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FELDSPAR SOLID SOLUTION SERIES IN FENITES FROM LOE SHILMAN CARBONATITE COMPLEX, NW PAKISTAN

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ABSTRACT

The carbonatite sheets at Loe Shilman in Khyber Agency, NW Pakistan, fenitize their country rocks to form a metasomatic zone, c. 100 metres wide, of alternate dark blue (mafic) and pale grey (felsic) banded fenites which grade into unfenitized slates and phyllites. The carbonatite sheets comprise a more extensive amphibole sovite which is intruded by biotite sovite in different parts of the complex. These sovites are in turn intruded by ankeritic carbonatite mainly along the southern contact with the country rocks.

Amongst the new minerals, formed as a result of three fenitizations (two sodic and one potassic), K-feldspars are formed as a result of contact thermal effect by the early amphibole sovite at the expense of phengite and argillaceous material. The more disordered K-feldspars, which were formed at high temperature (~700°C), in the inner zones 3, 4 and 5 are now readjusted to maximum-microcline to intermediate-microcline. While in zone 2 the more disordered relict K-feldspar escaped readjustment, and therefore, produces reverse zonation in contrast to the temperature gradient. The effect of biotite sovite is restricted to the thin veins composed of K-feldspar (Ba=1.4 wt %) and biotite. The samples SM93 and SM84, amongst the banded fenites, have been also metasomatized by the biotite sovite.

Albite, which coexists with other metasomatic minerals, formed first by the early amphibole sovite, was presumably more disordered towards the carbonatite contact. It is now readjusted to its present lowest structural state by the ankeritic carbonatite. The presence of relict disordered intermediate low-albite now shows reverse zonation in contrast to the temperature gradient. Both the solid solution series are well correlated with distance from the carbonatite igneous contact.

INTRODUCTION

Carbonatites are characteristically surrounded by fenitic aureole of metasomatized country rocks. These rocks are usually granites, syenites and granitic gniesses which show various stages of fenitization by the development of metasomatic minerals and are accompanied by loss of original texture. The intensity of fenitization is mostly controlled by fracture and texture of the country rocks and therefore no correlation is normally present between the intensity of fenitization and distance from the carbonatite contact.

Feldspars in granitic rocks, when fenitized by alkaline rocks/carbonatites or by other igneous intrusion, are transformed to new structural state in different stages depending upon distance from the contact and temperature of the igneous intrusions (Currie and Ferguson, 1971; Steiger and Hart, 1967; and Wright, 1967). This transformation from high to low disordering (orthoclase to maximum-microcline and high-albite to low-albite) in metamorphic contact aureole provides useful information about the relative temperature and pressure of the igneous intrusions. Extensive experimental work of Al and Si in tetrahedral site have been investigated by many workers (Orville, 1967, 1974; Parsons, 1968; MacKenzie, 1952, 1957; Kroll and Ribbe, 1983; Goldsmith and Jenkins, 1985).

Few data are available on the structural state of feldspars in metasomatic aureole in granitic country rocks and none in fenitized low grade metasediments. However, carbonatite sheets at Loe Shilman have produced a metasomatic zone of alternate mafic and felsic banded fenites which grade into the unfenitized slates and phyllites. In these banded fenites 5 zones were distinguished on the basis of appearance and disappearance, and disappearance of metasomatic and relict minerals (Fig. 1). Among the coexisting metasomatic minerals (amphibole, pyroxene, phlogopite-biotite, albite, K-feldspar) a complete solid solution series is present between magnesio-arfvedstone and magnesio-riebeckite (Mian and Le Bas, 1986) and phlogopite-biotite solid solution series (Mian and Le Bas 1987).

In this paper the reversal of degree of order in K-feldspar and albite from Loe Shilman banded fenites is discussed. K-feldspars formed from argillaceous material as a result of contact effect, and form a solid solution series between maximum-microcline and orthoclase, close to the contact in zone 5 and outward in zone 1, respectively. Similarly albite also makes a solid solution series between anomalously low-albite in zone 5 and low-albite in zone 1. The tielines between the coexisting K-feldspar and its analogue albite deviate from the normal trend given by previous workers (Wright, 1967; Currie and Ferguson, 1971). The metasomatic trend is also the same in feldspars studied from fenitized granite gniesses and quartzites at Silai Patti by the carbonatite sheets and feldspars from fenites at Koga formed by carbonatites.

GEOLOGICAL SETTING

The Loe Shilman carbonatite complex, by the Kabul River, 20 km north of Khyber Pass and 50 km NW of Peshawar, occurs to the extreme west of the NW alkaline province (Kempe and Jan, 1970; Jan et., 1981) (Fig. 1). The carbonatite intrusions are 170 meters wide, at least 3 km along, striking E-W, and lie astride the Afghanistan border. These carbonatites are emplaced along a northward dipping thrust plane, the Warsak thrust, between ?Palaeozoic metasediments and dolerites to the north and ?Precambrian slates and phyllites to the south (Fig. 1). An early and more extensive amphibole sovite is intruded by biotite sovite in different parts of the complex and ankeritic carbonatite along the southern contact with the slates and phyllites. The biotite sovite has yielded an average K-Ar biotite age of 31±2 Ma (Le Bas et al., 1987).

The fenites, south of the complex and close to the Afghanistan border, are in situ and less affected by subsequent movements. Whereas north of the complex the fenites have been completely displaced, except in the east, where they are tightly folded and tectonically emplaced.

