

THE FELDSPARS OF THE SIERRA ALBARRANA GRANITIC PEGMATITES, CORDOBA, SPAIN

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ABSTRACT

The feldspars from granitic pegmatites of the Sierra Albarrana Lower Paleozoic complex (Córdoba, Spain) are present in the following structural states: orthoclase, low and intermediate microcline, the latter being the most abundant of the three, as revealed by an X-ray-diffraction study (powder method). The Al-Si distribution is quite ordered, with triclinic phases of intermediate triclinicity, and moderate degree of order, together with highly ordered phases, whereas only two samples are more disordered and have monoclinic symmetry. The Al-Si distribution seems to follow an intermediate trend between a one-step and a two-step path of ordering. The geochemical data show that in the successive generations of feldspars, the Or and An contents decrease, whereas the Ab content increases. In the same way, the P, Rb and Cs contents increase, whereas the Sr and Ba contents decrease. Pb presents an erratic behavior. Toward the center of the pegmatite, t_{10} value increases, and t_{1m} and $2t_2$ decrease. The feldspars reveal the development of the magmatic, subsolidus and hydrothermal stages of crystallization of Parsons & Brown (1984). The first stage is demonstrated by the metastable persistence of disordered monoclinic feldspar (orthoclase). During the subsolidus stage, triclinic feldspar appears with an intermediate degree of order and the development of vein-textured and braided perthite and albite-pericline twinning. K-feldspar with a high degree of order (close to the low microcline end-member) and the development of patch perthite are indicative of the hydrothermal stage.

Keywords: feldspars, granitic pegmatites, X-ray diffraction, powder method, Al-Si order, orthoclase, microcline, Sierra Albarrana, Spain.

SOMMAIRE

Une étude par diffraction X sur poudres de feldspath perthitique provenant de pegmatites granitiques du complexe paléozoïque de Sierra Albarrana, à Córdoba, en Espagne, démontre la présence de l'orthose, du microcline ordonné et du microcline intermédiaire, le plus abondant. La distribution Al-Si est relativement bien ordonnée; la plupart des échantillons contiennent un feldspath triclinique à "triclinicité" intermédiaire, et montrent une association de celui-ci avec un microcline très bien ordonné, tandis que seulement deux échantillons contiennent un feldspath monoclinique, et donc plus désordonné. La distribution de Al et Si semble poursuivre une évolution intermédiaire entre une transition à une étape et à deux étapes. Les données géochimiques montrent que dans les générations successives de feldspaths, la teneur en Or et en An diminue, tandis que la teneur en Ab augmente. De la même façon, la teneur en P, Rb et Cs augmente, tandis que celle en Sr et Ba diminue. Le Pb a un comportement erratique. La valeur de t_{10} augmente vers le cœur de la pegmatite, et t_{1m} et $2t_2$ diminuent. Les grains de feldspath montrent un développement magmatique et des modifications subsolidus et hydrothermales (Parsons & Brown 1984). Le premier stade de cristallisation est partiellement préservé dans l'orthose. Au cours du stade subsolidus, le feldspath triclinique à degré d'ordre intermédiaire a fait son apparition, de même qu'une texture perthitique en veines et en tresses et les macles albite-péricline. Le feldspath potassique à degré d'ordre élevé, près du pôle microcline ordonné, et le développement de perthite en taches sont les manifestations du stade hydrothermal.

(Traduit par la Rédaction)

Mots-clés: feldspaths pegmatites granitiques, diffraction X, méthode des poudres, degré d'ordre Al-Si, orthose, microcline, Sierra Albarrana, Espagne.

INTRODUCTION AND GEOLOGICAL CONTEXT

The pegmatite deposits of Sierra Albarrana, of Hercynian age according to Azor *et al.* (1991), are located in the northern part of the province of Córdoba, near the

town of Fuenteobajuna, in the southwestern part of the Iberian Massif, in the Ossa Morena zone (Chacón *et al.* 1974, Garrote 1976, Eguluz 1987, Azor *et al.* 1991) (Fig. 1A). The host rocks (Fig. 1B) are Lower Paleozoic rocks belonging to three distinct complexes (Garrote *et*

TABLE 1. CHARACTERISTIC OF PEGMATITES AND HOST ROCKS

TYPE	PEGMATITES			HOST - ROCKS	
	SHAPE & DIMENSIONS	NUMBER OF BODIES	MINERALOGY	METAMORPHISM	LITHOLOGY
I. AMPHIBOLE-EPIDOTE PEGMATITES	Irregular bodies (1 - 100 cm)	2	Amph, Ep, Ab, Tur	Sil - K-Fd	Amphibolites and amphibolitic gneisses
II. AL-SILICATE PEGMATITES	Irregular bodies (1 - 100 cm) or tabular masses (max. length = 1 m; max. width = 20 cm)	10	Q, And, Sil, Ms, St, Chl	Sil - K-Fd Sil - Ms St - And	Muscovite schists
III. QUARTZ-FELDSPAR PEGMATITES	Irregular and tabular masses (max. length = 550 m; max. width = 100 m)	60	Q, K-Fd, Ab, Ms, Tur, Grt, Bt, Brl, Chrl, Chl, Rt, Ap, Zrn, Py, Mag, Ilm, U minerals	Sil - K-Fd Sil - Ms	Feldspar quartzites and gneisses

Amph = amphibole, Ep = epidote, Ab = albite, Tur = tourmaline, Q = quartz, And = andalusite, Sil = sillimanite, Ms = muscovite, Bt = biotite, Chl = chlorite, K-Fd = K-feldspar, Grt = garnet, Brl = beryl, Chrl = chrysoberyl, Rt = rutile, Ap = apatite, Zrn = zircon, Py = pyrite, Mag = magnetite, Ilm = ilmenite, St = staurolite.

al. 1980, Ortega-Huertas *et al.* 1982, Azor *et al.* 1991): 1) a succession of metamorphic rocks: quartzites, gneisses, schists, amphibolites and metabasites (Chacón *et al.* 1974, Garrote 1976, Delgado-Quesada *et al.* 1977, Quesada *et al.* 1990) (Fig. 1B, 1 to 6), 2) continental-type conglomeratic sediments, with abundant clasts of metamorphic rocks, lava flows and pyroclastic materials, which unconformably overlie the metamorphic rocks (Garrote & Sánchez-Carretero 1983, Gabaldón *et al.* 1983) (Fig. 1B, 7), and 3) postmetamorphic igneous rocks including the Alcornocal volcanic complex and the granitic stock of La Cardenchosa (Delgado-Quesada 1971).

A metamorphic zonation has been recognized in the Sierra Albarrana area (Garrote 1976): from high to low grade, sillimanite - K-feldspar, sillimanite-muscovite, staurolite-andalusite, garnet, biotite and chlorite (Fig. 1C). The distribution of pegmatites (Figs. 1B, C) is controlled by this metamorphic zonation. The pegmatites appear only in the three higher-grade zones.

The morphology and types of pegmatites are summarized in Table 1 according to their mineralogical composition and the characteristics of the host rocks. The feldspars described here are from type-III granitic pegmatites (Table 1). As these pegmatites do not contain a typical quartz core, we have only been able to establish the following zonation from border to center and from top to bottom of the pegmatite bodies in some outcrops

(Cerro de la Sal, Peña Grajera, Juan Calvillo: Figs. 2, 3 and 4).

1) Border zone (zone 2, Figs. 2-4): medium-grained pegmatites of granitic texture, whose size increases gradually inward. This zone contains quartz and perthitic feldspar and is rich in tourmaline, garnet, chlorite, muscovite and arborescent biotite.

2) Wall zone (zone 3, Figs. 2-4): coarse-grained, with a graphic texture, containing quartz, K-feldspar, albite and minor muscovite.

3) Intermediate zone or Central zone (zone 4, Figs. 2, 4; zone 3, Fig. 3): very coarse-grained (crystals of one to two meters) and giant pegmatitic texture, mainly made up of quartz and K-feldspar.

METHODOLOGY

Feldspar samples were collected from the principal type-III pegmatites in the following outcrops: Cerro de la Sal, Peña Grajera, Diéresis, Los Morales, Umbría, Colmenar, Beta, Coma, Cruz de Chaparral, Traviesas, Taravilla, Valverde, Alameda, Valdenoque, Juan Calvillo, Pozos de Juan Calvillo, Río Bembezar and Fuenteobejuna (Figs. 1B, 2, 3 and 4). All outcrops are irregular, tabular masses (Table 1).

The optical and textural characterization of the potassic feldspar and plagioclase was carried out by study of

FIG. 1. (A) Geographic location of Sierra Albarrana. (B) Geology of Sierra Albarrana and location of the main pegmatites (modification of the map of Contreras *et al.* 1983). (C) Metamorphic zonation (modification of the results of Contreras *et al.* 1983). (a) Host rocks: 1. Albarrana Formation: feldspathic quartzites with metapelitic layers, 2. Cabril Formation: pelitic gneisses, 3. Peña Grajera Formation: migmatitic gneisses, amphibolitic gneisses, amphibolites, 4. Montesina Formation: schists, 5. Bembezar Formation: schists, quartzites and metabasites, 6. Azuaga Formation: phyllites and metagreywackes, 7. Valdinierno Basin (Lower Carboniferous). (b) Pegmatites: 8. quartzofeldspathic pegmatites, 9. pegmatites with aluminum silicates, 10. pegmatites with amphibole or epidote (or both). Principal pegmatite quarries: Cerro de la Sal: CS, Peña Grajera: PG, Diéresis: D, Los Morales: LM, Umbría: U, Colmenar: CO, Beta: B, Coma: C, Cruz de Chaparral: CHA, Traviesas: T and TA, Taravilla: TAR, Valverde: VAG, Alameda: AL, Valdenoque: VD, Juan Calvillo: JC, Pozos de Juan Calvillo: MG, and Río Bembezar: RB. (c) Metamorphic zones: 11. Lower Carboniferous (postmetamorphic), 12. biotite and chlorite zones, 13. garnet zone, 14. staurolite-andalusite zone, 15. sillimanite-muscovite zone, 16. sillimanite - K-feldspar zone.

