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BEIDELLITE AND ASSOCIATED CLAYS FROM THE DeLAMAR MINE AND FLORIDA MOUNTAIN AREA, IDAHO

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Abstract—There has been much interest in the rare specimen of beidellite from the Black Jack Mine, Florida Mountain, Idaho. A variety of aluminous clays exists along veins such as the Black Jack vein, in rhyolite and latite flows, and in near-surface ash beds, often containing less than 1.0% MgO and 0.5% Na_2O. Associated clays include beidellite, illite, kaolinite, 10-Å halloysite, dickite, nacrite, rectorite and a tarasovite-like mineral. The predominant clay is mixed-layer illite–beidellite. The beidellites have Al_2O_3 contents ranging from about 28 to 33%, and predominantly Ca and K as interlayer cations. The typical beidellite dehydroxylation temperatures of about 595 °C readily differentiate the beidellite from montmorillonite, which has a dehydroxylation temperature in the range of 735 °C. A modified differential thermal analysis (DTA) method is given for readily estimating the interlayer cation populations of smectites, including Mg^{++} and Al^{+++} cations. Chemical analyses and layer charges of 11 beidellites from mines around the Black Jack Mine are given. The beidellites have an American Society for Testing and Materials (ASTM) classification of CH, ϕ value, internal friction angle of about 8° and an expansion pressure of about 9 kgf/cm² (88.3 kPa), similar to that of nontronite.

Key Words—Beidellite, Clay Chemistry, Differential Thermal Analysis, Illite–Beidellite, Rectorite, X-ray Powder Diffraction.

INTRODUCTION

The pure specimen of beidellite from the Black Jack Mine, Florida Mountain, near Silver City, Idaho, has generated much interest in its mode of formation and what other beidellites might be available. The unusual specimen at the Smithsonian is nearly pure except for some visible grains of quartz on one side. Large amounts of aluminous clays are present in the Florida Mountain and nearby DeLamar Mine areas as a variety of different minerals, but beidellites are not common. The Black Jack Mine was only one of numerous mines in Florida Mountain, and the entrance has caved shut. An open-pit mine is being developed on the west side of the mountain, and soon the previous mining area will be unrecognizable.

The purpose of this study is to conduct a preliminary survey and characterize the clay species collected from the historic Carson mining district. Also, a modified method of DTA is given for determination of the various clay interlayer cation populations, made possible by the pure clay specimens found in the area. The subject area is centered at the DeLamar Mine, Florida Mountain, and War Eagle Mountain (Figure 1). The area is approximately 80 mi south of Boise, Idaho, and 20 mi east of Jordan Valley, Oregon. The lower drainage tunnel for the mines in War Eagle Mountain is being reopened, and clay minerals there may soon be available. Both surface and underground workings from these areas are the sources for the aluminous clays collected. Only the existing interlayer cation populations of beidellites were investigated to correlate them with unaltered source minerals and, possibly, the main silver ore mineral, naumannite.

The area has a Cretaceous granodiorite basement intruded and overlain by basalts, rhyolites and latites. A rhyolite sequence covers all previous geologic structures as flows and domes, except where local unconformities may exist. In the study area, nearly all of the host rock has been altered by weathering and hydrothermal alteration (Cupp 1989). Argillic alteration is common and quite marked along veins in rock fractures and faults, and at rock contacts. The original rhyolite and latite country rock are deficient in Mg, 0.0. to 0.3% (Ekren et al. 1984), and this chemical signature is reflected in the secondary clays. The formation of different clays is modified in some cases by the hydraulics of the diverse fault systems (Lambert 1992). The clay deposits occur in seams and lenses that are less than 1 cm to more than 5 m in thickness and which may be continuous for more than 100 m. The mode of occurrence is in veins, or thick blankets where ash beds have been deposited in near-surface environments.

The silver and gold ore deposits in Florida Mountain are along at least 3 main veins. The primary vein, northerly trending and steeply dipping, consists of a thin, highly altered basalt dike containing discontinuous clay seams on the east side and bodies of ore on the west side (Lindgren 1899). The Black Jack beidellite was probably found along this vein. The Blaine

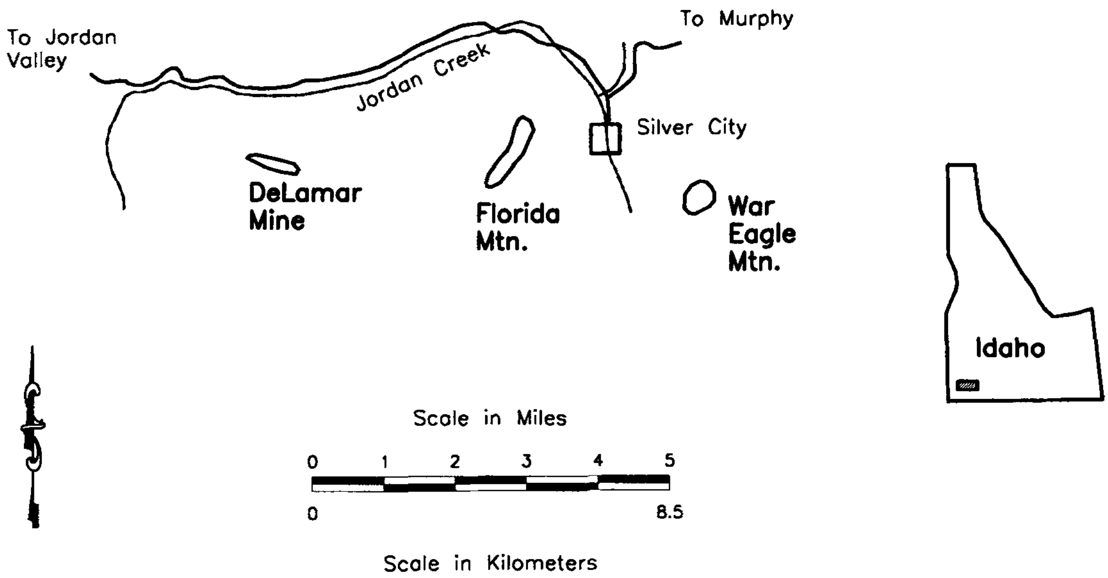

Figure 1. The 3 mining areas investigated in the Carson mining district.

