11.1: INTERTRAPPEAN LIMESTONE.

X Polars. 35%

Aragonite crystals with their radiating, tapering habit.
CHAPTER VII

SUMMARY AND CONCLUSION

1. Patharia hill is a site on which Saugar University campus is situated. This area has been selected for detailed geological studies because of its easy accessibility proximity and geological virginity.

   An area of about 20 sq. kms. has been mapped on a large scale (12 cm. = 1 km.) to bring out the details of its geology. The various aspects of this area studied are the geology, geomorphology, petrography, mineralogy, petrochemistry, engineering properties and geohydrology.

   Here the predominant rocks are volcanic - the Deccan Traps - with associated sediments - the Intertrappeans and Laterite. Thus in a small area varied rock types are available for detailed investigations.

2. Deccan Traps occur here as four lava flows numbered in ascending order as 1, 2, 3 and 4. Two distinct intertrappeans demarcate the lower flows from each other. Flows 3 and 4 are separated at some locales by the development of zeolite zone. The flows show lateral and
vertical variation in their thicknesses. On average the lava pile comprising Patharia hill has a total thickness of about 80 mts. The flows are of aa type and show variations in their field characters such as mode of occurrence, type of weathering, presence of secondary minerals and nature of joints. In general joints are incipient columnar and predominantly near vertical to near horizontal in their dips. They are prominently developed in NE-SW direction.

Amygdular minerals infilling the vesicles are zeolites, calcite, chalcedony, opal, jasper and green celadonite. Mesolite, scolocite and stilbite, identified by physical, chemical and X-ray diffraction methods constitute the zeolites of this area. They are produced in the reactions involving basalt and meteoric waters under the conditions of increased temperatures and pressures in the lower levels of the lava pile.

Intertrappeans comprise predominantly limestone with a varying admixture and lateral facies change to chert and clay. Both Calcite and Aragonite constitute the limestone. Clay of the Intertrappeans has been identified as Montmorillonite by simple colour tests.

Laterite is observed only behind the University rifle range, denoting an old erosional surface which incidently corresponds with the top of the flow No.2. X-ray investigations
indicate that laterite here is predominantly made up of gibbsite, haematite goethite, anatase, quartz and kaolinite.

3. Geomorphological studies of Patharia hill comprise the following:

The vertical profiles across the area at regular intervals are prepared and superposed on each other to find the nature of the topography and the erosion surface. They clearly show that Patharia hill presents a typical flat-topped, step-slopped Deccan Trappean topography, each step representing a flow. There is a prominent break in the slope at the altitude of 548 mts., marking an erosion surface of the geological past. This erosion surface coincides with the top of the flow No. 2.

Patharia hill is the location of residential Saugar University. Hence a large number of buildings and roads are constructed on this hill, without any consideration to the slope characteristics. Therefore average slope and slope stability maps are prepared and the areas of high slope angles prone to land slips and slides are demarcated. These areas are unsuitable for further road and building construction activity.

Drainage morphometry studies undertaken reveal that in this area the drainage is of radial dendritic type. Drainage density and drainage frequency vary between 1.13 to
2.84 km./km.² and 1 to 8 /km.² respectively. There are two orders of streams and an inverse relationship is noted between the order and number of the streams. High drainage density and drainage frequency, presence of vertical cliffs and rare active downward erosion by the streams indicate that the area is under active vertical erosion. Lack of depositional features and presence of boulders and pebbles in the stream valleys also suggest the streams to be in the youthful stage of development.

The rate of erosion and amount of material eroded from the area in the last 65 million years is calculated. The total material removed from an area of 1.56 sq. miles (4.0 km.²) is 437,544 Megatonnes. Assuming the rate of denudation to be constant in the last 65 million years, the amount of material removed is 6.7314461 Megatonnes/One million year.

4. Petrographic studies on the trap rocks of Patharia hill indicate that megascopically they are melanocratic, grey to black coloured aphanatic basalts. Vesicles are commonly observed in them, frequently infilled by secondary zeolites, chalcedony and green minerals.

Under the microscope these rocks, present a typical porphyritic and glomeroporphyritic texture. Predominant plagioclase and sparse pyroxene occur as phenocrysts. In
the latter augite exceeds pigeonite by 3 to 6 times. Groundmass consists of essential second generation plagioclase and pyroxene with minor opaques, glass and secondary minerals. Groundmass texture varies from intergranular, intersertal, granulophitic to pilotaxitic and imperfect flow oriented.

Anorthite content of the plagioclase determined by two different methods shows an average range of 66 to 70% An for phenocrysts and 50 to 60% An for groundmass. Simple and complex twins in plagioclases show antipathetic relationship from flow 1 to 4. Parallel twins are abundant in middle flows.

Modal compositions are determined and computed into various ratios such as glass/crystalline matter, pyroxene ratio, groundmass/phenocrysts and plagioclase/pyroxene in order to use them for distinguishing flows.