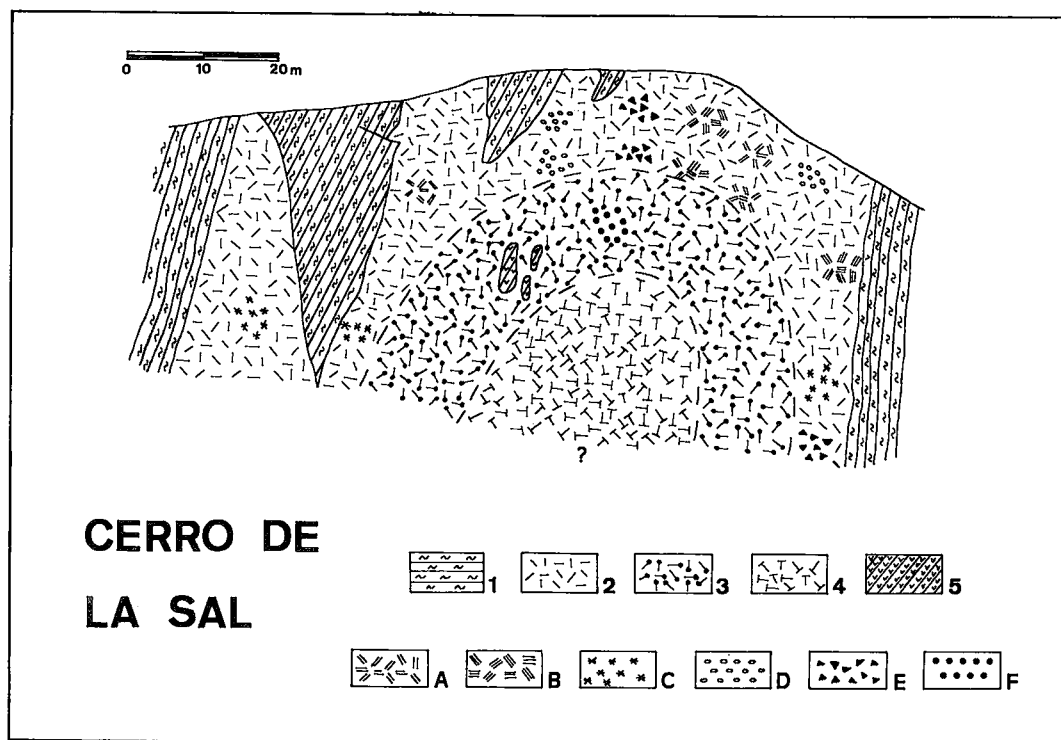


FIG. 2. Schematic cross-section of the Cerro de la Sal quarry showing internal zonation and location of samples: 1. Host rocks: quartzitic gneisses, 2. Border zone: quartz-perthite pegmatite (granitic texture), 3. Wall zone: quartz-perthite pegmatite (graphic texture), 4. Intermediate zone: quartz - microcline - albite pegmatite (giant pegmatite structure), 5. chlorite - muscovite - garnet nodules. A. Muscovite, B. Biotite, C. Chlorite, D. Garnet, E. Tourmaline, F. Beryl.

thin sections, some of which were stained with sodium cobaltinitrite (after one minute etching with HF fumes).

Feldspar grains were separated manually (under the binocular microscope) and then ground in an agate mortar for an investigation of structural and compositional properties by X-ray diffraction (powder method). A Philips PW1710 diffractometer was used with $\text{CuK}\alpha$ radiation, graphite monochromator and automatic slit. External standards of Si, CaF_2 and KBrO_3 were used in the calibration of the equipment. KBrO_3 also was used as an internal standard (in a 1:1 proportion with the feldspar).

Two diffractograms were made of each sample using the "POLVO" program of Martín-Ramos (1990) under the following experimental conditions: 40 kV, 40 mA, Recorder Full Scale = 1×10^3 counts per second, integration time = 0.6 s, and static record in order to avoid peak displacement. The first diffractogram was made between 27° and $32^\circ 2\theta$, with a scanning speed of $1^\circ 2\theta/\text{min}$ and counts recorded every $0.012^\circ 2\theta$ in order to differentiate between monoclinic and triclinic K-feld-

spar by the profile of the 131 and $\bar{1}\bar{3}1$ reflections; the second (full) diffractogram was made between 3° and $80^\circ 2\theta$, and counts recorded every $0.060^\circ 2\theta$.

The results were interpreted using the "LECTOR" routine ("POLVO" program, Martín-Ramos 1990), following the recommendations of Bish & Post (1989). The resulting reflections were indexed according to the data of Wright & Stewart (1968), Borg & Smith (1969) and Ribbe (1983a). The crystallographic parameters were refined by least squares using the program of Appleman & Evans (1973) ("LSUCRE").

The triclinicity index was calculated following the formula of Goldsmith & Laves (1954). The degree of Al-Si order was determined using: a) the method of Kroll & Ribbe (1987) derived from the $b - c^*$ and $\alpha^* - \gamma^*$ diagrams, b) on the basis of the translation distances in the $[110]$ and $[1\bar{1}0]$ directions following Kroll (1971, 1973, 1980) and Kroll & Ribbe (1987), c) on the basis of the "corrected" translations in the $[110]$ and $[1\bar{1}0]$ directions following Kroll & Ribbe (1987). The degree of internal strain was determined following Stewart &

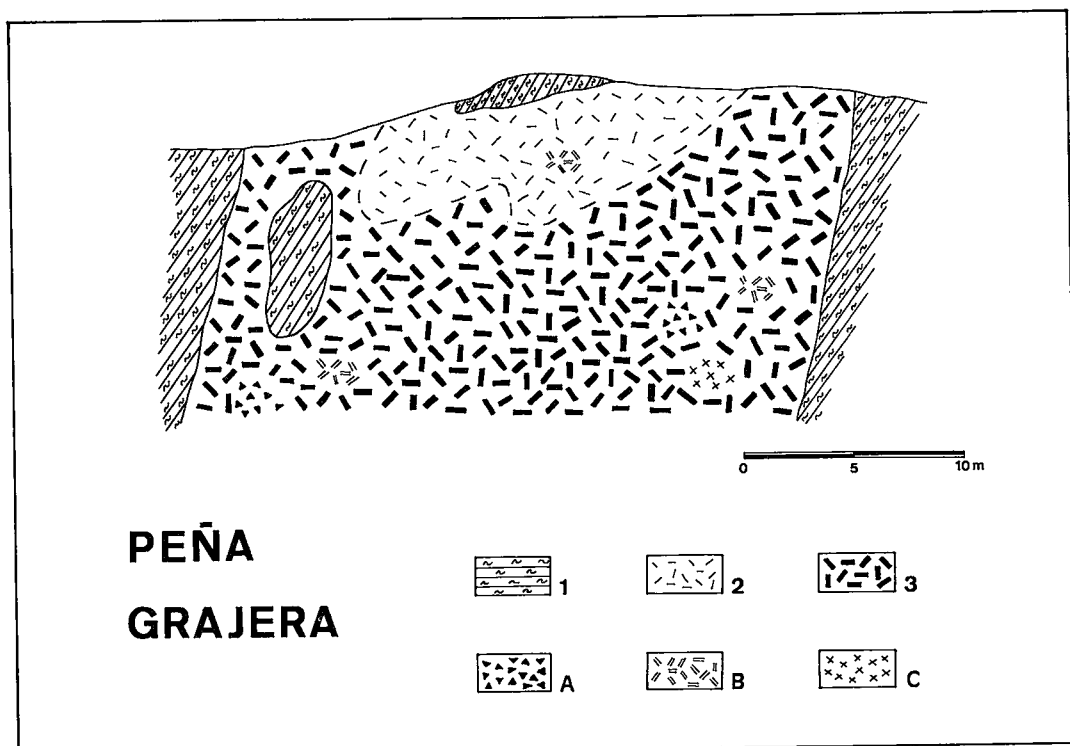


FIG. 3. Schematic cross-section of the Peña Grajera quarry showing internal zonation and location of samples: 1. Host rocks: tourmalinized feldspathic schists and quartzitic gneisses, 2. Border zone: quartz-perthite pegmatite (granitic texture), 3. Central zone: quartz-perthite-beryl pegmatite (giant pegmatite structure). A. Tourmaline, B. Muscovite, C. Quartz.

Wright (1974) (Δa parameter) and Kroll & Ribbe (1987) ($S.I.$ parameter).

The degree of solid solution of each feldspar was estimated from refined unit-cell parameters, on the basis that strong modifications in a axis dimension and cell volume are related to slight changes in composition, according to Waldbaum & Thompson (1968), Kroll & Ribbe (1983), Kroll *et al.* (1986) (compositions estimated from cell volume) and Hovis (1986) (compositions estimated from cell volume and a dimension).

The chemical analyses were carried out at the X-Ray Assay Laboratories in Toronto, Ontario using X-ray fluorescence (Si, Al, Fe, Mg, Na, K, Ca, Ti, P, Ba, Rb), neutron activation (Cs, Au, U), Inductively Coupled Plasma (Mn, B, Be, Pb, Sr, Y) and wet chemistry. The analytical determinations using the electron-probe microanalyzer were carried out at the Université Paul Sabatier in Toulouse. On the basis of these data, possible

temperatures of equilibration were obtained with the model of Fuhrman & Lindsley (1988).

TEXTURAL, STRUCTURAL AND COMPOSITIONAL CHARACTERISTICS OF THE FELDSPARS

The K-feldspar in the type-III pegmatites has white, pink or dark (blue or grey) coloring and a marked perthitic character. Following the nomenclature of Smith (1974), we found the perthite (Fig. 5) to have a vein texture (regular and irregular), which may gradually change to either patch or braid perthite, and interlocking perthite. Antiperthite is rare; the width of the albite blebs varies from 0.1 to 1.5 mm. The K-feldspar commonly contains albite-pericline twinning, with twinned areas coexisting in the same crystal with other apparently untwinned areas. Plagioclase crystals are less abundant

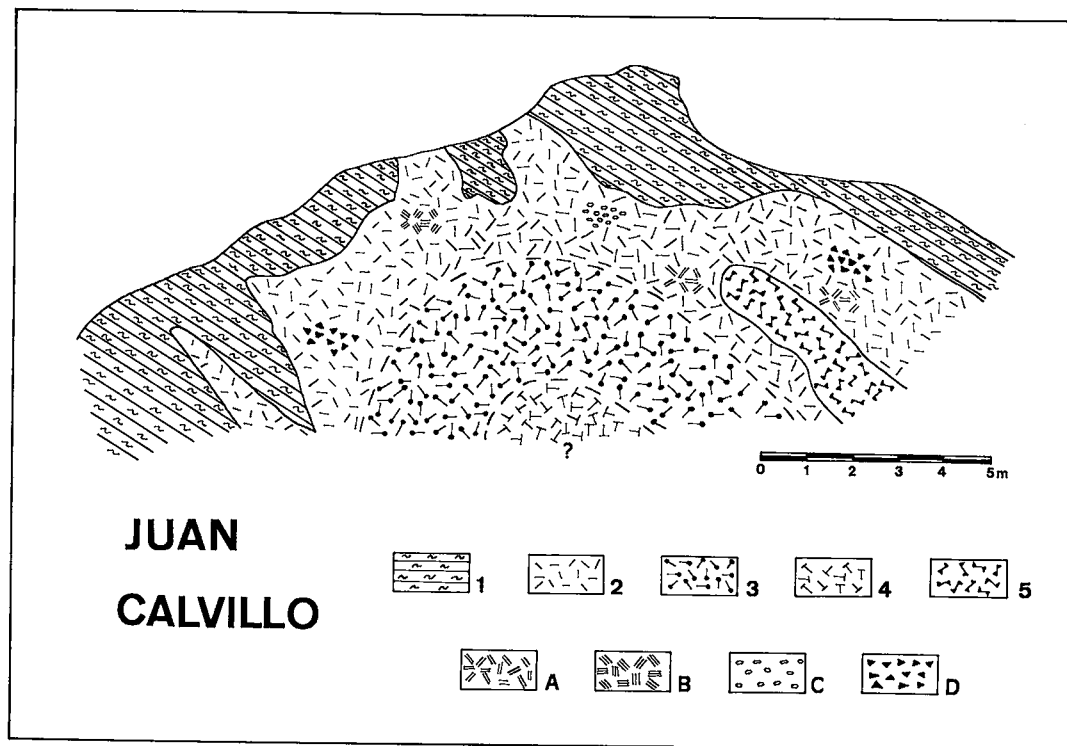


FIG. 4. Schematic cross-section of the Juan Calvillo quarry showing internal zonation and location of samples: 1. Host rocks: quartzitic gneisses and feldspathic schists, 2. Border zone: quartz-perthite pegmatite (granitic texture), 3. Wall zone: quartz-perthite pegmatite (graphic texture), 4. Intermediate zone: quartz-microcline-albite pegmatite (giant pegmatite structure), 5. Replacement body with biotite. A. Muscovite, B. Biotite, C. Garnet, D. Tourmaline.

than potassic feldspar, but invariably display polysynthetic twinning (Fig. 5e). Where they are juxtaposed, the K-feldspar seems to have replaced the plagioclase. Graphic K-feldspar-quartz intergrowths also are present.