Table 1. Clay minerals found in the DeLamar-Florida Mountain area, with dehydroxylation temperatures in °C measured by DTA.

~El (ft)	Minerals	Dehydro-xylation temp (°C)
	Glen Silver Pit	
6265	Beidellite	585
6225	Dickite	
6225	Beidellite	590
6225	1:1 Illite–beidellite	
6185	Beidellite	590
6145	K-rectorite	595
6125	Beidellite	585
6145	Nacrite	
6105	Alunite	
6105	6:4 Illite–beidellite	
	Clay Pit	
CP-4	Fe-beidellite	595
CP-6	Beidellite	745
CP-8	Beidellite	595
	Florida Mountain	
Phillips Mine	Illite	
Blaine Tunnel	Beidellite	610
Idawa Mine	Beidellite	610
Lvl 3, Trade Dollar Mine	Tarasovite-like	595
Phillips Mine	10-Å halloysite	
Empire Mine	Illite	
Miller & Walters Mine	Beidellite	597
Above Blaine Tunnel	Beidellite	615
Miller & Walters Mine	K-beidellite	565
Phillips Mine	Beidellite	635
Tip Top Mine	9:1 Illite–beidellite	

Tunnel follows the Black Jack vein extension, and the vein can be seen in the partially caved tunnel. Two specimens described in this report were taken from the vein, labeled "Blaine tunnel", and "above Blaine tunnel". The tarasovite-like specimen may also be from the same vein.

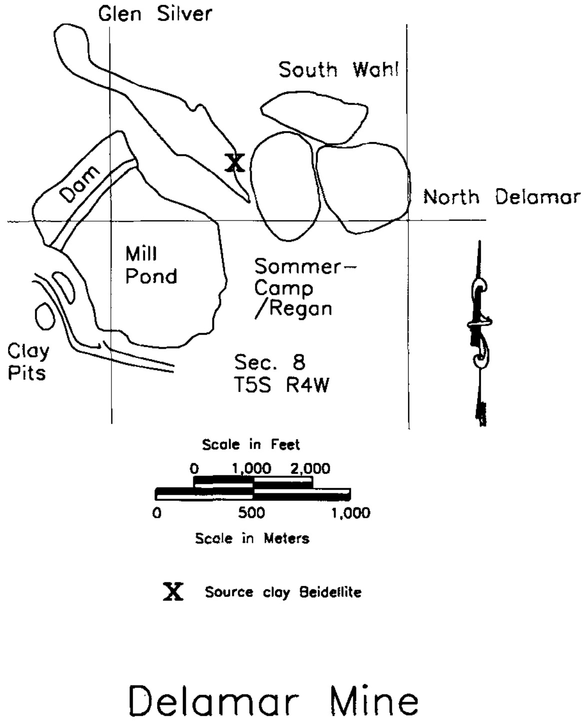

Figure 2. The mine pits, mill pond and clay pits of the DeLamar Mine. The Source Clay beidellite site is shown.

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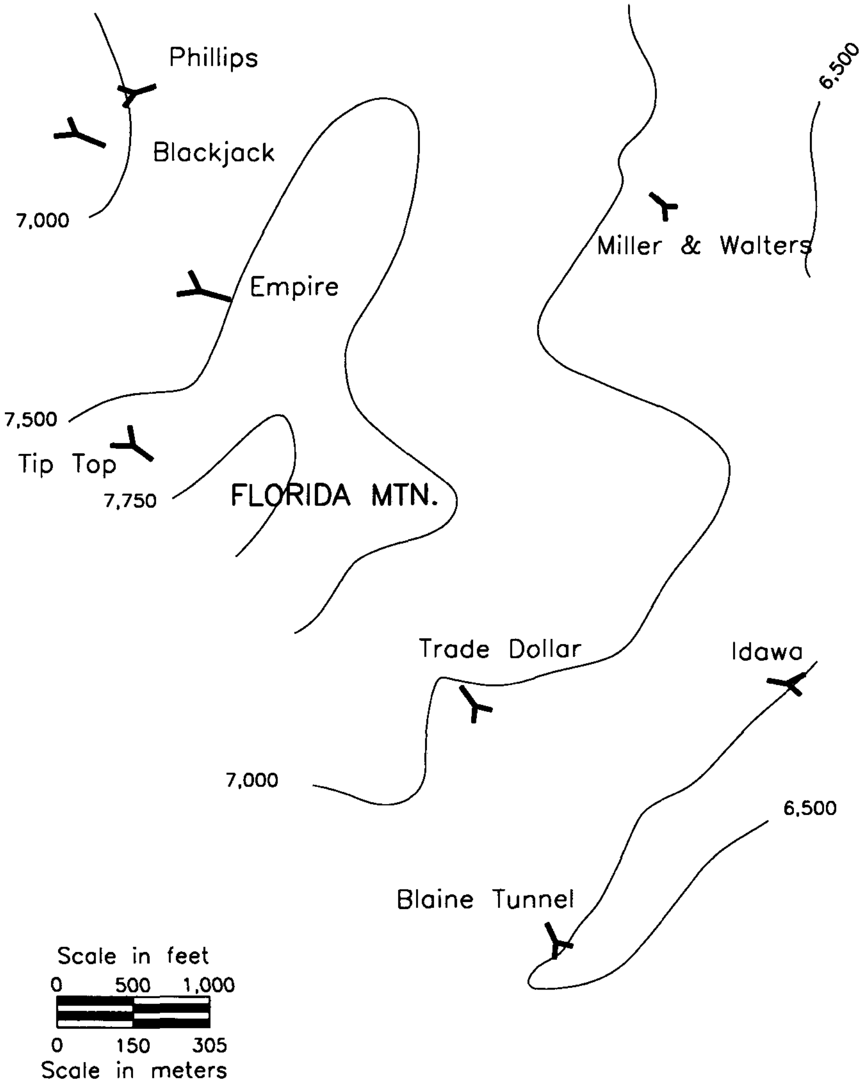

Figure 3. The mines in Florida Mountain where clay specimens were collected. The Black Jack Mine caved shut.

