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Cryolite-bearing and rare metal-enriched rhyolite, Sierra Blanca Peaks, Hudspeth County, Texas[1]

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ABSTRACT

The Round Top intrusion, one of five shallow rhyolite laccoliths in the Tertiary Trans-Pecos Texas magmatic province near Sierra Blanca, Texas, was chemically modified by pegmatitic vapor-phase crystallization. Evidence of pegmatitic crystallization includes the presence of cryolite (Na_3AlF_6), Li-rich trioctahedral micas with variable Fe contents, rutilated quartz, and vapor-rich fluid inclusions defining quartz overgrowths on magmatic grains. The laccoliths are enriched in Li, Be, F, Zn, Rb, Y, Zr, Nb, Sn, REEs, and Th and are depleted in Mg, Ca, and Ti relative to typical calc-alkaline rhyolites. They are peraluminous, making them unusual among Trans-Pecos silicic igneous rocks, which are typically peralkaline or metaluminous. The presence of cryolite and the strong HREE enrichment, which may also be the result of vapor-phase crystallization, sets the Sierra Blanca rhyolites apart from otherwise chemically similar topaz-bearing rhyolites. Accessory biotite and Li-rich micas are enriched in F, Mn, and Zn and are depleted in Mg and Ti. Rare metals are contained in part by bastnaesite(?), cassiterite, columbite, priorite(?), Nb-rich rutile, tantalite, thorite, HREE-rich xenotime, yttrocerite and yttrofluorite, and zircon. The rhyolites are the sources of F and Be in beryllium deposits in fluoritized limestones along the contacts with the laccoliths.

INTRODUCTION

Five rhyolite laccoliths are exposed approximately 120 km southeast of El Paso, just north of Interstate Highway 10 and just west of the town of Sierra Blanca, in Trans-Pecos Texas (Fig. 1). The five laccoliths, collectively called the Sierra Blanca Peaks, are, clockwise from the south, Sierra Blanca, Round Top, Little Round Top, Little Blanca, and Triple Hill. None of the peaks are capped by sedimentary rocks; it is possible that one or more of the intrusions broke through the surface as lava domes. There is, however, no evidence, such as a brecciated carapace, of this having occurred.

The laccoliths intrude Cretaceous limestone and are the source of Be-rich fluorspar deposits hosted by the limestone, generally below the floors of the laccoliths (McAnulty, 1980; Price et al., 1983); the laccoliths themselves display varying degrees of hydrothermal alteration and weathering. Rhyolite breccias along the contacts are locally fluoritized and kaolinized. Henry et al. (1986) determined a K-Ar age of 36.2 ± 0.6 Ma for biotite from the main body of the Sierra Blanca intrusion. Although none of the other laccoliths have been dated, the similarities in chemistry and mineral contents (Tables 1 to 3) suggest that they are probably contemporaneous with the Sierra Blanca intrusion. The laccoliths are part of the main phase of Tertiary magmatism in Trans-Pecos Texas (Henry and McDowell, 1986), but they are probably not cogenetic with the igneous rocks of the nearby Quitman Mountains complex (Shannon and Goodell, 1986).

The laccoliths represent compositional anomalies within the province in that they are peraluminous (Rubin et al., 1987; Table 1 and 2); most rhyolites of the region are peralkaline or metaluminous (Barker, 1977, 1987). Round Top is highly anomalous both chemically and mineralogically (Tables 1 to 3). It contains 2.5 vol% cryolite (Table 3), a mineral typically found in pegmatites. This paper presents mineralogical and chemical evidence that the primary igneous composition of Round Top has been modified by a pegmatitic vapor phase. Thus the norm calculation for Round Top [Table 2, J85-55 (A)], which indicates peralkalinity, should be considered an indication of postmagmatic crystallization. If the cryolite were removed from the rock, then the remaining material would be a corundum-normative high-silica rhyolite [Table 2, J85-55(R)].

PREVIOUS WORK

McAnulty (1980) first discussed the economic potential of the Sierra Blanca Peaks, and Barker (1980) provided chemical and petrographic analyses of samples from Sierra Blanca, Round Top, Little Round Top, and Triple Hill.

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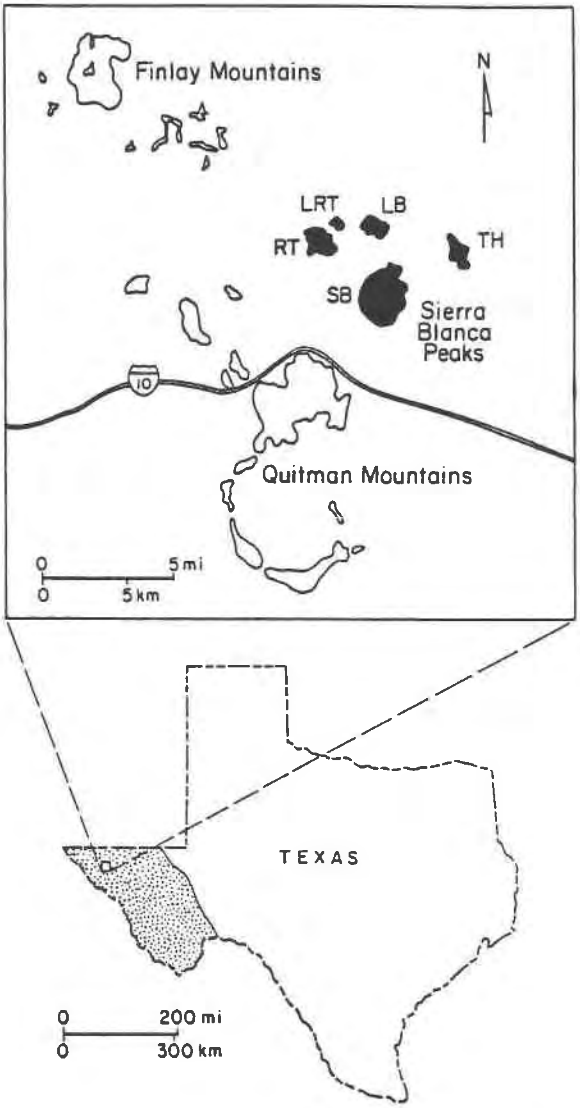

