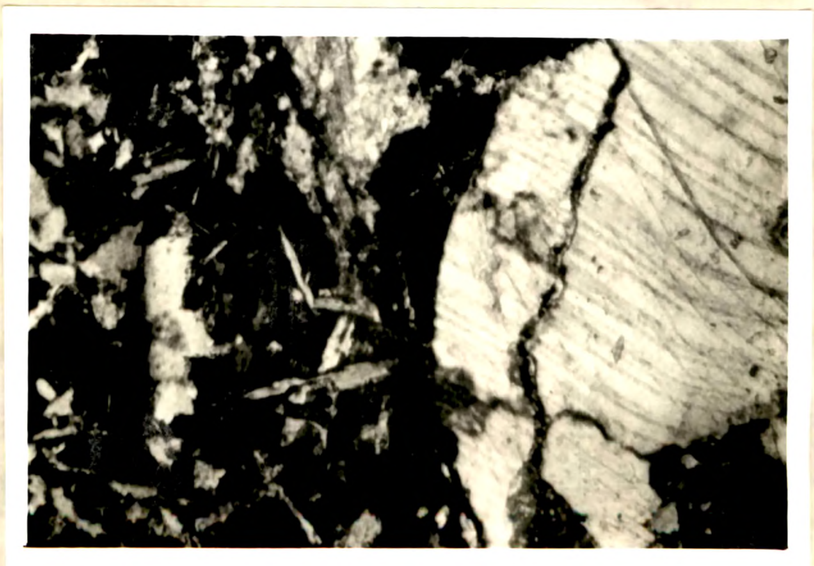


Photomicrograph of a spilitic basalt showing elongation of a chlorite-filled vesicular cavity (polarised light, X80).

PLATE 6.15

Photo~~micro~~graph of a specimen of granulated variety of spilite resembling "slag".

PLATE 6.16



Photomicrograph of the granulated spilite showing an elongated cavity filled with carbonate matter (cross nicols, X80).

In all the abovementioned textural varieties, one thing stands out prominently that sodic plagioclase is rather fresh. Even in such samples which have developed cleavages, the felspar laths have remained unaltered though broken and fragmented. On the other hand, the enclosing material is all chloritic and uralitic in most specimens. These chlorite/uralite mass may or may not show any preferred orientation. The cleaved and foliated spilites contain chlorite and uralite quite identical to those of the nonfoliated types.

It looks as if the cleavage formation synchronised with the hydrothermal and deuteric processes of the chloritisation and uralitization. At no places, the author came across any evidence of the albitization of more calcic plagioclase, and he is convinced that the sodic felspars of the spilites here are the primary magmatic product. This fact is quite clearly seen in the coarser diabasic spilites, where the fresh sodic plagioclase occurs ophitically with unaltered pyroxenes.

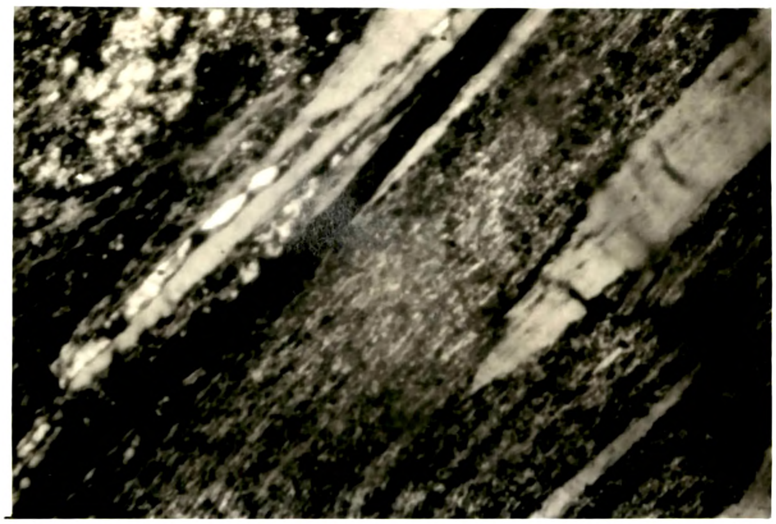
Tuffs and Tuffites

The metamorphosed tuffs are difficult rocks to describe. In hand specimens they are seen as fine grained dark green to greyish green foliated rocks, which could also be taken as green chloritic schists. Almost all samples of these tuffaceous rocks, contain abundant thin layers, streaks, lenses and irregular pods and patches of finely crystalline to cherty silica. The drawn out streaks and patches of quartz, generally conform to the foliation of the rock, but isolated veins and lenses also occur oblique to the schistosity. The main mass of the rock consists mostly of chlorite and shows a strong foliation. All transitions exist between dominantly chloritic and exclusively siliceous layers. The interbanding of the two varieties has imparted at many places streaky and banded appearance to the tuffs

Under the microscope, the tuffs reveal a variety of textures depending on the relative proportion of the chloritic and cherty constituents. The chlorite dominant portion generally shows well defined foliation and consists mainly of chlorite. This mineral is seen to occur in two modes. It either forms long clear plates or as streaks of fine scaly aggregates (Plate 6.17).

The two chloritic varieties occur along with a brown dusty material which also forms tiny elongated

PLATE 6.17

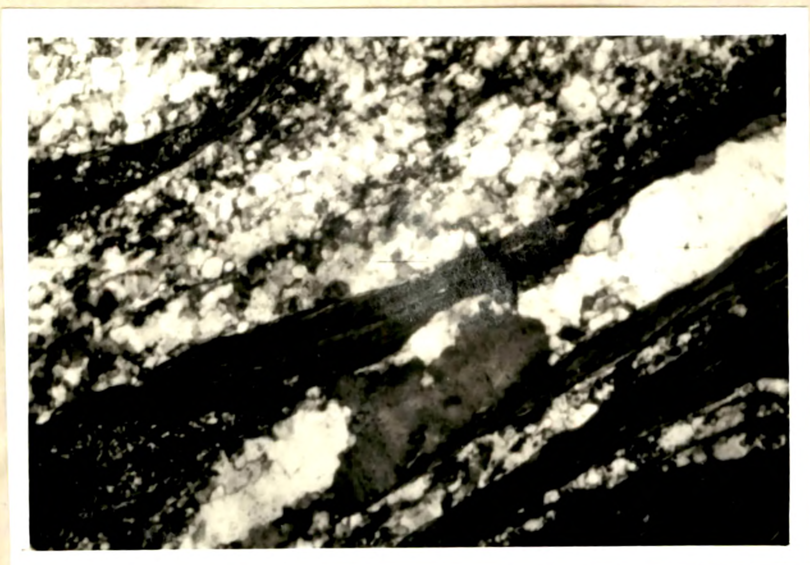


Photomicrograph of scaly and platy chlorites in tuffs, now resembling chloritic phyllite (cross nicols, X80).

streaks, parallel to the foliation. This ferruginous clayey substance perhaps represents either altered volcanic ash or released iron oxides during the alteration of tuffs. Within the above described foliated mass, are interspersed discrete grains of quartz here and there.

The siliceous layers and lenses, seen to consist of quartz grains, show a big variation in grain size. At most places, these are very fine cherty almost crypocrystalline. Within the cherty mass, irregular patches of somewhat bigger quartz grains are common. Lensoid aggregates and irregular patches of sutured quartz grains in the chloritic mass are also abundant (Plate 6.18). Mostly the cherty and quartzose layers and lenses lie along the schistosity, but numerous veins of crystalline quartz oblique to the foliation are recognised. These cross cutting veins are very interesting as they contain quartz grains elongated in the direction of foliation. Obviously, the tuffs contain two generations of quartz, the early cherts and the later veins. Both these are involved in the subsequent deformation, bringing about recrystallization at many places.

PLATE 6.18

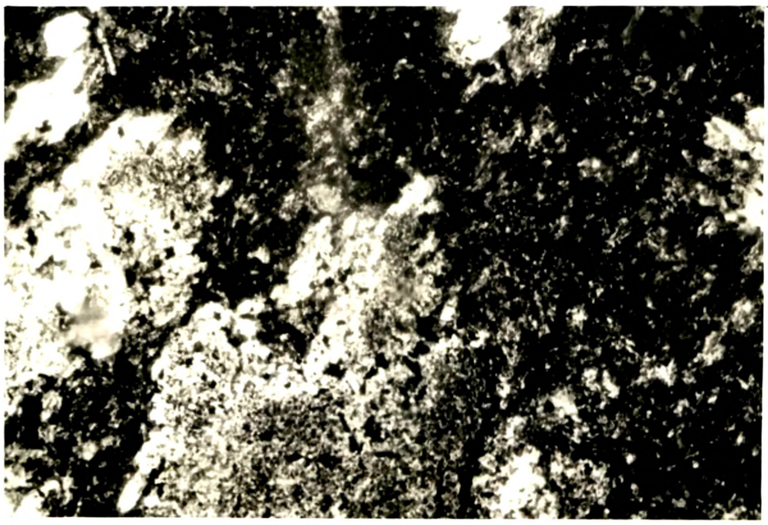


Photomicrograph of sheared tuff showing cherty and quartzose layers within chloritic mass (cross nicols, X80).

Irregular patches of chloritic portion are commonly seen embedded within the quartzose and chery layers. These show a less defined schistosity, considerable contortions (revealed by streaks of dusty iron oxide material), and in a few thin sections, the preservation of original tuffaceous nature is suspected.

