5

GEOCHEMISTRY

GEOCHEMISTRY

Geochemical investigation is of utmost importance to study the equilibrium conditions in rocks of diverse sedimentary precursors. Field and laboratory investigations have already indicated a close association of the rocks of granulite facies and amphibolite facies of regional metamorphism. It has become imperative to take a recourse to represent the mineralogical and chemical composition of the various rock types of the study area in appropriate diagrams, commonly taken into consideration for different metamorphic facies. Before proceeding with the presentation of this data in various diagrams, the author has mentioned in the following lines main chemical variations within pelitic and calcareous members. However for the purpose of graphical representation, basic rocks are not taken into consideration.

PELITIC MEMBERS

A perusal of chemical data (Table V.1) shows that within the pelitic members the SiO_2 and $Al_2 O_3$ vary between 64% to 68% and 14% to 19% respectively, and are closely comparable to chemical data of Wynne-Edwards (1967) and Cooray (1965). Likewise other major oxides like total iron (Fe^{++}, Fe^{+++}), MgO^{+}, CaO^{+} and alkalies (Na_2O + K_2O) are also broadly comparable with the above workers. Therefore, the author has taken into consideration plotting of this data also into appropriate diagrams.

It is significant to note that in pelitic components, the SiO_2 % as well as alkalies register an increase from cordierite garnet - sillimanite -gneissic granulites towards biotite gneisses. This increase in above constituents is also associated with concomitant decrease in total Fe and MgO. The increase in quartzo - felspathic constituents is attributed to migmatization that synchronised with amphibolite facies of regional metamorphism.

TABLE V.1 : CHEMICAL ANALYSIS OF PELITIC MEMBERS

Sample No.	Oxides in Percentage								Trace elements in PPM			
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	LOI	Ni	Co	Cu	Cd
A11.a	67.2	19.1	6.9	2.11	1.3	2.2	3.1	Ø.31	1Ø9	24	1Ø4	161
A4	68.2	18.5	5.7	2.4	1.8	2.1	3.4	Ø.49	115	29	1Ø9	159
A11.b	66.9	19.5	6.8	2.7	1.5	2.4	3.3	Ø.52	112	35	1Ø8	156
DA1	66.5	14.2	4.7	1.6	2.1	2.7	3.6	Ø.61	1Ø5	31	1Ø3	15Ø
DA2	67.Ø	13.8	4.9	1.4	1.6	2.1	3.2	Ø.55	1Ø6	31	1Ø6	148
A1Ø	64.5	14.6	5.1	2.6	1.5	1.9	3.5	Ø.58	1Ø3	28	1Ø7	143
DA4	68.9	14.5	5.3	1.9	1.4	2.6	3.4	Ø.5Ø	12Ø	25	1Ø2	17Ø
DA7	7Ø.1	13.34	3.9	1.2	2.1	3.3	3.2	Ø.45	118	29	1Ø5	135
DA9	69.7	12.9	2.8	Ø.Ø9	1.5	1.8	3.5	Ø.34	115	23	1Ø4	136

CALCAREOUS MEMBERS

The calcareous members show the SiO_2 weight % between 38% to 48% and total iron varies between 5% to 7%. Both of them are at slight variance from chemical data of above workers but CaO % and MgO % are significantly comparable. The LOI is also varying between 3.2 % to 5 % but in pure calcareous marbles the LOI goes as high as 40 % and CaO 58 % (Table V.2). The author therefore feels that the calcareous members are both purely calcareous (marbles) and partly calc - magnesian sediments.

Thus the metasedimentary group represents the metamorphosed equivalents of a series of pelitic, semipelitic and calcareous sediments which formed part of an early supracrustal succession. The pelitic rocks were probably aluminous shales to arenaceous shales and have the composition of argillaceous sediments.

BASIC ROCKS

The basic rocks, wherein meta gabbros and amphibolites are analysed (Table V.3), show considerable variation in major oxides. So far as amphibolites are concerned, the relevant chemical analyses are comparable to other amphibolites from those of SriLanka (Cooray, 1965) and Wynne-Edwards (1967). The chemical analyses of meta gabbros exhibiting cryptic layering show fairly

TABLE V.2 : CHEMICAL ANALYSIS OF CALCAREOUS MEMBERS

Sample No.	Oxides in Percentage								Trace elements in PPM			
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	LOI	Ni	Co	Cu	Cd
B4	38.4	8.25	5.3	6.12	35.9	2.75	Ø.78	3.65	86	27	75	162
B8	41.2	7.2	3.5	6.6	38.1	2.2	Ø.59	3.2	84	29	71	171
DB5	43.6	8.1	5.7	7.5	34.4	2.4	Ø.61	4.25	78	25	65	162
DB9	35.9	7.6	5.4	5.3	39.3	2.8	1.1	4.8	75	31	64	185
DA15	48.5	8.9	4.3	3.5	29.1	1.8	Ø.49	3.9	71	3Ø	72	189
DA19	5Ø.2	9.1	6.61	5.2	28.2	1.7	Ø.56	3.4	79	26	73	184
C2	37.5	6.91	4.4	7.2	32.5	2.1	Ø.71	4.2	76	85	78	188
C9	35.9	7.5	5.9	6.4	34.5	2.4	Ø.64	5.1	74	21	82	183
DN5	36.2	7.5	4.8	6.5	33.9	2.2	Ø.54	3.7	71	27	85	186
DN11	38.6	7.1	5.9	6.5	36.2	2.5	Ø.68	4.3	74	35	71	171
D2	4.6	2.4	1.1	3.2	85.2	1.8	Ø.4	15.5	84	27	76	182
D3	3.9	2.5	1.6	2.9	75.6	1.4	Ø.35	2Ø.2	81	23	84	189

TABLE V.3 : CHEMICAL ANALYSIS OF BASIC ROCKS

Sample No.	Oxides in Percentage								Trace elements in PPM			
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	LOI	Ni	Co	Cu	Cd
DN1	44.2	12.1	1.5	8.4	12.5	1.4	Ø.74	Ø.34	1Ø9	35	56	161
C1Ø	46.1	14.1	4.3	8.1	14.8	1.6	Ø.82	Ø.25	1Ø2	32	54	18Ø
C12	42.1	16.2	3.5	7.9	18.5	1.8	Ø.61	Ø.29	99	35	47	175
C9	45.5	18.4	3.3	8.1	15.7	1.2	Ø.59	Ø.38	1Ø6	39	42	182
A6	59.9	17.3	3.8	6.2	6.3	3.4	3.1	Ø.31	112	34	49	192
B6	58.7	15.6	4.1	7.4	9.2	2.9	2.5	Ø.29	119	25	52	183
B14	59.8	14.7	3.7	6.5	5.6	3.1	2.3	Ø.38	125	27	59	187

high concentration of CaO + MgO (26 % to 30 %). As CaO content is unusally high, the author thinks that this is on account of Ca- plagioclase rich layer dominating in the rocks subjected to chemical analyses. The alkalies are also much less in these metagabbros.

The basic rocks are always interstratified with rocks of known sedimentary origin and are parallel to the bedding planes of such sediments. The basic rocks are therefore themselves part of early supracrustal succession and may belong to volcanic or sedimentary origin.

Cooray (op.cit.) and Parras (1958) have suggested the transitional series of rocks between pyroxene granulites and calc granulites, but in present case, in one of the localities Nedardi where the meta gabbros occur within calc gneisses, no such transition is observable but at the same time this gabbroic body does show its involvement in granulite facies metamorphism. This aspect is already been elaborated in earlier chapters. The form of some basic bodies and the presence of igneous looking textures in the neighbouring areas (outside the limit of the study area) makes the author feel that some of the basic rocks have been intrusive originally. Whether of intrusive or extrusive origin, however, all basic rocks of appropriate composition appear to have been converted under high grade metamorphism conditions, to pyroxene -granulite subfacies. Metamorphic convergence has thus given them uniform textural and mineralogical characteristics.