In phenocrysts modal plagioclase on average ranges between 6.7% to 10.9% and in groundmass from 20.8% to 34.3%. Similarly modal pyroxene in phenocrysts ranges from 0.41% to 2.4% and between 34.9% to 45.5% in groundmass. Opaques vary from flow to flow in a range of 9.5% to 21.3% and Chlorophaeite and glass between 2.5% to 5.8% and 3.03% to 7% respectively.

Glass/crystalline matter, groundmass/phenocrysts ratios and % of opaques are characteristic modal attributes to distinguish the flows of the present area.
5. Petrochemical studies of lava flows of Patharia hill are undertaken to understand the distribution pattern of major and minor elements, the sequence of crystallisation, if any and the genetic relationship between the flows.

The lava sequence is systematically sampled along five traverses and 19 composite samples covering all the four flows are analysed for major elements and 16 samples for minor elements. The chemical analyses of Patharia lavas are compared with Deccan lavas of adjacent areas of lower traps and similarities and differences in their chemistry are discussed.

Variation of major chemical constituents with the height in the lava sequence of Patharia hill indicates a general increase in SiO$_2$, K$_2$O, FeO and decrease in MgO, MnO and CaO. This trend shows that with the time the successive lavas erupted here were of more and more evolved type. This may be attributed to a continuously evolving magma source.

Normative composition used to classify basaltic magmas reveals that lavas in Patharia hill belong to quartz-tholeiite type. This chemical character is further confirmed by calculating various other parameters such as $\Theta$, simplest weighted sum (S.W.S.) and plot in total Alkali-silica diagram. $\Theta$ ranges from 37.81 to 39.72 with S.W.S. varying between 7.98 to 9.08; thus both confirming the tholeiitic character. Similarly the plots of all the four flows in total Alkali-silica diagram fall in low K tholeiite field.
Various crystallisation parameters such as Differentiation Index, Solidification Index, Felsic Index, Mafic Index, 'M' Value, Ferro-femic Index are calculated in order to assess the petrochemical characters and fractionation trends of Patharia lava flows.

Differentiation Index (27.97 to 28.84) values show that like Deccan traps from other areas, lavas of the present area are late-middle stage basalts. Solidification index values (17.06 to 23.16) further confirm the above conclusion. Plots of the four flows of Patharia in Felsic Index - Mafic Index diagram fall around Deccan Trap trend in middle stage basalt region 'M' values (18.25 to 25.79) indicate evolved character of the erupted basaltic magma, Ferro-femic index (93) points to the superferric character of the lavas of Patharia hill.

In order to know the trends of differentiation major oxides are plotted against 'M' values. These diagrams reveal that with lowering of 'M' values, there is pronounced decrease in MgO and MnO with similar increase in FeO, K₂O and P₂O₅. There is slight decrease in CaO, Al₂O₃ and Fe₂O₃ and similar increase in TiO₂ and SiO₂.

Of late many workers pointed out the chemical affinity of Deccan lavas from many areas with rift volcanics. In order to study this aspect, Patharia lavas are plotted in
TiO₂ - K₂O - P₂O₅, P₂O₅ - TiO₂ and K₂O/K₂O + Na₂O = TiO₂/
P₂O₅ diagrams. The plots of all the four lavas fall in the areas of rift volcanics like oceanic ridge and Ethiopia types.

From the chemical data described so far it is inferred that parental tholeiitic basaltic magma of Patharia flows was in an advanced stage of evolution prior to its eruption and continued to evolve with the time. Contamination with sialic crust did not play any role during its evolution. It originated by partial fusion in ultra-mafic upper mantle under a thin continental crust. Thinning of the crust occurred during the northward drift of Indian subcontinent. Foundering accompanying the drift offered passages for the outpouring of the basaltic lavas.

6. Trace elements have been determined to know their distribution and vertical variation in the four flows of Patharia hill and to find out whether their contents or ratios can be utilised to distinguish the flows.

Variation in trace element contents with altitude is described, and it is shown that like quartz-normative tholeiites, Patharia hill basalts are richer in Li, Ba, Sr, V, Cu and Zr than the undersaturated basalts. There is no Eu anomaly.
Distribution of trace elements with increase in
differentiation index indicates that transitional elements
(Cr, Co, Ni, V) and Zn show a decrease with increase in D.I.
while Rb shows an increase. Sr, Li, La and Eu do not show
marked variation with increase in D.I. However their plots
in D.I. versus Sr, Li, La and Eu diagrams fall in quartz-
tholeiite field.

There is slight enrichment in Rb with increase in K.
As Patharia basalts belong to eastern Deccan Traps they show
enrichment in Cu in comparison with western Deccan lavas.
High Cu is due to high Fe content.