The unaltered unmetamorphosed tuffs are not encountered anywhere, and thus it is very difficult to say any thing about the original nature of the tuffaceous rock. A few isolated specimens, it appears, could be representing the variety nearest to the original rock. One is seen in thin section to comprise a very fine mixture of white mica, carbonate, quartz, chlorite, and iron oxides, all these forming a dusty and semi-opaque mass. Within such a mass, numerous equidimensional subrounded cavities filled with carbonate matter are abundant (Plate 6.19). It is difficult to say, whether these cavities represent original vesicles or glass fragments. This rock is extensively traversed by a network of fractures enclosing elliptical areas, and along these fractures the development of chlorite is conspicuously visible. Irrespective of the trends of the fractures the chlorite flakes show a constant preferred orientation, and this very clearly indicates the incipient stage of the

PLATE 6.19



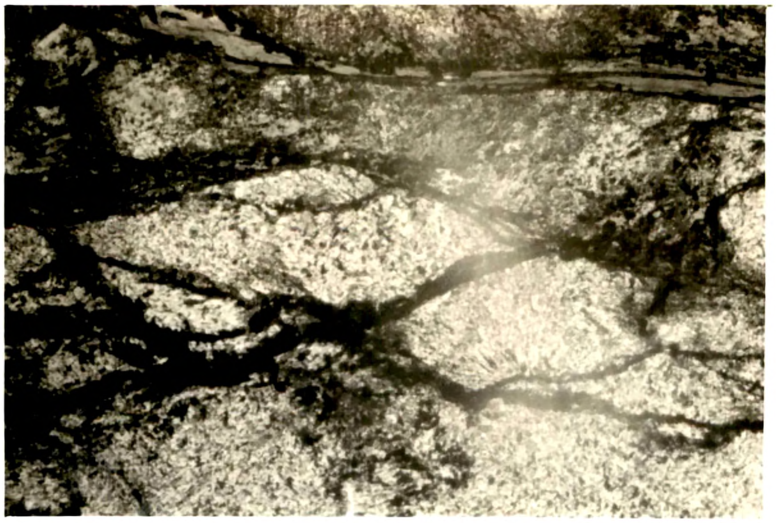
Photomicrograph of a rather rare thin section of unmetamorphosed tuff, with sub-rounded cavities filled with carbonate matter (cross nicols, X80).

cleavage development and chloritization. Another sample, somewhat more coarser in the sense that its thin section reveals a foliated chlorite mass enclosing eye shaped partly altered (glass) fragments. The rock shows distinct effect of shearing and it appears that fragments of volcanic glass, due to deformational strain have become granulated and 'eye shaped' showing a wavy dim low grey polarization colours (Plate 6.20).

Another interesting variety of tuff, has been recorded from the topmost part of the spilitic suite, just below the overlying quartzite. It is an extremely fine grained rock of pale green colour, strongly foliated and shows an intimate association of tiny streaks of chlorite and cherty material. Under the microscope it shows abundant fresh fragments of plagioclase embedded in a foliated chloritic and cherty mass. The felspars are the usual sodic plagioclase and are surprisingly fresh and unaltered. They do show fragmentation and a coarse preferred orientation (Plate 6.21).

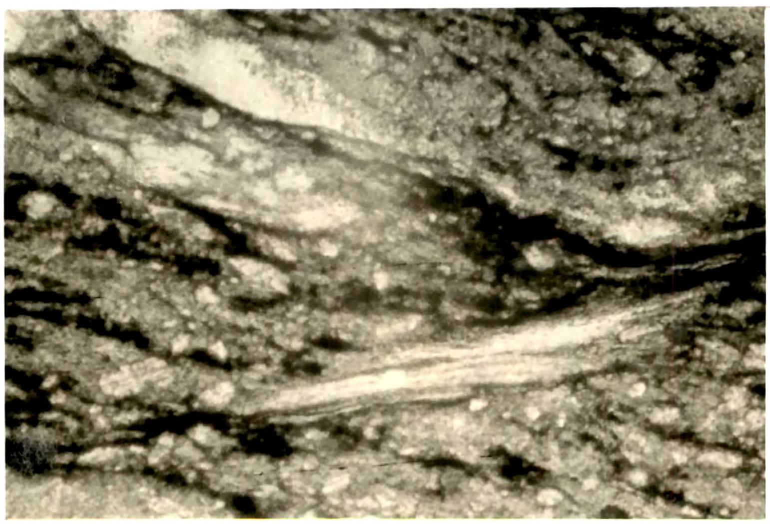
Tuffites are mixed rocks showing a transition from volcanogenic tuffs to clastic sediments, and consist of inter-bedded tuffaceous layers with those of silty and

PLATE 6.20



Photomicrograph of sheared tuff showing devetrified glass fragments, now granulated and eye-shaped (polarised light, X80).

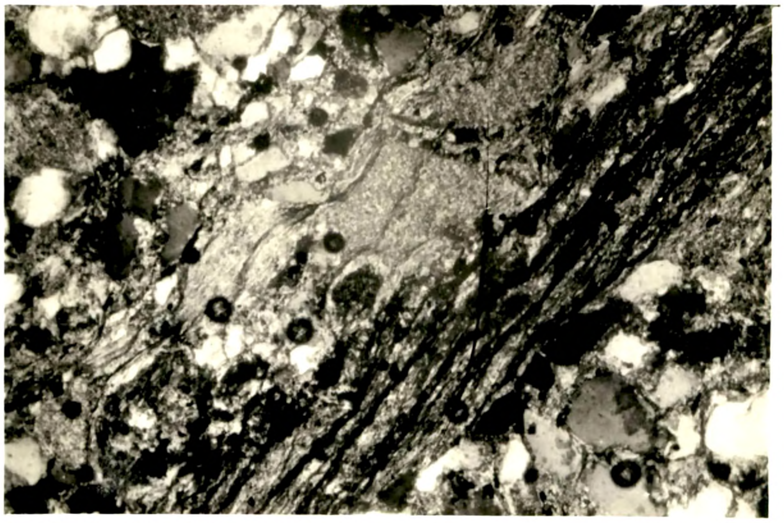
PLATE 6.21



Photomicrograph of sheared tuff, showing fragmentation of fresh sodic felspars (polarised light, X80).

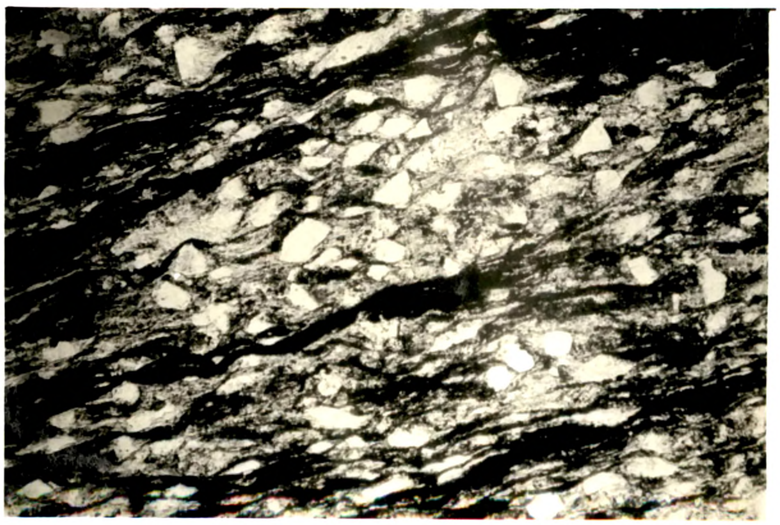
sandy material. In hand specimens, these show irregularly laminated structure. The volcanogenic material is either green or dark brown while the clastic layers are of light grey colour. Thin sections show that the two portions are mineralogically quite distinct. The tuffaceous layers are fine grained schistose and consist of a foliated aggregate of chlorite, sericite (white mica) and streaks of iron oxides. In some varieties, the abundance of an amorphous dark or chocolate brown opaque material- perhaps alterated volcanic ash or mud is noted. Occasionally, the volcanic layers abound in palagonite (Plate 6.22). The light coloured clastic layers, comprise typically impure sandstones and siltstones. The former are more common and are seen to consist of subangular grains of quartz embedded or cemented by volcanogenic material. The matrix or cement is either palagonitic or a fine aggregate of chlorite and white mica, or the chocolate brown opaque volcanic matter (Plate 6.23). In most sections, the clastics are exclusively quartz grains, but in some numerous grains of tourmaline are also recorded. A few sections show in addition to quartz, fragments of alteral palagonite glass (Plate 6.22).

PLATE 6.22



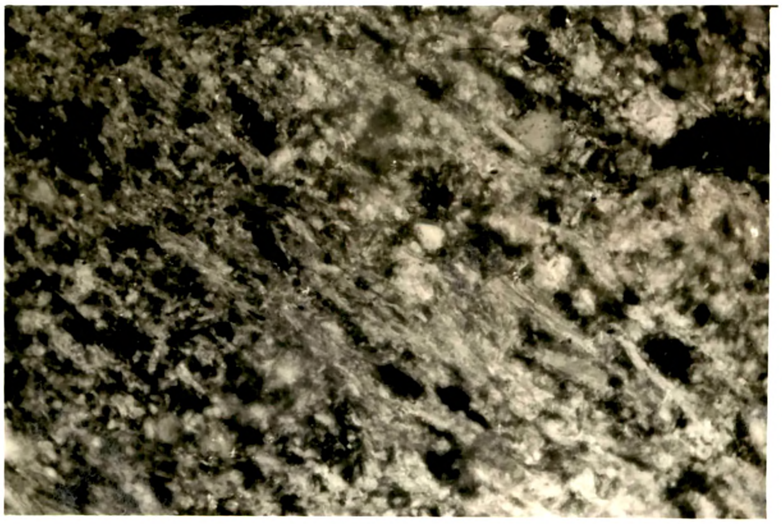
Photomicrograph of tuffites showing distinct volcanogenic and clastic layers, rich in palagonite (cross nicols, X80).

PLATE 6.23



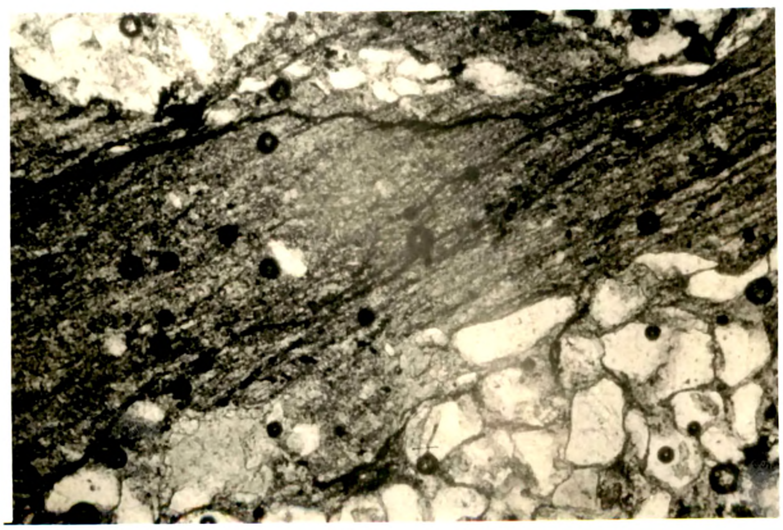
Photomicrograph of a typical tuffites showing subangular quartz grains embedded in volcanogenic material (polarised light, X80).

