Paragenesis, chemistry and structural state of adularia from granitic pegmatites

by Petr ČERNÝ and Ronald CHAPMAN

Department of Earth Sciences, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.

Abstract. — Adularia occurs in late hydrothermal assemblages of rare-element granitic pegmatites that correspond to Ginsburg's "alpine vein" stage of pegmatite consolidation. It is found mainly in late fractures, associated with low albite, quartz, celadonite, sericite, cookeite, cesian analcime, apatite, secondary minerals of Be, microlite, fluorite, carbonates, sulphides and clay minerals. Metasomatic aggregates of adularia are rare.

Non-perthitic adularias from 14 localities of primitive to highly fractionated granitic pegmatites have a relatively uniform morphology (predominantly the Felsöbanya-Maderaner habit) and composition (very low Na, Rb, Cs, Ca, Sr, Ba, Fe, P). Unit cell dimensions, IR-spectra and optical properties indicate structural states ranging from high sanidine to maximum microcline, along the two-step ordering trend. Some adularias exhibit the most extreme unit cell dimensions ever found, close to those of ideal high sanidine calculated by Ferguson (1980) and Kroll and Ribbe (1983 and pers. comm.), and to those of ideal maximum microcline as calculated by Ferguson (1980).

No correlation is evident between the chemistry and structural state of early rock-forming K-feldspars and those of the adularia. Also, no correlation is observed between the structural state of adularia and the K/Na ratio of the parent solutions that may be inferred from the associated minerals. The high rates of nucleation and growth in a low-energy environment, probably triggered by pressure release, have an overriding effect on adularia's composition and structural state, independent of the degree of subsolidus equilibrium attained earlier by the primary K-feldspars of the parent pegmatite. However, maximum-microcline adularias seem to be typical of peralkaline anorogenic complexes, whereas adularias of the high-sanidine type occur in peraluminous calc-alkalic pegmatites.

Key words : adularia, pegmatite, chemical composition, order-disorder, sanidine.

Paragenèse, composition chimique et état structural de l'adulaire des pegmatites granitiques.

Résumé. — Au sein des pegmatites granitiques à éléments rares, l'adulaire fait partie des paragenèses hydrothermales tardives, qui correspondent à l'étape des "fentes alpines" dans le schéma de cristallisation des pegmatites de Ginzbourg. Elle se présente, généralement, dans les fractures tardives, associée à : albite de basse température, quartz, céladonite, séricite, cookéïte, analcime à Cs, apatite, minéraux argileux. Les formations métasomatiques de l'adulaire sont rares.

Les adulaires non perthitiques provenant de 14 gisements allant de pegmatites peu évoluées à fortement fractionnées, présentent une morphologie (le faciès de Felsöbanya - Maderaner étant prédominant) et une composition relativement constantes (basses teneurs en Na, Rb, Cs, Ca, Sr, Ba, Fe, P). Les paramètres de la maille, les spectres infrarouges et les propriétés optiques indiquent des états structuraux allant de "high sanidine" à microcline extrême, suivant une tendance d'ordre à deux paliers. Certaines adulaires ont des paramètres de la maille proches de ceux d'une "high sanidine" idéale, calculés par Ferguson (1980) : il s'agit des valeurs les plus extrêmes jamais observées.

Aucune corrélation n'apparaît entre la composition chimique et l'état structural des feldspaths potassiques précoces de roche et l'adulaire. De même, aucune corrélation n'a été observée entre l'état structural de l'adulaire et le rapport K/Na des solutions parentales qui peut être déduit à partir des minéraux associés. Les grandes vitesses de nucléation et de croissance dans un milieu à faible énergie sont probablement dues à une baisse de pression et influent considérablement sur la composition et l'état structural de l'adulaire qui sont indépendants d'un degré d'équilibre subsolidus atteint auparavant par les feldspaths potassiques de la pegmatite - hôte. Cependant, la présence des adulaires de type microcline extrême semble typique des complexes anorogéniques hyperalcalins, tandis que les adulaires de type "high sanidine" apparaissent dans des pegmatites calco-alcalines hyperalumineuses.

Mots-clés : adulaire, pegmatite, analyse chimique, ordre - désordre, sanidine.

INTRODUCTION

Adularia is usually defined as a morphologically distinctive variety of potassium feldspar, typical of low-temperature hydrothermal environments. Characteristic crystals are bound predominantly by $\{110\}$ and $\{101\}$, with very subordinate $\{001\}$, and the pinakoid $\{010\}$ is

commonly missing. Adularia is generally not per-thitic, and its Na$_2$O content is low ($<$ 2.0 wt %). Optical and structural parameters are widely variable, occasionally even in a single "morphological unit". Structural state ranges from high sanidine to highly ordered microcline. Disordered types and those with variable structural state are the most common, whereas maximum microcline is very rare (Barth, 1928 and 1929 ; Köhler, 1948 ; Chaisson, 1950 ; Hafner and Laves, 1957 ; Bambauer and Laves, 1960 ; Gubser and Laves, 1967 ; Asquith, 1975a ; Akizuki and Sunagawa, 1978 ; Akizuki, 1981).

Adularia is found in a variety of hydrothermal parageneses : cavities and replacements in igneous and metamorphic rocks (Ansilewski, 1958 ; Nowakowski, 1959 ; Asquith, 1975b ; Munhá et al., 1980), sulphide bearing ore veins in metamorphic and subvolcanic environments (Nolan, 1935 ; Cornwall, 1951 ; White, 1955 ; Grabezhev and Yunikov, 1969 ; Optoyev and Batova, 1969 ; Chesterman et al., 1974 ; Rusinova et al., 1975), alpine mineral veins (Parker, 1973 ; Weibel, 1957 and 1961 ; Nissen, 1967 ; Bass and Ferrara, 1969 ; Halliday and Mitchell, 1976), fluorite deposits (Kraus, 1958) and active hot springs (Steiner, 1970 ; Blattner, 1975).

Pegmatitic occurrences of adularia probably are also widespread, but adularia is a rather minor and inconspicuous component of granitic pegmatites, and easily escapes detection. It belongs to a late hydrothermal mineral association dubbed by Ginsburg (1960) the "alpine vein" stage of pegmatite consolidation. The number of pegmatite localities at which adularia was noticed is limited (Shibata, 1952 ; Gavrusevich, 1957 ; Staněk, 1954 and 1962 ; Miškovský, 1955 ; Staněk and Čech, 1958 ; Hensen, 1967), and the details of its paragenesis, chemistry and structural state are largely unknown. The few random data, collected during studies of broader feldspar assemblages, are recorded in Černý (1972), Lenton (1979), Foord and Martin (1979), Martin (1982) and Černý et al. (1983).

The present paper summarizes the chemical, structural and some optical data on adularia from a variety of pegmatite types, and their paragenetic position in parent rocks. As shown in the final discussion, the properties of some of the examined samples expand the ranges established for adularias from other environments. Some of the high-sanidine data suggest a total Si, Al disorder never observed before in K-feldspar of any genetic type. Also, in some cases the parent pegmatite type, mineral association and textural features of the adularias themselves seem to be suggestive of the conditions favourable for the generation and/or preservation of specific structural states.

SAMPLES AND METHODS

Twenty eight samples of pegmatitic adularias from 14 localities examined in the present study are listed in table I. Although an attempt was made to secure specimens from diverse pegmatite fields and localities, virtually no pegmatitic adularias were located in museum collections, and only a few samples were found in research collections of other pegmatite investigators. Thus most of the samples came from the depository of the first author, as collected during the past 25 years.

Experimental coverage of the samples was severely restricted by limited quantity and quality of material available. Chemical analysis was performed by electron microprobe because only a few specimens could yield material sufficient for X-ray fluorescence and atomic absorption methods. X-ray diffraction study was limited to powder diffractometry, because growth deformation of crystals in most samples hindered separation of undeformed single-crystal fragments. In a few cases, clouding of adularias due to formation of a clay or micaceous mineral interfered with optical investigation and rendered IR absorption spectra unreliable.

PARAGENESIS

The adularias examined here come from four types of granitic pegmatites. Three of them are of calc-alkalic affinity, with characteristic peraluminous mineralogy (muscovite, garnet, cordierite, andalusite, topaz, gahnite). They belong to the beryl-columbite, complex spodumene- or petalite-bearing, and lepidolite types (Černý, 1984). The fourth type is of peralkaline kindred, associated with an anorogenic plutonic complex (Table II).

In all localities, crystallization of adularia postdated consolidation of the primary zonal se-

Sample #	Locality	Source
1 to 4	Věžná, western Moravia, Czechoslovakia*	research collection, P. Černý
5	Radkovice, western Moravia, Czechoslovakia	research collection, P. Černý
6	Nová Ves, near Český Krumlov, southern Bohemia, Czechoslovakia	Dr. F. Čech, Charles University, Prague
7	Puklice, near Jihlava, western Moravia, Czechoslovakia	Dr. F. Čech, Charles University, Prague
8 and 9	Biskupice "U starého čihadla", western Moravia, Czechoslovakia	research collection, P. Černý
10	Rubellite Dike, Lilypad Lakes at Fort Hope, northwestern Ontario	research collection, P. Černý
11 to 15	Tanco, Bernic Lake, southeastern Manitoba**	research collection, P. Černý
16 and 17	Silverleaf Claim, southeastern Manitoba	research collection, P. Černý
18	Buck Claim, Bernic Lake, southeastern Manitoba	P. G. Lenton, M.Sc. thesis material
19	High Grade Dike, Maskwa Lake, southeastern Manitoba	research collection, P. Černý
20	King Lithia Lode Fraction, near Keystone, Pennington County, South Dakota	research collection, P. Černý
21 to 24	Wausau, Wisconsin***	A. Falster, Wausau
25 to 27	Brown Derby No. 1, Gunnison County, Colorado	research collection, P. Černý
28	Etta, near Keystone, Pennington County, South Dakota	research collection, P. Černý

*samples 3 and 4 from the hand specimen KVZ-25 of Černý et al. (1983)
**sample 15 from the specimen examined in Černý (1972)
***sample 21 from pegmatite # 61; 22 and 23 from pegmatite # 63; sample 24 from pegmatite # 69 (A. Falster's registry)

TABLE I. — List of samples.
Liste des échantillons.

quence of the parent pegmatites, including quartz cores and pollucite bodies. It also postdated replacement processes that gave rise to saccharoidal albite and cleavelandite, lepidolite and greisenlike assemblages.