Fig. 1. Map showing relative position of Sierra Blanca Peaks and location within the Trans-Pecos magmatic province (stippled). SB = Sierra Blanca proper; RT = Round Top; LRT = Little Round Top; LB = Little Blanca; TH = Triple Hill.

Shannon (1986) and Shannon and Goodell (1983, 1986) presented a lithogeochemical analysis of the five Sierra Blanca laccoliths as well as the nearby Quitman Mountains intrusions, and Matthews and Adams (1986) performed a more general petrologic and geochemical study of the Sierra Blanca Peaks and nearby Finlay Mountain intrusions.

TABLE 1. Chemical analyses* of major (wt%) and trace (ppm) elements of Sierra Blanca intrusions

	Round Top J85-55	Sierra Blanca 81-60	Little Blanca 81-65
		(wt%)	
SiO_2	72.47	74.38	74.45
TiO_2	0.02	0.02	0.02
Al_2O_3	13.68	14.06	13.79
Fe_2O_3	0.72	0.29	1.12
FeO	0.69	0.53	0.18
MnO	0.08	0.05	0.05
MgO	0.01	0.01	0.01
CaO	0.08	0.45	0.38
Na_2O	6.48	5.06	5.00
K_2O	4.22	4.30	4.07
P_2O_5	<0.01	<0.01	<0.01
CO_2	0.00	0.15	0.22
H_2O	0.13	0.18	0.40
F	1.30	0.65	0.54
O≡F	−0.55	−0.27	−0.23
BeO	0.05	<0.01	<0.01
Total	99.38	99.86	100.00
		(ppm)	
Li	440	170	370
Be	170	4	18
V	<5	<2.5	7
Ni	<5	<2.5	<2.5
Cu	57	3	9
Zn	610	140	520
Rb**	1960	1090	1870
Sr	28	9	32
Y	220	n.a.	n.a.
Zr	1040	100	840
Nb	340	n.a.	n.a.
Mo	<5	5.6	4.0
Sn	130	20	19
Ba	<10	16	85
La	23	n.a.	n.a.
Ce	90	n.a.	n.a.
Pr	11	n.a.	n.a.
Nd	28	n.a.	n.a.
Sm	10	n.a.	n.a.
Eu	0.1	n.a.	n.a.
Gd	11	n.a.	n.a.
Tb	3.7	n.a.	n.a.
Dy	36	n.a.	n.a.
Ho	7.8	n.a.	n.a.
Er	33	n.a.	n.a.
Tm	6.7	n.a.	n.a.
Yb	55	n.a.	n.a.
Lu	7.2	n.a.	n.a.
Th	180	43	160
U	50	<5	<5

Note: n.a. = not analyzed.

* Analyses (except Rb) by S. W. Tweedy, Mineral Studies Laboratory, Bureau of Economic Geology: most major oxides, Sr, Zr, and Ba by ICP-AES, using lithium tetraborate fusion; FeO by vanadate oxidation-titration; H_2O by conversion to CO_2 and coulometric determination; CO_2 by coulometry, all reported on H_2O-free basis; Li, Be, P, V, Ni, Cu, Zn, Th, and U by ICP-AES using multiple acid digestion; F by ISE; Mo by amyl acetate extraction and spectrophotometry; Y, Nb, Sn, and REEs by ICP-MS.

** Rb analysis by X-ray fluorescence: performed by D. S. Barker, Department of Geological Sciences, University of Texas at Austin.

MINERAL ASSEMBLAGE

Petrographic analysis of samples from Sierra Blanca Peak, Little Blanca, and Round Top confirms similar mineral assemblage among the laccoliths with respect to major phases (Table 3); potassium feldspar, quartz, and albite make up 90 to 95 vol% of observed samples. The dominant accessory mineral is trioctahedral mica with variable Fe content; Fe-rich biotite is also present. Other accessories include magnetite (largely altered to hematite), zircon, and cryolite. Tourmaline, opaline silica, fluorite, and montmorillonite have also been observed on

TABLE 2. CIPW norm* (mol%) of Sierra Blanca intrusions calculated from chemical data in Table 1

	Round Top J85-55 (A)**	Round Top J85-55 (R)**	Sierra Blanca 81-60	Little Blanca 81-65
Q	20.07	30.87	25.26	27.05
C	0.00	0.96	0.29	0.52
Or	24.96	26.41	25.52	24.24
Ab	49.80	39.77	45.65	45.28
An	0.00	0.42	2.24	1.90
Ac	2.01	0.00	0.00	0.00
Ns	1.78	0.00	0.00	0.00
Di	0.32	0.00	0.00	0.00
Wo	0.16			
En	0.00			
Fs	0.16			
Hy	1.04	0.73	0.70	0.03
En	0.02	0.03	0.03	0.03
Fs	1.02	0.70	0.67	0.00
Mt	0.00	0.80	0.30	0.50
Il	0.03	0.03	0.03	0.03
Hm	0.00	0.00	0.00	0.46
Total	100.00	100.00	100.00	100.00

* Norms calculated with adjustments to Fe and CO_2 analyses as suggested by Irvine and Baragar (1971).

