

NARSARSUKITE FROM SAGE CREEK, SWEETGRASS HILLS, MONTANA*

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ABSTRACT

Narsarsukite, $\text{Na}_2\text{TiSi}_4\text{O}_{11}$, is described from the second of three localities in the Sweetgrass Hills, Montana. Narsarsukite is associated with manganpectolite, quartz, calcite, and galena in veins cutting an orthoclase-albite-aegirine-quartz hybrid rock in a zone adjacent to a syenite stock. Optical properties of the minerals and an indexed x -ray powder-diffraction pattern of narsarsukite are given.

This occurrence of the assemblage aegirine-quartz-narsarsukite is similar to other occurrences of narsarsukite in the Sweetgrass Hills and at Narsarsuk, Greenland. It is concluded that the formation of narsarsukite depends upon the reaction of emanations from alkalic magmas with siliceous wallrock under conditions such that a high partial pressure of oxygen is present.

INTRODUCTION

The Sweetgrass Hills in north-central Montana near the border of the United States and Canada consist of three related groups of stocks. The geology of the region is summarized by Ross (1950). East Butte, the group of stocks that contains the narsarsukite localities, is the largest, most easterly, and most complex of the three groups of stocks. The alkali-rich igneous rocks from East Butte are described in detail by Kemp and Billingsley (1921). The more than a dozen closely-spaced syenite and trachyte plutons of East Butte have domed and metamorphosed the sedimentary rocks that border them. Siliceous metasedimentary rocks adjacent to the plutons contain small deposits of iron and copper, and veins in marble close to the stocks contain fluorite and quartz. Brecciated highly metamorphosed rocks that have been intricately intruded by syenite make up a hybrid rock that was mapped separately by Ross (1950). The hybrid rock borders only the largest stock and is related to it. All the narsarsukite occurrences are in the hybrid rock, and quartz-bearing veins outside the hybrid rock do not contain narsarsukite.

The first description of narsarsukite from the Sweetgrass Hills was by Graham in 1935. Graham's locality is in the upper drainage basin of Halfbreed Creek, in the center of sec. 24, T. 36 N., R. 4 E. Another occurrence of narsarsukite was discovered by the writer in 1950; additional specimens were collected in September 1951. The new occurrence, about one mile northeast of Graham's locality, is in the NE $\frac{1}{4}$ of sec. 19, T. 36 N., R. 5 E., on the bottom and west bank of Sage Creek at an elevation of 5300 feet. The exposure is only about 6 feet by 6 feet, and is 150 feet upstream from the place where the wagon trail to the divide between Mount Royal and Mount Brown crosses Sage Creek. The Madi-

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son limestone crops out about 200 feet above the locality on the east side of Sage Creek canyon. Specimens from this locality are deposited at the U. S. National Museum under Museum number 106424.

Narsarsukite has also been noted in veinlets in blocks of hybrid rock in the float on the southwest side of Mount Royal (W. T. Pecora, oral communication, February 1958).

PETROGRAPHY

Hybrid Rock

Greenish-gray aphanitic hybrid rock is the host rock for the narsarsukite-bearing veinlets. The hybrid rock is dense and flinty even though cut by myriads of veinlets. Parts of the hybrid rock are mottled and show clearly the outlines of fragments of highly metamorphosed sedimentary rock. The breccia fragments average one centimeter in longest dimension. The parts of the hybrid rock that can be identified as syenite by their darker color are in general too fine-grained to permit recognition of minerals with a hand lens, although a few phenocrysts of feldspar about two millimeters in diameter are visible in some specimens.

The hybrid rock, as studied in thin section, is composed of porphyritic syenite enclosing vaguely defined darker and lighter fragments that differ from the syenite in proportions rather than kinds of minerals. Feldspar crystals averaging 0.5 mm. in size make up 95 per cent of the phenocrysts or about 20 per cent of the rock, and orthoclase greatly exceeds albite in amount. Aegirine phenocrysts are rare and are smaller. Many phenocrysts are broken or deformed.