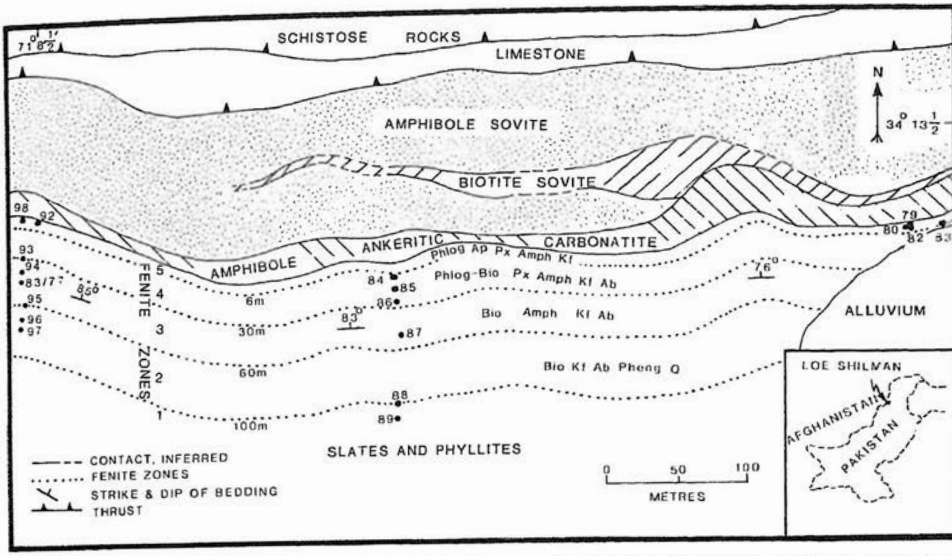

Fig. 1. Geological map of western part of the Loe Shilman Carbonatite Complex and its fenitized zones (1–5). The positions of the analysed samples are shown.

The banded fenites are syenitic in bulk composition and mineralogy, and grade into the unfenitized slates and phyllites. These fenites are composed of hard massive alternate dark blue and pale grey bands, of varying thickness, which are parallel to the E-W carbonatite contact and dip 76-85°N. The width of dark (mafic) bands in general decreases gradually from 1.5 meters, close to the carbonatite, to 5 mm, within a distance of 60 meters, beyond which no mafic bands are seen in the less and unfenitized slates and phyllites. The grey (felsic) bands become wider away from the carbonatite contact and grade into the unfenitized country rocks. The banded fenites are also intruded by thin sheets of carbonatites, and veins of these carbonatite are also present.

PETROGRAPHY

The banded fenites are formed as a result of sodic fenitization mainly by the more extensive amphibole sovite and later superimposed again by sodic fenitization by the amphibole ankeritic carbonatite (Fig. 1). These banded fenites are divided into 5 zones on the basis of mineral assemblages and each zone is marked by the appearance or disappearance of metasomatic minerals, or the presence of relict minerals. The detail petrography of these banded fenites is discussed by Mian and Le Bas (1986). Therefore only a summary of petrography relative to alkali feldspars is presented in this paper.

Zone 1

The least fenitized slates and phyllites (SM89 and SM88), some 110 and 100 m, respectively, from the carbonatite contact, are very fine grained thinly bedded and composed of light (silty) and dark grey (argillaceous) laminites showing graded bedding. A weak cleavage is developed across the bedding and is marked by elongated parallel wisp of fine-grained almost isotropic material and by coarser biotite-rich strips. The lower silty beds are composed of quartz, phengite, albite, K-feldspar and biotite. The detriatal quartz, which forms upto 32% of the sediments, is partly replaced by albite. The upper dark and almost isotropic argillaceous beds are composed of turbid interlocking mass of argillaceous material and feldspars.

Zone 2

The banded fenites are still very fine-grained, cleaved and show graded bedding. The alternate dark and pale grey beds are more pronounced than in zone 1. The dark grey beds are composed of fresh albite, fresh and dusty K-feldspar, biotite and phengite as major constituents, with minor magnetite and ilmenite. These beds are equivalent to argillaceous beds of zone 1. K-feldspar increases at the expance of phengite, and likewise relict quartz decreases and now forms only 9–12% of the rock.

The beds are cut by veins of fresh K-feldspar and biotite by later K-fenitizing fluids related to the biotite sovite.

Zone 3

This zone is marked by the incoming of Na-amphibole. The banded fenites are again very fine-grained and composed of alternate mafic and felsic (light brown) bands. These bands have, at places, sharp rather than gradational contact. The original bedding is still apparent and even some graded bedding is locally preserved. The mafic and felsic bands are the equivalent of the silty and argillaceous beds of zone 1, respectively. In this zone phengite and quartz are absent, apart from sample SM95 which contains 8% relict quartz and in which Na-amphibole first appears.

K-feldspar and albite are fresh and present in both mafic and felsic bands. Felsic bands are red brown and composed of interlocking and elongate small crystals of K-feldspar and albite, flakes of biotite and Na-amphibole. The mafic bands are composed of the same mineralogy and texture as the felsic bands but consist of less feldspar and more mafic minerals than felsic bands. Na-amphibole veins are also present which are bordered by fresh K-feldspar and albite. These are interpreted to have been formed as a result of Na-fenitization by the amphibole carbonatites.