The "Iron Dike" described by Lindgren (1899) at DeLamar was a broad pyritiferous clay layer formed from a vitrophyre precursor, up to 7 m thick. Following the description of various clay seams by Lindgren, some clay specimens were taken to the United States National Museum. Included in the specimens was one from the Black Jack Mine in Florida Mountain, a gouge clay what was analyzed and classified by Shannon (1923) as beidellite.

The clay deposits continue to play a significant role in the present mining and milling of ore at the DeLamar Mine, due to their presence as a gangue component in the typical ore. The clay has also caused significant slope failures. However, clay beds located near the mill tailing impoundment have provided excellent material for the impervious clay core in the construction of the main mill pond dam. The clay beds occur as Fe-rich beidellite up to 2 m thick in small basins and are pure enough to provide construction-grade clay.

MATERIALS AND METHODS

Samples of clays were collected from the mines (Table 1) from 1989 to 1994, including the beidellite sent to the Source Clays Repository, taken from near the top of the Glen Silver Pit at the DeLamar Mine (Figure 2), and from the mines shown on Figure 3 of Florida Mountain. The main impurities are silt and sand-size quartz and orthoclase. All of the beidellite specimens from Glen Silver Pit, except for that at el 6225 ft, contain small amounts of kaolinite, usually less than 5%. Alunite is listed as an integral part of the ore body-clay system at an approximate elevation of 6105

Table 2. X-ray diffraction data for air-dry and treated beidellite (Å).

	Idawa Mine d(Å)	DeLamar Mine d(Å)	Blaine Tunnel d(Å)	*hkl*†	Black Jack Mine‡
Air dry	4.482	4.471	4.480	020, 110, 021	4.42
	4.371	4.354	4.354		
	4.040	4.055	4.065	022	3.95
	3.587	3.524	3.490	023	3.54
	2.575	2.565	2.575	200, 130, 201	2.57
	2.547	2.528	2.547		
	2.520	2.508	2.510	202	2.52
	2.351	2.348	2.349	203	2.36
	2.237	2.234	2.237	204, 040, 220	2.24
	2.169	—	2.160	041, 042	2.19
	2.033	2.038	2.031	– –	– –
	1.696	1.696	1.691	240, 310, 241	1.693
	1.648	1.652	1.652	243	1.623
	1.494	1.491	1.493	060, 330	1.498
Conditions					
Air dry	15.10	15.10	15.05	001	15.1
+ Calgon		12.60	12.50		12.5
+ Ethylene glycol	16.75	17.00	16.75		16.8
+ Glycerol			17.85		17.6
Moist		18.80			
Heated 375 °C		9.65	9.75		9.6§
Heated 1050 °C	mullite				

† Calculated for beidellite intercalated with glycerol.
‡ Observed diffraction peaks for *hkl* spacings. (Weir and Greene-Kelly 1962).
§ Heated to 280 °C.

ft, and the 3:1 illite–beidellite (tarasovite-like) material is also listed.

The dehydroxylation temperatures for the beidellites are also listed in Table 1. Portions of each clay sample were air-dried for analysis, except for the 10-Å halloysite, which was pulverized while still moist. Specimens that were not pure clay were separated by sieving or by water suspension. All specimens were identified by X-ray diffraction (XRD) analyses, using a Picker spectrodiffractometer; then selected specimens were chemically analyzed by X-ray fluorescence (XRF) methods. The methods of sample preparation and variance of results are described in Post and Austin (1993). Additional tests included near-infrared (NIR) spectra, DTA and physical test methods. Also, exchangeable cations for 3 beidellite specimens were determined using ammonium-thiocyanate, and the cation exchange capacities (CEC) were determined using ammonium acetate. Physical properties were determined by ASTM standard test methods, including Atterberg limits, modified compaction, shear strength and expansion pressure.

The ASTM Test Method D3877-80, for expansion pressure, included only Part A, with test specimens prepared using static compaction at 6.89 MPa loading. A Fisher Differential Thermalyzer, with a Perkin Elmer 024 recorder, was used to differentiate the interlayer cation populations of the smectites. The thermocouple terminals were placed in the materials being tested. The endothermic peak positions and temperatures were calibrated by using a calibrated TG-DTA Mettler unit for the same samples.

RESULTS

XRD Data

The basal spacing of all-natural, air-dry, relative humidity ~30% beidellites tested is generally about 15.1 ± 0.3 Å, the specimen spacings being very sensitive to temperature and humidity changes. The first basal spacing is usually very strong, with 3rd, 4th and 5th basal spacings present; for example, the Blaine Tunnel beidellite had relative intensities of 615, 35, 6 and 26 units, for a scan of an oriented air-dry slide, using 1000 CPS, TC=3. The beidellite spacings expand to 16.75 to 17.00 Å with ethylene glycol, and 17.85 Å with glycerol, and collapse to 9.65 to 9.75 Å when heated to 375 °C. Oriented slides, when still moist, have a basal spacing of 18.80 Å (Table 2). The measured d(06*l*) spacings are 1.491 to 1.495 Å. Beidellites with very well-ordered crystal structures, such as the Black Jack beidellite, show XRD peaks that are not usually present. The XRD data for air-dry beidellites are given for the 3 well-crystallized specimens along with *hkl* indices suggested by Weir and Greene-Kelly (1962). Receiving slits of 1° divergence, 1° scatter and 0.002 in were used, with a 1 °2θ/min scan rate, to measure the moderate to weak reflections (Figure 4).

