PETROGRAPHY

The Panjal Trap is a greenish to grey coloured rock with some dark grey varieties. They are very hard, compact, massive, and generally fine grained. The two basal flows immediately overlying the Agglomeratic slates are porphyritic; the phenocrysts of plagioclase are distinctly seggregated in the form of a star giving rise to glomeroporphyritic texture. The phenocrysts are as large as 1.75 centimeters. The nature of phenocrysts in the two flows varies within and between the flows, the concentration and size decreases upwards till the uppermost portion of the second flow. Above that the rock is devoid of any visible phenocryst and forms a compact mass of fine-grained material often with amygdaloidal structure; chlorite, quartz, and epidote filling the cavities. Quartz veins, some more than 38 centimeters thick, are common; they are confined to bedding planes, joints, and fractures.

The rock is generally vesicular, the vesicles range in size from small specks to more than 5 centimeters (longest-axis). Most of the vesicles are elongated in shape. Rounded vesicles occur mostly in the upper parts of the flows,whereas the elongated ones predominate in the basal portions. Close examination of the vesicles reveal that the longest axis of the "pipe-amygdales" is inclined towards northeast. This indicates the flow movement towards southwest which corresponds to the present dip direction of the lava beds on Mount Kayol.

The composition of the filling material in the vesicles is more or less selective; chlorite is common in pipe-amygdules whereas epidote and quartz are found in rounded vesicles; zeolites are very scarce. Relatively more resistant nature of quartz to erosion has left small dome and ridge shaped protuberances on the exposed surfaces of these rocks at the sites of quartz-infilled cavities.

Under the microscope, the Panjal Trap is observed to be a hemicrystalline aggregate of plagioclase feldspar and pyroxene with a mesostasis of microlites of these minerals and their alteration products, and devitrified glass in the groundmass. Opaque minerals, varying in size from fine microscopic dust to small microphenocrysts, are common throughout the whole sequence of lava beds. Subophitic texture is prevalent in these rocks.

Except for the lower few flows the variation in the mineralogy of the Panjal Traps is not quite systematic. In some flows different mineral phases show repeated appearance which breaks the general sequence of mineralogical change in successive flows from bottom to top. This repetition of mineral phases seems probably related to the eruptive history of the lavas. However, a general trend in compositional variation of the main mineral phases is discernible.

Plagioclase occurs in three sizes — megaphenocrysts, microphenocrysts, and minute microlites. Megaphenocrysts, sometimes altered to kaolin, are confined to the lower two flows whereas the microphenocrysts and microlites form a common feature of the whole lava sequence. In the lower two flows microphenocrysts are rare ; instead, microlites constitute the common groundmass feldspar. The megaphenocrysts in general and some microphenocrysts are fractured; the fractures are healed up with green chlorite and epidote (Figure 3). In certain cases the fractures are bent and quartz has crystallized in the pressure shadows. The fractured nature of the phenocrysts, the presence of pressure shadows, and the bent twin lamelle of certain plagioclase crystals imply the intratelluric origin of the phenocrysts. The phenocrysts may have been subjected to stress during the upward movement of the magma at the time of eruption causing fractures in the entrained crystals. Some phenocrysts have geometrical-shaped, rectangular in general, inclusions of pyroxene, epidote, and chlorite (Figure 4). Epidote and chlorite inclusions probably represent the now altered originally existing pyroxene inclusions. Such inclusions are extremely rare in the microphynocrysts except in the lower few flows.

The composition of the plagiocalse is variable and has a close correlation with the size of this mineral. The magaphenocrysts, found only in the lower two flows, are highly calcic; their compositional range is between bytownite and labradorite

(An_{82} - An_{56}). The composition changes from calcic to sodic plagioclase with the decrease in size of the phenocrysts. Zoning towards decreasing An-content is observed along the peripheral portions of some crystals. Microphenocrysts have a compositional range that lies between labdorite and andesine (An_{64}- An_{45}). Zoning is rare in microphenocrysts. With the change in composition towards sodic end member, size of the microphenocrysts also decreases from lower to upper flows. The composition of the microlitic plagioclase is generally oligoclase (An_{20}- An_{13}) in all but lower two flows where the microlites have labradorite composition. Thus a complete gradation from calcic to sodic members of the plagioclase series is noted.

Small pyroxene inclusions in the phenocrysts and some early microphenocrysts of plagioclases, observed in a few lower flows, may indicate an earlier crystallization of pyroxene from the magma. Such an occurrence of pyroxene, besides a very few microphenocrysts of this mineral in the lower two flows, suggests that the crystallization of pyroxene at this stage was soon overtaken and dominated by the crystallization of plagioclase. From Flow number 3 upwards, the concentration of pyroxene, as microphenocrysts, increases though still remaining subordinate to plagioclase. However, in the upper few flows, both phases rarely occur as microphenocrysts and the rock shows a microcrystalline texture.