PLATE 6.24



Photomicrograph under high power of chlorite-sericite layers in tuffites (cross nicols,X160).

PLATE 6.25



Photomicrograph of tuffite showing oblique relationship between cleavage and sedimentary bedding (polarised light, X80).

Tuffites in which clastic portion is silty, show alternate layers of green chlorite or chocolate brown material and fine aggregate of chlorite and sericite (Plate 6.24).

An interesting feature of the tuffite is the frequent oblique relationship between the cleavage and the sedimentary bedding. This angular relationship is better developed in the tuffites that occur inter-stratified with the quartzite (Plate 6.25).

MINERALOGY

Plagioclase

As already mentioned, the plagioclase is only partially altered, and its original nature is still preserved. In all varieties it is sodic. The diabasic rocks contain big laths of plagioclase and it was quite possible to determine their composition on the Universal Stage. The phenocrysts in the fine basaltic variety could also be similarly identified. But in the case of fine needles and laths occurring as variolitic aggregates, their composition could be ascertained only with the Michel Levy Method of measuring extinction on (010) plane.

Most laths show twinning on Albite and Carlsbad laws. The average range of extinction of the large laths, measure on (010) plane is 8° to 15°. The $2V_z$ values range from 76°(+) to 84°(+). It is thus obvious that plagioclase is of Albiclase to Oligoclase variety, the An content varying from 4% to 12%.

A few coarse dolerites contain plagioclase which are rather calcic (An_{35-45}). It is however not clear whether the dolerites that contain these plagioclase are related to the spilitic suite or represent a very late intrusive phase, which is seen as dykes cutting even the Krols formation in the neighbouring areas.

Clinopyroxene

The pyroxene is preserved in a few coarse diabases and basalts. In the former, it occurs in ophitic relationship with plagioclase, and is invariably altered to chlorite and uralite. It has been identified as augite, showing optical properties as under:

Extinction angle $(Z \wedge C)$ - Between 40° and 54½°
$(2V_z)$ - 47° to 50°

According to Varadarajan (1973), this pyroxene is a calcic augite giving an atomic proportion of Ca = 41.5, Mg = 38.5 and Fe = 19.

<u>Uralite and Chlorite</u>

Uralite is present in most slides and together with chlorite, it forms the important alteration product of the original pyroxene and the volcanic glass fragments. It always occurs as sheaf like aggregates of tiny needles, occupying the interstitial areas between the plagioclase laths. In the fine grained varieties, it comprises randomly oriented acicular groundmass within which lie the variolitic aggregates of plagioclase needles. The uralite shows faint pleochroism in shades of green. It is distinguished from chlorite by a slight oblique extinction and somewhat higher 2nd order polarization colours. Asbestiform uralite has also been recorded to occur along a few veins.

The occurrence of chlorite is more varied, and following three varieties of chlorite are recognised:

(1) A scaly variety, comprising streaks of tiny shreds of light yellowish green colour, pleochroic in shades of green (X = pale yellowish green, Y = green, Z = green; $X < Y = Z$) interference colours being low first order greyish blue.

(2) Well formed elongated plates of clear light green colour, with distinct cleavage; very feebly pleochroic and mostly isotropic under crossed nicols; occasionally

showing anomalous interference colours of lavender tint and a straight extinction. On account of wrinkles the extinction tends to be wavy.

(3) Occasional occurrence within vesicular cavities, either as a lining to chalcedony or occupying the centres of the cavity. This variety of green colour is very fine, structureless and isotropic.

Of the three varieties, the first two appear to be alteration products of original pyroxene or glassy matter, but about the third variety, perhaps it represents the original vesicular infilling of the volcanic rock.

<u>Pumpellyite</u>

Pumpellyite is recorded occasionally and forms radiating aggregates of either acicular or small bladed grains, and generally occurs in amygdules and vesicles (Plate 6.9). Two varieties of this mineral have been recognised - one with blue-green and the other with greenish yellow-greenish brown pleochroism. This mineral was first reported by Varadarajan (1973).

Epidote

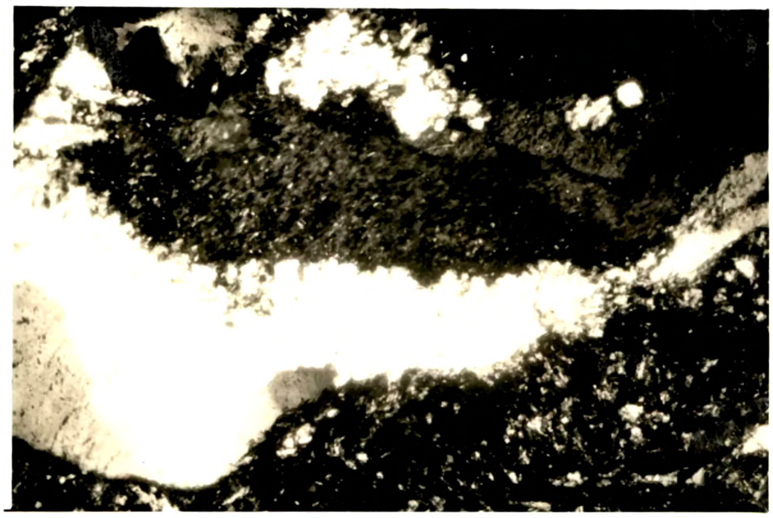
Epidote forms patches, veins, and stray grains and occurs in close association with uralite and chlorite, shows characteristic pistachio green colour and distinct pleochroism (Y > Z > X; Y = Light yellowish green, Z = Light greenish yellow and X = colourless); birefringence strong, showing 3rd order polarization colours; $2V_x$ ranges from 68° to 78°.

It is not clear how much epidote is primary, but a large proportion of it, appears to be secondary, having developed during the hydrothermal alteration of the rock.

Quartz, Chalcedony and Chert

Quartz occurs in fine grained amygdaloidal varieties (as cavity filling) of basalt (Plate 6.26). It forms either aggregates of anhedral interlocking grains, or oriented prisms normal to the wall of the cavity, with longer axis pointing to the centre (Plate 6.6). Quite often the cavity filling with anhedral quartz have a lining of chalcedony (Plate 6.7). Sometimes the entire amygdules are filled with radiating fibrous aggregates of chalcedony. The chert is mostly confined to the tuffs, and some basalts.

PLATE 6.26



Photomicrograph of an amygdule in spilite filled with quartz (cross nicols, X80).

It generally forms elongated streaks of very fine cryptocrystalline mass of silica. Within cherty mass, stray patches of sutured quartz aggregates are not uncommon. The latter phenomenon points to a recrystallization of chert to give rise to quartz.

Sphene and Leucoxene

Sphene is almost invariably present, but is more abundant and conspicuous in the finegrained and aphanitic varieties. It occurs as tiny anhedral non-pleochroic grains of pale brownish yellow colour. It shows the usual high relief and very bright polarization colours. An many places, sphene is seen altering to opaque brown iron oxide.

Sphene grains are obviously of two generation. Some might represent the primary grains, while the others are distinctly products of alteration of the mafic groundmass and of the plagioclase in some cases.

Leucoxene occurs mostly in the coarser variety. It forms skeletal patches, after ilmenite and is recognised by its whiteness and opacity.

Calcite

Calcite is recognised in some sections only and is confined to altered basalts. It either occurs in the amygdaloidal cavities or as irregular veins and patches.

Palagonite

This is the alteration product of glass fragments and is recorded in a few tuffs. Palagonite is seen as yellowish green very fine spherulitic aggregates that show very low polarisation colours.

Iron Oxides

These are mostly magnetite and ilmenite. The former is more common in the basalts and occur as tiny granules interspersed throughout the groundmass. It also form dusty streaks in the foliated portions. Ilmenite is more common in the diabase and forms skeletal crystals associated with leucoxene.

PETROCHEMISTRY

The chemical analyses of representative samples collected from the various parts of the area (Fig. 6.1) of coarse diabase and fine basalt, fully support their

