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Potash Feldspar of Possible Economic Value in the Barstow Formation, San Bernardino County California

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ABSTRACT

Tuffs in the Barstow Formation of Miocene age are altered mainly to zeolites, potash feldspar, montmorillonite, and a silica mineral. Potash feldspar is the major constituent of a conspicuous tuff, 1.5–4 feet thick, in the central part of the Mud Hills. This chemically analyzed feldspar-rich tuff shows a range of 12.4–16.4 percent K_2O. The very high potash feldspar content suggests that this deposit or others like it can become a source of feldspar for the glass and ceramic industries.

INTRODUCTION

Potash feldspar and zeolites are the chief alteration products of rhyolitic vitric tuff in the Barstow Formation, of middle to late Miocene age (Lewis, 1964), in the Mojave Desert region of California. Study of these alteration products, though directed mainly at the zeolites, has led to the discovery that at least one of the studied localities has a sizable body of rock containing about 90 percent potash feldspar. Deposits of such altered tuff have never been mined by the feldspar industry although their existence has long been recorded in geologic literature. The characteristics of this particular deposit so obviously suggest its economic value that this paper has been published to announce its existence and to describe it briefly, and at the same time to indicate that exploration for other deposits like it may be worth undertaking. How well the physical and chemical peculiarities of the feldspar in this deposit can be adapted to the needs of the glass and ceramic industries involves many problems that go beyond the ability of a geologist to evaluate. For this reason, only the more obvious favorable and unfavorable aspects will be discussed here.

The feldspar-rich tuff crops out in an area about 10 miles north of Barstow, the nearest principal town. The Union Pacific and the Atchison, Topeka, and Santa Fe Railroads serve Barstow. The Camp Irwin Road, a paved highway between Barstow and Camp Irwin, provides access to the area via the graveled Fossil Bed Road. The area is also served by unimproved dirt roads and jeep trails, but they will not sustain trucks unless improved.

Acknowledgments.—Appreciation is expressed to R. G. Schmidt, who recognized the occurrence of authigenic zeolites and potash feldspar in tuffs of the Barstow Formation as early as 1954 and who suggested the present study.

GENERAL GEOLOGY OF FELDSPAR DEPOSITS

Most commercial feldspar is mined from pegmatites or granitic rocks that can be beneficiated to yield a nearly pure feldspar concentrate. Feldspathic materials are also obtained from quartz-feldspar sands and from aplite and nepheline syenite. Feldspar deposits are mined chiefly by open-pit methods although a few are mined by underground operations (Wells, 1965, p. 3).

Until recent years feldspar was mined chiefly from zoned pegmatites and then was hand-cobbed to obtain a high-quality perthitic microcline. Feldspar obtained from zoned pegmatites contains some soda, which is mainly in the intimately associated sodic plagioclase but is also chemically combined in the potash feldspar. In mines where feldspar is the main product, only 25–50 percent of the rock is recovered as potash feldspar (J. J. Norton, 1965, written commun.). The other rock constituents, mainly quartz and plagioclase are discarded.

At the present time the feldspar mining industry depends mainly on large bodies of nearly homogeneous pegmatitic rock or on finer grained feldspathic igneous rock that cannot be hand-cobbed or belt picked but can be beneficiated by flotation. Unlike hand-cobbed feldspar, the flotation concentrate contains all the plagioclase of the rock as well as all the potash feldspar, and the K_2O content of flotation feldspar is thus less than that of hand-cobbed feldspar.

GEOLOGY, MINERALOGY, AND CHEMISTRY OF POTASH FELDSPAR-RICH TUFF

The feldspar-rich tuff crops out in a range of hills known locally as the Mud Hills, about 10 miles north of Barstow, San Bernardino County, California. In this area the Barstow Formation is well exposed in the Barstow syncline. The formation consists of about 3,000 feet of fluviatile and lacustrine rocks that unconformably overlie the Oligocene(?) to Miocene(?) Pickhandle Formation (Bowen, 1954). An additional thickness of unknown magnitude was eroded before the deposition of the overlying Quaternary alluvium.

