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WOOLLY ERIONITE FROM THE REESE RIVER ZEOLITE DEPOSIT, LANDER COUNTY, NEVADA, AND ITS RELATIONSHIP TO OTHER ERIONITES

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Abstract—Woolly erionite from the Reese River deposit, Nevada, is identical in appearance to that at the type locality, near Durkee, Oregon. Both of these erionites differ in appearance from all other erionite reported in the past 20 years from diverse rocks throughout the world which are described as prismatic or acicular in habit. The non-woolly erionites are especially common as microscopic crystals in diagenetically altered vitroclastic lacustrine deposits of Cenozoic age. The Reese River woolly erionite fills joints in gray to brownish-gray lacustrine mudstone of probably Pliocene age, in a zone about 1 m thick beneath a conspicuous gray vitric tuff. Compact masses of long, curly, woolly erionite fibers are in the plane of the joint and locally are associated with opal. Indices of refraction are $\omega = 1.468$ and $\epsilon = 1.472$; hexagonal unit-cell parameters are $a = 13.186(2)$ Å, $c = 15.055(1)$ Å, and $V = 2267.1(0.9)$ Å^3. A chemical analysis of woolly erionite yields a unit-cell composition of: $Na_{1.01}K_{2.84}Mg_{0.3}Ca_{1.69}Al_{8.18}Si_{27.84}O_{72} \cdot 28.51H_2O$.

Key Words—Authigenesis, Erionite, Fiber, Tuff, Zeolite.

INTRODUCTION

"Woolly" erionite, a zeolite, is present in a recently discovered second known locality for this interesting morphological variant. The erionite is nearly identical in physical and chemical properties to the poorly exposed type material of Eakle (1898) but is quite different in its geological setting. This new discovery near Austin, in Churchill County, Nevada, may provide important data on the genesis and characteristics of a natural zeolite that elsewhere is economically important. Although "woolly erionite" is etymologically redundant—*εριον* = *wool* in Greek—the terminology is needed to distinguish this variety from the more common and abundant varieties.

Erionite was originally named and described by Eakle (1898) who unfortunately provided only a vague description of the type locality. More than a half century passed before L. W. Staples rediscovered the site, and additional specimens were available to supplement the dwindling supply of original material (Staples and Gard, 1959). At the type locality near Durkee, Baker County, Oregon, the erionite occurs in thin seams in a gray, rhyolitic welded ash-flow tuff. Eakle named it erionite because of the woolly appearance of the material. Eakle's description of erionite is accurate and is repeated as follows: "The zeolite occurs as very fine threads, having a snow-white color and pearly luster. These threads resemble fine woolly hairs having the same curly nature and soft feel." Figure 1, a scanning electron micrograph (SEM) of woolly erionite from Durkee, clearly shows the woolly fibers in ribbons and bundles that ravel and fray into aggregate bundles.

Prior to the late 1950's, the only confirmed occurrence of erionite was that from the type locality (Staples and Gard, 1959); however, in the last two decades, numerous discoveries of erionite have been reported from diverse rock types and geological environments and from many countries throughout the world. Most of the erionite occurs as microscopic acicular, prismatic crystals in altered silicic tuffs, or less commonly as scattered clusters of megascopic crystals in cavities in mafic lavas. The most voluminous deposits of erionite are composed of micrometer-size crystals in altered tuffs of late Cenozoic age (Deffeyes, 1959; Sheppard and Gude, 1969). In many altered silicic tuffs, the erionite appears to occur as single prismatic cyrstals when examined under the petrographic microscope; but when examined by scanning electron microscopy, the "single" crystals are bundles of acicular, prismatic crystals (Figure 2). The erionite described herein is unusual in that it occurs in a lacustrine deposit and is nearly identical in appearance to the erionite from the type locality at Durkee (Figure 3). Individual fibers are less than 1 μm in diameter and 0.1–10 mm long. Most single strands occur in bundles that may be 10–20 μm thick. No other verified occurrences of woolly erionite have been reported.

