CHAPTER - VI

GEOCHEMISTRY

GENERAL

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GEOCHEMISTRY

GENERAL

Lateritisation being essentially a process of rearrangement of various rock constituents, a systematic analysis of the various horizons that comprise the laterite profile, is required to understand the nature and sequence of chemical transformations and to establish the character of the parent rock. The chemical composition of lateritic rocks is generally heterogeneous both laterally and vertically, but on the whole the compositional variation shows a broad uniform pattern. Accordingly, in the present study, a total of 34 samples from a few selected profiles and of cores taken from drilling sites were chemically analysed both for major and trace element contents. The data obtained are new from the area in the sense that all horizons and parent rock have been analysed. In the past, some of the previous workers had mostly studied only one or the other horizon. For the first time, chemical data from a number of more or less complete profiles, have been obtained. Samples from following 5 localities have been studied (For locations, please refer Fig. IV.1 and 4).

1. Amliyara profile
2. Amliyara bore hole profile
3. Amliyara quarry
4. Manjlau profile
5. Tarbhon profile

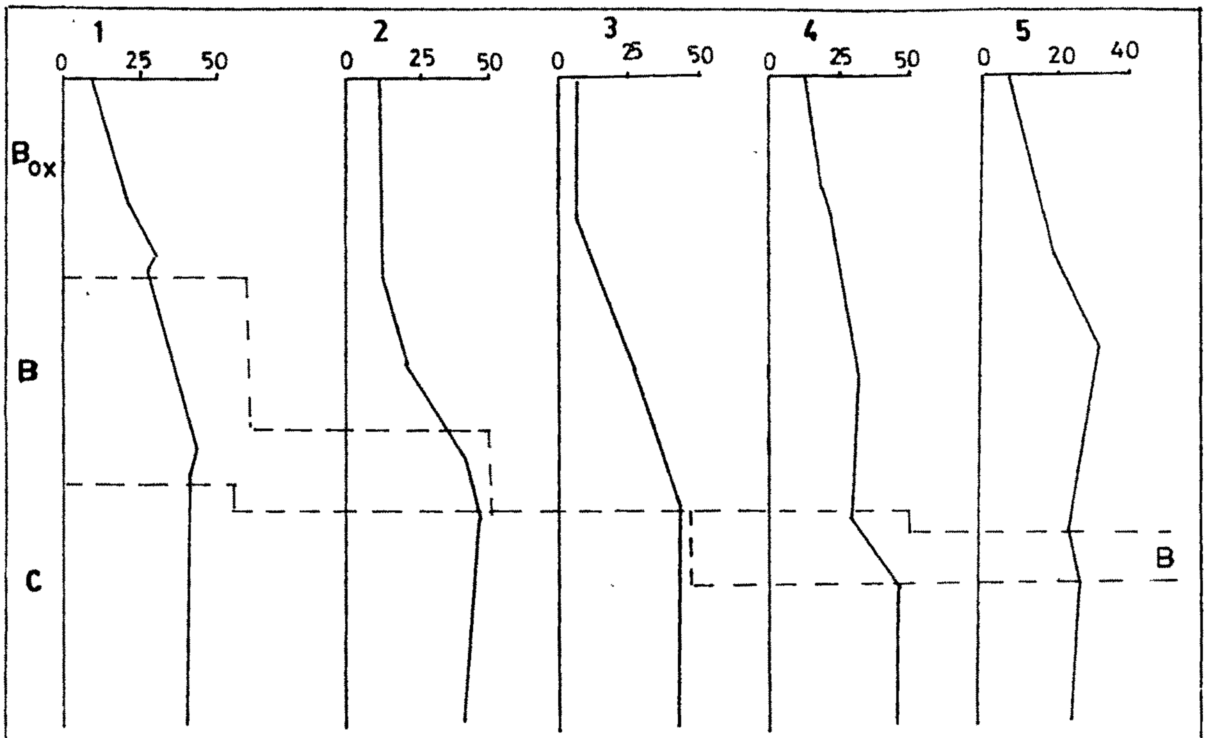
The analyses were carried out with the help of routine wet analytic methods and AAS (For details, please refer to Appendix IV, i to v and V, i to v). On the whole, the various observations and inferences of the present study fit into the interpretation that the Box and B-horizons are derived by the 'insitu' chemical alteration of basalt.

MAJOR OXIDES

Silica

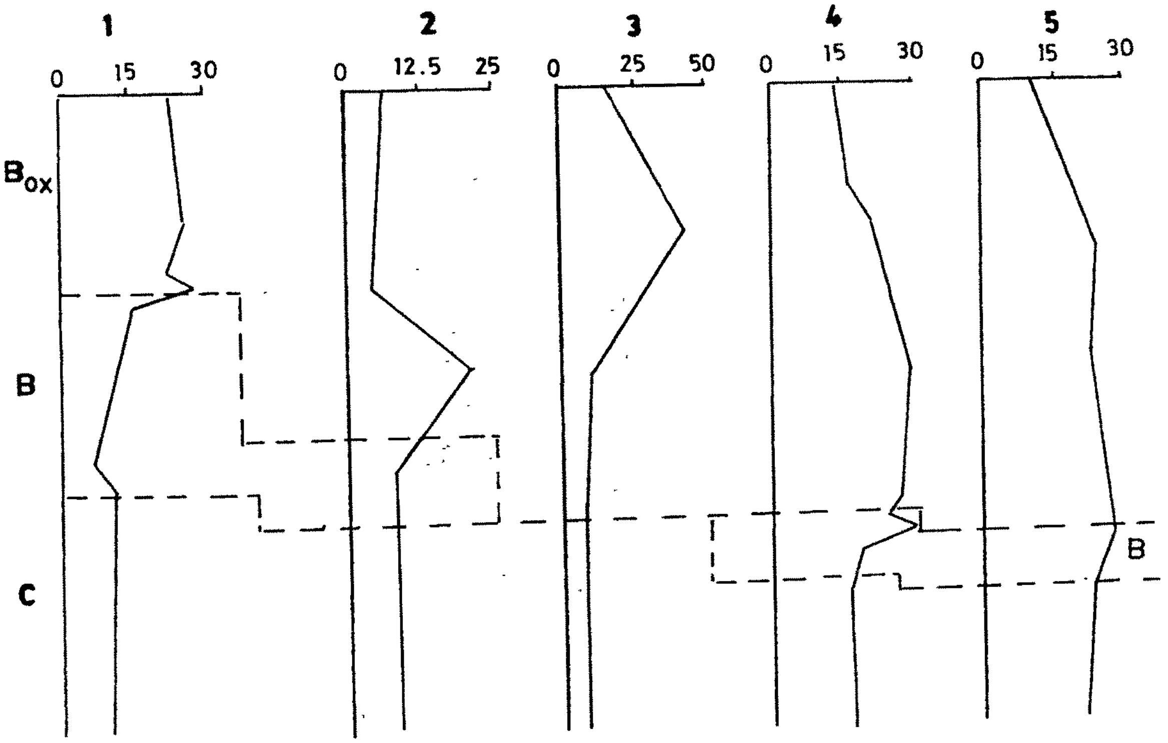
Silica would be present in laterite in various amounts and in several forms. It may occur as primary quartz (Benza, 1836; Buchnan, 1807; de Weisse, 1954) and also as aluminosilicates viz. kaolinite, halloysite, montmorillonite (Grim 1953).

A decrease in proportion of silica in laterite zone (Box) as compared to the parent rock is consistently seen in all localities of North and South Gujarat. The amount ranges between 32.93 to 7.06 %. In case of saprolite zone (B) the decrease is seen ranging between 46.72 to 24.35 %. Interestingly, the analyses show that reworked laterite and bauxite have a low content of silica i.e. only 8.38 to 6.59 % (Fig VI.1).



VARIATION DIAGRAM : SiO_2 %

Fig: VI.1.



VARIATION DIAGRAM : Al_2O_3%

Fig: VI.2.

Aluminium

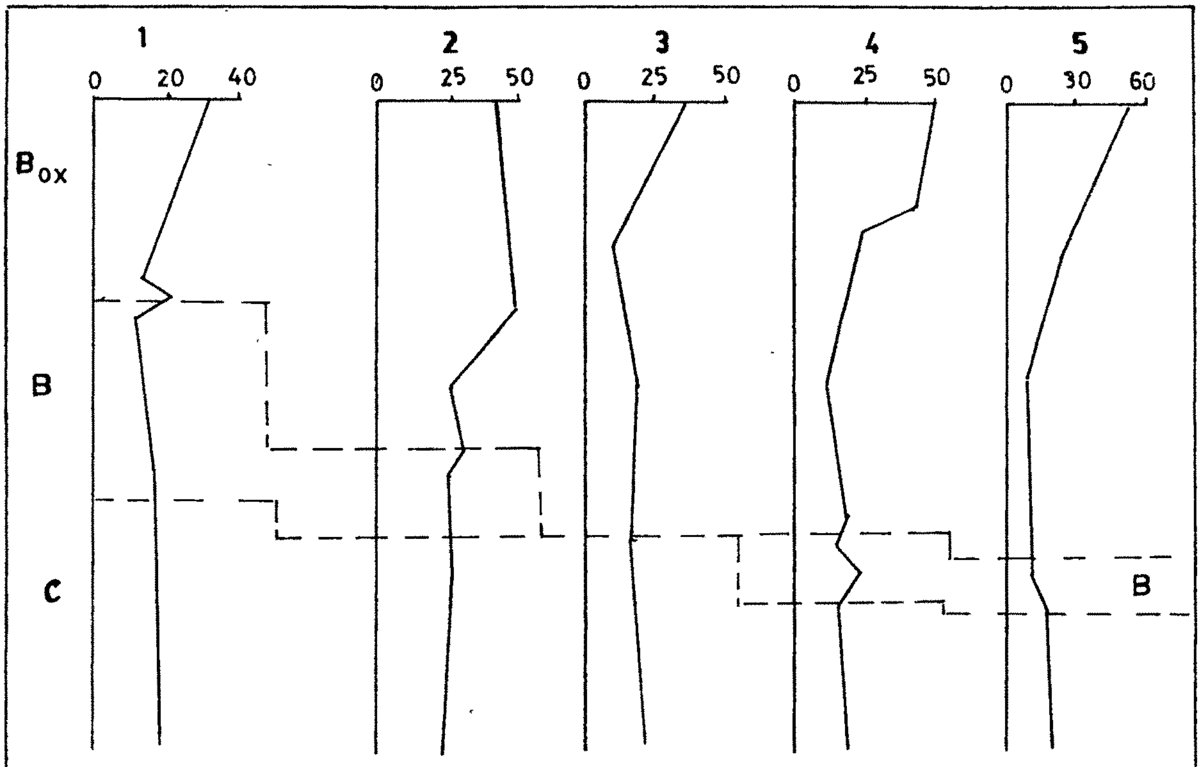
Gibbsite is the main carrier of alumina followed by kaolinite, montmorillonite, boehmite and halloysite. Its proportion mostly increases in laterite zone (Box horizon), the amount ranging from 5.88 to 28.93 %. In saprolite ('B') horizon all profiles show an increase in proportion, ranging from 6.31 to 29.52 %. The reworked bauxite shows alumina proportion of 45.67 % (Fig. VI.2). This recorded variation in its content correlates well with the proportion of the various aluminium bearing minerals.

Iron

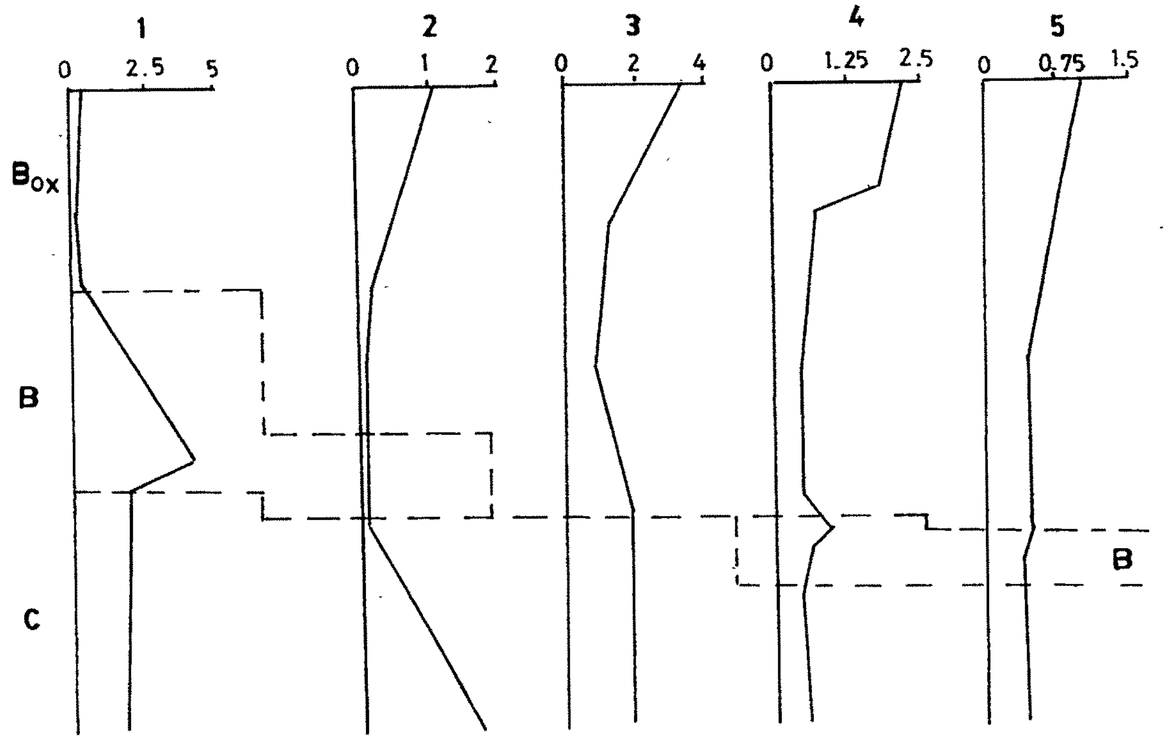
Goethite supplemented by Hematite, Maghemite and a little Lepidocrosite, are the main carriers of iron. Between Fe_2O_3 and FeO the former predominates. There is a wide variation in the content of Fe_2O_3in different horizons of the profile, its amount ranging from 9.52 to 51.57 % in Box horizons and from 12.92 to 26.65% in saprolite ('B') horizon (Fig. VI.3).

The FeO content is seen ranging between 0.43 and 2.35% in laterite horizon (Box) and between 0.11 and 4.19% in saprolite zone.

In case of reworked laterite, it has a high iron content (Fe O 38.22 % & FeO 3.24%) as compared to the reworked bauxite which has $Fe_2O_3$11.40% and FeO 1.17 %. Interestingly, Fe_2O_3



VARIATION DIAGRAM : Fe_2O_3% Fig: VI. 3.



VARIATION DIAGRAM : FeO% Fig: VI.4.

behaves in the same manner as FeO in South Gujarat but it is not so in North Gujarat (Fig.VI.4). This difference is mostly because of the possible presence of residual hematite in South Gujarat as compared to the less availability of Hematite in North Gujarat.

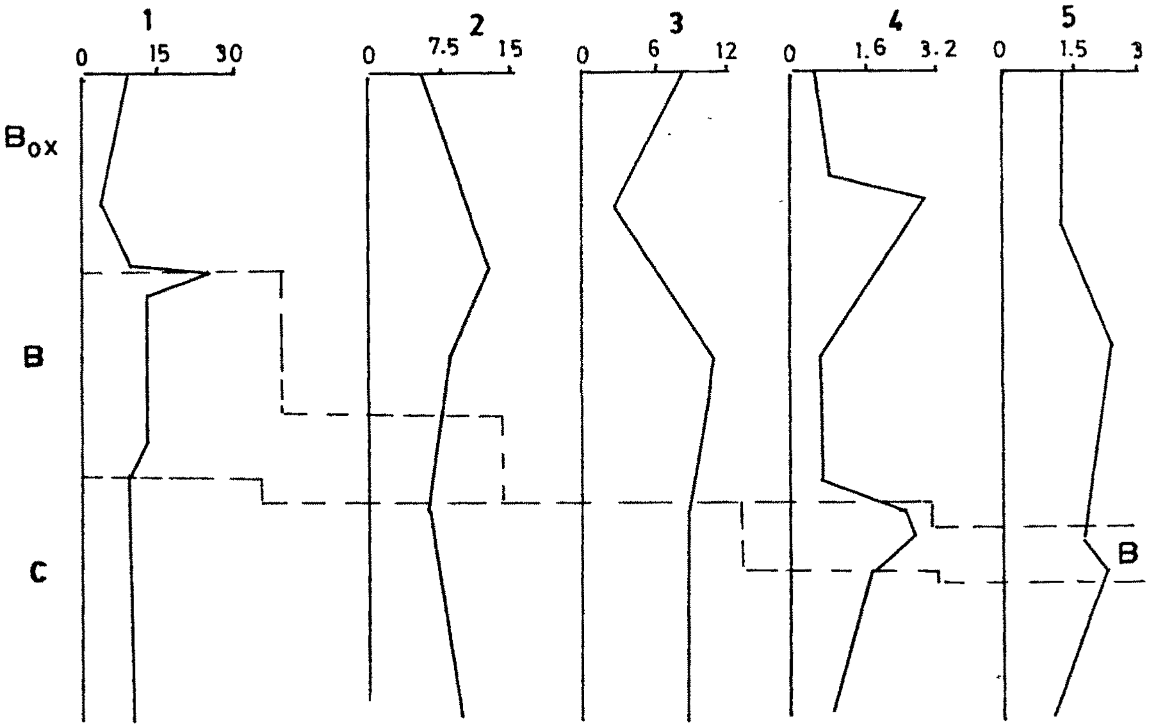
Calcium

Calcite is the main carrier of calcium in all profiles. The content of calcium in all the profiles is high and there is a wide variation of CaO content in the different horizons of the profile. It has a minimum of 0.71 % and a maximum of 9.04 % in Box horizon it ranges between 0.78 and 25.39 % (Fig. VI.5).