These banded fenites are cut by veins of K-feldspar and biotite, and rare calcite, which are interpreted as the result of biotite sovite.

Zone 4

This zone is characterized by coexisting Na-amphibole and Na-pyroxene. The bands are again fine-grained and alternately mafic and felsic. The bedding is still recognizable and even some graded bedding is preserved in places. The felsic bands, the equivalent of the dark brown, dark grey, and argillaceous beds of zones 3, 2 and 1, respectively, have an almost schistose appearance with aligned flakes of golden brown phlogopitic biotite and feldspathic elongated tabular patches with rounded ends. These patches are now composed of a mosaic of a few grains of clear albite and K-feldspar, which are interpreted to have formed from single crystals of feldspar analogous to the texture seen in the pseudo-trachyte of East Africa (Le Bas, 1977). Small porphyroblast and rectangular non-pleochroic green crystals of aegirine are scattered throughout the bands, sometimes disturbing the alignment of phlogopitic biotite and feldspar crystals. A few of the aegirine crystals even show a rotation texture, indicative of later shear movement.

The mafic bands, the equivalent of light brown, light grey, and silty beds of zones 3, 2 and 1, respectively, are composed of the same minerals, but slightly coarser, as the felsic bands in the following order of abundance: aegirine, Na-amphibole, albite, K-feldspar and phlogopitic biotite. One sample (SM93) and upto some extent another sample (SM84) are different. SM93 is cut by only aegirine veins. These veins have a clear margin composed of fresh albite and K-feldspar which grow at an angle to aegirine. As in zone 3 the differences in the modal compositions between the bands reflect changes in the original chemistry of the sediments rather than the effect of fenitization.

Cutting these bands are thin, 0.1 mm, veins composed of fresh K-feldspar, biotite, and a little calcite. Mian and Le Bas (1986) interpreted these veins as related to the biotite sovite.

Zone 5

The inner zone 5 (6 m wide) is characterized by the presence of higher proportion of aegirine and Na-amphibole as compared to feldspars. By the coming of apatite the phlogopitic biotite becomes phlogopite. Albite is not seem in the three metres adjacent to the carbonatite which is confirmed also by X-ray differaction analyses. However, albite is present in the outer part of zone 5, adjacent to zone 4. No traces of the original sedimentary features can be seen. The whole zone has been recrystallized, except in SM80 where some bedding can be seen.

K-feldspar and albite are coarser than zone 4 but still it is difficult under the microscope to distinguish between the two, apart from the inner part of zone 5, where K-feldspars have microclie twinning.

X-RAY POWDER DIFFERACTION DATA OF FELDSPARS FROM LOE SHILMAN

X-ray differaction data for alkali felspars are given in Tables 1 & 2. As the fenites from Loe Shilman are very fine-grained, it is difficult to sparate K-feldspar from albite, apart from the inner part of zone 5, adjacent to the carbonatite, where K-feldspar alone is present, and in the outer zone 1, where only albite is present. In the rest of the zones both feldspars coexist in each zone. Therefore feldspars were separated from the mafic minerals particularly Na-amphibole and aegirine which interfere with 2θ (060) and ($\bar{2}04$) Cuk_α of feldspars.

Peak positions were measured at the estimated center line of the top 1/3 of the peak. The 2θ (28.3) and (47.06) X-ray reflection of pure CaF_2 internal standard was included in each sample and the peaks were measured in the same way as the feldspars. Three X-ray powder pattern for 2θ (060) and ($\bar{2}04$) were run for each sample using copper radiation at 1/min for one run and 1/4 per min for two runs. The error calculated is based on the minimum and maximum of the three X-ray differaction pattern (Tables 1 and 2). For 2θ (131) and ($1\bar{3}1$) in albite the error was calculated from two runs both at 1/min. The rocks in which K-feldspar and albite coexist together, 2θ ($1\bar{3}1$) of albite and K-feldspar overlap one another and both peaks are resolved in a single sharp peak. Rarely this peak is present as broad or two peaks. In case of broad or distinct two peaks, lower portion of the peak is taken for albite and upper for K-feldspar. All the feldspar in Loe Shilman banded fenite are anomalous, for which 2θ ($20\bar{1}$) is measured based on Wright (1968) diagram.

The 100 intensity peak for albite is more prominent than 100 intensity peak for K-feldspar at 2θ (22.1) and (21.05), respectively. Therefore in combined single peak of albite and K-feldspar, the upper part close to the tip of the peak ($1\bar{3}1$) is considered for albite.

TABLE 1. XRD DATA OF K-FELDSPAR FROM FENITIES AT LOE SHILMAN

SM. No.	92	98	79	82	80	83	84*	85	86	93*	94	87	95	96	97
2θ (060)	41.840 (0.01)	41.825 (0.015)	41.830 (0.015)	41.824 (0.015)	41.850 (0.015)	41.825 (0.015)	41.850 (0.015)	41.835 (0.025)	41.850 (0.015)	41.856 (0.015)	41.815 (0.015)	41.800 (0.025)	41.810 (0.025)	41.725 (0.025)	41.735 (0.015)
2θ $(\bar{2}04)$	50.580 (0.015)	50.575 (0.015)	50.575 (0.015)	50.595 (0.020)	50.595 (0.015)	50.600 (0.015)	50.600 (0.015)	50.625 (0.020)	50.635 (0.025)	50.625 (0.025)	50.660 (0.025)	50.645 (0.025)	50.635 (0.025)	50.730 (0.025)	50.730 (0.025)
2θ $(20\bar{1})$	21.030 (0.025)	21.040 (0.025)	21.040 (0.055)	21.050 (0.025)	21.100 (0.025)	21.050 (0.050)	21.035 (0.010)	21.060 (0.015)	21.020 (0.005)	21.000 (0.025)	21.045 (0.025)	21.030 (0.015)	20.870 (0.025)	20.931 (0.035)	20.950 (0.025)
D	0.03	0.40	0.6	3	5	6	7	15	25	30	40	50	60	75	80