The phases of K-feldspar detected by X-ray diffraction, following Ribbe (1983b) and McGregor & Ferguson (1989), indicate a wide variation in the structural state: orthoclase, intermediate microcline (much more abundant than the former), low microcline and low albite. Table 2 shows the refined crystallographic parameters of the different K-feldspar samples studied. Note the presence of the four structural states mentioned above.

Triclinicity ("obliquity") derived from the 131 and $\bar{1}\bar{3}1$ reflections [$\Delta = 12.5(d_{131} - d_{\bar{1}\bar{3}1})$; Goldsmith & Laves 1954] ranges between 0.25 and 0.94 (Table 3), with a small additional monoclinic peak between reflections 131 and $\bar{1}\bar{3}1$ in the samples with low triclinicity, due to the coexistence of both structural states (monoclinic and intermediate triclinicity). Values of triclinicity based from refined unit-cell parameters (Δ = measured $\gamma^* - 90^\circ/2.29^\circ$; McGregor & Ferguson 1989) are more

reliable because of the large amount of low albite certainly present with the K-feldspar in the powder samples analyzed by X-ray diffraction. No significant variations were found in the values of the degree of Al-Si order obtained by the two different methods (Tables 3, 4).

The $b-c^*$ diagram (Fig. 6) shows that the K-feldspar presents a moderately ordered Al-Si distribution, only two samples having monoclinic symmetry (PG-2cz and JC-1iz; Table 3), whereas the $\alpha^* - \gamma^*$ diagram (Fig. 7) shows the presence of the structural states mentioned above (orthoclase, intermediate microcline, low microcline). Similar conclusions can be deduced from the study of Figure 8 (Table 4), in which the coexistence of moderately ordered triclinic phases with intermediate triclinicity can clearly be seen, together with samples with a high degree of Al-Si order (close to that of the low microcline end-member).

The Al-Si distribution observed in most of the samples seems to follow an intermediate tendency between a one-step and a two-step distribution path (Figs. 9, 10). However, two of the samples (PG-3cz and

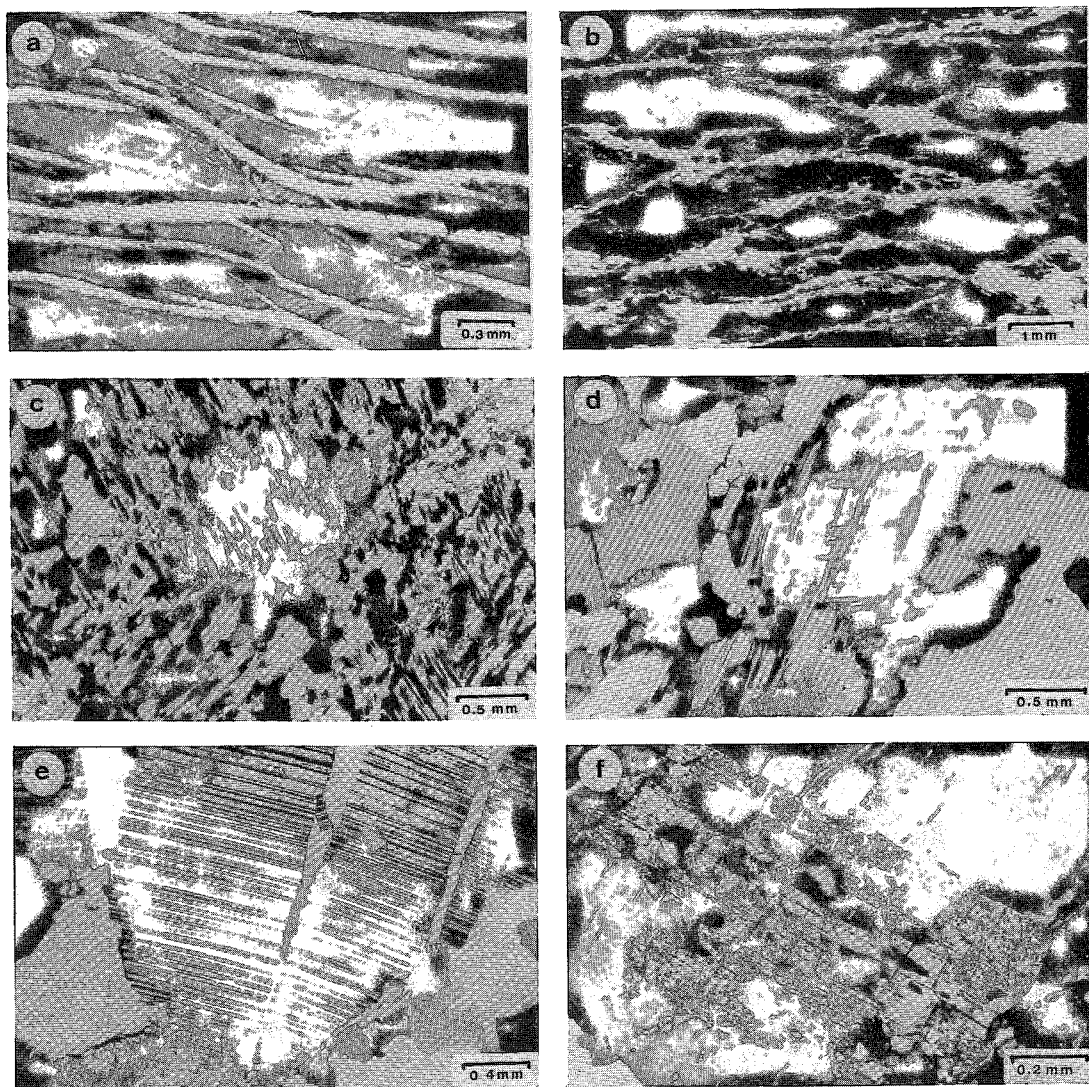


FIG. 5. Photomicrographs illustrating feldspar textures: (a) vein perthite, (b) patch perthite, (c) antiperthite (in a, b and c, the K-feldspar is dark, and plagioclase, light), (d) microcline: albite-pericline twinning, (e) albite: polysynthetic twinning (albite law), and (f) coexisting K-feldspar (dark) and plagioclase (light); the K-feldspar seems to replace the plagioclase. All photos in cross-polarized light.

JC-1bz) show a highly ordered Al-Si distribution, close to the low microcline end-member.

Despite the limitations of the powder-diffraction method, we have attempted to determine the degree of strain in the cell. Some strain can be detected in the structure of most of the K-feldspar examined (Table 5): Δa varies from -0.108 to $+0.154$ (Table 5), $S.I.$ from -20.03 to $+11.50$ (Table 5, Fig. 11). Such strain may be due to high Na contents in the bulk feldspars. It would also explain why many of the feldspar samples have anomalous parameters, since "strain" in the structure is

associated with the exsolution of the Na-phase and the inversion of symmetry, and is independent of the Al-Si distribution in each phase (Stewart & Wright 1974, Eggleton & Buseck 1980). Therefore, since the feldspar studied here is markedly perthitic, the strain index must be rather high. According to Stewart & Wright (1974), the higher degrees of internal strain could correspond to feldspar with more sodium-rich overall compositions. However, this hypothesis must be confirmed by transmission electron microscopy.