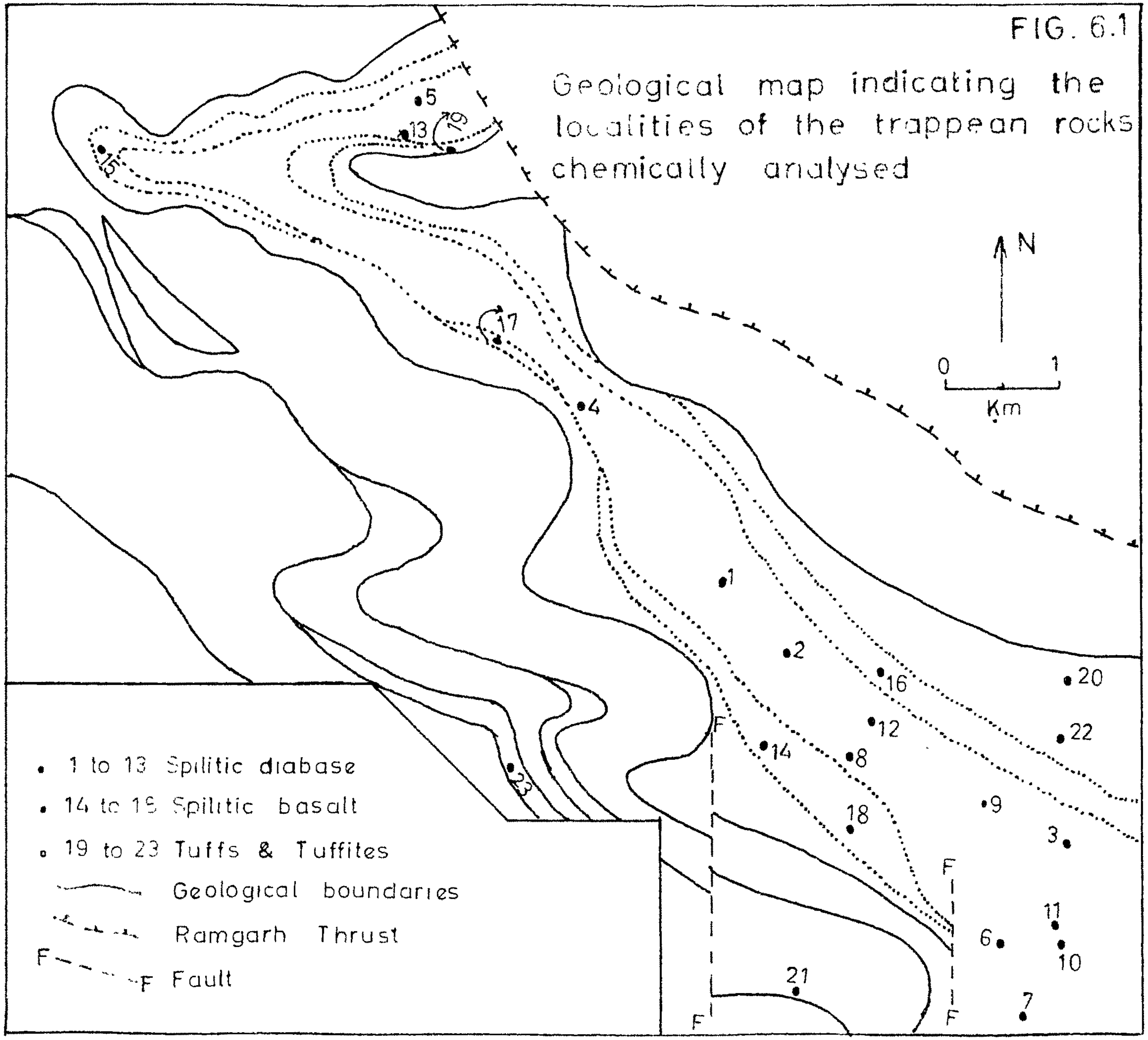


FIG. 6.1

Geological map indicating the localities of the trappean rocks chemically analysed spilitic nature. These show a high Na_2O and low K_2O in comparison to the other basaltic rocks. The percentages of the various oxides are given in the enclosed tables (Table Nos. 6.1, 6.2 and 6.3). The composition in Cations per 100 oxygen Anions (Mckie, 1966) is also calculated from this chemical data and values of Cations per 100 oxygen Anions are given in Table No. 6.4. Similarly ionic weight percentages (Green and Poldervarrt, 1958) of these rocks are given in Table No. 6.5. The main Niggli values i.e. al, fm, c, alk and si of these rocks have been calculated and shown in Table No. 6.6. Table No. 6.7 represents average chemical compositions of spilitic rocks, shown by the various authors. The author has constructed following diagrams on the basis of above data.

1. Variation diagram based on Si Vs other Cations of spilitic rocks (Fig. 6.2).
2. Triangular variation diagram based on
   (a) Mg-Fe-Al Cations
   (b) Mg-Ca-Al Cations and
   (c) Ca-Fe-Al Cations of spilitic rocks (Fig. 6.3).
3. Variation diagram based on $\frac{SiO_2}{K_2O/Na_2O}$ of spilitic rocks (Fig. 6.4).
4. Variation diagram based on the Niggli values (Fig.6.5).

TABLE 6.1

Spilitic Diabase (Weight percent)

Oxides	1	2	3	4	5	6	7
SiO_2	44.88	48.97	48.20	50.02	49.50	50.05	52.05
Al_2O_3	18.17	15.53	15.38	16.63	15.18	14.53	16.43
Fe_2O_3	1.77	3.83	2.02	2.54	1.34	4.04	2.00
FeO	10.37	7.14	12.08	10.03	11.03	9.23	7.98
Na_2O	3.66	5.50	5.56	5.50	5.94	3.50	3.38
K_2O	2.61	0.62	0.79	0.99	1.49	2.05	0.87
MgO	8.99	6.97	6.53	4.96	6.96	6.70	6.11
CaO	2.80	6.28	6.72	5.04	5.04	5.60	7.28
TiO_2	2.00	2.62	2.00	2.13	1.60	2.13	1.80
Loss on Ignition	4.52	2.92	1.57	2.52	2.69	2.57	2.86
Total	99.77	100.38	100.85	100.36	100.77	100.40	100.76
Ratio K_2O/Na_2O	0.70	0.11	0.14	0.17	0.25	0.58	0.25

Contd...

TABLE 6.1 (contd.)

Oxides	8	9	10	11	12	13
SiO_2	52.09	52.37	51.96	51.40	51.81	52.05
Al_2O_3	17.38	16.43	15.18	15.33	17.03	16.08
Fe_2O_3	1.02	0.50	0.97	4.49	2.02	0.68
FeO	9.65	11.09	11.94	8.48	10.09	10.87
Na_2O	5.62	2.90	2.64	5.24	4.00	5.08
K_2O	0.60	0.99	0.62	0.74	0.62	0.81
MgO	6.26	5.10	7.26	4.58	5.12	6.07
CaO	3.36	6.72	3.36	6.16	6.16	5.04
TiO_2	1.29	2.82	2.13	1.57	0.85	1.60
Loss on Ignition	2.52	1.70	3.39	2.41	2.47	2.29
Total	99.79	100.62	99.45	100.40	100.17	100.57
Ratio K_2O/Na_2O	0.11	0.34	0.23	0.14	0.15	0.15

TABLE 6.2

Spilitic Basalt (Weight percent)

Oxides	14	15	16	17	18
SiO_2	47.42	51.71	53.01	50.15	58.20
Al_2O_3	17.64	15.31	14.08	16.83	14.54
Fe_2O_3	3.09	0.36	1.94	0.70	3.44
FeO	10.01	9.54	10.43	12.67	7.90
Na_2O	5.50	4.91	5.50	3.82	4.66
K_2O	3.05	3.02	1.68	1.43	0.39
MgO	4.64	5.42	6.08	8.56	3.90
CaO	2.80	7.28	2.24	1.12	3.36
TiO_2	2.00	1.29	1.50	0.83	1.50
Loss on Ignition	3.90	1.96	3.37	4.74	2.10
Total	100.05	100.80	99.83	100.85	99.99
Ratio K_2O/Na_2O	0.55	0.61	0.30	0.37	0.08

TABLE 6.3

Tuffs with cherty layers

Oxides	19	20	21	22	23
SiO_2	49.43	54.20	60.24	61.56	62.05
Al_2O_3	19.07	17.62	15.82	14.03	18.52
Fe_2O	0.49	0.88	2.68	4.65	3.28
FeO	10.34	8.30	4.50	7.32	2.70
Na_2O	3.92	4.86	3.44	3.24	3.74
K_2O	0.74	0.40	2.24	0.58	2.37
MgO	8.18	9.33	4.98	4.01	2.63
CaO	2.80	1.12	1.12	2.24	1.12
TiO_2	1.29	-	0.83	-	0.10
Loss on Ignition	4.18	4.02	3.94	2.91	3.40
Total	100.44	100.73	99.79	100.54	99.91

TABLE 6.4

Spilitic Diabase

Cation values for 100 oxygen Anions

	1	2	3	4	5	6	7
Si	26.01	28.59	28.91	29.24	29.17	29.4	29.79
Al	12.43	10.64	10.83	11.48	10.64	10.6	11.08
Fe^{+++}	0.77	1.56	0.93	1.12	0.58	1.76	0.89
Fe^{++}	5.01	3.38	6.02	4.89	5.37	4.52	3.70
Na	4.08	3.03	6.41	6.26	6.73	3.87	3.63
K	1.96	0.42	0.50	0.70	1.06	1.48	0.61
Mg	7.85	6.02	5.87	4.36	6.12	5.90	5.22
Ca	1.75	3.88	4.32	3.13	3.14	3.52	4.38
Ti	0.87	1.04	0.90	0.91	0.70	0.89	0.78
H	17.54	11.25	6.00	9.78	10.30	9.81	10.60

contd...

TABLE 6.4 (contd.)

	8	9	10	11	12	13
Si	29.8	30.54	29.9	30.15	30.01	30.33
Al	11.81	11.28	10.2	10.47	11.56	10.98
Fe^{+++}	0.41	0.26	0.41	1.95	0.90	0.28
Fe^{++}	4.62	5.34	5.75	4.08	4.92	5.25
Na	6.25	3.28	2.87	5.87	4.42	5.67
K	0.41	0.69	0.41	0.48	0.40	0.63
Mg	5.42	4.44	6.15	3.98	4.35	5.27
Ca	2.04	4.19	2.04	3.80	3.70	3.15
Ti	0.52	1.21	0.86	0.66	0.34	0.7
H	9.66	6.56	12.50	9.68	9.14	8.54

TABLE 6.4 (contd.)

Spilitic Basalt

	14	15	16	17	18
Si	27.58	30.27	29.74	28.10	33.14
Al	12.11	10.54	9.18	11.20	9.74
Fe^{+++}	1.30	0.14	0.80	0.27	1.43
Fe^{++}	4.86	4.64	4.80	5.68	3.69
Na	6.23	5.55	5.96	3.96	5.1
K	2.24	2.24	1.14	0.98	0.20
Mg	4.06	4.74	5.09	6.91	3.31
Ca	1.75	4.53	1.30	0.67	2.02
Ti	0.87	0.53	0.13	0.33	0.65
H	15.19	7.44	12.27	16.96	7.99

TABLE 6.5

Cation (wt %) of Mg-Fe-Al

Spilitic Diabase

	1	2	3	4	5	6	7	8	9	10	11	12	13
Mg	30	28	24	20	27	27	25	25	21	27	19	21	25
(Total) Fe	22	23	30	27	26	28	21	22	26	27	29	26	24
Al	48	49	46	53	47	45	54	53	53	46	52	53	21

Spilitic Basalt

	14	15	16	17	18
Mg	18	23	25	29	18
(Total) Fe	28	24	28	25	28
Al	54	53	47	46	54

contd....

TABLE 6.5 (contd.)

Cation (wt %) of Mg-Ca-Al

Spilitic Diabase

	1	2	3	4	5	6	7	8	9	10	11	12	13
Mg	35	22	28	23	30	30	26	28	22	33	22	22	17
Ca	8	20	20	16	16	18	21	11	21	11	20	21	16
Al	57	58	52	61	54	52	53	61	57	56	58	57	57

Spilitic Basalt

	14	15	16	17	18
Mg	23	24	32	37	22
Ca	10	23	09	04	13
Al	67	53	59	59	65

contd....