Values in brackets are errors for each sample. D = Distance from the carbonatite contact (in metres). * Anomalous samples fenitized also by biotite carbonatite.

TABLE 2. XRD DATA OF ALBITE FROM FENITES AT LOE SHILMAN

SM. No.	82	80	83	84*	85	86	93*	94	87	95	96	97	88	89
2θ (060)	42.620 (0.015)	42.640 (0.015)	42.650 (0.015)	42.750 (0.050)	42.626 (0.015)	42.675 (0.015)	42.725 (0.040)	42.625 (0.025)	42.675 (0.025)	42.625 (0.025)	42.600 (0.025)	42.600 (0.020)	42.575 (0.020)	42.545 (0.040)
2θ $(\bar{2}04)$	51.150 (0.025)	51.160 (0.030)	51.175 (0.050)	51.125 (0.025)	51.155 (0.025)	51.200 (0.025)	51.145 (0.025)	51.200 (0.025)	51.170 (0.025)	51.175 (0.025)	51.188 (0.025)	51.213 (0.025)	51.200 (0.045)	51.265 (0.050)
2θ $(20\bar{1})$	22.050 (0.025)	22.050 (0.025)	22.050 (0.025)	22.100 (0.025)	22.100 (0.020)	22.070 (0.030)	22.050 (0.020)	22.060 (0.030)	22.050 (0.030)	22.060 (0.025)	22.080 (0.020)	22.110 (0.030)	22.100 (0.020)	22.100 (0.030)
2θ (131)	31.242 (0.015)	31.270 (0.020)	31.240 (0.025)	31.165 (0.025)	31.260 (0.010)	31.240 (0.025)	31.200 (0.020)	31.235 (0.020)	31.270 (0.015)	31.250 (0.015)	31.275 (0.015)	31.285 (0.015)	31.300 (0.020)	31.310 (0.015)
2θ $(1\bar{3}1)$	30.215 (0.012)	30.250 (0.020)	30.200 (0.025)	30.150 (0.020)	30.215 (0.010)	30.170 (0.015)	30.175 (0.020)	30.165 (0.020)	30.180 (0.015)	30.150 (0.015)	30.175 (0.015)	30.170 (0.015)	30.150 (0.020)	30.160 (0.015)
Δ 131	1.027	1.020	1.040	1.015	1.049	1.070	1.025	1.072	1.090	1.100	1.100	1.115	1.150	1.150
D	3	5	6	7	15	25	30	40	50	60	75	80	100	110

Δ 131 = 2θ $(1\bar{3}1)$ — 2θ (131). See Table 1 for explanation.

CHEMISTRY OF FELDSPARS FROM LOE SHILMAN

Energy dispersive microprobe representative analyses from different zones, at 15 kv on Cambridge microscan Mark 5, of K-feldspar and albite were made (Table 3), apart from K-feldspars present in the later vein as a result of biotite sovite. The K-feldspars in the beds or bands have no or little barium and mostly below detection limit, while in the later veins barium content is upto 1.4 wt % (Table 3). Based on low barium (1.4 wt% to nil) content, the K-feldspar, in beds/bands, formed at the expence of argillaceous material and phengite, can be distinguished from those present in the veins formed by the distal K-fenitizing fluids emanating from the later biotite sovite.

Albite, which is formed as a result of metasomatism by both amphibole sovite and ankeritic carbonatite, is always fresh and has constant chemical composition (Table 4). All these feldspars particularly albite have slightly higher iron content. Analysis of the feldspars by wave dispersive methods was not possible because of the very small size of the grains.

ORTHOCLASE AND MAX.-MICROCLINE SOLID SOLUTION SERIES

The least fenitized slates and phyllites of zone 1 (Fig. 1), c.110 metres from the carbonatite contact, show the sings of fenitization by the development of fresh albite and biotite. Little K-feldspar is present as very fine grains, which give poor analyses and are not stiochiometric. In K-feldspar the 100 intensity peak at 2θ 21.05 ($20\bar{1}$) is very weak and therefore (060) and (204) (30 and 18 intensities, respectively) are not considered in zone 1.