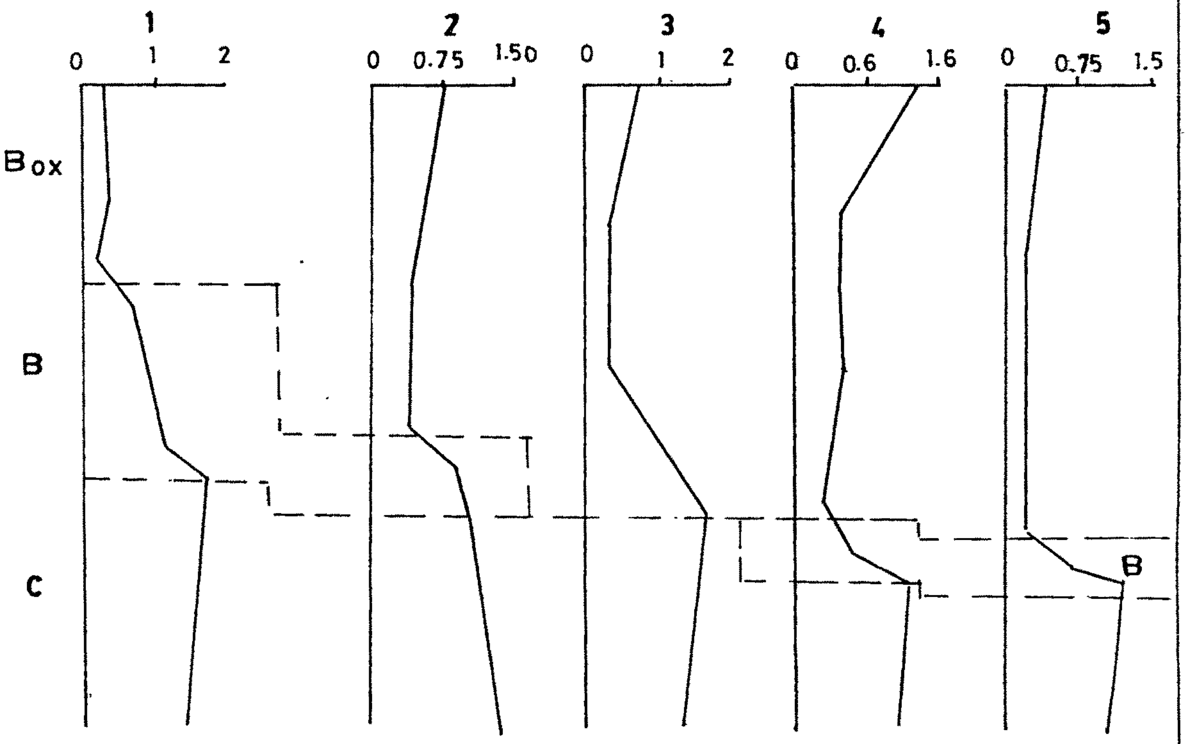
Magnesium

Montmorrilonite and Ankerite are the main carriers of magnesium, but its content is always small. Comparatively, the accumulation and precipitation of magnesium in saprolite is more than that in the laterite zone. The maximum and minimum proportions of the magnesium noticed is 1.51 to 0.16 % in laterite zone and 1.68 to 0.18 % in the saprolite zone respectively (Fig. VI.6).

The amount of magnesium in reworked profiles show a sharp decrease. The source of magnesium is from olivine and augite of the parent rock.



VARIATION DIAGRAM : CaO % Fig:VI.5.



VARIATION DIAGRAM : MgO % Fig:VI.6.

Alkalis

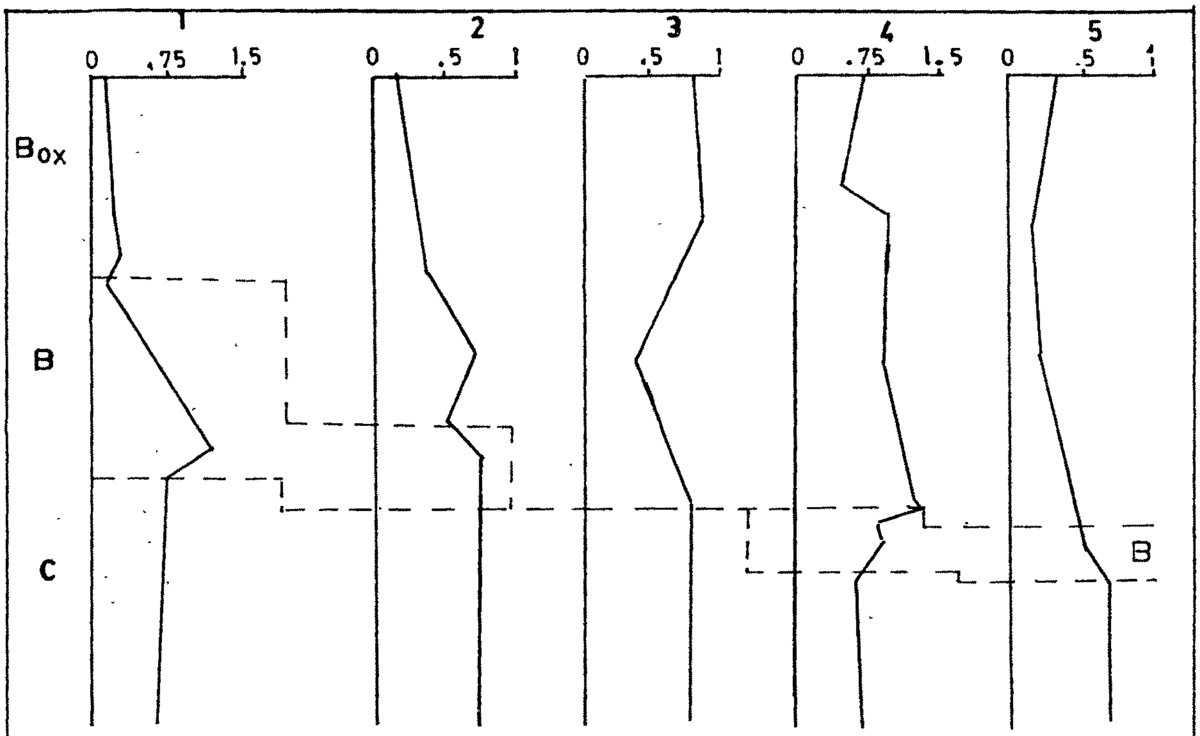
The potash and Soda are mainly confined to the saprolite zone and their proportion decreases upward towards the top of profile. The maximum and minimum amount of potash in laterite zone is 0.36-0.04 % and in saprolite zone is 1.07- 0.03 % respectively. There is an exception in case of Munjlau profile, which shows an increase of potash in the topmost horizon. The maximum and minimum of soda in laterite and saprolite zones are (1.24 - 0.14 %) and (1.34-0.20 %) respectively (Fig. VI. 7 & 8).

Most of the alkalis in laterite profile come from the plagioclase feldspar (labradorite), a primary mineral of the parent rock. Clay minerals like kaolinite, halloysite etc. are the carriers of soda and potash. Montmorillonite in a few cases has also provided soda.

Titanium

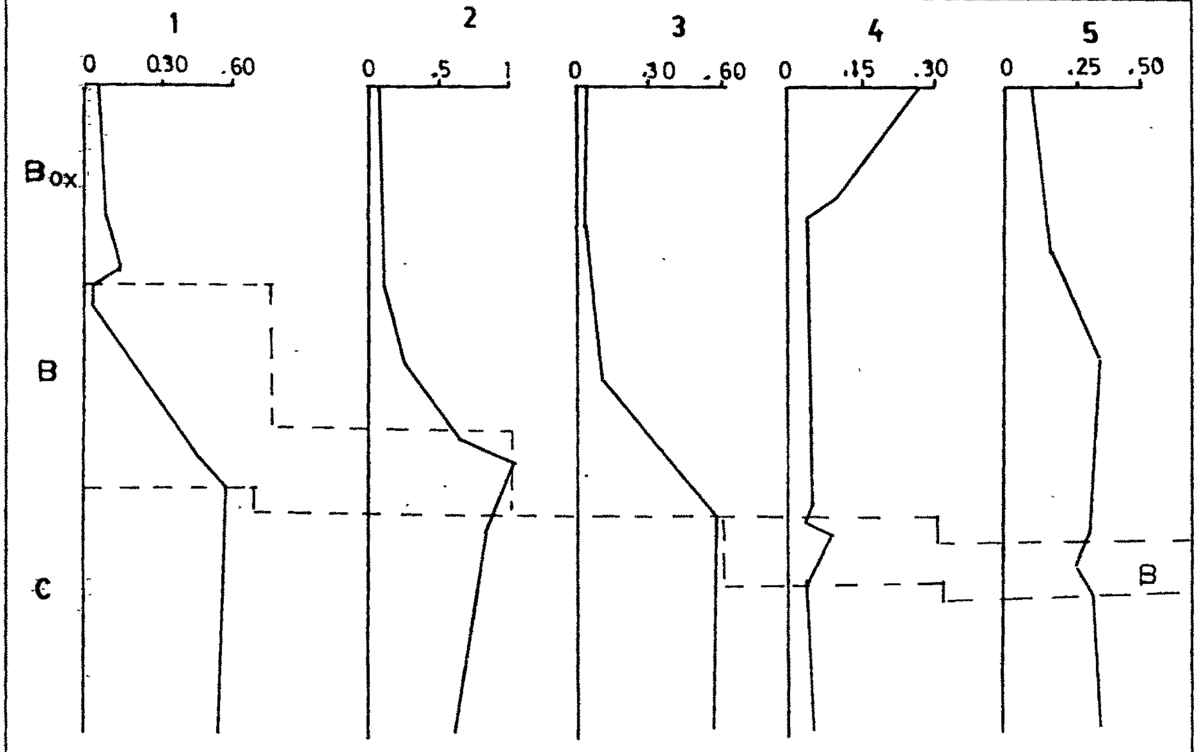
The high content of titanium is yet another important chemical feature. It ranges from 2.67 to 7.12 % in 'Box' horizon and between 1.20 and 4.92% in 'B' horizon. Anatase is the main contributor of titanium followed by rutile. TiO_2 shows a positive correlation with Al_2O_3.

In case of reworked laterite and bauxite the amount of titanium is seen to decrease as compared to the <u>insitu</u> laterite of nearby area, the former have a titanium content of 2.33 to 3.11 % (Fig. VI.9).



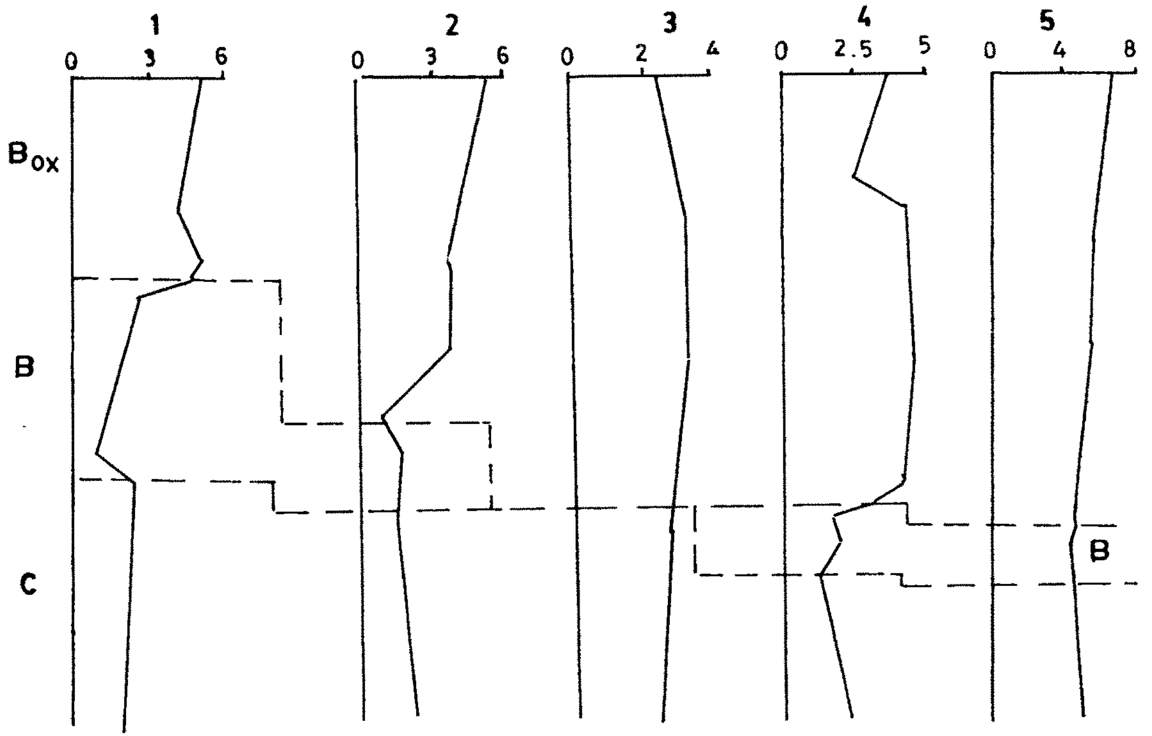
VARIATION DIAGRAM : Na_2O %

Fig: VI.7.



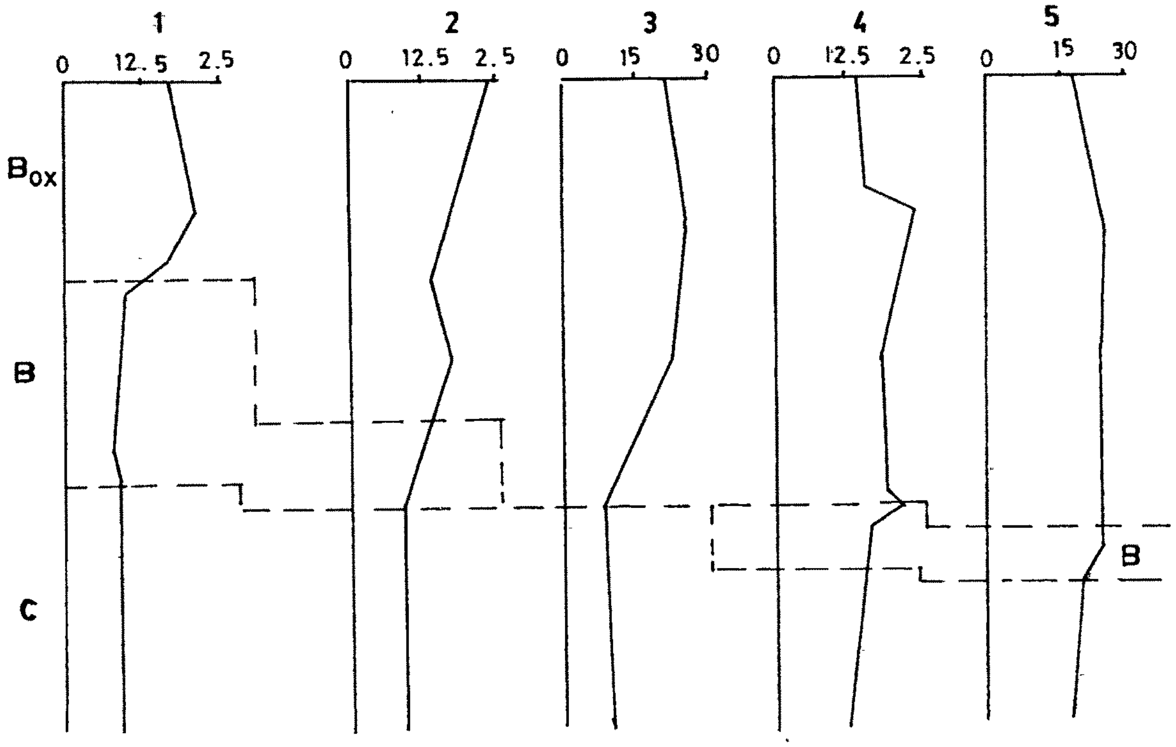
VARIATION DIAGRAM : K_2O %

Fig: VI.8.



VARIATION DIAGRAM : TiO_2 %

Fig : VI. 9.



VARIATION DIAGRAM : LOI % Fig: VI. 10.

Loss On Ignition (LOI)

The 'Loss on Ignition' is at the cost of gibbsite, goethite, kaolinite and montmorillonite. Some minor loss could be attributed to boehmite, halloysite and lepidocrosite. The values for the LOI ranges for laterite zone from 25.34 to 13.99% and for saprolite zone, 24.53 to 8.06 % respectively (Fig.VI.10). Though no well defined trend in LOI is observed, it can be generalised that the values are comparatively higher at the contact of Saprolite and laterite.