OCCURRENCE

The Reese River zeolite deposit, which is adjacent to the woolly erionite site, is about 50 km north of Austin, Nevada, and about 2 km northeast of Nevada State Highway 305 at the southwestern end of Carico Lake Valley (Figure 4). Papke (1972) described the zeolite deposit discovered by Deffeyes (1959), which is chiefly in unplatted secs. 26 and 35, T24N, R43E, and the rocks

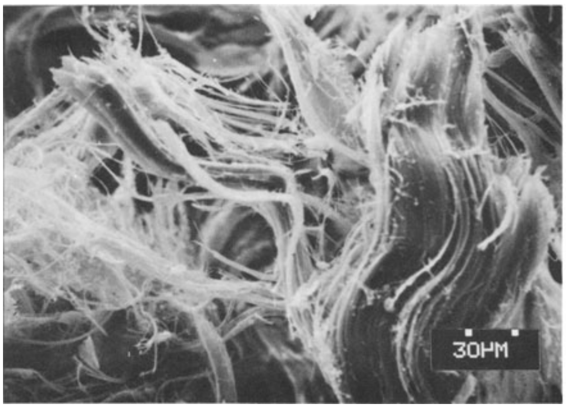

Figure 1. Scanning electron micrograph of woolly erionite from the type locality at Durkee, Oregon.

Figure 3. Scanning electron micrograph of woolly erionite from a joint in mudstone, Reese River, Nevada.

of the area as mainly lacustrine mudstone, tuffaceous mudstone, tuff, and minor sandstone and conglomerate of probable Pliocene age. Although the woolly erionite occurs about 0.7 km north of the area studied by Papke, the host rocks are part of the same lacustrine sequence that he described. The Reese River woolly erionite was discovered by H. Donald Curry in 1965 and brought to our attention by him in 1975.

The new locality for woolly erionite is on the south slope of a small barren hill in the NW¼NE¼ of unplatted Sec. 26, T24N, R43E (lat. 39°55′37″N, long. 117°06′04″W) at an elevation of about 1620 m (5320 ft), and about 0.25 km southeast of the Carico Lake Valley Road. The erionite occurs chiefly as joint fillings in poorly exposed brownish-gray mudstone of unknown thickness stratigraphically just beneath a 1-m thick conspicuous gray vitric tuff. Woolly erionite is difficult to find in place unless an exposure of mudstone can be located. Scattered clots and felt-like plates (Figure 5) as much as 5 cm across weather free from the soft mud-

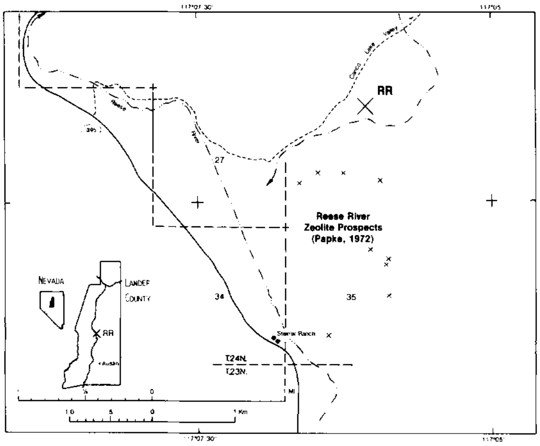

Figure 4. Index map showing the location of the woolly erionite (RR) and the Reese River zeolite district.

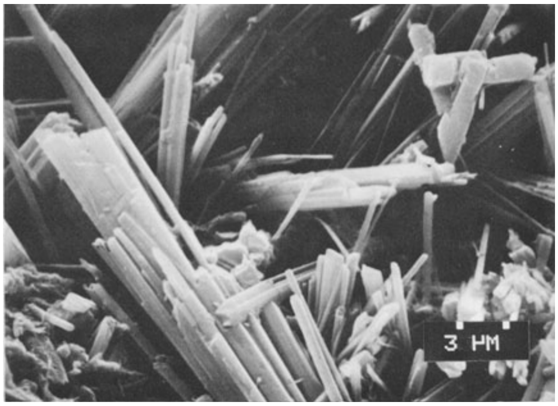

Figure 2. Scanning electron micrograph of acicular, prismatic erionite from a lacustrine tuff at Durkee, Oregon.

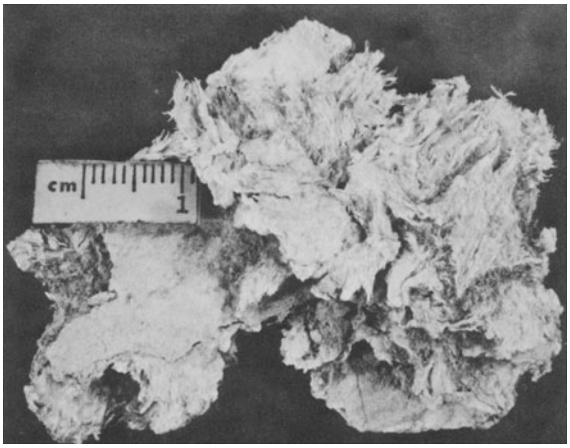

Figure 5. Mat of woolly erionite fibers weathered from a joint in mudstone, Reese River, Nevada.