Kaolinite found in the Sommercamp-Regan Pit, and dickite and nacrite from the Glen Silver Pit, have basal

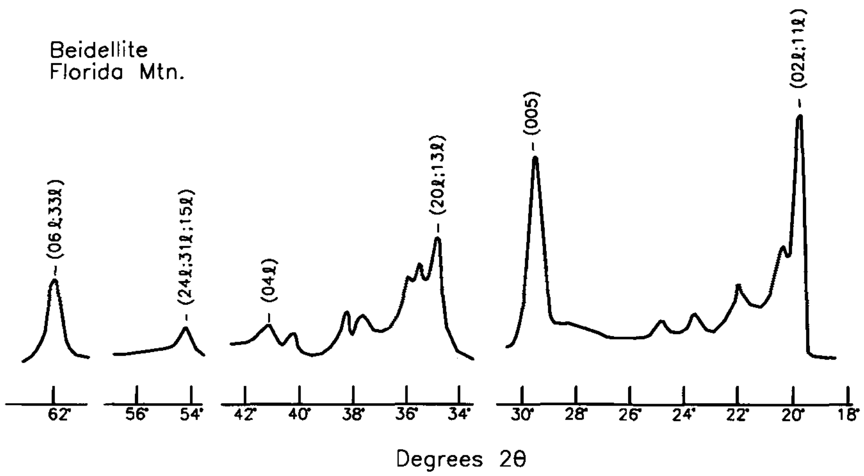

Figure 4. A partial XRD scan for beidellite from the Miller-Walters Mine adit, with partial peak indexing, suggested by Weir and Greene-Kelly (1962).

spacings of 7.13, 7.16 and 7.14 Å, successively. All of the kaolinites investigated show small basal spacings of 7.13 to 7.14 Å. The dickite contains some alunite and the nacrite contains some dickite. The K-rectorite from the Glen Silver Pit shows 12 repeat basal spacings giving an average $d(001)$ of 26.897 Å and coefficient of variance (CV) = 0.316 for glycolated material (S. W. Bailey, personal communication). The air-dry basal spacing is $d(001)$ of 25.10 Å, calculated using the higher-order basal reflection spacings.

Some nearly pure alunite was found near the Glen Silver Pit clay seams during 1993. The dominant clay throughout the DeLamar Mine pits is mixed-layer illite–beidellite, with a ratio of about 6:4. A seam with a ratio of nearly 1:1 illite–beidellite also was found there. The determination of the illite–beidellite layering combinations was done on the basis of procedures given by Reynolds (1980). Mixed-layer kaolinite/beidellites were also found in specimens from the Miller-Walters Mine and the Phillips Mine.

Fine specimens of beidellite, illite, 10-Å halloysite and tarasovite-like clay were found in mines in Florida Mountain (Table 1), along with the various kaolinite–beidellite mixed-layer clays (Figure 3). The halloysite from the upper Phillips Mine has a basal spacing $d(001)$ of 10.03 Å, a $d(02l)$ of 4.415 Å and a $d(11l)$ of 4.350 Å (Table 3). The Empire Mine illite is mainly $1M$ structure with some $2M_1$ stacking, and a basal spacing $d(001)$ of 10.01 Å. Illite also is common in the Tip Top Mine and the Phillips Mine, and occurs

Table 3. X-ray diffraction data for 10-Å halloysite, rectorite, 3:1 illite–beidellite.

10-Å halloysite			Rectorite			3:1 Illite/beidellite #3		
d(Å)	*I*	*hkl*	*d*(Å)	*I*	*hkl*	*d*(Å)	*I*	*hkl*
10.02	60	001	calc 25.12		001	calc 44.97		001
4.414	18	021	12.56	58	002	11.3		003
4.35	17	111	5.012	9	002	5.00	12	009
3.343	9	003	4.485	22	02ℓ	4.48	25	02ℓ
2.558	7	201	3.528	4		4.35	3	
2.49	3	004	3.140	4	008	3.648	6	
2.34	3	041	3.070	2		3.336	6	
1.971	2	005	2.564	15		3.058	5	
1.678	2	241	2.442	3		2.663	3	
1.484	5	061	2.239	2		2.558	16	
			1.685	3		2.430	3	
			1.652	2		2.390	3	
			1.493	12	06ℓ	2.350	2	
						2.239	4	0020
						2.149	2	
						2.004	3	
						1.947	2	
						1.669	4	
						1.624	3	
						1.493	11	06ℓ