TABLE 3. REPRESENTATIVE MICROPROBE ANALYSES OF K-FELDSPAR FROM FENITES AT LOE SHILMAN

SM. No.	83	94	87	87*	96	97*
SiO_2	62.83	64.50	63.10	63.30	63.19	62.70
Al_2O_3	18.47	18.07	18.02	18.10	18.35	18.56
Fe_2O_3	0.10	0.06	0.44	0.49	0.16	0.00
CaO	0.00	0.05	0.09	0.08	0.00	0.00
Na_2O	0.48	0.32	0.76	0.46	0.35	0.67
K_2O	16.68	16.98	16.19	15.96	16.27	15.33
BaO	0.00	0.26	0.00	0.76	0.00	1.43
Total	98.56	100.24	98.60	99.15	98.32	98.69
		No. of ions on the basis of 32 Oxygens				
Si	11.859	11.977	11.897	11.904	11.914	11.858
Al	4.110	3.956	4.005	4.013	4.079	4.138
Fe^{3+}	0.014	0.018	0.062	0.069	0.023	0.000
Ca	0.000	0.010	0.018	0.016	0.000	0.000
Na	0.175	0.012	0.277	0.167	0.127	0.245
K	4.017	4.024	3.895	3.829	3.913	3.698
Ba	0.000	0.019	0.000	0.055	0.000	0.106

* Analysis from the vein

TABLE 4. REPRESENTATIVE MICROPROBE ANALYSES OF ALBITE FROM FENITES AT LOE SHILMAN

SM. No.	83	94	87	96	89
SiO_2	68.80	68.96	68.60	67.13	67.53
Al_2O_3	19.34	19.62	19.44	19.44	19.56
Fe_2O_3	0.30	0.30	0.44	0.46	0.41
CaO	0.02	0.00	0.00	0.05	0.00
Na_2O	11.80	11.02	11.23	11.01	11.06
K_2O	0.13	0.16	0.15	0.16	0.15
Total	100.39	100.06	99.86	98.35	98.71
		No. of ions on the basis of 32 oxygens			
Si	11.980	11.993	11.957	11.927	11.951
Al	3.972	4.021	3.995	4.071	4.081
Fe^{3+}	0.040	0.043	0.067	0.068	0.061
Ca	0.003	0.000	0.000	0.019	0.000
Na	3.986	3.716	3.797	3.793	3.795
K	0.028	0.036	0.033	0.037	0.034

However, in zone 2 (SM97 and SM96) at about 80 and 75 metres respectively, from the contact, the peaks for 060 and 204 are sharp (Fig. 2). The K-feldspars in zone 2 is plotted close to orthoclse on Wright (1968) diagram. In zones 3 and 4, K-feldspars show gradual increase in obliqiuty till these attain maximum triclinicity in zone 5 close to the carbonanitite contact. The existence of maximum-microcline, close to the contact, and that of intermediate-microcline, close to the orthoclase domain present in the outer zone 2, show a reverse zonation in contrast to temperature gradient. These K-feldspars are well correlated with the distance from the carbonatite contact. Attention is drawn to SM93 and SM84 which plot with zone 5 (Fig. 2).

A good correlation of the structural state of K-feldspars with distance is present where the values increase gradually from zone 5 to zone 3, and abruptly increase in zone 2. The samples SM93 and SM84 behave different from the rest of the samples in zone 4 (Fig. 3).

Unfortunately K-feldspar are not present in the metasediments and no K-metasomatism is present, apart from minor veins formed as a result of biotite sovite. All K-feldspars are formed at the expence of the argillaceous material and phengite. Therefore, these K-feldspars cannot be compared with any other data, though very little is available on metasomatic feldspars.

INTERPRETATION OF REVERSE ZONATION IN CONTRAST TO TEMPERATURE

The possibility of detrital orthoclase in the original sediments can be ruled out as the country rocks are low grade slates and phyllites where K-feldspars are not present as described above. In case detriatal K-feldspars were present in the original sediments then at low grade regional metamorphism these detriatal K-feldspars would not have escaped from the new low temperature environment.

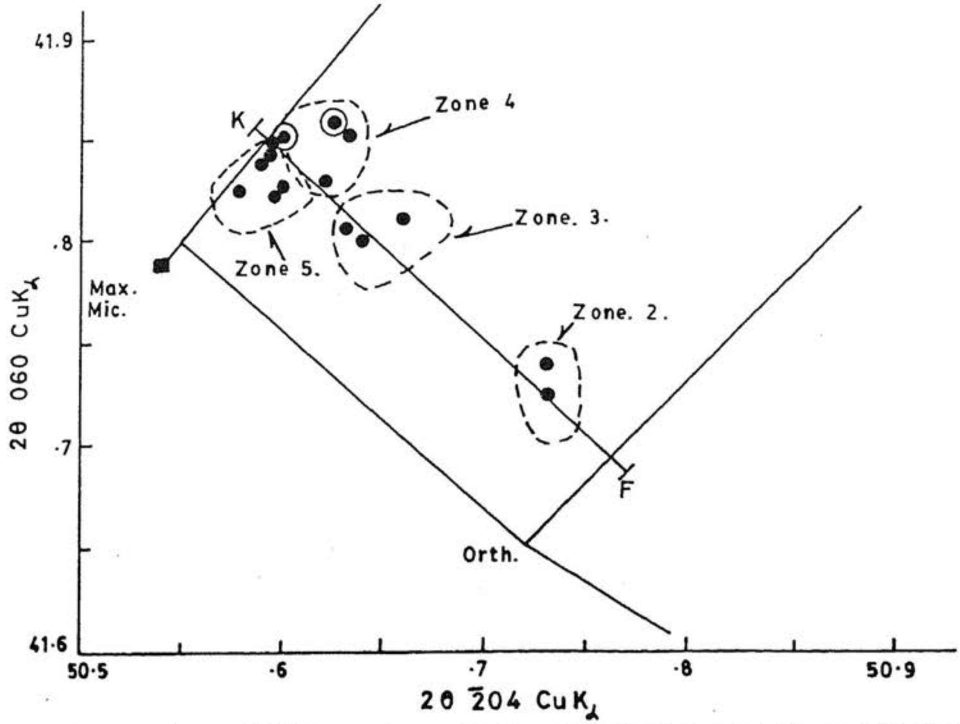

Fig. 2. The structural state of K-feldspars in zoned fenites at Loe Shilman carbonatite complex showing regular variation from orthocase to max.-microcline from zones 2–5. Dotted lines are errors for each zone. The encircled dots are the anomalous samples (SM84 and SM93) in zone 4 which plot towards the max.-microcline. KF is the section line for Fig. 3. The diagram is after Wright (1968).