In the vicinity of Rainbow Basin and Owl Canyon (fig. 1), the axis of the Barstow syncline trends nearly east, and the beds on each limb dip 20°–35°. Several northwestward-trending faults offset the beds and locally cause steeper dips. Differential erosion of the more resistant rock, such as sandstone, conglomerate, carbonate rocks, and altered tuff has produced hogbacks. Areas underlain by thick sequences of claystone are reduced to badlands.

Although tuffs make up only a small part of the Barstow Formation in the Mud Hills, more than 30 individual tuff layers, less than an inch to several feet thick and mostly in the upper half of the formation, can be recognized in the vicinity of Rainbow Basin. The tuffs originally were mainly rhyolitic vitric tuffs containing varying amounts of crystal and lithic fragments. All now are altered to some degree, and most contain only a small quantity of relict glass, if any at all. Zeolites are the most abundant of the authigenic silicate minerals formed by alteration of the tuffs, but some beds of tuff are rich in montmorillonite, opal, or potash feldspar. Locally some altered tuffs are monomineralic, although most consist of two or more authigenic minerals.

The feldspathized tuff is part of one of the most conspicuous and continuous tuffs in the formation and is herein called the lower marker tuff, a name given informally by T. W. Dibblee, Jr. (1963, written commun.). The tuff, consisting of several beds that are less than 1 inch to 2 feet thick, has a total thickness of 1.5–4 feet within the mapped area (fig. 1). The tuff thins gradually eastward to the edge of the mapped area; however, it then thickens farther eastward and is as much as 7 feet thick at the east end of the Mud Hills. Ordinarily, the upper 6–12 inches consists of thinly interbedded tuff and greenish claystone. The lower marker tuff generally is white to light gray but locally is partly or wholly pale yellow or green. The rock below and above the tuff is generally claystone.

Throughout the Mud Hills the lower marker tuff is altered. Although zeolites, mainly clinoptilolite, are the common authigenic minerals, potash feldspar is the dominant authigenic mineral in the eastern part of Rainbow Basin and for approximately 1 mile eastward along the strike. Pods and lenses of clinoptilolite or analcime are locally present, particularly in the vicinity of Rainbow Basin and Owl Canyon; however, except in these zeolitic pods and lenses, the tuff generally consists of 80–100 percent potash feldspar.

The potash feldspar phase of the lower marker tuff generally can be distinguished in the field from both the clinoptilolite and analcime phases. The tuff is soft, powdery, and friable where composed mainly of potash feldspar; it can easily be disaggregated with the fingers. Clinoptilolite-rich tuff is hard and commonly breaks with a conchoidal fracture. Analcime-rich tuff has a sugary texture and individual euhedra commonly can be seen with a hand lens. Tuff consisting of a mixture of potash feldspar and clinoptilolite or analcime can be correctly indentified only by microscopic or X-ray examination.

The authigenic potash feldspar forms rather nondescript low-birefringent aggregates of irregular crystals that range in size from 2–10 microns. The aggregates superficially resemble chert but are similar to authigenic potash feldspar described by Hay and Moiola (1963) from tuffaceous beds of