The secondary nature of hornblende or biotite suggests that the amphibolites might be derived from pyroxene granulite by retrogressive metamorphism. In present case the absence of transitions between pyroxene granulites and amphibolites, the virtual absence of pyroxenes in amphibolite indirectly supports the author's contention that hornblende and biotite derived from pyroxene in metagabbros and that of biotite in hornblende granulites and most of the amphibolites have developed in response to amphibolite facies regional metamorphism synchronous with orogeny.

The author has prepared following diagrams AFM, A'FM, ACF, AKF, Kohler Raaz diagram. Keeping in view their utility in the interpretation of coexisting mineral assemblages, ACF, AKF diagrams have been constructed for pelitic and calcareous rocks. The principle is that, minerals found to coexist should lie in the same field of diagram, whereas mutually exclusive minerals should be separated by boundary lines. The diagram so derived are compared with ACF, AKF diagram already proposed for various subfacies by FyFe et. al., (1958) and Winkler (1968).

ACF Diagram

The ACF diagram (Fig. V.1) has been prepared for the calcareous rocks of the study area to show Ca, Al, Mg and Fe minerals occurring in metamorphosed calcareous rocks. The high values of "C" component upto 75% indicates richness in Ca and this is substantiated by presence of calcite and scapolite. The paucity of Mg and Fe is indicated by sporadic presence of diopside and/or dolomite.

AKF Diagram

The minerals containing alkalies normally cannot be represented in an ACF diagram and therefore AKF diagram (Fig. V.2) has been prepared for pelitic rocks where biotite and/or muscovite +k-felspar are present. In such rocks normally there is excess of SiO_2. The plot of chemical analyses of the samples of the study area fall in the relevant fields suggesting, the presence of cordierite, sillimanite, garnet, k-felspar. It also indicates excess of Al_2O_3 and SiO_2 in these rocks.

KOHLER - RAAZ Diagram

Köhler - Raaz (1951), presented a new method with the use of four cornered diagram which has +qz, F, Fm and -qz as the apecies, the continuous line given as demarcator between the two fields, sedimentary and

Fig. V-1

ACF DIAGRAM

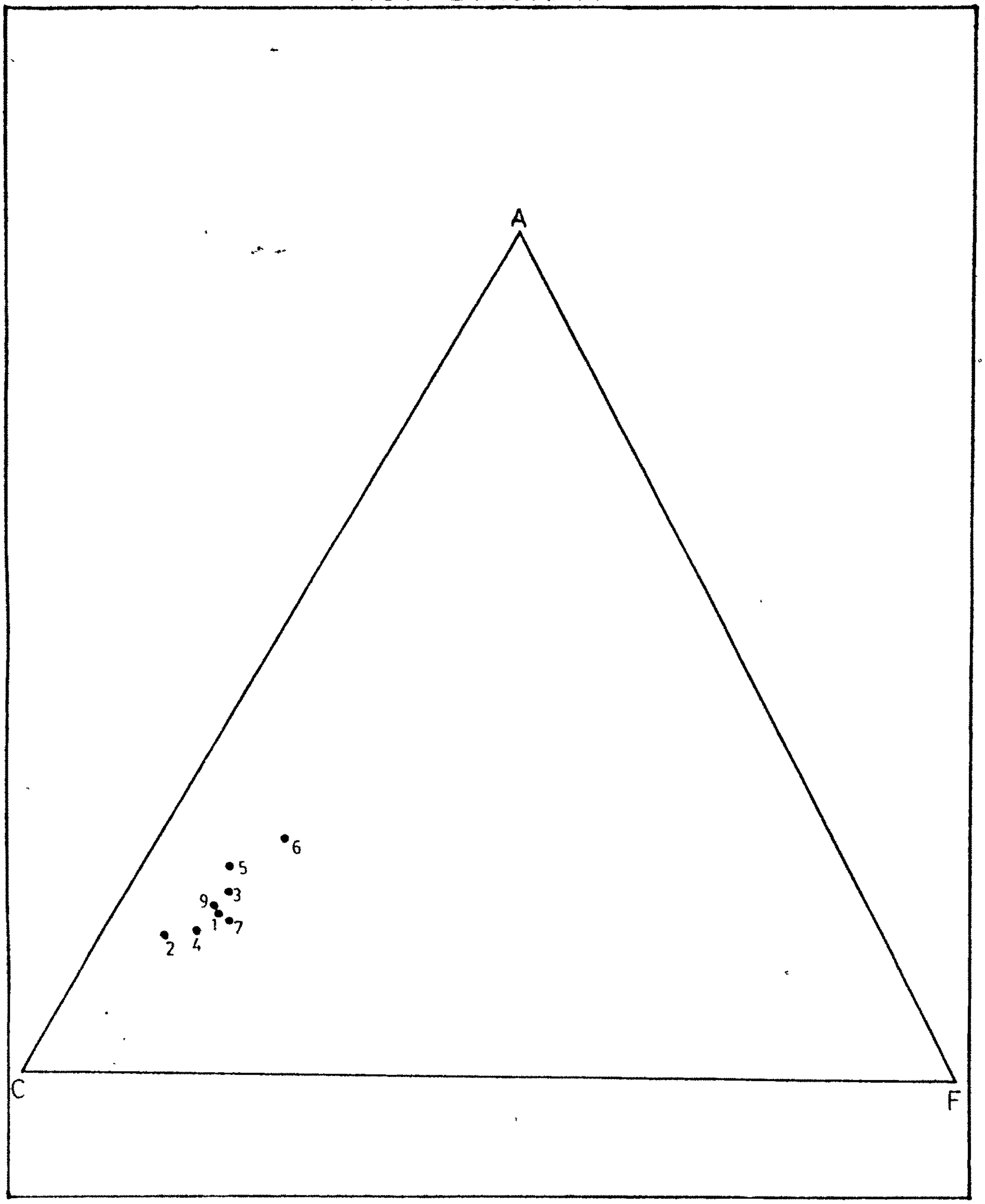
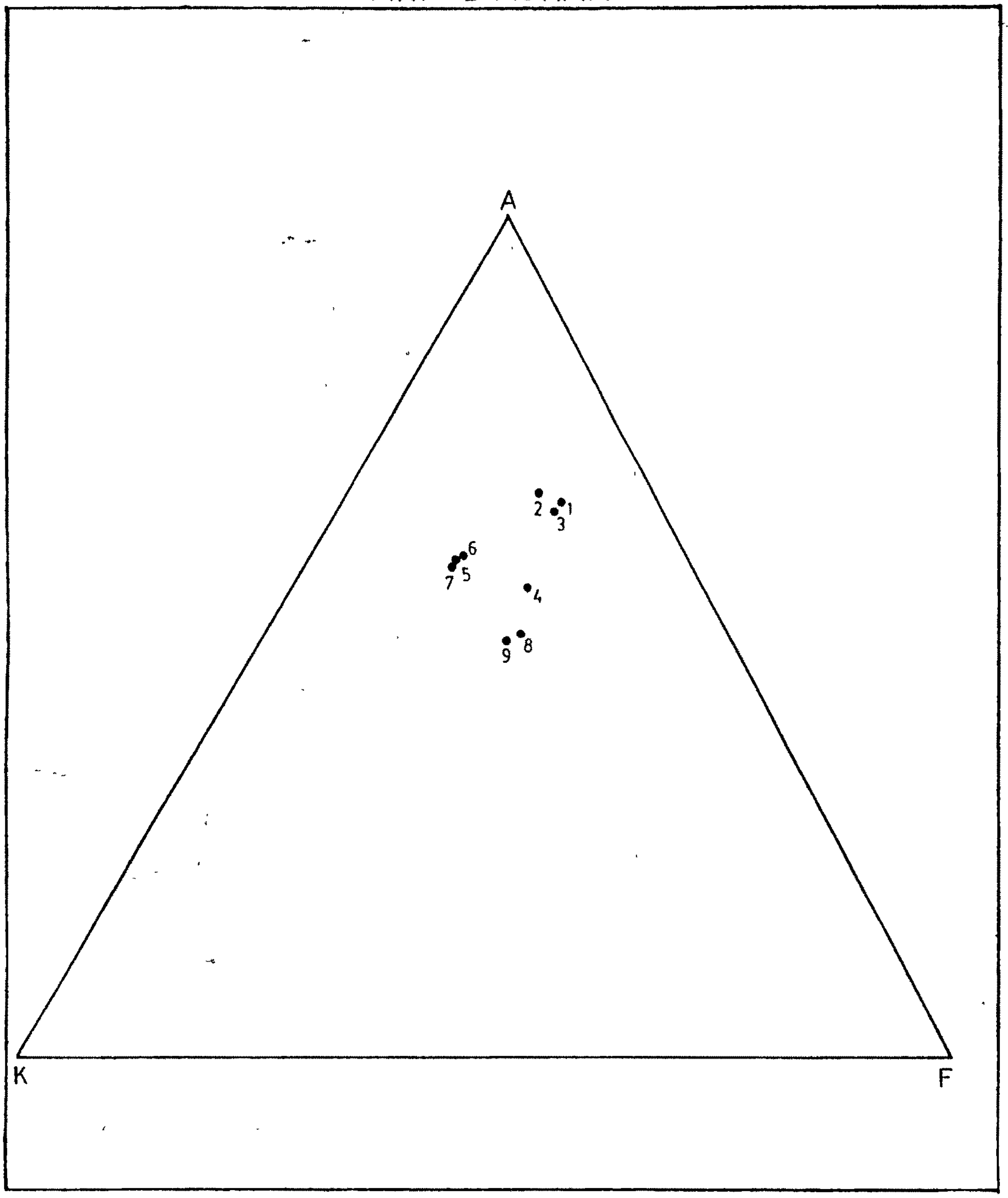