A coherent relationship is shown by Co, Li and V
with MgO. Plots of Co and Cr versus MgO fall in quartz-
tholeiitic field. V shows strong coherence with Fe₂O₃ than
MgO and FeO. All these variations can be accounted for by
varying degrees of crystallisation of plagioclase and
pyroxene at shallow depths.

The positive correlation in K vs Rb and K vs. Sr
and Ba diagrams indicates no crustal contamination, while
plots in K vs K/Rb, Sr vs Rb and Ba vs Rb show scatter of
points. These features along with high Ti and relatively
high Rb point to the selective diffusion of incompatible
elements into the magma.
Various major oxide and elemental ratios are presented to utilise them for distinguishing four flows and to note the trends of differentiation if any.

There is not much variation in these ratios. This points to the common parental source for the Patharia lavas.

$\text{SiO}_2/\text{Al}_2\text{O}_3$ progressively increases from flow 1 to 4 and $\text{CaO} + \text{MgO}/\text{Na}_2\text{O} + \text{K}_2\text{O}$ increases from flow 1 to 3 with sudden drop in top flow. $\text{K}/\text{Rb}$ shows linear increase from bottom to top flows. The mean value (234) falls midway between the values of oceanic and continental tholeiites. $\text{Li}/\text{Eu}$, $\text{Rb}/\text{Sr}$, $\text{Ni}/\text{Co}$ and $\text{K}/\text{Ba}$ show a gradual decrease from flow 1 to 3 and then sudden rise in flow 4. $\text{Ba}/\text{Sr} \times 1000$ and $\text{Co}/\text{Fe}$ show antipathetic relationship with $\text{Rb}/\text{Sr}$, $\text{La}/\text{Eu}$, $\text{Ni}/\text{Co}$ and $\text{K}/\text{Ba}$. All these are not of much use in distinguishing the four flows.

$\text{SiO}_2/\text{Al}_2\text{O}_3$ and $\text{K}/\text{Rb}$ are useful criteria in conjunction with field criteria to distinguish flows.

Increase of $\text{SiO}_2/\text{MgO}$ and decrease of $\text{MgO}/\text{FeO}$ in flows 1 and 2 with no such relation in flows 3 and 4 indicate the lower two flows slightly differentiated as compared to upper flows.

$\text{Ni}/\text{Co}$ ratio, a good index to determine the stage of differentiation does not show much variation. Hence the Patharia basalts have not undergone much differentiation.
$H_2O$ content of the four flows does not show much variation. However the lower flows (1 and 2) are relatively coarse grained than upper flows (3 and 4). This difference is due to the abundance of other volatiles in the lower lavas, which reduced the viscosity and promoted coarse crystal growth.

7. Basalts of Patharia hill are used extensively as building material. Hence engineering and physical properties of these rocks have been studied and correlated with petrographic and mineralogical parameters. Engineering property determined is only the compressive strength. Physical parameters studied are specific gravity, hardness, porosity, sorption and refractive index of the glass.

Specific gravity and hardness do not show any regular variation pattern. However both are low in bottom flows and high in top flows. In the sequence of the flows of Patharia hill, porosity and sorption decrease from bottom to top. Refractive index in general increases towards the top. With the exception of flow No.2 compressive strength increases towards the top.

Compressive strength shows sympathetic relation with specific gravity and antipathetic relation with porosity.
Study of the correlation between compressive strength and petrographic parameters such as modal plagioclase, pyroxene, opaques and groundmass/phenocryst ratio reveals that, the former increases with increase in modal pyroxene, opaques and groundmass/phenocryst ratio and decrease with increase of modal plagioclase.

8. Under hydrogeological studies of the present area, mode of occurrence of the groundwater, reservoir characteristics and quality of water are studied.

Joints, cooling cracks, vesicles and weathering induce the porosity and permeability in the traps of Patharia hill. All the wells are located in the lower two flows, with greater frequency in No.1 than No.2. This is due to the former having comparatively larger granularity, higher vesicularity and greater intensity of weathering than the latter.

The quality studies of the water pertains to physical parameters such as conductivity, pH, total and calcium hardness and chemical parameters such as alkali and alkaline earth elements, acid radicals and total dissolved solids.

pH of the water of the wells, irrespective of their location indicates that it is alkaline. This can be attributed to its occurrence in basaltic rock terrain.
Total dissolved solids are determined from conductivity. The water of the wells on flow No. 1 possess more T.D.S. than the water from the wells of flow No. 2. Iso-T.D.S. map of the area indicates that wells in flow No. 1 have lower T.D.S. in western portion than in eastern part.

The total and calcium hardness of the waters show that they belong to hard to very hard category.