In most localities, adularia and associated minerals are found in late fissures cross-cutting one or more of the above pegmatite units. Notable exceptions are the Wausau pegmatites in which adularia lines miarolitic vugs, and the Lithia King Lode Fraction, Radkovice, Puklice and Nová Ves pegmatites where adularia seems to have crystallized in dissolution cavities. In the Rubellite Dike and Brown Derby Nº 1 pegmatites, adularia forms massive pods of irregular shape, bound by quartz and albite, which appear to be of metasomatic origin but with no relics or circumstantial evidence of the replaced phase (or assemblage ; figure 1a).

There is little evidence of potassium metasomatism of pre-existing feldspars. Even in the apparent replacement pods mentioned above, angular cleavelandite fragments are preserved within adularia aggregates (Figure 1c, d) and euhedral cleavelandite is overgrown by adularia in epitaxial orientation. However, sericitic mica is commonly present along the contacts of albite and adularia, replacing mainly the former feldspar (Figure 1b).

Minerals associated with pegmatitic adularia are similar in kind to the paragenesis of adularia in alpine mineral veins, described by, e.g., Parker (1973). Albite, quartz, cesian beryl and probably some muscovite seem to have crystallized simultaneously with the adularia at different localities. Specific types of micas (sericite, celadonite), chlorites (cookeite) and clay minerals (montmorillonite-illite), secondary Be-bearing silicates (bavenite, milarite, bertrandite, phenacite), apatite, cesian analcime, fluorite, carbonates and traces of sulphides are the most typical species precipitated after the formation of adu-
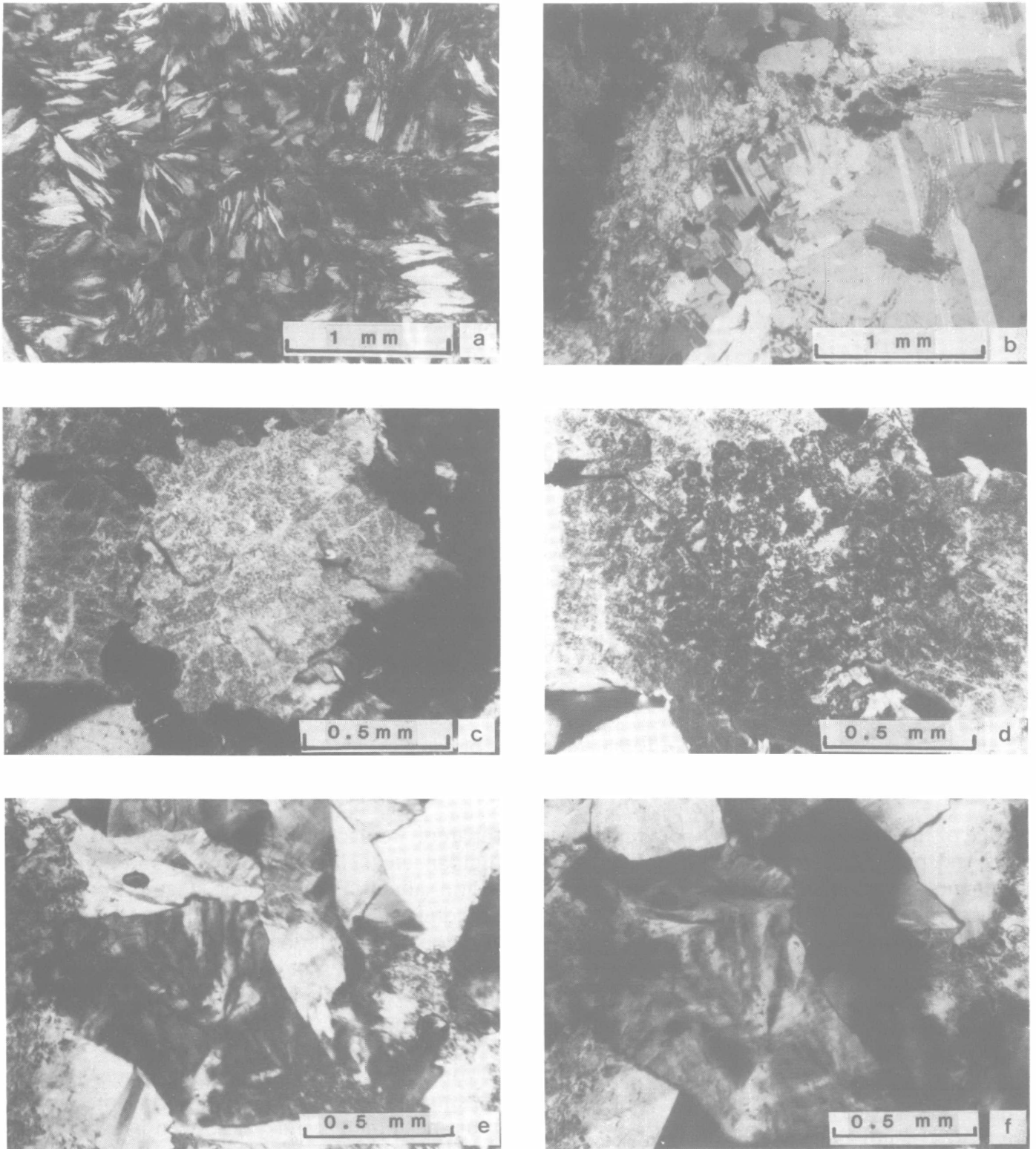
FIG. 1. — (a) Granular adularia (grey to black) with flakes of cookeite (white) ; Radkovice, Czechoslovakia, crossed polars. (b) Granular adularia (grey to black) separated from albite (twinned) by a seam of muscovite ; Brown Derby N° 1, Colorado, crossed polars. (c) Granular maximum-microcline adularia (light grey to black, clouded) with a fragment of twinned albite (lower left) and veined by sericite (white) ; Rubellite Dike, Ontario, crossed polars. (d) Central grain of adularia from (c) showing mosaic twinning pattern. (e) (f) Diamond-shaped sections through orthoclase-type adularia crystals, subnormal to [001], displaying sector-twinning and complex extinction patterns, in two different positions to crossed polars ; Nová Ves, Czechoslovakia.

I.   Be, Nb-Ta, Ti, (REE, Y, Zr)-bearing pegmatites

      Věžná - milky Felsöbanya-Maderaner crystals (≤3 mm) lining fractures in tourmaline, K-feldspar
           or albite; associated with (later) celadonite, milarite and bavenite, rarely fluorite and
           microlite.

II.   Complex Li, Rb, Cs-enriched pegmatites

      Spodumene-bearing:

           Etta - coarse-grained (3-10 mm) white aggregates and sheaf-like crystals in their cavities, in
                cleavelandite and altered spodumene; associated with (early) muscovite and (late) quartz.

           Lithia King Lode Fraction - white to translucent, irregular and strongly corroded grains
                (≤30 mm) in vuggy albitic pegmatite; associated with (later) apatite.

           Rubellite Dike - fine-grained (0.5-1.5 mm) buff-coloured aggregates penetrating foliated
                saccharoidal albite and lepidolite, associated with (later) muscovite and fluorite.

           High Grade Dike - greenish-gray fine-grained (0.2-1.5 mm) veinlets cross-cutting pollucite;
                micaceous and clayey clouding.

      Petalite-bearing:

           Tanco - milky to waterclear, divergent crystal clusters of the Felsöbanya-Maderaner type
                (mostly ≤2 mm, rarely to 6 mm) in corroded spodumene + quartz pseudomorphs after spodumene
                or in vuggy saccharoidal albite; associated with (early) cesian beryl, albite and quartz,
                and (late) cookeite, cesian analcime, apatite, calcite and montmorillonite-illite.

           Silverleaf - buff-coloured fine-grained (≤0.5 mm) aggregates and occasional Felsöbanya-
                Maderaner crystals in fractures of sheared and sericitized albitic pegmatite.

           Buck Claim - transparent rust-coloured divergent crystals of the Felsöbanya-Maderaner type
                (<1 mm) in open fractures in the quartz core, associated with (later) apatite.

           Nová Ves - buff-coloured Felsöbanya-Maderaner type crystal aggregates (≤2 mm) with relics
                of platy albite and lepidolite.

III. Li, F (Rb,Cs)-enriched lepidolite pegmatites

           Brown Derby No. I. - Fine-grained (≤2 mm) pink masses and corroded crystals in their vugs,
                enclosing relictic cleavelandite and lepidolite, and associated with sericite and (later)
                fluorite.

           Radkovice - epitaxial shingle-like overgrowths of Felsöbanya-Maderaner morphology on open
                fractures in orthoclase and intermediate microcline in the intermediate and core-margin zone.

           Biskupice - epitaxial shingle-like overgrowths of Felsöbanya-Maderaner morphology covering
                fractures in orthoclase and intermediate microcline in the core-margin zone; associated
                with albite.

           Puklice - crystals of Felsöbanya-Maderaner morphology (<1.2 mm) in tiny vugs in saccharoidal
                albite, quartz, lepidolite and pollucite, associated with sericite and (later) fluorite.