The finer-grained hybrid rock is holocrystalline, with euhedral aegirine, and anhedral feldspar and quartz. Minerals in the fine-grained syenite and the breccia fragments average 0.01 mm. in size. Orthoclase and albite make up about 65 per cent of the rock, while aegirine makes up about 25 per cent. Quartz and very minor amounts of biotite and apatite are also present as well as calcite, pectolite, and unidentified cloudy alteration products of feldspar. Pectolite and calcite have replaced some of the feldspar. The pectolite is the same variety in the hybrid rock and in the veins, and is described in the section on descriptive mineralogy. Narsarsukite occurs in the hybrid rock only in tiny pegmatitic patches or veinlets.

Feldspar and Aegirine of the Hybrid Rock

The composition of the potassic feldspar is $Or_{90}(Ab+An)_{10}$ as determined by the $(20\bar{1})$ method (Bowen and Tuttle, 1950). This single phase monoclinic feldspar has the optic plane normal to $[010]$, is biaxial negative, and has a large optic angle. The properties are those of orthoclase (MacKenzie and Smith, 1956, Fig. 1).

The plagioclase is low albite of composition $An_5(Ab+Or)_{95}$ according to the indices of refraction (Chayes, 1952) and the $(131)-(1\bar{3}1)$ separation (Smith, J. R., and Yoder, 1956; Smith, J. V., 1956). The orthoclase and albite show some zonal growth, and twinning is common in albite.

Aegirine is present as euhedral rods and needles, as sheaves and radiating clusters, and as irregular clots. It is highly pleochroic, X=green, Y=blue green, and Z=yellowish green, and the absorption is $X=Y<Z$. The optic sign is negative, the optic angle is estimated to be 80° , the dispersion is strong, and $Z \wedge c$ is 79 degrees.

Pectolite-Quartz-Narsarsukite Veinlets

Hundreds of closely spaced veinlets make up as much as ten per cent of the rock in irregularly oriented fracture zones that cut the hybrid rock. The veinlets range from 0.01 mm. to 5 mm. in thickness, and are tens of centimeters in length. They cut phenocrysts and relict fragments alike, but apparent displacement along the fractures does not exceed a few millimeters. Pectolite is the dominant vein mineral, making up approximately half of the material in the veins. Quartz and narsarsukite are also abundant, making up 25 and 20 per cent respectively of the vein material. Calcite and galena are the remaining primary minerals in the veins. The paragenetic sequence appears to be pectolite and narsarsukite oldest, followed by galena and calcite, with quartz youngest of all.

The minerals of the veins are weathered in some specimens. The pectolite has been attacked most readily, and has darkened to a buff or brown color, or has become a cellular mass. The absence of black oxides in the alteration products suggests that the manganese content of the pectolite was low. The removal of pectolite and calcite in solution usually has been completed before the narsarsukite has been noticeably affected. Altered narsarsukite is a light buff or yellowish-brown material that probably contains leucoxene and other minerals. Galena cubes have become mantled with chalky cerussite and have persisted probably by virtue of this protective covering. The last stages of weathering have resulted in the solution of all the minerals except quartz, leaving an open meshwork of poorly shaped crystals. Specimens in this stage of weathering are common in the float in Sage Creek and other creeks draining East Butte, suggesting the narsarsukite-bearing veins may be quite common in unexposed parts of the area.

DESCRIPTIVE MINERALOGY

Narsarsukite

Narsarsukite occurs as honey yellow euhedral tablets flattened on $\{001\}$ and oriented such that the c -axis of most crystals lies in the plane of the veinlet. The largest crystals are seven millimeters across and three

millimeters thick. Some crystals are translucent and show faint symmetrical zones that differ slightly in color.

Prismatic cleavage on $\{010\}$ is distinct, and is fair on $\{110\}$. The hardness is 6 on the basal plane and in the prism zone. The specific gravity was determined with a Berman microbalance, and the average of five determinations on samples weighing from 13 to 20 milligrams was $2.783 \pm .014$.