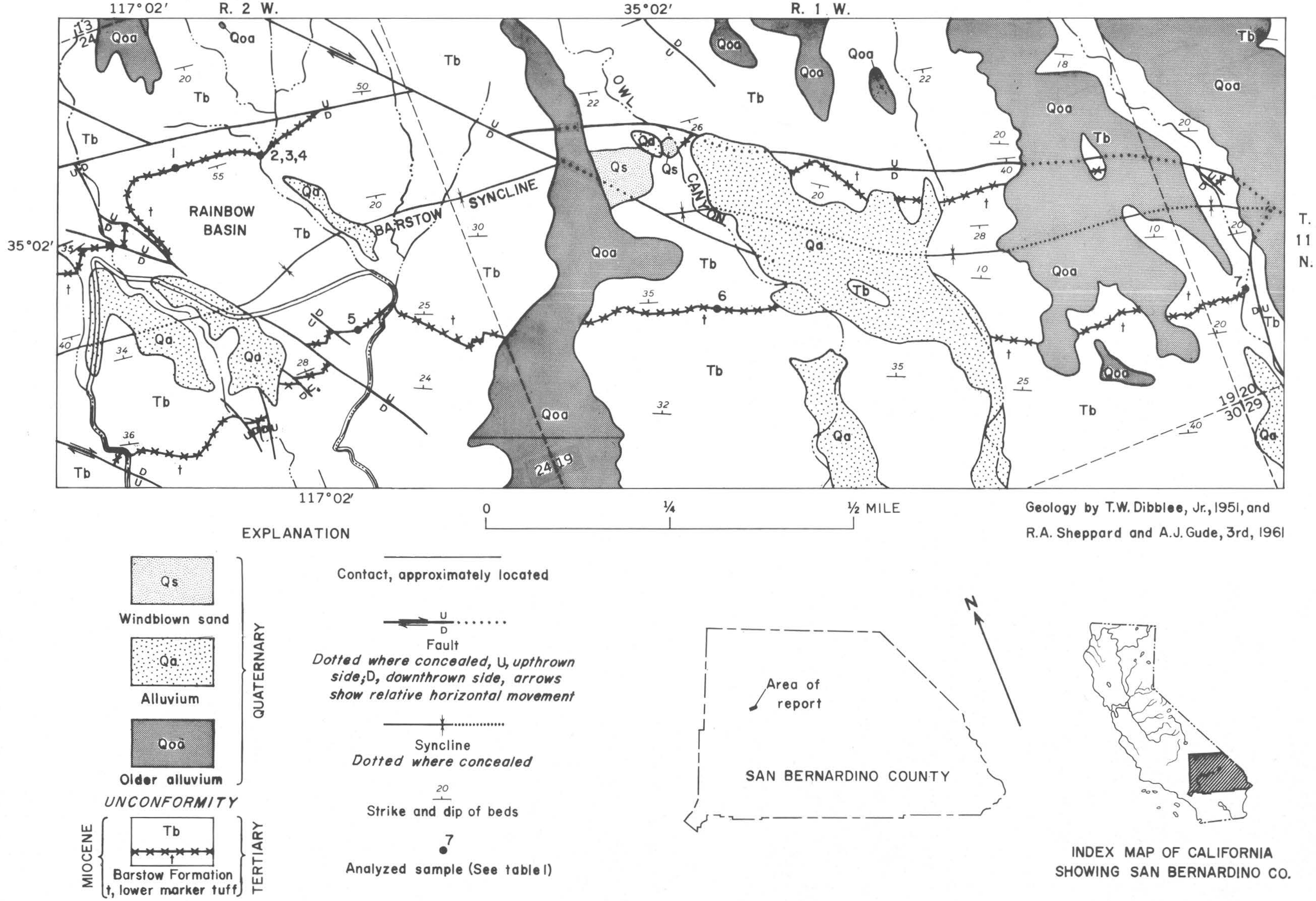

Figure 1.—Map of the central part of the Mud Hills, San Bernardino County, Calif., showing sample locations.

Searles Lake. The mean index of refraction is 1.518 (±0.001), which suggests nearly pure potash feldspar. Other optical constants could not be measured from the very small crystals.

Study of X-ray diffractometer powder data indicates that the potash feldspar is monoclinic and has the following cell constants as refined on a digital computer by least-squares analysis: $a = 8.593 \pm 0.002$ A; $b = 12.967 \pm 0.003$ A; $c = 7.165 \pm 0.001$ A; $\beta = 116° 3.3' \pm 1.0'$; cell volume = 717.25 ± 0.19 A^3. If the feldspar from the tuff is comparable to common boron-free feldspar, the composition can be estimated from the *a* cell edge to be 95 percent $KAlSi_3O_8$. The structural state estimated from the *b* and *c* cell edges is that of sanidine, but the cell seems to be distorted because the composition indicated by the *b* and *c* edges is very different from that indicated by the *a* edge (D. B. Stewart, 1965, written commun.).