IV.   Subalkalic pegmatites of anorogenic affiliation

           Wausau - rusty-brown botryoidal clusters and crusts of Zillertal-Fibbia crystal type, rarely
                grading into Felsöbanya-Maderaner habitus, in miarolitic vugs on (early) microcline-perthite;
                associated with (early) microcline, albite and quartz, and (later) bertrandite, phenacite,
                anatase, pyrite, jamescnite, boulangerite, calcite, siderite and goethite.

TABLE II. — Paragenesis.

Paragenèses.

laria. Association of pegmatitic adularia with sericitic mica and fluorite appears to be rather common, having been noted in other localities as well (Gavrusevich, 1957 ; Staněk, 1962). Table II summarizes the paragenetic relationships at the localities examined in the present study.

CHEMICAL COMPOSITION

Electron microprobe analyses were performed on a MAC-5 instrument, on polished sections of grains randomly selected from separates destined for X-ray and IR study. Energy-dispersive ana-

(a) Adulaire granulaire (gris à noir) avec des écailles de cookeite (blanc) : Radkovice, Tchécoslovaquie, polariseurs croisés. (b) Adulaire granulaire (gris à noir) séparé de l'albite (maclée) par une couche de muscovite ; Brown Derby n° 1, Colorado, polariseurs croisés. (c) Adulaire microcline maximum granulaire (gris clair à noir, flou) avec un fragment d'albite maclée (en bas à gauche) et veiné par de la cericite (blanc) ; Rubellite Dike, Ontario, polariseurs croisés. (d) Grain central d'adulaire de (c) montrant un maclage mosaï-que. (e) (f) Sections en losange à travers des cristaux d'adulaire de type orthoclase, subnormales à [001] présentant un maclage en secteur et une extinction complexe, dans deux positions différentes par rapport aux polariseurs croisés ; Nová Ves, Tchécoslovaquie.

	2	6	7	10	11	13	14	20	21	22	25	28
SiO_2	64.0	63.7	63.7	64.7	64.5	65.1	65.0	64.3	63.7	64.7	64.2	63.7
Al_2O_3	18.1	18.0	17.8	18.4	18.2	18.2	17.9	18.3	18.2	18.4	18.1	18.0
BaO	<0.1	<0.1	0.58	0.12	<0.1	<0.1	<0.1	<0.1	0.25	<0.1	0.41	0.32
Na_2O	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.48	<0.1	<0.1	0.14	<0.1
K_2O	16.4	16.8	16.3	16.1	16.7	16.5	16.3	15.5	16.4	16.8	16.2	16.2
Rb_2O	<0.1	<0.1	<0.1	0.29	<0.1	<0.1	<0.1	0.46	<0.1	<0.1	<0.1	<0.1
Total	98.5	98.5	98.38	99.61	99.4	99.8	99.2	99.04	98.55	99.9	99.05	98.22
Si	3.004	2.999	3.008	3.004	3.003	3.012	3.022	3.003	2.995	2.998	3.003	3.005
Al	1.001	0.998	0.990	1.007	0.999	0.993	0.981	1.007	1.008	1.005	0.997	0.998
Ba	-	-	0.011	0.002	-	-	-	-	0.005	-	0.006	0.006
Na	-	-	-	-	-	-	-	0.043	-	-	0.013	-
K	0.982	1.009	0.976	0.953	0.992	0.973	0.967	0.923	0.983	0.993	0.967	0.974
Rb	-	-	-	0.006	-	-	-	0.014	-	-	-	-
$\Sigma(R^{1+}+R^{2+})$	0.982	1.009	0.987	0.961	0.992	0.973	0.967	0.980	0.988	0.993	0.986	0.980

Atomic contents calculated on the basis of 8 oxygens.

TABLE III. — Chemical composition.
Compositions chimiques.

lysis for Si, Al, Na (albite standard) and K (orthoclase) was done at the acceleration voltage of 15 kV and specimen current of 0.005 mA. Wavelength-dispersive mode was used for Rb (K-feldspar), Cs (pollucite), Ca (titanite), Sr ($SrTiO_3$), Ba (benitoite) and Fe (pyrope). Accelerating voltage was 20 kV and specimen current 0.04 mA for all these elements except Rb and Sr, for which 25 kV was used. All standards were obtained from C.M. Taylor Co., Stanford, CA except for the Tanco pollucite analyzed at the Department of Earth Sciences, University of Manitoba.

The examined adularias proved to be very close to the ideal end-member composition of $KAlSi_3O_8$ (Table III). Cs_2O, CaO, SrO and Fe_2O_3 are invariably below 0.1 wt. %. BaO, Na_2O and Rb_2O were found in negligible quantities in a few samples, and traces of P_2O_5 were detected only in sample 20. Unit cell contents indicate that the adularias are stoichiometric, or possibly slightly peraluminous but the deviation is well within the limits of experimental error (Table III). The low content of alkaline earths and of alkalis other than K are corroborated by the results obtained by Černý et al. (1984) on other grains of specimen 4 in the electron and ion microprobe laboratories at the University of Chicago.

Several analyses of albite associated with adularia, some of which were published by Černý et al. (1984 ; Věžná, Czechoslovakia), show that albite is also close to the pure end-member composition, with K_2O and CaO each less than 0.15 wt. %.

OPTICAL PROPERTIES

The study of optical properties was hindered by the fine-grained nature of most specimens, complex optical structure of some, and extensive clouding in others. Nevertheless, a general subdivision of the examined adularias into five categories was possible :

1) samples 3, 4, 11 to 16, 18 and 19 are optically homogeneous, with o.a.p. // to (010) and (-) 2V small to intermediate, indicative of high sanidine ;

2) samples 1, 2, 6 and 17 display sector zoning and undulatory extinction, with both orientation of o.a.p. and value of (-) 2V variable (Figure 1e, f) ;

3) samples 25 and 28 also have complex optical structure, consisting of interior lamellar // to (100) and outer envelope of four segments underlying the faces of {110} ; the pattern is closely similar to the adularia optics described by Bambauer and Laves (1960) and by Dimitriadis and Soldatos (1978 ; Ouranoupolis occurrence) ;

4) samples 5 and 7 to 9 have simple monoclinic optics, with a fine moirée extinction in samples 7 to 9, and o.a.p. perpendicular to (010), suggestive of orthoclase ; and

5) samples 10 and 20 to 24 display fine twinning on (001) that appears to be of mosaic texture in sample 10 (Figure 1c, d) but of the common microcline grid pattern in samples 21 to 24.

Thus the optical behavior indicates variable structural states, identifiable in some cases but

obscured in others by complex sectorial and lamellar structure.

X-RAY DIFFRACTION STUDY

X-ray powder diffractograms confirm wide variations in structural state as indicated by optical properties. The diversity of the 131 and 131 + 1̄31 peak configurations can be used for a rough three-fold subdivision of the examined adularias into strictly monoclinic phases, monoclinic with negligible to substantial quantities of intermediate microcline, and triclinic (Table IV, figure 2).

Unit cell dimensions were determined by the least-squares refinement (Appleman and Evans, 1973) of powder data obtained on the Philips automated X-ray powder diffractometer system PW1710. Admixture of CaF_2 ($a = 5.4636 \pm 0.0002$ Å) was used as an internal standard. The

