

Geology, Geochemistry and Alteration Characteristics of Bombay Volcanic Complex, Deccan Traps of West Coast, India.

Abstract: *The complex litho-assemblages expose along the west coast around Mumbai (W India), the Bombay Volcanic Complex (BVC), is anomalous and distinct from the largely tholeiitic Deccan Traps. The BVC encompasses heterogeneity and wide range in lithologies that range from basic to acidic volcanic and intrusives. Geological investigation carried out by the authors has identified Deccan related pyroclastic and volcanoclastic assemblages and atypical flow units in the BVC. These rocks also show moderate to severe alteration, more pronounced in the volcanic ejecta. Alteration in the basaltic component has reached a more stable stage marked by large scale palagonitization and chloritization. The felsic ejecta, exposed in low tide regions, displays a more pronounced chemical alteration, facilitated by prolonged sea water interaction.*

Key words: Bombay Volcanic Complex, Deccan Traps, Volcanic flows and Ejecta, Alteration

volcanic ejecta though very insignificant in terms of volume but certainly has a bearing on the mechanism and mode of emplacement. This has been studied in detail by the authors including the physical features and their degree of alteration.

C inverse relationship of silica with TiO_2 , MgO , FeO is clearly seen.

The chondrite normalized REE diagram of the agglomerates (Fig 4.7a & b) show rather flat pattern that does not match with the fractionation levels indicated by other parameters including silica concentration. This could once again be attributed to some assimilation / contamination. The same phenomenon may have been responsible for scattering of major oxides data. The moderate enrichment in LREE and no change in HREE is the characteristic feature. One sample shows Tb anomaly which is rather difficult to explain and may be due some analytical error. The $\sum\text{REE}$ values for various samples vary between 276.53 and 488.36 ppm, the $(\text{La/Lu})_N$ ratio also varies between 1.80 and 4.42 the value of LREE range between 19 and 90 where as that of HREE between 4 and 25, suggesting, marginal enrichment in LREE. Highly variable $\sum\text{REE}$ value (67-341ppm) and the $(\text{La/Lu})_N$ ratios (1.5 to 21.5) could be due to mixing of different proportions of melt at various levels of fractionation prior to emplacement and cooling.

Geochemistry Of Felsic Rocks

The felsic rocks are fine grained and intensely weathered and altered being exposed in the coastal tract. The geochemical data on felsic rocks shows strong to subtle variations in the major oxide concentration. The SiO_2 varies from 58.8 to 87.97%, Al_2O_3 from 1.84 to 25.44%, TiO_2 from 0.2 to 4.5% (majority with $>3\%$). Fe_2O_3 is generally low except for one sample with anomalously high value (24.5% of Fe_2O_3). Na_2O varies from 0.04 to 0.87% and K_2O from 0.07 to 0.88% while CaO varies between 0.1 and 1.12%. The trace element enrichment may indicate a highly fractionated liquid; The unusual geochemical characteristics and absence of

systematic trends are hard to explain through standard petrogenetic processes. This implies either overprinting of primary geochemical signatures by selective leaching of certain elements or possibly a heterogeneous source (mixing of different magmas). Yet another possibility is the chemical leaching of the felsic rocks as they are exposed under sea water environment. The alkalis were removed, enriching other elements like silica and Al_2O_3 . High silica in case of tuffs could be due to admixture of clay in tuffs but in flows it is puzzling.

Despite largely anomalous geochemical data and high volatile content, an attempt was made to evaluate the behaviour of various elements, on dry basis. However, the ambiguous geochemical parameters have been excluded from petrochemical interpretations. In the silica variation diagrams (Fig. 4.8a to 4.8 f) P_2O_5 , MnO, Cr and Zr show a progressive decrease with increasing SiO_2 whereas Sr shows a conspicuous increase with SiO_2 , MnO and P_2O_5 , indicating probable assimilation of magma as they show two prominent clusters (Fig. 4.8c to 4.8e). The trace element data, when plotted against the evolution index ($1/3 \text{ Si} + \text{K} - 2 (\text{Ca} + \text{Mg})$), also show a close correspondence with the trace / silica variation diagrams. (Fig 4.9 a to 4.9 e) The peculiar feature of these diagrams is the segregation of data along two separate crystallization trends, possibly indicating mixing of magma at various levels. The steep Sr negative anomaly is indicative of plagioclase separation before the melt was emplaced. Some of the samples show negative Nb anomaly while others define a positive one, possibly indicating some crustal incorporation in the melt. Zr shows positive anomaly. Negative Rb anomaly can be related to removal of K_2O during alteration. Steep LREE slopes in the chondrite normalized REE diagrams (Fig 4.10a & 4.10b) suggest enrichment in LREE and partial depletion in HREE. The REE enrichment levels are quite different although there appears to be a consistency in patterns. The $\sum\text{REE}$ in the present case varies between 53 and 488 ppm and the $(\text{La}/\text{Lu})_N$ ratio between 1.80 and 4.43.

Alteration

Post-emplacement alteration resulting in modifications in original geochemical signatures is recorded in the felsic and basic ejecta of the west coast. Hydrothermal alteration is one such process that results in formation of chlorite, calcite and silicification of various rock types. Another principal alteration processes include devitrification, palagonitisation and hydraulic fracturing. Devitrification is the most common mode of alteration in the felsic as well as basic volcanic ejects. Occurrence of devitrification spherulites, (Fig 4C,g) devitrification trains and sieve texture and development of partial granophyric texture (Fig 4C,b) in glassy / vitric tuffs were recorded from Thane creek. Various stages in devitrification of glass shards were also observed in basic tuffs (Fig 4B) The stages of devitrification as described by Lofgren (1971b) are hydration stage, spherulitic stage and granophyric stage. Among these the spherulitic stage has been exhibited by the basic ejecta. The hydration stage of alteration is not preserved as the rocks have already exceeded the stage and further altered to advanced stages. In the felsic ejecta from Junchundra Khopdepada, partly preserved unwelded ignimbrite hydration fractures could be observed (Fig 4B)). Development of granophyric texture due to total recrystallisation of vitric tuffs has also been observed in some cases (Fig 4B). A possible gel-palagonite formation was also recorded from the rocks of the area. The gel-palagonite formation is the initial stage of palagonitisation that begins at a high temperature of 200°C giving rise to fibro palagonite at about 50°C . The process of palagonitisation is fastest between 50° and 100°C (Jacobson, 1972, 1978) while it may take few thousand years at surface temperatures (Jonson, 1961; Furnes, 1976). Development of chlorite in basic tuffs indicates that the process of alteration may have reached completion as the chlorite is stable for a wide range of temperature. Smith (1976), Kuwiyoshi and Liou (1976) and Viereck et. al (1982) have propounded that chlorite is the common end product of alteration of palagonite and basaltic glass and stable under a wide range of P – T conditions.

As enumerated above volcanic felsic ejecta display unusual geochemistry such as excessive silica and low K_2O in the agglomerates and felsic rocks. This can be referred to the intense chemical alteration in terrestrial and submarine (aqueous) environments. Alteration is a complex process and felsic and mafic glasses are affected differently during alteration, therefore, both the types are discussed separately. In case of basaltic glass the sideromelane alters to intermediate but chemically different product. Palagonite is eventually transformed into thermodynamically stable crystalline phase smectite. This entire process takes place under solid state conditions. In contrast, alteration of silicic glass involves an initial stage of diffusion controlled hydration and alkali ion exchange but

minor chemical changes. This is commonly followed by glass matrix destruction and precipitation of secondary phases in pore spaces created by the dissolution of glass. Reasons for these differences are poorly understood but probably related to difference in glass structure. The initial resistance of silicic glass is due to higher concentration of network forming elements Si and Al. Higher concentration of alkali in the silicic glass would help in creating higher pH because of early release of alkalis into pore solution, and higher pH facilitates rapid dissolution of SiO_2 . Experimental studies by Hawkins and Rustom (1963) and Khitrov et al. (1970) indicate greater solution and reactivity of basaltic than silicic glass at elevated temperatures. The alteration of glass shards exhibits fairly advanced stage of alteration as partial dissolution and precipitation of authigenic zeolite could be observed. Alteration of silicic glass where the SiO_2 exceeds 60% (it is upto 78% in the present case) hydration takes place due to absorption of upto 3% water due to base ion exchange. The most significant change is the dissolution of alkalis resulting in the depletion in Na and enrichment in K due to abundance of potassium in sea water. in the present case, As the rocks are exposed under sea water in the present case the depletion in Na is clearly evident, but under normal temperature and during initial stages of sea water weathering potassium gets enriched which is not the case here. This could be explained by the fact that during advanced stages of alteration potassium gets depleted. Hence the rocks of the area have suffered advanced stage of intense sea water alteration. There is also a change in concentration of generally immobile elements like Ti and Al. The tuffs of the area have high Al_2O_3 which again signifies that these were deposited and leached under sea water environment. Besides lower concentrations of K_2O , Na_2O and CaO , the felsic ejecta of the area also contain higher Al_2O_3 , Fe_2O_3 (iron also gets oxidized to Fe_2O_3 and concentrated) and partial enrichment in LREE. Juteau et al. (1979) have attributed relative increase in the LREE to prolonged submarine alteration i.e. very high water rock ratio (Staudigel and Hart, 1983). The other elements lost during the alteration are Zn, Cu, Ni, Mn, Sc, Co and Hf and to a lesser extent, Cr (Ailinyzik and Sommer, 1981). These elements may be available for redistribution and re-precipitation during hydrothermal ore deposits. Palagonitisation is profusely seen in the basic ejecta / tuffs (Fig4 B). The glass shards have dark brown skin developed around them indicating palagonitisation. Palagonite is wax like brown altered hydrous basaltic glass. There are differences in the opinion about the formation of palagonite, its nature and composition, but this is the most common alteration product of basaltic glass/ vitric tuff. Its occurrence is most widespread in the submarine tuffs. Palagonite forms due to high temperature fumarolic alteration of sideromelane (Jacobson, 1978) along the margins of the sideromelane shards and droplet of sideromelane glass. Such feature could be seen as the shard margins are defined by dark brown lining, whereas the core remains light brown to greenish grey coloured sideromelane. Core of the sideromelane shard may remain fresh, in deposits as old as of Cretaceous age (Staudigel, et al., 1979, 1981). Palagonitisation proceeds at 50°C to 100°C but much slower at lower temperatures (Jacobson, 1972, 1978). It involves hydration and ion exchange that requires greater element mobility. During the palagonite formation in Hawaiian submarine basaltic glass. Na, Ca and Mn were lost, whereas K, Fe and Ti were gained relative to unaltered glass (Moore, 1966), probably due to exchange with sea water. The terrestrial conditions indicate loss of potassium during Palagonitisation. Approximately 60% of the REEs are removed during palagonitisation but relative abundances stay constant due to very low concentration of these elements in sea water (Staudigel and Hart, 1983). Higher concentration of Ti in basaltic tuffs of the area indicates a high degree of palagonitisation. It is considered to be immobile but due to increase in pH the mobility increases and Ti is fixed in leucosene and redistributed during the advance stages of alteration.