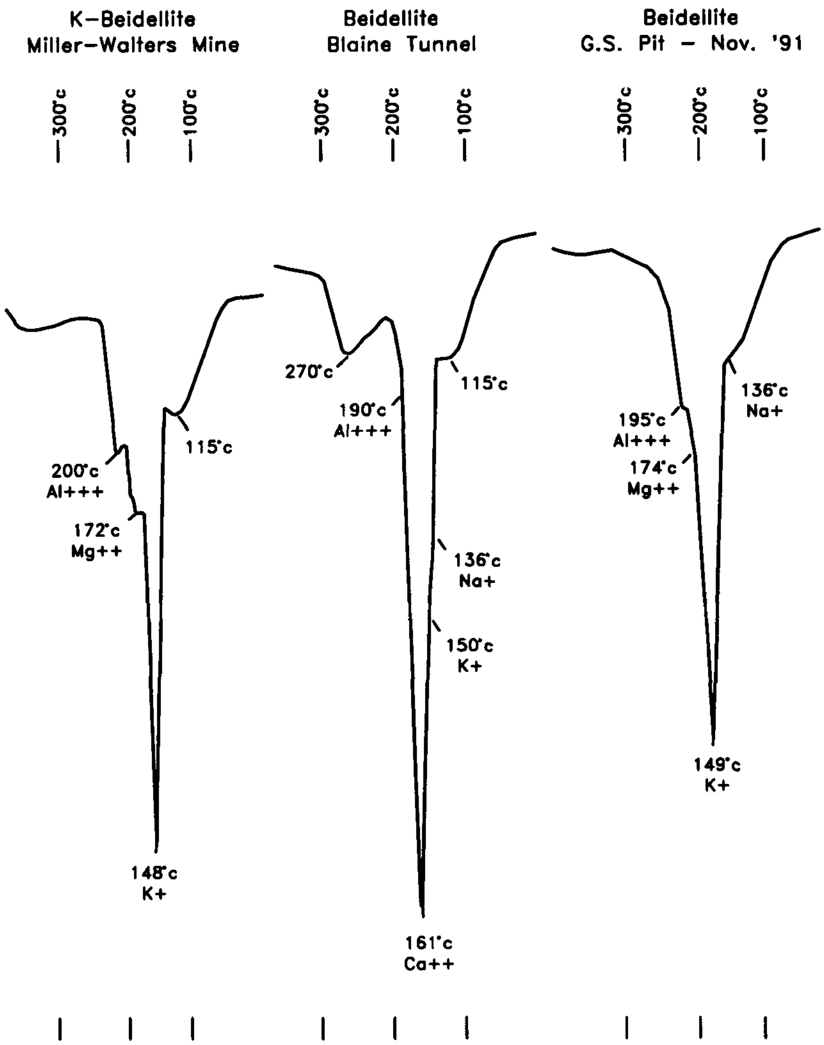

Figure 5. DTA patterns are shown characterizing predominant interlayer cation populations of Ca^{++} (161 °C), K^{+} (148 °C), and $Al^{++} \pm Mg^{++}$ (~200 and ~172 °C).

throughout the Florida Mountain mines. The tarasovite-like clay, 3:1 illite–beidellite, regular stacking order, occurs in level 3 of the Trade Dollar Mine. The stacking order is not sufficiently regular to show more than 4 orders of basal spacing when glycolated, even though NIR spectra and chemical analyses of several specimens indicate a uniform composition. The calculated *d*(001) basal spacing is 46.93 Å when glycolated and 44.97 Å air-dry, calculated on the basis of higher-order basal spacings. Diffraction data for air-dry rectorite from the Glen Silver Pit is also included. On the basis of the studies of illite/smectites by McCarty and Reynolds (1995), the mica-like layering in the rectorite is 1*M*, shown by the peaks at 3.527 $(\bar{1}12)$ and 3.070 Å (112).

DTA Data

A modified DTA apparatus gives the ability to observe the individual interlayer cation endotherms for smectites, illite/smectites, sepiolite, chlorites and serpentines. The key items are the sensitive fast-response recorder and the differential thermocouple terminals located in the specimen and reference material, rather than against the specimen container. Some of the beidellites, showing strong, sharp XRD patterns and containing varying dominant cation populations, give sharp endotherms (Figure 5). The DTA scan responses are directly related to the interlayer cation contents (Mackenzie 1950; Greene-Kelly 1957; Post 1995), here determined by XRF analyses. Shown are specimens of K-beidellite, Ca-beidellite and beidellite with a predominantly K-Al cation population. The endotherms rise linearly to individual peaks, and any shoulder indicates another different cation content. The recorder was set at 1 mV and 20 cm/h, with a furnace heating rate of 25 °C/min. The DTA scans were made for more than 60 different analyzed smectite speci-

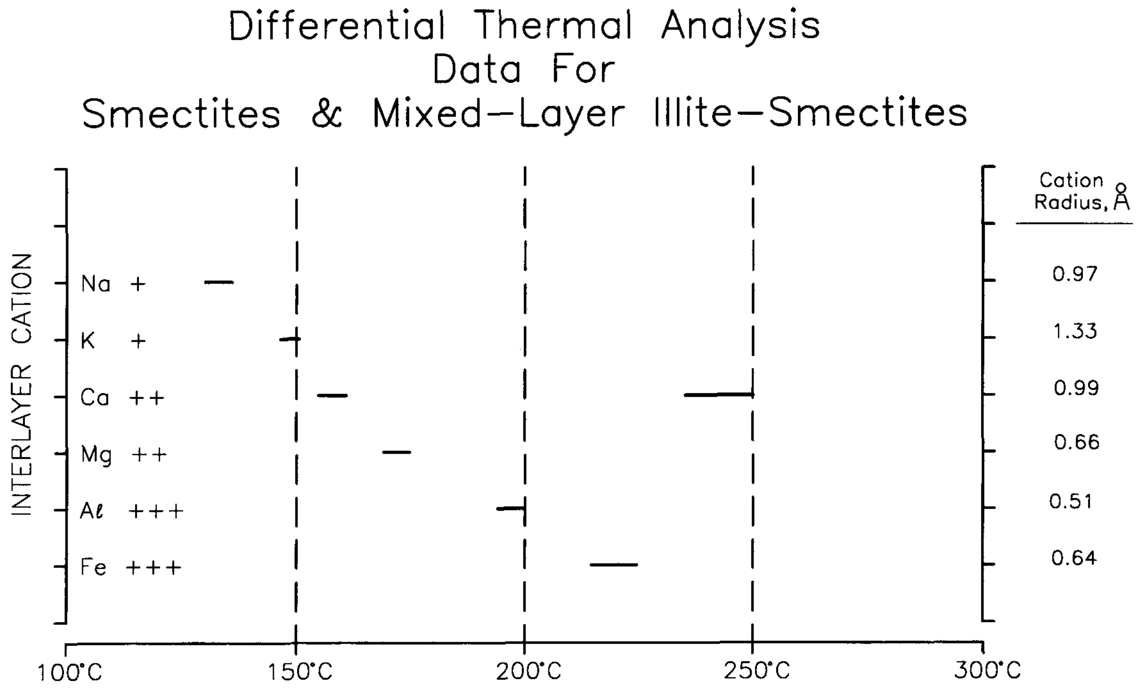

Figure 6. Disruption temperatures for 6 different interlayer cations when heated during DTA scans.

Table 4. Chemical analyses of 6 beidellites from the DeLamar Mine (%), and numbers of ions.