The original vitroclastic texture of the tuff generally is poorly preserved by the authigenic feldspar. Both field and petrographic evidence indicate that most, if not all, the potash feldspar formed, not directly from vitric material but from clinoptilolite or analcime. The pods and lenses of clinoptilolite or analcime probably are remnants of an earlier alteration. Relicts of analcime and clinoptilolite can be seen in some thin sections of altered tuff consisting mainly of potash feldspar. Inasmuch as the vitroclastic texture is generally obliterated by analcime, those parts of the feldspar-rich tuff that lack relict vitroclastic texture probably formed from an analcime precursor, whereas those parts that have relict texture formed from a clinoptilolite precursor.

The lower marker tuff locally contains small percentages of authigenic montmorillonite, chalcedonic quartz, and calcite in addition to the zeolites or potash feldspar. Chalcedonic quartz is most commonly concentrated at the top and bottom of the tuff, although thin veinlets and spherical segregations are present locally in the interior. Most of the tuff also contains about 1 percent crystal fragments of plagioclase, quartz, sanidine, biotite, hornblende, zircon, and apatite. All these crystals are presumably pyrogenic.

Analyses of bulk samples of the potash feldspar-rich tuff are given in table 1. Except for No. 4, the analyses are remarkably similar. The K_2O content ranges from 12.4–16.4 percent, and the Na_2O content ranges from 0.39–0.82 percent. Optical and X-ray study indicates that most of the Na_2O is in analcime rather than in solid solution with the potash feldspar. The percent of B_2O_3 is high for natural potash feldspar, and the percent of Al_2O_3 is somewhat lower than average; therefore, B_2O_3 is assumed to replace part of the Al_2O_3. No boron mineral has been recognized by optical or X-ray study, but further study thereon is in progress. Those components other than K_2O, Al_2O_3 (B_2O_3), and SiO_2 essential for pure potash feldspar probably are contained in minor amounts of analcime, chalcedonic quartz, montmorillonite, calcite, and iron oxides.

The chemical analyses were recalculated as modal minerals, and these minerals are also given in table 1. The potash feldspar content of the tuff ranges from about 87–94 percent. Analysis 4 was not recalculated because its content of impurities was high. This sample contains only 12.4 percent K_2O and was collected from the top of the lower marker tuff where there are thinly interbedded feldspar-rich tuff and greenish claystone rich in montmorillonite.

ECONOMIC CONSIDERATIONS

The most obvious merit of this deposit is its very high content of potash feldspar. Whether the very high K_2O content of the feldspar is also a merit is less certain because the feldspar presently used has less K_2O and much more Na_2O than does this feldspar; furthermore, the Al_2O_3 content is unusually low, and its place is in part taken by B_2O_3. An obvious need is to test how these chemical properties influence the behavior of the feldspar with respect to its use in glass or ceramics. The very fine grain size and friability seem to be advantageous because grinding costs would be low; however, it is uncertain whether feldspar of this unusual physical character would cause difficulties in manufacturing processes.

Feldspar should be low in iron oxides for most glass and ceramic uses. Glass-grade feldspar generally should not contain more than 0.05 percent iron oxide, though amber glass may contain as much as 0.50 percent

Table 1.—*Chemical analyses and calculated mineral content of potash feldspar-rich tuff from the Barstow Formation, Mud Hills, Opal Mountain quadrangle, California*

Analysis number	1	2	3	4	5	6	7
Laboratory number	164953	164956	164957	164958	D100508	164955	164952

Chemical analyses

[Analyses 1–4, 6–7: rapid rock analyses by Paul Elmore, Samuel D. Botts, and Lowell Artis. Analysis 5: standard rock analysis by Ellen S. Daniels. B_2O_3 determined as B by quantitative spectrographic analysis by Janet D. Fletcher]

	1	2	3	4	5	6	7
SiO_2	65.1	65.3	64.2	66.9	65.41	65.4	65.1
Al_2O_3	16.6	16.6	17.2	14.0	16.64	16.2	16.6
B_2O_3	.55	.97	.58	.90	.55	.93	.68
Fe_2O_3	.69	.51	.63	1.6	.10	.06	.41
FeO	.04	.04	.08	.16	.09	.04	.04
MgO	.10	.00	.00	1.4	.04	.00	.10
CaO	.23	.08	.06	.10	.13	.58	.15
Na_2O	.82	.41	.41	.69	.41	.50	.39
K_2O	14.8	15.8	16.4	12.4	15.47	15.3	15.8
H_2O^+	1.0	.75	.53	1.2	.66	.63	.47
H_2O^-	.27	.25	.28	1.0	.12	.28	.32
TiO_2	.00	.00	.00	.13	.02	.00	.00
P_2O_5	.07	.09	.07	.11	.01	.07	.07
MnO	.04	.03	.02	.10	.02	.03	.04
CO_2	.09	<.05	<.05	.05	.15	.22	.09
Cl	--------	--------	--------	--------	.01	--------	--------
F	--------	--------	--------	--------	.01	--------	--------
Total	100	101	100	101	99.84	100	100