** Norm for Round Top sample J85-55 presented according to analyzed composition (A) and recalculated (R) to exclude 2.5 vol% cryolite (Na_3AlF_6). See text for further explanation.

fracture and weathering surfaces at Little Blanca and Sierra Blanca proper.

Potassium feldspar

Potassium feldspar makes up approximately half of the rhyolite by volume. It occurs as phenocrysts, possibly alteration products of albite phenocrysts, in Sierra Blanca proper only, and as groundmass grains and mantles around albite phenocrysts (Fig. 2) in all of the laccoliths. It is commonly cloudy owing to a combination of inclusions (occasionally forming hourglass patterns) and alteration. This cloudiness makes positive identification of the feldspar difficult, but it is probably sanidine (Fig. 3). Potassium feldspar compositions range from $\mathrm{Or_{98}Ab_{02}An_{00}}$ to $\mathrm{Or_{61}Ab_{39}An_{00}}$ (Table 4; Fig. 3), with traces of Fe^{3+} and Ba, and probably Rb, given the high Rb content of the rhyolites (Table 1), but the compositions in Sierra Blanca proper are much more potassic than those in Round Top and Little Blanca (Fig. 3).

TABLE 3. Modal compositions (vol%) of Sierra Blanca intrusions

	Round Top J85-55	Sierra Blanca 81-60	Little Blanca 81-65
Qtz	30	27	34
Kfs	51	50	52.5
Pl	11	17	9
Mica	4.5	6	3
Mag-Hem	1	trace	1
Cry	2.5	—	—
Zrn	trace	trace	<0.5
	Trace minerals		
bastnaesite(?)	X	X	X
cassiterite	X	X	X
coffinite	X	—	—
columbite	X	X	X
priorite(?)	—	X	—
Nb-rich rutile	X	—	—
tantalite	—	—	X
thorite	X	—	X
xenotime	X	X	—
ytrrocerite-yttrofluorite	X	X	X

Note: Model based on 1000 points in each sample. Trace minerals listed alphabetically.

Abbreviations: Qtz = quartz; Kfs = potassium feldspar; Pl = plagioclase; Mica = trioctahedral mica and biotite; Mag-Hem = magnetite or hematite; Cry = cryolite; Zrn = zircon.

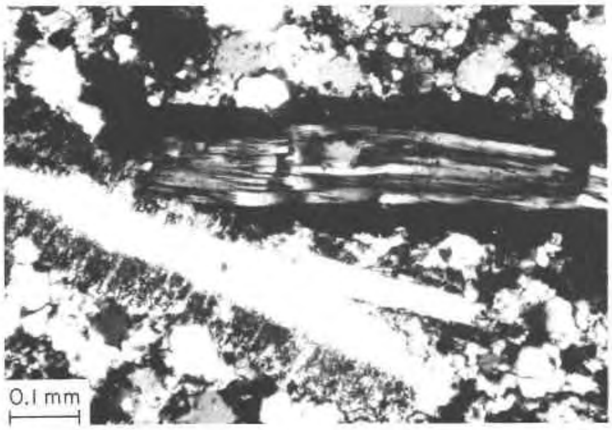

Fig. 2. Photomicrograph showing deformed polysynthetic twinning in albite phenocryst rimmed by potassium feldspar (at extinction), and cloudy potassium feldspar rimming clear albite phenocryst.

Quartz

Although quartz is a common constituent of the rhyolite, it displays several different textures. Some quartz grains contain needlelike inclusions of Nb-rich rutile; these rutilated quartz grains always occur with cryolite (Fig. 4). Another common texture is that of quartz overgrowths on pre-existing quartz grains; these overgrowths are frequently delineated by concentric patterns of vapor-rich fluid inclusions (Fig. 5). These textures are similar to those commonly observed in granitic pegmatite.

Albite

Albite occurs as phenocrysts, occasionally as glomerocrysts, and more rarely as groundmass grains. Albite is often mantled by potassium feldspar. Compositions range from $\mathrm{Or_{01}Ab_{99}An_{00}}$ and $\mathrm{Or_{13}Ab_{87}An_{00}}$ to $\mathrm{Or_{01}Ab_{90}An_{09}}$, but albite in Sierra Blanca proper is relatively Ca-rich (to $\mathrm{An_{09}}$), whereas albite in Round Top and Little Blanca is virtually Ca-free (Table 4; Fig. 3). Albite always displays polysynthetic twinning, which is commonly kinked (Fig. 2). The origin of the kinking is uncertain. One possible explanation is deformation of the rhyolitic magma after crystallization of albite phenocrysts. If this had occurred while the magma was not completely solidified, the molten portion (groundmass) would not retain evidence of deformation, whereas the crystallized portion (albite)

