

Sector-zoned kaersutite in camptonites from Morocco

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Abstract

Camptonites from the Taourirt region of Morocco contain kaersutite crystals that exhibit clear sector zoning. The electron microprobe reveals systematic variations between sectors, with preferential enrichment of Mg and Si in sector (011) and higher values for Fe, Ti and Al in sectors (110) or (100). These differences are similar to those recorded in clinopyroxenes with hour-glass zoning where this type of crystallization has been known for more than a century.

KEYWORDS: amphibole, kaersutite, sector zoning, Morocco.

Introduction

SECTOR zoning, otherwise called hour-glass structure, is a common type of zoning in magmatic as well as metamorphic minerals. It was observed and illustrated in augite, for example, at the onset of petrographic microscopic observation (e.g. Teall, 1888; Lacroix, 1893–1895) and has been mentioned in textbooks ever since. Recently this phenomenon has been considered again, mostly in pyroxenes (Nakamura, 1973), and interpreted as a growth phenomenon related to selective adsorption of minor and trace elements on to adjacent and crystallographically non-equivalent faces of the crystal in relation to different growth velocities (Baronnet, 1984). Sector zoning, though uncommon, is now also known in fast quenched feldspars (Bryan, 1972; Havette and Nativel, 1977) and was recently found in trioctahedral micas (Velde and Yoder, 1977). The purpose of this paper is to report the occurrence of sector zoning in amphiboles from intrusive basic rocks from Morocco.

Petrography

Sector-zoned amphiboles were found in four mineralogically similar specimens (K1, EG12, EGa and EG11) of camptonites from Eastern Morocco. These rocks were intruded in Eocene times. They form small (less than 3 m wide) dykes. Most dykes outcrop N of the village of Taourirt, along secondary road N 409. The crystals described in this paper were found in specimens collected on

outcrops situated 1 km N of Ferme Dubois ($x = 722.50$, $y = 428.85$ on the Taourirt sheet of the 1:50 000 map of Morocco) and 2 km NW of Ferme Dubois ($x = 719.92$, $y = 431.85$). Other camptonites do not differ from those in which we found the sector-zoned kaersutites and hence we believe that identical features may be found in other camptonites from the same area. Their mineralogical composition comprises the association clinopyroxene, amphibole, and feldspar, with accessory apatite and Fe-Ti oxides (Mokhtari, 1985). The groundmass (mostly feldspar) is frequently altered. Abundant xenocrysts include inherited spinels of various Cr/(Al + Cr) ratios; olivine (altered); clinopyroxene of varied compositions; amphiboles; and Ti-phlogopites. The amphiboles, pyroxenes, and micas, phases that are stable species in the camptonite melt, may be surrounded, sometimes after partial dissolution, by authigenic rims with the same compositions as the phases crystallized from the magmatic liquid. Minerals with identical compositions to those found in the camptonites are also known as xenolith-forming crystals in the Quaternary basaltic rocks of the middle Atlas (Moukadiri, 1983), and could correspond to fragments of an ultrabasic basement through which the Quaternary basalts as well as the Tertiary camptonites were intruded. The compositions of clinopyroxenes coexisting with amphibole in one of the specimens investigated have been determined with the electron microprobe, and representative analyses are listed in Table 1. The compositions of the phases interpreted as xenocrysts are not considered in this paper.

Amphibole composition

The amphiboles belong to the kaersutite group using the Leake (1978) classification. They are similar in composition to amphiboles described by Rock (1982) in basic rocks from the Monchique alkaline complex. In the Moroccan camptonites amphibole does not, as a rule, exhibit a wide range of composition, and zonations are frequently limited to a small normal Fe/(Fe + Mg) variation.