The composition of the K-feldspar phase of the

TABLE 2. REFINED CRYSTALLOGRAPHIC PARAMETERS OF POTASSIC FELDSPAR

SAMPLE	a(Å)	b(Å)	c(Å)	$\alpha(^{\circ})$	$\beta(^{\circ})$	$\gamma(^{\circ})$	a*(Å)	b*(Å)	c*(Å)	$\alpha(^{\circ})$	$\beta(^{\circ})$	$\gamma(^{\circ})$	VOL(Å ³)	N
CS-1bz	8.576(7)	12.981(7)	7.207(5)	90.36(6)	115.94(5)	89.10(5)	0.1297(1)	0.0770(1)	0.1543(1)	90.04(6)	64.06(5)	90.83(5)	721.4	30
CS-1wz	8.576(8)	12.990(9)	7.193(7)	90.03(9)	115.79(7)	89.36(9)	0.1295(1)	0.0770(1)	0.1544(1)	90.27(8)	64.21(7)	90.69(9)	721.5	20
CS-1iz	8.573(2)	12.982(2)	7.197(2)	89.81(5)	115.84(9)	89.52(9)	0.1296(3)	0.0770(1)	0.1544(2)	90.44(9)	64.16(9)	90.62(9)	720.9	18
CS-2iz	8.578(4)	12.970(3)	7.198(3)	90.06(9)	115.84(9)	88.88(9)	0.1296(6)	0.0771(2)	0.1544(3)	90.48(9)	64.16(9)	91.22(9)	720.6	18
PG-1bz	8.587(4)	12.936(3)	7.222(2)	90.06(9)	116.19(8)	88.76(9)	0.1298(6)	0.0773(2)	0.1543(2)	90.54(9)	63.81(9)	91.35(9)	719.7	16
PG-2bz	8.571(9)	12.965(9)	7.220(7)	90.28(6)	116.08(6)	88.94(9)	0.1299(1)	0.0771(1)	0.1542(1)	90.20(7)	63.92(6)	91.04(9)	720.5	32
PG-1cz	8.564(9)	13.010(9)	7.202(9)	90.23(9)	115.98(9)	89.43(9)	0.1299(2)	0.0769(1)	0.1545(2)	90.02(9)	64.02(9)	90.52(9)	721.2	36
PG-2cz	8.571(9)	13.015(9)	7.198(9)	90	116.14(7)	90	0.1300(1)	0.0768(1)	0.1547(1)	90	63.86(7)	90	720.9	30
PG-3cz	8.564(9)	12.950(9)	7.224(9)	90.42(9)	115.83(9)	87.90(9)	0.1298(1)	0.0773(1)	0.1538(2)	90.55(9)	64.17(9)	92.13(9)	720.6	29
JC-1bz	8.560(9)	12.964(9)	7.229(8)	90.62(8)	115.91(7)	87.86(9)	0.1300(2)	0.0772(1)	0.1538(1)	90.35(9)	64.10(7)	92.07(9)	721.1	35
JC-2bz	8.586(5)	12.983(8)	7.220(4)	90.17(5)	115.98(4)	89.22(6)	0.1296(1)	0.0770(1)	0.1541(1)	90.19(5)	64.02(4)	90.78(5)	723.4	27
JC-1wz	8.597(9)	12.948(9)	7.202(9)	90.30(9)	116.00(9)	89.24(9)	0.1294(2)	0.0772(2)	0.1545(2)	90.04(9)	64.00(9)	90.70(9)	720.5	25
JC-1iz	8.574(9)	13.008(9)	7.207(9)	90	116.01(9)	90	0.1298(1)	0.0769(1)	0.1544(2)	90	63.99(9)	90	722.4	21
JC-2iz	8.580(4)	12.973(5)	7.211(4)	90.35(4)	115.95(3)	89.04(4)	0.1296(1)	0.0771(1)	0.1542(1)	90.08(5)	64.05(4)	90.90(4)	721.6	25
D-1nz	8.580(6)	12.977(8)	7.210(6)	90.35(7)	115.95(5)	89.07(6)	0.1296(1)	0.0771(1)	0.1542(1)	90.06(7)	64.05(5)	90.86(5)	721.7	24
D-2az	8.577(9)	12.958(9)	7.212(6)	90.28(8)	115.96(5)	89.01(8)	0.1297(1)	0.0772(1)	0.1542(1)	90.17(8)	64.04(5)	90.96(8)	720.6	34
D-3nz	8.568(9)	12.968(9)	7.214(7)	90.36(9)	116.02(6)	88.63(9)	0.1299(1)	0.0771(1)	0.1543(1)	90.27(8)	63.98(6)	91.34(9)	720.1	21
D-4nz	8.579(9)	12.960(9)	7.207(8)	90.19(9)	115.92(9)	88.93(9)	0.1296(2)	0.0772(1)	0.1543(1)	90.30(9)	64.08(9)	91.10(9)	720.6	25
D-5nz	8.580(9)	12.977(9)	7.211(9)	90.12(9)	115.94(8)	89.21(9)	0.1296(1)	0.0771(1)	0.1542(2)	90.26(9)	64.06(9)	90.82(7)	721.9	18
D-6nz	8.571(7)	12.965(6)	7.211(5)	90.26(4)	115.97(4)	89.16(4)	0.1298(1)	0.0771(1)	0.1543(1)	90.12(4)	64.03(4)	90.81(4)	720.3	28
D-7nz	8.575(9)	12.990(9)	7.213(6)	90.44(9)	115.90(6)	89.08(8)	0.1297(1)	0.0770(1)	0.1541(1)	89.96(9)	64.10(6)	90.81(8)	722.7	18
U-1iz	8.564(9)	12.969(9)	7.198(6)	90.08(9)	115.83(9)	89.25(9)	0.1297(1)	0.0771(1)	0.1543(2)	90.27(9)	64.17(9)	90.80(7)	719.5	18
U-2iz	8.571(9)	12.972(9)	7.210(7)	90.30(8)	115.90(7)	89.00(9)	0.1297(2)	0.0771(1)	0.1542(1)	90.15(8)	64.10(7)	90.97(9)	721.0	17
LM-1iz	8.585(9)	12.973(9)	7.206(9)	90.28(9)	116.00(9)	89.25(9)	0.1296(1)	0.0771(1)	0.1544(2)	90.06(9)	64.00(9)	90.72(9)	721.2	17
C-1nz	8.575(9)	12.956(9)	7.208(8)	90.30(7)	115.82(8)	89.02(8)	0.1296(2)	0.0772(1)	0.1541(2)	90.14(6)	64.18(8)	90.95(7)	720.7	18
T-1nz	8.568(9)	13.016(9)	7.210(9)	90.25(9)	115.89(9)	89.12(9)	0.1298(1)	0.0768(1)	0.1542(1)	90.15(9)	64.11(9)	90.86(9)	723.2	16
TA-1nz	8.573(9)	12.967(9)	7.217(8)	90.24(9)	115.95(9)	89.12(9)	0.1297(2)	0.0771(2)	0.1541(2)	90.16(9)	64.05(9)	90.86(9)	721.2	17
TAR-1nz	8.580(8)	12.952(9)	7.211(8)	90.21(9)	115.97(8)	89.07(9)	0.1297(2)	0.0772(1)	0.1542(2)	90.23(9)	64.03(8)	90.94(9)	720.3	19
VA-1nz	8.582(8)	12.940(8)	7.209(8)	89.93(9)	116.16(8)	89.16(9)	0.1297(1)	0.0773(1)	0.1544(1)	90.49(9)	63.94(8)	90.97(8)	719.1	21
VAG-1nz	8.578(9)	12.947(9)	7.210(8)	90.12(9)	115.88(6)	89.12(9)	0.1296(1)	0.0772(1)	0.1542(1)	90.29(9)	64.12(6)	90.92(9)	720.4	19
VD-1iz	8.578(9)	12.963(8)	7.207(9)	90.26(6)	116.02(7)	89.05(8)	0.1297(1)	0.0772(1)	0.1544(2)	90.18(7)	63.98(7)	90.93(8)	720.0	19
AL-1nz	8.571(9)	12.963(9)	7.211(8)	90.26(9)	115.98(9)	88.97(9)	0.1298(2)	0.0772(1)	0.1543(2)	90.21(9)	64.02(9)	91.03(9)	720.1	17
FO-1nz	8.526(9)	12.993(9)	7.225(9)	90.37(9)	115.82(9)	88.82(9)	0.1303(2)	0.0770(2)	0.1538(2)	90.16(9)	64.18(9)	91.13(9)	720.3	18

Sample legend: CS: Cerro de la Sal, PG: Peña Grajera, JC: Juan Calvillo, D: Diéresis, U: Umbría, LM: Los Morales, C: Coma, T: Traviesas I, TA: Traviesas II, TAR: Taravilla, VA: Valverde, VAG: Mina Barita, VD: Valdenoque, AL: Alameda, FO: Fuenteobejuna; bz: border zone, wz: wall zone, iz: intermediate zone, cz: central zone, nz: no zonation. N = Lines used in refinements.

Numbers in parentheses are the standard deviation of the digits to their immediate left.

perthite deduced from *a* and *V* is listed in Table 5. Note the high proportion of the Or component (>90%) in the potassic phase.

FELDSPAR GEOCHEMISTRY

The results of the chemical analyses of the different feldspars are given in Table 6. Figures 12 and 13 show the concentrations of selected elements. For our comments on the chemical aspects, we have followed the interpretations of Smith (1974, 1983) and Shmakín (1979).

In terms of the ternary system Or–Ab–An, the successive generations of perthitic K-feldspar show a progressive decrease in Or and An and an increase in Ab (Fig. 14). The alkali elements change regularly throughout the zonal crystallization of the pegmatite (Fig. 2).

Thus from border to center of a pegmatite body, K, Ca and the K/Na ratio decrease, *i.e.*, Na increases.

In K-feldspar, Ti and Fe contents are low, particularly in the case of Ti (<0.01%), whereas Fe appears in somewhat larger quantities but likely in discrete mineral phases, reaching values of 0.05% in some samples. The plagioclase also shows low Ti contents (up to 0.02%), although somewhat higher than in the K-feldspar, whereas the levels of Fe are much higher than in K-feldspar (Table 6, columns 2, 3). On the other hand, the P content, which reaches 0.73 wt% P₂O₅ in some of the K-feldspar, is highest in those grains having the most strongly micropertthitic character (Fig. 12); such concentrations are sufficient to take on petrogenetic significance, in accordance with the findings of Černý *et al.* (1985). The concentration of P increases from early (border) to later (internal) generations, its concentration

TABLE 3. TRICLINICITY AND Al/Si DISTRIBUTION IN POTASSIC FELDSPAR

SAMPLE	TRICLINICITY (Δ)		Al/Si DISTRIBUTION ($b-c^*$ and $\alpha-\gamma^*$ plot)				
	(I)	(II)	Σt_i	Δt_i	t_{10}	t_{1m}	Σt_i
CS-1bz	0.32	0.36	0.866	0.389	0.627	0.239	0.134
CS-1wz	0.25	0.30	0.812	0.269	0.541	0.271	0.188
CS-1iz	0.44	0.27	0.843	0.194	0.519	0.324	0.157
CS-2iz	0.77	0.53	0.886	0.473	0.679	0.207	0.114
PG-1bz	0.94	0.59	1.000	0.524	0.762	0.238	0.000
PG-2bz	0.81	0.45	0.942	0.452	0.697	0.245	0.058
PG-1cz	0.78	0.23	0.730	0.243	0.487	0.244	0.270
PG-2cz	0.00	0.00	0.668	0.000	0.334	0.334	0.342
PG-3cz	0.91	0.93	1.000	0.899	0.949	0.051	0.000
JC-1bz	0.88	0.90	1.000	0.916	0.958	0.042	0.000
JC-2bz	0.37	0.34	0.912	0.330	0.621	0.291	0.088
JC-1wz	0.97	0.31	0.939	0.327	0.633	0.306	0.061
JC-1iz	0.00	0.00	0.748	0.000	0.394	0.394	0.212
JC-2iz	0.29	0.39	0.908	0.411	0.660	0.249	0.091
D-1nz	0.84	0.38	0.894	0.399	0.647	0.248	0.105
D-2nz	0.56	0.42	0.967	0.421	0.694	0.273	0.033
D-3nz	0.51	0.59	0.920	0.583	0.751	0.169	0.080
D-4nz	0.51	0.48	0.946	0.455	0.700	0.246	0.054
D-5nz	0.61	0.36	0.900	0.334	0.617	0.283	0.100
D-6nz	0.50	0.35	0.932	0.359	0.645	0.287	0.068
D-7nz	0.33	0.35	0.876	0.397	0.637	0.240	0.123
U-1iz	0.57	0.35	0.894	0.318	0.606	0.288	0.106
U-2iz	0.43	0.42	0.924	0.428	0.676	0.248	0.076
LM-1iz	0.54	0.31	0.868	0.323	0.596	0.272	0.132
C-1nz	0.50	0.41	0.992	0.420	0.706	0.286	0.008
T-1nz	0.45	0.38	0.774	0.377	0.575	0.198	0.227
TA-1nz	0.49	0.38	0.961	0.374	0.668	0.293	0.039
TAR-1nz	0.92	0.41	0.980	0.397	0.689	0.291	0.020
VA-1nz	0.84	0.42	0.977	0.352	0.664	0.313	0.023
VAG-1nz	0.78	0.40	1.000	0.371	0.686	0.314	0.000
VD-1iz	0.61	0.41	0.902	0.403	0.653	0.249	0.098
AL-1nz	0.75	0.45	0.936	0.441	0.688	0.248	0.064
FO-1nz	0.45	0.49	0.952	0.505	0.729	0.223	0.048

Sample legend: CS: Cerro de la Sal, PG: Peña Grajera, JC: Juan Calvillo, D: Diéresis, U: Umbria, LM: Los Morales, C: Coma, T: Traviesas I, TA: Traviesas II, TAR: Taravilla, VA: Valverde, VAG: Mina Barita, VD: Valdenoque, AL: Alameda, FO: Puenteobajuna; bz: border zone, wz: wall zone, iz: intermediate zone, cz: central zone, nz: no zonation.
(I): $\Delta = 12.5$ ($d_{31} - d_{32}$) (Goldsmith & Laves 1954).
(II): $\Delta = \text{measured } \gamma^* - 90^\circ/2.29^\circ$ (McGregor & Ferguson 1989).
Al/Si distribution: Kroll & Ribbe (1987).

being considerably lower in the plagioclase than in the coexisting K-feldspar (as with the findings of London *et al.* 1990). There does not appear to be any correlation between the P and Ca contents, which indicates that apatite microinclusions are not responsible for these values.

The B content of plagioclase tends to increase with An content of the plagioclase, and ranges from 13 to 35 ppm. The B contents of the K-feldspar are a bit lower (from <10 to 30 ppm), in agreement with the observations of Smith (1974). The plagioclase presents higher contents of Be (5–15 ppm) than the K-feldspar (3–5 ppm). These data agree with those given by Solodov (1958) for coexisting K-feldspar and plagioclase in four rare-metal pegmatites.