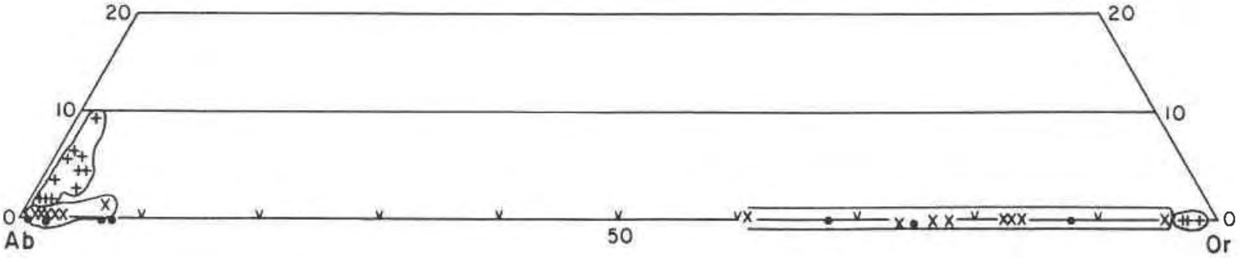

Fig. 3. Ternary plot of feldspar compositions (see also Table 4) from Round Top (points), Sierra Blanca proper (+), and Little Blanca (x).

would. Assimilation of local Precambrian crust (xenoliths) that had been deformed previously could also explain the deformation texture. At this point there is no clear resolution to this ambiguity.

Micas

Two general mica groups are represented within the laccoliths: Fe-rich biotite, which occurs as phenocrysts, and trioctahedral mica with variable Fe content, which occurs in the groundmass. The biotite is brown, whereas the relatively Fe-poor trioctahedral mica varies from nearly colorless to pale green, resembling phengite. Biotite has been observed only at Sierra Blanca proper, where both euhedral, presumably primary magmatic biotite and corroded, presumably hydrothermal biotite occur. Both magmatic and hydrothermal biotites are enriched in Fe, F, Mn, and lesser Zn but contain little Mg and Ti (Table 5). The biotite compositions reflect enrichments in F and Zn and depletions in Mg and Ti (Table 1) relative to biotites in typical calc-alkaline rhyolites.

Groundmass mica varies in composition, especially with respect to Fe, Al, and Si, but contains unusually high amounts of Mn, Zn, and F (Table 5). Microprobe analyses of both biotite and other mica yield low totals (Table 5), even after accounting for OH content and Fe^{3+}. Li is a common constituent and Be a rarer one in micas that occur in granitic pegmatites and other incompatible lithophile–enriched felsic rocks (Deer et al., 1966, p. 193–219; Luecke, 1981; Bailey, 1984; Černý and Burt, 1984). Given the high Li and Be content of the intrusions (Table 1), it is probable that both mica types, particularly the Fe-poor mica, contain appreciable amounts of Li and possibly small amounts of Be. Microprobe analyses of representative micas from Round Top, Sierra Blanca proper, and Little Blanca were recalculated by distributing Li and Be analyzed in the whole rock into M and T sites in the mica structure, respectively. Assuming that all the Li and Be in the rocks (Table 1) are incorporated into the micas (Table 3), recalculated totals are much more reasonable (Table 5).

There are, of course, other variables that affect oxide totals from microprobe analyses of micas. A constant molar Fe^{3+}/Fe_{total} ratio of 0.1 is assumed, and concentrations are normalized to 10 oxygens and 2 hydroxyl sites (for a total cationic charge of 22). Changing the Fe^{3+}/Fe_{total} value introduces only minor changes in recalculated oxide totals, as does substituting small amounts of O^{2-} for OH^{-}. It is also possible that Be is entering feldspar, particularly albite (Luecke, 1981; Smith, 1983), but the presence of Be in feldspar or mica would not affect microprobe totals in either phase to the same degree that Li would. Although analytical error must be considered, we do not expect it to account for more than 2 wt% in the oxide totals. We routinely achieve totals of 100 ± 2 wt%,

TABLE 4. Microprobe analyses (wt%) of feldspars from Sierra Blanca Peaks

	J85-55		81-60		81-65
No.:	40	52	26	39	79
SiO_2	69.0	68.7	65.3	67.0	65.7
Al_2O_3	19.7	19.5	19.1	19.8	19.3
Fe_2O_3*	0.42	0.26	0.00	0.07	0.18
CaO	0.01	0.00	0.00	1.97	0.06
BaO	0.00	0.00	0.00	0.00	0.00
SrO	0.00	0.00	0.00	0.00	0.00
Na_2O	11.6	10.2	0.18	11.2	4.30
K_2O	0.20	2.29	16.8	0.25	10.3
Total	100.9	100.9	101.4	100.3	99.8
Or	01	13	98	01	61
Ab	99	87	02	90	39
An	00	00	00	09	00

Note: Sample numbers correspond to localities given in Table 3.
* Total Fe as Fe_2O_3.