Fig. V-2

AKF DIAGRAM



igneous. The calculation of Köhler-Raaz values of the pelitic rocks of the study area shows their plot in sedimentary field thus distinctly pointing sedimentary parentage of the pelitic rocks.

From this diagram (Fig. V.3) it is significant to note that, the sample No. 9 is exclusively of biotite gneisses and that of sample No. 5 is of cordierite - biotite gneisses, while most of the samples plot towards quartz rich field. This scatter indicates effect of migmatization. For comparison, the author has selected pelitic granulites, cordierite biotite gneisses and biotite gneisses from SriLanka (Cooray, 1965) and from Canada (Wynne - Edwards, 1967) and they also show scatter (Fig. V.4). They have also suggested that the effect of migmatization in these rocks reflects in variation of mineral proportions.

A'FK Diagram

A'FK diagram has been constructed for number of metamorphic zones on the basis of petrographic observations. They suggest those paragenesis that arise in rocks of different chemical compositions when metamorphosed at specific conditions. These diagrams do not provide any information with regard to the accessories such as ilmenite, titanite, rutile, apatite etc. This diagram is based on the conditions that SiO_2

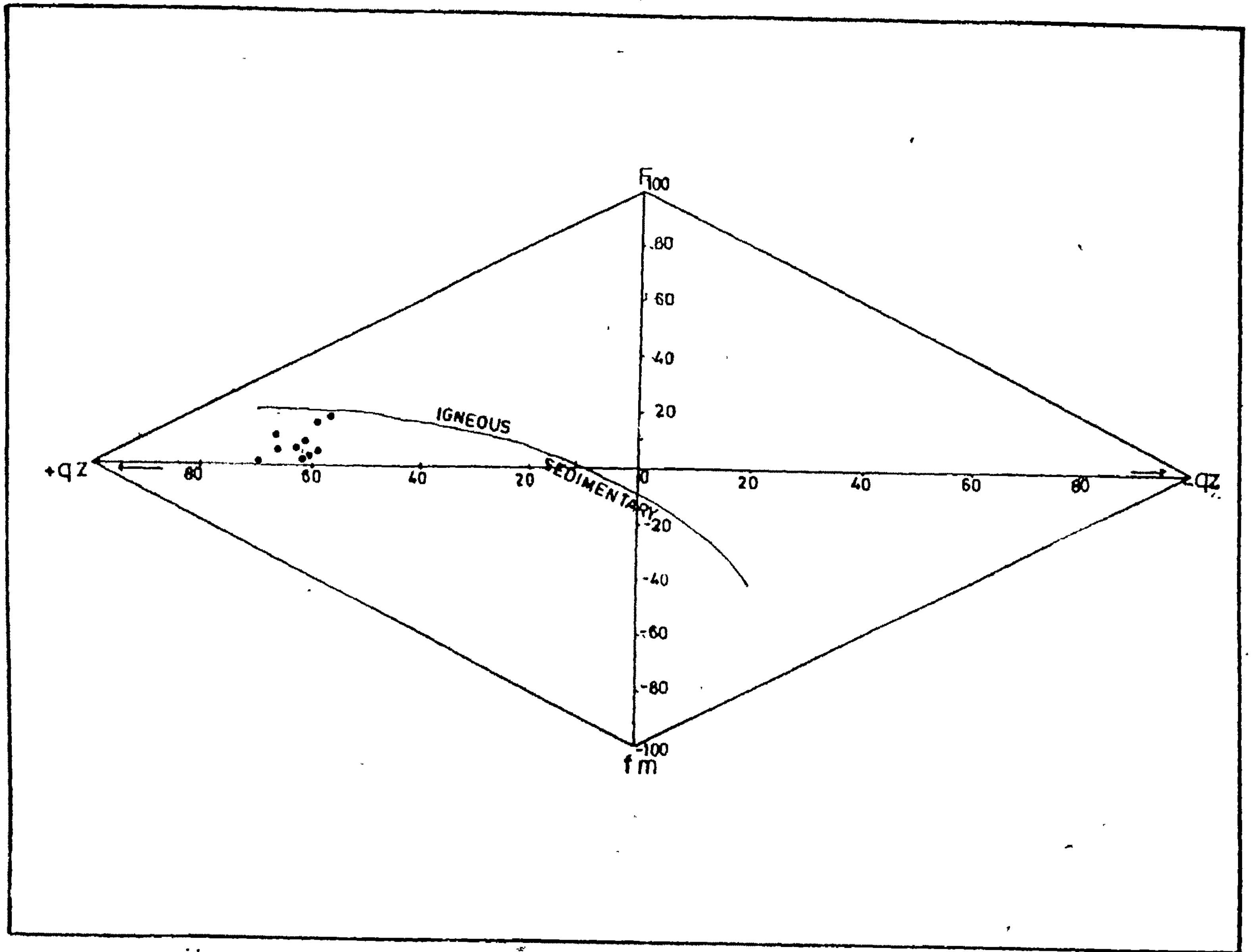


Fig. V-3 KÖHLER RAAZ DIAGRAM FOR PELITIC MEMBERS OF STUDY AREA

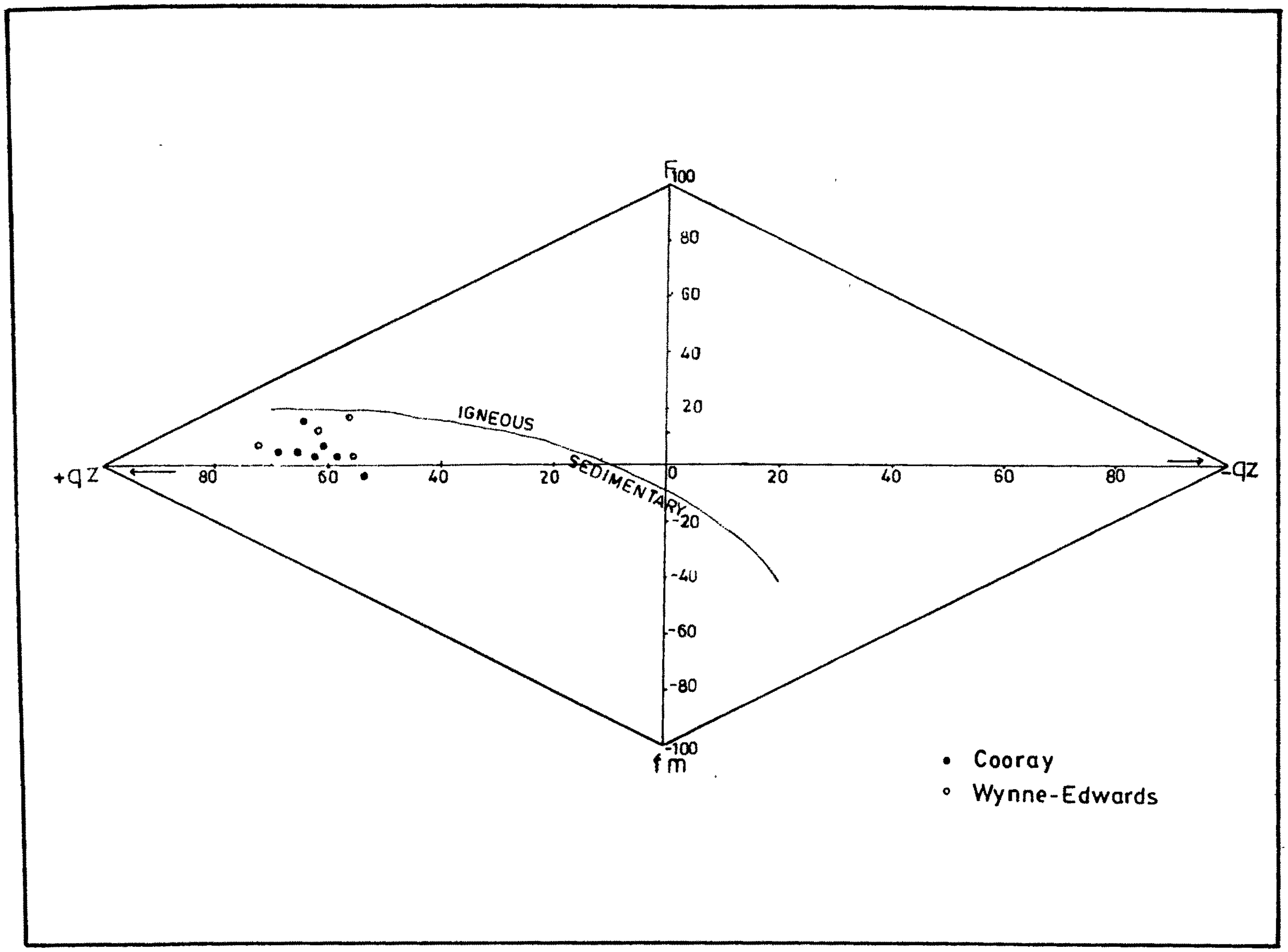


Fig. V-4. KOHLER RAAZ DIAGRAM FOR PELITIC MEMBERS OF COORAY (1965) AND WYNNE-EDWARDS (1967) is present in excess in the form of quartz. This facilitates the understanding of metamorphic transformations.

From this plot (Fig. V.5) it is seen that all the points in pelitic members except one fall in sillimanite, cordierite, k-felspar field but are more concentrated towards cordierite component. The abundance of cordierite in these rocks and rarity of sillimanite supports this view. Points fall in cordierite-garnet - k-felspar field obviously indicates richness in garnet content in these rocks.

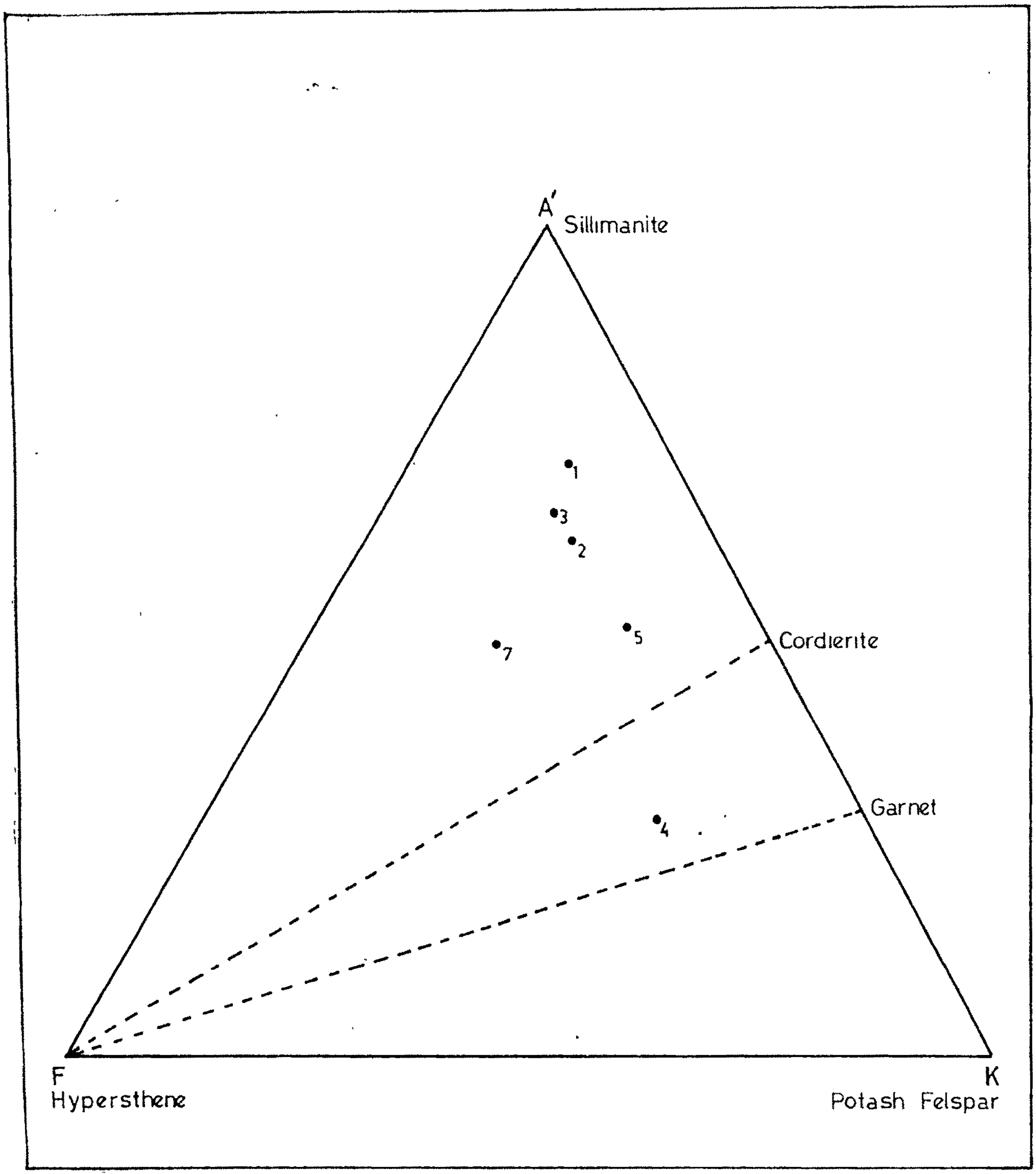
Almandine, sillimanite and cordierite are coexisting phases in these rocks. The coexistence of cordierite and almandine is therefore considered typomorphic and occupies the relatively low load pressure region of granulite facies environments. The sporadic presence of hypersthene in this pelitic rocks also supports this view i.e. low pressure granulite province.