Devitrification is also common in both felsic and basic ejecta in the study area. Partial devitrification of glass shards to complete recrystallisation resulting in granophyric texture is seen in the rocks in Thane area. Alteration of shards at the centre and precipitation of secondary zeolite and chlorite suggest advanced stage of devitrification. Like palagonitisation, devitrification also involves de-polymerisation effects of water in breaking the Si-O-Si bond and hydrolyzing the SiO_4 tetrahedra to OH. The hydrolyzed SiO_4 tetrahedra are free to reorganize and nucleate quartz and feldspar crystals in the presence of alkalis (Lofgren, 1970). Addition of alkalis to the solution increases the devitrification rate by four to five magnitudes. The rocks of the area are exposed to sea water environment that has higher alkali content resulting in profuse devitrification of the rock. Lipman (1965 and 1967) noted that the devitrification can make significant changes in the bulk rock chemistry. Accompanying hydration and devitrification has caused

significant changes in SiO₂, H₂O, Fe₂O₃/FeO, Na₂O, K₂O content that may reach upto 2% in the individual element oxide. Hence it can be very vividly observed that both have undergone advanced stages of alteration. Prolonged exposure to the sea resulted in the anomalous changes, which are not akin to the usually accompanied alterations observed in the felsic glass under non marine conditions.

Discussion and conclusion

The physical features of the basalt and associated volcanic ejecta, their disposition features and contact relations, cannot be explained by the normal eruption mode of the Deccan basaltic flows. Therefore, these rocks need to be treated as an independent entity and named as Bombay volcanic complex. Findings of the present study reaffirm the notion that these rock associations can only be explained through an alternate mechanism of emplacement/eruption. We have tried to classify the volcanic ejecta and associated basalts and characterize the ejecta in detail. The alteration characteristics of the ejecta have shown more severe alteration in the low tide zone as compared to exposures in the extra tidal zone. Further, it has been observed that in basaltic flows and basic ejecta, the alteration has reached a much stable stage indicated by presence of chlorite. Anomalous chemical characteristics of the rocks, especially the felsic ejecta, can be related to severe sea water alteration, under a very high water rock ratio. Since the elemental behavior indicate differentiated nature of the melt prior to emplacement, especially in respect of felsic components, while the basic component exhibits contamination/ mingling of the magma as displayed by the pendent like features contained in the flows besides lapillies of glass. It can be summarized that the alteration in the basaltic ejecta is wide spread, denoted by large scale palagonitization and chloritization and has reached a more stable stage. The felsic ejecta display a more pronounced chemical alteration, which is accelerated due to its geographic location and responsible for anomalous chemical behavior of the acidic flows and the related ejecta. The heterogeneous association of volcanoclastic and pyroclastic rocks with anomalous basaltic flows still needs a more detailed study regarding the emplacement mechanism.

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S.No.	Sample N	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO
1	RWR-1	47.77	3.16	10.19	7.7	9.63	0.16	4.4	9.52
2	RWR-2	56.19	4.14	15.93	15.1	0.63	0	0	9.56
3	RWR-4	49.19	3.1	13.36	2.4	12.6	0.2	3.4	8.96
4	RWR-5	44.22	3.66	12.1	5.2	11.7	0.24	3.8	9.8
5	RWR-7	48.77	3.91	10.5	5.4	11.88	0.2	3.4	9.52
6	RWR-8	52.25	0	21.18	3	5.4	0.06	2.2	8.68
7	RWR-10	53.03	0.97	10.6	3.8	8.46	0.24	2.6	15.22
8	RWR-11	58.01	0	18.48	4.1	3.15	0.08	1.8	7.84
9	A2	69.1	4.5	17.5	1.6	-	0.03	0.3	0.1
10	A3	58.8	2.2	9.3	24.5	-	0.01	0.3	0,25
11	BHUI	76	1.3	7.3	10.1	-	0.1	0.6	0.4
12	D	82.4	0.2	12.5	0.4	-	0.01	0.3	0.15
13	RKS-1	68.2	1	19.4	3.4	-	0.1	0.3	0.2
14	RKS-8	67.2	0.8	21.1	1.3	-	0	0.4	0.5
15	RKS-26	88.7	1.4	5.3	2.3	-	0.02	0.3	0.3

**Index for Geochemical Plots
(fig. 4.1 To 11)**

-  Basalt
-  Gabbro Dykes
-  Agglomerate
-  Basalt from Tungar Section
-  Acidic flows and tuffs

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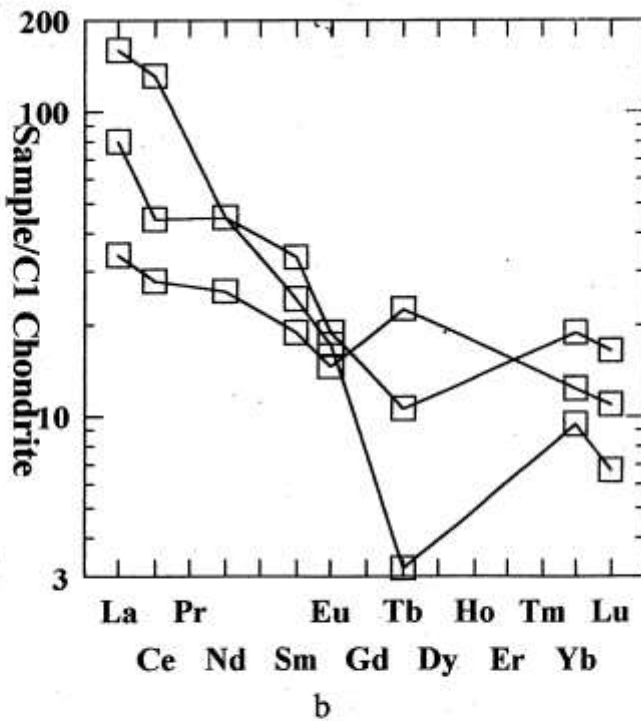
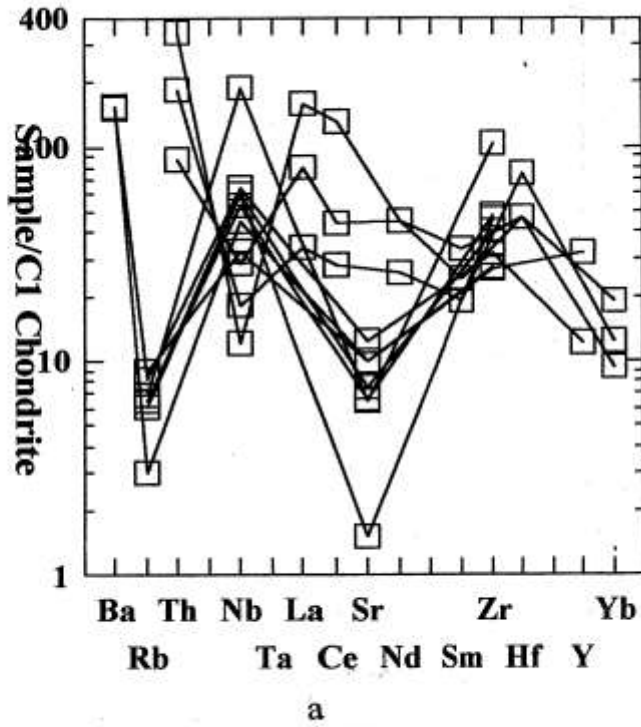


Fig. 4.10a and 4.10b

Trace element and REE plots respectively, for felsic rocks.



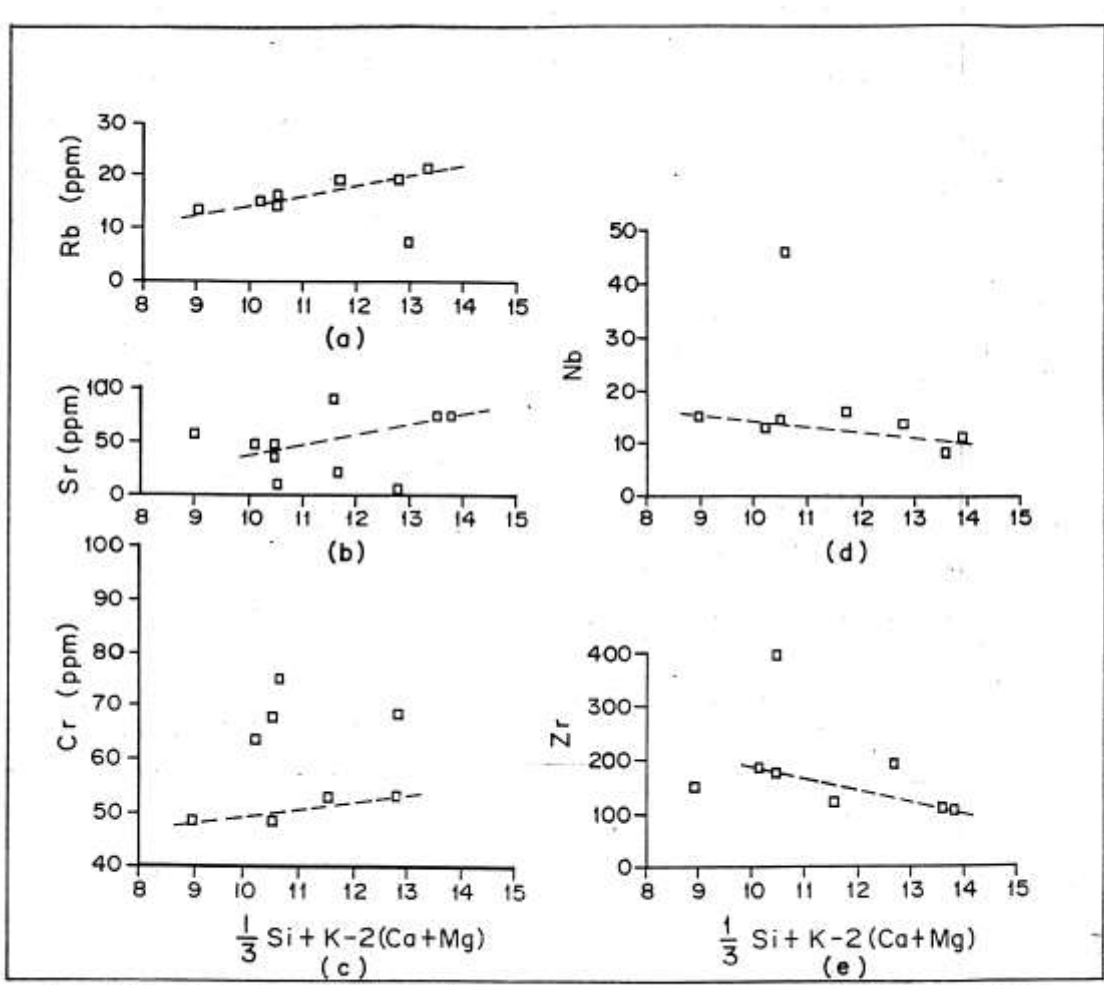


Fig. 4.9 Evolution Index/Trace element variation diagram for felsic rocks of the area, after Nockolds & Allen