MAJOR OXIDE VARIATION

The trends of variation in the major constituents of laterites in all profiles from North to South Gujarat, shows the following characteristics :

i. Decrease of SiO_2towards the laterite zone

ii. Increase of Al_2O_3 in the kaolinite, bauxite and lateritic bauxite horizons.

iii. Gradual decrease in Fe_2O_3 in saprolite zone and enrichment in the top horizons viz., bauxitic laterite, unindurated laterite and duricrust.

iv. FeO behaves identical to that of Fe_2O_3in all the profiles.

v. Gradual increase of TiO_2 upward in the profile and enrichment in unindurated laterite and duricrust horizons.

vi. Enrichment of CaO in kaolinite and topmost portion of laterite zone.

vii. Depletion of MgO in laterite zone and its enrichment in bentonite horizon near the base.

viii. Depletion of Na_2O and K_2O in laterite zone and their enrichment in saprolite zone.

ix. Gradual increase of L.O.I. values in saprolite zone upto lateritic-bauxite contact and then a decrease further upwards.

MAJOR ELEMENT RATIOS

The bulk chemical ratios viz. (1) SiO_2/Al_2O_3 , (2) SiO_2/Fe_2O_3 , and (3) TiO_2/Fe_2O_3 and (4) TiO_2/Al_2O_3 for different horizons of the North Gujarat profile are presented in Table VI.1 and Fig.VI.11. In a general way, the various chemical values for SiO_2 /Al_2O_3, SiO_2/Fe_2O_3 and TiO_2/F_2O_3, show a decreasing trend towards upper horizons viz. bauxitic-laterite and duricrust, but in the kaolinite to bauxite horizons, the ratios show an increase. However in saprolite zone the ratios do not exhibit any well defined described trend. The ratio of TiO_2/Al_2O_3 is more or less constant right from weathered basalt to the ferruginous kaolinite horizons. Further up, it does not follow any trend.

The bulk chemical ratios of the South Gujarat profiles are presented in Table VI.2 and Fig. VI.12. The above ratios in different horizons show the same behaviour as that shown by North Gujarat profiles. In case of the ratio of TiO_2/Al_2O_3 to alumina, it is mostly constant throughout the profile in South Gujarat,

Table VI.1 Bulk Chemical Ratios of the Laterite Profile

(North Gujarat)

Horizon	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{TiO_2}{Al_2O_3}$	$\frac{TiO_2}{Fe_2O_3}$
Duricrust	0.44	0.30	0.24	0.16
Bauxitic laterite	0.84	1.11	0.18	0.23
Bauxite	1.47	2.20	0.26	0.38
Ferruginous Kaolinite	1.09	1.23	0.19	0.22
Bentonite	2.08	2.41	0.20	0.23
Weathered basalt	7.40	2.60	0.19	0.07
Fresh basalt	4.09	2.45	0.25	0.15

Table VI.2 Bulk Chemical Ratios of the Laterite Profile
(South Gujarat)

Horizon	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{TiO_2}{Al_2O_3}$	$\frac{TiO_2}{Fe_2O_3}$
Duricrust	0.57	0.14	0.57	0.14
Unindurated laterite	0.73	0.91	0.23	0.29
Lithomarge	1.35	3.46	0.23	0.60
Ferruginous Kaolinite	0.86	1.68	0.17	0.34
Transitional zone	1.02	1.76	0.17	0.29
Bentonite	1.09	1.49	0.18	0.24
Basalt	1.12	1.00	0.23	0.21

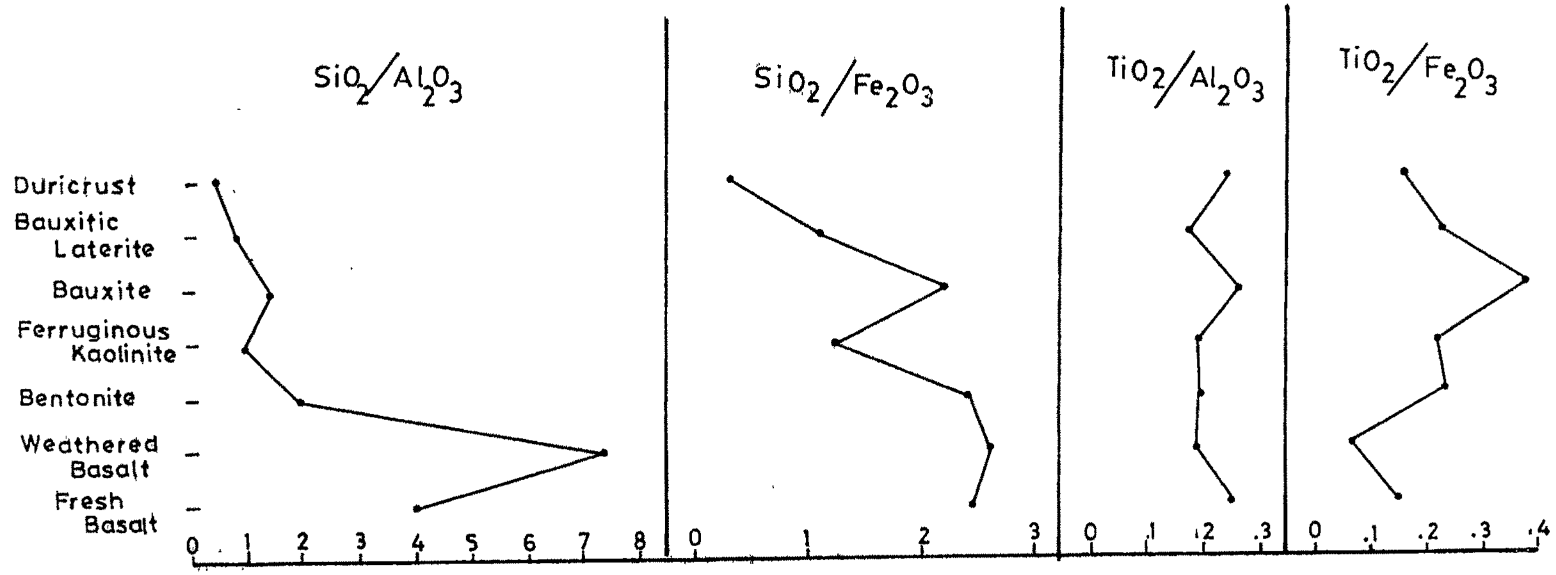


Fig: **VI.11.** Ratios of Bulk Chemical Constituents in the North Gujarat Profiles (Average Values)

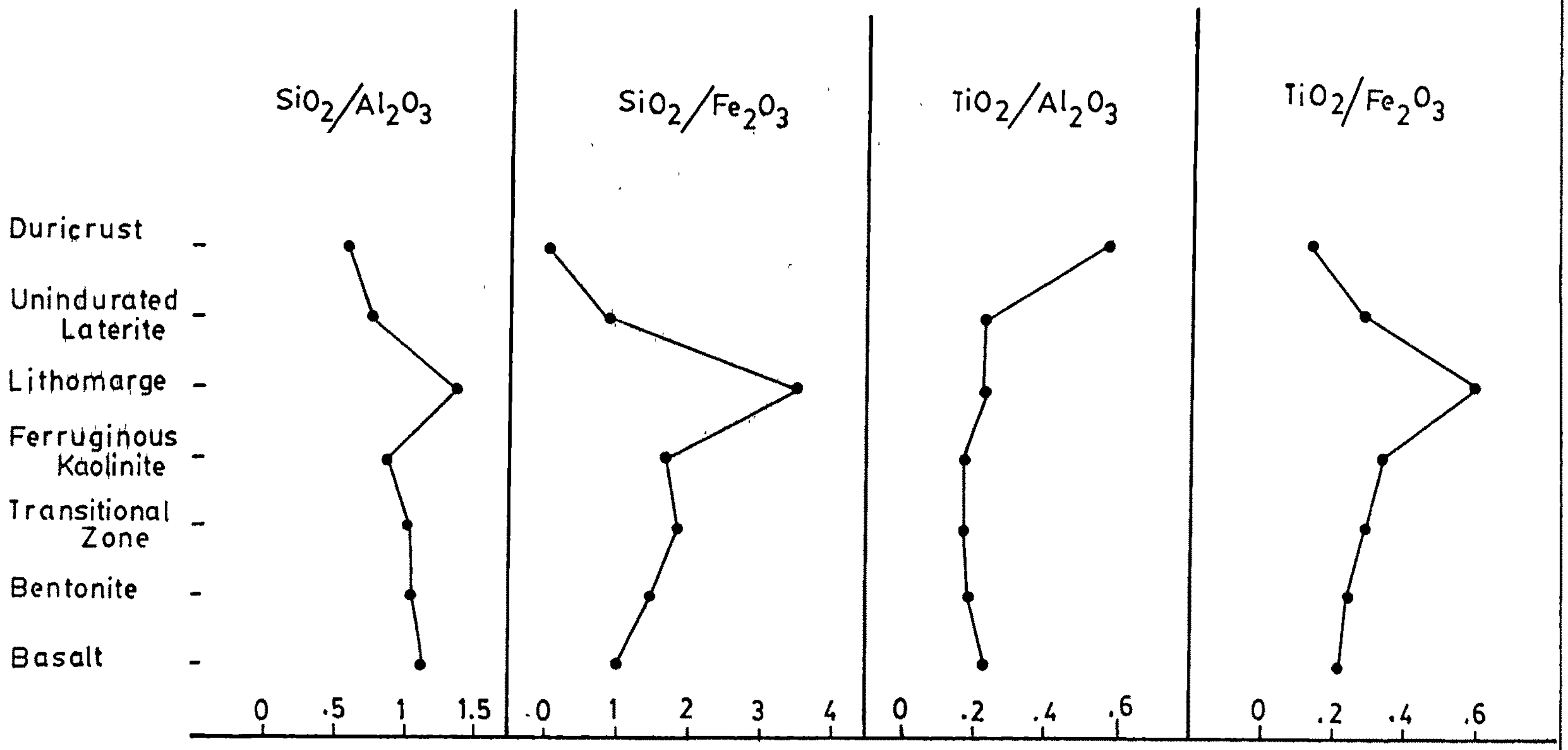


Fig: VI.12. Ratios of Bulk Chemical Constituents in the South Gujarat Profiles (Average Values) excepting a sharp increase in the uninduarated laterite to duricrust.

Alteration Trend of $SiO2$ - Al_2O_3- Fe_2O_3System

The average values of Sio_2 , Al_2O_3 and $Fe_2O_3$of the parent rock (basalt) and the mean values for the same constituents of laterite profiles are plotted (Fig. VI.13) in the triangular diagram of Schellmann (1986).

The diagram indicates a process of disilicification and an increase in alumina as well as iron. The diagram also shows that the alteration trend for Mainland Gujarat closely corresponds with those obtained for lateritic weathering of basalt from some other parts of the world (Schellmann, 1977,1981,1986).

Classification based on SiO_2- Al_2O_3- Fe_2O_3diagram

Schellumann (1989) has classified laterites by considering the .different parameters like composition, metal content, physical properties, correlations with terrain, etc. But he has preferred to classify the rock on the basis of SiO_2- Al_2O_3-Fe_2O_3 diagram, which ideally provides the chemical characteristics of the rock and categorises it from the point of view of intensity of lateritisation. In his SiO_2-Al_2O_3-Fe_2O_3diagram the laterites are subdivided (on the basis of the decreasing relative SiO_2 contents) into three equidistant fields corresponding to weak, medium and strong lateritisation.

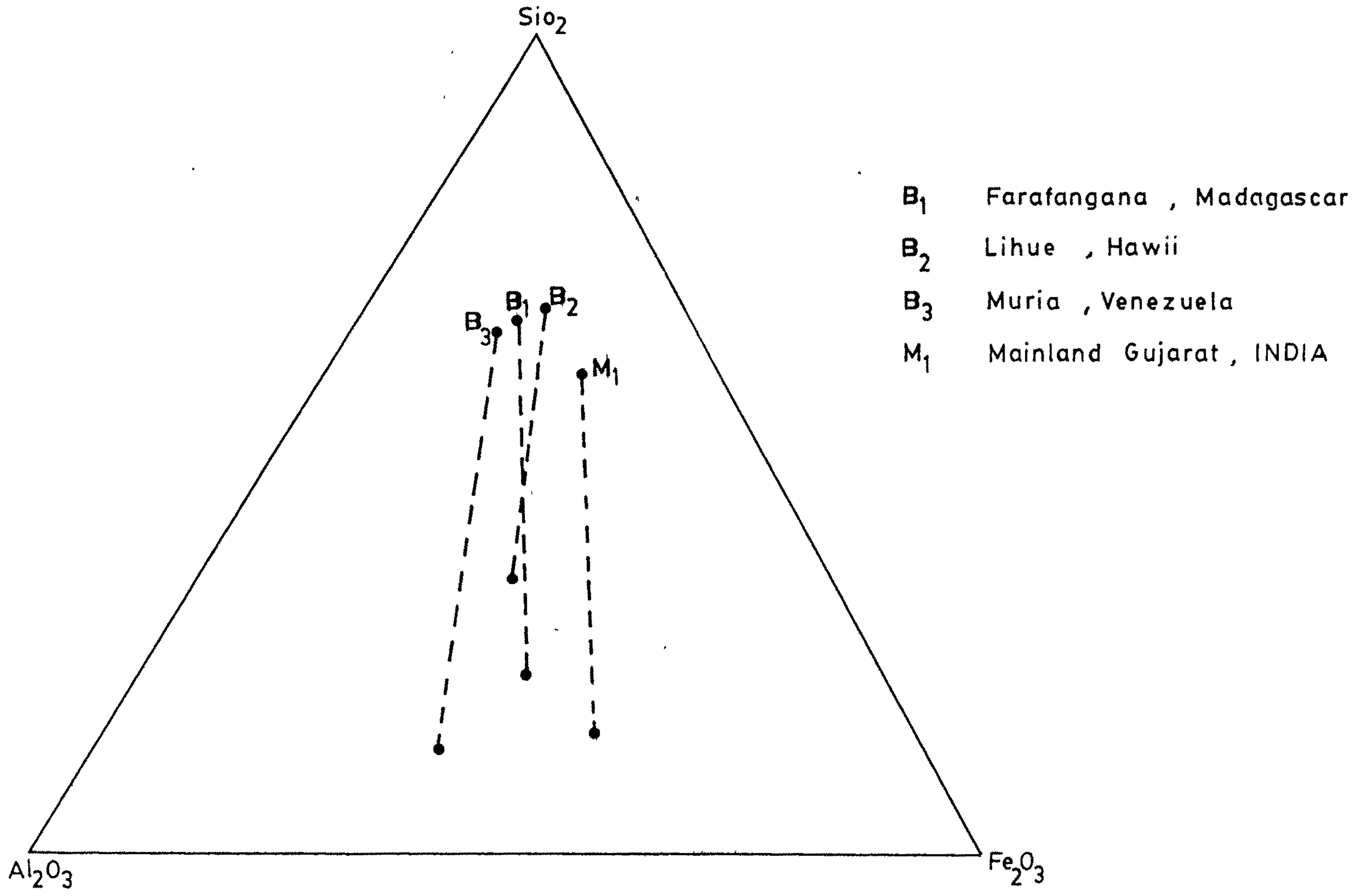


Fig: **VI.13.** CHANGES IN Al_2O_3, Fe_2O_3 AND SiO_2 CONTENTS OF BASALTIC ROCKS DURING LATERITIC TRANSFORMATION

The chemical data of the Mainland laterite have been plotted by the present author on Schellmann diagram (Fig.VI.14) and it is observed that the intensity wise the lateritization in Mainland Gujarat falls within the fields of weak to moderate lateritisation.

Chemical Correlation trends : Fe_2O_3/ Al_2O_3v/s LOI

The variation diagram showing plots of Fe_2O_3vs LOI shows a characteristic negative trends both in the laterite zone as well as the saprolite zone (Fig.VI.15) whereas the plots of Al_2O_3 vs LOI show a positive trend in all the profiles (Fig. VI.16).

Obviously, the Fe and Al enrichment have been respectively inversely proportional to the concentration of water molecules.

The positive correlation is typically indicative of these elements having been introduced from elsewhere, and negative correlation shows removal of element from the profile.