TABLE 6.5 (contd.)

Cation (wt %) of Ca-Fe-Al

Spilitic Diabase

	1	2	3	4	5	6	7	8	9	10	11	12	13
Ca	9	20	20	16	16	18	23	11	20	11	19	19	16
(Total) Fe	28	26	31	29	30	31	23	26	26	33	30	26	28
Al	63	54	49	55	54	51	54	63	54	56	51	55	56

Spilitic Basalt

	14	15	16	17	18
Ca	9	23	8	4	12
(Total) Fe	30	24	34	33	30
Al	61	53	58	63	58

TABLE 6.6

Niggli Values

Spilitic Diabase

	1	2	3	4	5	6	7	8	9	10	11	12	13
Si	105	123	110	128	118	125	135	138	140	141	135	134	134
al	25	23	21	25	22	21	25	27	26	24	24	26	24
fm	55	46	50	46	49	52	45	48	46	58	45	46	48
c	08	17	16	14	13	15	20	10	19	10	17	17	14
alk	12	14	13	15	16	12	10	15	09	08	14	11	14
(al + fm) - (c + alk)	60	38	42	42	42	46	50	50	44	64	38	44	44

Spilitic Basalt

	14	15	16	17	18
si	123	130	147	126	184
al	27	22	23	25	27
fm	46	41	53	60	47
c	08	20	07	04	11
alk	19	17	17	11	15
(al + fm) - (c + alk)	46	26	52	70	48

TABLE 6.7

Sample Nos / Oxides	K	L	M	N	O
SiO_2	51.22	48.60	53.15	54.20	49.65
TiO_2	3.32	1.94	1.50	1.31	1.57
Al_2O_3	13.66	16.10	14.39	17.17	16.00
Fe_2O_3	2.84	7.60	1.28	3.48	3.85
FeO	9.20	4.00	9.33	5.49	6.08
MnO	0.25	0.34	0.14	0.15	0.15
CaO	6.88	6.20	7.04	7.92	6.62
MgO	4.55	3.66	4.74	4.36	5.10
Na_2O	4.93	4.50	4.58	3.67	4.29
K_2O	0.75	1.76	1.01	1.11	1.28
P_2O_5	0.29	0.34	0.19	0.28	0.26
H_2O^+	2.90	2.54	2.04	0.86	3.49
CO_2	0.94	1.45	0.10	-	1.63
	100.72	99.60	99.60	100.00	99.97

K = Average spilite (SUNDIUS, 1930, p.9).
L = Somewhat potassic spilite, Wellington, New Zealand (REED,1957,p.37).
M = Spilite somewhat high in potash, eastern orogen (GILLULY,J. (1935) Am. Jour. Sci., Vol.29,p.235).
N = Andesite (NOCKOLDS,S.R.(1954). Average chemical composition of some igneous rocks. Bull. Geol.Soc.Am. 65, p.1007).
O = Average spilite (VALIANCE,1960).

FIG. 6.2 Variation diagram based on Si/other cations.

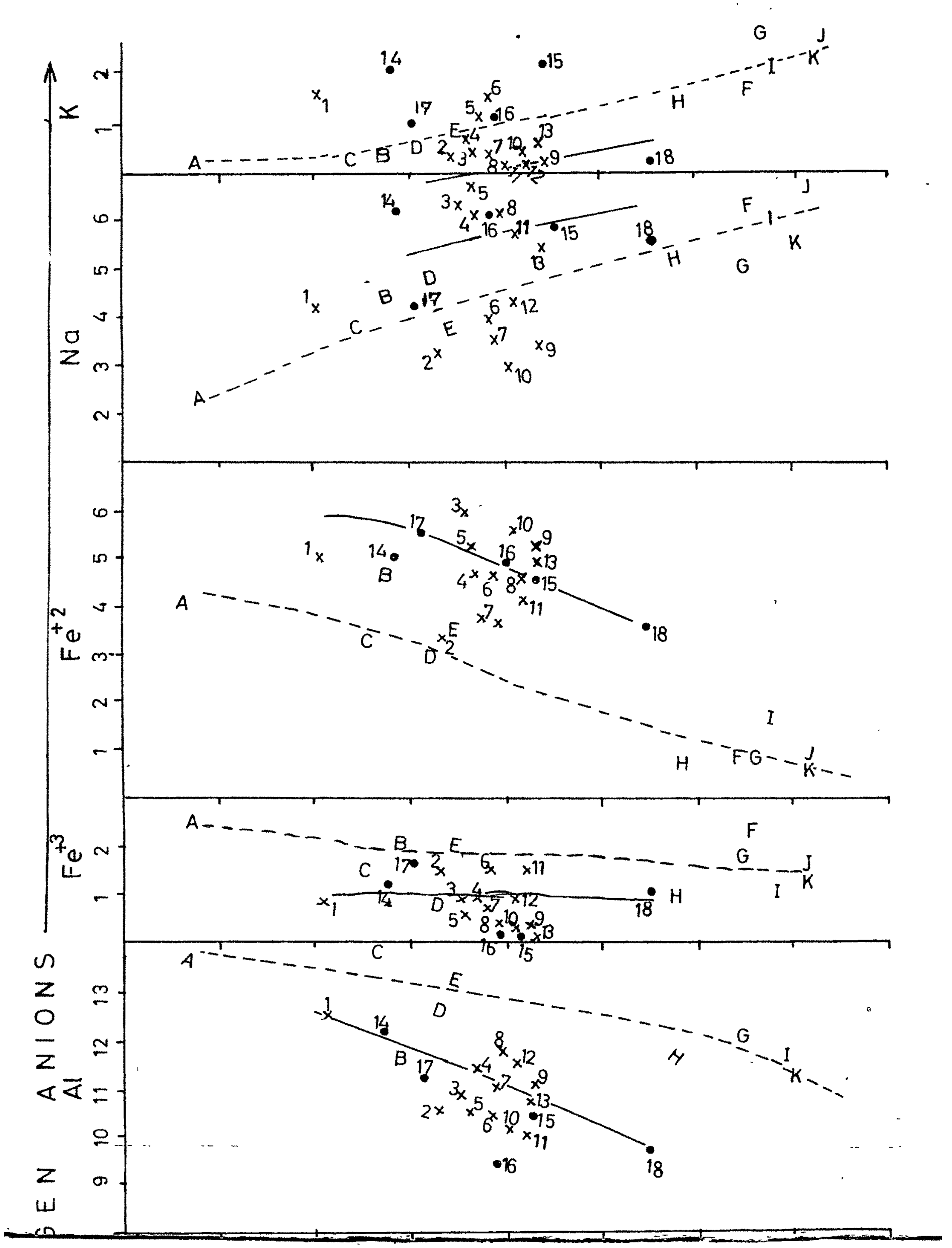


FIG. 6.3

Variation diagrams based on various cations.

(a) Mg - Fe - Al Cations
(b) Mg - Ca - Al Cations
(c) Ca - Fe - Al Cations

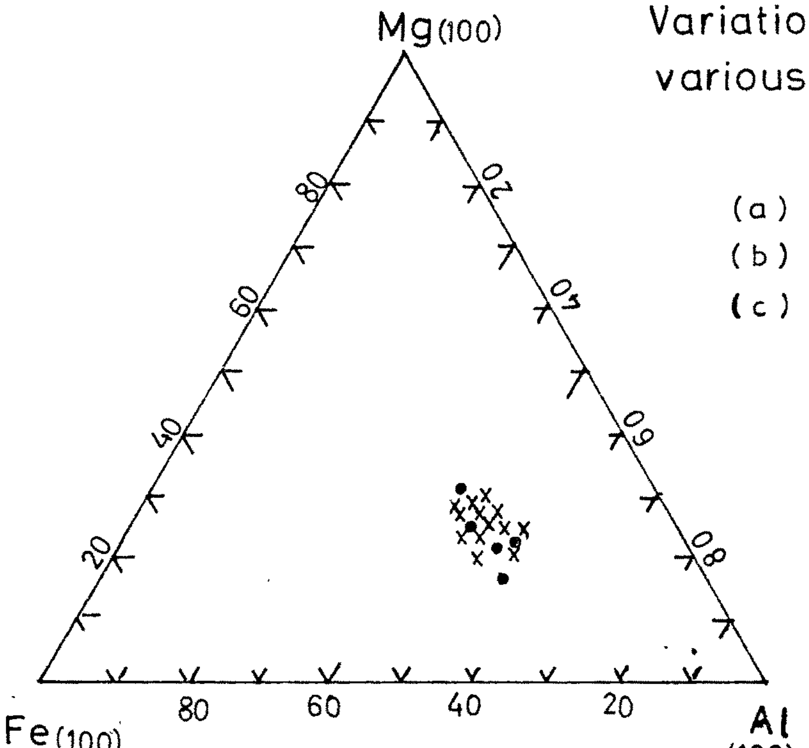


FIG. 6.3(a)

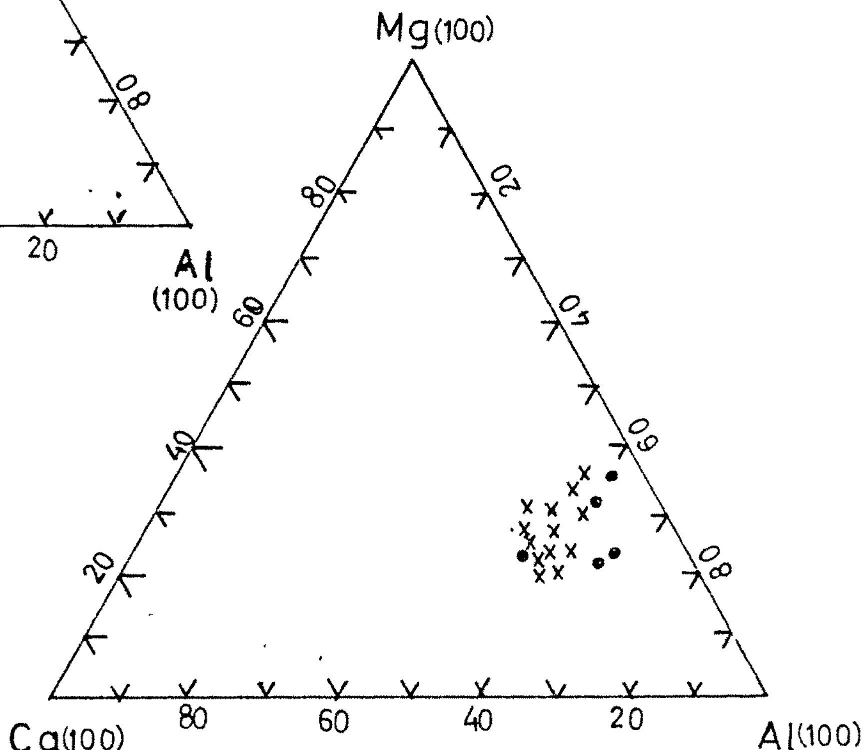


FIG. 6.3 (b)