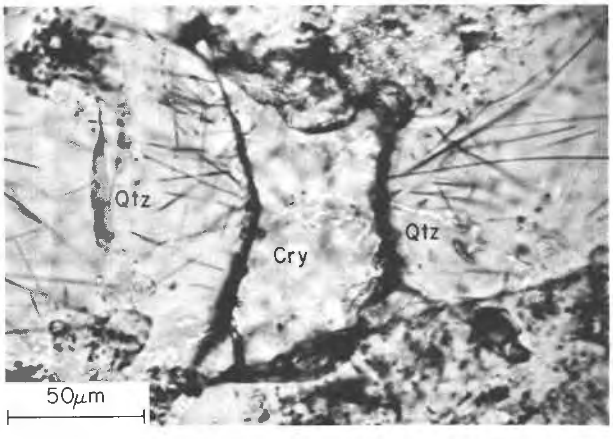

Fig. 4. Photomicrograph of rutilated quartz (Qtz) with cryolite (Cry).

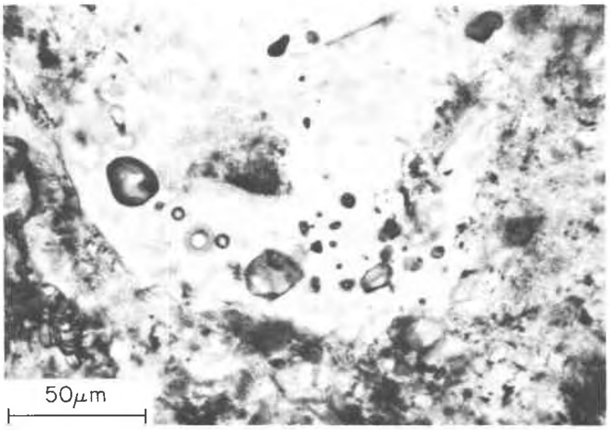

Fig. 5. Photomicrograph of vapor-rich fluid inclusions in quartz. Notice semicircular pattern of inclusions defining quartz overgrowth.

after taking into account the affects of Fe^{3+} and H_2O, on a biotite standard analyzed as an unknown and on biotites from more typical igneous rocks. We did not quantitatively analyze for Rb in the micas, but we did detect it by qualitative wavelength scan. Considering the high Rb content of the rhyolites (Table 1), it is likely that the micas contain detectable amounts of Rb.

Microprobe analyses of the Li-rich trioctahedral micas with variable Fe content a continuous chemical variation from relatively Fe-rich zinnwaldite compositions (mica nos. 33B and 68 in Table 5) to compositions approaching polylithionite (no. 70A in Table 5). Černý and Burt (1984) noted similar chemical variations in zinnwaldites from rare-element pegmatites. Given these assumptions, recalculated oxide totals for biotite (81-60, no. 38B) and other Fe-rich trioctahedral micas (J85-55, no. 33B; 81-65, no. 68) are acceptable. Fe-poor micas (J85-55, no. 70A; 81-65, no. 72) still yield low totals, probably due to the inverse relationship between Fe content and Li (and Be?) content. This relationship is a result of the exchange reaction $Li^+ + Al^{3+} = 2Fe^{2+}$, as noted by Černý and Burt (1984). For example, doubling the assumed Li content of mica no. 70A in Table 5 has the effect of lowering the calculated number of vacancies on M sites, a measure of the dioctahedral component in the mica, to 0.08 and raising the oxide total to 98.3 wt%. It is thus probable that within a given sample, Li is not evenly distributed among the micas, as assumed in the recalculations listed in Table 5, but is preferentially incorporated into the Fe-poor trioctahedral micas.

TABLE 5. Microprobe analyses (wt%) and recalculated analyses (atomic concentration) of micas from Sierra Blanca Peaks

	J85-55		81-60	81-65	
No.:	70A	33B	38B	68	72
SiO_2	49.4	41.0	33.8	43.2	45.7
TiO_2	0.04	0.65	1.58	0.63	0.59
Al_2O_3	18.5	15.7	12.3	14.1	18.4
FeO*	5.42	19.8	33.3	20.0	12.4
MnO	2.13	1.91	2.52	1.61	1.42
MgO	0.00	0.01	0.52	0.04	0.02
ZnO	2.30	2.88	0.83	2.28	1.66
CaO	0.00	0.00	0.00	0.01	0.00
K_2O	10.0	8.55	8.49	8.83	9.49
Na_2O	0.15	0.40	0.44	0.34	0.33
F	5.58	4.01	2.33	4.03	4.24
Cl	n.a.	n.a.	n.a.	0.08	0.05
Total(A)	93.5	94.9	96.1	95.1	94.3
O≡(F,Cl)	−2.35	−1.69	−0.98	−1.72	−1.80
Total	91.2	93.2	95.1	93.4	92.5
K	0.916	0.830	0.905	0.858	0.887
Na	0.021	0.059	0.071	0.050	0.047
Ca	0.000	0.000	0.000	0.001	0.000
□-A	0.063	0.111	0.024	0.091	0.066
Fe^{2+}	0.293	1.134	2.094	1.146	0.684
Fe^{3+}	0.032	0.126	0.233	0.127	0.076
Mg	0.000	0.001	0.065	0.004	0.002
Mn	0.130	0.123	0.178	0.104	0.088
Zn	0.122	0.162	0.051	0.128	0.090
Li**	0.621	0.658	0.218	0.787	0.758
Ti	0.002	0.037	0.099	0.036	0.032
□-M	0.505	0.038	0.023	0.083	0.303
Al	1.565	1.408	1.211	1.265	1.589
Si	3.546	3.119	2.824	3.289	3.349
Be**	0.184	0.196	0.004	0.029	0.028
F	1.267	0.965	0.616	0.970	0.983
Cl	0.007	0.008	0.008	0.010	0.006
OH	0.726	1.028	1.376	1.019	1.011
Oxide total†	96.0	98.7	98.7	98.4	97.4

Note: Sample numbers correspond to localities given in Table 3. Abbreviations: (A) = Analyzed total; □A = vacancies on A site; □-M = vacancies on M sites; n.a. = not analyzed.