	Glen Silver Pit				Clay Pit	
	1st Bench	2nd Bench	3rd Bench	No. Ramp	Spec. 6	Spec. 8
SiO_2	57.90	59.00	57.89	57.82	63.13	60.99
Al_2O_3	30.18	28.43	32.62	32.03	25.13	27.87
Fe_2O_3	2.05	1.23	0.07	0.53	3.22	1.70
MgO	0.76	2.33	1.06	1.39	1.35	1.44
MnO	0.02	0.00	0.02	0.01	0.13	0.05
TiO_2	0.80	0.26	0.43	0.36	0.16	0.11
CaO	0.75	1.04	0.53	1.17	1.68	2.06
K_2O	2.39	1.62	1.88	1.33	0.43	0.11
Na_2O	0.30	0.51	0.30	0.10	0.37	0.40
BaO	0.04	0.09	0.04	0.05	0.02	0.06
H_2O	4.77	4.78	4.82	4.80	4.90	4.85
	99.96	99.29	100.29	99.59	100.52	99.64
			Numbers of Ions			
Tetr.						
Si	3.63	3.70	3.60	3.60	3.89	3.76
Al	0.37	0.30	0.40	0.40	0.11	0.24
	4.00	4.00	4.00	4.00	4.00	4.00
Oct.						
Al	1.87	1.79	1.93	1.95	1.71	1.80
Fe^{3+}	0.10	0.06	0.03	0.03	0.15	0.08
Mg	0.07	0.22	0.07	0.06	0.09	0.13
	2.04	2.07	2.03	2.04	1.95	2.01
Inter.						
Ca/2	0.10	0.14	0.07	0.16	0.22	0.27
K	0.19	0.13	0.15	0.11	0.03	0.01
Na	0.04	0.05	0.04	0.01	0.05	0.05
Mg/2	—.—	—.—	0.03	0.07	0.03	—.—
Al	—.—	—.—	0.06	—.—	—.—	—.—
	+0.33	+0.32	+0.35	+0.35	+0.33	+0.33
Layer ch.	−0.33	−0.32	−0.36	−0.35	−0.33	−0.33

Table 5. Chemical analyses of 5 beidellites from 4 mines in Florida Mountain (%).

	Blaine Tunnel	Idawa Mine	Miller-Walters Mine (adit)	Miller-Walters Mine (drift)	Adit above Blaine Tunnel
SiO_2	58.71	57.93	57.07	59.54	62.88
Al_2O_3	30.90	32.12	31.73	32.46	26.05
Fe_2O_3	1.91	0.97	1.63	0.45	1.55
MgO	0.87	0.25	1.86	0.70	0.61
MnO	0.02	0.00	0.01	0.10	0.08
TiO_2	0.00	0.00	0.01	0.00	0.00
CaO	1.95	2.44	1.65	0.10	1.84
K_2O	0.24	0.03	0.90	1.52	0.59
Na_2O	0.01	0.05	0.35	0.00	0.35
BaO	0.01	0.02	0.02	0.03	0.03
H_2O	4.85	5.84†	4.84	4.88	4.82
	99.47	99.65	100.07	99.78	CaF_2 0.74
					99.54
Number of Ions					
Tetr.					
Si	3.64	3.60	3.54	3.66	3.90
Al	0.36	0.40	0.46	0.34	0.10
	4.00	4.00	4.00	4.00	4.00
Oct.					
Al	1.90	1.96	1.85	1.99	1.81
Fe^{3+}	0.09	0.05	0.07	0.02	0.07
Mg	0.04	0.02	0.17	0.02	0.06
	2.03	2.03	2.09	2.03	1.94
Inter.					
Ca/2	0.27	0.32	0.22	0.01	0.24
K	0.02	0.00	0.07	0.12	0.05
Na	0.00	0.01	0.04	0.00	0.04
Mg/2	0.04	–.–	–.–	0.04	–.–
Al	–.–	–.–	–.–	0.09	–.–
	+0.33	+0.33	+0.33	+0.26	+0.33
Layer ch.	−0.33	−0.33	−0.33	−0.27	−0.33

† Measured water content.

mens, with results summarized in Figure 6. The beidellites tested can readily be differentiated from montmorillonites, because the beidellites tend to have dehydroxylation endotherms near 595 °C, varying from 565 to 635 °C (Table 1), whereas montmorillonite endotherms are closer to 735 °C, with considerable variation. Greene-Kelly (1957) showed the Black Jack beidellite endotherm at about 600 °C, and even the Fe-beidellite, containing about 11.8% Fe_2O_3, has a dehydroxylation endotherm at 595 °C. It appears that specimen CP-6 is a transition smectite between beidellite and montmorillonite (Post and Noble 1993), with an SiO_2 content of about 63.1% and an endotherm at 745 °C (composition given in Table 4). The K-rectorite and tarasovite-like clays have moderate endotherms near 595 °C. Five beidellites give exotherms from about 1000 to 1040 °C, with CP-4 Fe-beidellite at about 940 °C. Although Kawano and Tomita (1991) show that heated beidellite with K^+ interlayer cations will rehydrate more readily than Mg^{++} interlayer cations, DTA scans indicate that not all of the K^+ may rehydrate. Also, although the hydration energy of Na^+ is greater than that of K^+, DTA scans show that the Na^+ ions always disrupt and drop to the clay surface at a lower temperature (~134 °C) than the K^+ ions (~149 °C).

Chemical Data

Previous partial chemical analyses were given (Post and Noble 1993) for 5 beidellite specimens and 2 illites from the study area, and for the Source Clay beidellite (Hetzel and Doner 1993). More complete XRF analyses are given here (Table 4) for 4 specimens of beidellite from the DeLamar Mine and 2 from the clay pit. The Si, Al and Mg data are precise to the nearest ±0.1%. The half-cell ion contents are calculated by the method of Ross and Hendricks (1945). The XRF analyses are given for 5 beidellites from 4 mines in Florida Mountain, with calculated half-cell ion contents (Table 5). Partial chemical analyses are given for rectorite, illite and muscovite specimens (Table 6). Two illite specimens from the Tip Top Mine contain 9.73% K_2O and 9.68% K_2O. The minor-element composition of muscovite in a synkinematic pegmatite in the Miller-Walters Mine is included in Table 6 to show that it contains small amounts of minor elements when

Table 6. Partial chemical analyses of rectorite, illite, muscovite specimens and 3:1 illite–beidellite (%).