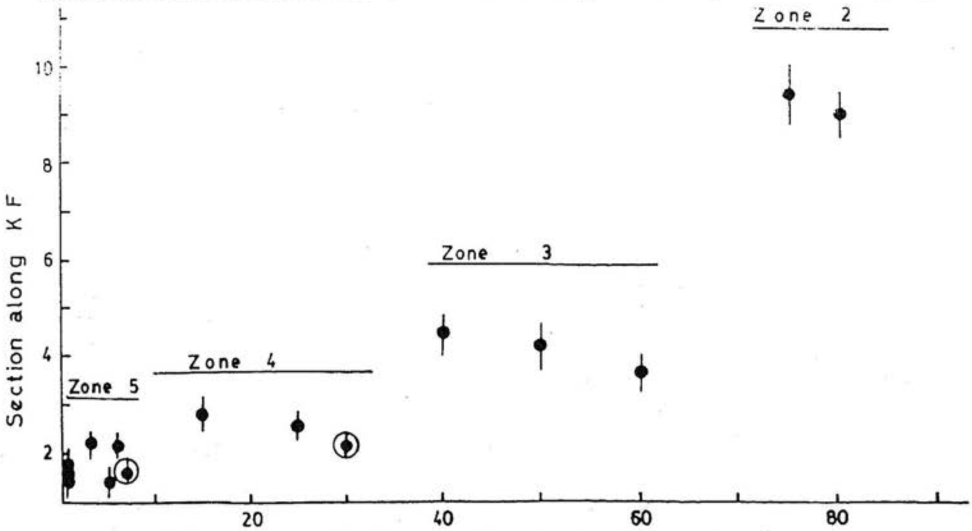

Fig. 3. The structural state of K-feldspars in zoned fenites at Loe Shilman showing good correlation with the distance from the carbonatite contact. KF is the section line for which arbitrary values are taken (1–10) for maximum-miocrocline and orthoclase respectively (see Fig. 2). Symbols some as in Fig. 2.

Therefore, after ruling out the possibility of detriatal K-feldspars, the only possible interpretation for their formation is by the contact effect of the carbonatite sheets, which is in accordance with the field data. In metamorphic auroles and also experimentally it is considered that orthclose is formed at higher temperature than max.-microcline. Therefore, the possible explanation for this reversal order and disorder can be explained if the temperature of fenitization by the earlier amphibole sovite is higher than the later ankeritic carbonatite. The disordered K-feldspar in zone 2 are interpreted to have been formed in an hydrous condition of the first sodic metasomatic fluids, rich in fluorine and CO_2 by the earlier amhibole sovite at a higher temperature. These feldspars are not affected by the later Na-metasomatism at a lower temperature by the later ankeritic carbonatite. Therefore in zone 2 the disordered K-feldspars, which were relatively ordered before the second metasomatism are the relict K-feldspars now present in zone 2. The more disordered K-feldspar (orthoclase), towards the contact by the increasing temperature, were present before the second metasomatism and interpreted to have been disordered. These disordered K-feldspars would have been present close to the orthoclase and high-albite tieline if the second metasomatism were not superimposed. The more disordered K-feldspar were readjusted to the low temperature environment by the ankeritic carbonatite in zone zones 3, 4 and 5. The effect of ankeritic carbonatite can not be traced upto zone 4 in the whole rock chemistry and the presence of phlogopite and phlogopitic biotite at the expance of biotite. However the temperature effect may have been extending upto zone 3 (Mian and Le Bas, in prep).

This type of reverse zonation is also shown by Currie and Ferguson (1971). Their data are analogous to our data and in both the cases the max. microcline occur close to the carbonatite contact and intermediate microcline and orthclose in the outer zones. According to Currie and Ferguson (1971) the unaffected K-feldspars are also orthoclase, and suggested temperatures for fenitization as 700°C and 450°C in the inner and outer zones, respectively. However, there was, and is, no feldspar in the metasediments at Loe Shilman prior to the first fenitization but possibly orthclase was present before the second Na-metasomatism as a relict from the first.

LOW-ALBITE AND ANOMALOUSLY LOW-ALBITE SOLID SOLUTION SERIES

In the east fenitized rock (zone 1), as stated earlier, the signs of metasomatism appear by the formation of albite and biotite. In each sample, albite gives sharp peaks at 2θ (060) and (204) (Fig. 4). Like K-feldspars, these albites are also anomalous in each zone.