TRACE ELEMENTS

The trace elements occur as solid solution substitutions to the major elements in different minerals and that the substitution is controlled by the ionic radius, ionic charge and coordination numbers of the replacing and the replaced ions. The significance of trace elements behaviour during rock alteration has been discussed by several investigators (Goldschmidt, 1937;

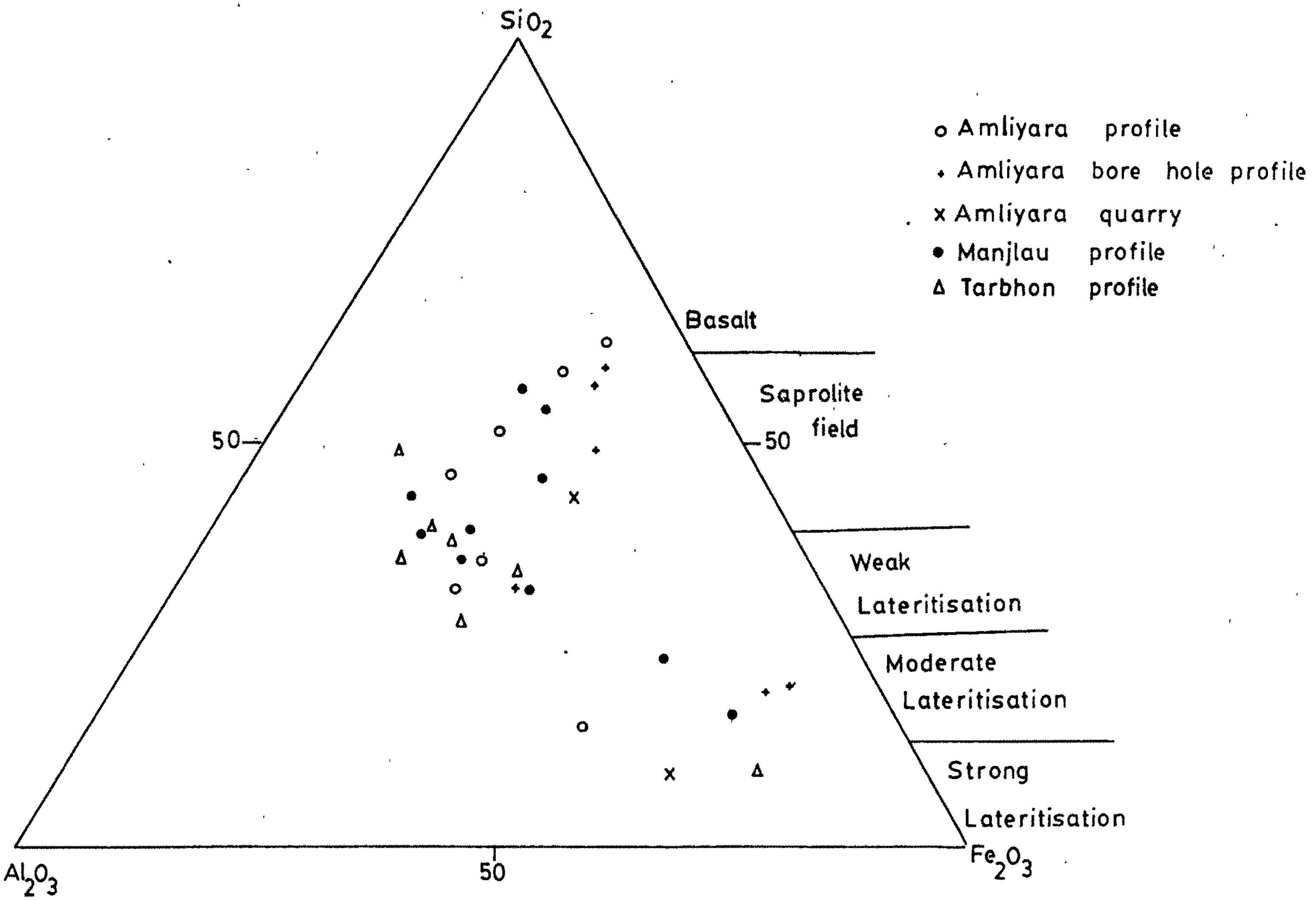
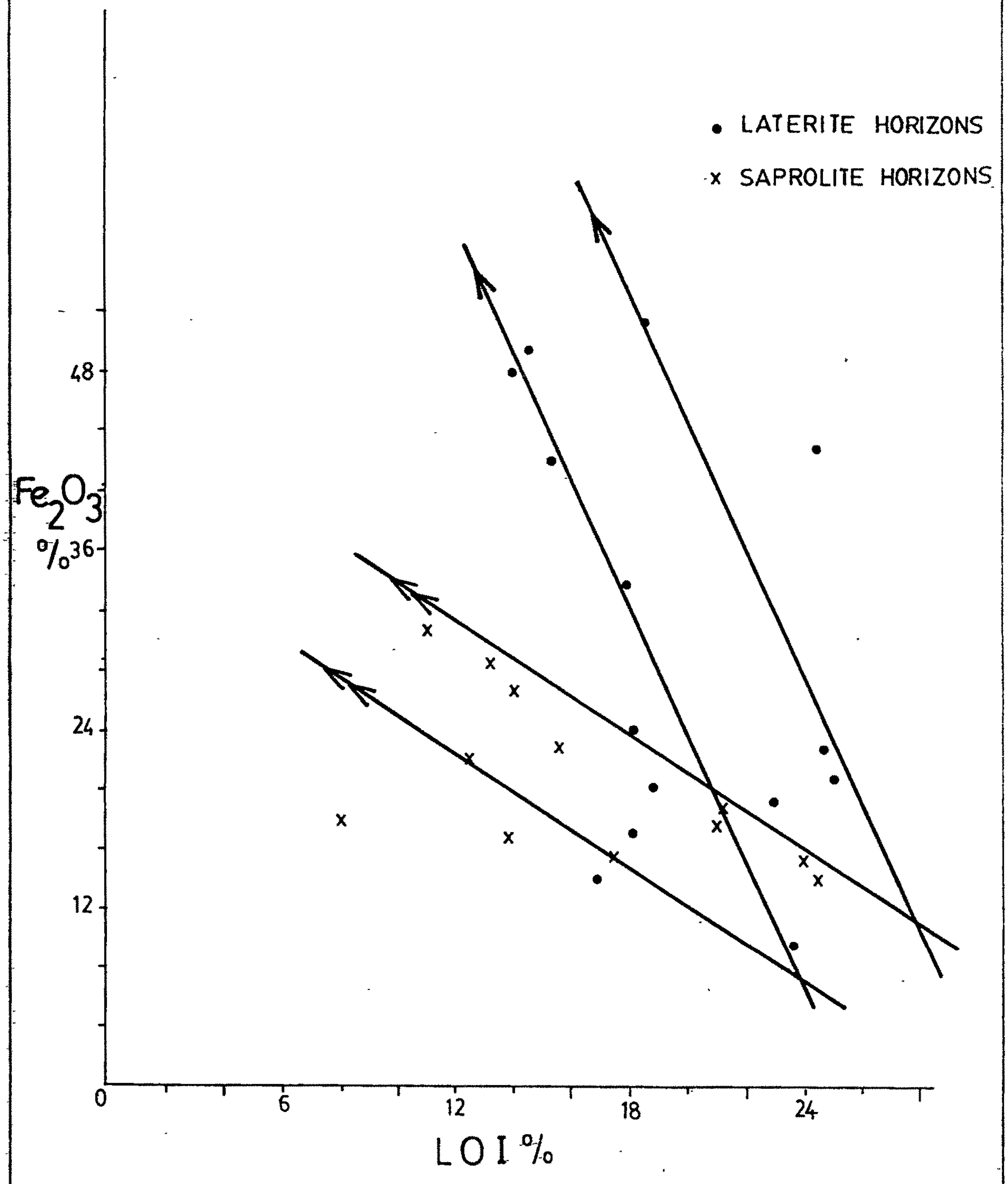


Fig: **VI.14.** FIELDS OF BASALT ALTERATION IN THE SiO_2—Al_2O_3—Fe_2O_3 DIAGRAM

Fig: VI.15. VARIATION DIAGRAM: Fe_2O_3 VS L.O.I



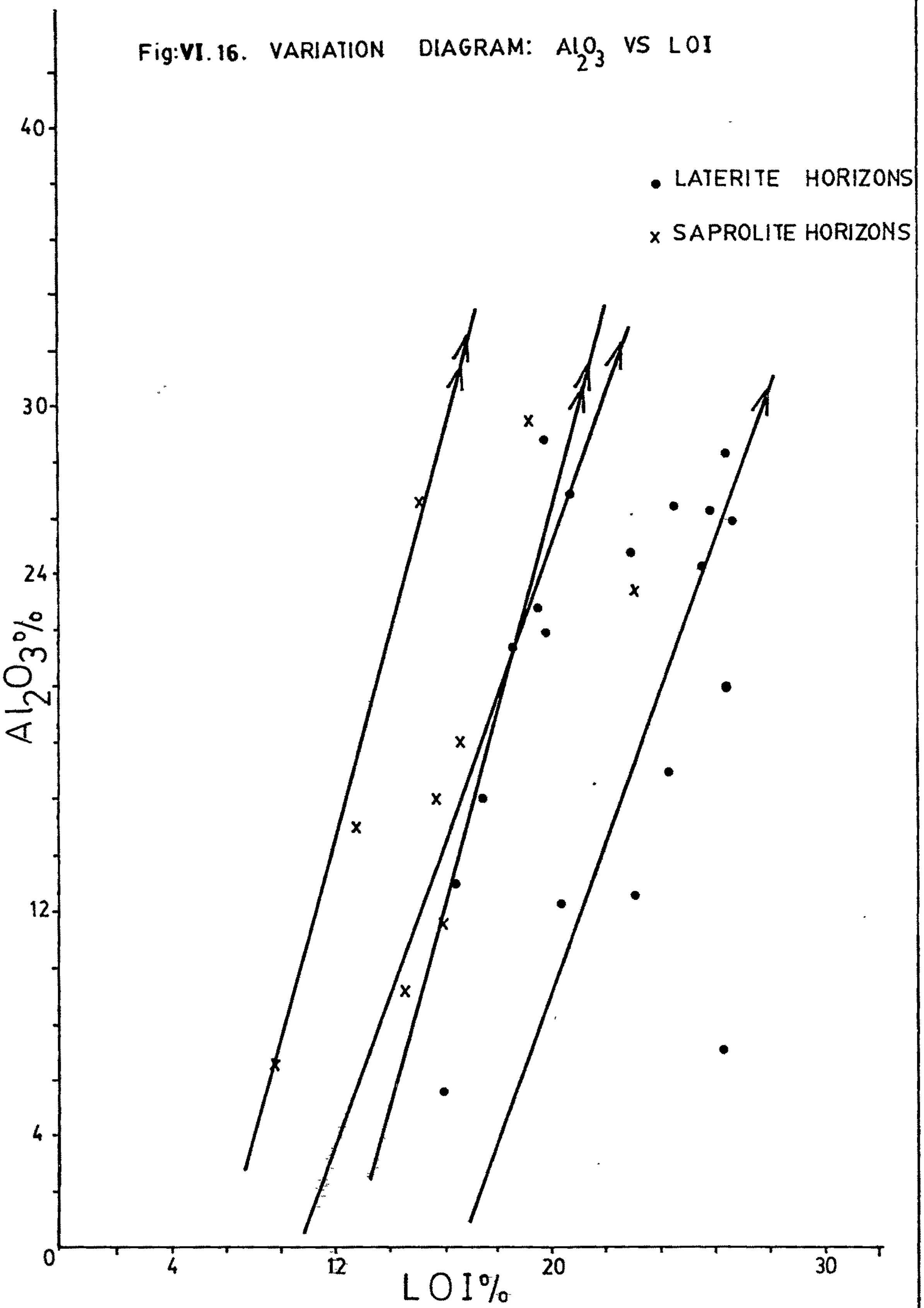


Fig:VI.16. VARIATION DIAGRAM: Al_2O_3 VS LOI

Gordon and Murata, 1952; Valeton, 1972; Norton, 1973; McFarlane,1976; Sahasrabudhe 1978; Khandali, 1982; Esson 1984, Banerjee 1986, 1989; Banerji, et al (1988); Devaraju and Khanadali (1983); Khanadali and Devaraju (1987); Esson and Carlos (1978) Balasubramanian, 1987; Soman & Slukin, 1987; Schellmann, 1986, 1989).

The behaviour of each element during inorganic chemical alteration is explained by the concept of ionic potential (Cartledge, 1928). The elements can be grouped according to their ionic potential (Z/r i.e. ionic charge or valency/ionic radius) as shown in Fig. VI.17 (Goldschmidt, 1937; Gordon and Murata, 1952). The groups fall into three principal fields, separated by lines of equal ionic potential z/r. Group I consists of elements with z/r upto 3.0 and which remain in ionic solution during chemicl alteration and transportation and form basic oxides. Group II elements have Z/r between 3.0 and 9.5 which are amphoteric and form both basic and acid oxides. The ions of these are associated with hydroxyl radicals from aqueous solutions. In Group III, elements with ionic potential between 9.5 and 12.0 are included; these elements are beyond the upper limit of the elements concentrated in laterite.

The concentration ratios of the trace elements in the different zones of the five profiles were compared with those of the source rock (basalt). The ratios of concentration or depletion for each element have been obtained by dividing its

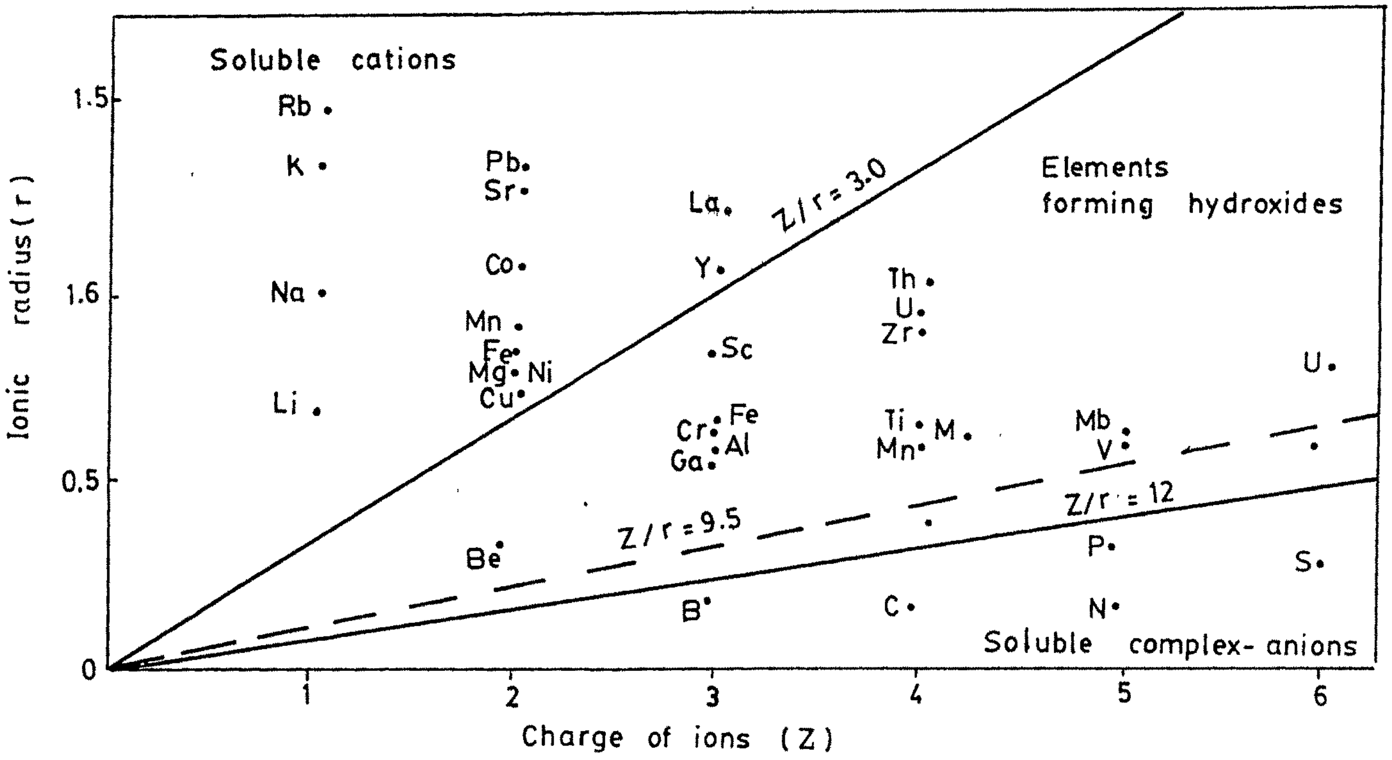


Fig: **VI.17.** RELATION OF IONIC POTENTIAL AND HYDROXIDE FORMATION

(After Goldschmidt, 1937)

content in the horizon with its content in the basalt; following the method used by Gordon and Murata (1952) and Wolfenden (1965).

The concentration ratios for major and trace constituent in various profiles are given in Tables VI. 3, 4, 5 and 6. The variation diagrams showing the plots of these values Fig.VI Nos. 18,19,20 and 21, ideally reveal the trends of the behaviour of the various constituents. It is seen that Fe, Al and Ti ratios more or less behave in identical manner, showing an increase in the laterite zone. The behaviour of Na, K, Si and Ca, on the other hand points to a fall in the values from lithomarge to laterite horizons. Only Mg indicates a steady decrease in the values upwards. So far as the trace elements are concerned, all of them, by and large, show identical behaviour. They point to an initial increase in the transitional zone, then the values go down towards lithomarge, and finally increase in the laterite horizon.

The concentration ratios Zr, Cr, Co, V when compared to the parent rock (basalt) show enrichment in most profiles in ratios ranging between 1.02 to 1.42. This points to the fact that the concentration of all these elements in upper portion is not only from source rock (basalt) but also it is from lateral movement and migrations of these lements from nearby area. Topography differences (depressions in peneplain) the subsurface water - table gradient and level differences in Eh and pH, have been the factors responsible for the lateral migration of these elements.