TABLE 1. ELECTRON MICROPROBE ANALYSES OF CLINOPYROXENE IN SPECIMEN EG 11

	1	2
SiO ₂	47.06	45.66
Al ₂ O ₃	6.60	6.74
FeO (°)	6.62	6.80
MgO	13.16	12.89
CaO	23.12	23.04
Na ₂ O	0.58	0.45
MnO	0.14	0.12
TiO ₂	2.67	3.38
Cr ₂ O ₃	0.02	0.04
Total	99.97	99.12
Structural formulae based on 4 cations and 6 oxygens		
Si	1.742	1.711
Al	0.288	0.298
Fe ³⁺	0.119	0.121
Fe ²⁺	0.086	0.092
Mg	0.726	0.720
Ca	0.917	0.925
Na	0.042	0.033
Mn	0.004	0.004
Ti	0.074	0.095
Cr	0.001	0.001
Total	4.0	4.0

Analysis 1, phenocryst
Analysis 2, microphenocryst
FeO (°) = Total iron as FeO

Sector zoning is a rare feature in the rocks studied. It is shown by large as well as small crystals, and the rocks in which the zoning is found do not differ in texture from those that lack sector-zoned crystals. An illustration of a small euhedral sector-zoned crystal is shown in Fig. 1.

Methods

Zoned crystals were studied with an automated CAMEBAX electron microprobe. Operating conditions were: accelerating voltage, 15 kV; current, 15 nA; counting time varied, depending on the element abundance, between 20 and 50 seconds. The orientation of the zones with respect to the orientation of the crystals was determined using a LEITZ universal stage.

Structural formulae were computed on the basis of 23 oxygens. All attempts to calculate a Fe³⁺/Fe²⁺ ratio according to the various existing methods failed. As pointed out by Rock (1982) the sum of cations excepting Ca, Na, and K in kaersutites is equal to or usually less than 13 so that calculations assuming an ideal 13 ions are inapplicable.

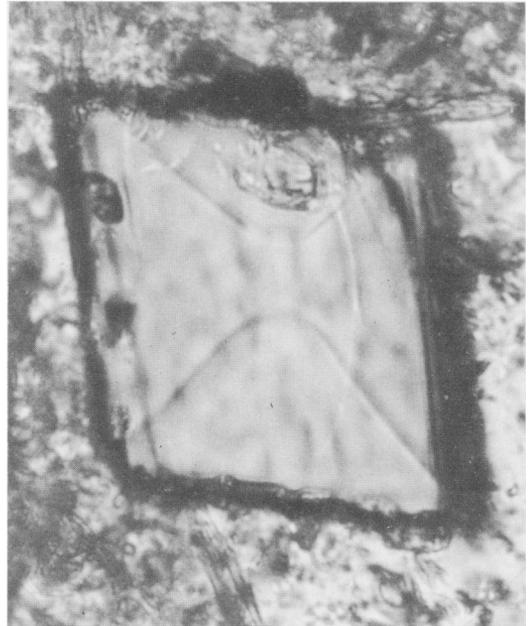


FIG. 1. Sector-zoned kaersutite crystal in specimen K1. The length of the crystal is 0.07 mm. Plane polarized light.

Results

The best results were obtained on a section of amphibole found in specimen K1 that was clearly cut parallel to the growth directions of adjacent sectors (Fig. 2). In all cases, analyses were made on each side of the border-line between two contiguous sectors so as to be able to evaluate differences in composition between isochronous points situated on simultaneously developed growth zones of contiguous sectors.

In all sector zones there are regular variations in composition in the direction of growth, from the centre of the crystals towards the edge. In this outward direction the zoning is normal, with Mg decreasing while Fe increases; Al also increases while Si decreases, a common trend in chain silicates from rocks undersaturated with respect to silica. The variations in TiO₂ are irregular, and