In zone 1, where no K-feldspar is detectible in X-ray differaction pattern, the low-albite falls in low to intermediate structural state. Similar to K-feldspar, albite becomes more ordered towards the carbonatite contact in zones 2, 3, 4 and in part of zone 5 (Fi.g 4). These zonations in Fig. 4 are roughly correlated with the distance from the carbonatite contact. Samples SM93 and SM84 are exceptions where these albites are falling in the lowest stage and are more ordered than in zone 5. This is interpreted as to have been fenitized three times by amphibole and biotitic sovites and ankeritic carbonatite. The relict albite, formed by the first sovite, is present and its gradual increase reflects the readjustment by the low temperature ankeritic carbonatite (Fig. 5).

Ticlines can be drawn between the coexisted K-feldspars and albite which deviate from the trend given by Wright (1967) and many other workers. Similar to K-feldspars, the reverse zonation from low-albite to anomalously low-albite can be explained as stated earlier.

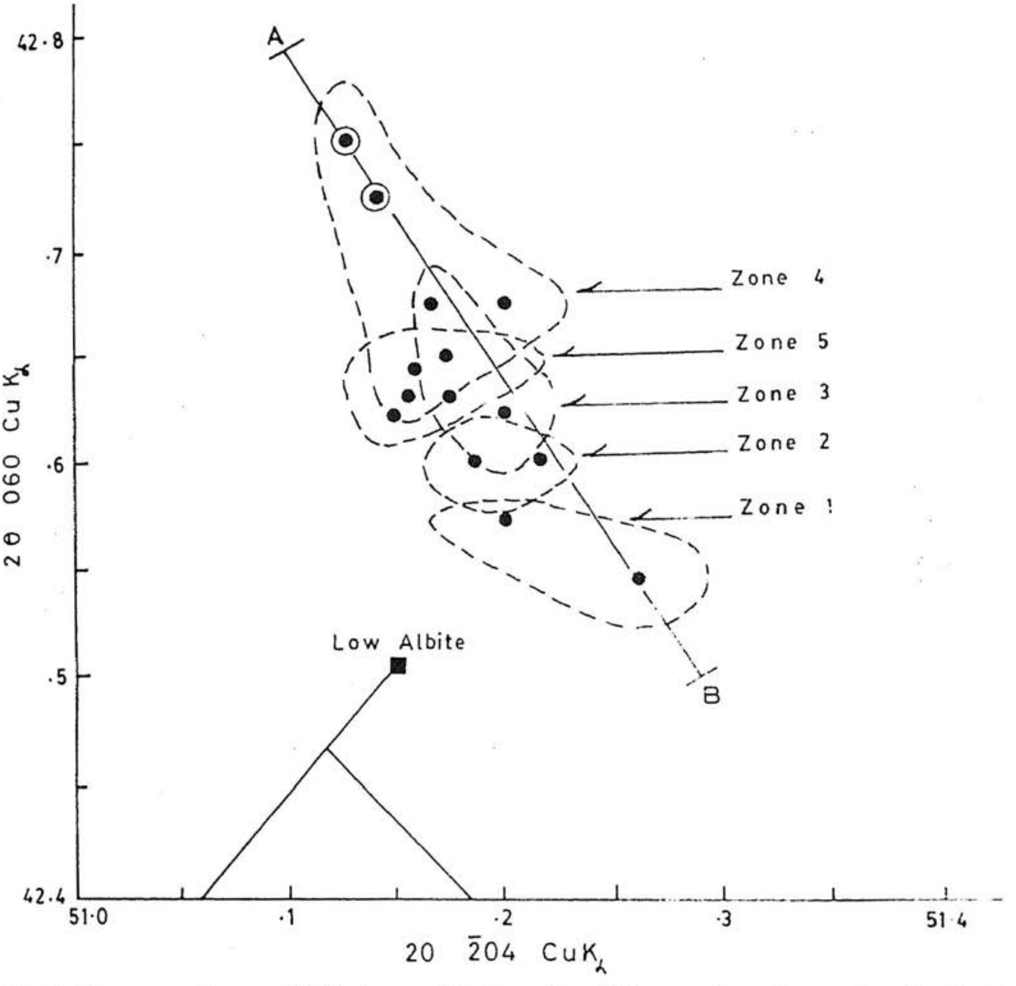

Fig. 4. The structural state of albite in zoned fenites at Loe Shilman carbonatite complex showing low albite in zones 1 and 2, and anomalously low albite in zones 3, 4 and 5. The anomalous samples SM84 and SM93 are plotted even further away from the rest of two samples in zone 4. AB is the section line for Fig. 5. The diagram is after Wright (1968). Symbols some in as in Fig. 2.

High to low reversal of degree of order and disroder in an anyhydrous condition at 18 kbars has been shown by Goldsmith and Jenkens (1985), using $\Delta 131 = 2\theta\ (131) - 2\theta\ (1\bar{3}1)$ as the indicator of degree of Al/Si order. They atain the order an disorder at 680°C 2θ 131 = 1.13 and show an increase upto 2.00 at 950°C. However, in albites of banded fenites at Loe Shilman, Δ131 increase regularly with distance from the carbonatite contact. In the inner zone 5 Δ131 is approximately 1.00 and increases to 1.15 in the outer zone 1, about 110 metres from the contact. This increase of Δ131 is well correlated with distance (Fig. 6).

There is a smooth increase in disordering away from the contact (anomalously low in zone 5 and low-intermediate in zone 1) (Fig. 6). Samples SM93 and SM84 show the lowest structural state compared to the other two sampls in zone 4 and fall even lower than the samples of zone 5.