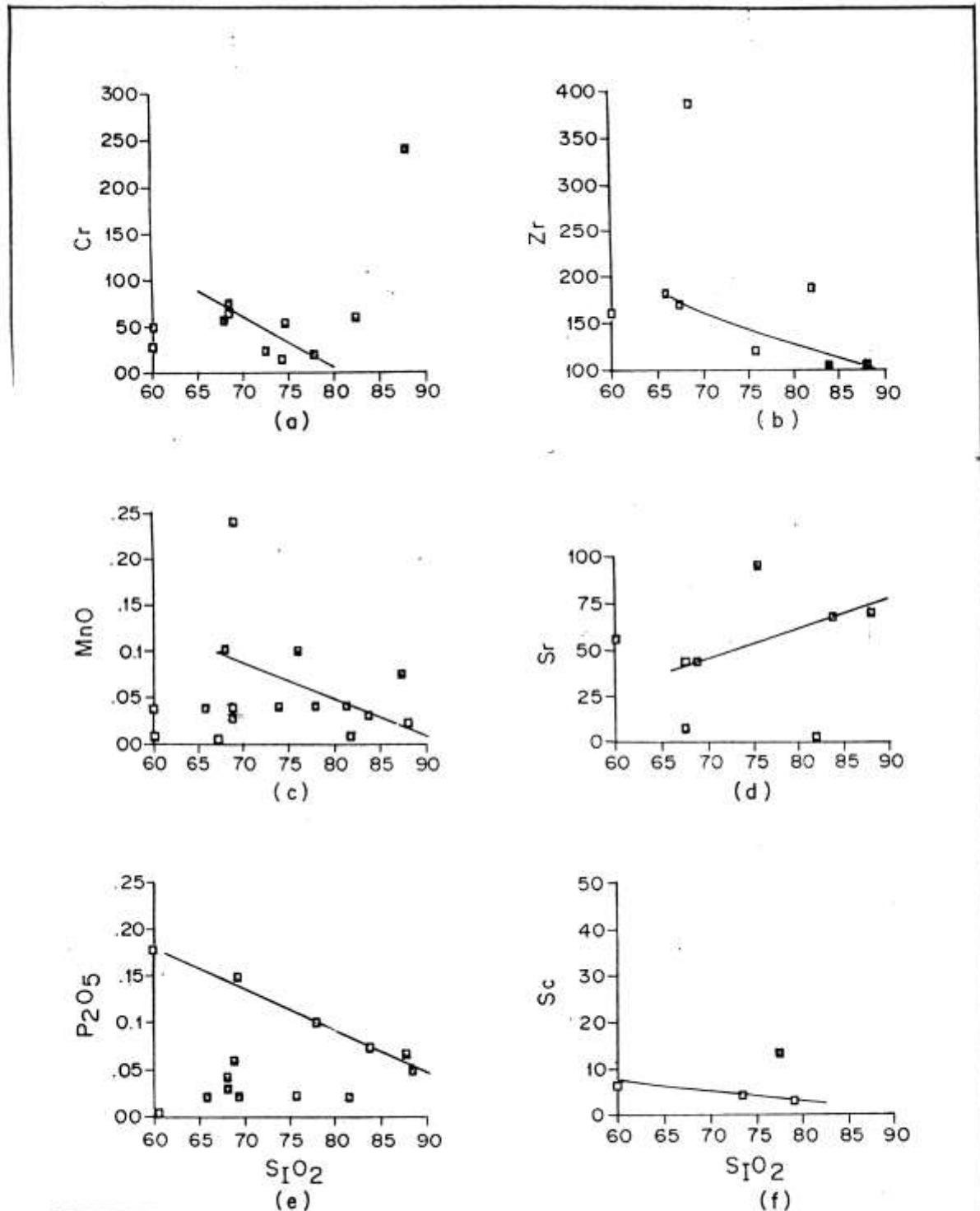
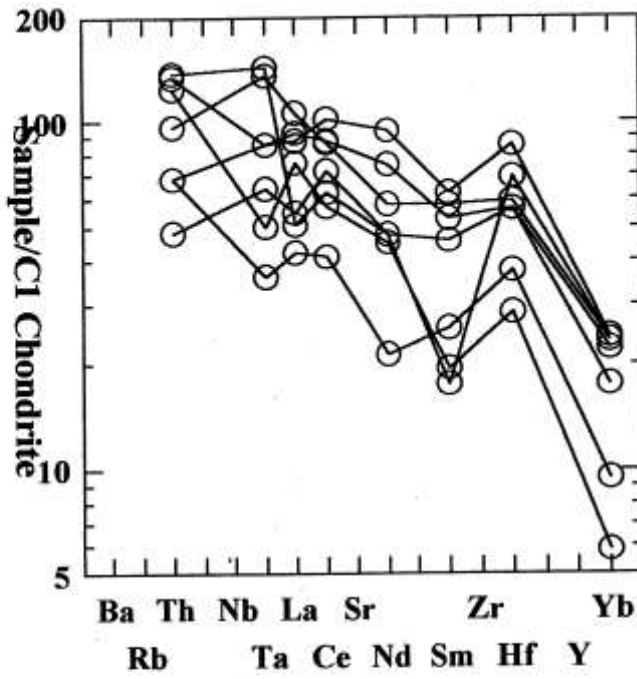
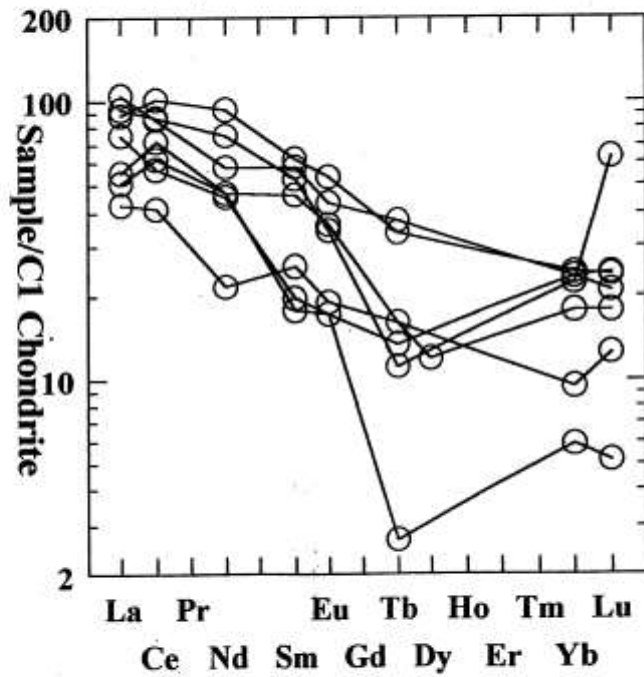


Fig.-4.8. Silica variation diagrams for felsic volcanic rocks .



a



b

Fig. 4.7a and b

Trace element and REE plots respectively, for agglomerates.



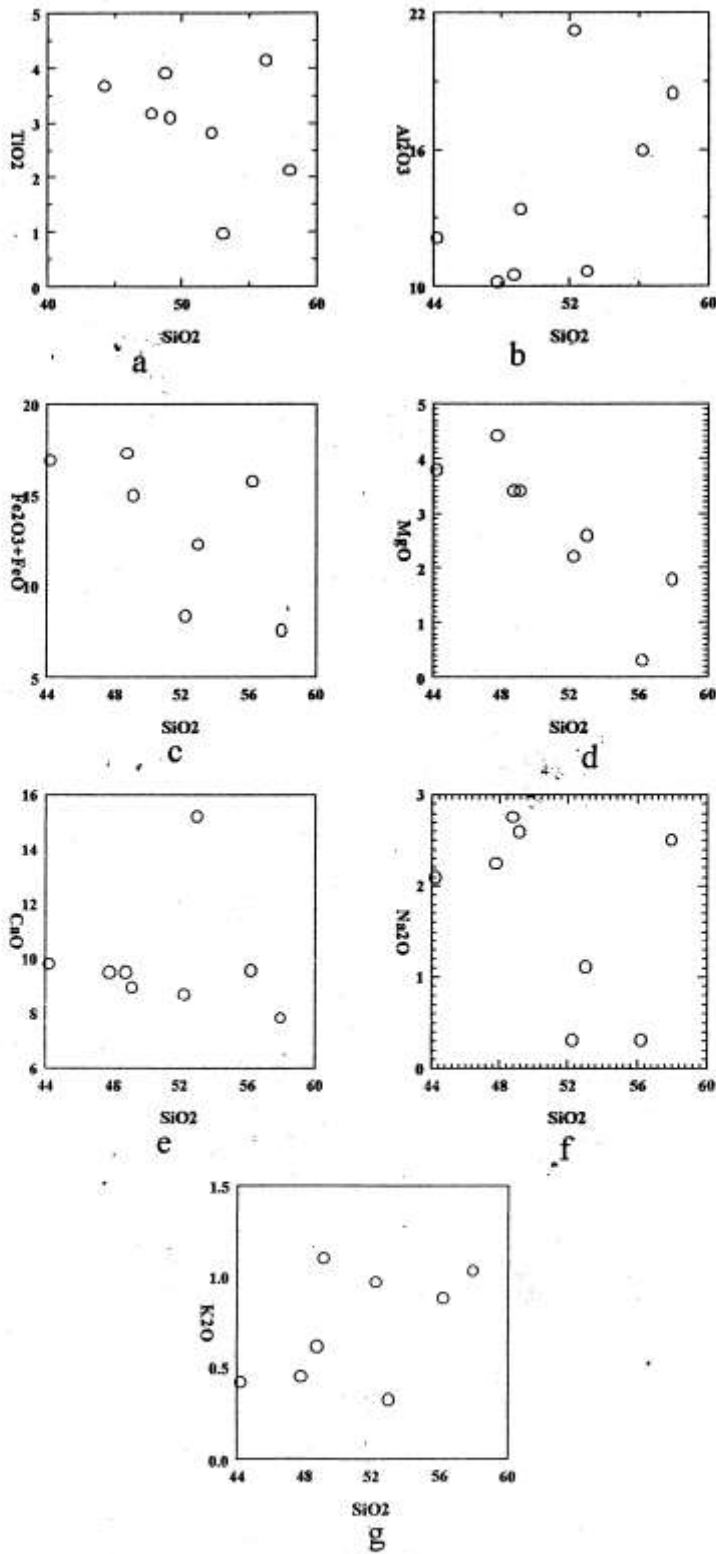


Fig. 4.6a to 4.6g

Silica variation diagrams plotted for agglomerates.