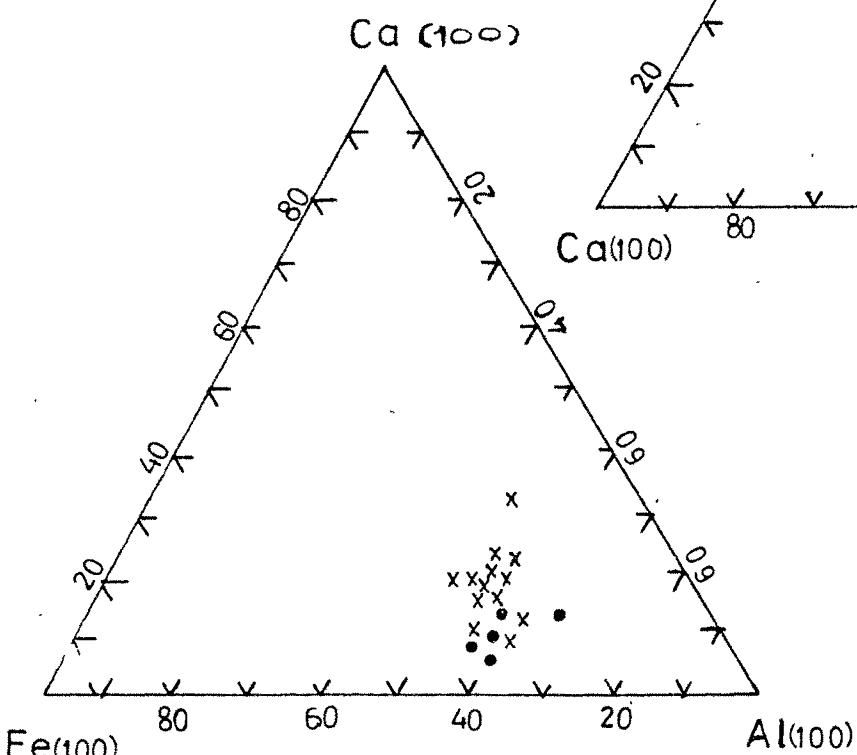
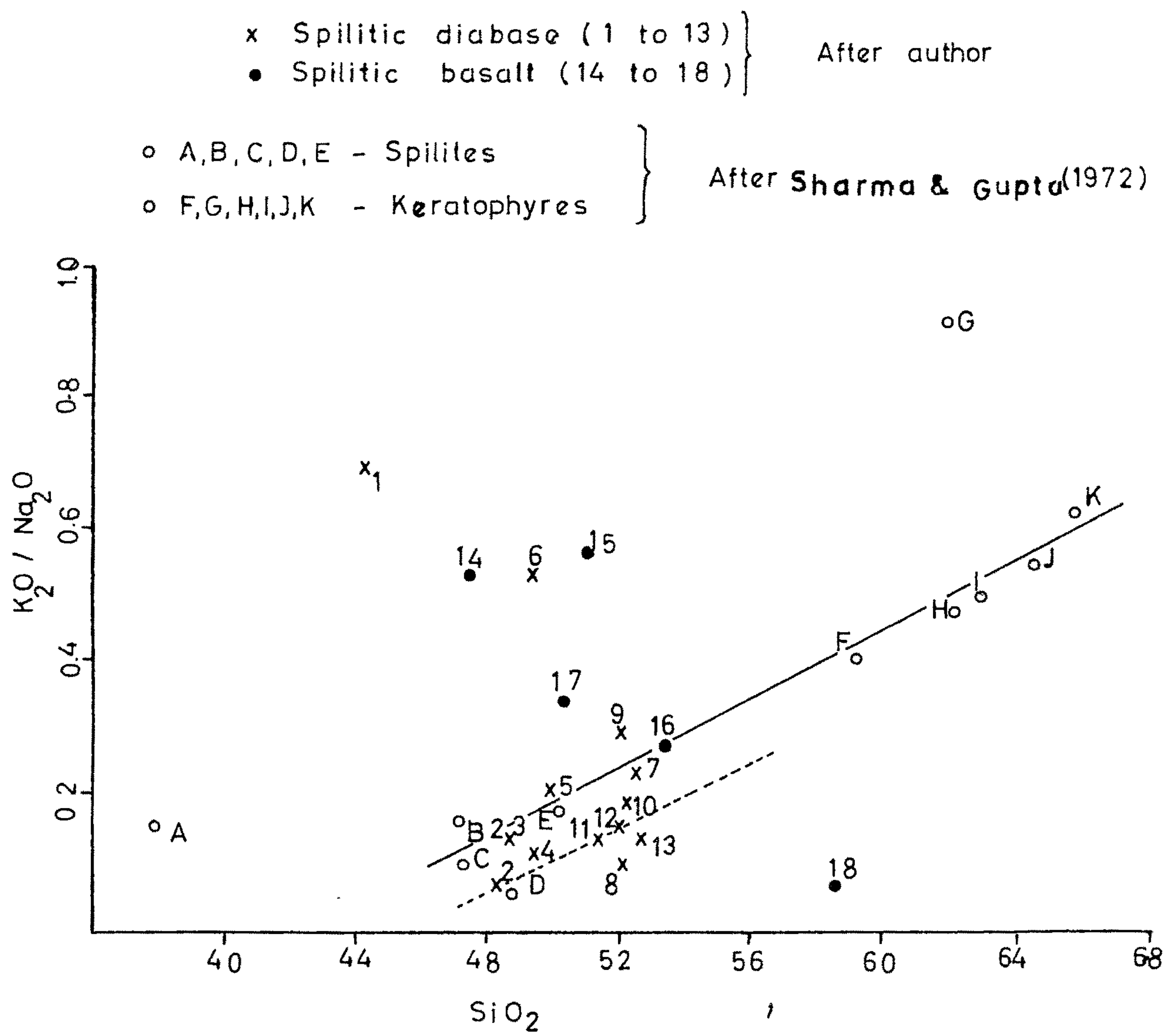


FIG. 6.3 (c)

Variation diagram based on $\frac{SiO_2}{K_2O/Na_2O}$ ratio



Variation diagram based on Niggli values

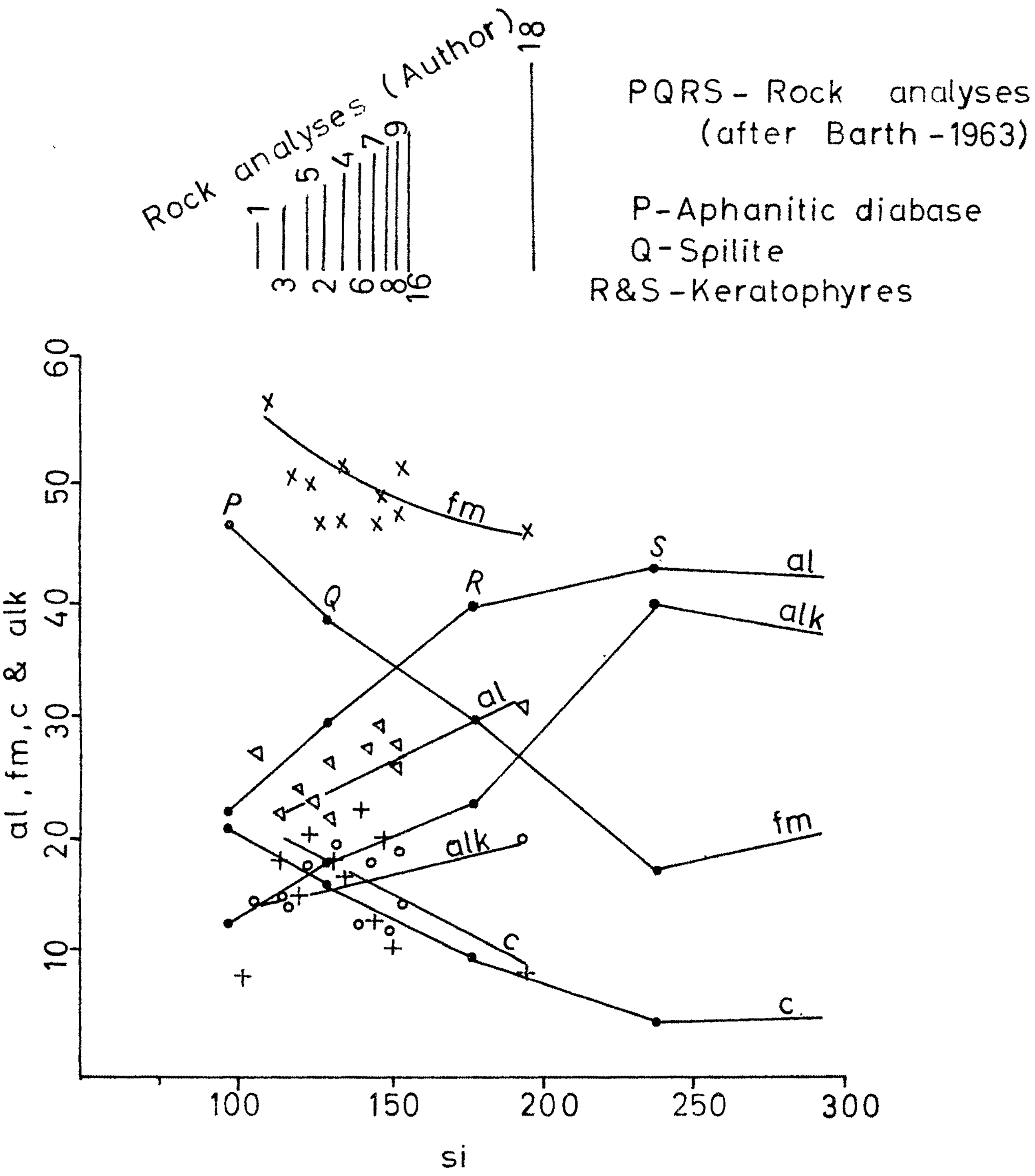


FIG. 6.6

Simonen's diagram (1960) based on Niggli values showing fields of spilitic diabase and spilitic basalt