* Total Fe as FeO.

** Li values calculated by assuming that all Li in sample (950 ppm Li_2O for J85-55, 370 ppm for 81-60, and 800 ppm for 81-65) is in micas and that Li is distributed evenly through all micas, regardless of Fe content. Be values calculated in a similar manner. See text for further explanation.

† Oxide total for this site distribution (includes H_2O, Li_2O, BeO, FeO, Fe_2O_3).

Cryolite and related minerals

The presence of cryolite (Na_3AlF_6) (Fig. 4) in the Sierra Blanca Peaks had been suspected (P. C. Goodell, pers. comm., 1985) but not heretofore confirmed. McAnulty (1980) identified gearksutite, ralstonite, and thomsenolite, all alteration products of cryolite, in rhyolite breccias in the Sierra Blanca Peaks. Energy dispersive analysis (EDA) of a relatively unweathered sample from a bulldozer-cut in the Round Top intrusion confirmed the presence of cryolite (Fig. 6), which makes up about 2.5 vol% of the sample (Table 3). The cryolite in the groundmass is often anhedral and frequently occurs with rutilated quartz (Fig. 4) although it also occurs by itself. Cryolite has also been observed in hand sample as euhedral crystals on fracture surfaces. Texturally, cryolite appears to postdate major mineral phases in the rhyolites. Ralstonite has been tentatively identified by EDA in samples from the Little Blanca intrusion; the degree of weathering and alteration appears to be an important criterion in determining the likelihood of finding cryolite or a related phase. The high F content of the rhyolite (up to 1.30 wt%, Table 1) is

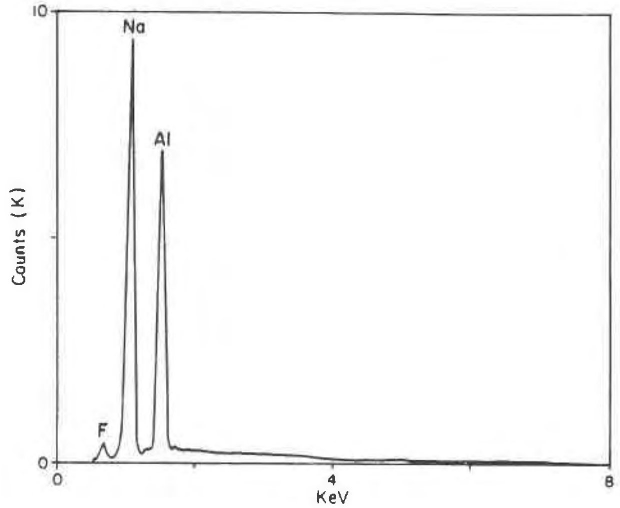

Fig. 6. Energy-dispersive spectrum of cryolite (Na_3AlF_6).

important in the creation of a Na-Al-F fluid (Christiansen et al., 1984, 1986) that would stabilize cryolite relative to topaz (Burt and London, 1982, Fig. 2). The extremely low Ca content (as low as 0.08%, Table 1) probably explains the stability of cryolite and related minerals relative to fluorite within the intrusive rock.

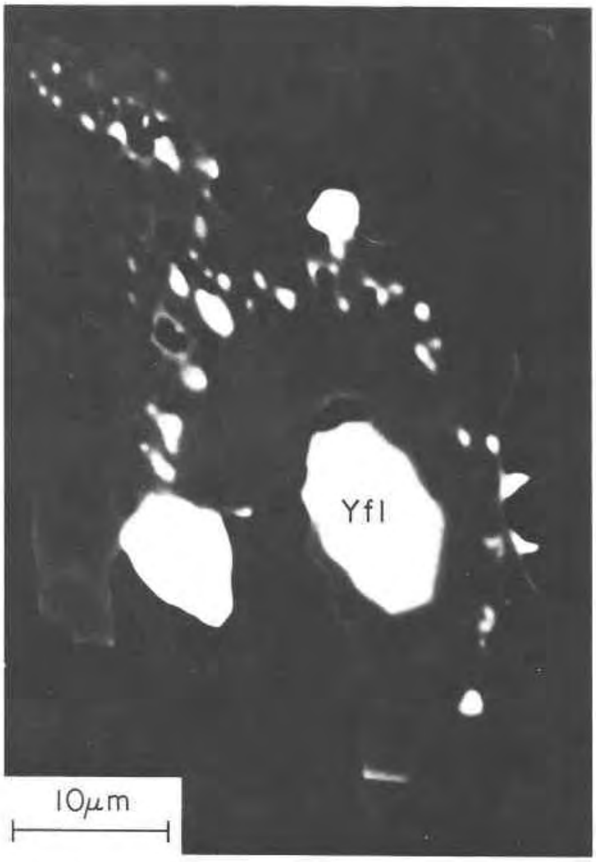

Fig. 7. Backscattered electron image of yttrofluorite (Yfl) and thorite (other bright spots) in zircon (dark gray).