A'FM Diagram

The pelitic rocks of the study area containing mineral assemblage like cordierite, almandine, sillimanite, k-felspar, quartz, hypersthene and spinel have been plotted in a extended A'FM diagram used by Reinhardt and Skippen (1970). The various mineral

Fig. V-5

A'FK DIAGRAM



assemblages are represented by single mineral. The two minerals are connected by a tie line or three minerals (Fig. V.6). The minerals common to all assemblages are indicated at the upper right of the figure. The plot of analyses in the above diagram shows the presence of

Sillimanite + almandine + biotite -----(1)

Sillimanite + cordierite + biotite ----(2)

Hypersthene + almandine (garnet) + biotite --(3)

The coexistence of almandine and cordierite in pelitic rocks has been recorded in several granulitic terrains. In the present case cordierite - almandine - sillimanite - hypersthene are stable phases within granulite facies. It is commonly observed that biotite increases and contributes to the formation of hydrous ferromagnesian minerals. It might be expected that the hypersthene or other minerals will lead to the appearance of biotite in a subsequent stage. Sillimanite occurs as a compatible associate of cordierite and garnet in plagioclase bearing gneisses that lack stable biotite. When the biotite is present in these gneisses, it occurs as felted intergrowths armouring much larger grains of cordierite. The biotite therefore may be interpreted as retrograde mineral and the stable assemblage is a cordierite garnet sillimanite (Zen, 1963). Taking into consideration all the mineral assemblages, the author has reproduced Reinhardt's A'FM

Fig. V-6

A'FM DIAGRAM

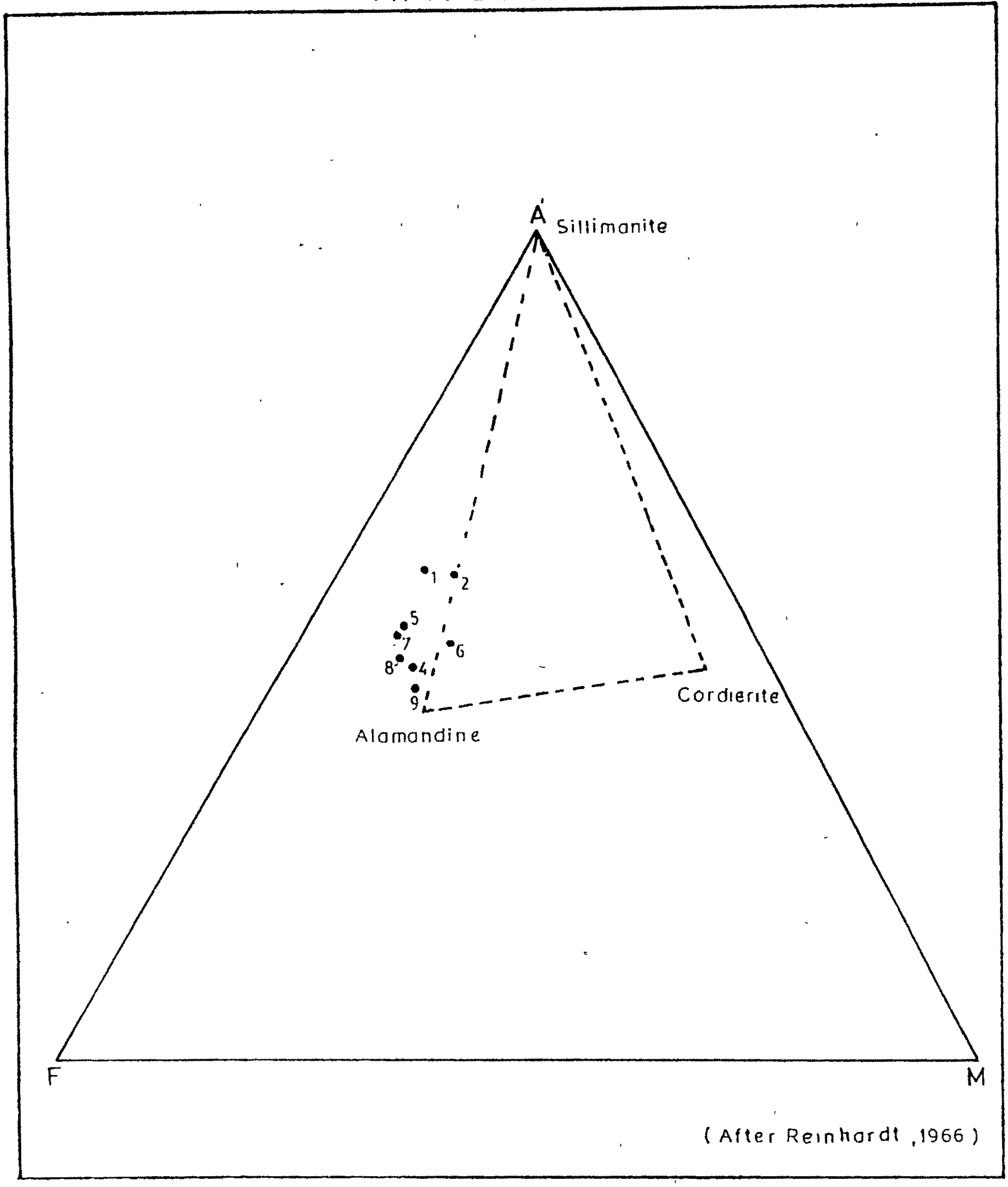


diagram (Fig. V.6) in the present case provides valuable guidance in arriving at the conclusions drawn in metamorphic history.