Calculated mineral content

	1	2	3	4	5	6	7
Potash feldspar[a]	87.1	93.0	94.4	--------	91.0	89.7	92.6
Analcime[b]	5.7	3.1	3.1	--------	3.1	3.5	2.6
Quartz	5.3	3.1	1.2	--------	4.5	5.0	3.4
Other (by difference)	1.9	.8	1.3	--------	1.4	1.8	1.4
Total	100.0	100.0	100.0	--------	100.0	100.0	100.0

[a] The potash feldspar content includes $KAlSi_3O_8$ and $KBSi_3O_8$.

[b] Analcime has an ideal formula of $NaAlSi_2O_6 \cdot H_2O$, and this was used in these calculations: however, analcime from rhyolitic vitric tuffs is known to be more siliceous (Ross, 1928, p. 196: Wilkinson and Whetten, 1964, p. 544), and hence, the analcime content may be slightly higher and the quartz content slightly lower than indicated here.

1-5. Rainbow Basin, sec. 24, T. 11 N., R. 2 W.
1. NW¼NE¼ sec. 24.
2. Base of lower marker tuff. NE¼NE¼ sec. 24.
3. Middle of lower marker tuff. NE¼NE¼ sec. 24.
4. Top of lower marker tuff. NE¼NE¼ sec. 24.
5. SE¼NE¼ sec. 24.
6. Owl Canyon, NE¼SW¼ sec. 19, T. 11 N., R. 1 W.
7. Canyon half a mile east of Owl Canyon SW¼SW¼ sec. 20, T. 11 N., R. 1 W.

iron oxide (Wells, 1964, p. 2). Bulk samples of the potash feldspar-rich tuff from the Barstow Formation contain an average of 0.46 percent total iron oxides if sample 4 is not included. This iron oxide content is high compared with that in hand-cobbed feldspar. Perthites from pegmatites of the Black Hills, South Dakota, for example, average only 0.09 percent Fe_2O_3 (Higazy, 1949, p. 559). Alaskite, containing about 0.3 percent Fe_2O_3 (Olson, 1944, p. 23), currently is mined for feldspar near Spruce Pine, N. C. Subsequent treatment by flotation and magnetic separation yields a usable product. The feldspar-rich tuff described herein has only a slightly higher content of iron oxides, and much of this iron is contained in montmorillonite, which probably can be removed by simple beneficiation processes.

COMPARABLE DEPOSITS ELSEWHERE

Authigenic potash feldspar is known to occur in sedimentary rocks of various lithologies and ages (Tester and Atwater, 1934; Baskin, 1956). Although the authigenic feldspar content of these rocks generally is less than 10 percent, there are exceptions. Gruner and Thiel (1937) described shales and siltstones of Ordovician age that consist mainly of potash feldspar. Siltstone in the upper member of the Dripping Spring Quartzite of Precambrian age in southeastern Arizona consists of 60–90 percent feldspar (Granger and Raup, 1964, p. 36–38). Authigenic potash feldspar forms as much as 80 percent of Ordovician bentonitic tuffs from Minnesota (Weiss, 1954) and constitutes as much as 50 percent of tuffaceous beds of Searles Lake, Calif. (Hay and Moiola, 1963, p. 323; Smith and Haines, 1964, p. 24–25).