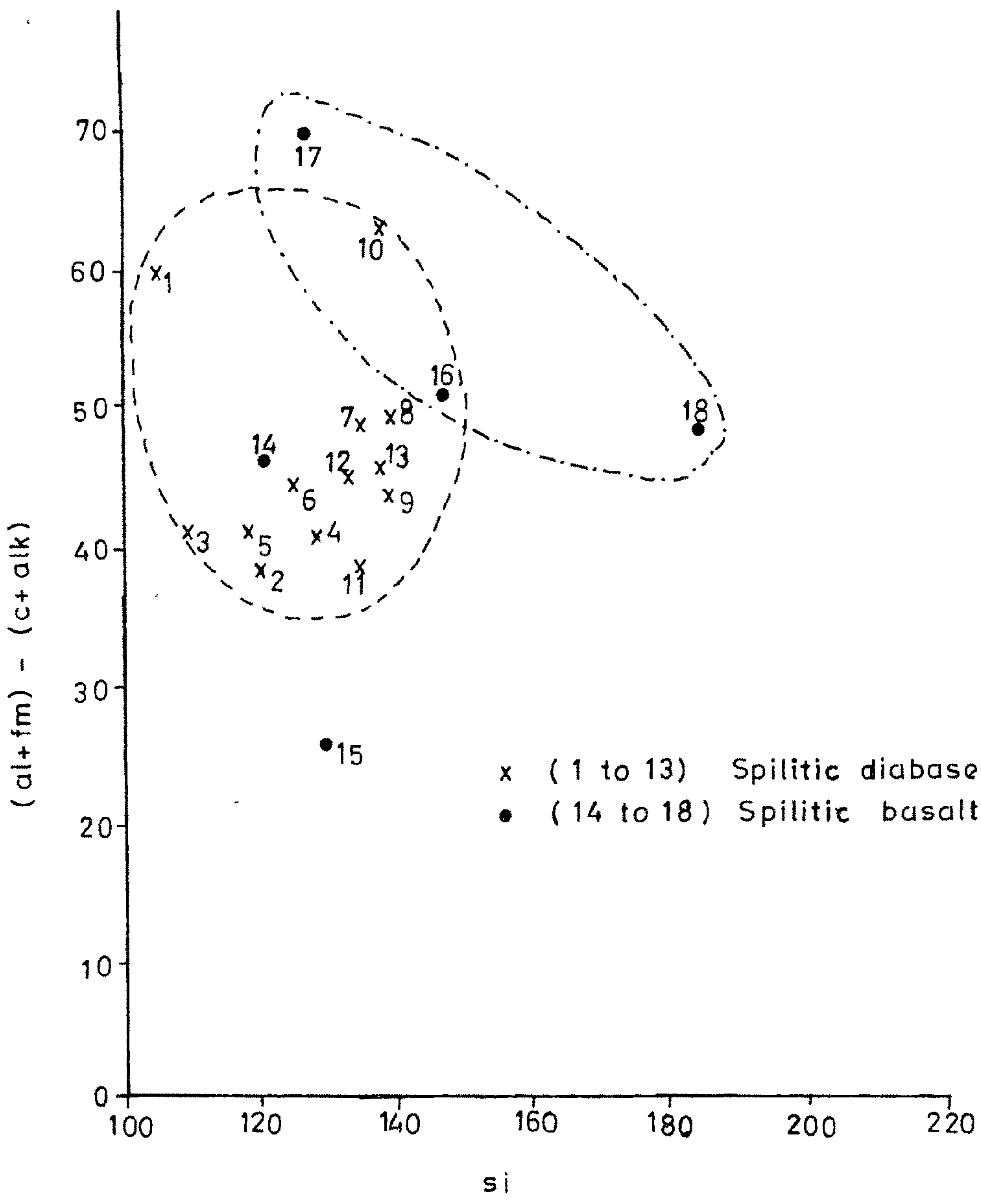
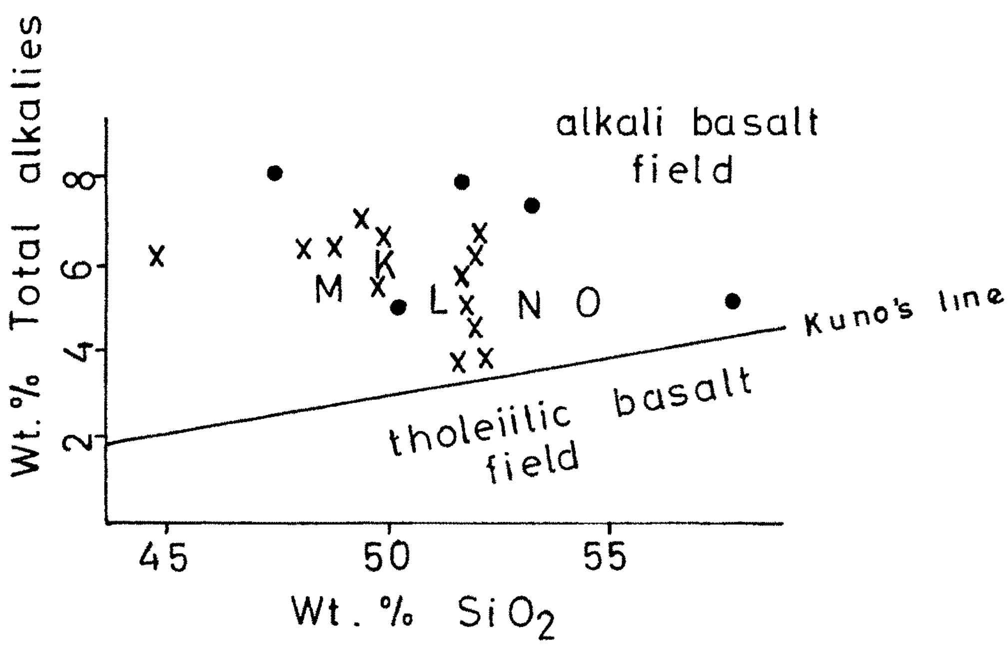


FIG. 6.7

Kuno's diagram showing the alkali basaltic field for the spilitic rocks of the Bhimtal-Bhowali area (after Kuno - 1959).



• Spilitic basalt } Author's area
x Spilitic diabase }

K, L, M, N, O - Average spilites shown in table 6.7 (after Kuno - 1959)

5. Simonen's diagram based on Niggli values (Fig.6.6).(1960)

6. KUNO'S diagram (Fig. 6.7).(1959)

In the absence of keratophyric rocks the various diagrams mentioned above do not reveal a clear differential trend of an alkaline magma (Fig. 6.7) either originally rich in sodic content or enriched in soda at later stages; but the plots of the diabase and basalts do indicate a very distinct trend of decreasing basicity from coarse to fine varieties. The author has, for the purpose of comparison included similar diagrams for typical spilite-keratophyre associations recorded by Sharma and Gupta (1972) and by Barth (1963).

As already mentioned earlier, the basic rocks of the study area have been classified into spilitic diabases and spilitic basalts mainly on textural/grainsize basis. However, some of the spilitic basalts, when plotted in various chemical diagrams show their distribution overlapping with the field of diabases. This may be due to original variation in chemical characters of these rocks and such variation in chemical characters of spilitic rocks has also been suggested by Vallance (1960), Amstutz (1968), Patwardhan (1974).

The author analysed a few typical tuffs also (Table No. 6.3) but as these rocks contained cherty layers and sometimes fragments of other rocks also, their chemical data could not be considered of any material use. These have therefore been not plotted on any of the diagrams.

ORIGIN OF SPILITES

General

Spilites are problematic rocks and ever since the term was introduced by Bonnard in 1819 (Vallance, 1960, p.8), it has remained controversial. According to Amstutz (1968, p.738), "After 1900, the term spilite (and that of keratophyre) was used in two different ways. Many regarded the presence of albite and chlorite as proof of a secondary origin and therefore considered all green spilites to be secondary altered basaltic rocks. Others, however, held it possible that under certain circumstances these two minerals, as well as calcite, quartz, prehnite, epidote etc. could form as primary crystallization products".

The controversy whether the spilites are of primary or of secondary origin, is yet unresolved. As early as

1911, while reviewing the origin of British spilites, Dewey and Flett (1911) followed Bailey and Grabham (1909) and considered spilites as secondary rocks. On the other hand Benson (1913-1915) in his monograph on the spilitic lavas of the New South Wales suggested that these rocks could be of primary origin. According to him, the various primary textural features like flow lines, amygdules and scoria pattern could hardly be explained in any way, other than as primary features. Turner and Verhoogen (1962, p.260-262) have ideally discussed the spilitic problem in the following words:

"In certain spilites and albite diabases there is nothing to show that the albite of individual spilitic rocks is other than a product of direct crystallization from a magma.

"Spilitic rocks, by reason of their early appearance in geosynclinal belts, are particularly liable to be affected by regional metamorphism, and many of the greenschists of orogenic zones are doubtless of such origin. Since low-grade metamorphism corresponding to the greenschist facies leads to the same assemblage of minerals (albite, epidote, chlorite, actinolite, calcite) as may also result from low-temperature metasomatism of basic rocks, the general presence and local concentration of albite in partially metamorphosed 'greenstones' is no criterion of spilitic parentage. Writers on the spilitic problem, whose experience has been drawn largely from lavas showing incipient effects of regional metamorphism, have not always appreciated the character of unmetamorphosed spilites such as those of New South Wales and New Zealand. There are many recorded instances where shales invaded by albite diabases of spilitic kindred have been converted to adinoles by contact metamorphism involving introduction of soda. However, similar soda metasomatism commonly occurs in connection with intrusion of normal diabases. Furthermore, from the widespread occurrence of jaspers and manganiferous sediments in close association with spilites, it would seem that silica, iron, manganese, and perhaps magnesium are the main constituents of late-magmatic solutions emanating from spilitic rocks. A number of writers believe that silica in particular is commonly expelled in such vast amounts as to allow its precipitation, either by chemical or by organic agencies to give those thick extensive beds of chert with which spilitic lavas so frequently are broadly associated. From the characteristically close association of spilitic rocks with marine sediments, and from the prevalence of pillow structure among typical spilites it is clear that these are mostly submarine lavas poured out on the sea floor or injected into unconsolidated sediments. It is equally obvious from the great thickness of associated arkosic sandstones and graywackes consistently present, that the volcanic activity of this type occurs during the development and slow sinking of geosynclines or unstable basins. So it is doubtful whether the bedded radiolarian cherts that are so conspicuous in spilitic provinces represent abyssal deposits as was believed to be the case by Steinmann and others".