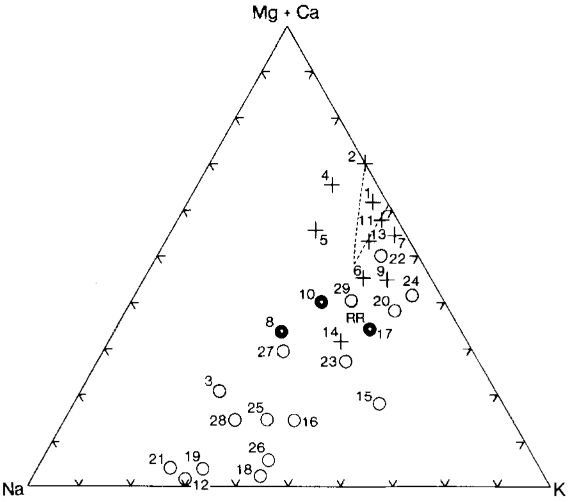

Figure 6. Erionite compositions in atomic percentages for Mg + Ca, Na, and K. Sample occurrences and references are given in Table 2. Solid circles = woolly erionites; open circles = erionites from sedimentary rocks; plus signs = erionites from mafic lavas; short dashes enclose a field of 15 data points averaged at No. 1.

Table 1. Chemical and physical data for woolly erionite, Reese River, Nevada.

	Conventional rock analysis[1] (weight percent) A	B	Unit-cell composition (atoms per unit cell, O = 72)	
SiO_2	56.78	58.02	Si	27.84
Al_2O_3	14.16	14.47	Al	8.18
Fe_2O_3	0.05	0.05	Fe^{3+}	0.02
FeO	0.17	0.17	Fe^{2+}	0.07
MgO	0.41	0.42	Mg	0.30
CaO	4.62	3.29	Ca	1.69
Na_2O	1.06	1.08	Na	1.01
K_2O	4.54	4.64	K	2.84
H_2O+	9.47	9.68	H_2O+	15.49
H_2O-	7.96	8.14	H_2O-	13.02
TiO_2	0.04	0.04	O	72.00
P_2O_5	<0.05	—[2]	—	—
MnO	<0.01	—	$Si:(Al + Fe^{3+}) = 3.39$	
CO_2	1.10	—		
Total	100.36	100.00		

Optical properties

$\omega = 1.468$, $\epsilon = 1.472$, uniaxial positive, length slow

X-ray unit-cell parameters

Hexagonal $P6_3/mmc$, $a = 13.186(2)$ Å, $c = 15.055(1)$ Å, $V = 2267.1(0.9)$ Å^3

[1] Column A = Uncorrected data. Analyst S. T. Neil, U.S. Geological Survey, Menlo Park, California. Column B = Analysis corrected for CO_2 plus required CaO to make calcite.

[2] Dashes = No data.