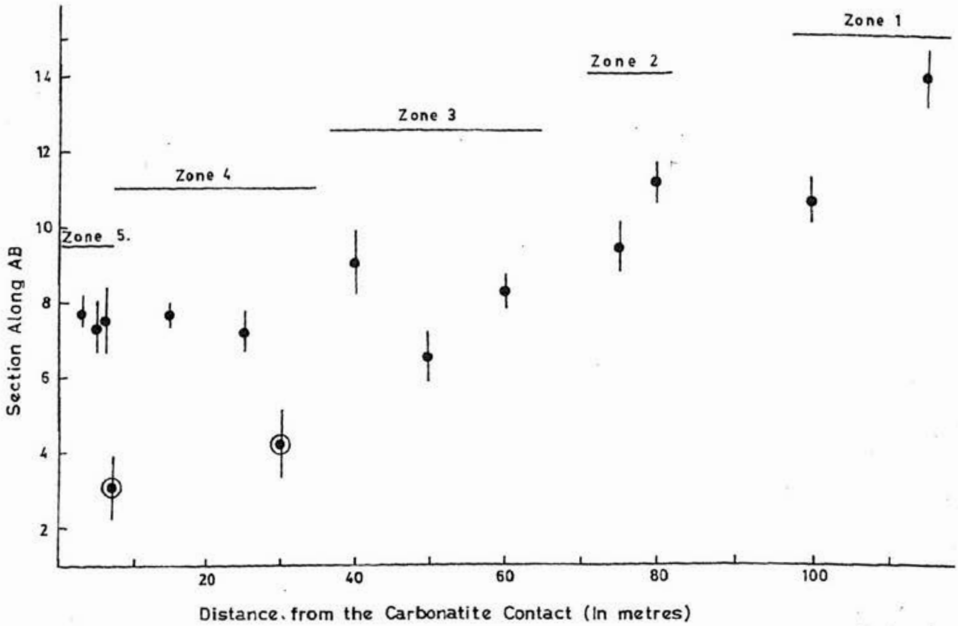

Fig. 5. The structural state of albite in fenites at Loe Shilman carbonatite complex, showing good correlation with the arbitrary values with the distances from the carbonatite contact. Note the anomalous samples SM84 and SM93 in zone 4. AB is the section line for which arbitrary values are taken (1–15) for anomalously low albite and low albite respectively (see Fig. 4). Symbols same as in Fig. 2.

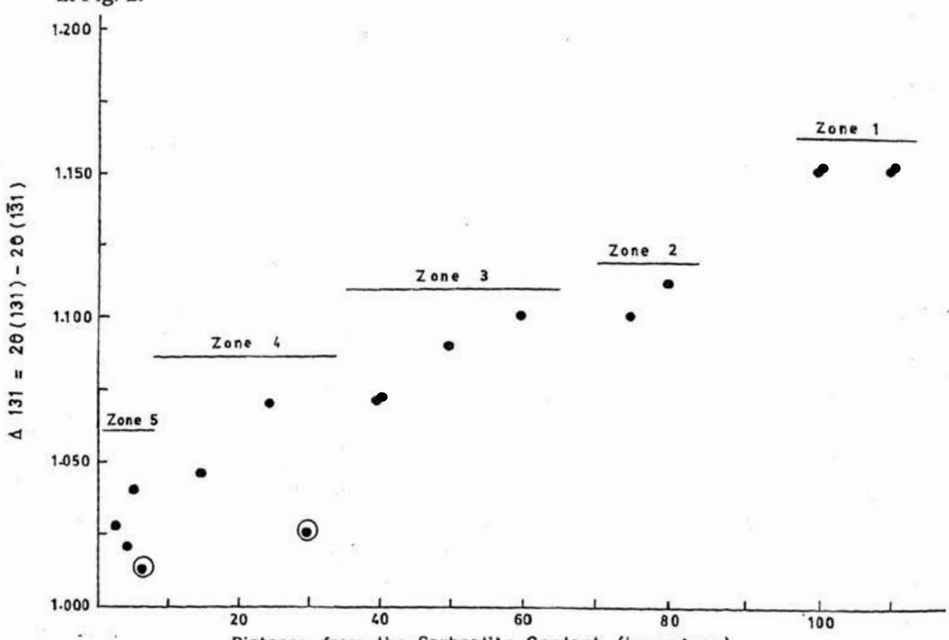

Fig. 6. The structural state of albite D131 = 2q (131) — 2q (131) is plotted against the distance from the carbonatite contact in zoned fenites at Loe Shilman. SM84 and SM93 fall in the lower state as compared to the other two samples of zone 4. Symbols some as in Fig. 2.

CONCLUSION

The K-feldspars and albites form solid solution series between maximum-microcline (zone 5) and intermediate orthoclse (zone 2), and anomalously low-albite (zone 5) and intermediate low-albite (zone 1), respectively, and constitute reverse zonation in contrast to temperature. This reverse zonation is interpreted as the result of an anhydrous Na-fenitizing fluid, by the ankeritic carbonatite, rich in Fluorine and CO_2 at appox. 400°C by the superimpostion of previous more diordered feldspars. The more diordered feldspars were originally formed in the same environments at approx. 700°C by the early amphibole sovite. Both the solid solution series are well correlated with the distance from the carbonatite contact.

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