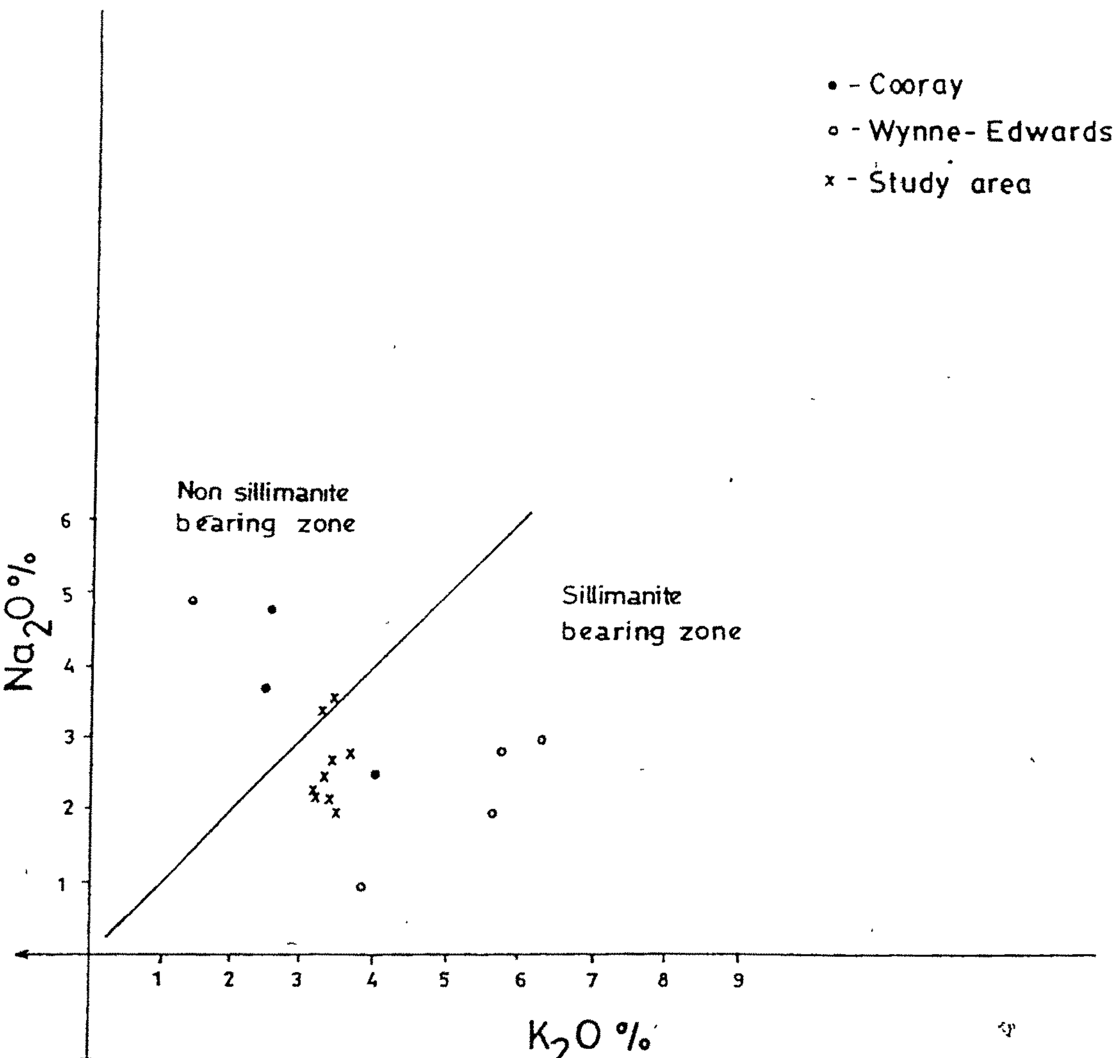
CHEMICAL TRENDS - MAJOR ELEMENTS

In order to show the variations in the mineralogy and chemistry of pelitic members, the author has prepared the diagrams given by Sims and Gable (1967) and Gable and Sims (1969). For the purpose of comparison, the author has also plotted the chemical data of Cooray (1965) in SriLanka and Wynne-Edwards (1967) in Canada.

In these diagrams, the variations between various oxides have been represented. From this plot it is evident that the cordierite - garnet - sillimanite gneissic granulites and cordierite biotite gneisses fall in sillimanite bearing rocks while the biotite gneisses occupy transitional field between sillimanite and non-sillimanite bearing rocks (Fig. V.7). The plots of Wynne-Edwards (op.cit.) and those of Cooray (op.cit.) also fall in these two fields. From this diagram it is possible to infer that sillimanite bearing biotite gneisses which have more K_2O than Na_2O, contain coexisting garnet and cordierite and generally contain abundant microcline, conversely, non-sillimanite bearing biotite gneisses contain more Na_2O than K_2O and are barren of cordierite and have little microcline. The

Fig V-7

DIAGRAM SHOWING PLOTS OF Na_2O VS K_2O



author attributes these differences to primary differences in the composition of sedimentary rocks and to modifications caused during migmatization processes. At the same time the enrichment of Al_2O_3 in all the three rock types are indicated by the presence of sillimanite, garnet and cordierite. The relatively large volumes of quartz in the cordierite biotite gneisses and biotite gneisses and their banded appearance suggest that these are derived from their sedimentary precursors like impure sandstones as well as arenaceous shales.

The plot of SiO_2 % Vs CaO% (Fig. V.8a,b,c and d) in pelitic members of the study area lie in biotite, sillimanite, quartz, cordierite for cordierite bearing rocks while the biotite gneisses showing increase in SiO_2 content fall in biotite - plagioclase - garnet - gneiss field.

From the variation diagrams it can be generalised that the cordierite almandine indicates richness in Mg and cordierite - almandine - biotite suggest Mg poor Fe rich sediment. There is overall increase in Fe content in cordierite - garnet -sillimanite gneissic granulites and cordierite - biotite gneisses but towards biotite gneisses the Mg content falls but SiO_2 and alkalies (Na_2O + K_2O) show an increase.

Fig. V- 8a.

VARIATION DIAGRAMS FOR PELITIC MEMBERS

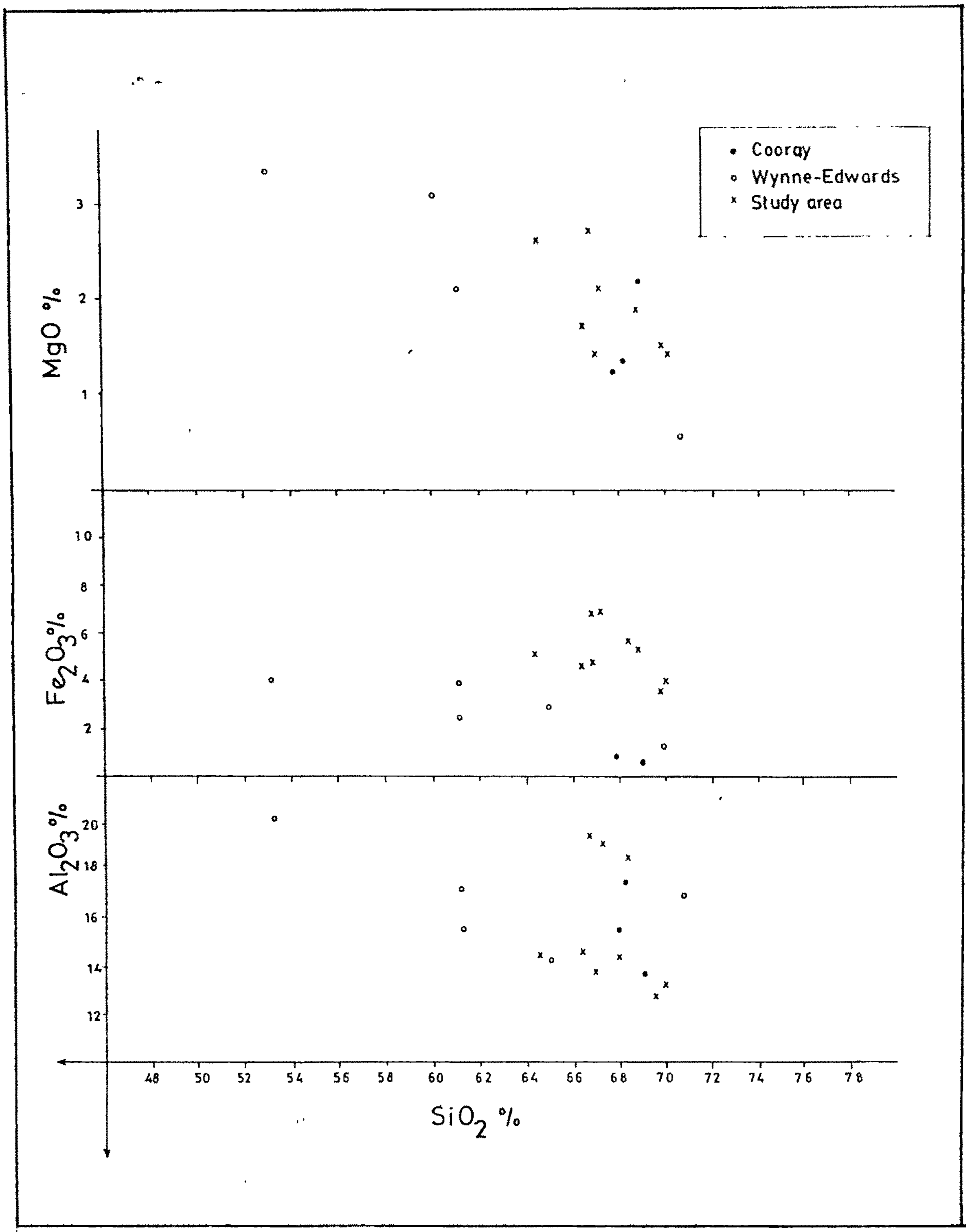


Fig. V-8b.