SAMPLE	Δ	a, Å a*, Å⁻¹	b, Å b*, Å⁻¹	c, Å c*, Å⁻¹	α α*	β β*	γ γ*	V, Å³ V*, Å⁻³
3	0.00 (-0.59)	8.602(2) 0.12937(3)	13.024(4) 0.07678(3)	7.185(2) 0.15488(5)		116° 1.5(1.4)' 63°58.5(1.4)'		723.35(.29) 0.001382
4	0.00 (-0.38)	8.594(3) 0.12945(5)	13.028(6) 0.07676(3)	7.180(3) 0.15493(6)		115°58.8(2.1)' 64° 1.2(2.1)'		722.64(.37) 0.001384
5	0.00 (-0.60)	8.603(5) 0.12926(7)	12.998(5) 0.07694(3)	7.196(2) 0.15455(4)		115°56.9(1.8)' 64° 3.1(1.8)'		723.54(.39) 0.001382
6	0.00	8.602(5) 0.12927(9)	13.034(5) 0.07672(3)	7.180(4) 0.15487(9)		115°56.4(2.9)' 64° 3.6(2.9)'		723.93(.50) 0.001381
7	0.00	8.595(2) 0.12947(3)	13.005(3) 0.07689(1)	7.188(2) 0.15482(3)		116° 1.1(1.1)' 63°58.9(1.1)'		721.95(.20) 0.001385
8	0.00 (-0.78)	8.580(3) 0.12967(4)	12.980(4) 0.07704(3)	7.201(2) 0.15452(5)		116° 0.2(1.4)' 63°59.8(1.4)'		720.80(.31) 0.001387
9	0.00 (-0.65)	8.598(4) 0.12950(5)	12.988(4) 0.07699(2)	7.199(2) 0.15466(3)		116° 5.2(1.6)' 63°54.8(1.6)'		722.03(.32) 0.001385
10	0.88	8.593(5) 0.12958(7)	12.965(4) 0.07718(2)	7.226(4) 0.15401(7)	90°36.6(3.0)' 90°20.6(3.0)'	116° 1.2(2.1)' 63°59.0(2.1)'	87°54.4(2.1)' 92° 1.9(2.1)'	722.89(.39) 0.001383
12	0.00	8.603(2) 0.12924(4)	13.050(4) 0.07663(2)	7.171(2) 0.15505(5)		115°55.8(1.7)' 64° 4.2(1.7)'		724.12(.30) 0.001381
13	0.00	8.596(2) 0.12939(3)	13.040(3) 0.07669(2)	7.166(2) 0.15523(5)		115°58.2(1.2)' 64° 1.8(1.2)'		722.12(.23) 0.001385
15	0.00	8.597(2) 0.12941(4)	13.038(3) 0.07670(2)	7.172(3) 0.15513(5)		115°59.7(1.3)' 64° 0.3(1.3)'		722.57(.25) 0.001384
16	0.00 (-0.60)	8.607(4) 0.12927(7)	13.024(5) 0.07678(3)	7.175(3) 0.15508(8)		116° 0.0(2.0)' 64° 0.0(2.0)'		722.89(.41) 0.001383
18	0.00	8.602(2) 0.12934(3)	13.046(4) 0.07665(2)	7.172(2) 0.15515(3)		116° 0.4(1.0)' 63°59.6(1.0)'		723.37(.22) 0.001382
19	0.00	8.601(2) 0.12924(3)	13.042(3) 0.07667(2)	7.171(1) 0.15500(3)		115°53.5(1.1)' 64° 6.5(1.1)'		723.69(.19) 0.001382
20	0.94	8.577(4) 0.12976(6)	12.965(4) 0.07719(2)	7.220(3) 0.15403(4)	90°31.6(2.7)' 90°29.0(2.0)'	115°56.4(1.7)' 64° 3.6(1.7)'	87°48.1(3.0)' 92°11.4(2.3)'	721.36(.37) 0.001386
21	0.99	8.565(2) 0.12994(3)	12.959(3) 0.07724(2)	7.219(1) 0.15405(3)	90°41.6(1.7)' 90°23.6(1.7)'	115°56.3(1.1)' 64° 4.1(1.1)'	87°36.3(1.3)' 92°19.6(1.3)'	719.84(.20) 0.001389
22	0.98	8.571(3) 0.12985(4)	12.957(3) 0.07724(2)	7.218(1) 0.15408(3)	90°38.2(1.4)' 90°24.8(1.4)'	115°56.9(1.1)' 64° 3.4(1.1)'	87°41.7(1.2)' 92°15.3(1.2)'	720.26(.22) 0.001388
23	0.98	8.572(3) 0.12985(6)	12.953(3) 0.07726(2)	7.215(2) 0.15417(4)	90°35.4(1.7)' 90°27.8(1.7)'	115°58.3(1.7)' 64° 1.8(1.7)'	87°42.0(1.4)' 92°16.3(1.5)'	719.64(.28) 0.001390
24	0.95	8.570(2) 0.12990(4)	12.960(2) 0.07723(1)	7.218(1) 0.15412(3)	90°38.8(1.3)' 90°23.8(1.3)'	115°58.8(0.9)' 64° 1.5(0.9)'	87°42.5(0.8)' 92°14.0(0.9)'	720.09(.17) 0.001389
25	0.00 (-0.51)	8.600(2) 0.12937(4)	13.002(7) 0.07691(4)	7.201(2) 0.15451(3)		116° 0.2(1.4)' 63°59.8(1.4)'		723.70(.57) 0.001382
27	0.00 (-0.62)	8.588(5) 0.12954(7)	12.991(3) 0.07698(2)	7.203(1) 0.15446(3)		115°59.3(1.5)' 64°06.6(1.5)'		722.29(.44) 0.001384
28	0.00 (-0.40)	8.599(2) 0.12927(3)	13.006(6) 0.07689(4)	7.197(2) 0.15444(4)		115°53.7(1.4)' 64° 6.3(1.5)'		724.13(.33) 0.001381
Ab-12		8.141(3) 0.13741(3)	12.983(3) 0.07844(3)	7.160(2) 0.15654(3)	94°11.8(1.3)' 86°25.6(1.3)'	116°37.7(0.6)' 63°27.4(0.6)'	87°45.8(1.1)' 90°24.0(1.1)'	664.28(.20) 0.001505
Ab-13		8.140(2) 0.13741(2)	12.788(2) 0.07841(2)	7.162(1) 0.15648(2)	94°12.6(1.1)' 86°24.9(1.1)'	116°36.7(0.5)' 63°28.4(0.5)'	87°45.2(0.8)' 90°24.4(0.8)'	664.73(.14) 0.001504
Ab-15		8.138(3) 0.13745(3)	12.786(4) 0.07843(3)	7.158(1) 0.15658(2)	94°14.3(1.2)' 86°23.3(1.1)'	116°37.3(0.8)' 63°27.8(0.9)'	87°44.6(1.2)' 90°24.1(1.0)'	664.01(.20) 0.001506

Ab samples are albite associated with adularia of the given sample number.

Numerals in brackets represent standard deviation in terms of the lowest significant decimal place(s) (1σ).

Underlined value of triclinicity is the predominant one.

TABLE IV. — Unit cell dimensions.

Dimensions de la maille.

cell edge of the reagent-grade CaF_2, respectively annealed and pulverized at 500 and 800 °C, was determined by internal calibration with the 1982 NBS silicon standard (a = 5.430825 ± 0.000036 Å). The above cell edge of CaF_2 is close to that used by Wright and Stewart (1968 ; 5.4620 Å), and refinements of feldspar data corrected to 2θ values of CaF_2 calculated from the two cell edges yield virtually identical cell dimensions.
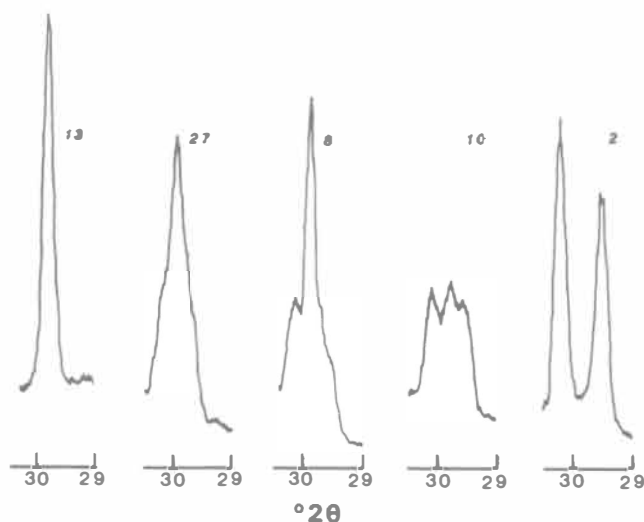

FIG. 2. — The 131 and 131 + 1̄31 diffractions representative of different types of adularia. Sample numbers are those of table I.

Pics de diffraction 131 et 131 + 1̄31 représentatifs de différents types d'adulaire. Les numéros des échantillons sont ceux du tableau I.

Repetitive unit cell refinements were performed on 4 samples of different structural state, using different methods of peak measurement and consequently different wavelengths of the Cu radiation (K_α and $K_{\alpha 1}$). In all cases, the unit cell data clustered within less than 1.0σ around the values obtained by refinement of the instrument printout, which defines the position of peak tips and correlates with the $CuK\alpha_1$ wavelength. Unit cell dimensions derived in this manner from 16 diffractions in the 20-55°2θ (CuK_α) range are given in table IV and figure 3.

Four groups of adularias can be distinguished in the *b* - *c* quadrilateral of Stewart and Wright (1974), as shown in figure 3 :

1) the strictly monoclinic adularias (Figure 2a) plot distinctly outside the high sanidine corner (samples 12, 13, 15, 18, 19) ;

2) some of the monoclinic feldspars with subordinate triclinic phase(s) (Figure 2b, c) fall within the high sanidine field (samples 3, 4, 6 and 16), whereas

3) others are in the orthoclase region (samples 5, 7, 8, 9, 25, 27 and 28) ;

4) the triclinic adularias (Figure 2e) cluster about the maximum microcline values (samples 10, 20 and 21 to 24).

Large standard deviations are typical of most of the monoclinic feldspars in groups (2) and (3) that contain some triclinic material. Interference of triclinic phases evidently affected the positions of even those peaks that were selected by Wright and Stewart (1968) and Orville (1967) as reliable for cell refinement of monoclinic patterns. Attempts to refine unit cell dimensions of monoclinic adularias with substantial quantities of intermediate microcline phase did not yield meaningful results (samples 1, 2 and 26 ; figure 2d).

All adularias for which unit cell dimensions could be refined yield $\Delta b^* c^*$ and $\Delta \alpha^* \gamma^*$ values indicative of the two-step ordering path in Smith's (1974a, Fig. 7-19) diagram (Figure 4).

INFRARED ABSORPTION SPECTRA

IR absorption spectra of most of the examined adularias were collected between 14.9 and 19.3 μm, on pellets prepared from a mixture of 0.22 g KBr and 0.0006 g feldspar. The spectra were recorded on the Nicolet MX-1 Fourier-transform IR spectrometer calibrated by laser interferometry and checked with an international polystyrene standard (Table V).

Due to scarcity of material, CaF_2-calibrated feldspar powders prepared for X-ray diffraction had to be used in some cases (samples 7, 13 and 18). Comparisons of spectra obtained from other adularias with and without CaF_2 showed just negligible (<0.015 μm) and random shifts of absorption maxima. These shifts were within the ranges of readings obtained for several mounts of the same sample, and evidently unaffected by the gently sloping background which is characteristic of CaF_2 in the examined wavelength range.