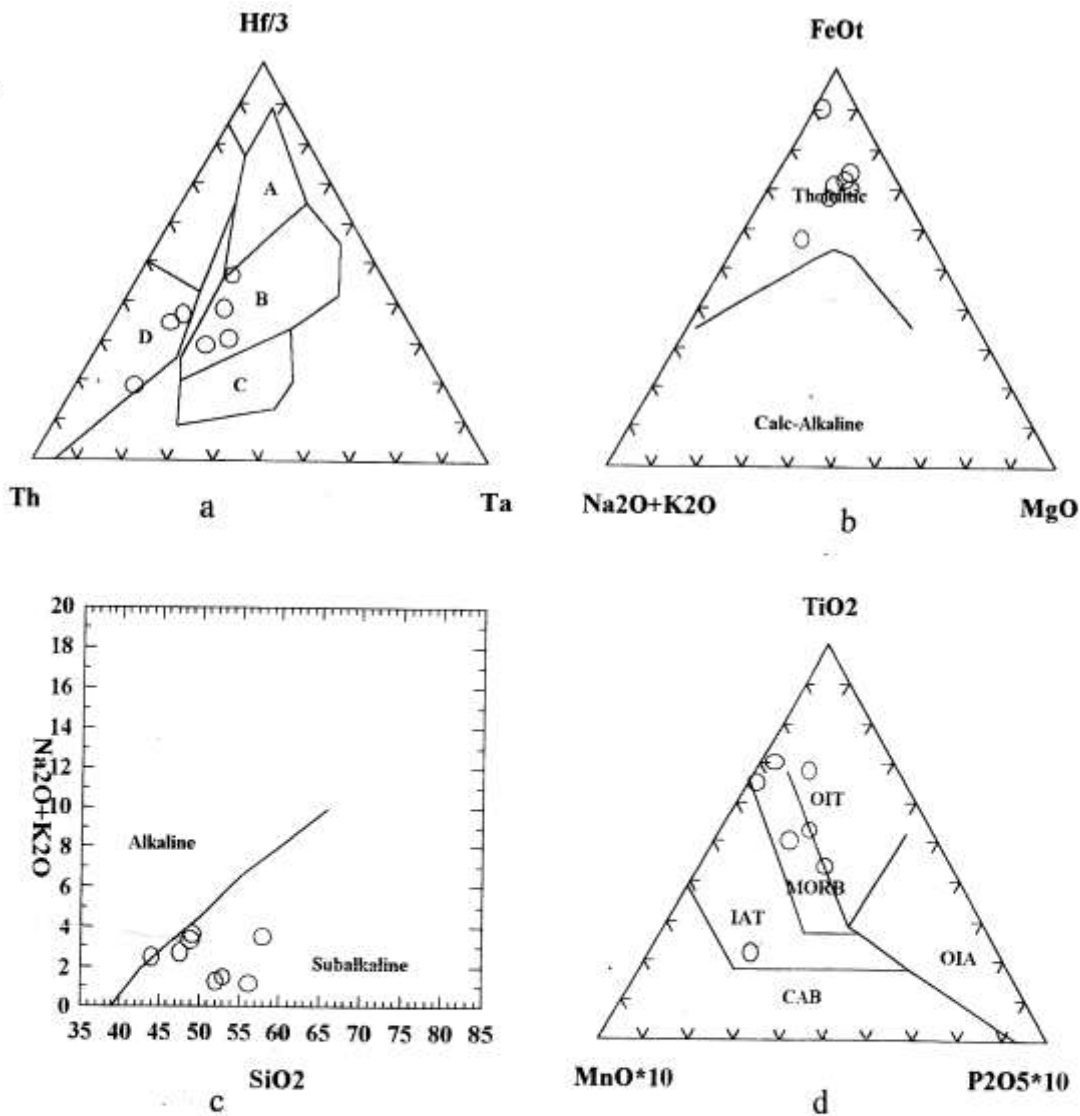


Fig. 4.5

- a Hf-Th-Ta diagram for classification of agglomerates.
- b AFM diagram used for classification of agglomerates.
- c Total alkali V/s. Silica binary diagram used for classification of agglomerates.
- d Mullens classification diagrams (TiO₂-MnO-P₂O₅) used for classification of agglomerates.

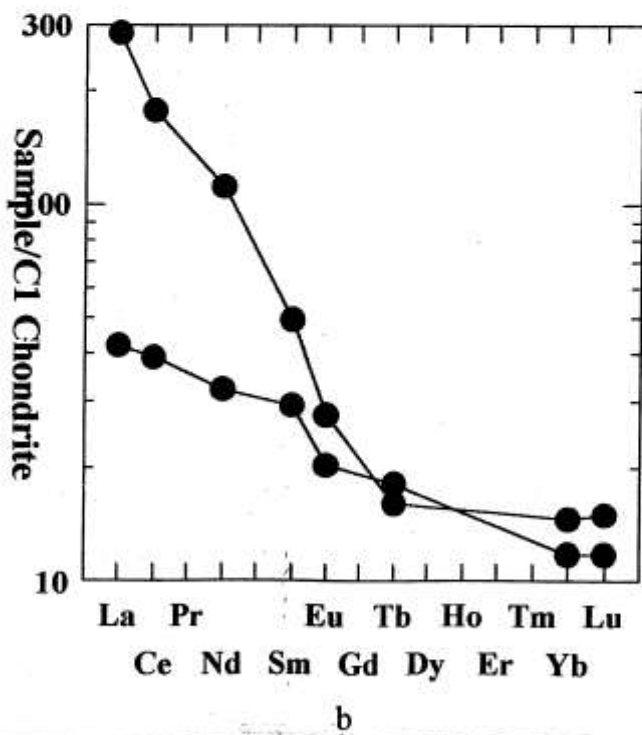
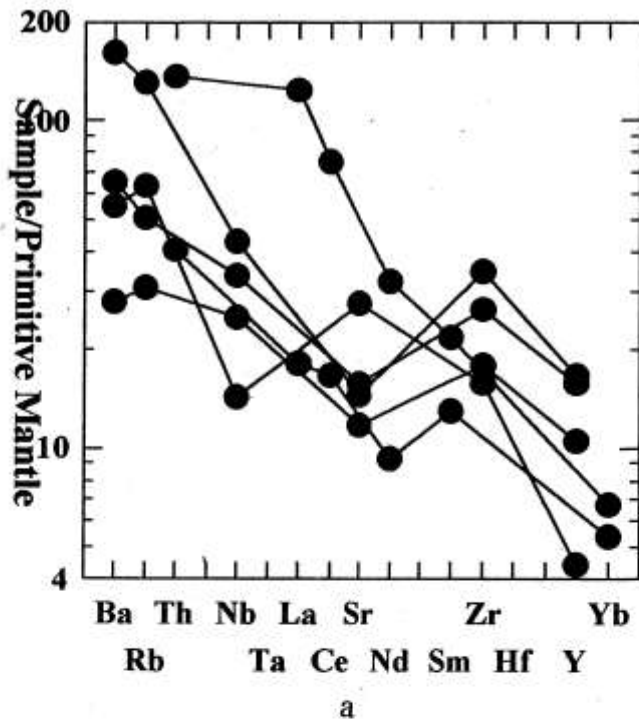


Fig. 4.4

- a Trace element distribution in basaltic rock plotted against primitive cont.
- b REE plot for basaltic rocks.