In the outcrops examined here (Table 6, Fig. 12), the concentrations of Rb and Cs of both the K-feldspar and plagioclase increase weakly inward, whereas those of Sr and Ba decrease, which agrees with the hypotheses of Shmakina (1979) and Smith (1983). This is particularly noticeable in the case of Rb and in the K/Rb ratio (Fig. 13), which varies from 66 in the border areas to 121 in the internal zone. These findings parallel those published by Černý *et al.* (1985). In four samples in which K-feldspar and plagioclase coexist, the Rb, Cs and, to a lesser extent, Ba contents are seen to be strongly

TABLE 4. Al-Si DISTRIBUTION IN TETRAHEDRAL POSITIONS ACCORDING KROLL & RIBBE (1987)

SAMPLE	((110) vs $(\bar{1}\bar{1}0)$ corrected translations)						
	Σt_{tr}	Δt_{tr}	Σt_i	Δt_i	t_{10}	t_{1m}	Σt_i
CS-1bz	15.567	0.113	0.867	0.389	0.628	0.239	0.133
CS-1wz	15.575	0.080	0.815	0.275	0.545	0.270	0.185
CS-1iz	15.570	0.060	0.841	0.206	0.523	0.317	0.160
CS-2iz	15.564	0.140	0.888	0.482	0.685	0.203	0.112
PG-1bz	15.545	0.156	1.000	0.535	0.767	0.233	0.000
PG-2bz	15.556	0.133	0.936	0.456	0.696	0.240	0.064
PG-1cz	15.586	0.071	0.740	0.244	0.492	0.248	0.260
PG-2cz	15.598	0.000	0.658	0.000	0.329	0.329	0.342
PG-3cz	15.536	0.263	1.000	0.902	0.951	0.049	0.000
JC-1bz	15.543	0.267	1.000	0.917	0.958	0.042	0.000
JC-2bz	15.560	0.097	0.904	0.333	0.618	0.286	0.096
JC-1wz	15.556	0.096	0.932	0.328	0.630	0.302	0.068
JC-1iz	15.583	0.000	0.750	0.000	0.375	0.375	0.280
JC-2iz	15.561	0.120	0.905	0.412	0.659	0.245	0.095
D-1nz	15.563	0.117	0.892	0.400	0.646	0.245	0.108
D-2nz	15.552	0.124	0.958	0.425	0.691	0.266	0.043
D-3nz	15.559	0.171	0.921	0.587	0.754	0.167	0.079
D-4nz	15.555	0.134	0.941	0.461	0.701	0.240	0.059
D-5nz	15.562	0.099	0.895	0.340	0.617	0.278	0.105
D-6nz	15.557	0.105	0.925	0.362	0.643	0.282	0.075
D-7nz	15.566	0.115	0.875	0.395	0.635	0.240	0.125
U-1iz	15.563	0.098	0.891	0.325	0.608	0.283	0.109
U-2iz	15.559	0.126	0.919	0.431	0.675	0.244	0.081
LM-1i	15.566	0.094	0.867	0.324	0.596	0.271	0.133
C-1nz	15.549	0.123	0.978	0.422	0.700	0.278	0.022
T-1nz	15.580	0.110	0.783	0.379	0.581	0.202	0.217
TA-1nz	15.555	0.111	0.950	0.377	0.664	0.286	0.050
TAR-1nz	15.550	0.117	0.969	0.402	0.685	0.284	0.031
VA-1nz	15.550	0.106	0.967	0.363	0.665	0.302	0.033
VAG-1nz	15.545	0.110	0.999	0.377	0.688	0.311	0.001
VD-1iz	15.561	0.119	0.901	0.407	0.654	0.247	0.098
AL-1nz	15.557	0.130	0.931	0.445	0.688	0.243	0.069
FO-1nz	15.556	0.147	0.940	0.506	0.723	0.217	0.060

Sample legend: see Table 3.

partitioned in the K-feldspar over the coexisting plagioclase (*cf.* Černý *et al.* 1984).

According to Černý *et al.* (1985), the Rb content of K-feldspar decreases after the crystallization of the major zones and during later metasomatic alteration. This finding would explain the low Rb content found in one sample from the Diéresis quarry (D-4nz), where the metasomatic overprint is quite clear. As mentioned

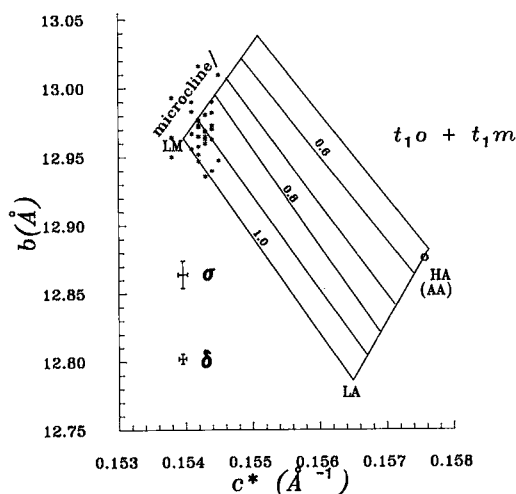


FIG. 6. Plot of $b-c^*$ used for determining $(t_{10} + t_{1m})$ in triclinic K-feldspar with $t_{10} \neq t_{1m}$. Theoretical end-members: LM low microcline, HA high albite, AA analbite, LA low albite (Kroll & Ribbe 1987); σ : maximum error ($\Delta\sigma_x = 0.0003$, $\Delta\sigma_y = 0.0009$); δ : minimum error ($\Delta\delta_x = 0.0001$, $\Delta\delta_y = 0.002$).

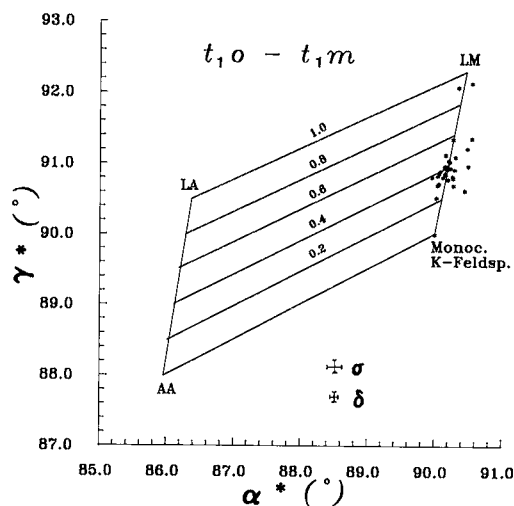


FIG. 7. Plot of $\alpha^* - \gamma^*$ used for determining $(t_{1o} - t_{1m})$ in K-feldspar. Theoretical end-members: LA low albite, LM low microcline, AA analbite (Kroll & Ribbe 1987); σ : maximum error ($\Delta\sigma_x = 0.09, \Delta\sigma_y = 0.09$), δ : minimum error ($\Delta\delta_x = 0.04, \Delta\delta_y = 0.04$).

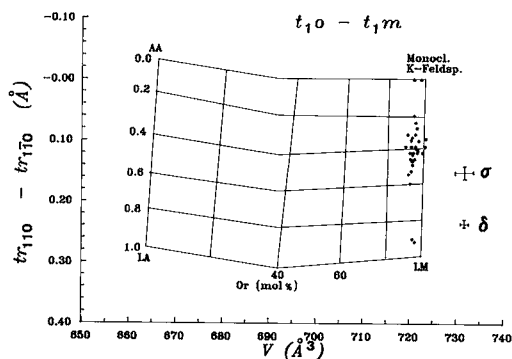


FIG. 8. Plot of $V - (tr_{110} - tr_{1\bar{1}0})$ used for determining $(t_{1o} - t_{1m})$ and orthoclase content (Or mol%) in K-feldspar. Theoretical end-members: LA low albite, AA analbite, LM low microcline, HS high sanidine (Kroll & Ribbe 1983); σ : maximum error ($\Delta\sigma_x = 2.1, \Delta\sigma_y = 0.013$), δ : minimum error ($\Delta\delta_x = 0.9, \Delta\delta_y = 0.006$).

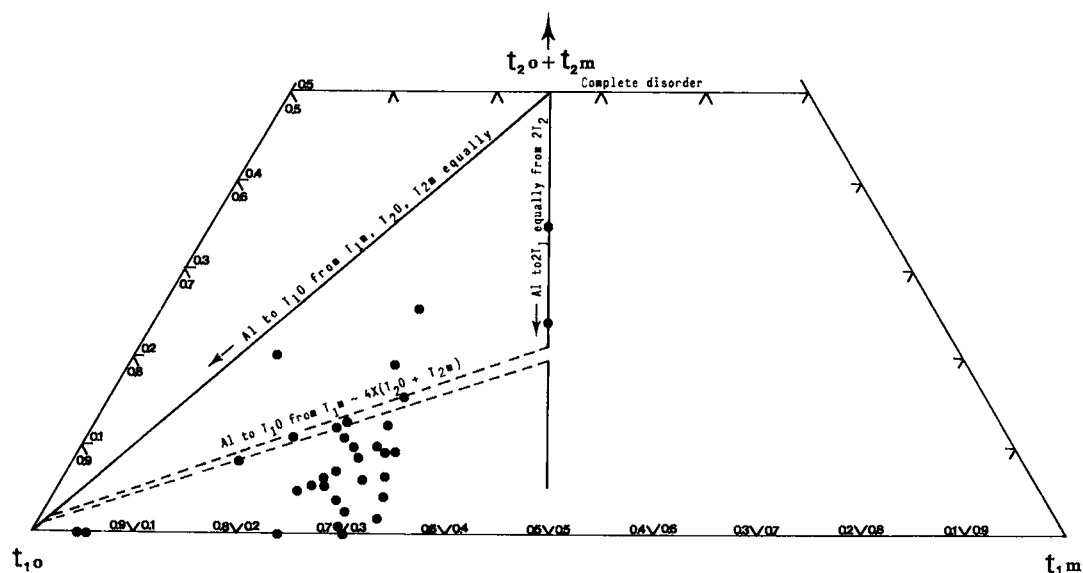


FIG. 9. Triangular plot of the distribution of Al in tetrahedral sites in K-feldspar specimens in the manner of Stewart & Wright (1974, Fig. 8). The path of Al-Si ordering in some of those authors' sodium feldspar, where the Al moves to t_{1o} in equal proportions from t_{1m} , t_{2o} and t_{2m} , is indicated by the continuous line starting at the t_{1o} vertex. Samples of intermediate microcline are ordered according to the model in which the Al moves to t_{1o} from t_{1m} approximately four times faster than from t_{2o} and t_{2m} (dotted lines). The straight vertical line, along which $t_{1o} = t_{1m}$, represents monoclinic feldspar. All paths of ordering are taken from Stewart & Wright (1974).

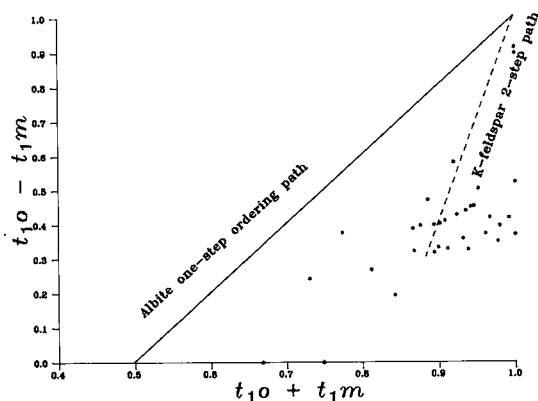


FIG. 10. Plot of $(t_{10} + t_{1m})$ versus $(t_{10} - t_{1m})$ for K-feldspar showing one-step and two-step ordering paths in alkali feldspar (Eggleton & Buseck 1980).

above, the Sr content of both feldspars decreases (Fig. 12) as crystallization of the pegmatitic units proceeds (Shmakin 1979). It must be pointed out that all the feldspars from the Diéresis quarry present Sr contents of more than 100 ppm. The Cs values are normal for feldspars from pegmatitic outcrops, according to the data

of Smith (1974). The Ba content of the K-feldspar shows a slight decrease from border to center of the pegmatite. This is also clear in the Ba/Rb ratio, which varies from 188 for the border zone to 249 in the internal zone of the pegmatite. Similar data also were given by Shmakin (1979) and Černý *et al.* (1984).