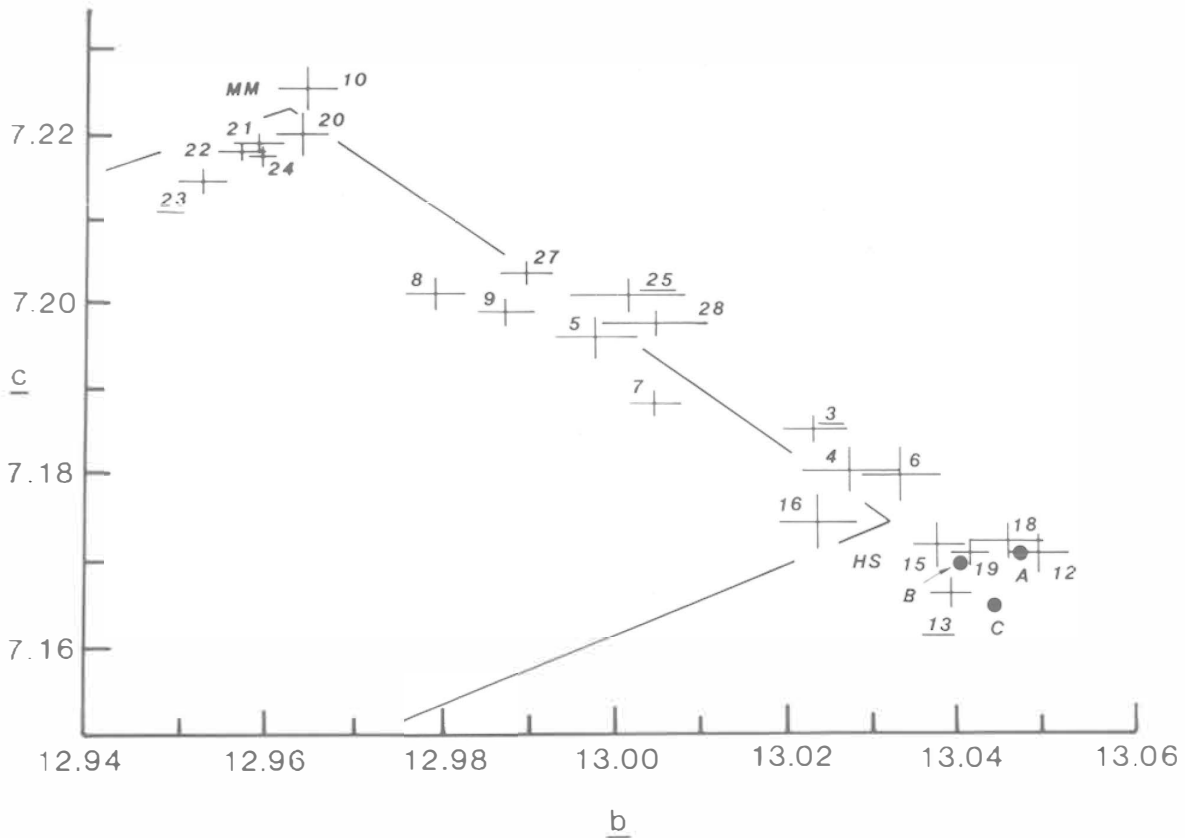Four types of spectra may be distinguished among the examined adularias, as shown in

FIG. 3. — Unit cell dimensions b and c of the examined adularias in relation to the maximum microcline (MM) and high sanidine (HS) data preferred by Stewart and Wright (1974). Infrared spectra of the underlined samples are shown in figure 5. Sample numbers refer to those of table I. Solid dots refer to calculated high sanidines : A-Ferguson (1980), B-Kroll and Ribbe (1983), C-Kroll and Ribbe (pers. comm., 1983).

Dimension de maille b et c des adulaires examinées en relation avec les données du microcline maximum (MM) et de la "high sanidine" (HS) telles que les préfèrent Stewart et Wright (1974). Les spectres infrarouge des échantillons soulignés sont présentés à la figure 5. Les numéros des échantillons se réfèrent au tableau I. Les gros points correspondent aux "high sanidines" calculées par : A. Ferguson (1980), B. Kroll et Ribbe (1983) ; C. Kroll et Ribbe (Comm. pers., 1983).
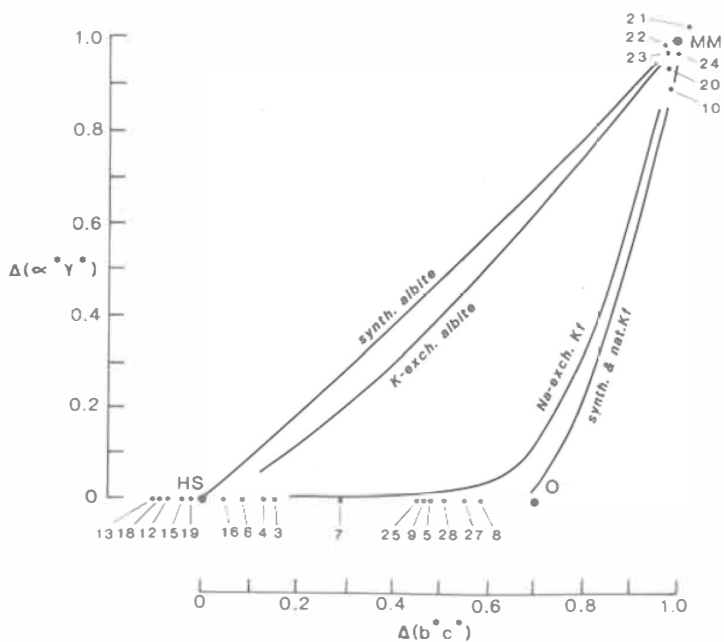
Sample #	A(μm)	B(μm)	Sample #	A(μm)	B(μm)
3	15.666	18.291	18	15.791	18.200
6	15.785	18.259	19	15.809	18.217
7	15.664	18.355	20	15.553	18.456
9	15.525	18.486	23	15.433	18.585
10	15.455	18.585	25	15.502	18.486
12	15.814	18.152	26	15.549	18.453
13	15.783	18.162	27	15.528	18.486

TABLE V. — Characteristic IR absorption maxima.

Bandes d'absorption IR caractéristiques.

FIG. 4. — Plot of $\Delta(b^*c^*)$ vs. $\Delta(\alpha^*\gamma^*)$ (Smith, 1974) for the examined adularias. Sample numbers refer to those of Table I.

Diagramme de $\Delta(b^*c^*)$ en fonction de $\Delta(\alpha^*\gamma^*)$ (Smith, 1974) pour les adulaires examinées. Les numéros des échantillons se réfèrent à ceux du tableau I.

figure 5, closely corresponding to the four groups of *b* - *c* plots in figure 3 :

1) high-sanidine structures outside the *b* - *c* quadrilateral display typical three-peak assemblages (samples 12, 13, 18 and 19 ; see n° 13 in figure 5) ;
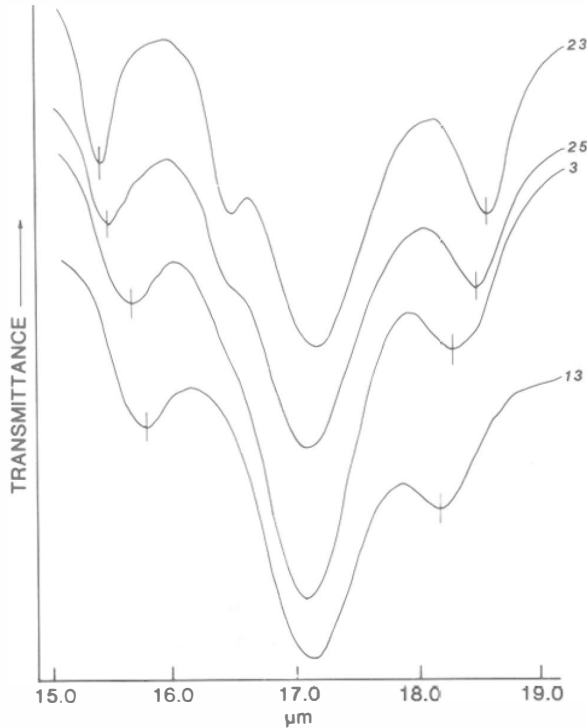

FIG. 5. — Critical range of the IR spectra representative of different types of adularia. Sample numbers refer to those of table I. Compare to figure 6.

Domaine critique des spectres IR représentatifs des différents types d'adulaire. Les numéros des échantillons se réfèrent à ceux du tableau I. Cf. figure 6.

2) high sanidines with subordinate intermediate microcline show a steep-sloping shoulder on the central absorption peak at about 16.40 μm (samples 3, 6 and 7 ; see n° 3 in figure 5) ;

3) orthoclases with subordinate intermediate microcline have a more prominent shoulder at about 16.45 μm (samples 9, 25, 26 and 27 ; see n° 25 in figure 5), and

4) maximum microclines show a well-defined satellitic absorption at about 16.50 μm (samples 10, 20 and 23 ; see n° 23 in figure 5).

In the above sequence from high sanidine to maximum microcline, the separation of the outer peaks at 15.X and 18.X μm progressively in-

creases, as shown in figure 5. Plots of the data obtained in the present study are aligned parallel to the data by Hafner and Laves (1957) but shifted to lower wavelengths. They overlap the plots of the adularia from Disentis, Switzerland (Hafner and Laves, 1957), and run somewhat across the data of Akizuki and Sunagawa (1978) and Martin (1968) (Figure 6).

DISCUSSION

Several properties of the described feldspars deserve comment, being either specific to this
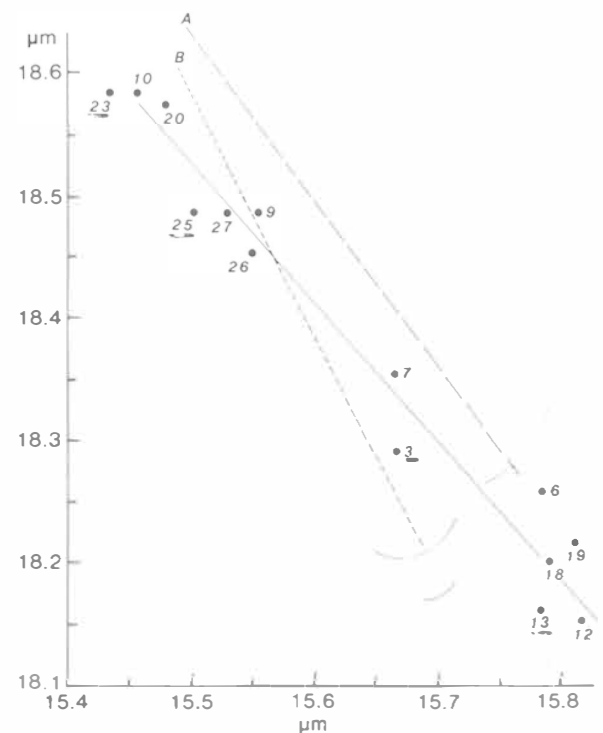

FIG. 6. — Plot of the critical IR absorption maxima for the examined adularias. Sample numbers refer to those of table I. A - average trend of data by Hafner and Laves (1957) ; B - average trend of data by Akizuki and Sunagawa (1978) ; arcs indicate lowermost margins of the above data spreads and of that from Martin (1968). Infrared spectra of the underlined samples are reproduced · in figure 5.