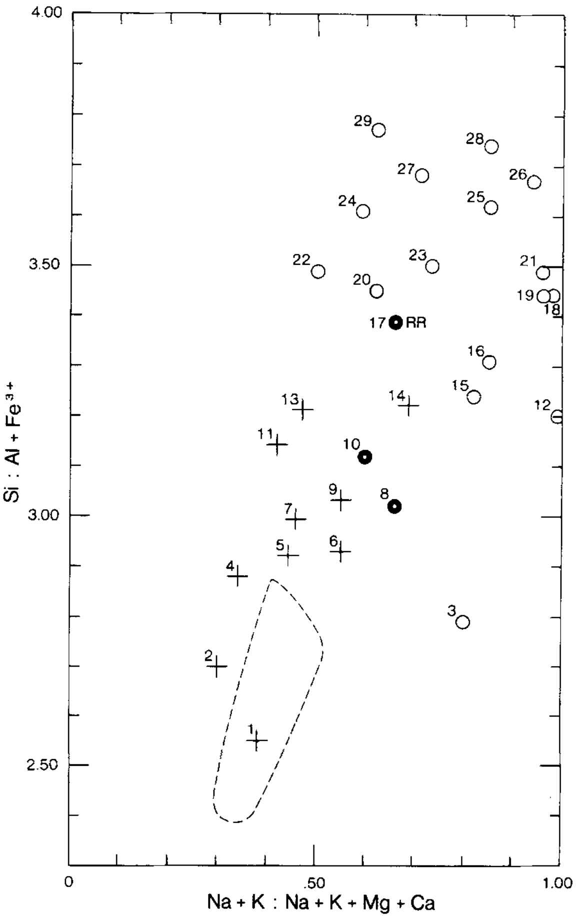

Figure 7. Erionite compositional variations shown by the ratios Si:(Al + Fe^{3+}) and (Na + K):(Na + K + Mg + Ca). Sample occurrences and references are given in Table 2. Solid circles = woolly erionites; open circles = erionites from sedimentary rocks; plus sign = erionites from mafic lavas; short dashes enclose field of 15 data points averaged at No. 1.

stone, travel down the slope, and can then be traced back upslope to a source just below the surficial debris.

Although the woolly erionite is most abundant in the interval of mudstone about a meter beneath the tuff, it also occurs sporadically at least 6 m below the tuff-mudstone contact. The erionite also occurs more rarely in thin fracture fillings and inter-shard spaces within the lower few centimeters of the vitric tuff. The mudstone consists of smectite, calcite, quartz, and plagioclase. No zeolites, other than the erionite that fills fractures, have been detected in the mudstone by X-ray powder diffraction or by scanning electron microscopy.

CHEMICAL AND PHYSICAL PROPERTIES

One of the nearly monomineralic fibrous clots was scrubbed by ultrasonic treatment to remove adhering mudstone matrix. This clean mass was shredded and

Table 2. Occurrences and references for analyzed erionites, listed in order of increasing Si:(Al + Fe^{3+}).

Analysis no.	Locality	Host rock	Reference
1	Sasbach, Kaiserstuhl, West Germany[1]	Limburgite	Rinaldi (1976)
2	Milwaukie, Oregon	Miocene-Pliocene(?) Yakima Basalt Subgroup	Wise and Tschernich (1976)
3	Kaipara, New Zealand	Miocene, marine andesite tuff	Sameshima (1978)
4	Nidym River District, Siberia, U.S.S.R.	Lower Triassic lavas	Belitskiy and Bukin (1968)
5	Mazé, Niigata Prefecture, Japan	Olivene basalt	Harada *et al.* (1967)
6	Sardinia, Italy	Fractures in weathered andesite	Passaglia and Galli (1974)
7	Clifton, Arizona	Middle Tertiary olivine basalt	Wise and Tschernich (1976)
8	Durkee, Oregon	Pliocene welded ash-flow tuff	Eakle (1898)
9	Thumb Butte, Arizona	Middle Tertiary olivine basalt	Wise and Tschernich (1976)
10	Durkee, Oregon	Pliocene welded ash-flow tuff	Staples and Gard (1959)
11	Cape Lookout, Oregon	Miocene tholeiitic basalt	Wise and Tschernich (1976)
12	Lake Natron, Tanzania	Miocene-Pliocene trachytic lacustrine tuff	Hay (1966)
13	Shurdo, Akhaltsikhi District, Georgia S.S.R.	Eocene tuff breccia	Batiashvili and Gvakhariya (1968)
14	Yaquina head, Oregon	Miocene tholeiitic basalt	Wise and Tschernich (1976)
15	Rome, Oregon	Pliocene(?) fluviatile or lacustrine tuff	Eberly (1964)
16	Eastgate, Nevada	Pliocene lacustrine tuff	Sheppard and Gude (1969)
17	Reese River, Nevada	Pliocene lacustrine tuff	This report
18	Pine Valley, Nevada	Pliocene-Pleistocene lacustrine tuff	Sheppard and Gude (1969)
19	Lake Magadi, Kenya	Pleistocene-Holocene trachytic lacustrine tuff	Surdam and Eugster (1976)
20	Jersey Valley, Nevada	Miocene-Pliocene lacustrine tuff	Sheppard and Gude (1969)
21	Cady Mountains, California	Miocene or Pliocene lacustrine tuff	Sheppard *et al.* (1965)
22	Durkee, Oregon	Pliocene lacustrine tuff (orange)	Gude and Sheppard (unpublished data)
23	Jersey Valley, Nevada	Miocene-Pliocene lacustrine tuff	Sherry (1979)
24	Beaver Rim, Wyoming	Eocene fluviatile or lacustrine tuff	Boles and Surdam (1979)
25	Crooked Creek, Oregon	Pliocene lacustrine tuff	Sheppard and Gude (1969)
26	Moonstone Formation, Wyoming	Pliocene tuff	Surdam and Eugster (1976)
27	Durkee, Oregon	Pliocene lacustrine tuff (white)	Gude and Sheppard (unpublished data)
28	Lake Tecopa, California	Pleistocene lacustrine tuff A	Sheppard and Gude (1968)
29	Wikieup, Arizona	Pliocene lacustrine tuff	Sheppard and Gude (1973)