According to Turner and Verhoogen (op.cit. p.267) it would seem much more likely that the spilites are in some way derived from magma of alkaline olivine-basalt or tholeiitic composition, either by differentiation or contamination of 'normal' basaltic magma, or else by metasomatic introduction of soda into rocks which first crystallised as 'normal' basalts. The probability of some such mode of origin is strengthened by the prevalence of 'normal' basalts in geosynclinal terranes. There is a most convincing petrographic evidence that in many spilites and keratophyres albite has replaced a pre-existing felspar of more calcic composition, relict inclusions of which may still persist within the albite crystals. It is probable, too, that variation in temperature and pressure in submarine lavas accumulating to variable thickness and at different depths also determines whether initially calcic plagioclase becomes replaced by albite, zeolites, or epidote or remains unaltered. Albitization of plagioclase is commonly accompanied by development of chlorite, calcite, epidote and actinolitic amphibole at the expense of augite in spilitic rocks.

Described below are the views put forth by Turner and Verhoogen (Op. cit. p.268-272) on spilite genesis,

"Two alternative mechanisms, currently invoked to explain albitization of spilites in their characteristic geosynclinal environment, merit attention:

1. The marine environment of spilites may be directly responsible. Sea water is a possible source of Na^+ ions and of water necessary for soda metasomatism. It is conceivable, even probable, that sea water entrapped, vaporized and streaming upward through hot but largely solidified submarine basic lavas, could bring about the type of alteration observed in spilites and could also contribute Ca, Fe, Mn,Mg, and Si to the surrounding sea in sufficient quantity to account for the chemically precipitated cherts,

jaspers, manganese ores, and possibly limestones associated with many spilites. Much the same effect might be achieved by sea water absorbed from invaded wet sediments into intrusive basic magma. Compaction and incipient metamorphism of the basal sediments of geosyncline during sinking and early compression must involve reduction in porosity, and hence expulsion (presumably upward) of vast quantities of aqueous saline solutions originally held in the pores. Solutions of such origin, encountering magma or still heated igneous rocks in their upward passage could contribute notably to their metasomatism. These possibilities are in no way invalidated by certain rare keratophyres, and possibly spilites too, that have been erupted sub-aerially. Metasomatism of a type very generally brought about by the action of sea water presumably could also be reproduced under favourable condition by other agencies in another environment e.g. by saline ground water in sediments of desert basins.

2. It is also possible to appeal to autometasomatism- chemical alteration of an igneous rock by residual

aqueous fluids derived from its own parent magma-under special, but admittedly obscure, conditions in some way controlled by geosynclinal sinking synchronous with volcanism. It might be supposed that a specially sodic (spilitic) magma tends to develop under such conditions and to give rise, as crystallization proceeds, to sodic residual solutions necessary for albitization and related processes. Or alternatively basic magma might be of 'normal' basaltic composition, the critical factor for albitization being one connected with the marine environment e.g. quick surface chilling, and consequent retention of volatile materials which otherwise would have escaped. A variant of the autometasomatism hypothesis is Battey's suggestion that keratophyres may develop from normal rhyolites by redistribution and differential concentration of the two alkalis through the agency of aqueous solutions diffusing at moderately elevated temperatures through the consolidated volcanic pile."

"<u>Primary Albite in spilites</u>: Although the secondary nature of albite and associated low-temperature minerals of some spilites have been demonstrated beyond reasonable doubt, there is a strong and persistent opinion in current literature to the effect that in other spilites the albite and even the chlorite are primary magmatic minerals. This is strongly suggested by textural relations between albite and augite or chlorite in spilites lacking any trace of metamorphism. Indeed if this textural evidence is rejected, it follows that volcanic textures in general are of dubious genetic significance. Finally, the data that are beginning to accrue from laboratory experiments on hydrous systems are not inconsistent with the possibility that albite and chlorite could crystallise from hydrous melts at temperatures of the order of 650°C. Whether of primary or secondary origin, the albite of spilites is the low-temperature polymorph."

"Evolution of spilites: The authors tentatively favor a rather complex scheme of petrogenesis starting with normal basaltic magmas and leading by converging lines of descent to spilites. Differentiation of the parent magmas, assimilative reaction with rocks situated in the basal levels of the geosyncline, concentration of soda in late-magmatic aqueous extracts, and chemical activity induced by entrapped sea water and rising connate waters squeezed up from deeply buried sediments, are all factors of possible significance in the evolution of keratophyres and spilites."

"Judging from the common association of mugearites with alkaline olivine basalts, fractional crystallization of the basalt magma may very generally lead to development of a sodic liquid differing from average spilite mainly in its higher content of alumina and in the presence of significant amounts of potash. Such a liquid could be formed merely by removal of early formed olivine, pyroxene, and possibly basic plagioclase in appropriate quantities. This could be well the first step in the evolution of spilite from a basaltic magma. Some spilites indeed contain sufficient potash and alumina to approach rather closely the composition of mugearites. Tholeiitic magmas must also be considered as possible parents of spilites. Battey has emphasized certain chemical similarities between tholeiitic and spilitic series, and suggests that under the influence of high concentrations of water the trend of differentiation of a tholeiitic magma may, lead into a spilite keratophyre line."

"If simple fractional crystallization alone were responsible for evolution of spilitic rocks from a basaltic parent, we should expect to find rocks of strictly spilitic composition in differentiated basic sills, especially where (as in teschenite and theralite intrusions) these sills are rich in soda and water. Such cases have not been recorded; we must turn to some other influence, peculiar to the geosynclinal environment. In this connection it seems unlikely that the occurrence of a sodic igneous association in an environment where soda-rich sediments and sodic waters both abound can be pure coincidence. Geosynclines are sites for accumulation of vast thickness of felspathic sandstones (graywackes), the major constituents of which are quartz and oligoclase. Analyses of such rocks, as contrasted with those of other sandstones and shales, persistently show great predominance of soda over potash. In view of the relatively low temperature and high albite content of the quartz-albite eutectic, it is reasonable to suppose that basaltic magma, held for a long period in contact with graywackes or their metamorphic equivalents the albite-quartz-epidote schists, could incorporate into the liquid state material chemically equivalent to an albite-quartz mixture. Water presumably would facilitate such contamination process. Prevalence of albite-quartz veins and laminae in low-grade schists of graywacke parentage testifies to the ease with which the components of albite diffuse and segregate in the presence of water at temperatures far below those that prevail in reservoirs of molten basalt."

"Superposed on the effects of differentiation and contamination, and operating in the same general direction there could be the possible effect of connate and sea waters. In the deeper levels these perhaps could diffuse into the still liquid magma and might there be effective in causing local upward concentration of soda by some process of "alkali-volatile diffusion" akin to that which many writers believe to play an important part in the evolution of alkaline magmas in general. There is ample evidence, too, that near the sea floor metasomatism, including albitization, of solid but still heated rock may also be effected through the agency of externally derived waters."

Amstutz (1968, p.750) has also suggested almost a similar origin of spilite in the following words,

"The hypothesis with the least number of assumptions is consequently, the following: the mode of formation may be understood as resulting from a transfer and differentiation of constituents in a separate aqueous phase during primary crystallization. The hydrous nature of the melt may be normally a result of primary differentiation or, in places may be caused to contamination from surrounding rocks or by some unknown fusion process in a hydrated portion of the earth's mantle".

Spilites of Study Area

The spilite rocks of the study area, as described in the foregoing pages of this chapter do reveal adequate characters to indicate that their mineralogy and textures are typically primary. These show strong mineralogical and textural resemblance with the spilitic rocks described by Amstutz (1968). It is thus obvious that basalts and diabases of Bhimtal-Bhowali represent volcanism that formed a part and parcel of the geosynclinal event.

In almost all varieties of the spilites occurring in the study area, the felspar (albiclase) shows all 'primary' features, and the author has no reason to take this mineral as a product of metamorphism. As regards the chlorite, it is difficult to assign a single mode of formation for all varieties. Chlorite occurring as vesicular fillings appears to be primary, while that comprising the matrix could have a hydrothermal origin. Wherever, the rock is foliated, the chlorite shows a preferred orientation. It is not clear whether this chlorite is of later origin or the hydrothermal changes synchronised at places, with shearing. To the author, pumpellyite also appears to be a 'primary' amygdaloidal infilling. In the absence of any prehnite the author is still not sure how far, the rock shows prehnite-pumpellyite-metagraywacke facies of metamorphism superposed by green-schist facies as suggested by Varadarajan (1973). Of course, this aspect needs further and more detailed investigation.

The field and laboratory studies of the trappean rocks reveal following salient features.

1. The basic rocks of the area are of spilitic affinity and represent a geosynclinal volcanism that heralded the deposition of the overlying Krol group sequence.
2. The volcanism and sedimentation took place almost simultaneously. In the earlier period, volcanism was dominant, but this did not preclude the deposition of a few pebbly graywacke beds.

Patel S.G. (personal communication) has informed the author that further south the trappean rocks contain within them fairly prominent quartzite layers.

With the passage of time, the sedimentation predominated over volcanism. The two trap flows that occur in the quartzite-slate sequence higher up represent the waning phase of the volcanism.

It is worthwhile to mention here that the purple slates that occur in association with the quartzite and of the Infra-Krol upward, happen to be tuffaceous and of volcanogenic material.

It is thus quite obvious that the volcanism represented by spilites, heralded the sedimentary process that in subsequent times gave rise to the gigantic Krol sequence of this part of Kumaon.