Corrélation entre les maximums d'absorption IR critiques pour les adulaires examinées. Les numéros des échantillons se réfèrent à ceux du tableau I. A : Tendance moyenne des données de Hafner et Laves (1957) ; B : Tendance moyenne des données de Akizuki et Sunagawa (1978) ; les arcs indiquent les limites extrêmes de l'étalement des données ci-dessus et de celles de Martin (1968). Les spectres infrarouges des échantillons soulignés sont reproduits à la figure 5.

genetic type of adularia or of general signifi-cance.

Chemical composition

Adularias are generally distinguished by their low content of subordinate and trace elements : Na<1.5, Rb<0.37, Sr<0.25, Ba<1.7 (rarely up to 3.2) wt. % (Weibel, 1957 and 1961 ; Ry-bach and Nissen, 1967 ; Gubser and Laves, 1967 ; Smith, 1974b ; Dimitriadis and Soldatos, 1978). However, the pegmatitic adularias exa-mined here show substitutions that are minimal even by these adularia "standards" (Table III).

The low Na and Ca contents suggest very low temperatures of crystallization. The low contents of Ba and Sr may reflect the strong depletion of these elements typical of highly fractionated granitic pegmatites, as well as crystallochemical control by the K-feldspar structure at very low temperatures. Late-stage hydrothermal mobiliza-tion of trace Ba and Sr does occur even in the most fractionated pegmatites, but these elements seem to prefer precipitation in crystallochemi-cally more accommodating species (e.g., wellsite and Ba- or Sr-phosphates such as bjarebyite and palermoite).

Crystallochemical control also appears to be responsible for the negligible Rb contents. It may be significant in this respect that the only samples with $Rb_2O>0.1$ wt. % are somewhat non-typical, deviating in their morphology and mode of occurrence from classic adularia and having a high degree of Si, Al order (samples 10 and 20 ; cf. table II and IV). They may be closer to late triclinic K-feldspar varieties from granitic pegmatites, such as those veining pollucite (Quensel, 1957 ; Černý and Simpson, 1978), rather than to adularia proper.

The near-perfect stoichiometry of the exa-mined adularias suggests minimal involvement of H_2O, $(OH)^-$ or $(H_3O)^+$ in their constitution, definitely below the levels at which they might affect unit cell dimensions. (The presence of aqueous species in the structure of alkali feld-spars in general, and adularia in particular, was established by several authors [cf. Smith 1974b, p. 7], and more recently confirmed by Solomon and Rossman [1979]).

The near-ideal $KAlSi_3O_8$ composition of the adularias is particularly conspicuous in compari-son with the chemistry of primary feldspars in their parent pegmatites. For example, the rock-forming K-feldspar in the Věžná pegmatite contains up to 1.20 wt. % BaO and (before per-thitic exsolution) 5.0 wt. % Na_2O. In Tanco, blocky K-feldspar from the internal zones has on the average 2.5 wt. % Rb_2O and 0.30 wt. % Cs_2O.

Structural state : crystallochemical significance

Adularias are notorious by their diversity in Si, Al order-disorder. Structural state not only varies from high sanidine to appreciably ordered microcline, but it shows different modes of do-main texture and metastable transitional states not encountered in igneous or metamorphic rock-forming K-feldspars. Extensive ranges of struc-tural order-disorder occur in single morphologi-cal units, and are commonly recognizable only by single-crystal optical, X-ray or electron diffraction methods (Chaisson, 1950 ; Bam-bauer and Laves, 1960 ; Gubser and Laves, 1967 ; Nissen, 1967 ; Akizuki and Sunagawa, 1978).

The examined pegmatitic adularias show the same diversity. They also demonstrate the fre-quently observed mismatch between optical pro-perties and symmetry indicated by X-ray powder diffraction (samples 6, 17 and 25 to 28). The unit cell dimensions, symmetry and resulting subdivision of most of the examined samples (as discussed in the sections on X-ray diffraction and IR absorption) are inevitably simplified, due to averaging in pulverized bulk samples. Broadening of the 131 diffraction in most of the "monoclinic" samples (Figure 2) indicates hete-rogeneity in Si, Al ordering which goes farther than waves of coherent triclinic domains unde-tectable by X-ray powder diffraction (cf., e.g., Smith, 1974a, pp. 246-247, 469-470).

Only two types of pegmatitic adularias, dis-playing the extremes of Si, Al order and disorder, show a good match of optical, X-ray diffraction and IR data.

Microcline-type adularias have a degree of Si, Al order slightly higher than recorded for adula-rias from other environments (cf. Gubser and Laves, 1967). This would be true even if the samples 10 and 20, discussed in the preceding section, were considered atypical. It is note-

worthy that the unit cell dimensions of the Na-"free" Wausau samples 21 to 24 correspond to an incompletely ordered microcline with about 7 % Ab_{ss}, when compared to the values preferred by Stewart and Wright (1974 ; cf. figure 3) and Kroll and Ribbe (1983). However, the Wausau data coincide with the unit cell dimensions of fully ordered $KAlSi_3O_8$ as extrapolated by Ferguson (1980).

The other end of the order-disorder spectrum displayed by the examined adularias is, to the best of our knowledge, exceptional among high sanidines of any provenience, and thus deserves particular attention.

Extreme high-sanidine data

Samples 12, 13, 15, 18 and 19 group in an area of the b - c plot in which no data were recorded to date (Figure 3). Unit cell dimensions falling outside the high-sanidine corner of Stewart's and Wright's (1974) b - c quadrilateral have been determined for natural, synthetic and cation-exchanged feldspars by several authors (Luth and Querol-Suñé, 1970 ; Weitz, 1972 ; Fournier, 1976 ; Openshaw et al., 1976 ; Martin, 1982). However, most of these data are within 2σ from the quadrilateral, and show a relatively high value of c (7.176 to 7.188 Å) ; they occupy the region populated by samples 3, 4 and 6 in figure 3. In contrast, the five adularias quoted above spread up to 5σ away from the high sanidine data preferred by Stewart and Wright (1974 ; $b=13.033$, $c=7.174$ Å) and Smith (1974 ; $b=13.0289$, $c=7.1763$ Å), and their c parameters are rather low (7.166 to 7.174 Å).

Compositional factors cannot be responsible for these deviations in unit cell dimensions, as the feldspars are stoichiometric and very close to pure $KAlSi_3O_8$. Two possible explanations can be suggested :

1) a strain distorting the structure and leading to anomalous unit cell dimensions. Slight curvature of individual crystals composing the divergent sheafs of adularia aggregates, characteristic of samples 12, 13, 15, 18 and 19, may be suggestive of structural strain, and the resulting undulatory extinction as well. On the other hand, the absence of perthitic exsolution, the simple and homogeneous optical orientation and structure, and the sharp X-ray powder diffractions

contradict this explanation. The b . c vs. a relationship (Bernotat, 1982 ; in Kroll and Ribbe, 1983) also indicates an unstrained structure. Thus the only explanation seems to be

2) total Si, Al disorder never recorded before in natural sanidine and never attained in synthetic or K-exchanged feldspars. It should be noted that some data on natural sanidine with 8 to 13 mol. % Ab (Cole et al., 1949 ; Weitz, 1972) are identical, within the experimental error, with Stewart's and Wright's (1974) and Smith's (1974a) preferred values for pure potassic high sanidine. Thus, total Si, Al disorder in a virtually pure $KAlSi_3O_8$ should be expected to extend b and reduce c towards the values shown by the adularias quoted above. Such a shift is confirmed by the recent calculations of unit cell dimensions for the structural high-sanidine end member performed by Ferguson (1980), Kroll and Ribbe (1983) and Kroll and Ribbe (unpublished ; pers. comm. 1983). Figure 3 demonstrates the values calculated by the above authors in the b - c diagram (Ferguson, 1980 : $b=13.045$, $c=7.171$ Å ; Kroll and Ribbe, 1983 : $b=13.031$, $c=7.177$ Å ; Kroll and Ribbe, pers. comm. 1983 : $b=13.044$, $c=7.165$ Å).

A more detailed investigation of the high-sanidine adularias (which is beyond the scope of the present study) is in progress, and crystal structure refinement is anticipated for suitable samples (R.B. Ferguson).

Paragenesis and origin

Three features of the paragenesis of pegmatitic adularia appear to be important for interpretation of its origin :

1) the low temperature regime indicated by the associated minerals, and by the near-end-member compositions of adularia and associated albite. Experimental work of Orville (1963) and Fournier (1976) suggests temperatures much below 400 °C, and adularias of comparable chemical composition are known to crystallize at about 250 °C (Nissen, 1967 ; Steiner, 1970) ;

2) the location of most occurrences in open fissures, vugs or porous breccias suggestive of possible low-pressure conditions of crystallization, and

3) the fine grain size of most adularias and

diverging sheaf-like growth style that indicate, along with the predominantly disordered structural states, rapid nucleation and crystallization rates.