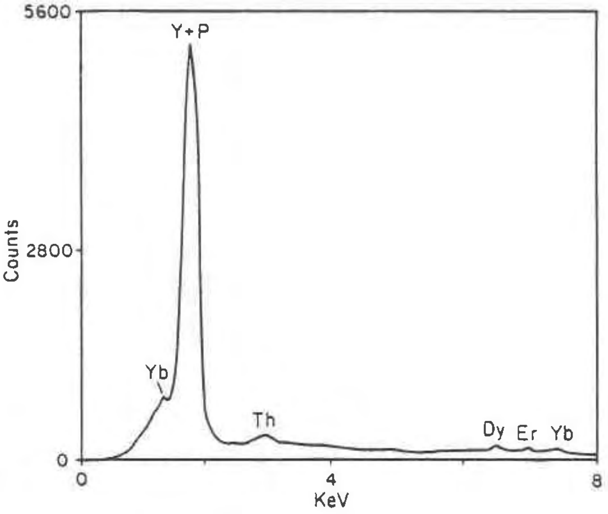

Fig. 8. Energy-dispersive spectrum showing HREE peaks in xenotime.

Trace elements and trace minerals

All the laccoliths are enriched in many typically incompatible lithophile elements, including Li, Be, F, Rb, Y, Zr, Nb, Sn, REEs, and Th [Table 1; see also Matthews and Adams (1986) and Shannon and Goodell (1986) for additional data on trace-element concentrations in the Sierra Blanca Peaks]. The presence of these elements is manifested in the occurrence of several unusual minerals, including HREE-rich xenotime, yttrocerite and yttrofluorite, columbite, tantalite, cassiterite (with varying amounts of Nb and Pb), bastnaesite(?), priorite(?), and thorite, as well as zircon and Nb-rich rutile (Table 3). Round Top, which is also enriched in U (Table 1), contains coffinite (Table 3). Most of the trace minerals occur as intergrowths in potassium feldspar, commonly where they are associated with alteration products of the feldspar, or in quartz. Thorite is present as discrete inclusions in zircon (Fig. 7) in Round Top and Little Blanca, but zircons in Sierra Blanca proper, which has a lower Th content (Table 1), are merely Th-rich without a separate Th phase. McAnulty (1980) identified bertrandite as inclusions in the fluorite replacement of limestone country rocks, but no discrete Be minerals have been identified within the rhyolite.

Trace minerals are usually less than 100 μm and frequently less than 10 μm in longest dimension; many grains are large enough to see in thin section but are difficult to distinguish because of the general cloudiness of much of the sample. The best method of identifying the trace minerals is observation of backscattered electron images of the sample, followed by qualitative analysis using both energy- and wavelength-dispersive methods. Minerals containing essential quantities of light elements, such as

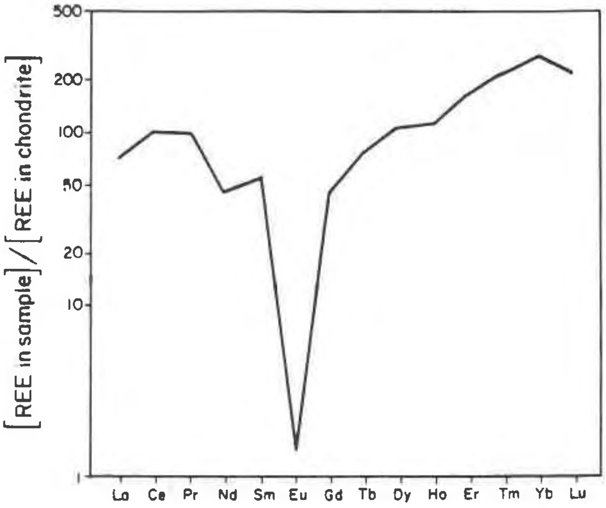

Fig. 9. REE concentrations (chondrite-normalized) in Round Top laccolith.

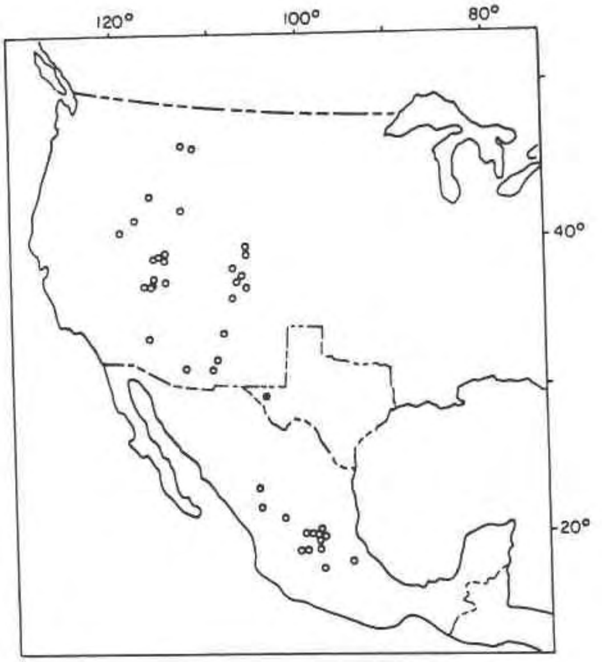

Fig. 10. Map showing occurrences of topaz rhyolites (open circles) in western United States and Mexico (Christiansen et al., 1983). Sierra Blanca Peaks (solid circle) included for reference.

the C in bastnaesite, can be only tentatively identified with this technique.