TABLE VI.3 Ratios of concentration/depletion of major oxides in different horizons of laterite profiles compared with basalts (North Gujarat)

	Duricrust	Bauxitic laterite	Bauxite	Kaolinite	Bentonite	Basalt
Fe	2.71	1.60	0.73	0.54	0.68	1
Al	2.13	2.43	2.99	0.96	0.87	1
Ti	1.99	1.69	2.01	1.88	1.09	1
Ca	0.90	0.33	0.94	0.08	2.65	1
Si	0.23	0.50	0.71	0.66	0.70	1
Mg	0.12	0.18	0.09	0.18	0.34	1
Na	0.20	0.29	0.38	0.32	0.26	1
K	0.08	0.15	0.25	0.05	0.05	1

TABLE VI.4 Ratios of concentration/depletion of trace elements in different horizons of laterite profiles compared with basalts (North Gujarat)

	Duricrust	Bauxitic laterite	Bauxite	Kaolinite	Bentonite	Basalt
Mn	5.18	4.32	3.95	2.41	1.86	1
Co	1.50	1.19	1.42	1.60	1.42	1
Zn	1.22	1.02	1.10	1.16	1.10	1
Pb	1.19	1.05	1.41	1.36	1.36	1
Cr	1.09	1.21	1.15	1.17	1.07	1
Zr	1.06	1.03	1.00	0.94	0.90	1
Ni	0.91	0.77	0.14	0.93	1.04	1
Cu	0.86	1.02	0.84	0.65	0.83	1
V	0.75	1.36	0.97	1.31	1.30	1

TABLE VI.5 Ratios of concentration/depletion of major oxides in different horizons of laterite profiles compared with basalts (South Gujarat)

	Laterite	Lithomarge	Kaolinite	Transitional zone	Bentonite	Basalt
Fe	2.85	0.89	0.59	0.61	0.73	1
Al	1.66	1.09	0.87	0.96	0.90	1
Ti	1.17	1.10	0.95	0.87	0.85	1
Ca	1.21	2.09	1.61	1.57	2.00	1
Si	0.76	1.31	0.97	1.06	1.07	1
Mg	0.21	0.16	0.16	0.60	1.15	1
Na	0.19	0.29	0.67	0.71	0.94	1
K	0.50	1.00	0.89	0.75	0.92	1

TABLE VI.6 Ratios of concentration/depletion of trace elements in different horizons of laterite profiles compared with basalts (South Gujarat)

	Laterite	Lithomarge	Kaolinite	Transitional zone	Bentonite	Basalt
Mn	1.14	1.29	1.43	1.71	1.14	1
Co	1.55	1.17	1.98	1.55	1.70	1
Zn	0.80	0.30	0.98	1.20	1.02	1
Pb	0.74	0.63	1.06	0.63	1.37	1
Cr	1.42	1.45	0.89	1.08	1.19	1
Zr	2.68	2.18	1.69	1.41	1.07	1
Ni	1.43	0.59	1.18	0.83	0.88	1
Cu	1.13	1.95	1.15	1.15	0.62	1
V	1.52	1.15	1.37	0.94	1.16	1

Fig: **VI.18**. Variation trends of various major oxide ratios in different profiles (North Gujarat)

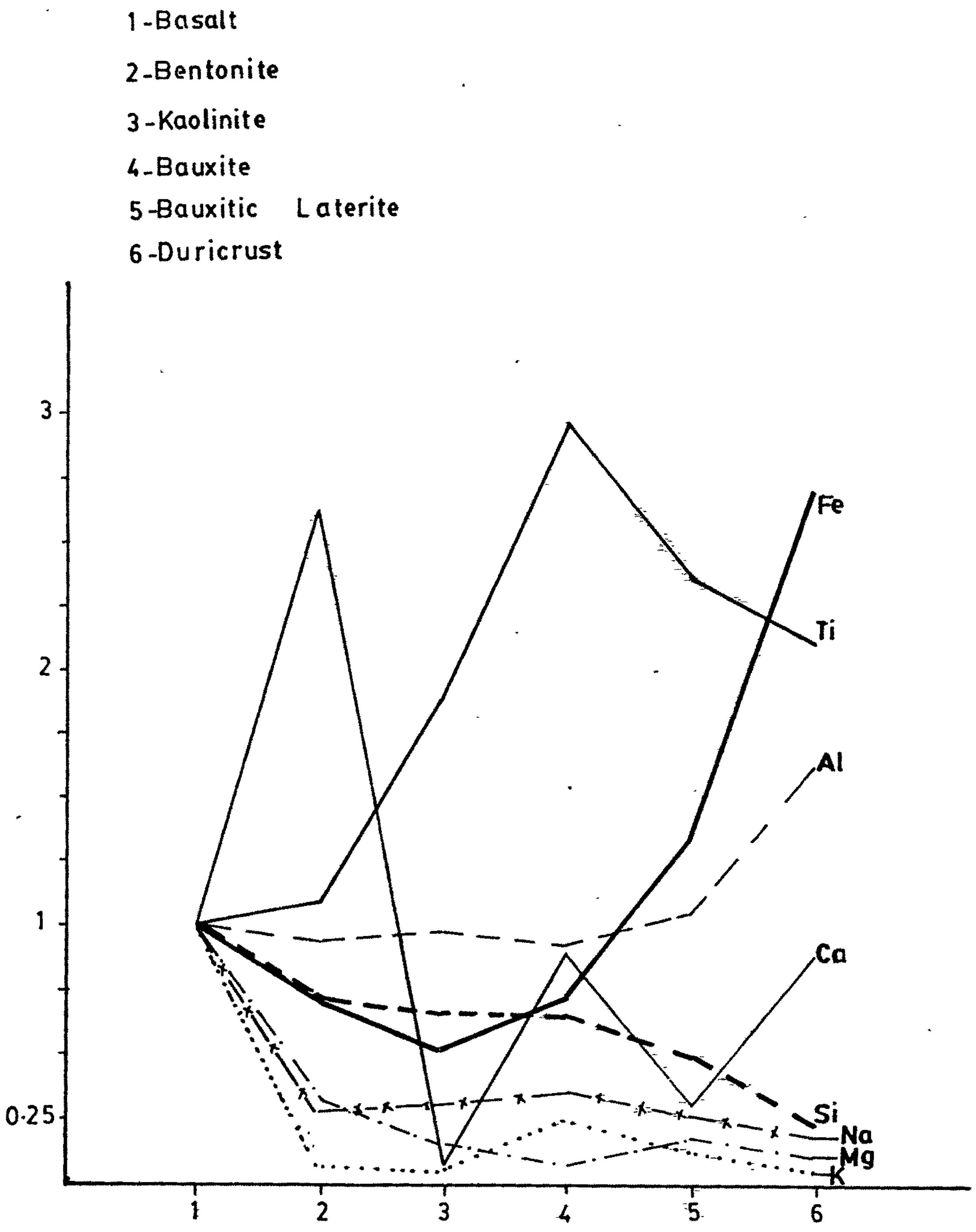


Fig: VI.19. Variation trends of various trace element ratios in different profiles (North Gujarat)

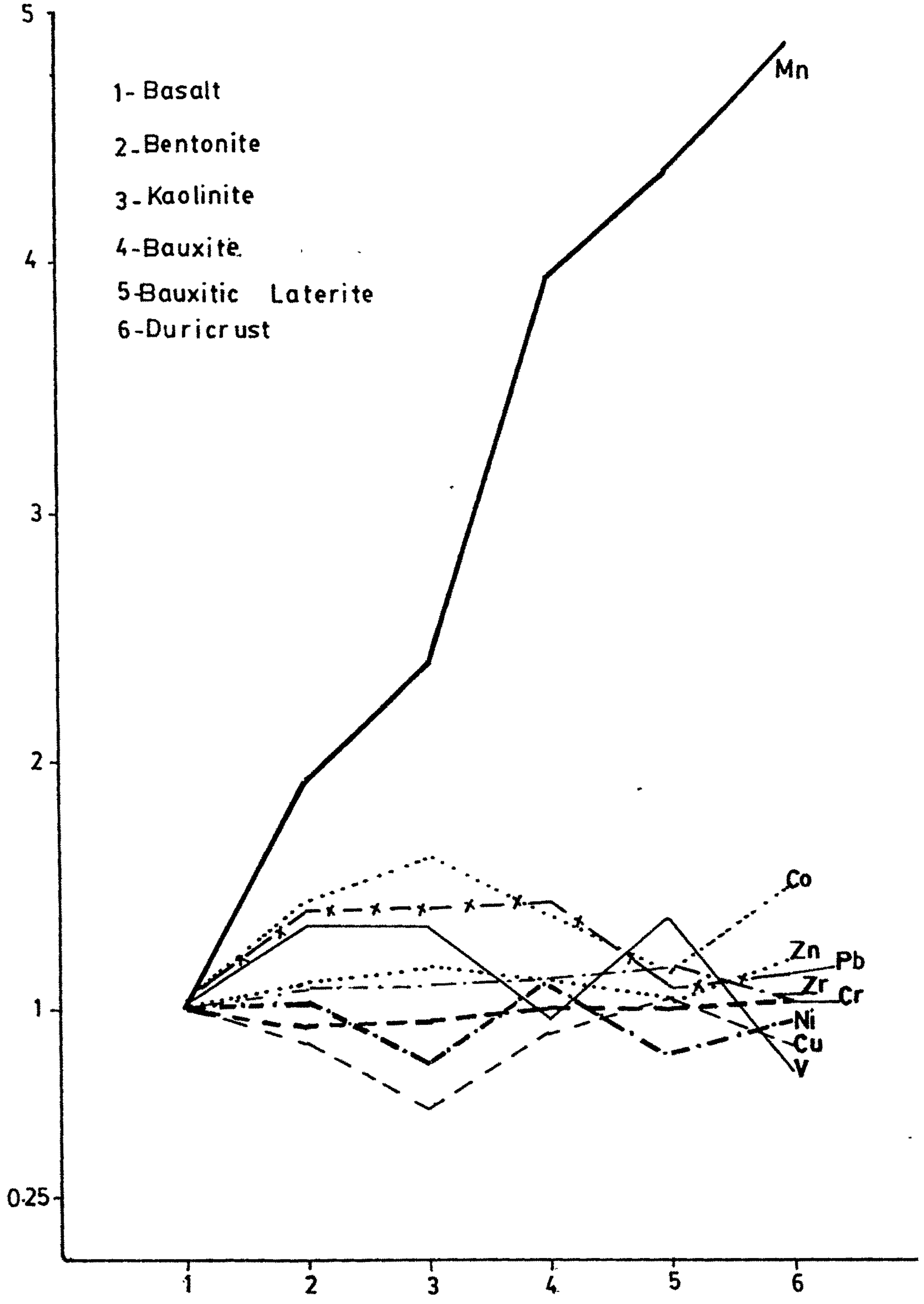


Fig:VI.20. Variation trends of various major oxide ratios in different profiles (South Gujarat)

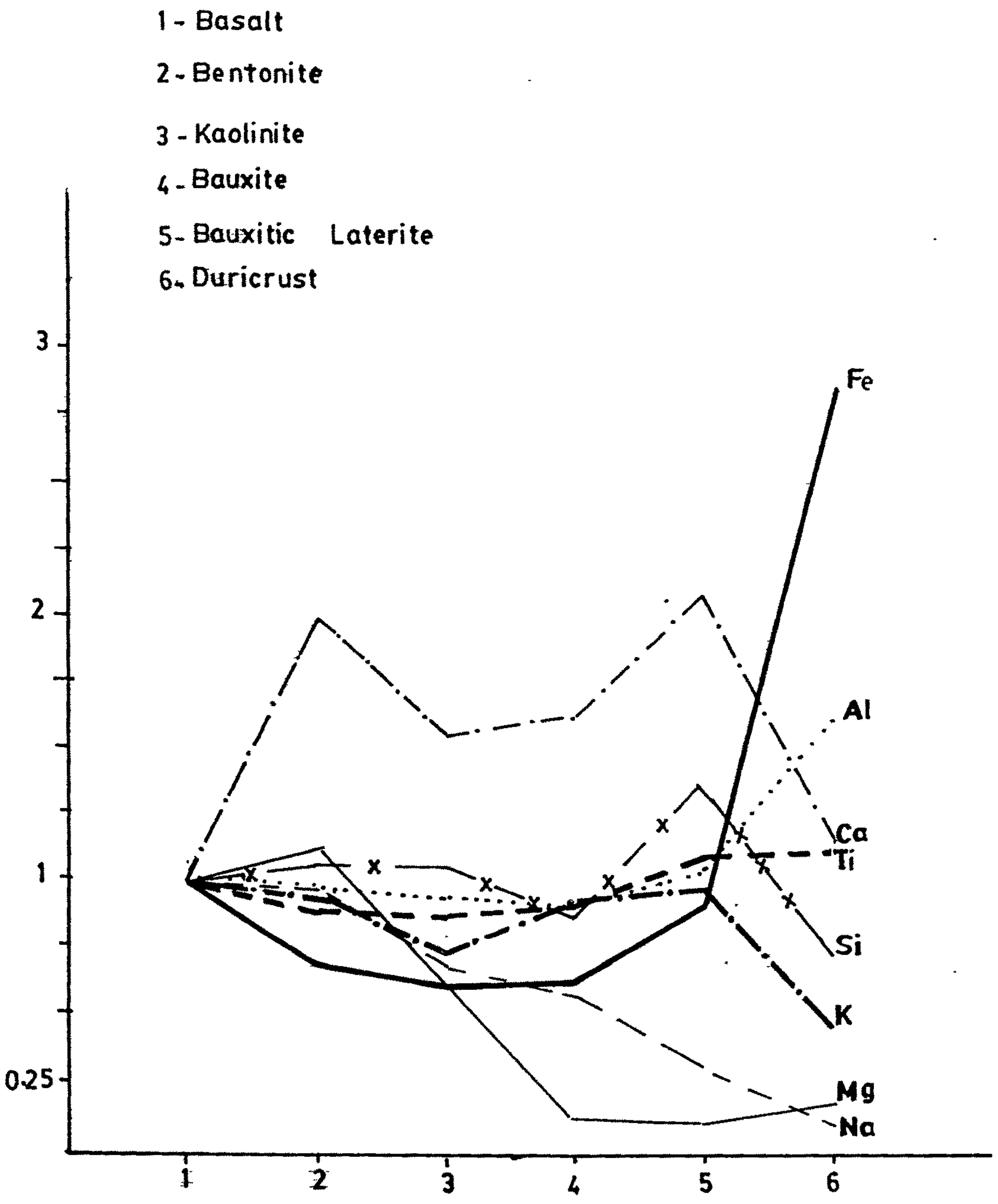
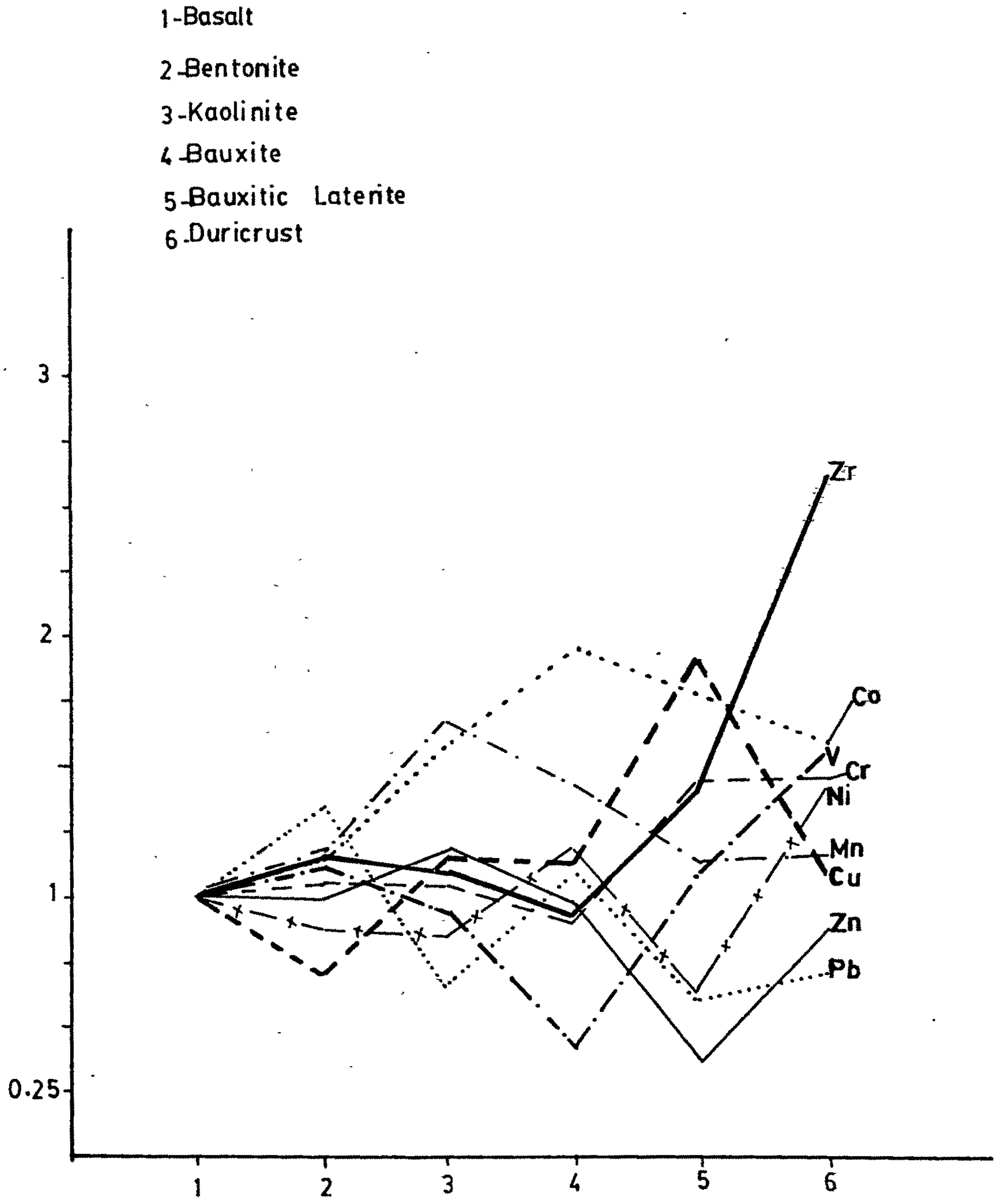


Fig:VI.21. Variation trends of various trace element ratios in different profiles (South Gujarat)



It is not unlikely that the intensity and directions of joints and fractures, also played their due role in this process of lateral movement of constituents.