The mechanism proposed by Foord and Martin (1979) and Martin (1982) for the late K-feldspar overgrowths in miarolitic vugs of the Pikes Peak pegmatites is suggested here for the origin of pegmatitic adularias. Deformation producing open fissures and, in other cases, rupture of miarolitic or leaching vugs led to drastic reduction in P_{fluid} and consequent rapid nucleation and growth of precipitates on cavity surfaces. In contrast to the preceding massive albitization of the parent pegmatites, the abundance of adularia and relative rarity of co-existing albite in open cavities suggests pressure-quenching and un-mixing of the hydrothermal fluid into liquid + gas, with consequent shift to lower K/(K+Na) in its bulk composition which forces precipitation of K-feldspar (Lagache and Weisbrod, 1977). Pressure- or temperature-induced changes in the anion activity in the fluid could also have disturbed the $K/(K+Na)_{liquid}$ vs. $K/(K+Na)_{solid}$ equilibrium (Pichavant, 1983) ; increased a_{F^-}, suggested by the common association of adularia with fluorite (Table II), promotes precipitation of K-feldspar.

The overall history of the parent fluid was undoubtedly complex, and different in individual cases, as indicated by the variable mineral association. For example, secondary Be-bearing minerals post-dating crystallization of adularia are suggestive of alkaline environment in some cases (beryllosilicate of Ca bavenite and beryl-loaluminosilicate of K, Na, Ca milarite) but relatively acidic in others (silicates of Be phenacite and bertrandite).

Structural state : genetic aspects

The structural state of adularia has been interpreted in three principal ways :

1) metastable crystallization of disordered feldspar followed by variable degree of ordering, controlled mainly by post-crystallization thermal regime (e.g. Bambauer and Laves, 1960 ; Gubser and Laves, 1967) ; other factors promoting or retarding ordering in solid state, as discussed by Martin (1974), would also be applicable ;

2) direct crystallization in the different structural states as observed today, including the cases of structurally sector-zoned crystals, controlled mainly by the growth rate (e.g. Steiner, 1970 ; Akizuki and Sunagawa, 1978) ; and

3) anisotropic contraction upon cooling, leading to structure distortion which reduces the activation energy required for cation ordering, leading to sectorial distribution of different structural states (Dimitriadis and Soldatos, 1978).

Another mechanism to be considered may be the

4) K/(K+Na) ratio in the "original environment" proposed by Ferguson (1960, 1979, 1980) as regulating the Si, Al order-disorder in high-temperature (e.g. magmatic) feldspars, with high Na concentrations promoting ordered structures.

The data collected in the present study are not conclusive enough to support or contradict some of these hypotheses, mainly because of lack of information on the nature and distribution of different structural states within individual single crystals. However, four aspects of the structural states can be commented on, some of which support the mechanism quoted in (1) above.

With insignificant (and only partial) exceptions, the structural state of the adularias is independent of, and considerably to extremely different from that of the rock-forming K-feldspars of their parent pegmatites. For example, Tanco and High Grade Dike pegmatites carrying high-sanidine adularias have primary K-feldspars grid-twinned with triclinicity values of 0.85 to 1.00. Similarly, the near-sanidine adularias from Věžná reside in a pegmatite with rock-forming K-feldspars in the orthoclase - intermediate microcline range. The near-orthoclase, structurally heterogeneous adularias from the Brown Derby N° 1 dike are hosted by a pegmatite with primary K-feldspars in the triclinicity range of 0.80 - 1.00. These discrepancies indicate a totally different set of conditions under which the crystallization and/or post-crystallizational history of these two feldspar types proceeded. The only exception is the orthoclase-type adularia forming oriented intergrowths on fractures in rock-forming orthoclase (samples 5, 8 and 9), where the structural state of adularia could have been induced by the substrate.

Excluding the somewhat non-typical samples

10 and 20, adularias from peraluminous pegmatites associated with orogenic calc-alkalic granites are typically disordered high sanidines to orthoclases. In contrast, adularias from pegmatites associated with mildly alkaline to peralkaline anorogenic granitoids tend to be well ordered. This latter case, represented here only by the Wausau samples, is also documented by the data of Gavrusevich (1957), Foord and Martin (1979), and Martin (1982). The overall alkali saturation vs. peraluminous chemistry of the parental environment (Martin, 1974, 1982) seems to exert a significant influence on the ordering of adularia after its crystallization in a metastable disordered state.

It appears, however, that the K/(K+Na) ratio of the parent solutions has no effect on the structural state. For example, the paragenesis of the Wausau adularias suggests a K-enriched environment and yet the adularia is close to maximum microcline. Conversely, in the case of Tanco adularia associated with albite and/or cesian analcime (suggestive of highly sodic fluids with K/(K+Na)≤0.15), the adularia is invariably high sanidine.

Shielding of adularia from the influence of late fluids is essential for preservation of metastable disordered states. According to Foord and Martin (1979) and Martin (1982), fissures and cavities should have been effectively evacuated and sealed to preserve high-sanidine structure. This is suggested by Martin's (1968, 1974) conversion of high sanidine into orthoclase at temperatures as low as 350 °C, in experiments of a mere 2 to 3 month duration. The ordering rate is probably extremely retarded below 250 °C, a temperature suggested for at least some of the examined adularias at the beginning of this section. Nevertheless, the conditions must have been extraordinary to preserve the extreme high-sanidine disorder of the Tanco and other adularias for 2.6 billion years.

ACKNOWLEDGEMENTS

REFERENCES

AKIZUKI, M. (1981). — Crystal growth and phase transition of intermediate microcline. *Neues Jahrb. f. Mineral.*, Mh., 1981, 181-189.

AKIZUKI, M. and SUNAGAWA, I. (1978). — Study of the sector structure in adularia by means of optical microscopy, infrared absorption, and electron microscopy. *Mineral. Mag.*, 42, 453-462.

ANSILEWSKI, J. (1958). — On microcline and triclinic adularia from Bialskie Gory gneisses (Polish Sudeten). *Bull. Akad. Pol. Sci.*, *Ser. Chim. Geol. et Geogr.*, 7, 275-282.

APPLEMAN, D.E. and EVANS, H.T., Jr. (1973). — Job 9214 : indexing and least-squares refinement of powder diffraction data. *U.S. Geol. Survey, Computer Contrib.*, 20, 67 p. ; NTIS Doc. PB2-16188.

ASQUITH, G.B. (1975a). — Origin of optical zoning in adularia. *Texas Journ. Sci.*, 26, 628-631.

ASQUITH, G.B. (1975b). — Late magmatic adularia from cavities in camptonite sills - Sacramento Mountains, Otero County, New Mexico. *Texas Journ. Sci.*, 26, 331-338.

BAMBAUER, H.U. and LAVES, F. (1960). — Zum Adularproblem I. *Schweiz. Mineral. Petr. Mitt.*, 40, 177-205.

BARTH, T.W.F. (1928). — Ein neuer Zwilling bei triklinem Feldspat, Aklin B. *Zeits. Krist.*, 68, 473-475.

BARTH, T.W.F. (1929). — Die Symmetrie der Kalifeldspäte. *Fortschr. Mineralogie*, 13-14, 185-189.

BASS, M.N. and FERRARA, G. (1969). — Age of adularia and metamorphism, Ouachita Mountains, Arkansas. *Amer. Jour. Sci.*, 267, 491-498.

BLATTNER, P. (1975). — Oxygen-isotopic composition of fissure-grown quartz, adularia, and calcite from Broadlands geothermal field, New Zealand

with an appendix on quartz-K-feldspar-calcite-muscovite oxygen isotope geothermometers. *Amer. Jour. Sci.*, *275*, 785-800.

ČERNÝ, P. (1972). — The Tanco pegmatite at Bernic Lake, Manitoba, VIII. Secondary minerals from the spodumene-rich zones. *Canad. Mineral.*, *11*, 714-726.

ČERNÝ, P. (1984). — Granitic pegmatites. Monograph Series on Geology of Ore Deposits, A.C. BROWN, ed., in press.

ČERNÝ, P. and SIMPSON, F.M. (1978). — The Tanco pegmatite at Bernic Lake, Manitoba. X. Pollucite ; *Canadian Mineralogist*, *16*, 325-333.

ČERNÝ, P., SMITH, J.V., MASON, R.A. and DELANEY, J.S. (1984). — Geochemistry and petrology of feldspar crystallization in the Věžná pegmatite, Czechoslovakia. *Canad. Mineralogist*, in press.

CHAISSON, U. (1950). — The optics of triclinic adularia. *Jour. Geol.*, *58*, 537-547.

CHESTERMAN, C.W., SILBERMAN, M.L., KOSKI, R.A. and FABBI, B.P. (1974). — Hydrothermal potassium feldspar at Bodie, Mono County, California, and its use in determining the age and conditions of ore deposition. *9th Gen. Meeting I.M.A. Berlin-Regensburg, Abstr.*, *43*.

COLE, W.F., SÖRUM, H. and KENNARD, O. (1949). — The crystal structures of orthoclase and sanidinized orthoclase. *Acta Cryst.*, *2*, 280-287.

CORNWALL, H.R. (1951). — Differentiation in lavas of the Keweenawan series and the origin of the copper deposits of Michigan. *Bull. Geol. Soc. Amer.*, *62*, 159-202.

DIMITRIADIS, S. and SOLDATOS, K. (1978). — Optical and structural properties of adularia from Xanthi and Ouranoupolis, Greece, and their interpretation. *N. Jb. Miner., Abh.*, *133*, 88-105.

FERGUSON, R.B. (1960). — The low-temperature phases of the alkali feldspars and their origin. *Canad. Mineralogist*, *6*, 415-436.

FERGUSON, R.B. (1979). — Whence orthoclase and microcline ? A crystallographer's interpretation of potassium feldspar phase relations. *Canad. Mineralogist*, *17*, 515-525.

FERGUSON, R.B. (1980). — From unit cell parameters to Si/Al distribution in K/feldspars. *Canad. Mineral.*, *18*, 443-458.