In addition to its occurrence in tuffs of the Barstow Formation and at Searles Lake, authigenic potash feldspar has been reported in tuffs from the following formations of the western conterminous United States: Eocene Tepee Trail Formation in Wyoming (Deffeyes, 1959, p. 603), Eocene Green River Formation in Colorado and Wyoming (Milton and others, 1960, p. 179–180; Hay, 1965), Jurassic Trowbridge Formation in Oregon (Dickinson, 1962, p. 259–260), Miocene and Pliocene Esmeralda Formation in Nevada (Moiola, 1964), and upper part of the Oligocene(?) and Miocene Tropico Group at the Kramer borate district, California (Hay, 1965). Further mineralogical study of altered tuffaceous rocks of Cenozoic age from the southwestern United States probably will reveal additional deposits rich in authigenic potash feldspar. Some of these deposits may have commercial potential for use in the glass and ceramics industries or even as a source of potash for fertilizer (Everest and others, 1964).

REFERENCES CITED

Baskin, Yehuda, 1956, A study of authigenic feldspars: Jour. Geology, v. 64, p. 132–155.

Bowen, O. E., 1954, Geology and mineral deposits of Barstow quadrangle, San Bernardino County, California: California Div. Mines Bull. 165, p. 1–185.

Deffeyes, K.S., 1959, Zeolites in sedimentary rocks: Jour. Sed. Petrology, v. 29, p. 602–609.

Dickinson, W. R., 1962, Metasomatic quartz keratophyre in central Oregon: Am. Jour. Sci., v. 260, p. 249–266.

Everest, D. A., Napier, E., and Wells, R. A., 1964, Extraction of potassium from adularia shale: Chem. and Ind., v. 40, p. 1684–1685.

Granger, H. C., and Raup, R. B., 1964, Stratigraphy of the Dripping Spring Quartzite, southeastern Arizona: U.S. Geol. Survey Bull. 1168, 119 p.

Gruner, J. W., and Thiel, G. A., 1937, The occurrence of fine grained authigenic feldspar in shales and silts: Am. Mineralogist, v. 22, p. 842–846.

Hay, R. L., 1965, Zeolites and zeolitic reactions in sedimentary rocks: Geol. Soc. America Special Paper [in press].

Hay, R. L., and Moiola, R. J., 1963, Authigenic silicate minerals in Searles Lake, California: Sedimentology, v. 2, p. 312–332.

Higazy, R. A., 1949, Petrogenesis of perthite pegmatites in the Black Hills, South Dakota: Jour. Geology, v. 57, p. 555–581.

Lewis, G. E., 1964, Miocene vertebrates of the Barstow Formation in southern California, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–D, p. D18–D23.

Milton, Charles, Chao, E. C. T., Fahey, J. J., and Mrose, M. E., 1960, Silicate mineralogy of the Green River Formation of Wyoming, Utah, and Colorado: Internat. Geol. Cong., 21st, Copenhagen 1960, Rept., pt. 21, p. 171–184.

Moiola, R. J., 1964, Origin of authigenic silicate minerals in the Esmeralda "Formation" of western Nevada [abs.], *in* Abstracts for 1963: Geol. Soc. America Spec. Paper 76, p. 116–117.

Olson, J. C., 1944, Economic geology of the Spruce Pine pegmatite district, North Carolina: North Carolina Dept. Conserv. Devel. Bull. 43, pt. 1, 67 p.

Ross, C. S., 1928, Sedimentary analcite: Am. Mineralogist, v. 13, p. 195–197.

Smith, G.I., and Haines, D.V., 1964, Character and distribution of nonclastic minerals in the Searles Lake evaporite deposit, California: U.S. Geol. Survey Bull. 1181–P, 58 p.

Tester, A. C., and Atwater, G. I., 1934, The occurrence of authigenic feldspars in sediments: Jour. Sed. Petrology, v. 4, p. 23–31.

Weiss, M. P., 1954, Feldspathized shales from Minnesota: Jour. Sed. Petrology, v. 24, p. 270–274.

Wells, J. R., 1965, Feldspar: *in* Mineral facts and problems, 1965 ed.: U.S. Bur. Mines Bull. 630, 7 p. [preprint].

Wilkinson, J. F. G., and Whetten, J. T., 1964, Some analcime-bearing pyroclastic and sedimentary rocks from New South Wales: Jour. Sed. Petrology, v. 34, p. 543–553.