The behaviour of individual trace elements during the process of lateritisation is given below :

Manganese

The known distribution of Mn in igneous rocks (Rankama and Sahama, 1949) indicates that almost all the Mn in the parent rocks occurs in the ferromagnesian minerals with Mn^{2+} replacing Fe^{2+} Manganese occurs in laterite in various mineralogical forms, lithophorite and birnessite being most common, and hollandite and tadorakite less so (Taylor and Mckenzie, 1964).

In several respects manganese behaves similarly to iron. Both are readily oxidized, form soluble organic complexes (Heintze and Mann, 1947), and may be precipitated by bacteria (Tihel, 1925). The enrichment of manganese in topmost horizon is reported by Valeton, 1972; Norton, 1973 and Oti, 1987.

In the study area, the manganese shows enrichment in the topmost horizons of the laterite profiles. This element behaviour is however different in Manjlau profile, where it shows a decrease in its amount in the duricrust horizon (Fig. VI.22).

INDEX

1 . Amliyara Profile

2 . Amliyara Bore Hole Profile

3 . Amliyara Quarry

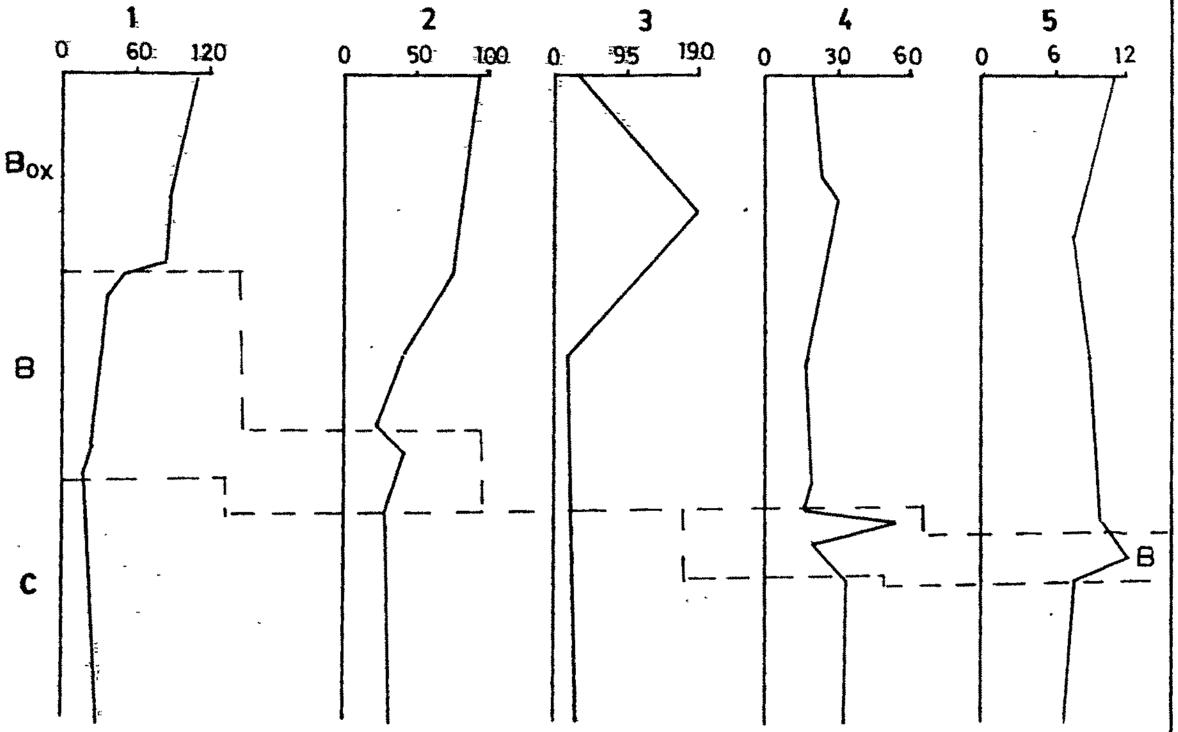
4 . Manjlau Profile

5 . Tarbhon Profile

B_{ox} – Laterite Zone

B – Saprolite Zone

C – Parent Rock



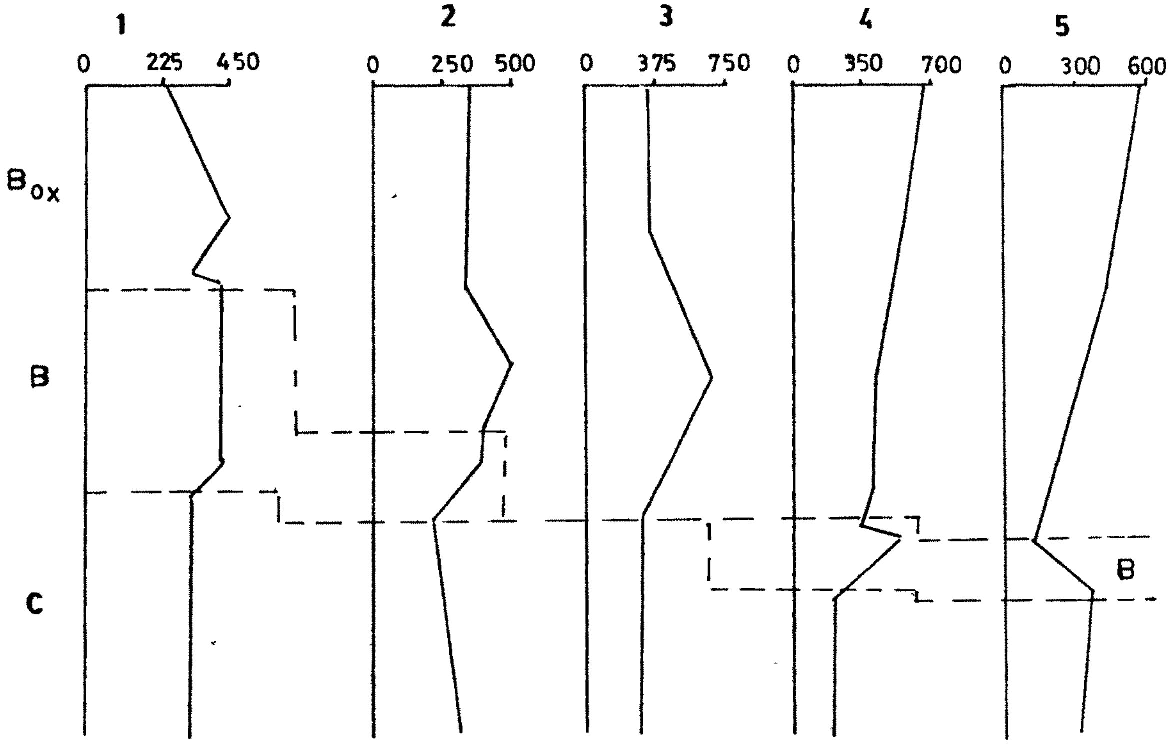
VARIATION DIAGRAM : Mn ppm Fig: VI.22.

This anomalous behaviour of Manganese has been attributed to a higher amount of $CaCO_3$ by Balsubramanian (1987).

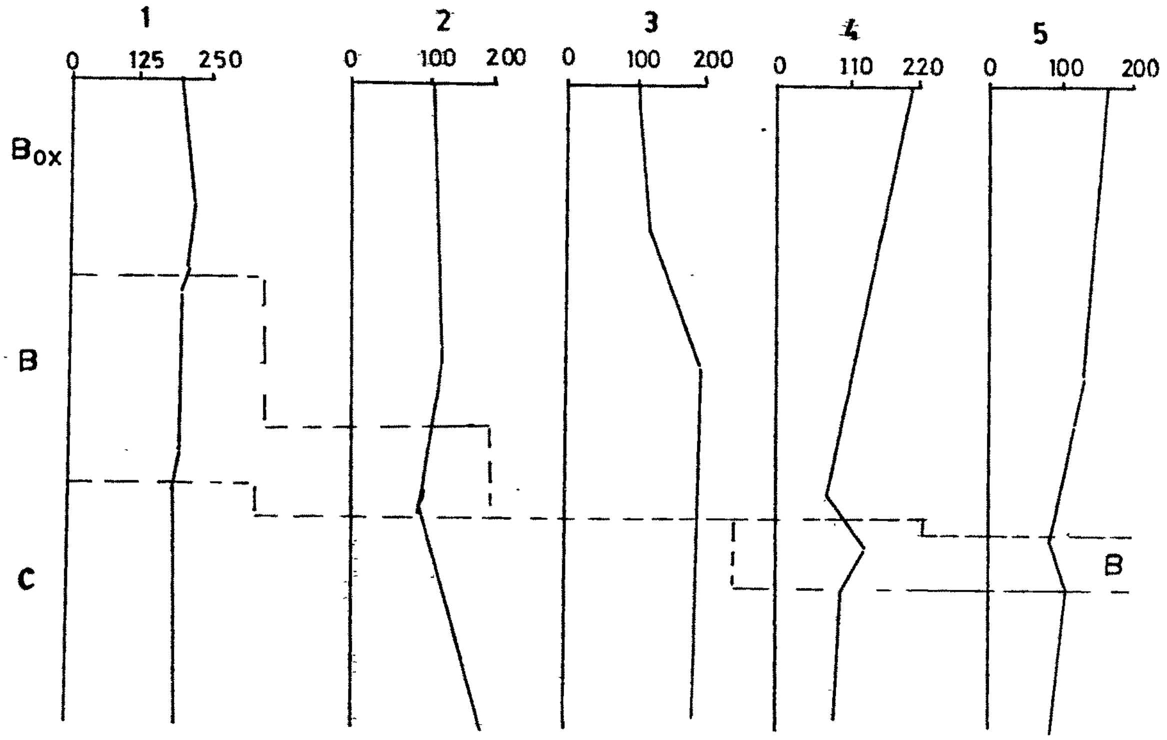
Vanadium

Vanadium shows more or less a uniform concentration (with some variations) in all the horizons of the laterite profile from bentonite to duricrust though there is distinct increase upward. The maximum concentration is observed in duricrust 672 ppm and as low as 117 ppm in ferruginous kaolinite horizon. Vanadium occurs in augite olivine and iron ores (magnetite) of the parent Deccan basalt. Rankama and Sahama (1949) and Goldschmidt (1954) have shown Vanadium to be common in magmatic magnetite, V^{3+} (0.65 Å) readily replacing Fe^{3+} (0.67 Å). Goldschmidt (1954) states that the Vanadium ions removed from the augite during the alteration processes remain in solution over a wide pH range and may be locally precipitated by the presence of ferric hydroxide. This suggests that the high ferric hydroxide content of the unindurated laterite and duricrust may be responsible for the high Vanadium content.

High Vanadium content and its enrichment upward is reported by others also (Valeton, 1972; Rao and Krishnamurthy, 1981; Shukla et al, 1983). Interestingly the interstitial clay material between boulders of reworked laterite shows high concentration (712 ppm) of Vanadium (Fig. VI.23).



VARIATION DIAGRAM : V ppm Fig: VI.23.



VARIATION DIAGRAM : Cr ppm Fig: VI. 24

Chromium

Chromium is probably present in iron ores and plagioclase as Cr -O complexes in the tetrahedral positions (Ringwood, 1955). This is an extremely resistant mineral (de Vletter, 1955) and its small quantities have been recorded in laterite by various authors (Valeton, 1972; McFarlane, 1976; Rao and Krishnamurthy, 1981; Oti, 1987). Iron and chromium have been observed to behave similarly in the profile (Frasche, 1941; McFarlane, 1969) both increasing upwards as silica shows decreased trend in its amount.

According to the MaLaughlin 1959 most of the chromium in the laterite profile occurs either in kaolinite zone or in the iron rich zone, but no such correlation between the contents of kaolinite and chromium is discrenible in the present samples.

The present author has recorded its maximum concentration in bauxitic laterite horizon (224 ppm) and minimum in kaolinite horizon (73 ppm). Their degree of enrichment in upper horizon is different in North and South Gujarat. In North Gujarat its behaviour is mostly constant in laterite zone (Box) as compared to its enrichment in the same zone in South Gujarat (Fig. VI.24).

Zircon

Zircon is regarded as a resistant index mineral (Tiller, 1963), and is set apart from any of the major elements of igneous rock due to the combination of high charge and radius. It behaves like titanium.

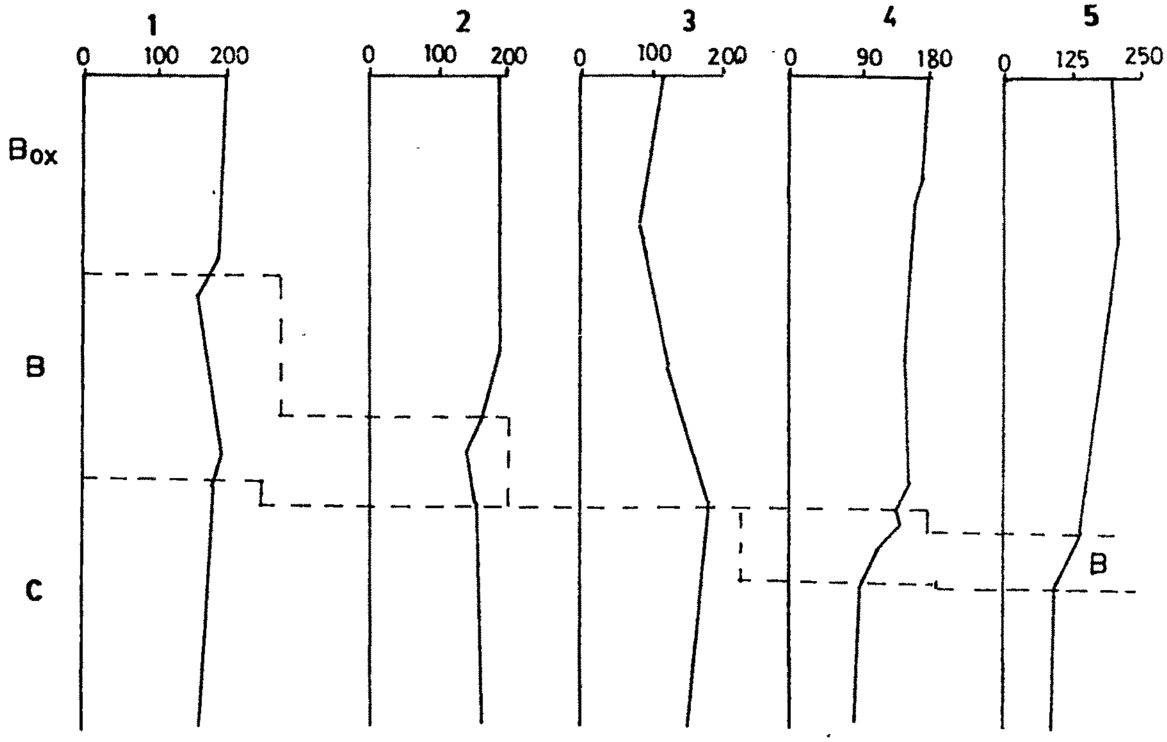
It's enrichment upwards is evidenced in all profiles from North and South Gujarat. The enrichment of Zircon in the upper portions of profiles has been reported by others also, viz., Valeton, 1972; Nayak, 1981; Rao and Krishamurthy, 1981; Nair and Mathai, 1981.

The maximum and minimum amount of Zircon is 217 to 81 ppm in laterite profile. The enrichment of Zircon is observed in laterite zone (Box) and its comparative depletion in saprolite zone (B). Reworked laterite and bauxite show decrease in proportion i.e. 114 ppm and 85 ppm only (Fig. VI.25).