FERGUSON, R.B. (1982). — K-feldspar structural end-members ideal sanidine, ideal orthoclase and ideal maximum microcline. *Progr. Abstr., GAC-MAc meeting 1982 Winnipeg*, *7*, 49.

FOORD, E.E. and MARTIN, R.F. (1979). — Amazonite from the Pikes Peak batholith. *Mineral. Record*, *10*, 373-384.

FOURNIER, R.O. (1976). — Exchange of Na^+ and K^+ between water vapor and feldspar phases at high temperature and low vapor pressure. *Geochim. Cosmochim. Acta*, *40*, 1553-1561.

GAVRUSEVICH, B.A. (1957). — On the mineralogy of the miarolitic vugs of the Korosten pluton. *Mineral.*

Sbornik Lvov, *11*, 95-107 (in Russian).

GINSBURG, A.I. (1960). — Specific geochemical features of the pegmatitic process. *Int. Geol. Congress, 21st sess. Norden, Rept.* Pt. *17*, 111-121.

GRABEZHEV, A.I. and YUNIKOV, B.A. (1969). — Triclinicity of potassic feldspar as one indication of the depth of formation of hypogene ore deposits. *Doklady Acad. Sci. USSR*, *188*, 198-200 (in Russian).

GUBSER, R. and LAVES, F. (1967). — On X-ray properties of "adularia". *Schweiz. Mineral. Petr. Mitt.*, *47*, 177-188.

HAFNER, S. and LAVES, F. (1957). — Ordnung/Unordnung und Ultrarot-Absorption. II. Variation der Lage und Intensität einiger Absorptionen von Feldspäten. Zur Struktur von Orthoklas und Adular. *Zeits. Krist.*, *103*, 204-225.

HALLIDAY, A.N. and MITCHELL, J.G. (1976). — Structural, K-Ar and $^{40}Ar-^{39}Ar$ studies of adularia K-feldspars from the Lizard complex. England. *Earth Planet. Sci. Letters*, *29*, 227-237.

HENSEN, B.J. (1967). — Mineralogy and petrography of some tin, lithium and beryllium bearing albite-pegmatites, near Doade, Galicia, Spain. *Leidse Geol. Meded.*, *39*, 249-259.

KÖHLER, A. (1948). — Zur Optik des Adulars. *Neues Jahrb. Miner. A.*, *5-8*, 49-55.

KRAUS, G. (1958). — Tektonik und Genese der Flusspatgänge östlich von Regensburg (Bayerischer Wald). *N. Jahrb. Miner., Abh.*, *92*, 109-146.

KROLL, H. and RIBBE, P.H. (1983). — Lattice parameters, composition and Al, Si order in alkali feldspars. *Reviews in Mineralogy*, *2*, Feldspar Mineralogy, 2nd ed., Mineral. Soc. America, 57-99.

LAGACHE, M. and WEISBROD, A. (1977). — The system : two alkali feldspars - $KCl-NaCl-H_2O$ at moderate to high temperatures and low pressures. *Contrib. Mineral. Petrol.*, *62*, 77-101.

LENTON, P.G. (1979). — Mineralogy and petrology of the Buck Claim lithium pegmatite, Bernic Lake, southeastern Manitoba. Unpublished M. Sc. thesis, Dept. Earth Sci., Univ. of Manitoba, Winnipeg, 164 p.

LINDGREN, W. and RANSOME, F.L. (1906). — Geology and gold deposits of the Cripple Creek district, Colorado. *U.S. Geol. Survey Prof. Paper 54*, 97 p.

LUTH, W.C. and QUEROL-SUÑÉ, F. (1970). — An alkali feldspar series. *Contrib. Mineral. Petrol.*, *25*, 25-40.

MARTIN, R.F. (1968). — Hydrothermal synthesis of low albite, orthoclase, and non-stoichiometric albite. Ph. D. thesis, Stanford University, 144 p.

MARTIN, R.F. (1974). — Controls of ordering and subsolidus phase relations in the alkali feldspars. *In* "The Feldspars", W.S. MacKenzie and J. Zussman, ed. ; Manchester University Press, 313-336.

MARTIN, R.F. (1982). — Quartz and the feldspars. *In* "Granitic Pegmatites in Science and Industry", P. Černý, ed., Mineral. Assoc. Canada Short Course

Handbook, *8*, 41-62.

MIŠKOVSKÝ, J. (1955). — Pollucite from Puklice, near Jihlava. *Acta Musei Moraviae Brno. 40,* 89-92 (in Czech).

MUNHÁ, J., FYFE, W.S. and KERRICH, R. (1980). — Adularia, the characteristic mineral of felsic spilites. *Contrib. Mineral. Petrol., 75,* 15-19.

NISSEN, H.-U. (1967). — Domänengefüge, Natriumgehalt, Natriumentmischung und Gitterkonstanten von Alkalifeldspäten (Mikroklin, Orthoklas, Adular) der Schweizeralpen. *Schweiz. Mineral. Petr. Mitt., 47,* 1140-1145.

NOLAN, T.B. (1935). — The underground geology of the Tonopah mining district, Nevada. *Univ. Nevada Bull., 29,* N° 5, 35 p.

NOWAKOWSKI, A. (1959). — On the adularized dyke rock in the vicinity of Klimontow (Holy Cross Mts.). *Bull. Akad. Pol. Sci., Ser. Chim., Geol. et Geogr., 6,* 751-757.

OPENSHAW, R.E., HEMINGWAY, B.S., ROBIE, R.A., WALDBAUM, D.R. and KRUPKA, K.M. (1976). — The heat capacities at low temperatures and entropies at 298.15 K of low albite, analbite, microcline and high sanidine. *Jour. Research. U.S. Geol. Survey, 4,* 195-204.

OPTOYEV, D.O. and BATOVA, A.I. (1969). — The distribution of alkali metals in feldspars of post-magmatic rocks of the Dzhida mining district. *Zapiski Vses. Mineral. Obshtch., 98,* 18-28.

ORVILLE, P.M. (1963). — Alkali ion exchange between vapor and feldspar phases. *Amer. Jour. Sci., 261,* 201-237.

PARKER, R.L. (1973). — Die Mineralfunde der Schweizer Alpen, Basel, Wepf & Co, 433 p.

PICHAVANT, M. (1983). — (Na,K) exchange between alkali feldspars and aqueous solutions containing borate and fluorite anions : experimental results at P = 1 kilobar. Programme and Abstracts, 3rd NATO A.S.I. on Feldspars, Feldspathoids and Their Parageneses, Rennes, 102.

QUENSEL, P. (1956). — The paragenesis of the Varuträsk pegmatite. *Ark. Mineral. Geol., 2,* 9-125.

RUSINOVA, O.V., RUSINOV, V.L. and GREBENCHIKOV, A.M. (1975). — Triclinicity of potash feldspars from certain hydrothermal ore deposits. *Zapiski Vses. Mineral. Obshtch., 104,* 336-340 (in Russian).

RYBACH, L. and NISSEN, H.-U. (1967). — Zerstörungfreie Simultanbestimmung von Na, K und Ba in Adular mittels Neutronaktivierung. *Schweiz. Mineral. Petr. Mitt., 47,* 189-197.

SHIBATA, H. (1952). — Mineralization in granite pegmatites in Japan and Korea, Part II. *Sci. Repts. Tokyo Univ. Lit. Sci., sect. C, 2,* 107-144.

SMITH, J.V. (1974a). — Feldspar Minerals. I. Crystal Structure and Physical Properties. Springer-Verlag, New York.

SMITH, J.V. (1974b). — Feldspar Minerals. II. Chemical and Textural Properties. Springer-Verlag, New-York.

SMITH, J.V. and RIBBE, P.H. (1966). — X-ray emission microanalysis of rock-forming minerals. III. Alkali feldspars. *Jour. Geology, 74,* 197-216.

SOLOMON, G.C. and ROSSMAN, G.R. (1979). — The role of water in structural states of K-feldspar as studied by infrared spectroscopy. *Geol. Soc. America, Abstr. with Progr., 11,* 521.

STANĚK, J. (1954). — Spodumene and bavenite from Jeclov. *Acta Musei Moraviae, 39,* 67-77 (in Czech).

STANĚK, J. (1962). — Mineralogically significant pegmatites of the Jihlava region. *Folio Prir. Fak. Univ. J.E. Purkyně Brno, III., Geologia,* 79-105.

STANĚK, J. and CECH, F. (1958). — A new lithium pegmatite from Nova Ves near Český Krumlov. *Cas. pro Miner. a Geol., 3,* 407-410 (in Czech).

STEINER, A. (1970). — Genesis of hydrothermal K-feldspar (adularia) in an active geothermal environment at Wairakei, New Zealand. *Mineral. Mag., 37,* 916-922.

STEWART, D.B. and WRIGHT, T.L. (1974). — Al/Si order and symmetry of natural potassic feldspars, and the relationship of strained cell parameters to bulk composition. *Bull. Soc. franç. Minér. Crist., 97,* 356-377.

WEIBEL, M. (1957). — Zum Chemismus der alpinen Adulare II. *Schweiz. Mineral. Petr. Mitt., 37,* 545-553.

WEIBEL, M. (1961). — Chemische Untersuchungen an alpinen Kluftmineralien. *Schweiz. Mineral. Petr. Mitt., 41,* 8-11.

WEITZ, G. (1972). — Die Struktur des Sanidins bei verschiedenen Ordnungsgraden. *Zeits. Krist., 136,* 418-426.

WHITE, D.E. (1955). — Thermal springs and epithermal ore deposits. *Econ. Geol., 50th, Anniv. Volume,* 99-154.

WRIGHT, T.L. and STEWART, D.B. (1968). — X-ray and optical study of alkali feldspar : I. Determination of composition and structural state from refined unit cell parameters and 2V. *Amer. Mineral., 53,* 38-87.