[1] Fifteen analyzed data points from three crystals are averaged as a single sample.

chopped in a micromill to yield fine particulate material for analysis.

The chemical and physical properties of the woolly erionite from Reese River are given in Table 1. These properties are also compared graphically with data for 28 selected erionites from 25 other localities (Table 2 and Figures 6–9). Ten localities are in mafic lavas (principally basalts), one is in a marine andesitic tuff, and the remaining 15 sites are in fluviatile and lacustrine sedimentary rocks that originally consisted chiefly of silicic glass. The chemical difference within a zeolite species is influenced by the composition of the fluids resulting from rock–water interactions, and in most observed cases at nonhydrothermal, low temperature–pressure conditions.

The properties of the Reese River woolly erionite (labeled "RR") are shown in the four diagrams discussed below and are within the known limits of properties of erionites from the various sedimentary environments, whereas the Durkee woolly erionite has characteristics of a mafic lava heritage. It should also be noted that the chemical and physical properties of erionites, as well as of other zeolites, vary as much among specimens collected at the same locality (see Nos. 8 and 10, 20 and 23, 22 and 27) as they do among samples from widely separated deposits.

The ternary diagram (Figure 6) shows the cation compositions of the 28 erionites selected from the references (Table 2) and the Reese River woolly erionite (RR). In general, the samples from sedimentary rocks are enriched in alkali ions and plot in the lower part of the diagram. The Reese River erionite is one of the more potassium-rich specimens and plots in a diffuse region between the two rock-type categories. The Durkee woolly erionite (Nos. 8 and 10), however, is among the potassium-poor samples. Note that the field of erionite data is bounded by potassium compositions of 25% K and approximately 60% K. The maximum amount of either Na or of Mg + Ca is thus about 75%.

The cation chemistry shown in Figure 6 reaffirms a

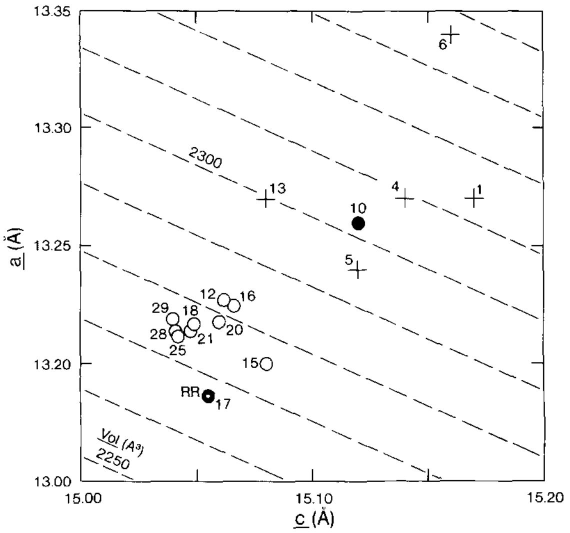

Figure 8. Erionite unit-cell variations. Sample occurrences and references are given in Table 2. Solid circles = woolly erionites; open circles = erionites from sedimentary rocks; plus signs = erionites from mafic lavas; dashed slanting lines = contours representing unit-cell volumes.

suggestion by Sheppard and Gude (1969) that the relatively narrow range in potassium content may be imposed by structural requirements. Subsequent crystal-structure determinations by Gard and Tait (1971, 1972) were summarized in their 1972 paper as follows: ". . . each cancrinite-type cavity contains one K ion that cannot be removed or replaced without disrupting the frame. . . . This explains the narrow range of K content in erionite and offretite noted by Sheppard and Gude . . . ." Breck (1974, p. 79) stated ". . . potassium . . . is locked within the structure in positions in which it is not free to move."