The composition of the pyroxene in the lower two flows, as also the composition of the pyroxene inclusion in the plagioclase, is Ca-rich; it is represented by Ca-rich clinopyroxene. In the next few successive flows pyroxene microphenocrysts continue to be Ca-rich till in the middle flows (Flow nos. 12 and 13), zoning to Fe-rich pyroxene is noted. Mauve-brown ferroaugite, as a distinct phase, first appears in Flow number 14 where it joins Ca-rich augite. From the middle part of the Flow number 14, Ca-rich augite starts a decline with concomitant increase in ferroaugite. Zoning from Ca-rich cores to Fe-rich peripheries becomes prominent as indicated by the increase in refractive indicies and 2V in the outer portions of pyroxene microphenocrysts. In the upper portions of flow number 23 and in the whole of Flow number 28, ferroaugite occurs as the sole pyroxene phase. However, in Flow numbers 29, 30, and 32, Ca-rich augite again appears as a major microphenocryst mineral though these flows are scarcely microporphyritic.

Groundmass pyroxene follows a similar trend in composition from Ca-rich clinopyroxenes in the lower porphyritic flows to Fe-rich variants in the upper flows. Pigeonite (2V=27°) joins Ca-rich augite in Flow number 3 and continues as such, but with increasing proportions, upto Flow number 11 and afterwards appears as a single groundmass pyroxene phase till Flow number 14 where ferroaugite joins pigeonite. However, as is the case with phenocrystic phase, in Flow numbers 29, 30, and 32, Ca-rich augite again appears in the groundmass of these flows. This may suggest that the composition of the magma at a particular stage was mainly responsible for a particular pyroxene to appear at that stage.

Opaques are common in all the flows from base to top. However, in the lower flows they form an insignificant amount of the total volume and are confined to the microcrystalline groundmass mesostasis. In general, opaques can be distinguished into two different size fractions, the larger ones may be called microphenocrysts and the smaller ones may be considered as part of the groundmass. In the lower flows the nature of the opaques could not be determined due to their dusty occurrence. However, magnetite and ilmenite can be identified in the middle and upper flows. Magnetite occurs as separate equant grains and also forms inclusions in both the plagioclases and pyroxenes. Ilmenite usually forms patches and skeletal crystals. Leucoxene, the alteration product of ilmenite, is generally observed along the borders of ilmenite crystals; some crystals are completely altered to leucoxene. The concentration of both ilmenite and magnetite gradually increases in the upper flows. This indicates low partial oxygen pressure in the magma.

Apatite is a common accessory with a tendency to increase in the upper flows. Few apatite crystals occur in the vicinity of altered pyroxene crystals which suggests that such apatite crystals may have formed as a result of the alteration of pyroxenes.

Epidote, chlorite, tremolite - actinolite and anthophyllite are important alteration products. Pistacite variety of epidote, colourless to yellowish, is common especially among the upper flows. It occurs both as granular and columnar aggregates; granular form is, however, observed mainly in the groundmass portion of the rock. Zoisite and clinozoisite are also present. Clinozoisite is rare in the lower flows whereas in the upper flows it is predominant. Piedmontile is also occasionally observed in middle and upper flows. Penine, next abundant alteration product after pistacite (epidote), is also common as vesicle infilling. It shows typical Berlin blue interference colour. The other varieties of chlorite present, both as alteration products of pyroxene and plagioclase, and also as vesicle infillings, are clinochlore, showing pleochroism from colourless to green, and prochlorite with higher refractive index than clinochlore and penine. Tremolite-actinolite occur in columnar and fibrous forms; the columnar forms show polysynthetic twinning. Actinolite is more common in higher flows. Zeolites are very rare both as vesicle infilling as well as alteration product. Heulandite is observed in some basal beds, and stilbite, with distinct sheaf-like aggregates, is present in a few upper flows.

Biotite and albite are also present. Biotite does not have well developed cleavage. Albite forms small euhedral crystals with fine lamellar twinning. Both these minerals are

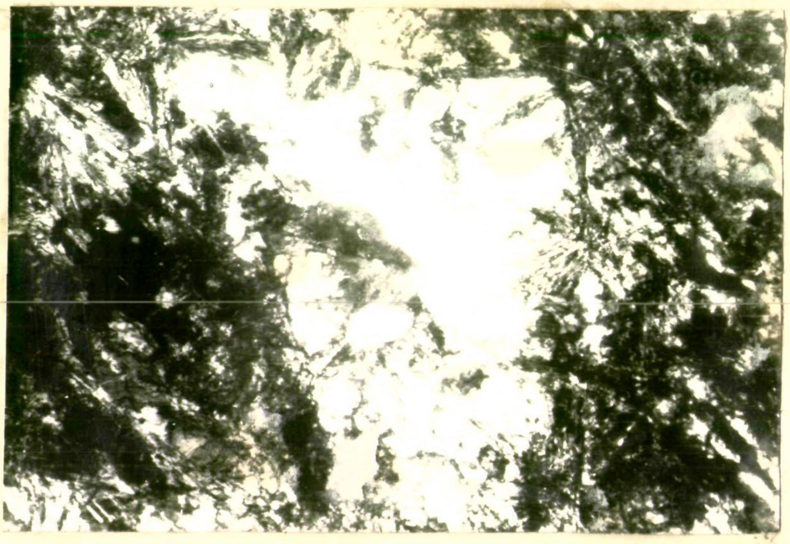

Figure 5. Showing development of biotite across vesicle boundary

observed along cleavage traces and fractures; they also commonly form overgrowth structures. The characteristic feature of biotite and albite is their development across primary textural features like crystal boundaries (Figure 5). This may suggest that they may be of secondary origin. Both these minerals are rare in the lower three flows but occur commonly in varying amounts in the upper flows. They have probably formed as a result of alkali metasomatism related to the granitic intrusion of Tertiary age that occurs in nearby Gangbal, Kangan area to the northwest of Lidderwat.