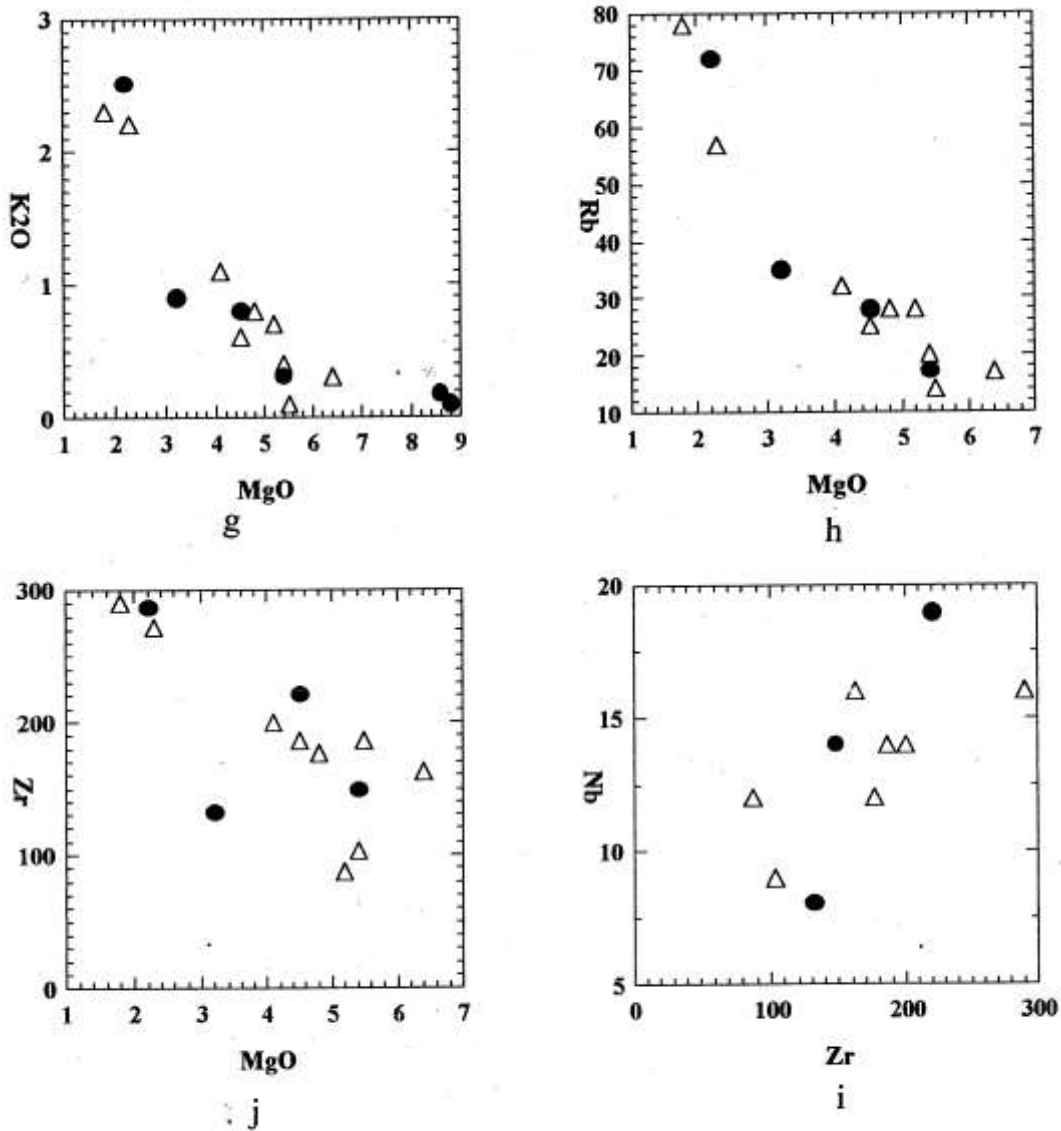


Fig. 4.3

Variation diagram MgO V/s Various oxides

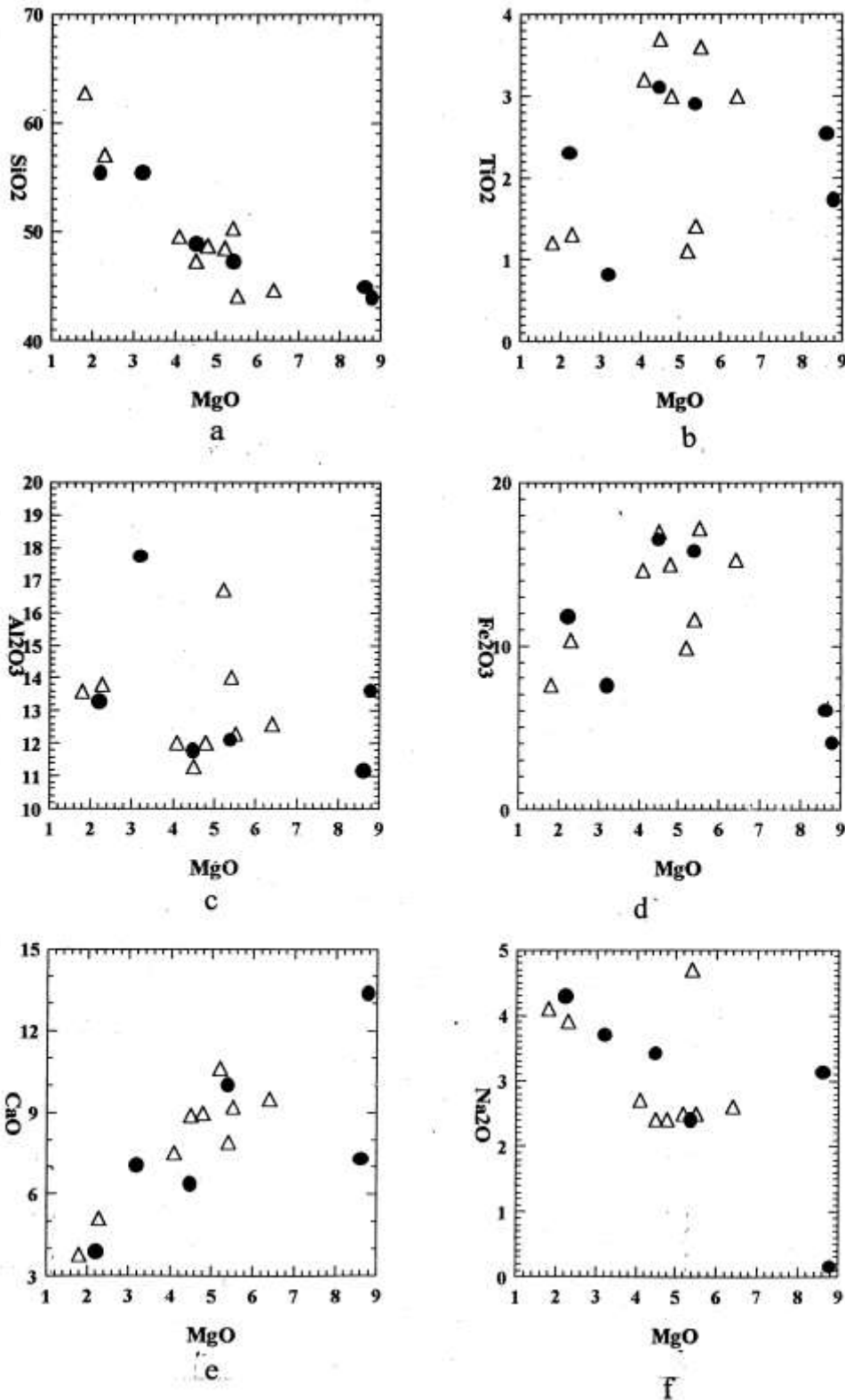


Fig. 4.3(a-f) - Variation diagrams, MgO V/s Various oxides

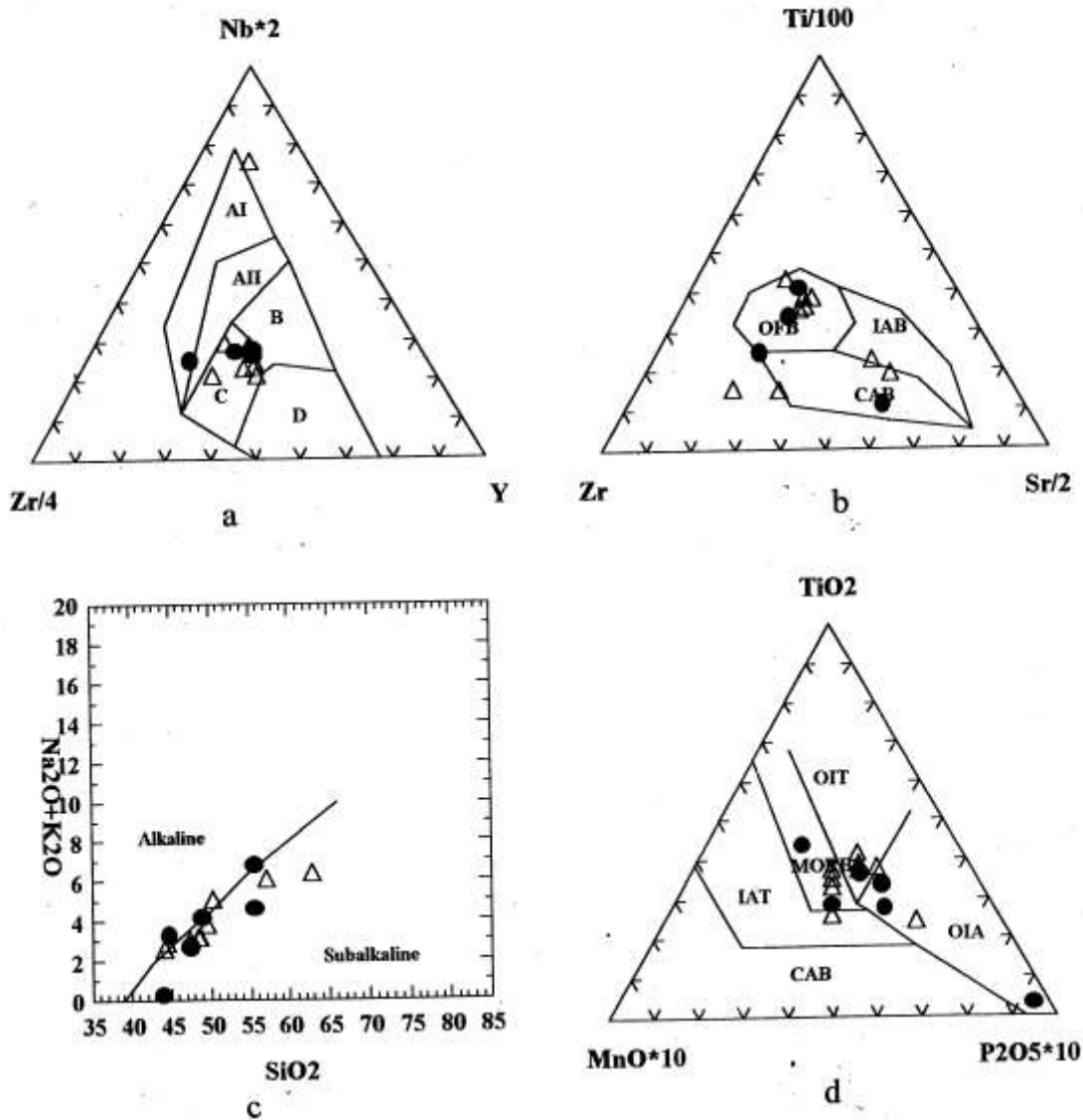


Fig. 4.2

- a Nb-Zr-Y ternary classification diagram after Meschede, 1986.
- b Ti-Zr-Sr ternary classification diagram after Pearce and Cann, 1973.
- c Binary diagram total alkali V/s. Silica.
- d TiO₂-MnO-P₂O₅ diagram after Mullen, 1983.

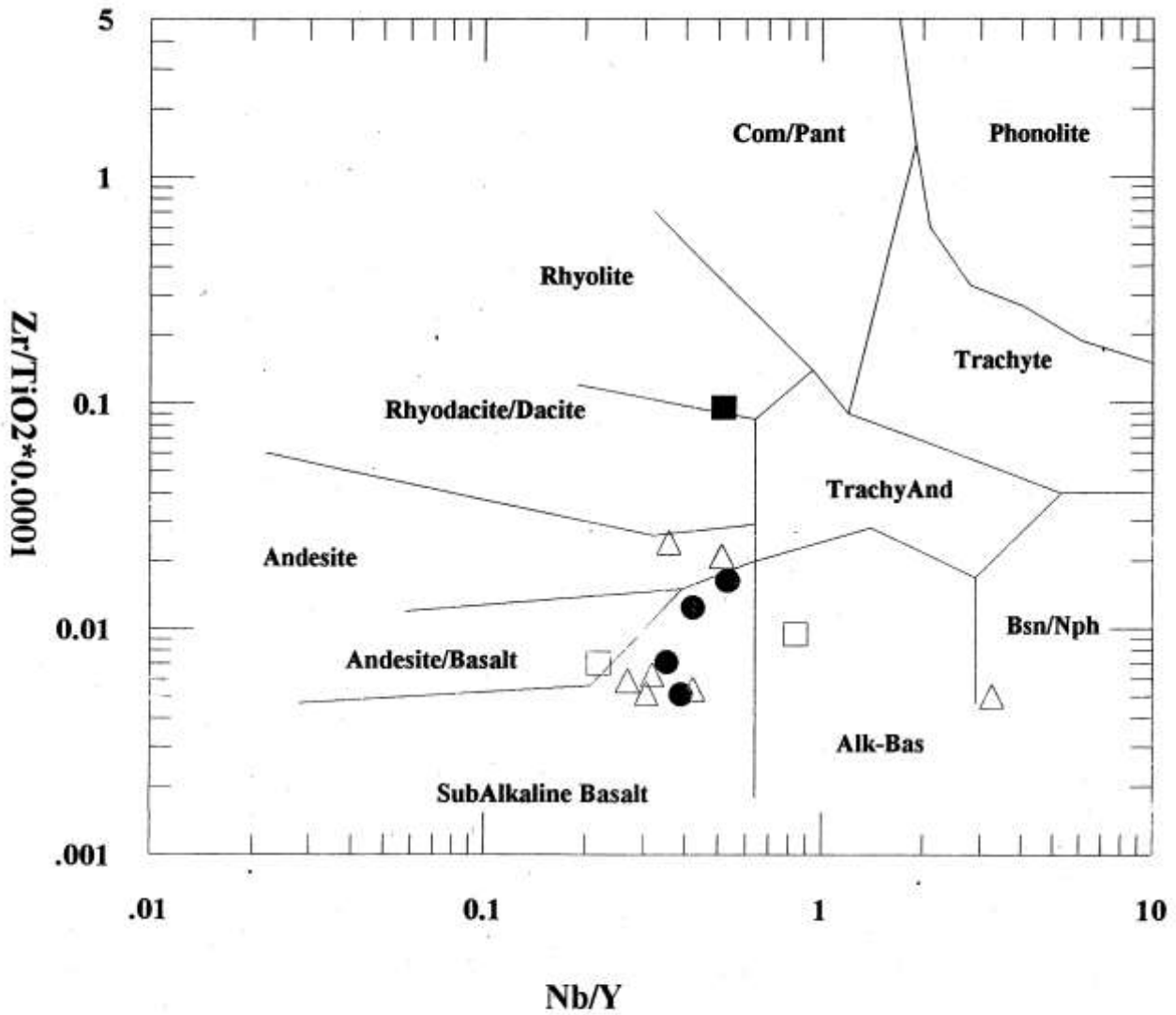


Fig. 4.1b
Zr/TiO₂-Nb/Y diagram after Winchester and floyed, 1977.