	K-rectorite Glen Silver Pit	Illite Empire Mine	Muscovite Miller-Walters Mine	3:1 Illite–beidellite Trade Dollar Mine
SiO_2		46.9		
Al_2O_3	35.1	35.4		31.2
Fe_2O_3	0.30	1.53	3.10	0.79
MgO		0.64		0.40
TiO_2	0.64	1.20	0.35	0.00
K_2O	4.52	9.13		4.86
CaO	1.04	0.08	0.06	0.18
BaO	0.37	0.19	0.08	0.02
Rb_2O	0.14	0.13	0.08	0.07
Nb_2O_5	0.000	0.040	0.007	0.000
Ga_2O_3	0.000	0.000	0.020	0.022
MnO	0.00	0.00	0.05	0.05
NiO			0.001	
ZnO			0.041	

compared to other muscovites in the western United States (Post and Austin 1993).

The exchangeable cations in 3 beidellites—CP-6, Blaine Tunnel, and Glen Silver Pit, third bench—included 17.0, 23.6 and 13.0 meq/100 g of Mg, and 47.3 meq/100 g of Al for the pit bench beidellite. The DTA scan (Figure 4) clearly shows the presence of Al^{+++} in the interlayer cation population (195 °C). The measured Ca^{++} and Na^{+} exchangeable cation values correlated well with XRF values, but not for K^{+} contents. The exchangeable K^{+} was measured as less than 0.004% to 0.016%, whereas the XRF values for the same specimens ranged from 0.19% to 2.14% K^{+}. The unaltered cation populations were determined in this study, whereas Hetzel and Doner (1993) saturated their beidellite specimen with Na^{+} and removed the small

Table 7. Water-holding capacities of 5 beidellites.

	Idawa Mine	Black Jack Mine	GS-2, 1st bench	CP-6	CP-8
Basis 110 °C / 110–300 °C	3.98%	3.97%	2.55%	3.16%	4.13%
Basis 110 °C / 300–1050 °C	5.62	5.56	5.63	5.45	5.58
Basis 300 °C / 300–1050 °C	5.84	5.78	5.70	5.60	5.81

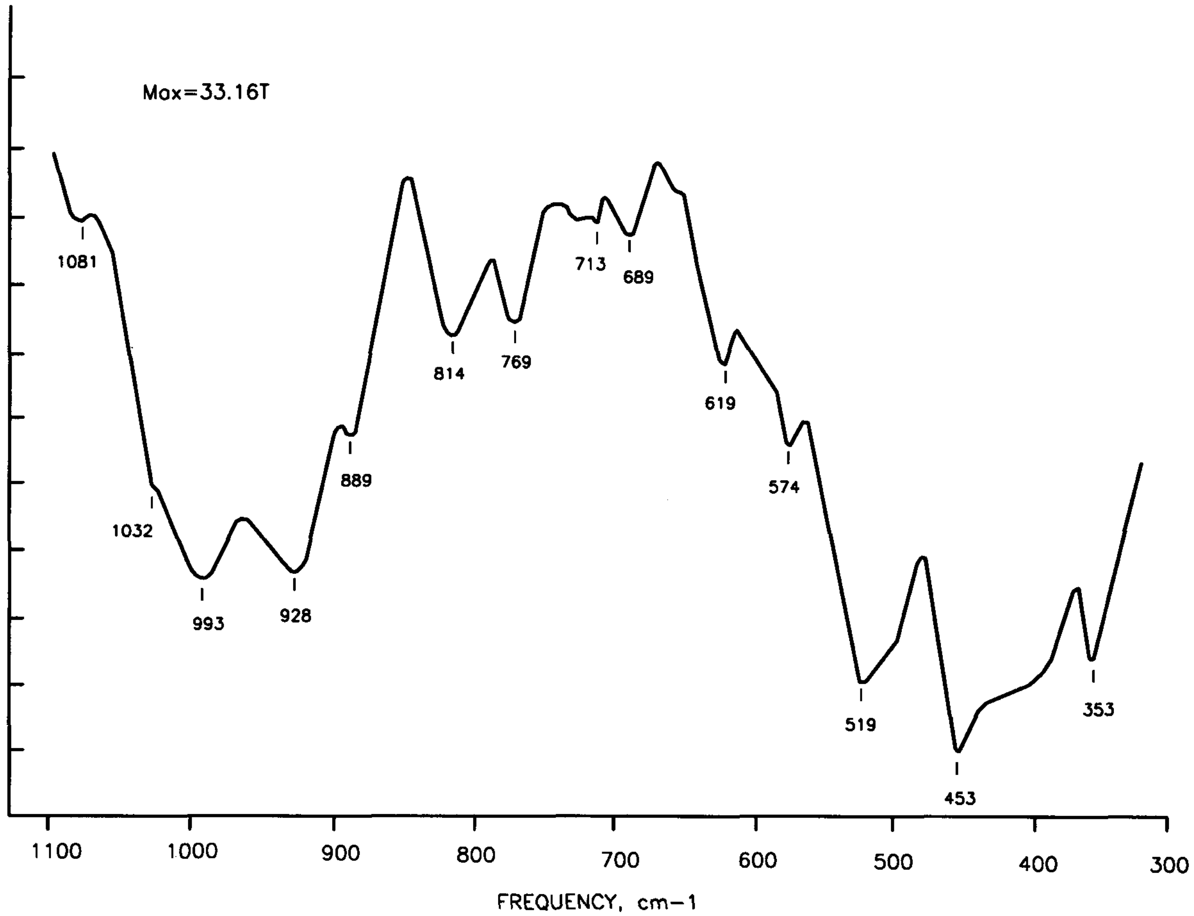

Figure 7. Mid-infrared spectral scan of beidellite from the Blaine Tunnel.