The restriction of the plagioclase phenocrysts to only lower two flows may suggest that the composition of magma that fractionated these phenocrysts was Ca - Al rich relative to Fe and Mg. This may have favoured early crystallization of more calcic plagioclase phenocrysts instead of Ca-rich pyroxenes, and also caused the resultant subophitic texture that is so conspicuous in the lower lava beds. This stage of fractionation was probably soon disturbed by the eruption of the magma on the surface; the plagioclase did not crystallise as large phenocrysts to any appreciable amounts with the result the composition of the magma was not much affected and as such, plagioclase dominates in the groundmass also. This, again, caused the development of subophitic relationship of plagioclase and pyroxene in the groundmass, besides Ca-rich composition of both these minerals.

The Panjal magma may have been originally Ca - Al rich or there may have been some other factor responsible for the enrichment of Ca - Al in the liquid. Cox et al. (1968), from petrographic and geochemical evidence, suggested that the more evolved character of augite-plagioclase phyric basalts than the olivine bearing variants in the Northern Province of Karroo dolerits, South Africa, is due to the separation of olivine from magma at an early stage. As noted earlier, olivine was not observed in the Panjal Traps of the area under study. Wadia (1928, 1934), Middlemiss (1909, 1910), Krishnan (1968), and others have also reported the absence of olivine from these rocks all along their extension. Pareek (1976), however, reported the occurrence of olivine bearing members of the Panjal Traps. Thus, the fractionation stage of such olivine-bearing and olivine-free rocks of the Panjal Traps may be correlated with the olivine-bearing and olivine-free basalts of Northern Province of Karroo dolerites, South Africa. The separation of olivine from the Panjal magma during its ascent from deeper regions in the mantle to the shallow reservoirs in the crust may have resulted in the decrease of the mafic constituents in the magma with concomitant enrichment in Ca and Al. The rate of ascent seems to have been very slow resulting in the complete separation of olivine. The possibility of resorption of olivine (high pressure phase) at shallow depths under low pressure conditions does not appear to favour less mafic character of these rocks because under that condition mafic content of the rock should not be low. Also, in such condition the chances for the existence of some mafic (olivine) xenocrysts in these rocks would be more. However, this is not observed; as such, resorption of olivine in low pressure environment may be ruled out.

The early separation of anhydrous phases (olivine and may be some pyroxene) at a deeper levels, as inferred, may have caused the built up of the volatile concentration in the residual liquid. When this liquid, highly charged with volatile constituents, reached shallow depths in the crust , the volatiles probably escaped with explosive force resulting in the formation of Agglomeratic slate on the surface.

Francis (1967, 1968) observed that the proportion of the pyroclastic material increases in the later part of Dinantian lavas, Scotland which he attributed to the increasingly explosive nature of eruption of lave during post-Dinantian period in this area. Francis related the change from quite extrusion to explosive type of lava eruption to the increase in thickness of the sedimentary cover in this area. Macdonald (1975) found that with the change in the mechanism of lava eruption in the Dinantian period, there was also a change in the magma composition from mildly alkaline or transitional type to strongly undersaturated character. He argued that a similar change in magma chemistry and the mechanism of lava eruption observed in Hawaiian islands (Macdonald, 1968), and Anjuan in the Comores (Flower, 1973) may not be related to sedimentation model of Francis (1968). He suggested that this may rather be explained by increase in volatile content and depth of magma generation. However, for post-Dinantian lavas, he ascribed the increase in the pyroclastic material to the change in chemistry as well as to the increase in thickness of sedimentary cover.

The suggestions of Francis (1968) and Macdonald (1975) for the explosive nature of eruption in Dinantian lavas and the resultant formation of pyroclastic material does not appear applicable for the formation of Agglomeratic slate underlying the Panjal Traps. The increase in the volatile content in the Panjal magma may be attributed to the separation of anhydrous mineral phases as suggested earlier.

The low partial water pressure, created in the magma chamber by the escape of volatiles, and high Ca - Al composition of the magma may have favoured the early crystallization of calcic plagioclase. This stage was probably soon followed by the eruption of magma on the surface and the formation of aphyric flows (with the exception of the lower two flows). The reappearance of some highly calcic mineral phases in certain upper flows indicates that the magma chamber was tapped at different levels during eruption that caused the upwelling of lava of different compositions.