The rhyolite is enriched in REEs, but it is particularly enriched in HREE. The EDA spectra of bastnaesite(?), yttrocerite, and xenotime display distinguishable peaks of one or more of Gd, Dy, Er, and Yb (Fig. 8), and whole-rock analysis indicates pronounced enrichment in most HREE (Fig. 9).

DISCUSSION

Tertiary and Quarternary topaz-bearing rhyolites are widely distributed across the western United States and parts of Mexico (Fig. 10; Christiansen et al., 1983). As suggested by Shannon and Goodell (1986), topaz rhyolites are chemical analogues to the Sierra Blanca laccoliths. The trace-element patterns of both groups are similar with regard to enrichment in F and most incompatible lithophile elements (Burt et al., 1982; Christiansen et al., 1983, 1986). In addition, there are striking similarities between the Be- and U-rich fluorspar replacements at Sierra Blanca and those associated with topaz rhyolite at Spor Mountain, Utah (Lindsey, 1977).

Although the Sierra Blanca intrusions are chemically similar to topaz rhyolites, they differ in some respects. The Sierra Blanca rhyolites are only mildly peraluminous, having normative corundum contents of less than 1 wt% (Table 2). Their peraluminosity and high F contents are mineralogically expressed by the presence of F-rich micas rather than topaz. Topaz may occur locally in the Sierra Blanca rhyolite (W. T. Miller, pers. comm., 1985), but it has not been identified in the samples collected by us or by Barker (1980), Matthews (1983), or Shannon (1986).

Rhyolites of the Trans-Pecos magmatic province are typically peralkaline or metaluminous (Barker, 1977, 1987). The only other area of the province where peraluminous rhyolites have been identified is in the Christmas Mountains area, 230 km southeast (C. D. Henry and J. G. Price, unpubl. data). Interestingly, fluorite deposits chemically and structurally similar to those at Sierra Blanca occur in the Christmas Mountains area (McAnulty, 1974; Daugherty, 1982) as well as in Coahuila, Mexico, 90 km farther southeast (Kesler, 1977; Simpkins, 1983). In contrast to the Sierra Blanca area, peralkaline rhyolites are abundant in the Christmas Mountains area, and much of the peraluminous character may be a result of alkali loss during weathering or deuteric alteration of peralkaline intrusions. The Sierra Blanca rhyolites appear to be unique in containing the unusual Li-rich micas.

Several chemical and mineralogical features suggest that the Round Top intrusion was chemically modified by pegmatitic vapor-phase crystallization. The HREE enrichment (275 times chondritic abundances for Yb) can be explained by an influx of a F-rich pegmatitic phase. London and Hervig (1986) documented HREE partitioning into a vapor phase in experiments on a peraluminous rhyolite. The presence of minerals typical of pegmatities (cryolite, Li-rich micas, and rutilated quartz) further suggests pegmatitic crystallization, as do vapor-rich fluid inclusions and associated quartz overgrowths.

Barker (1980) noted similar fluid inclusions in quartz from Little Round Top and other Sierra Blanca peaks. Interpretation of the trace-element compositions of any of the laccoliths, which are all enriched in HREE (Matthews and Adams, 1986; Shannon and Goodell, 1986) should consider the possibility that the peraluminous nature and the odd trace-element compositions, which are clearly unusual for the Trans-Pecos magmatic province, are the result of modification of otherwise more typical metaluminous or peralkaline magmas by vapor-phase processes.

SUGGESTIONS FOR FUTURE WORK

More data are needed to constrain the origin of the chemically and mineralogically unusual Sierra Blanca rhyolites. Shannon and Goodell (1986) pointed out similarities between the rhyolites and anorogenic granites or topaz rhyolites and suggested an origin involving crustal melting. Burt et al. (1982) and Christiansen et al. (1983, 1986) demonstrated that the localization of many grossly similar peraluminous rhyolites in the western U.S. and Mexico is most likely due to partial melting of Precambrian continental crust. Enrichment in various lithophile metals appears to be related to degree and depth of devolatilization (e.g., Burt, 1984), partitioning of the metals between melt, crystals, and vapor phases (e.g., London and Hervig, 1986), and stability of accessory minerals that contain many of the incompatible elements (e.g., Nash, 1986). Because the Sierra Blanca rhyolites differ somewhat from typical topaz rhyolites, the crustal-melt hypothesis needs to be checked. Isotopic studies (Nd, Pb, O, and perhaps Sr on selected minerals) need to be undertaken on the rhyolites and on Precambrian rocks of the region. In addition, the degrees of modification of primary magmatic compositions by vapor-phase crystallization, hydrothermal alteration (kaolinization and fluoritization) associated with fluorite-beryllium ore deposition, deuteric alteration, and weathering need to be investigated.

The Sierra Blanca rhyolites, which have highly enriched Be and F contents, are clearly the sources of F and Be in the beryllium deposits in limestones along the contacts. Research is needed to determine how the Be and F were extracted from the intrusions, whether by the pegmatitic vapor phase responsible for many of the unusual mineralogical and chemical characteristics of Round Top or by a lower-temperature fluid dominated by meteoric water. The intrusions should also be examined in terms of their potential as low-grade, bulk-tonnage resources of some of the rare metals that occur in discrete minerals.

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