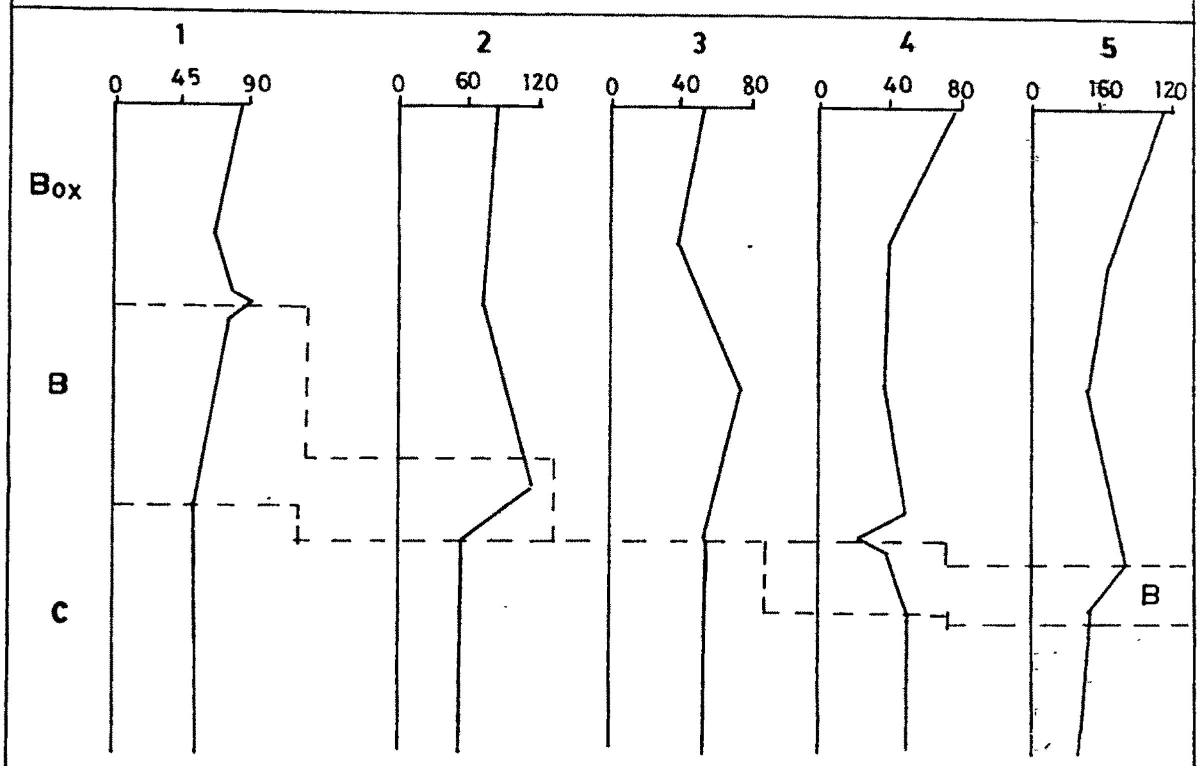
Cobalt

Cobalt is incorporated in the ferromagnesian minerals of the parent rock (Carr and Turekian, 1961). These minerals are converted to goethite and lepidocrosite, which would be the only minerals to contain cobalt in the different horizons of the laterite profile.

As it could be seen in North and South Gujarat profiles, there is a similarity between the concentration patterns of Cobalt and iron, and the upper portions of laterite zone viz. duricrust, unindurated laterite and bauxitic laterite show a relative concentration of cobalt (Fig. VI.26).



VARIATION DIAGRAM : Zr ppm Fig: VI. 25.



VARIATION DIAGRAM : Co ppm Fig: VI. 26.

Nickel

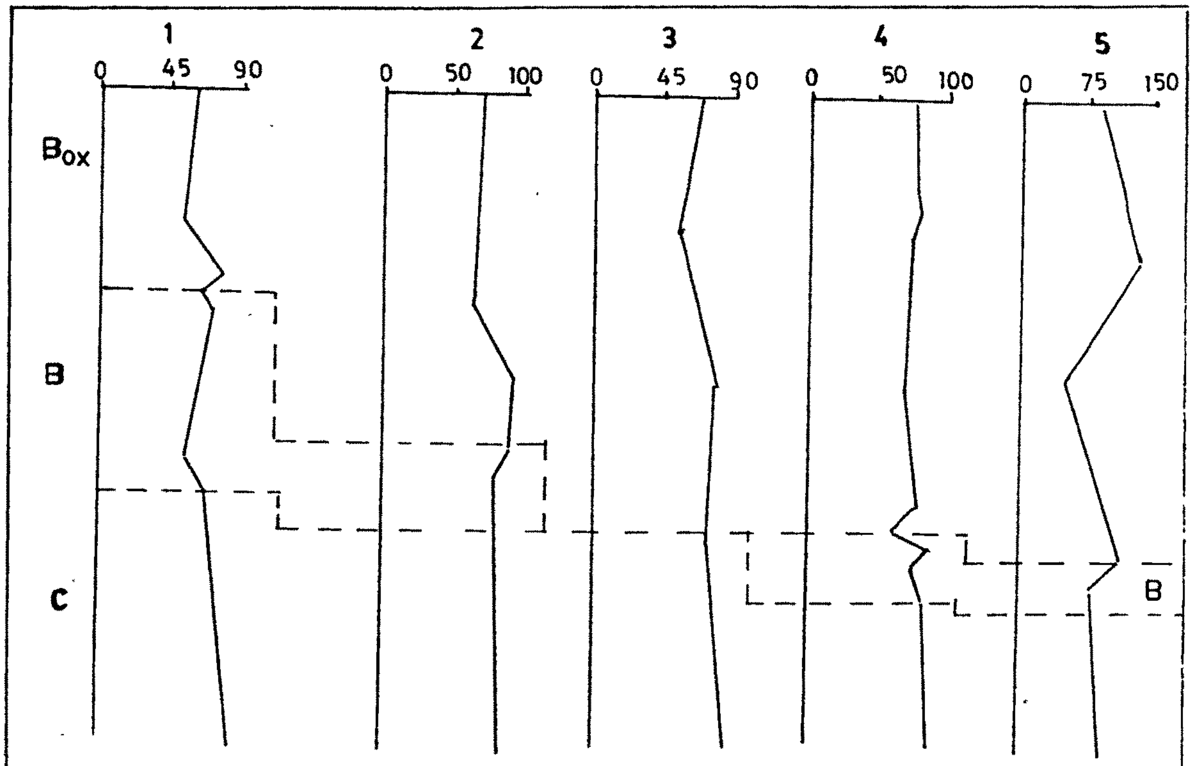
Most of the nickel in the parent rock is present in the ferromagnesian minerals like olivine and pyroxene (Rankama and Sahama, 1949; Goldschmidt, 1954).

In a laterite profile, Nickel occurs as hydrated nickel silicates (Fisher, 1958; de Vletter, 1955) and is concentrated near the bottom of the profile (Frasche 1941; Fisher, 1958; de Vletter, 1955). Nickel at the top of the profile goes into solution. However, the solutions do not travel far, but upon reaching a horizon where magnesia and silica are available, at the near base of profile, the nickel is redeposited (Fisher 1958; de Vletter, 1955).

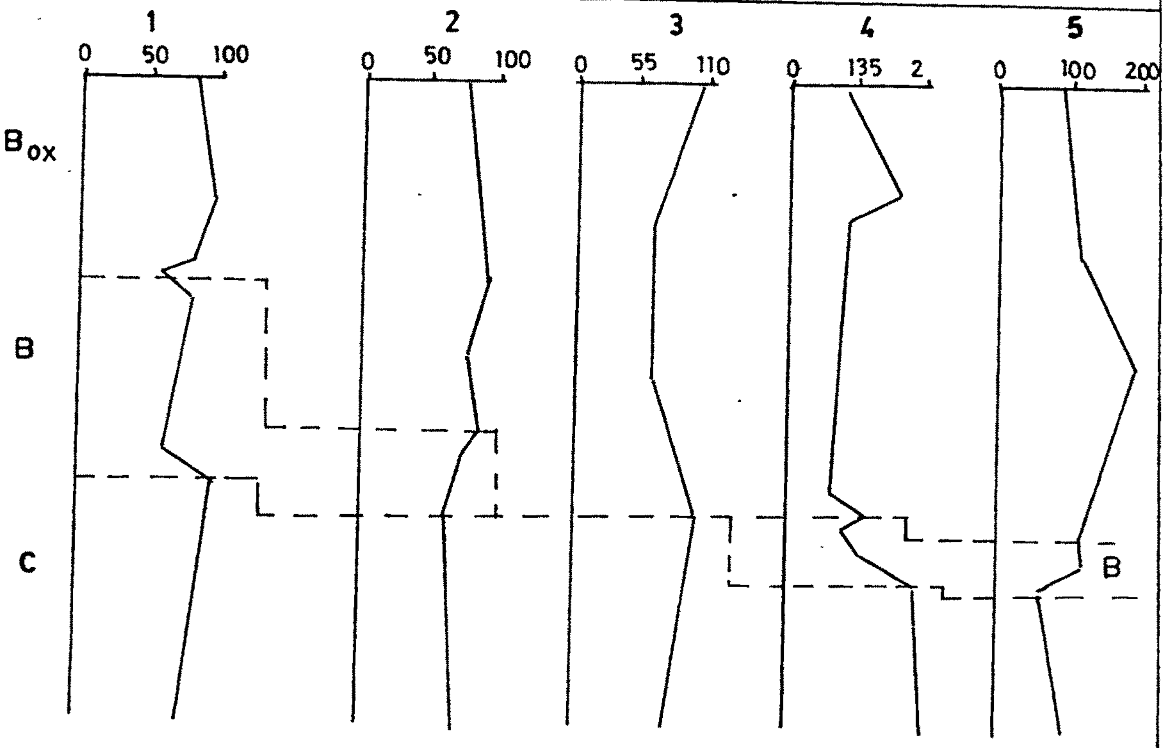
A comparatively high Nickel concentration is accordingly observed in saprolite zone of the various profiles. Concentration of Nickel in saprolite is also reported by others (Balsubramanian 1987; Schellmann, 1989). The kaolinite horizon shows nickel concentration of 112 ppm and bauxitic laterite have 54 ppm (Fig. VI.27).

Copper

Copper is depelted in the upper horizons and is enriched in the saprolite zone below it. The ionic potential of Cu is less than 3 (Goldschmidt, 1937), hence, it is expected to pass into



VARIATION DIAGRAM : **Ni** ppm Fig:**VI. 27.**



VARIATION DIAGRAM : **Cu** ppm

Fig:VI. 28.

ionic solution and therefore, shows depletion in the laterite zones of the profile (Fig.VI.28) in all localities.

Lead

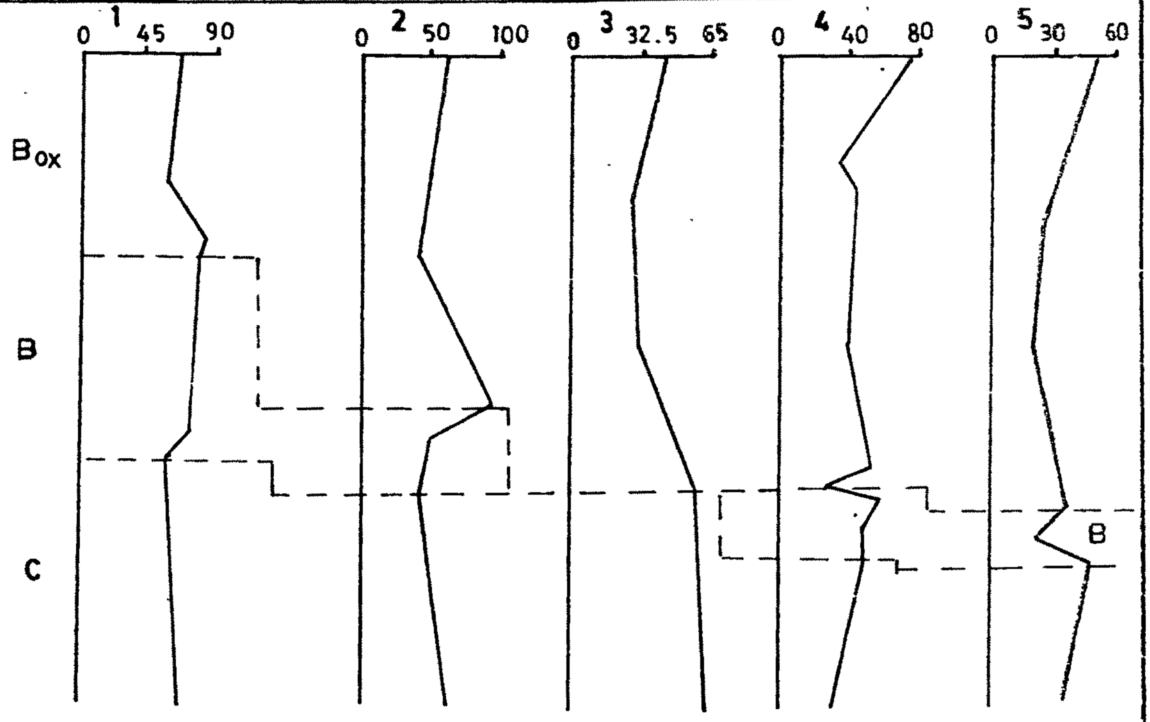
Lead concentration does not show any pattern or trend. In some profiles it shows a concentration in the laterite horizons (duricrust to unindurated laterite) while at other places, it is restricted to saprolite (Kaolinite). The reason could be that the ionic potential of lead is less than 3. Hence it is expected to pass into ionic solution and therefore, is depleted or enriched in some of the laterite horizons perhaps by lateral movement (Fig.VI.29).

Zinc

Zinc occurs in the ferro-magnesian minerals of magmatic rocks (Goldschmidt, 1954). The properties of Zn closely resemble to those of Cu^{2+} as they have similar ionic radii, but in the Mainland Gujarat laterite profiles studied, no correlation is seen between the two. In South Gujarat, Zinc is slightly depleted in the upper horizons and enriched in Saprolite, but in North Gujarat, no variation is seen, except in reworked profiles (Fig. VI.30).

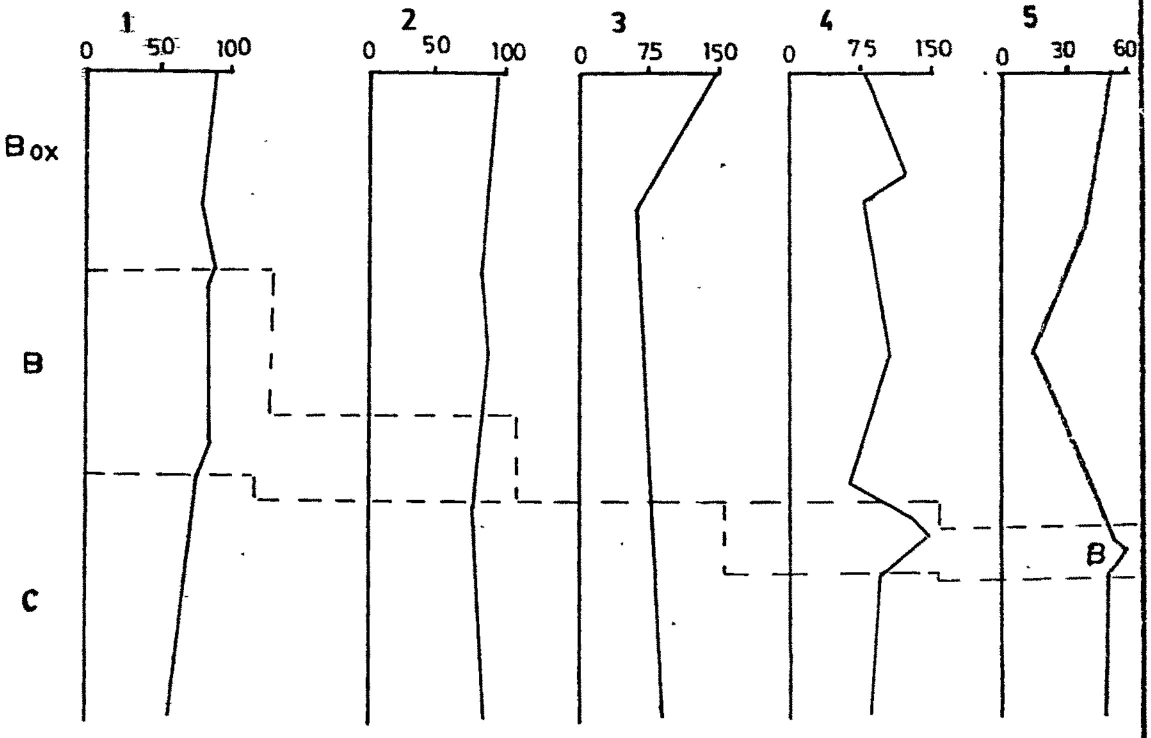
Chemical Correlation Trends : Zr vs Cr

A positive correlation of zircon with chromium is seen in the laterite zone, with some exceptions in a few bauxitic



VARIATION DIAGRAM : **Pb** ppm

Fig: VI.29.



VARIATION DIAGRAM : **Zn** ppm

Fig: VI.30.

laterite horizon. The positive trend is seen in the saprolite zone also, except in some of the kaolinite horizons (Fig. VI.31). Identical positive correlations between the two have been reported from Tagaung Taung, Burma (Schellmann, 1989).

Chemical Correlation Trend : Zr vs TiO_2

A positive correlation of zircon with titanium is seen in all horizons of laterite zones from North and South Gujarat. The negative correlation is seen in saprolite zone (Fig. VI.32).

Chemical Correlation Trend : Zr vs Co

A fair positive correlation between zircon and cobalt is seen in all laterite profiles, with some exceptions in unindurated laterite of laterite zone and bentonite horizon of saprolite zone (Fig. VI.33).

Chemical Correlation Trend : V vs Cr

A positive correlation of vanadium with chromium is noticed throughout the laterite profiles, with some exceptions in a few bentonite horizons of saprolite zone (Fig. VI.34).

The positive correlations are typically indicative of these elements having been introduced from elsewhere, and negative correlations point to the elements removal from the profiles.