Chemical constituents, alkalies and alkaline earths (Ca, Mg) in well waters of Patharia hill are well below the limits prescribed for normal waters, for use in boilers and ice-manufacture. Acid radicals (CO$_3^-$, HCO$_3^-$ and Cl) in general are below the limits ascribed to normal waters except in case of wells Nos. 1 and 2. The water here carries more CO$_3^-$ than the prescribed limit. This can be attributed to their location in contact with the intertrappean limestone. As T.D.S. of the waters is well below 300 mg/L; it is useful for drinking purposes, dyeing, textiles and manufacture of pulp, rayon and plastics.

9. An attempt is made to correlate the soil composition with the quality of water. Twenty trace elements were determined in three soil samples.

The soil is rich in Mn, Zn, Cr, As, Te with Cu, Ni and Co. Toxic elements Pb, Cd, Hg are below the prescribed
limits of geological hazards. Elements Ag, Cu, Sn and Zn show notable variation in their concentrations from sample to sample. No correlation between quality of the water and trace elements in the soil could be established; but the chlorophaeite content of the basalt flows is found to be related to the size of the fruits of the plants belonging to Solanaceae family. Higher the content, larger is the size of the fruits.

10. Two intertrappeans occurring between lower flows of the present area are subjected to petrographic, chemical, physical and engineering property studies. Predominently they are composed of cherty limestone with lateral variation to clay and chert. The lower intertrappean (between flows 1 and 2) is quite extensive while the upper intertrappean (between flows 2 and 3) is local. Calcite and Aragonite are the minerals constituting the limestone, chert is sparsely distributed.

The insoluble residue shows an increase from eastern part to west in lower intertrappean and decrease from lower to upper intertrappean. It comprises altered felspar, secondary green earth minerals, altered pyroxene, cryptocrystalline silica and quartz. This mineral composition indicates that the basalt is the source material for intertrappeans. Occasional presence of zircon and microcrystalline quartz points to a subordinate sedimentary source probably Vindhyans.
Major and trace elements determined show that SiO$_2$, CaO, CO$_2$, Fe$_2$O$_3$, MnO, MgO, Alkalies, H$_2$O, B, Cs, Li, Cr, V, Ni, Co, Cu, Zn, Y increase and Cl, Rb, Sr, Ti decrease from east to west in lower intertrappean. The variation from lower to upper intertrappean consists in the decrease of SiO$_2$, Fe$_2$O$_3$, MnO, MgO, K$_2$O, B, Ba, Sr, Cr, Co, Zn and Ti and in the increase of CaO, Na$_2$O, CO$_2$, H$_2$O, F, Rb, Ca, Cl and Ni.

Alkalies and silica present in limestone show contamination by detrital ferruginous material during deposition. The source for this must be trappean plagioclase and pyroxene. Fe$_2$O$_3$ points to oxidising conditions, during precipitation. The trappean source is further confirmed by Ni, Cr, V and Co.

CaO and MgO content of the limestone is within prescribed limits for the manufacture of cement. But as the outcrops are limited in extent and also Fe$_2$O$_3$ is more than 1%, the limestone can not be used for cement manufacture. However chemically it is well suited for quick and slacked lime manufacture.

Ca/Mg and Ca/Sr ratios are determined for ascertaining the depths and temperatures at the time of deposition. Generally the former decreases and the latter increases towards the pre-Cambrian. The values obtained for two intertrappeans of the present area corroborate the above conclusions.
Physical and engineering properties such as porosity, permeability, Brinel's hardness, specific gravity, dielectric constant and crushing and compressive strengths are studied and interpreted.

11. Elastic properties - compressional and shear velocities, density and compressibility and physical properties namely refractive index and vesicularity of the basalt samples of the four flows of Patharia hill and their glasses are determined.

Composite samples of the four flows are prepared and above properties are studied in both the crystalline and glassy states. The glasses of the samples are prepared in silica crucible by heating in an induction furnace. The temperature of fusion ranges between 1230° - 1240°C. Lower flows (1 and 2) fuse at higher temperature, than the upper flows (3 and 4).

Two mm. cores of crystalline rock samples and plates and cubes of their corresponding glasses were subjected to ultrasonic method to determine compressional and shear velocities.

Subtle variations are seen in elastic and physical properties determined.
Density of glasses of lower flows is higher than that of higher flows. Lower flows have brown glasses while glasses of upper flows are black probably due to concentration of opaques. Refractive index of glass is highest in flow No.1 and lowest in flow No.2.

In cores specific gravity does not show any trend being highest in the lowest flow and lowest in flow No.2.

Flows Nos.1 and 4 have highest porosity while the remaining flows have lower values. Vesicularity shows behaviour similar to porosity.

Compressive and shear velocities of cores and glasses gradually decrease from flow No.1 to 4. Compressibility can be used to distinguish flow No.1 from flow No.4.

As the dependent parameters, engineering and physical properties do not show any perceptible and significant variations in Patharia lava flows, it is concluded that these lavas were erupted from the magma of the same chemical composition.