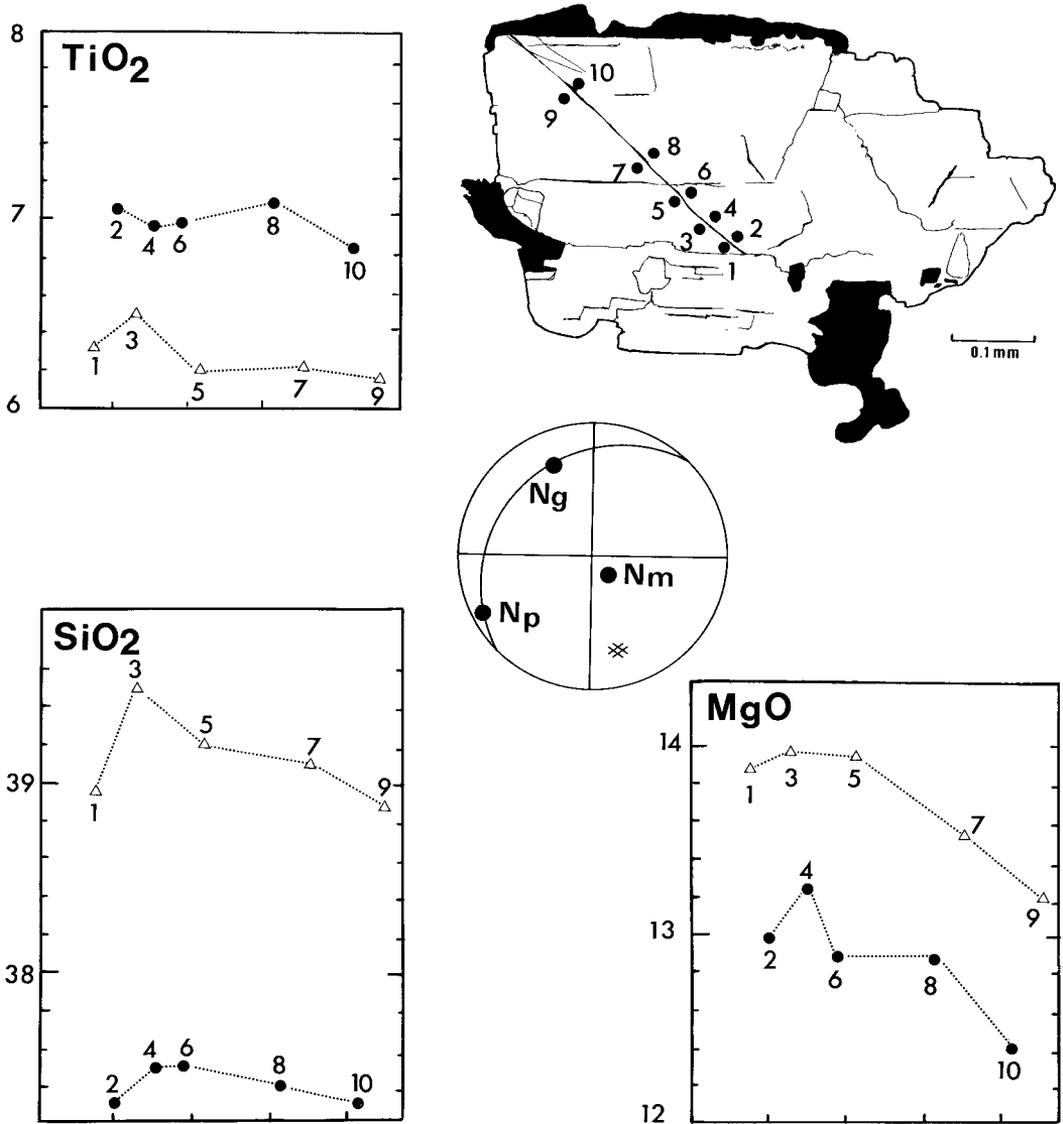


FIG. 2. Schematic drawing of an (incomplete) sector-zoned kaersutite crystal from specimen K1. Dark patches represent hematite. The electron microprobe results (see Table 2) for MgO, SiO₂, and TiO₂ are plotted against the distance of the analysed spot along the sector boundary (measured from an arbitrary point). Solid circles, sectors (110) and (100); open triangles, sector (011).

might be more akin to an oscillatory zoning than to a regular zoning pattern.