The Pb, as in most feldspars (Smith 1974), shows no definite pattern of behavior. Attention should be drawn to the high U content, which can reach 16 ppm in the central zones of the Cerro de la Sal quarry. These values are much higher than those given by Smith (1974), who suggested that they may be present as impurities. The Y content is clearly lower than the data reported by Carl (1962). Finally, the Au values (up to 6 ppm in Diéresis and 5 ppm in Peña Grajera) are slightly higher than those given by Tilling *et al.* (1973) as normal for granitic pegmatites.

Cluster and correlational statistical analyses were carried out to study the relation between the structural and chemical parameters (Table 7, Fig. 15). The results of these analyses (Table 7) show values coherent with the other observations made and reveal the importance of Al_2O_3 , which is closely connected to the cell parameters (c , α , γ) of the K-feldspar, and also to the distribution parameters (t_{10} , t_{1m} , $2t_2$). The values obtained for P_2O_5 show identical results, due to its behavior parallel to that

TABLE 5. INTERNAL STRAIN INDEX AND CONTENT OF ORTHOCLASE COMPONENT IN PERTHITIC FELDSPAR

SAMPLE	I		II					
	Δa	S.I.	1	2	3	4	5	6
CS-1bz	+ 0.058	- 2.887	0.9539	0.9644	0.9565	0.9656	0.9682	0.9626
CS-1wz	+ 0.054	+ 1.819	0.9580	0.9681	0.9607	0.9698	0.9726	0.9635
CS-11z	+ 0.056	+ 1.986	0.9394	0.9501	0.9425	0.9509	0.9537	0.9540
CS-21z	+ 0.096	+ 5.584	0.9324	0.9428	0.9355	0.9441	0.9469	0.9689
PG-1bz	+ 0.076	+ 3.482	0.9072	0.9182	0.9111	0.9186	0.9211	0.9940
PG-2bz	- 0.063	- 5.310	0.9286	0.9392	0.9323	0.9399	0.9429	0.9500
PG-11z	- 0.071	- 9.672	0.9498	0.9604	0.9529	0.9614	0.9643	0.9296
PG-21z	- 0.063	- 8.803	0.9399	0.9500	0.9432	0.9519	0.9295	0.9118
PG-31z	- 0.071	- 3.486	0.9399	0.9500	0.9432	0.9519	0.9295	0.9118
JC-1bz	- 0.074	- 10.890	0.9455	0.9562	0.9482	0.9573	0.9600	0.9206
JC-2bz	- 0.049	- 10.047	1.0000	1.0000	1.0000	1.0000	1.0000	0.9890
JC-1wz	+ 0.154	+ 11.503	0.9285	0.9389	0.9319	0.9402	0.9428	1.0000
JC-11z	- 0.060	- 11.208	0.9847	-----	0.9858	0.9955	0.9180	0.9181
JC-21z	- 0.054	- 2.437	0.9603	0.9705	0.9628	0.9719	0.9746	0.9735
D-1nz	- 0.055	- 3.169	0.9638	0.9739	0.9658	0.9752	0.9780	0.9727
D-2nz	+ 0.048	+ 1.353	0.9314	0.9425	0.9349	0.9432	0.9455	0.9659
D-3nz	- 0.066	- 3.498	0.9180	0.9285	0.9215	0.9298	0.9320	0.9409
D-4nz	+ 0.075	+ 3.566	0.9313	0.9420	0.9346	0.9429	0.9454	0.9702
D-5nz	- 0.054	- 3.757	0.9700	0.9799	0.9722	0.9814	0.9845	0.9729
D-6nz	+ 0.022	- 0.405	0.9235	0.9343	0.9272	0.9352	0.9378	0.9497
D-7nz	- 0.059	- 9.277	0.9933	1.0000	0.9938	1.0000	1.0000	0.9605
U-1iz	+ 0.082	+ 4.705	0.9027	0.9133	0.9065	0.9147	0.9165	0.9307
U-2iz	- 0.008	- 1.811	0.9437	0.9542	0.9464	0.9556	0.9581	0.9516
LM-11z	+ 0.040	+ 0.830	0.9496	0.9600	0.9524	0.9615	0.9642	0.9863
C-1nz	+ 0.080	+ 4.046	0.9360	0.9467	0.9392	0.9479	0.9502	0.9608
T-1nz	- 0.066	- 15.773	1.0000	1.0000	1.0000	1.0000	1.0000	0.9409
TA-1nz	- 0.062	- 4.022	0.9490	0.9595	0.9518	0.9606	0.9636	0.9537
TAR-1nz	+ 0.080	+ 3.951	0.9248	0.9355	0.9282	0.9369	0.9390	0.9732
VA-1nz	+ 0.127	+ 8.985	0.8913	0.9018	0.8951	0.9028	0.9045	0.9798
VAG-1nz	+ 0.099	+ 5.944	0.9249	0.9355	0.9283	0.9366	0.9390	0.9689
VD-11z	+ 0.068	+ 2.893	0.9163	0.9272	0.9199	0.9276	0.9302	0.9681
AL-1nz	+ 0.031	+ 0.173	0.9182	0.9290	0.9224	0.9304	0.9324	0.9505
FO-1nz	- 0.108	- 20.032	0.9241	0.9348	0.9277	0.9360	0.9385	0.8324

I. Internal strain indexes: Δa = after Stewart & Wright (1974). S.I. = after Kroll & Ribbe (1987).

II. Solid solution composition in K-feldspar from X-ray data following the models of 1) Waldbaum & Thompson (1968) (compositions estimated from cell volume).

2) Kroll & Ribbe (1983) (compositions estimated from cell volume for K-feldspar with structural state intermediate or completely unknown).

3) Kroll & Ribbe (1983) (compositions estimated from cell volume for LA-LM series).

4) Kroll *et al.* (1986) (compositions estimated from cell volume).

5) Hovis (1986) (compositions estimated from cell volume).

6) Hovis (1986) (compositions estimated from a x axis).

Sample legend: see Table 3.

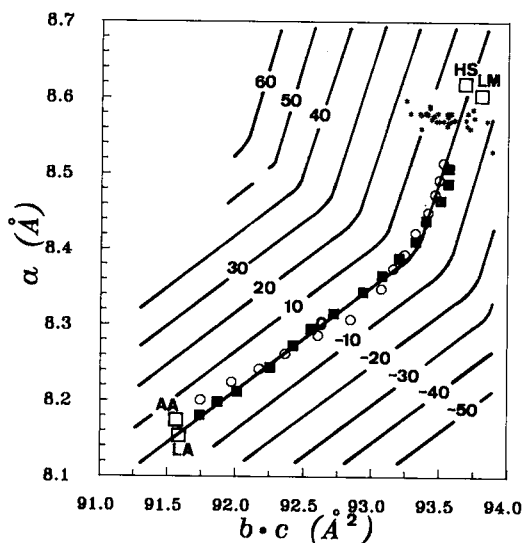


FIG. 11. Strain index (S.I.) in K-feldspar (Kroll & Ribbe 1987). Unstrained K-feldspar: LA-LM series (black squares). AA-HS series (open circles). This study: asterisks.

of Al. Thus the tendencies toward the center of the pegmatitic body would indicate an increase in the t_1o value and a decrease of t_1m and $2t_2$. It seems clear that there is a high degree of correlation between structural and chemical parameters, and we may therefore consider the possibility of evolution toward increasingly ordered members, with a higher degree of triclinicity in the successive generations of feldspar that appear.

In order to characterize the different types of pegmatites and estimate their potential for mineralization, we have represented the values of K/Cs versus Na_2O as did Gordiyenko (1971, 1976) (Fig. 16). All the K-feldspar samples examined plot in the field of the rare-metal pegmatites and, within this field, most are represented in the area of pegmatites with Li minerals (except the K-feldspar from the Peña Grajera quarry, which plots the field of pegmatites with Li, Be and Ta minerals).

TABLE 6. CHEMICAL ANALYSES OF MAJOR ELEMENTS AND TRACE ELEMENTS IN PERTHITIC K-FELDSPAR AND PLAGIOCLASE

	CS-1bz	CS-1wz	CS-1iz	CS-2iz	PG-2bz	PG-1cz	PG-3cz	JC-1bz	D-3nz	D-4nz		CS-2bz	CS-2wz	D-3nz	D-9nz
SiO ₂	64.10	64.20	63.80	64.50	64.70	65.30	65.10	64.80	64.60	64.90		65.70	65.20	64.40	64.30
TiO ₂	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01		0.02	0.02	0.02	0.02
Al ₂ O ₃	19.40	19.60	19.60	19.40	19.20	19.30	19.20	19.00	19.10	19.00		20.90	20.60	21.50	21.90
Fe ₂ O ₃	0.02	0.01	0.01	0.01	0.02	0.05	0.03	0.05	0.05	0.05		0.03	0.03	0.13	0.20
MgO	0.10	0.10	0.11	0.10	0.09	0.10	0.09	0.10	0.11	0.11		0.10	0.11	0.13	0.21
CaO	0.05	0.06	0.08	0.07	0.01	0.01	0.01	0.01	0.03	0.01		0.99	0.87	1.70	0.92
Na ₂ O	2.92	3.54	3.18	3.68	2.98	3.33	3.28	2.99	2.62	2.58		11.10	11.00	10.20	10.50
K ₂ O	12.40	11.80	12.30	11.50	12.50	11.70	11.70	12.20	13.20	13.00		0.75	1.10	1.33	1.34
P ₂ O ₅	0.38	0.46	0.73	0.48	0.23	0.31	0.25	0.15	0.04	0.04		0.10	0.51	0.04	0.03
LOI	0.31	0.31	0.39	0.39	0.62	0.39	0.39	0.47	0.31	0.39		0.77	0.62	0.70	1.00
SUM	99.80	100.20	100.30	100.20	100.40	100.60	100.10	99.90	100.20	100.20		100.50	100.10	100.20	100.50
Or	73.45	68.46	71.50	67.07	73.41	69.79	70.10	72.86	76.76	76.85		4.04	5.92	7.24	7.42
Ab	26.34	31.24	28.10	32.62	26.59	30.21	29.90	27.14	23.14	23.15		91.44	90.16	84.94	88.29
An	0.71	0.30	0.40	0.30	0.00	0.00	0.00	0.00	0.10	0.00		4.52	3.92	7.82	4.29
B	10	10	23	16	10	10	10	10	30	10		35	19	13	32
Be	4	4	5	4	4	4	4	3	4	5		11	15	5	12
Rb	503	525	687	581	663	727	734	419	514	468		16	58	40	60
Cs	9	8	23	10	31	49	44	5	8	7		1	1	1	3
Sr	25	29	22	10	52	15	25	62	138	160		82	10	184	307
Ba	209	260	205	241	205	102	149	590	523	696		111	127	179	299
Mn	18	17	13	15	16	19	14	13	20	11		23	39	26	39
Pb	26	22	20	18	16	12	12	24	22	18		14	12	8	10
U	<0.5	<0.5	16.8	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5		0.5	0.9	12.5	3.2
Y	<10	<10	<10	<10	<10	<10	<10	<10	12	<10		<10	<10	<10	<10
Au	<5	<5	<5	<5	5	<5	5	<5	6	<5		<5	<5	<5	<5

A) Chemical analyses from the X-Ray Assay Laboratories (Toronto, Ontario, Canada).