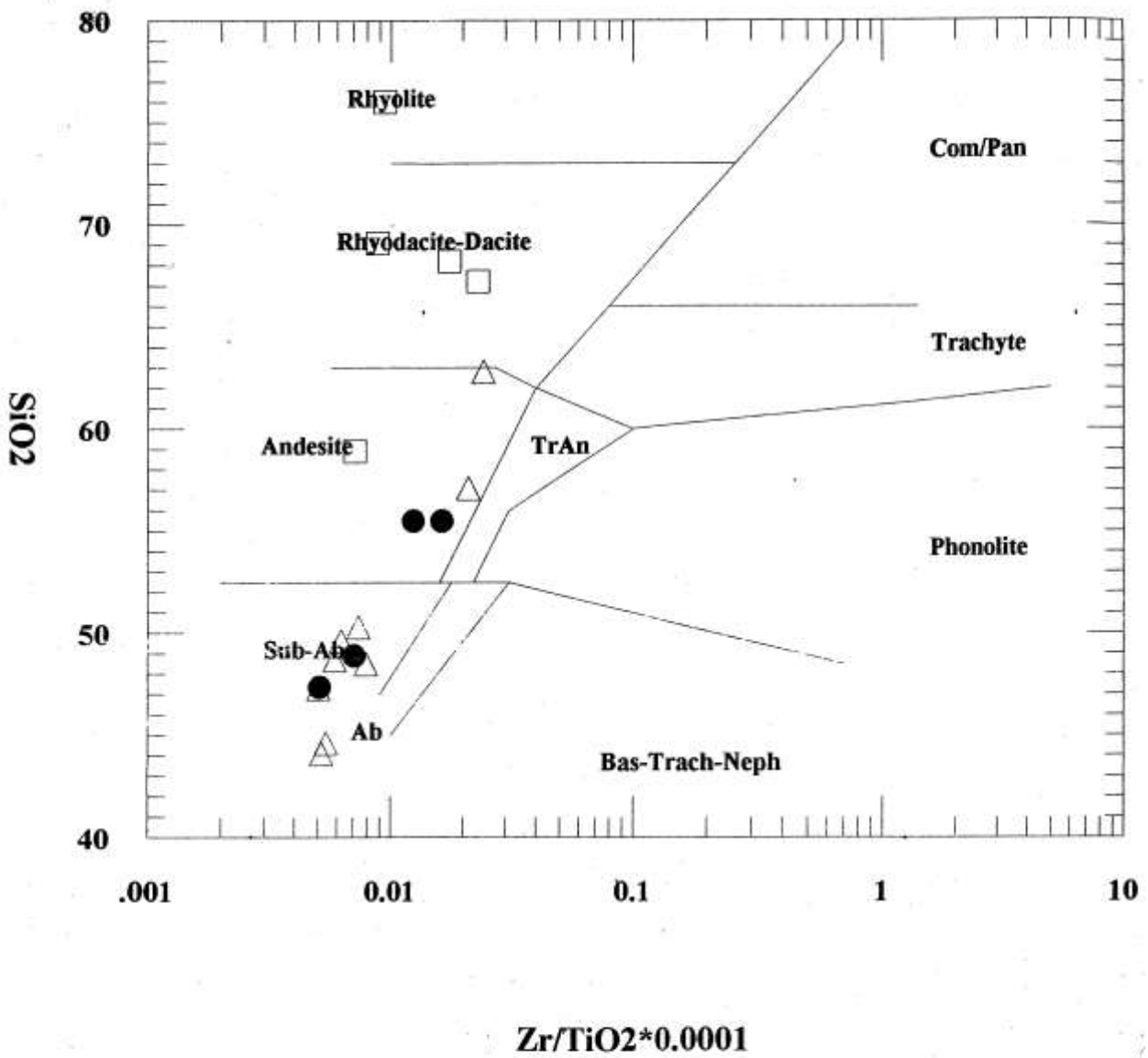


Fig. 4.1a

SiO₂-Zr/TiO₂ diagram after Winchester and Floyed, 1977.

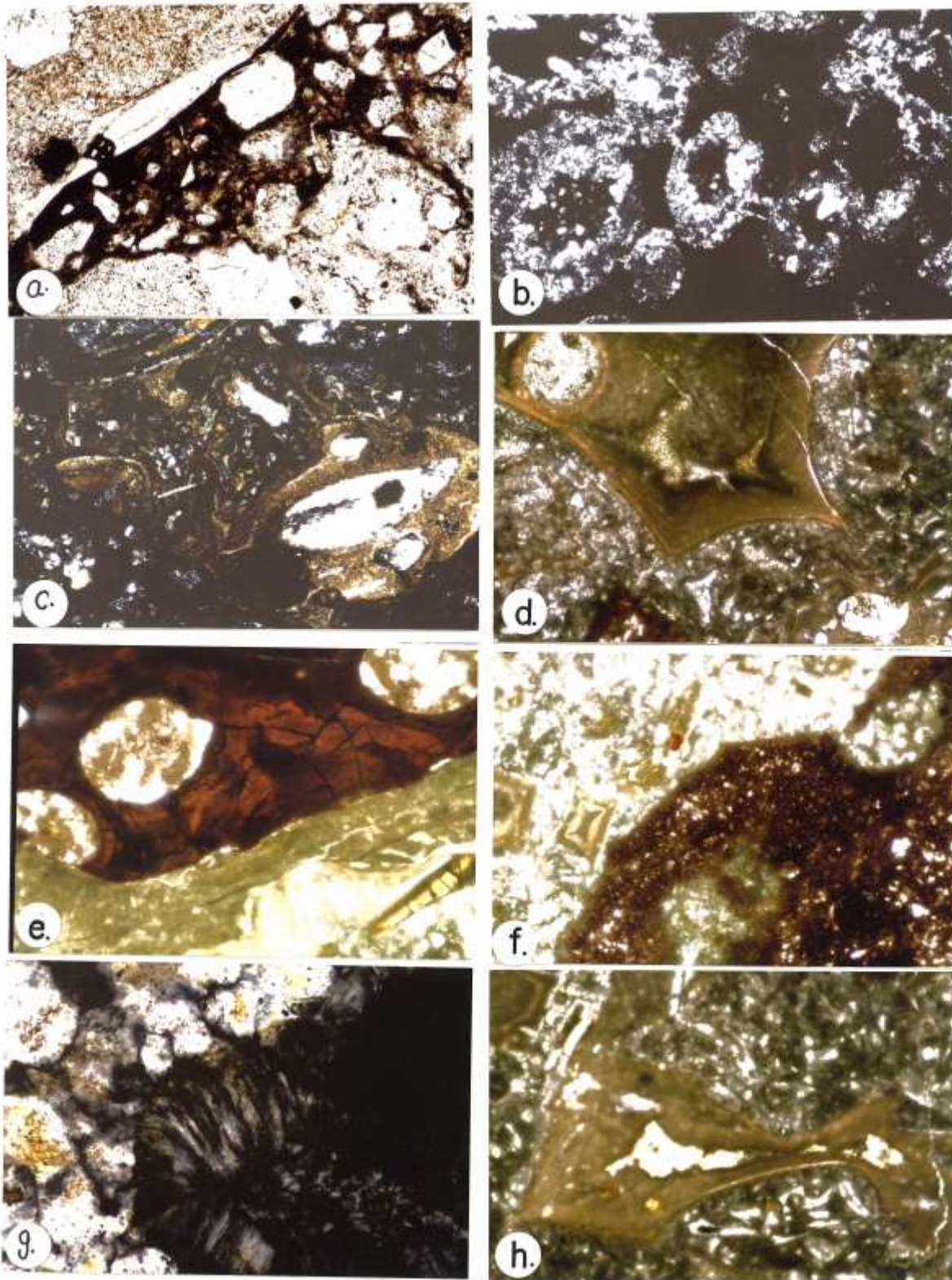


Fig. 4C (a-h)