VARIATION DIAGRAMS FOR PELITIC MEMBERS

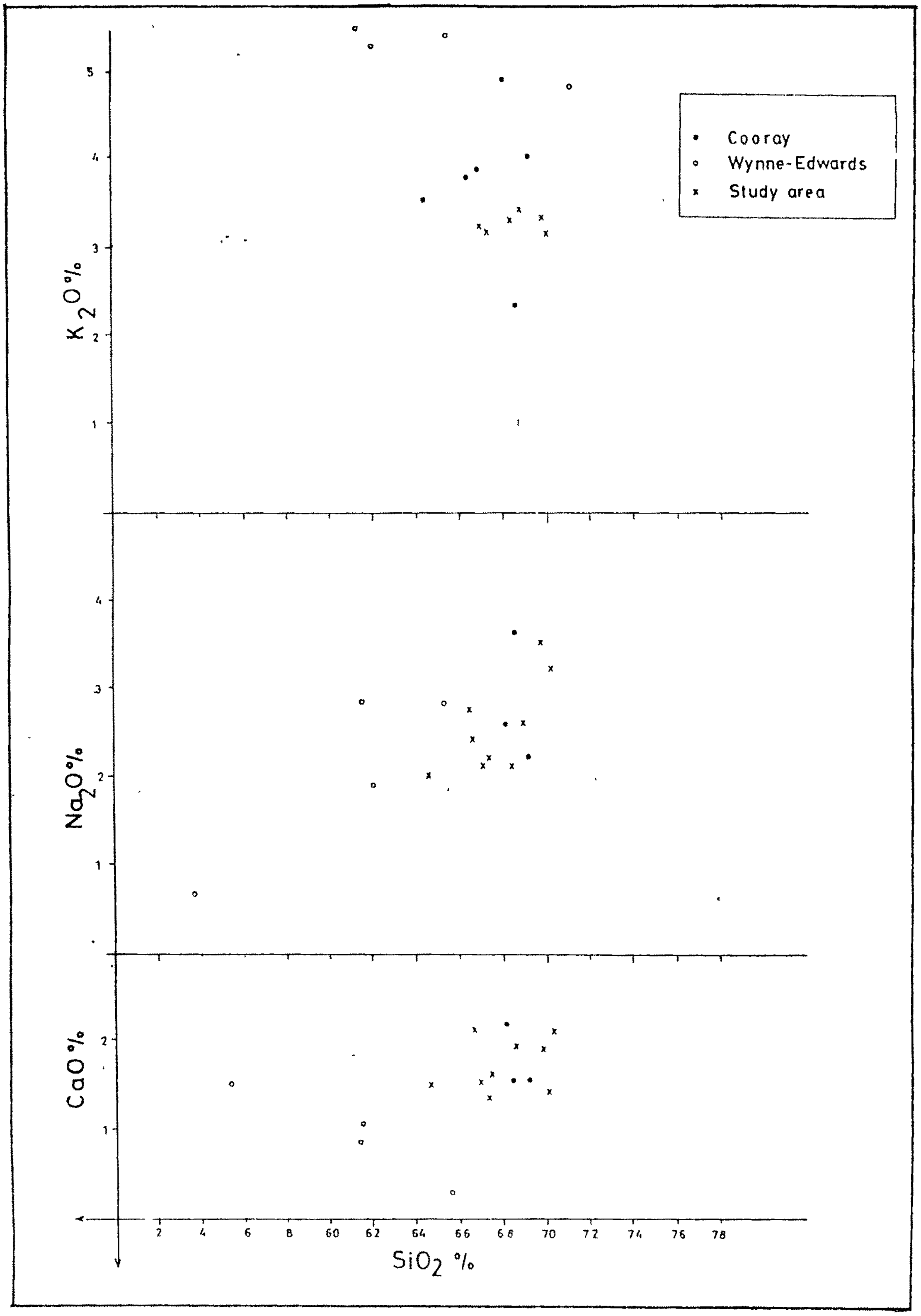


Fig. V-8c

VARIATION DIAGRAMS FOR CALCAREOUS MEMBERS

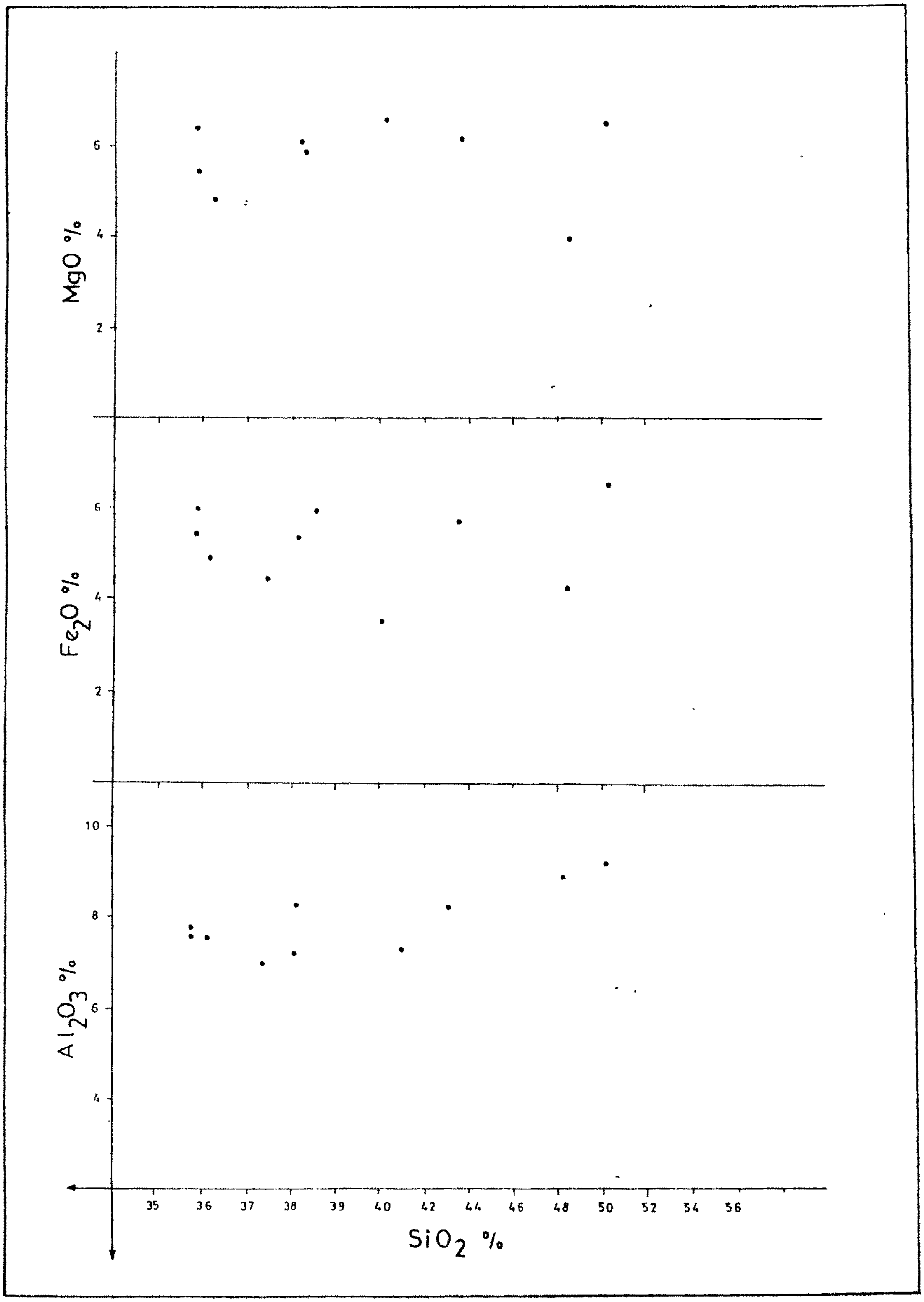
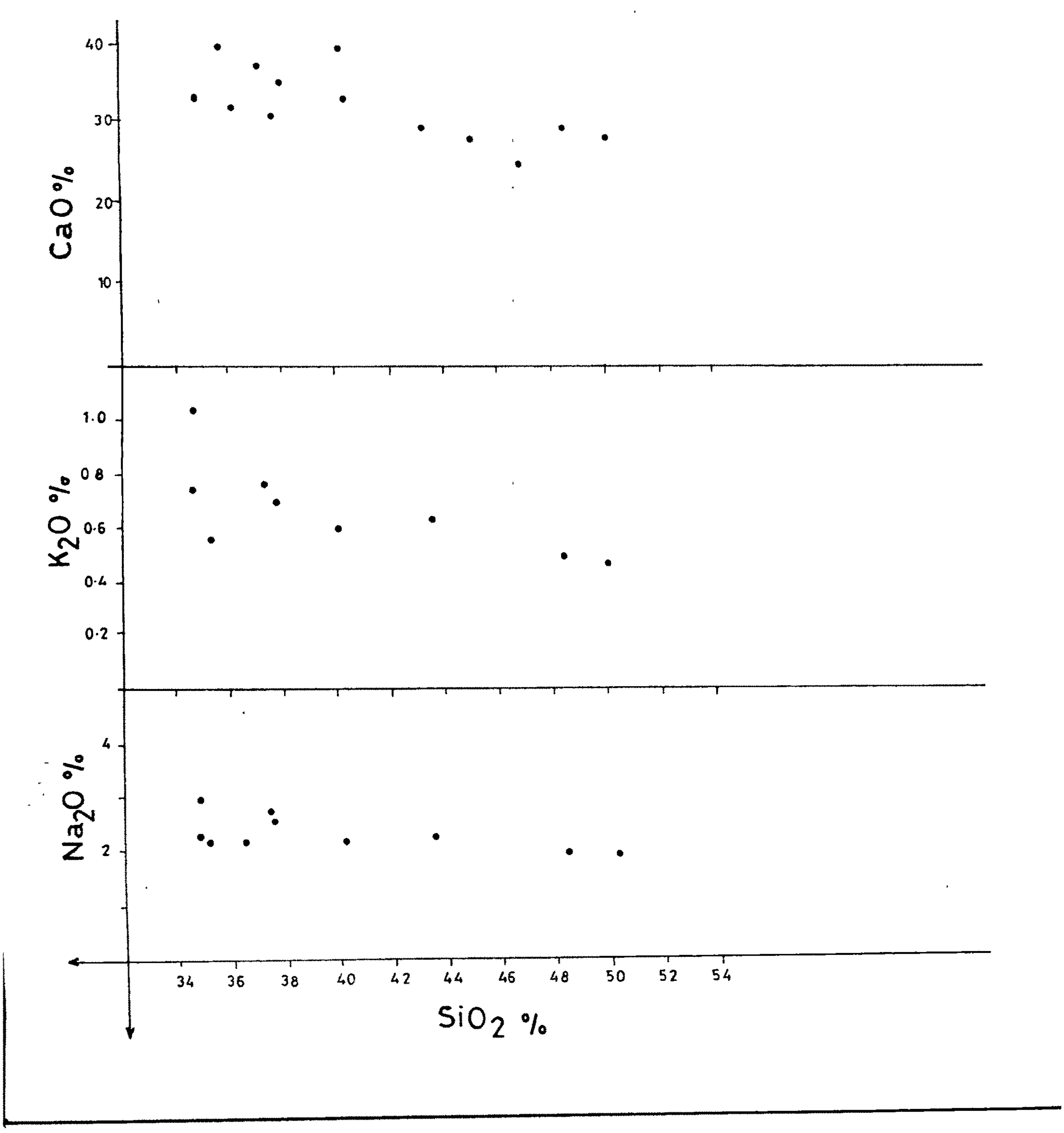


Fig. V-8d

VARIATION DIAGRAMS FOR CALCAREOUS MEMBERS



The major elements in all these rocks are strikingly similar to their sedimentary precursors. The pelitic group of rocks appear to have been derived from aluminous and siliceous sediments. The variations in Fe and Al also indicates variation in composition of these parent sediments. Calcareous metasediments are derived from a mixture of calcareous and calc -magnesian sediments. Basic rocks which normally show enrichment of Fe and Mg are derived by the metamorphism of concordant basic igneous intrusions.

The semipelitic and pelitic units are essentially clastic rocks deposited in the shallow waters of the nearshore region. The calcareous and calc-magnesian sediments correspond to mixed clastic and chemical materials deposited away from the shore region. The overall chemical and mineralogical features suggest derivation of sediments from a provenance with diverse rock types.

CHEMICAL TRENDS - TRACE ELEMENTS

In order to understand the nature of variation of trace elements in the metasedimentaries and basic igneous rocks, few representative trace elements like Ni, Co, Cu, Cd, are determined (Table V.1,2 and 3) in a all these rocks. On comparing the chemical data of rocks of the study area with the trace elements in pelitic rocks of Shaw (1954) it is found that the values for this trace elements broadly agree with the values of the respective trace elements in the argillaceous sediments. Therefore the author think that these rocks in the study area were originally argillaceous sediments.

In the study area the metasediments i.e. pelitic rocks are invariably associated with the amphibolites and meta gabrros (metamorphosed basic igneous rocks). In view of the similar association in the other parts of the world, one may be led to think that these rocks may represent the 1) "the piled up material" during the assimalation of the aluminous sediments by the basic magma or 2) they may represent metapelites into which magnesia was introduced by the invading granites or 3) they may represent the metapelites possibly of marly composition. As the contact between the pelites and the metamorphosed basic rocks is sharp and there is absence of reaction rocks between these two, the possibility of assimilation of the aluminous sediment by the basic magma appears to be rendundent, As is suggested by RamaRao and Krishnachar (1937) and RadhaKrishna (1954) that magnesia was metasomatically introduced by the intruding granite does not appear to be valid in present case as magnesia cannot be introduced by the invading granite as they are too poor in magnesia.

The author therefore feels justified to conclude that the pelitic rocks of the study area were formed by metamorphism of pelitic sediments under granulite facies of regional metamorphism. Sadashiviah and Hanagodinmath (1973), Devaraju and Sadashiviah (1975) have also put forth similar views for the pelitic rocks.