Differences between sectors

The best crystal (found in the specimen K1) will be considered first (Fig. 2 and Table 2). The

variations in the elements follow the normal zoning pattern indicated above. However, isochronous points show very clear differences. Sector (011) shows higher values for Mg and Si, and lower values for Fe, Al, and Ti than sectors (100) and (110). There is also a noticeable difference in K, more abundant in the (100) and (110) sectors, i.e.

TABLE 2. ELECTRON MICROPROBE ANALYSES OF SECTOR-ZONED KAERSUTITE CRYSTAL (SPECIMEN K1)

	1	3	5	7	9	2	4	6	8	10
SiO ₂	38.88	39.51	39.18	39.10	38.77	37.31	37.45	37.56	37.46	37.32
Al ₂ O ₃	13.74	13.73	13.90	13.86	13.69	14.82	14.66	14.86	14.74	14.48
FeO (°)	8.80	8.79	8.88	9.15	9.52	8.98	9.11	9.11	9.25	9.97
MgO	13.88	13.97	13.94	13.51	13.23	13.01	13.24	12.88	12.89	12.40
MnO	0.13	0.19	0.10	0.14	0.12	0.12	0.11	0.14	0.11	0.08
CaO	12.12	12.29	12.37	12.22	12.28	12.25	12.32	12.08	12.28	12.00
Na ₂ O	2.57	2.57	2.46	2.45	2.52	2.33	2.54	2.42	2.53	2.40
K ₂ O	1.27	1.25	1.30	1.28	1.28	1.40	1.35	1.36	1.35	1.33
TiO ₂	6.36	6.51	6.19	6.22	6.16	7.05	6.96	6.96	7.09	6.84
SrO	0.12	0.34	0.29	0.30	0.32	0.35	0.18	0.36	0.30	0.38
Cl	0.12	0.12	0.14	0.14	0.09	0.09	0.11	0.12	0.12	0.12
Total	97.99	99.27	98.75	98.37	97.98	97.71	98.03	97.85	98.12	97.32
Structural formulae based on 23 oxygens										
Si	5.727	5.749	5.734	5.749	5.738	5.540	5.544	5.568	5.547	5.586
Al	2.386	2.355	2.398	2.402	2.388	2.594	2.558	2.596	2.573	2.555
Fe ²⁺	1.084	1.070	1.087	1.125	1.178	1.115	1.128	1.129	1.145	1.248
Mg	3.047	3.029	3.040	2.960	2.918	2.879	2.921	2.845	2.844	2.766
Mn	0.016	0.023	0.012	0.017	0.015	0.015	0.014	0.018	0.014	0.010
Ti	0.705	0.712	0.681	0.688	0.686	0.787	0.775	0.776	0.790	0.770
Ca	1.913	1.916	1.940	1.925	1.948	1.949	1.954	1.919	1.948	1.924
Na	0.734	0.725	0.698	0.699	0.723	0.671	0.729	0.696	0.726	0.697
K	0.239	0.232	0.243	0.240	0.242	0.265	0.255	0.257	0.255	0.254
Sr	0.010	0.029	0.025	0.026	0.027	0.030	0.015	0.031	0.026	0.033
Total	15.861	15.840	15.857	15.831	15.864	15.844	15.894	15.835	15.868	15.842
"mg"	26.20	24.53	26.30	27.50	28.70	27.90	27.80	28.40	28.70	31.10

"mg" = 100 Fe/(Fe+Mg). See fig. 2 for locations of analysed points on the crystal.
FeO (°) = total iron as FeO