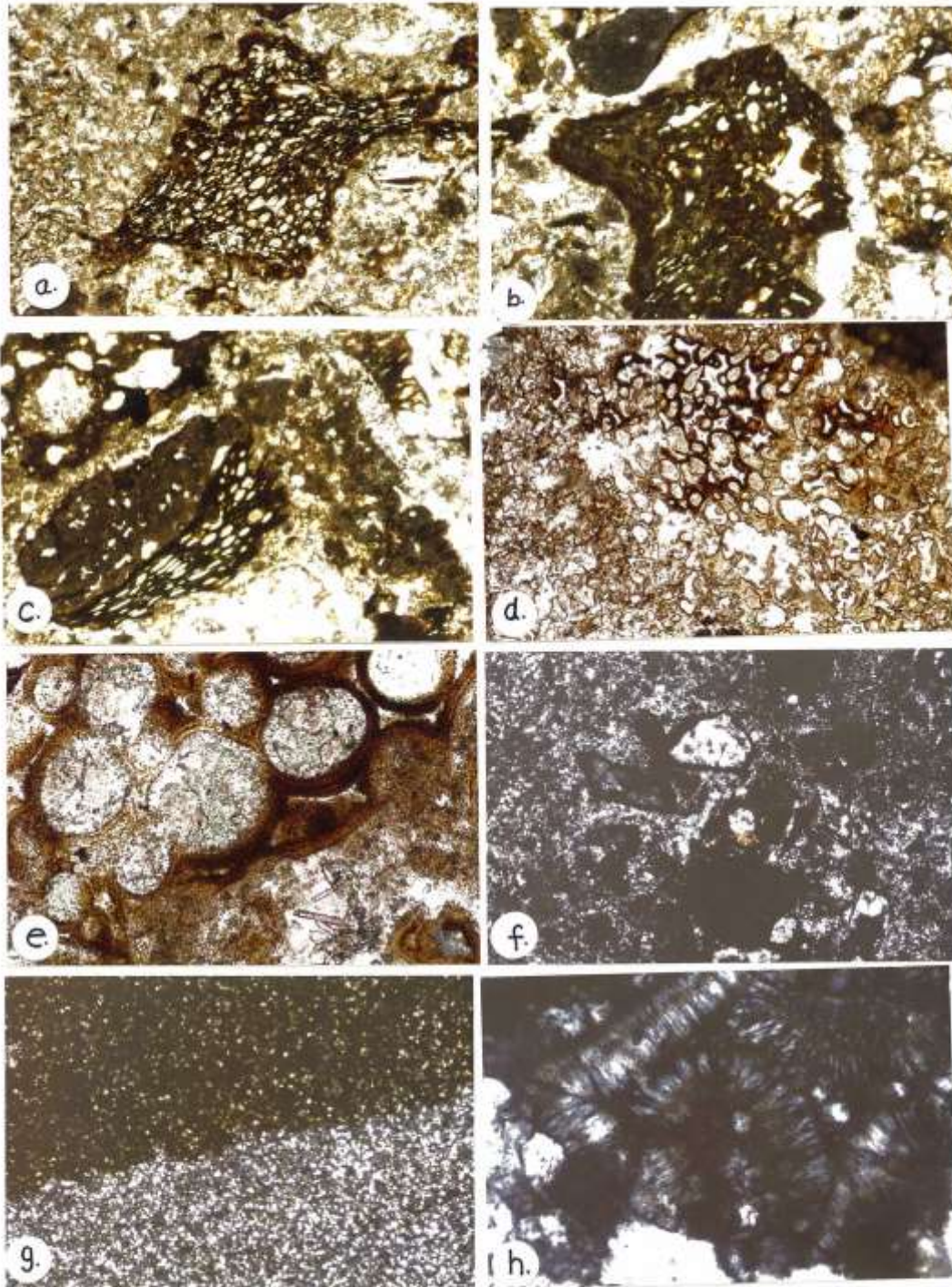


Fig. 4 B (a-h)

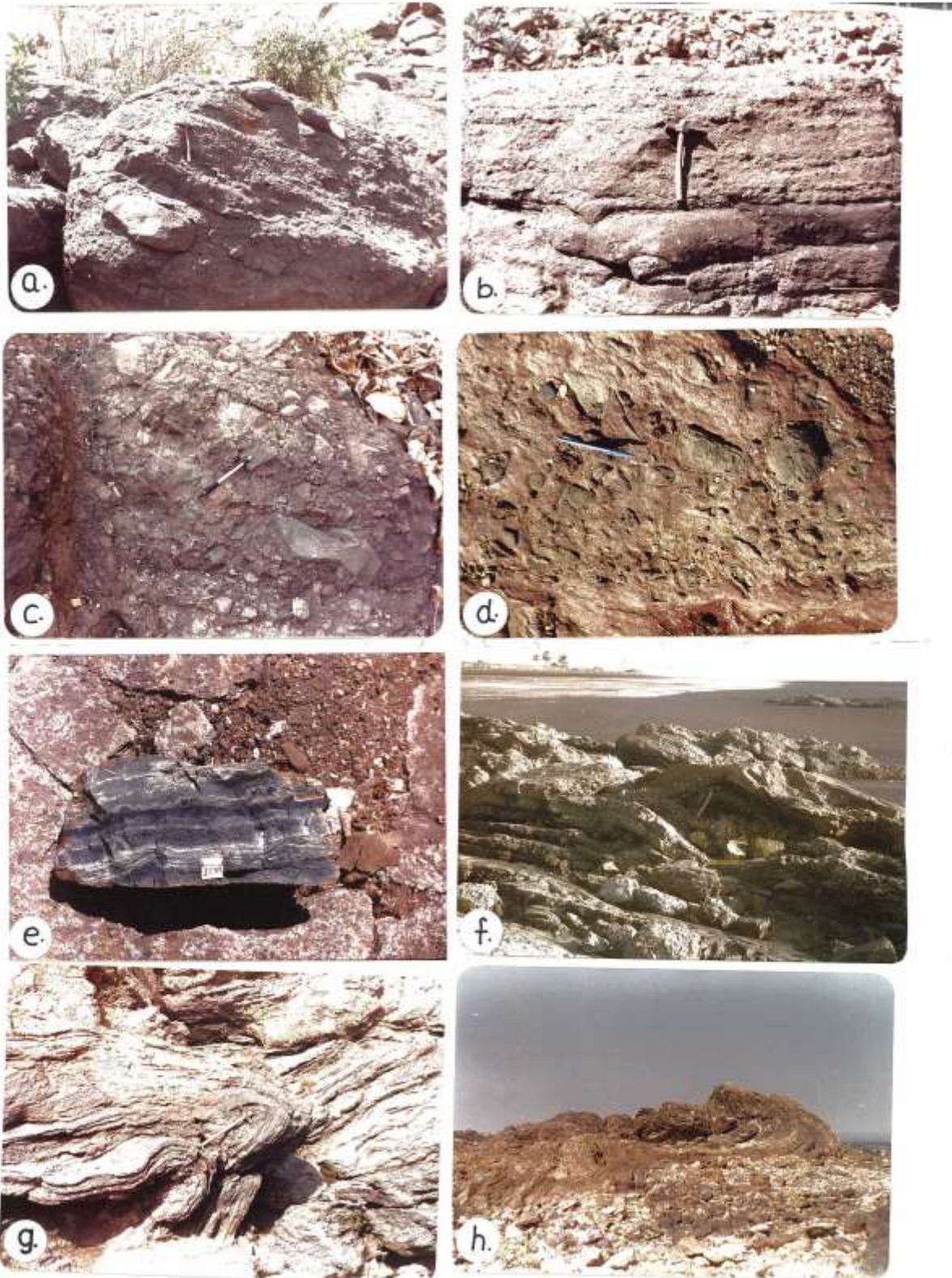


Fig. 4A (a-h)

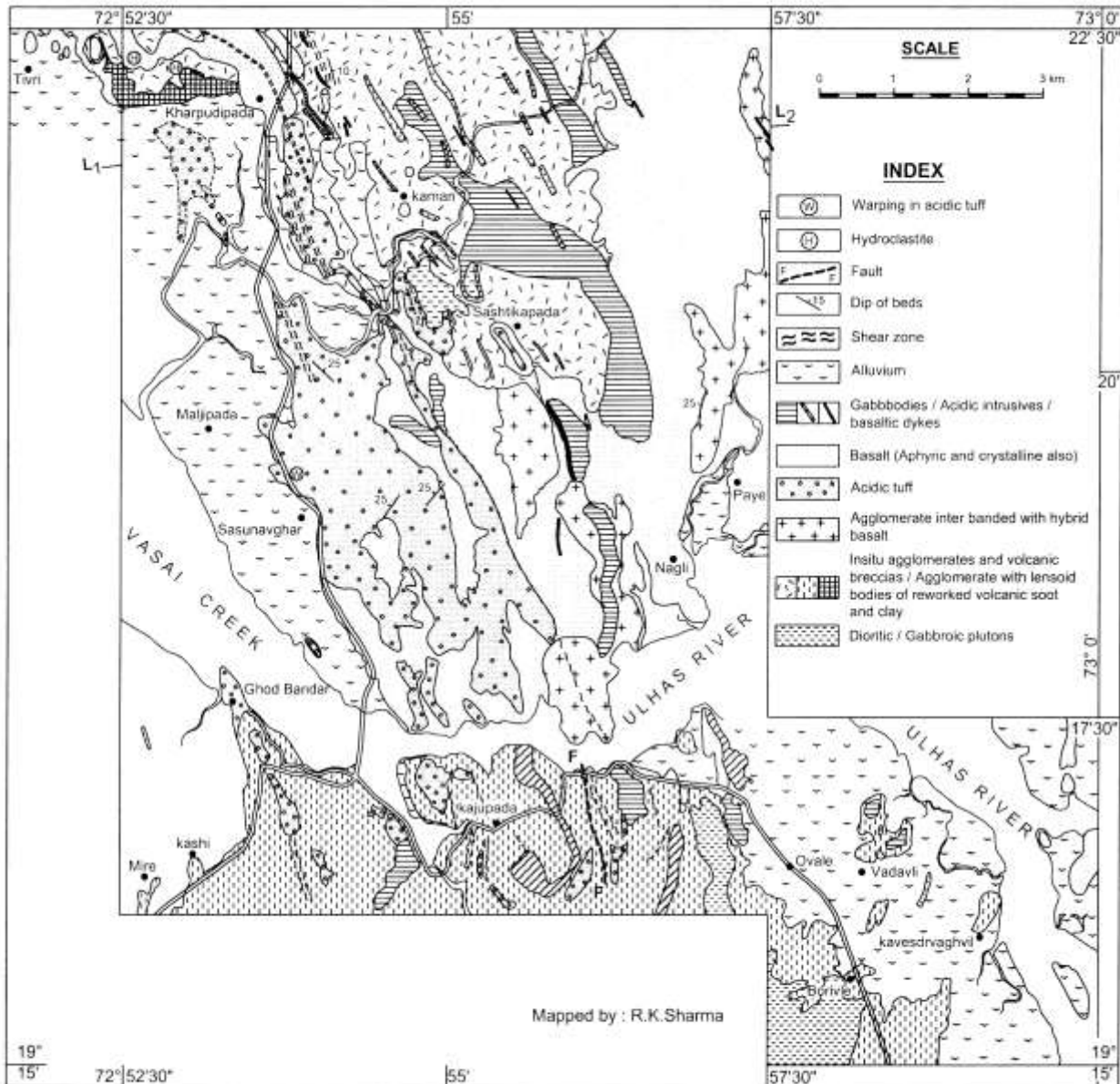


Fig. 4 Geological Map of Part of Thane District, Maharashtra (TS No. 47 A/15/SW and 47 A/15/SE)