Major element compositions in wt %. Or, Ab & An content in mol %. Trace element compositions in ppm (Au in ppb). The four last column correspond to Na-feldspar analyses. Sample legend: see Table 3.

	CS-3bz	CS-3bz	PG-3bz	PG-2cz	PG-2cz	PG-4cz	PG-4cz	D-10nz	D-10nz
SiO ₂	68.98	63.24	67.92	63.46	67.63	63.43	66.71	63.91	63.50
TiO ₂	n.d.	n.d.	0.02	0.00	0.02	0.00	n.d.	0.00	0.00
Al ₂ O ₃	19.15	18.51	19.75	18.76	19.46	18.57	19.93	18.73	21.51
Fe ₂ O ₃	n.d.	n.d.	0.00	0.06	0.02	0.00	n.d.	0.10	0.00
MnO	n.d.	n.d.	0.02	0.00	0.01	0.06	n.d.	0.02	0.02
MgO	n.d.	n.d.	0.01	0.00	0.02	0.00	n.d.	0.03	0.00
CaO	0.19	0.00	0.20	0.00	0.12	0.00	0.44	0.00	2.69
Na ₂ O	11.94	1.51	11.48	1.16	11.45	0.72	11.40	0.82	9.94
K ₂ O	0.18	15.23	0.15	15.92	0.13	16.46	0.15	15.99	0.28
P ₂ O ₅	n.d.	n.d.	0.00	0.28	0.10	0.20	n.d.	0.05	0.00
BaO	0.06	0.26	n.d.	n.d.	n.d.	n.d.	0.02	0.07	0.17
SUM	98.05	98.75	99.56	99.65	98.94	99.45	98.65	99.52	99.53
Or	1.47	90.98	1.27	93.21	1.11	95.81	1.25	95.12	2.17
Ab	96.99	9.02	97.04	6.79	97.86	4.19	95.08	4.88	76.99
An	1.54	0.00	1.69	0.00	1.03	0.00	3.67	0.00	20.84

B) Chemical analyses from Na and K-phase of the perthitic alkali feldspar by Electron Microprobe Analyses. n.d. = not determined. Sample legend: see Table 3.

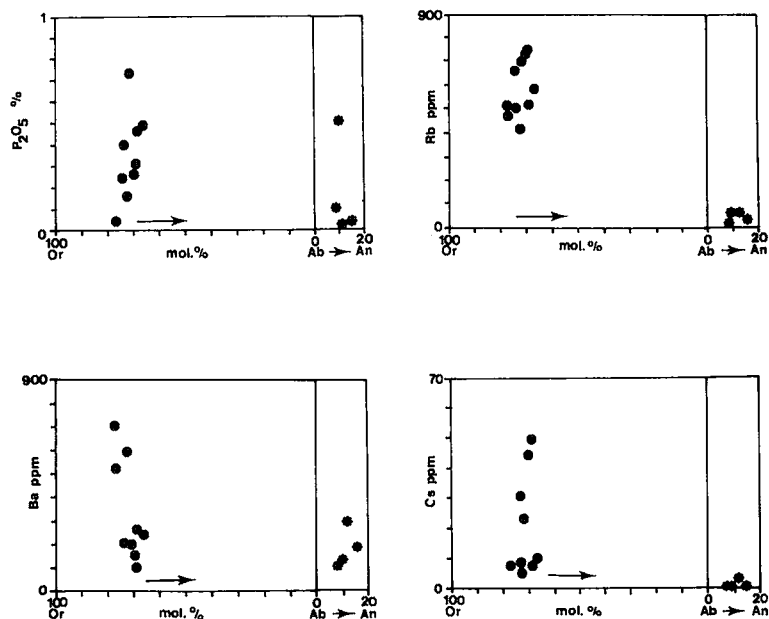


FIG. 12. Concentrations of P, Rb, Ba, Cs and Sr content *versus* compositional variations in K-feldspar and plagioclase. Values of mol% Or are deduced from chemical data of Table 6. The arrow indicates evolution toward the center of the pegmatitic body.

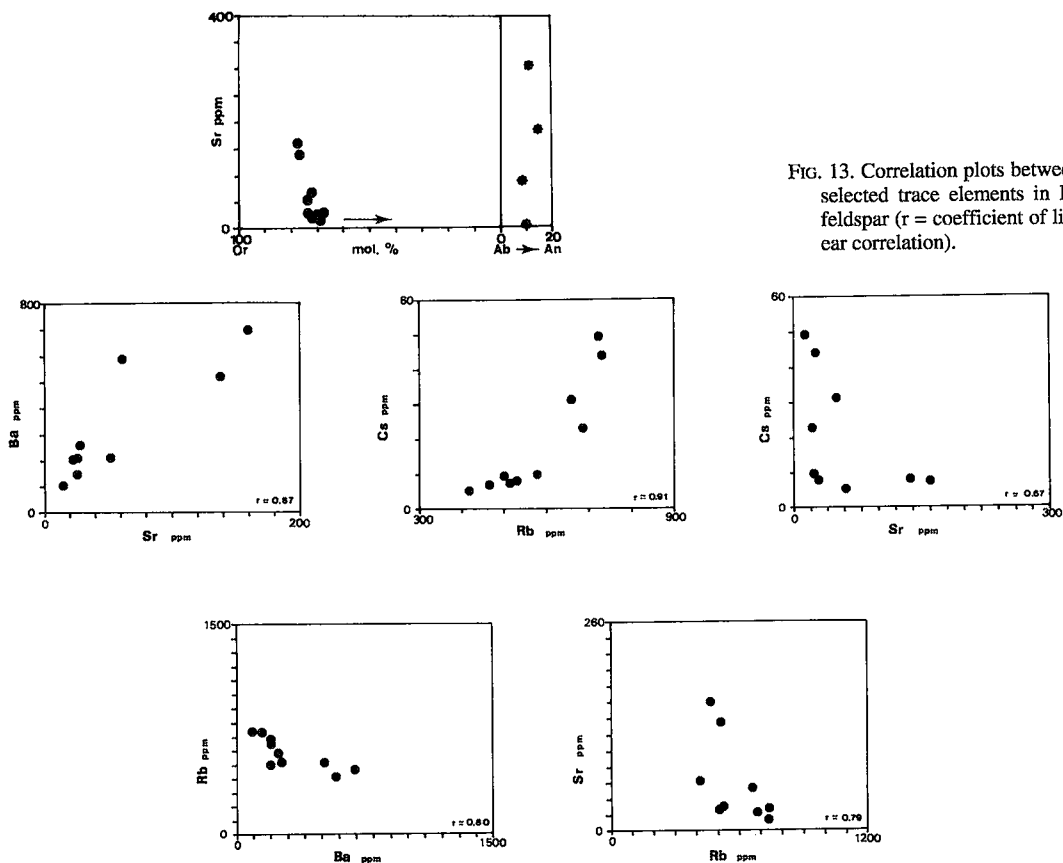


FIG. 13. Correlation plots between selected trace elements in K-feldspar (r = coefficient of linear correlation).

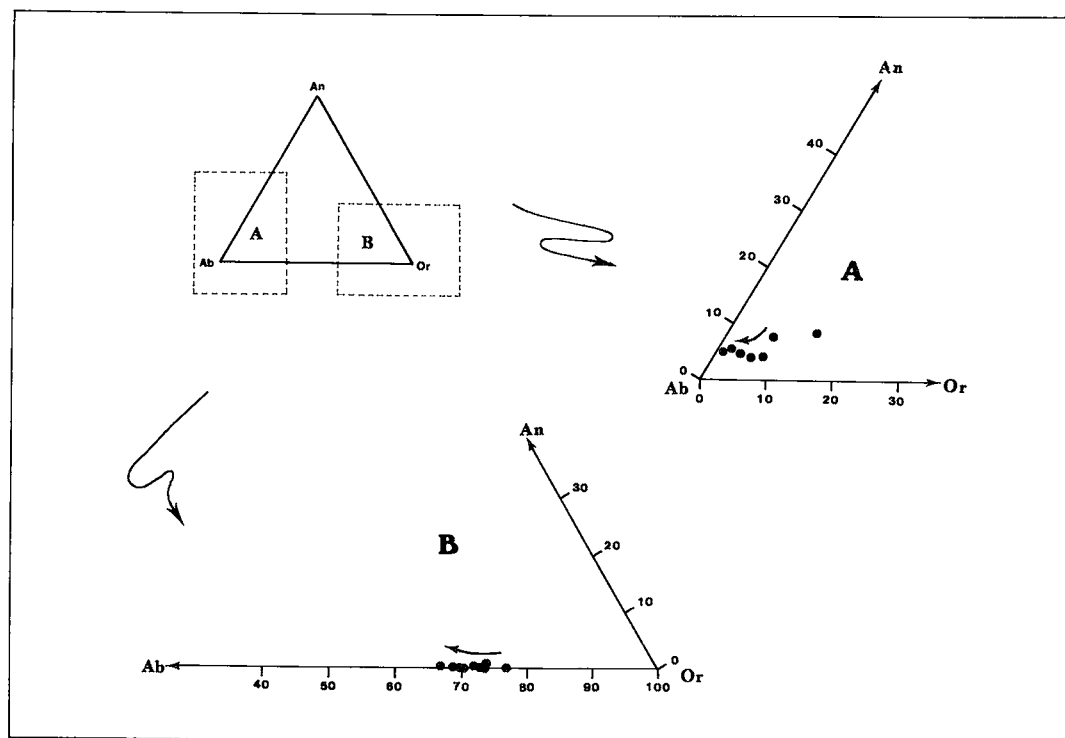


FIG. 14. Evolution of K-feldspar and plagioclase composition in the Or–Ab–An triangular plot. The arrow indicates evolution toward the center of the pegmatitic bodies.

The temperatures resulting from the application of the two-feldspar geothermometer by Fuhrman & Lindsley (1988) gave a mean temperature of $500^{\circ} \pm 30^{\circ}\text{C}$.

PETROGENETIC INTERPRETATIONS

The feldspars in the Sierra Albarrana pegmatites show, to differing degrees, the development of stages of magmatic, subsolidus or postmagmatic, and hydrothermal or deuteric crystallization, according to the terminology of Parsons & Brown (1984).

Thermobarometry, using the biotite–garnet exchange and plagioclase – garnet – aluminum silicate – quartz equilibrium, led to González del Tánago & Peinado (1990) to estimate the metamorphic path in which the thermal peak is reached at $675^{\circ} \pm 25^{\circ}\text{C}$ and 4.9 ± 0.5 kbar. These temperatures and pressures correspond to the upper amphibolite facies of regional metamorphism, where temperatures of $750^{\circ} - 625^{\circ}\text{C}$ were reached, producing partial fusion and migmatites. Under these conditions, the first K-feldspar to be formed is disordered and monoclinic (orthoclase). Except for two samples, disordered K-feldspar was not found. The metastable persistence of orthoclase in some pegmatitic

bodies (Peña Grajera and Juan Calvillo) could reflect the development of the magmatic stage of Parsons & Brown (1984), and a relatively rapid decompression, which would have prevented the inversion to a triclinic feldspar. This uplift may be a consequence of the distensive process that affected the region during the Hercynian orogeny (Quesada & Dallmeyer 1993) and produced deep fractures parallel to the axis of Sierra Albarrana. These fractures aided the magmatic activity responsible for the formation of the Los Pedroches batholith, the Villaviciosa – La Coronada complex, etc. (Delgado *et al.* 1985, Sánchez-Carretero *et al.* 1990). Although these processes are not related genetically nor spatially to the pegmatites, they do indicate the existence of a distensive process on a regional scale. This would explain the prominence of low microcline (without orthoclase) in these pegmatites compared to most granitic pegmatites. In the remaining samples, the more ordered monoclinic K-feldspar and triclinic K-feldspar result from arrested ordering of the primary K-bearing feldspar, which occurred as temperature fell and in the presence of alkali-rich solutions (Stewart & Wright 1974, Eggleton & Buseck 1980).