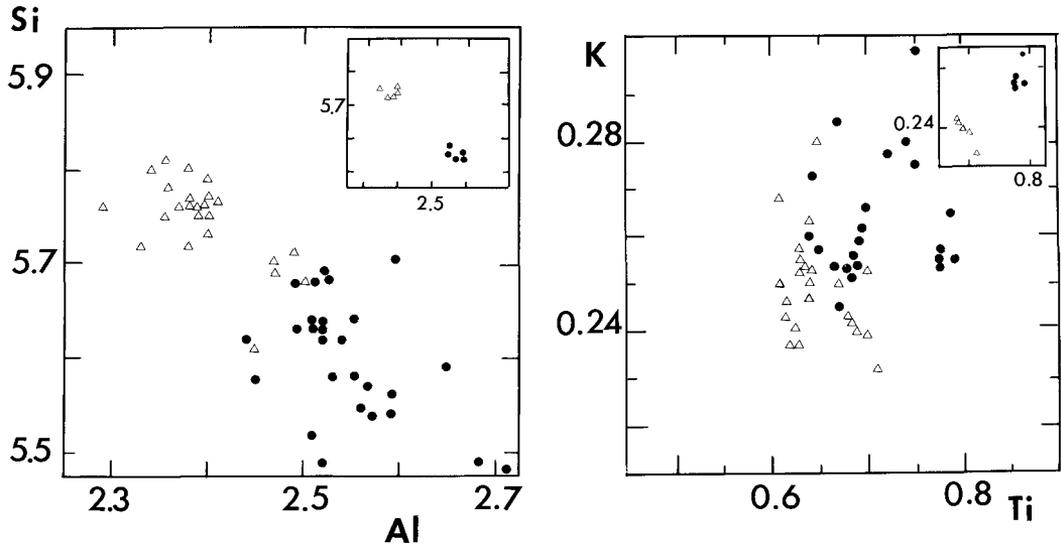


FIG. 3. Plots of Si and Al, and K and Ti in all analysed sector-zoned amphibole crystals. Inserts, analyses from specimen K1. Solid circles, sectors (100) and (110); open triangles, sector (011).

showing an apparent correlation with Ti (Fig. 3). No systematic differences were found in the distribution of the minor elements. Trace element determinations were conducted on an amphibole fraction separated from rock specimen EGa in order to find any unusual trace element pattern. No abnormal abundance of any element was detected. Bulk chemical composition of one of the specimens investigated is listed in Table 3, together with results of the instrumental neutron activation analysis of the bulk rock and of an isolated fraction of amphibole. The separated amphibole fraction was not exclusively composed of crystals with hour-glass zoning.

TABLE 3. ANALYSIS RESULTS FOR SPECIMEN EG a

	1	2	3	4
SiO ₂	39.62		U 0.32	1.34
Al ₂ O ₃	10.83	Or 3.84	Th 1.06	4.6
Fe ₂ O ₃	6.36	An 16.79	Zr 213	273
FeO	5.81	Ne 7.84	Hf 5.6	5.6
MnO	0.15	Lc 4.84	Ta 9.54	7.0
MgO	12.30	Di 35.21	Sr 1714	506
CaO	13.52	Fo 10.11	Cs 2.1	1264
Na ₂ O	1.71	Ma 8.40	Rb 77.9	0.83
K ₂ O	1.71	He 0.56	Sb 0.02	43.0
TiO ₂	3.73	Il 7.08	Cr 153	447
P ₂ O ₅	0.77	Ap 1.80	Co 70.5	56.1
L.I.	2.57		Ni 259	218
Total	99.08		Sc 26.2	28.8
			La 29.8	51.8
			Ce 68.7	105
			Eu 2.84	3.54
			Tb 0.92	0.98
			Sm 7.5	8.5
			Yb 0.91	1.31
			Nd	62

1, 2 Bulk chemical composition and CIPW norm

3, INA data on amphibole crystals

4, INA data on whole rock.

All the results obtained from all four analysed sector-zoned crystals analysed are plotted in bivariate variation diagrams (Fig. 3), where the distribution of the elements can be seen to follow the scheme found for one crystal from specimen K1. There is indeed a difference in the chemical composition of the two sectors with respect to the elements considered above. Furthermore, there is a systematic difference in the Fe/(Fe + Mg) content of isochronous points in all the crystals studied. In Fig. 4 the variations in composition in the four crystals studied are summarized. Sectors (100) and (110) are systematically richer in Fe, expressed as Fe/(Fe + Mg), than sector (011). These same prismatic sectors that can be considered as corresponding to slow growth directions appear also enriched

in Ti, K, and Al relative to the other sectors. A similar variation pattern for Ti and Al was described in sector-zoned titanaugite by Hollister and Gancarz (1971). As shown in Fig. 4 this systematic variation persists with varying proportions of iron and magnesium. It is consequently difficult to understand why this phenomenon has not been previously reported; it is possible that it is not uncommon but has simply been overlooked.