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Table 8. Physical properties of clay minerals from the DeLamar-Florida Mountain mines.

Test	Results			Method
Atterberg limits:	LL	PI	Classif.	ATM
GS-3 beidellite	109	74	CH	Test Method
CP Fe-beidellite	113	64	CH	D4318-84
Empire mine illite 1a	47	19	ML	&
GS 1:1 illite-beidellite (classif.)	104	76	CH	D2487-92
Modified compaction:	% w opt		γd max	ASTM
GS-3 beidellite	15.7		1756 kg/m^3	Test Method
CP Fe-beidellite	23.5		1550	D1557-91
Empire mine illite 1a	11.1		2020	
GS 1:1 illite-beidellite	16.1		1799	
Shear strength:	ϕ_e		C	ASTM
GS-3 beidellite	8°		38 kPa	Test Method
CP Fe-beidellite	8°		78	D2850-87
Empire mine illite 1a	21°		7	
GS 1:1 illite-beidellite	13°		38	
Expansion pressure:	kgf/cm^2		% W_i	ASTM
GS-3 beidellite	9.08 (89 kPa)		9.4	Test Method
GS 1:1 illite-beidellite	3.23 (32 kPa)		5.2	D3877-80

amount of kaolinite present, altering the clay system. The Source Clay beidellite (Table 4), 1st bench, ordinarily has a layer charge of −0.33, whereas the altered clay had a calculated half-cell charge of −0.47.

The method of calculation for smectite unit cell composition given by Ross and Hendricks (1945) is only an approximation method, in that there is no way to determine what Mg^{++} and Al^{+++} interlayer cation combination is present. Many Wyoming bentonites contain interlayer Al^{+++} cations, as observed by DTA scans, but chemical analyses seldom show this.

When heated, smectites lose free water, then bound water and then hydroxyl water. There is almost no weight loss in the 300-°C temperature range, as the remaining bound water is lost; thus, crystalline solids are calculated from specimen weight at 300 °C for these beidellites. The Idawa Mine beidellite is a pure clay with water contents nearly identical to that of the Black Jack beidellite. The water contents of 3 less-pure clays are given in comparison.

The measured water content in beidellites is always in excess of calculated water content. All of the analyses in Tables 4 and 5 were performed on the basis of calculated water content, except for the Idawa Mine beidellite.

NIR Data

Previous NIR data were given for 5 beidellites, in comparison to the Smithsonian beidellite, and 3 illites (Post and Noble 1993). The K-rectorite from the Glen Silver Pit (Table 1) has a strong NIR band at 4569 cm^{-1} frequency (2189 nm wavelength), and the tarasovite-like clay has a strong NIR band at 4555 cm^{-1} (2217 nm). These bands lie about halfway between spectral bands of beidellite and muscovite having comparable band frequencies. The mid-infrared spectrum of beidellites from the Blaine Tunnel is included to complement the NIR data previously given (Figure 5). The fundamental OH band is at a frequency of 3641 cm^{-1} (2746 nm).

Physical Properties

Beidellites contain approximately 10 to 14% moisture content when air-dry. The water-holding capacities, given as Atterberg limits (Table 7) for beidellites and mixed-layer illite–beidellite, are similar to those of Ca-montmorillonites (Ali-Kalush 1985), with CH classification, whereas the illites behave more as fine silt (ML). Compacted beidellite has a much lower optimum moisture content (% w opt) than compacted montmorillonite and a higher maximum dry density (γ_d max) comparable to that of nontronite (Post 1989). The effective internal friction angle (ϕ_e) of beidellite is quite low at about 8°, with illite at about 21°, and mixed-layer illite-beidellite having an intermediate value of about 13°.

The expansion pressure of beidellite is quite low where the main seat of charge is in the tetrahedral sheet structure (Sato et al. 1992), compared to montmorillonite. The GS-3 beidellite shows an expansion pressure of only 9.08 kgf/cm^2 (89.0 kPa) in comparison to Panamint Valley nontronite with 11.93 kgf/cm^2 (117.0 kPa) (Post 1981).

CONCLUSIONS

The clay enrichment of the alteration vein material is derived mainly from the rhyolite and latite porphyry

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resting on granodiorite, and these geologic structures have low Mg contents and high Al contents. Hence, the smectite formed tends to be beidellite. The results of the typical mica analysis for the Florida Mountain area indicates that there is also a low content of at least 10 trace elements in the granodiorite. The investigation of clay deposits in the War Eagle Mountain mines (Figure 1), although just begun, shows the presence of kaolinite, illite and mixed-layer illite–beidellite. The physical properties of the clays given are particularly important because of the destructive slide failures which have occurred.

The use of DTA data is an easy and convenient method of estimating the cation population of layer silicates, and the procedure can be improved. It is shown that Al does occur fairly commonly as an interlayer cation in smectites. Mixed-layer illite–beidellites from the area are common, but have not been found with beidellite layer contents greater than 50%. All illites are mixtures of $2M_1$ and $1M$ structures, and the predominantly $1M$ illites tend to be found near the ore bodies. The nature of formation of beidellite remains to be determined. Some beidellites occur in veins along faults and others as alteration of orthoclase feldspar phenocrysts.

The indexing of beidellite diffraction patterns remains a problem because the peaks may shift slightly with moisture change or glycolation; but, clearly, the (02*l*) diffraction peak can be listed as the (020) peak (Table 2) because the next diffraction peaks appear as the (021) and (022) peaks for differentiation (Weir and Greene-Kelly 1962). Future sources of beidellite for the Source Clays Repository are dependent upon whether the Black Jack Mine adit is opened, the main ore vein is encountered in the new open pit or the Sinker drainage tunnel under War Eagle Mountain give access to new clay bodies.

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