In Figure 7, the chemical components, other than water, are shown as ratios of the cations, (Na + K):(Na + K + Mg + Ca), and the framework elements, Si:(Al + Fe^{3+}). The clear trend on this diagram, upward and toward the right, denotes the effect of the host rocks on the chemistry of the erionites. Erionites from mafic lavas are more aluminous and more alkaline-earth rich than are erionites from the sedimentary rocks where the silicic vitric tuffs alter to silica-rich and alkali-rich erionites. A Si:(Al + Fe^{3+}) ratio of about 3.2 separates the major environments of deposition. Noticeable exceptions are the New Zealand marine andesitic tuff (No. 3) and the two Durkee woolly erionite specimens (Nos. 8 and 10). Both of these occurrences have probable sources in mafic rocks, as noted above in the discussion of Figure 6. Woolly erionite (RR) with a ratio of 3.39 is well within the siliceous sedimentary rock-type field.

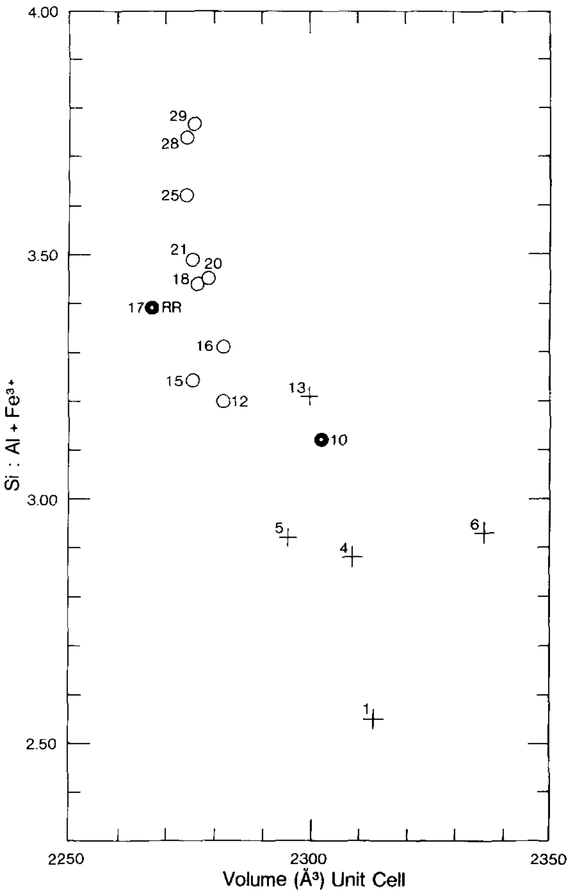

Figure 9. Erionite unit-cell volume (Å³) and compositional variations. Sample occurrences and references are given in Table 2. Solid circles = woolly erionites; open circles = erionites from sedimentary rocks; plus signs = erionites from mafic lavas.

X-ray diffraction data have been published for only 16 of the 29 erionites in the compilation. Figure 8 is a plot of these data showing the unit-cell parameters: *a* (Å), *c* (Å), and *V* (Å³). Composition of the host rock affects the crystal structure characteristics as well as the chemical properties. Thus, erionite unit cells are smaller for samples from siliceous tuffaceous sedimentary rocks than from mafic lavas. The available unit-cell data as plotted show two clusters that represent erionites from mafic lavas and sedimentary rocks. If additional unit-cell data were available for all the chemically analyzed erionites, the clusters would probably coalesce and fill the gap between the field. Thus, a continuous band would extend upward and toward the right in Figure 8. The Reese River woolly erionite (RR) has the smallest volume (2267.1 Å³) and the smallest value for *a* (13.186 Å).

The type woolly erionite from Durkee has properties that match those of erionite samples from mafic lavas even though it is found in a rhyolitic welded ash-flow tuff in specimens culled from a long-abandoned and inaccessible fire-opal mine. The tuff itself is at the base or in the lower part of a lacustrine sequence that unconformably overlies scattered thin basalt flows. Inasmuch as no information is available on the exact position of the erionite seams in the mine, one can only infer that the source solutions for the erionite may have been derived from a concealed basaltic body.