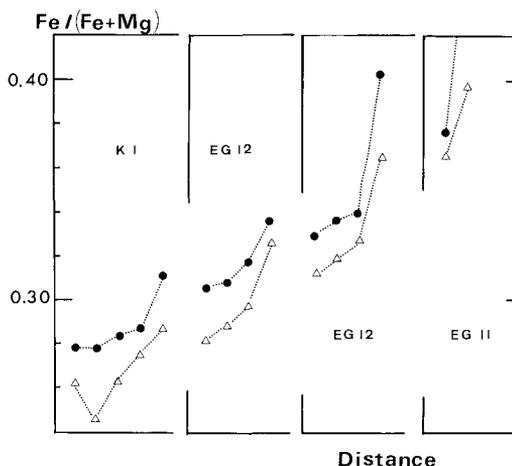


FIG. 4. Variations of Fe/(Fe + Mg) in four crystals from specimens K1, EG 12, and EG 11. Solid circles, sectors (100) and (110); open triangles, sector (011). The ratio is plotted, for each crystal, against distance from an arbitrary point situated near the centre of the crystal section.

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References

- Baronnet, A. (1984) Growth kinetics of the silicates. A review of basic concepts. *Fortschr. Mineral.* **62**, 187–232.
- Bryan, W. B. (1972) Morphology of quench crystals in submarine basalts. *J. Geophys. Res.* **77**, 5812–9.
- Havette, A., and Nativel, P. (1977) Apport de l'analyse ionique à l'étude minéralogique d'une ignimbrite à chimisme de benmoréite du cirque de Salazie (île de la Réunion). *Bull. Soc. Fr. Mineral. Cristallogr.* **100**, 20–7.
- Hollister, L. S., and Gancarz, A. J. (1971) Compositional sector-zoning in clinopyroxene from the Narce area, Italy. *Am. Mineral.* **56**, 959–79.

- Lacroix, A. (1893-5) *Minéralogie de la France et de ses colonies. Description physique et chimique des minéraux. Etude des conditions géologiques de leurs gisements. Tome Premier*. Paris, Librairie Polytechnique, 719 pp.
- Leake, B. E. (1978) Nomenclature of amphiboles. *Am. Mineral.* **63**, 1023-52.
- Mokhtari, A. (1985) *Etude pétrologique et minéralogique des roches éruptives alcalines éocènes (théralites) de la région de Taourirt (Maroc Oriental)*. Thèse 3^e cycle, Université P. et M. Curie, No. 85-33, 42 pp.
- Moukadiri, A. (1983) *Les enclaves ultrabasiques associées aux basaltes alcalins dans le district volcanique d'Azrou-Timahdite (Moyen Atlas, Maroc)*. Thèse de 3^e cycle, Géologie, No. 745, Université de Clermont Ferrand, 150 pp.
- Nakamura, Y. (1973) Origin of sector zoning of igneous clinopyroxenes. *Am. Mineral.* **58**, 986-90.
- Rock, N. S. M. (1982) Chemical mineralogy of the Monchique alkaline complex, Southern Portugal. *Contrib. Mineral. Petrol.* **81**, 64-78.
- Teall, J. J. H. (1888) *British Petrography: with special reference to the igneous rocks*. London, Dulau and Co. 469 pp.
- Velde, D., and Yoder, H. S. Jr. (1977) Trioctahedral micas in melilite-bearing eruptive rocks. *Carnegie Inst. Washington, Yearb.* **76**, 483-5.

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