Fig:VI.31. VARIATION DIAGRAM Zr VS Cr

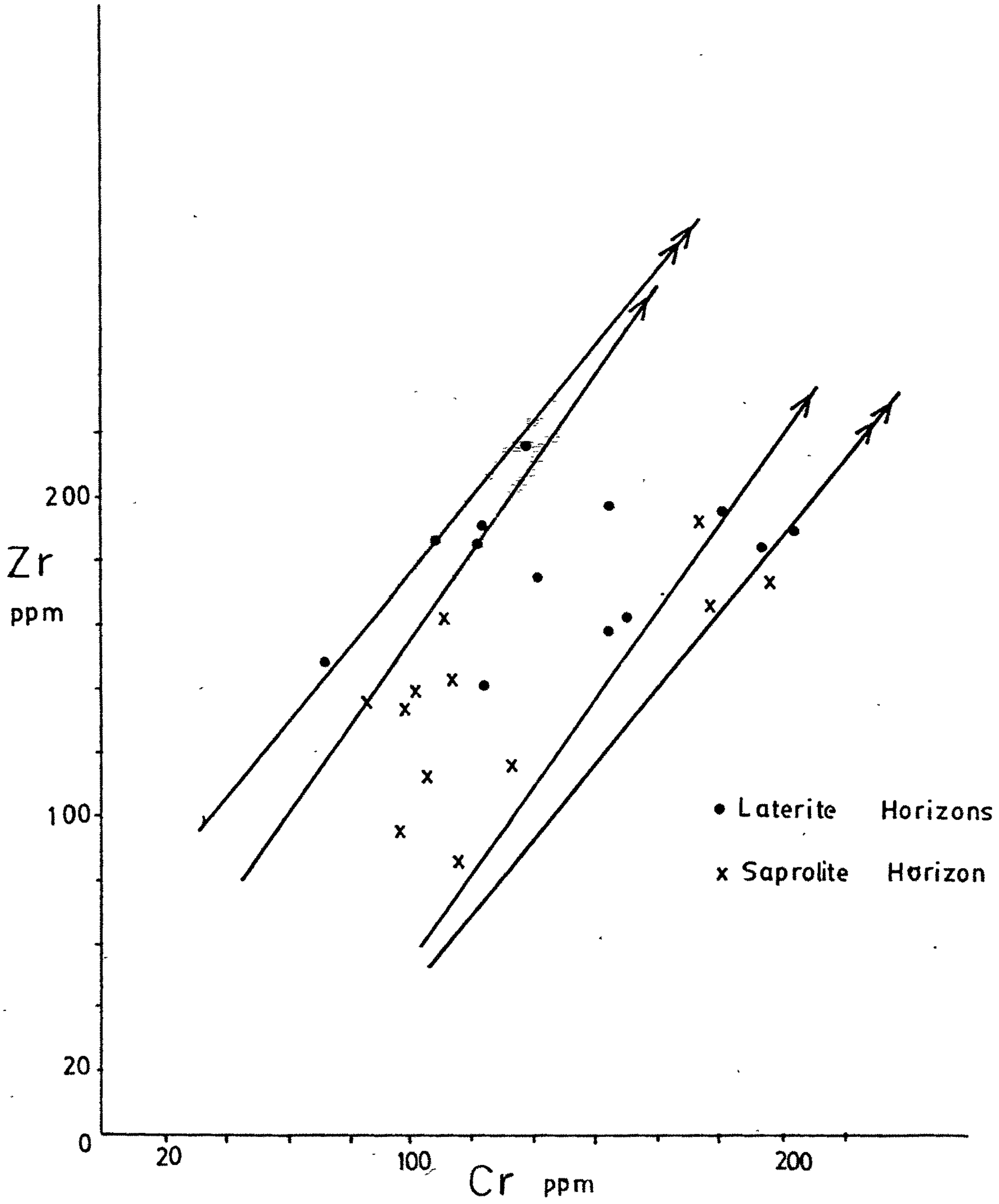


Fig: VI.32. VARIATION DIAGRAM : Zr VS TiO_2

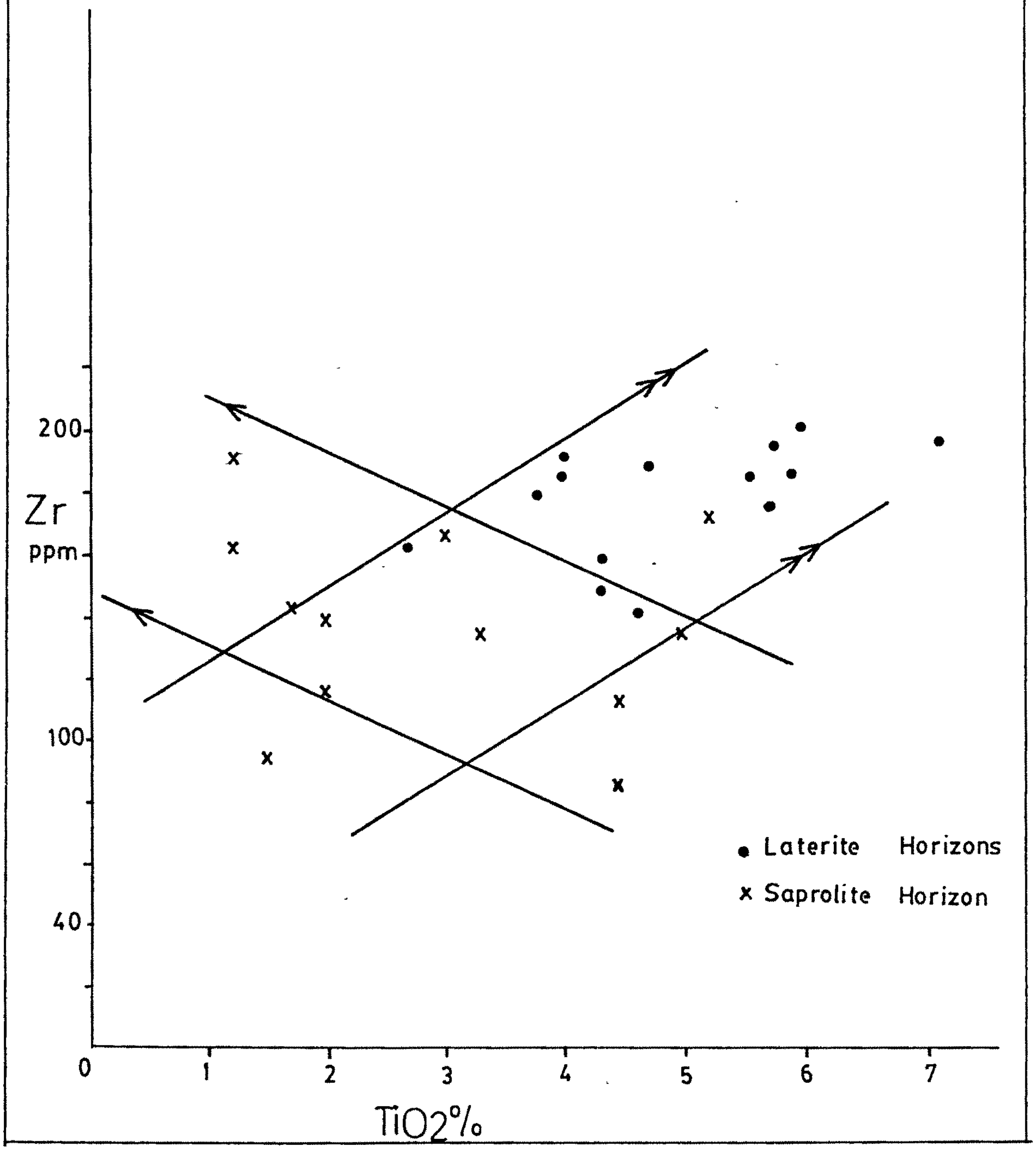


Fig:VI.33. VARIATION DIAGRAM : Zr VS Co

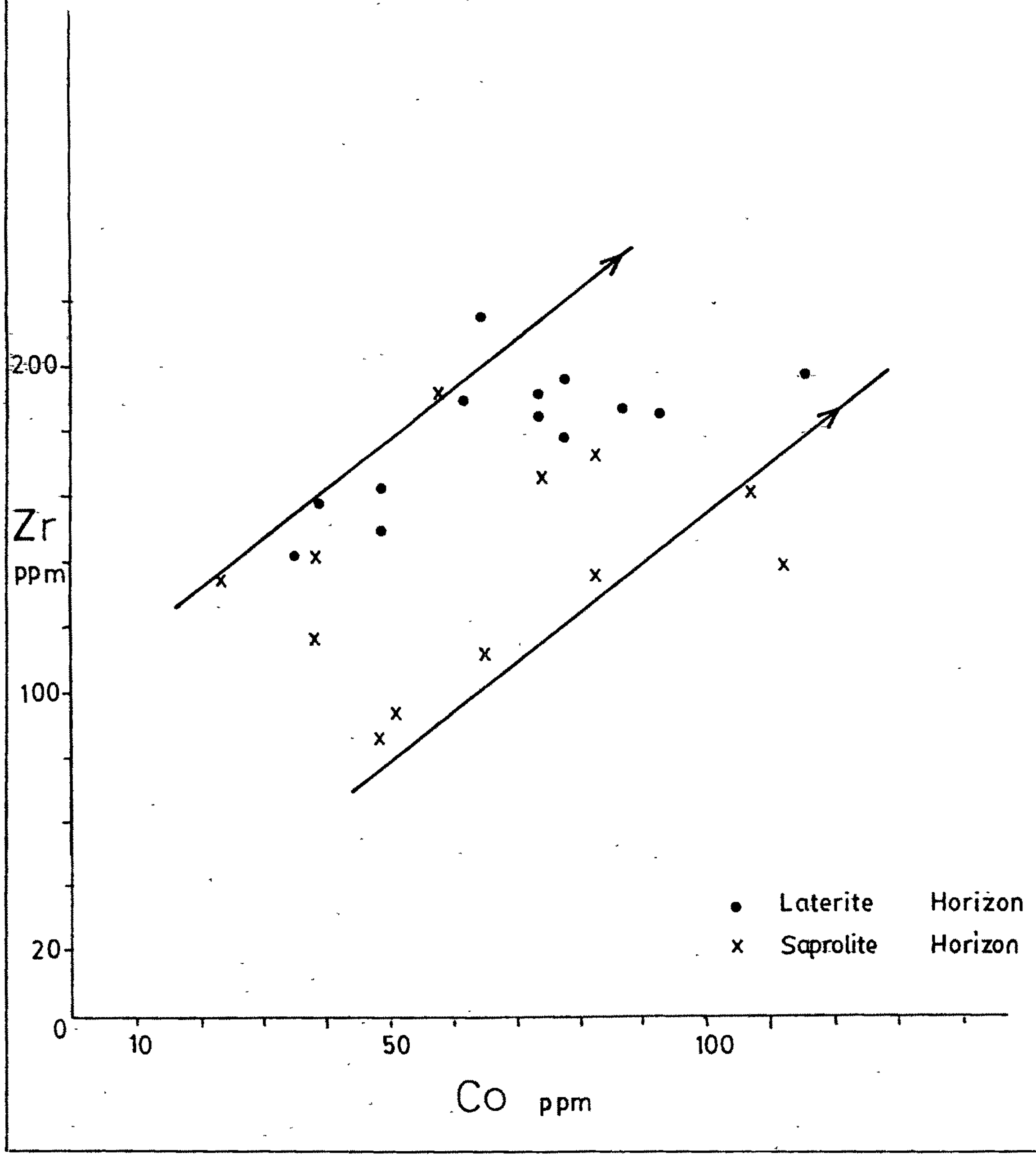
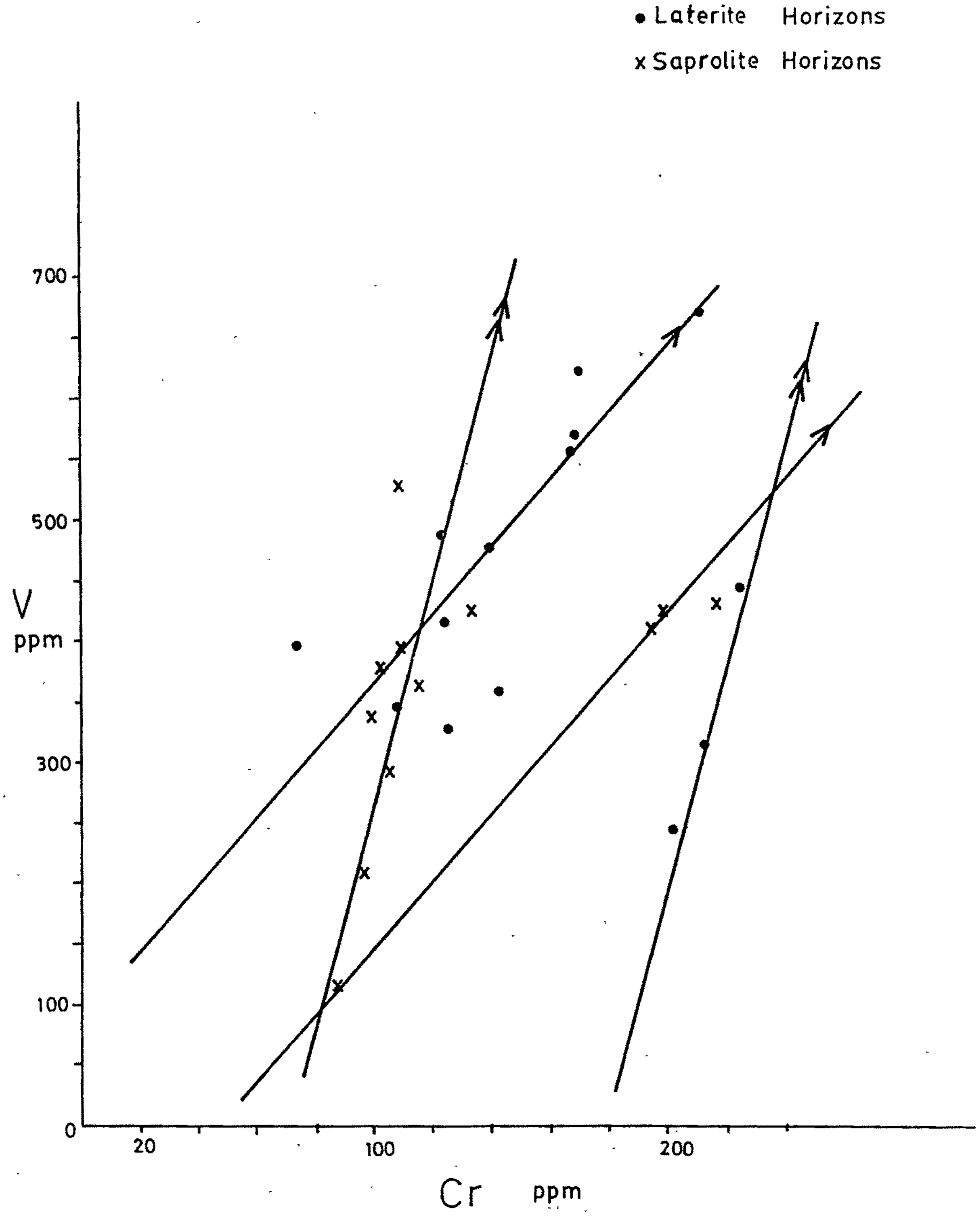


Fig:VI. 34. VARIATION DIAGRAM : V VS Cr



SALIENT GEOCHEMICAL FEATURES

1. Silica occurs as quartz, kaolinite, halloysite, montmorillonite, etc. in laterite rocks, and mostly shows a decreasing trend towards the top of the profile.

2. Aluminium occurs as gibbsite, kaolinite, montmorillonite, halloysite and boehmite in laterite rocks, and these mostly show a increasing trend upwards especially in two Box horizons, lateritic bauxite and bauxite.

3. Iron occurs as goethite, hematite, maghemite in laterite rocks, and shows enrichment upward.

4. Titanium occurs as the product of anatase and rutile in lateritic profiles and shows an increase upward and its high content is typical of basalt lateritisation. It is showing positive correlation with aluminium.

5. Positive correlations between Al_2O_3Vs LOI, Zr vs Co, Zr vs Cr, and V vs Cr are indicative of these elements having been introduced from elsewhere.

6. Negative correlations between Fe_2O_3vs LOI, Zr vs TiO_2 in saprolite zone is indicative of elements removed from profile.

7. Calcium which is derived from calcite has been in a conspicuous amount throughout the profiles.

8. Magnesium occurs as montmorillonite and ankerite and shows a decrease in amount towards the upper portion of the profiles.

9. Alkalis (potash and soda) are mainly confined to the saprolite zone and their proportions decrease towards the upper portions.

10. Manganese initially derived from ferromagnesian minerals shows enrichment in upper portions of the profiles. Its anomalous behaviour in some profiles has been attributed to higher amount of $CaCo_3$.

11. Vanadium is derived from augite, olivine, iron ores which during alteration is removed and gets enriched in the upper portion of the profiles.

12. Chromium, Zircon and Cobalt show positive correlations and enrichment in the upper portions.

13. Nickel concentration is seen in saprolite zone. The nickel in solution on reaching a horizon where magnesia and silica are available, (Saprolite zone) is redeposited.

14 Copper shows enrichment in saprolite zone of laterite profile. Lead does not show any pattern in its migration.

15. Intensitywise the lateritisation process in Mainland Gujarat was moderate to strong.

16. Reworked laterite and bauxite tends to become enriched during transportation and deposition.

17. The enrichment in the quantity of various trace metals (Mn, Zr, Cr, Co) and major element (Al) in the upper parts of the

Mainland Gujarat laterite profiles show lateral migration of these elements when compared to the parent rock (basalt).

The geochemical behaviour of the various constituents during the process of lateritisation has been highlighted to give an idea of how the changes have taken place. Although, the trends broadly coincide with the expected behaviour and agree with finding elsewhere, but in details, there are many features which need explanation. Looking to the scope of the present study and the rather restricted development of laterites, answers to some of the discrepancies is difficult to provide. The author has therefore refrained from giving explanations, and has just mentioned them and wait till the precise mechanisms of laterite formation are better understood.