Portions of ten crystals were examined with the optical goniometer. None of the crystals had perfect morphology, but all showed prominent

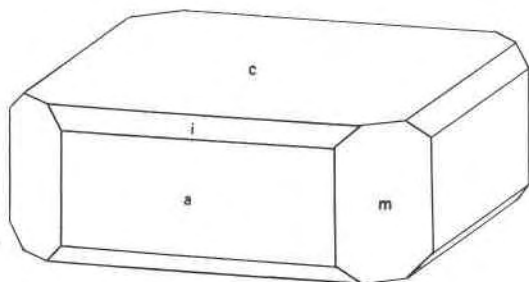


FIG. 1. Habit of narsarsukite from Sage Creek, Sweetgrass Hills, Montana.

basal faces and distinct first and second order prisms. Opposed tetragonal dipyrarnidal faces were observed on some crystals. An idealized crystal of typical habit is shown in Fig. 1. The crystals showed other forms, but their development was such that no crystal had more than one or two faces of each additional form, and no decision can be made from the morphology as to the symmetry along the two equal axes. The $\{hk0\}$ faces are very small. The morphological work by Flink (1901) and the single crystal x -ray studies by Gossner and Strunz (1932) and Warren and Amberg (1935) show that the horizontal axes are not two-fold and do not contain a vertical plane of symmetry. However, it is certain that narsarsukite crystals have a center of symmetry. The center of symmetry is indicated from the new morphological evidence, from the natural etch pits on the crystal faces, from weak symmetrical compositional zoning indicated by the color of the crystals, and by a negative test for piezoelectricity with a Giebe-Schiebe detector. The symmetry class is therefore tetragonal dipyrarnidal, $4/m$.

Crystals oriented according to the axial ratio obtained from the x -ray study described below show the following forms: $\{001\}$, $\{010\}$, $\{110\}$, $\{130\}$, $\{120\}$, $\{011\}$, $\{021\}$, $\{221\}$. The order of prominence of the forms is $\{001\}$, $\{010\}$, $\{110\}$, $\{011\}$, $\{120\}$, $\{130\}$, $\{021\}$, $\{221\}$.

TABLE 1. OPTICAL PROPERTIES OF NARSARSUKITE

	Sage Creek, Montana	Halfbreed Creek, Montana (Graham)	Greenland (Graham)
ϵ	1.658-1.662	1.653-1.655	1.625-1.636
ω	1.610-1.614	1.608-1.612	1.604-1.609
Sign	Uniaxial (+)	Uniaxial (+)	Uniaxial (+)
Birefring.	.049	.041-.046	.021-.029
Pleochroism:	E=honey yellow O=colorless	E=honey yellow O=colorless	E=colorless or pale yellow O=colorless

The optical properties of the narsarsukite from Sage Creek are cited in Table 1 together with similar data for material from other occurrences. The values obtained by Graham were verified by examination of material he collected. Narsarsukite from Sage Creek has slightly higher indices and birefringence than Graham's material.

An indexed *x*-ray powder-diffraction pattern of narsarsukite from Sage Creek is given in Table 2. The cell dimensions determined from this

TABLE 2. X-RAY POWDER-DIFFRACTION DATA, NARSARSUKITE, Na₂TiSi₄O₁₁, SAGE CREEK, SWEETGRASS HILLS, MONTANA

Tetragonal dipyramidal; *I* 4/*m* (*C*_{4h}⁸), *a*₀=10.72₀ Å, *c*₀=7.94₈ Å, *c/a*=0.741.

CuK α (Ni filter), λ =1.5418 Å; Camera diameter 114.59 mm.; *d*_(obs.) cut-off at 15.0 Å; corrected for film shrinkage.

<i>hkl</i>	<i>d</i> (calc.)	<i>d</i> (obs.)	<i>I</i>	<i>hkl</i>	<i>d</i> (calc.)	<i>d</i> (obs.)	<i>I</i>
110	7.580	7.609	3	521	1.931	1.931	1
200	5.360	5.365	10	440	1.895	1.896	1
211	4.105	4.107	2	512	1.858	1.861	1
002	3.974	3.976	5	600	1.787	1.787	3
220	3.790	3.787	3			1.716	1
310	3.390	3.394	8			1.695	1
301	3.259	3.260	8			1.665	2
202	3.192	3.191	2			1.630	1
222	2.743	2.745	1			1.593	1
400	2.680	2.674	1			1.550	2
312	2.579	2.579	6			1.513	1
330	2.527	2.524	6			1.488	1
420	2.397	2.396	1			1.452	1
213	2.319	2.320	2			1.410	1
402	2.222	2.221	1			1.391	1
510	2.102	2.103	1			1.369	1
422	2.053	2.054	1			1.327	3
004	1.987	1.982	3				
323	1.978						
				18 additional weak lines			