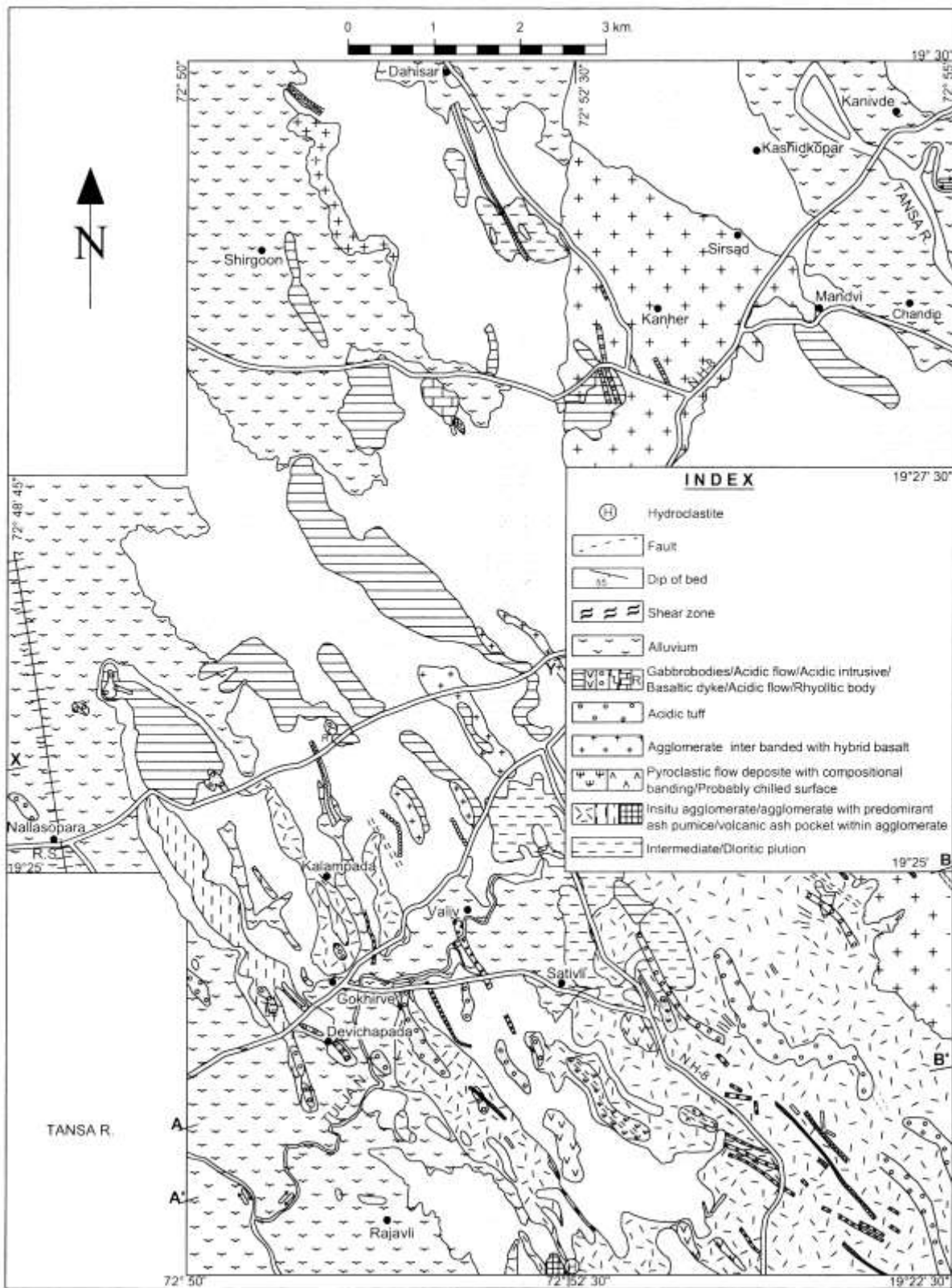


Fig. 3 : Geological Map of Thane District, Maharashtra (TS. No. 47A/15/NW and 47A/15/NE)

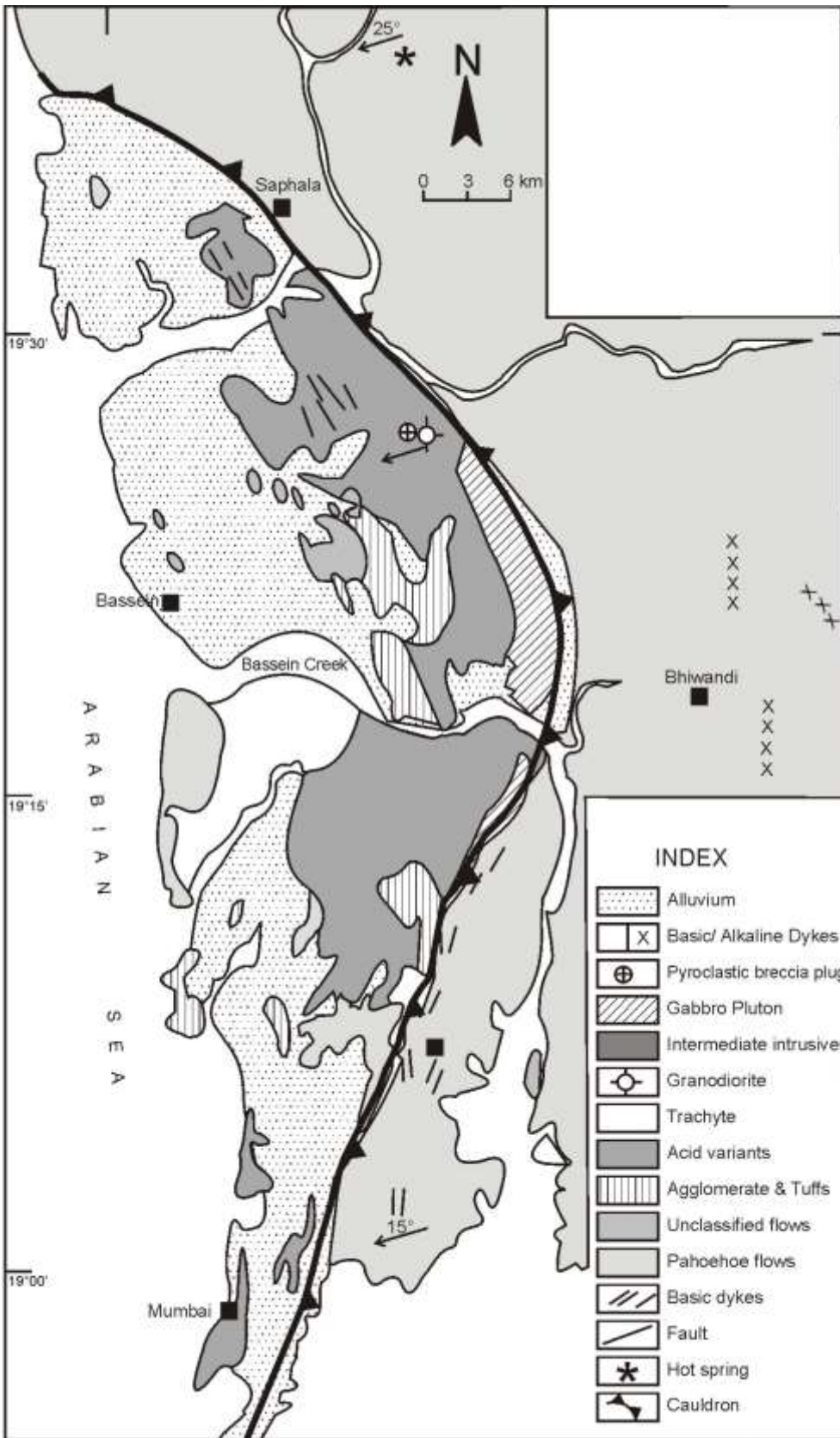


Fig. 2 :Geological map of BVC and surrounding areas (Modified after Gadbole, 1987)

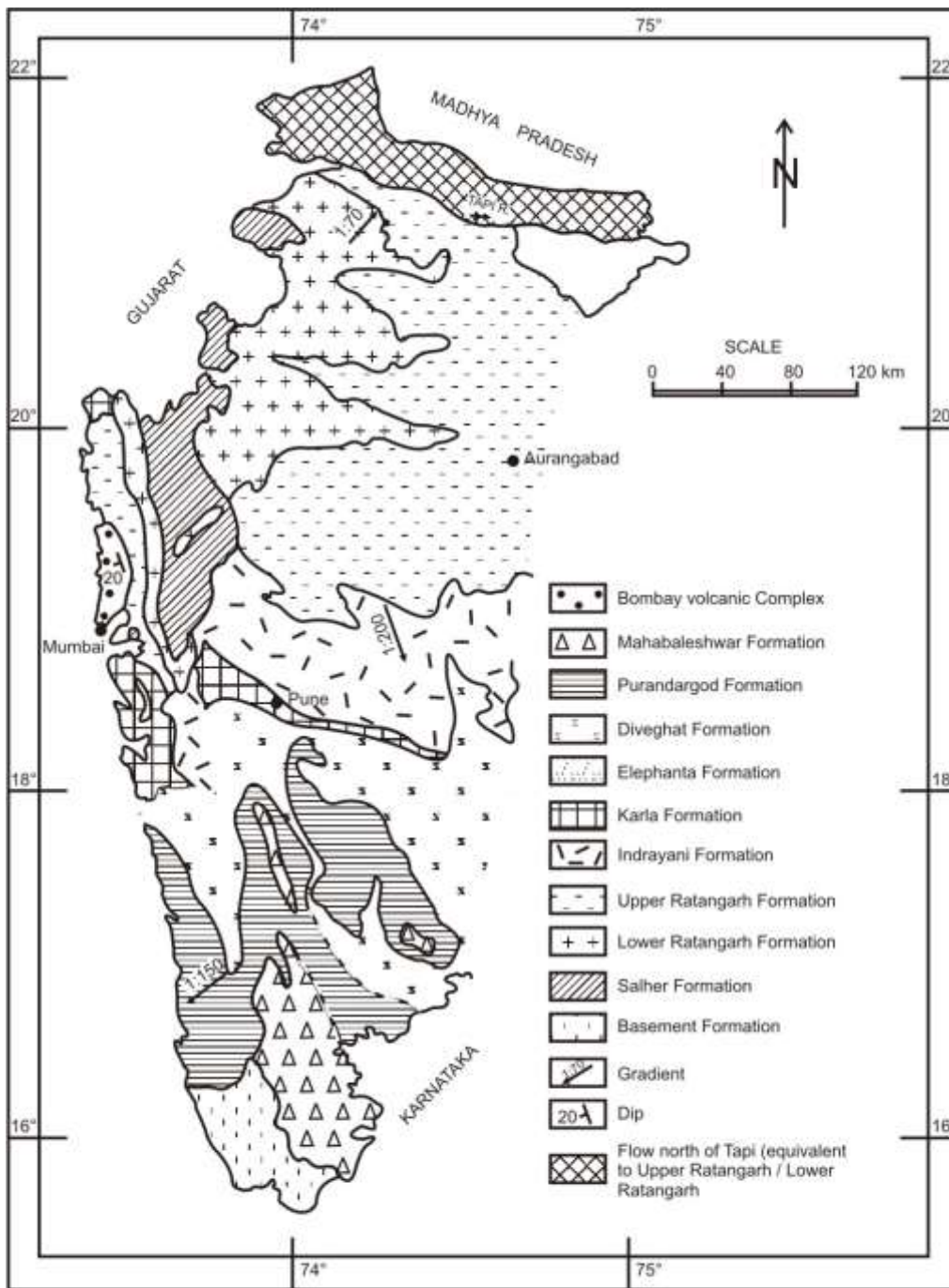


Fig. 1 : Sketch map showing distribution of lava formation in western Maharashtra. (after Godbole et. Al., 1996)