Al–Si ordering, inversion of monoclinic to triclinic symmetry (at approximately 500°C , according to Brown

TABLE 7. LINEAR CORRELATION-COEFFICIENTS BETWEEN STRUCTURAL AND CHEMICAL PARAMETERS OF K-FELDSPAR

	a	b	c	α	β	γ	Vol	T ₁₀	T ₁₀₀	Zr ₂	Sr ₁	Sr ₂	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	P ₂ O ₅	Or	Ab	An	B	Be	Rb	Cs	Sr	Ba	Mn	Pb		
a	1.000																															
b	0.036	1.000																														
c	-0.618	-0.620	1.000																													
α	-0.615	-0.413	0.854	1.000																												
β	0.023	0.061	0.448	0.344	1.000																											
γ	0.556	0.736	-0.818	-0.792	0.018	1.000																										
Vol	0.235	0.493	-0.222	-0.024	0.073	0.308	1.000																									
T ₁₀	-0.480	-0.818	0.835	0.763	0.012	-0.991	-0.332	1.000																								
T ₁₀₀	0.656	0.572	-0.777	-0.823	0.034	0.969	0.187	-0.929	1.000																							
Zr ₂	0.212	0.952	-0.762	-0.573	0.057	0.854	0.438	-0.915	0.700	1.000																						
Sr ₁	0.861	0.099	-0.703	-0.663	-0.451	0.513	0.211	-0.464	0.587	0.254	1.000																					
Sr ₂	0.831	-0.154	-0.618	-0.719	-0.445	0.379	-0.129	-0.317	0.493	0.073	0.866	1.000																				
SiO ₂	-0.507	-0.138	0.479	0.556	0.284	-0.453	-0.217	0.402	-0.533	-0.192	-0.618	-0.503	1.000																			
Al ₂ O ₃	0.453	-0.040	-0.335	-0.223	-0.311	0.116	0.110	-0.085	0.179	-0.031	0.639	0.484	-0.644	1.000																		
Fe ₂ O ₃	0.403	0.555	-0.731	-0.754	-0.434	0.681	0.438	-0.698	0.627	0.661	0.515	0.456	-0.686	0.146	1.000																	
MgO	-0.515	-0.091	0.480	0.626	0.398	-0.403	-0.220	0.369	-0.454	-0.216	-0.565	-0.571	0.708	-0.126	-0.830	1.000																
CaO	0.304	0.180	-0.413	-0.379	-0.063	0.338	-0.100	-0.339	0.392	0.226	0.411	0.359	-0.357	0.717	0.013	0.247	1.000															
Na ₂ O	0.548	0.287	-0.698	-0.713	-0.448	0.522	0.195	0.512	0.532	0.407	0.712	0.652	-0.867	0.604	0.820	-0.753	0.568	1.000														
P ₂ O ₅	0.131	-0.308	0.230	0.168	0.490	-0.018	-0.402	0.096	0.122	-0.317	-0.068	0.000	-0.118	0.319	-0.491	0.438	0.547	-0.198	-0.943	1.000												
Or	0.294	0.438	-0.616	-0.741	-0.475	0.557	0.382	-0.567	0.526	0.519	0.501	0.391	-0.669	0.140	0.922	-0.814	0.016	0.793	0.676	-0.548	1.000											
Ab	-0.011	-0.358	0.390	0.356	0.525	-0.163	-0.368	0.231	-0.038	-0.403	-0.194	-0.165	0.062	0.195	-0.643	0.387	0.440	-0.398	-0.997	0.966	-0.665	1.000										
An	-0.016	0.346	-0.364	-0.327	-0.511	0.138	0.361	-0.209	0.011	0.390	0.163	0.136	-0.021	-0.227	0.614	-0.561	-0.467	0.358	0.994	-0.974	0.638	-0.999	1.000									
B	0.516	0.295	-0.502	-0.369	-0.264	0.454	0.399	-0.441	0.453	0.354	0.647	0.396	-0.817	0.516	0.683	-0.632	0.199	0.790	0.183	-0.082	0.626	-0.180	0.146	1.000								
Be	0.074	-0.034	-0.203	-0.039	0.050	0.136	-0.469	-0.126	0.173	0.054	0.073	0.289	-0.399	0.401	0.140	-0.052	0.609	0.502	-0.156	0.367	0.158	0.198	-0.225	0.159	1.000							
Rb	0.592	0.045	-0.520	-0.730	-0.118	0.583	-0.167	-0.516	0.690	0.243	0.550	0.668	-0.295	0.122	0.285	-0.214	0.504	0.301	-0.184	0.299	0.286	0.207	-0.228	0.177	0.265	1.000						
Cs	-0.207	0.217	-0.102	-0.332	0.004	0.729	-0.096	-0.258	0.169	0.314	-0.269	-0.073	0.205	-0.767	0.356	-0.267	-0.412	-0.033	0.428	-0.457	0.409	-0.441	0.450	-0.156	0.018	0.266	1.000					
Sr	-0.439	0.220	0.176	-0.010	0.156	0.050	-0.031	-0.099	-0.045	0.241	-0.517	-0.386	0.514	-0.918	0.073	0.059	-0.515	-0.390	0.280	-0.420	0.119	-0.314	0.358	-0.371	-0.235	0.066	0.915	1.000				
Ba	0.092	-0.409	0.254	0.247	0.338	-0.200	-0.455	0.259	-0.083	-0.408	-0.079	0.064	0.208	0.293	-0.691	0.640	0.536	-0.391	-0.845	0.869	-0.760	0.867	-0.864	-0.395	0.229	0.245	-0.532	-0.423	1.000			
Mn	0.040	-0.441	0.286	0.324	0.114	-0.365	-0.266	0.411	-0.260	-0.508	0.044	0.047	0.112	0.557	-0.682	0.591	0.551	-0.280	-0.673	0.673	0.651	0.867	-0.686	-0.318	0.130	-0.007	-0.799	-0.678	0.861	1.000		
Pb	-0.133	0.530	-0.159	0.114	0.356	0.283	0.067	-0.347	0.139	0.517	-0.305	-0.315	0.008	-0.174	0.211	0.042	-0.083	0.099	0.067	0.001	-0.050	-0.055	0.055	0.212	0.232	-0.309	0.131	0.152	-0.156	-0.381	1.000	
	0.239	-0.003	-0.064	0.098	-0.059	0.022	0.255	0.007	0.070	-0.092	0.342	0.088	-0.677	0.825	0.107	-0.128	0.413	0.446	-0.286	0.383	0.056	0.302	-0.329	0.608	0.207	-0.207	-0.796	-0.856	0.179	0.417	0.080	1.000

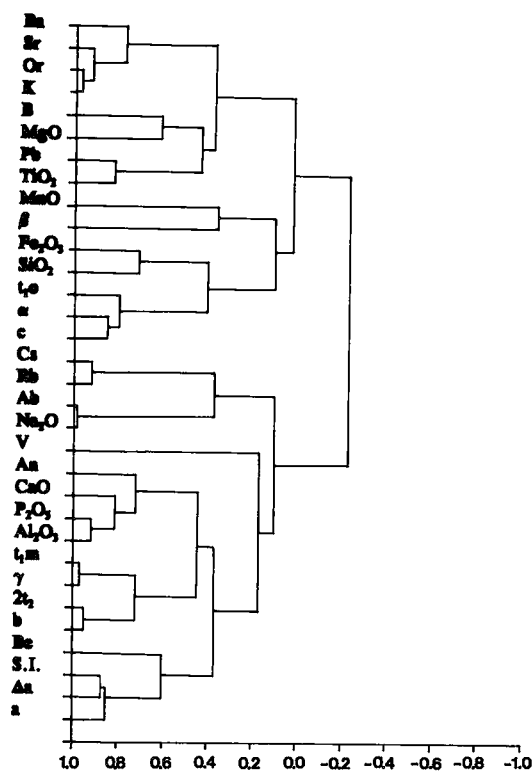


FIG. 15. Cluster analyses between the structural and chemical parameters of K-feldspar. The similarity criterion used is the coefficient of linear correlation.

& Parsons 1989) and formation of perthite took place at the subsolidus stage. As a result, a triclinic K-rich feldspar appeared, having an intermediate degree of Al-Si order (intermediate microcline), accompanied by the development of vein and braid perthites, as well as albite-pericline twinning (Fig. 5). This K-feldspar commonly is pink. The appearance of the tartan twinning in the microcline is proof of the existence of a monoclinic precursor. The subsolidus stage, which is widely represented in the feldspar populations examined here, persisted to temperatures as low as 400°C (Parsons & Brown 1984). The foregoing agrees with the temperature $500^\circ \pm 30^\circ\text{C}$ resulting from the application of the two-feldspar geothermometer (Fuhrman & Lindsley 1988).

At temperatures below 400°C, the hydrothermal stage took place, with interactions between the feldspar and a fluid phase. The appearance of feldspar with a high degree of Al-Si order (close to the low microcline end-member) and the development of patch perthite (Fig. 5) are indicative of this stage, which is clearly represented in the Diéresis outcrop. This K-feldspar commonly is white.

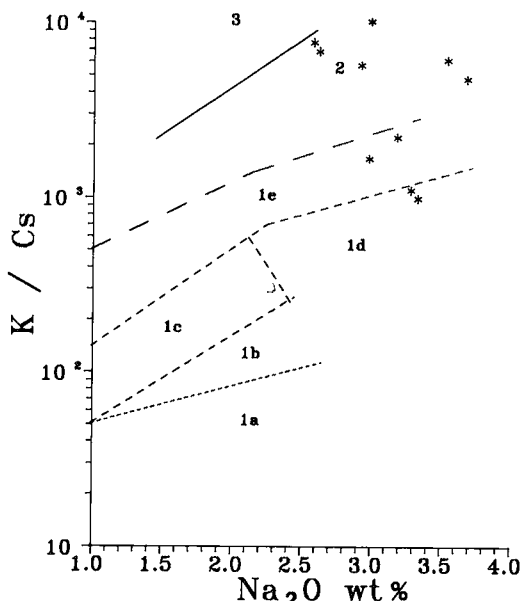


FIG. 16. Plot of K/Cs against Na_2O for K-feldspar of Phanerozoic pegmatites. Continuous line: boundary between micaceous pegmatites (3) and rare-element pegmatites (1) and (2). Broken lines: boundaries between different geochemical series of rare-element pegmatites (1) containing Cs minerals, (2) containing Li without Cs minerals, (1a, 1b, 1c) Li, Rb, Cs, Be, Ta minerals with pollucite; (1d) Li, Be, Ta minerals without pollucite; (1e) sterile bodies (Gordiyenko 1976). This study: asterisks.

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