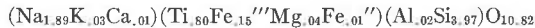
TABLE 3. CELL DIMENSIONS OF NARSARSUKITE

	Stewart (Montana)	Gossner and Strunz* (Greenland)	Warren and Amberg* (Greenland)
<i>a</i>	10.72 ₀	10.80	10.76
<i>c</i>	7.94 ₈	8.01	7.92
<i>c/a</i>	0.741 ₄	0.741	0.735

* kX converted to Å by multiplication by 1.00202 (Bragg, 1947).

pattern are listed in Table 3 and compared with values obtained by Gossner and Strunz (1932) and Warren and Amberg (1934) from specimens from Greenland. Fair agreement is shown. X-ray powder diffraction patterns of narsarsukite from Sage Creek, Montana, and Narsarsuk, Greenland, have identical spacings and intensities.

The molecular weight of the unit cell of narsarsukite from Sage Creek was calculated to be 1532 from the measured cell dimensions and specific gravity, which is equal to four formula units of weight 383. This corresponds very closely with the formula weight of $\text{Na}_2\text{TiSi}_4\text{O}_{11}$ of 382. Calculations of this sort by Warren and Amberg, and Gossner and Strunz yielded similar results. The chemical analysis by Ellestad (Graham, 1935) of narsarsukite from Montana calculates to the following when the determinations of ferric and ferrous iron by Schaller (Graham, 1935) are substituted for Ellestad's value:



The chemical evidence indicates that narsarsukite from Montana has much less substitution of ferric iron for titanium than does the material from Greenland. To check if this difference was the principal one causing the higher birefringence of the Montana material, quantitative spectrographic analyses on carefully purified material from Sage Creek and from Narsarsuk (U. S. National Museum No. 94332, $\omega = 1.608$, $\epsilon = 1.631$) were performed by Harry J. Rose, Jr., of the U. S. Geological Survey. The spectrographic analysis confirmed that iron was more abundant in the specimen from Narsarsuk, and titanium was more abundant in the specimen from Sage Creek. In addition, narsarsukite from Sage Creek was found to be significantly richer in niobium (0.6% Nb vs. 0.2%) and vanadium (0.2% V vs. 0.03%), both of which tend to increase the refraction and birefringence.

Pectolite

Pectolite occurs as white or light buff blades and clusters of radiating prisms and fibers lying in the plane of the vein. Some replacement of

feldspar by pectolite was noted along the vein borders. The crystals are elongated along the *b*-axis, and are flattened on {100}. The largest crystals seen were three centimeters long and three or four millimeters wide. Their thickness is less than a millimeter. The {100} cleavage is well developed and is more perfect than a distinct cleavage on {001}. Some of the crystals are twinned on (100), and others contain many low birefringent inclusions flattened parallel to (100). The optical properties of the pectolite are as follows: $\alpha=1.603$; $\beta=1.609$; $\gamma=1.640 (\pm 0.002)$; biaxial positive; $2V \approx 45^\circ$ (obs), 48° (calc); dispersion weak, $r < v$; $X \wedge c = 14^\circ$. Cleavage plates on (001) extinguish parallel to the trace (100); (100) plates extinguish 4° from the trace of (001). An *x*-ray powder-diffraction photograph was identical with one of pectolite from Bergen, New Jersey. The optical properties correspond to those of manganpectolite containing approximately 10 mol per cent $Mn_2NaSi_3O_8(OH)$ (Schaller, 1955, 1025).

Quartz, Calcite, and Galena

Quartz occurs as smoky or colorless subhedral to euhedral crystals averaging 1 to 2 millimeters in size, and only a few crystals are 3 to 4 millimeters in longest dimension. In a few cases euhedral quartz crystals which project into veinlets grew in optical continuity with broken quartz grains along the margin of the fracture. Calcite occurs as irregular white to colorless grains that rarely exceed 2 millimeters in size. Cubes of galena 1 millimeter on an edge are found associated with the calcite and quartz.

COMPARISON WITH OTHER LOCALITIES

Graham's locality near Halfbreed Creek was not visited but specimens collected by him and now in the collection of the U. S. National Museum (No. 105717) were examined. The epidote reported by Graham was not found and is believed to have been aegirine, and the clinozoisite reported is pectolite. No alunite was found.

The mineralogy at Graham's locality differs from that at Sage Creek in that the hybrid rock is somewhat richer in quartz, and the narsarsukite is not restricted to veins. Pectolite is not nearly as abundant, but much more galena is present. Paragenetic relations suggest that narsarsukite, pectolite, galena, and quartz were essentially contemporaneous.

Descriptions of the paragenetic sequence and assemblages at Narsarsuk, Greenland, are given by Flink (1901) and Gordon (1924), and are well summarized by Bøggli (1953, 319): Narsarsukite "is generally accompanied by the minerals which most frequently occur in the pegmatite veins of this locality viz., feldspar and aegirine, but it is most charac-

teristic of the mineral that it nearly always occurs together with quartz. Of the minerals mentioned the aegirine is as a rule older than narsarsukite, the others younger, which also applies to the various rarer minerals; there is however a younger generation of small crystals of narsarsukite." Microcline, albite, galena, and calcite are common members of the assemblage, but no pectolite is reported as occurring with narsarsukite. It can be seen that the assemblages are similar in Greenland and Montana.

GEOCHEMISTRY OF NARSARSUKITE

The occurrence of narsarsukite seems to depend upon circumstances where there is an excess of silica, a high partial pressure of oxygen, and an abundance of sodium and titanium. The last two conditions are probably characteristic of alkalic igneous rocks in general, but these rocks are undersaturated in silica so that a variety of unusual alkali-alkaline earth titanium silicates usually form during crystallization. It appears that reaction of emanations from alkalic magmas with siliceous wallrock is required for the formation of narsarsukite, and the formation of this mineral can be regarded in a way analogous to skarn minerals in lime-silicate metasomatism. It follows that the most probable sites for other occurrences will be where quartzites or other highly siliceous country rocks are cut by alkalic intrusive rocks and conditions are such that a high partial pressure of oxygen is present. Under conditions of lower partial pressure of oxygen, neptunite ($\text{Na}_2\text{FeTiSi}_4\text{O}_{12}$) forms, or pre-existing narsarsukite will be altered to neptunite (Flink, 1901, 129-130).

The coexistence of aegirine and narsarsukite suggests that hematite, rutile, magnetite or even ilmenite might also be expected, representing an excess of either iron or titanium. Strangely enough these minerals are not reported, and their absence is not easily explained. If saturation with iron and titanium could be established and if narsarsukite and aegirine form a discontinuous solid solution series where Fe^{III} substitutes for Ti in the formula $\text{Na}_2\text{Ti}_{1-x}\text{Fe}_{2x}\text{Si}_4\text{O}_{11+x}$, it might be possible to use these two minerals as a geologic thermometer. Possibly ramsayite, $\text{Na}_2\text{Ti}_2\text{Si}_2\text{O}_6$, is the sodium titanium silicate stable with quartz and rutile, and the assemblage quartz-narsarsukite-rutile is not possible. However there is as yet no evidence on this point.

The geologic evidence suggests that the total rock cover at the time of deposition of narsarsukite in the Sweetgrass Hills did not exceed 5000 feet. Assuming total vapor pressure in the mineralized zones to be equal to or only slightly greater than rock pressure, the maximum vapor pressure probably did not exceed 1000 atmospheres. The temperature of deposition cannot be determined at present, but the apparently relatively low calcium content of the hybrid rock and the presence of two

alkali feldspars in it are taken to indicate that the temperature could not have greatly exceeded 650° C. at 1000 atmospheres, otherwise only a single phase alkali feldspar would be present. The presence of pectolite is also taken to indicate relatively low intensity conditions of mineralization. The strikingly similar assemblages from Narsarsuk may also be representative of quite low intensity conditions.

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