The combined Si:(Al + Fe^{3+}) ratio and unit-cell volume data shown in Figure 9 reinforce the observations from the preceding diagrams. Silica-rich, small unit-cell erionites are found in tuffaceous sedimentary host rocks, whereas less siliceous, magnesium-calcium enriched, larger unit-cell erionites occur in mafic lavas.

Neither chemical nor physical properties distinguish woolly erionite from other erionites. However, the influence of the host rock on all the erionites is clear. Siliceous tuffaceous sediments yield alkali-, and silica-rich, small unit-cell erionites, whereas mafic lavas host more aluminous erionites with larger unit cells. Although the gray vitric tuff at Reese River is the most likely source for the constituents that ultimately formed the erionite, a problem still remains. Why does the erionite form as woolly crystal masses here and at Durkee rather than the common prismatic, acicular variety found in abundance elsewhere?

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Резюме—Шерстеподобный эрионит из осадков реки Рииз в Неваде являлся тождественным по виду к тому, который находится около Дуркии в Орегоне. Оба эти эрионпты отличаются по виду от всех остальных найденных в последние 20 лет в породах в различных частях мира эрионитов, которые описываются как призматические по поведению. Нешерстеподобные эрионпты встречаются особенно часто как микроскопические кристаллы в диагенетически измененных витрокластических озерных осадках кайнозойской эпохы. Шерстеподобный эрионит из реки Рииз выполняет соединения в серых до коричнего-серых озерных иллистых породах, вероятно из плиоценовой эпохы, в зоне около 1 метра толщины под заметным серым стекловипным туфом. Компактные массы длинных закрученных шерстеподобных волокон эрионита находятся в плоскости соединений и местно ассоциируются с опалом. Показатели рефракции равны: $\omega = 1{,}468$ и $\epsilon = 1{,}472$; параметры гексагональной элементарной ячейки: $a = 13{,}186(2)$ Å, $c = 15{,}055(1)$ Å, и $V = 2267{,}1$ (0,9) $Å^3$. Химический анализ шерстеподобного эрионита дает следующий состав элементарной ячейки: $Na_{1,01}K_{2,84}Mg_{0,3}Ca_{1,69}Al_{8,18}Si_{27,84}O_{72} \cdot 28{,}51H_2O$. [E.C.]

Resümee—Wolliger Erionit von der Reese River Lagerstätte, Nevada, entspricht in der Erscheinungsform dem der Typlokalität in der Nähe von Durkee, Oregon. Diese beiden Erionite unterscheiden sich in der Erscheinungsform von allen anderen Erioniten, die in den letzten 20 Jahren in verschiedenen Gesteinen in der ganzen Welt beschrieben wurden. Alle diese Erionite weisen prismatische oder nadelige Formen auf. Die nichtwolligen Erionite treten vor allem als mikroskopisch kleine Kristalle in diagenetisch umgewandelten, vitroklastischen, lakustrischen Lagerstätten aus dem Känozoikum auf. Der wollige Erionit von Reese River füllt Gänge in einem grauen bis braungrauen lakustrischen Tonstein von wahrscheinlich pliozänem Alter in einer etwa 1 m dicken Zone unter einem auffälligen grauen, glasigen Tuff. Kompakte Massen aus langen, gekräuselten, wolligen Erionitfasern liegen parallel zu den Kluftebenen, gelegentlich zusammen mit Opal. Die Brechungsindizes sind $\omega = 1{,}468$ und $\epsilon = 1{,}472$; die hexagonalen Zellparameter sind $a = 13{,}186(2)$ Å, $c = 15{,}055(1)$ Å, und $V = 2267{,}1(0{,}9)$ Å^3. Eine chemische Analyse des wolligen Erionit ergibt eine Zusammensetzung der Elementarzelle von $Na_{1,01}K_{2,84}Mg_{0,3}Ca_{1,69}Al_{8,18}Si_{27,84}O_{72} \cdot 28{,}51H_2O$. [U.W.]

Résumé—L'érionite laineuse du dépôt de la rivière Reese, Nevada, est identique en apparence à celle de la localité type près de Durkee, Oregon. Ces deux érionites sont différentes en apparence de toute autre érionite rapportée dans les dernières 20 années de roches diverses à travers le monde, et qui est prismatique ou aciculaire de constitution. Les érionites non-laineuses sont particulièrement courantes en tant que cristaux microscopiques dans des dépôts vitroclastiques lacustrins altérés. L'érionite laineuse de la rivière Reese remplit des joints dans une argilite lacustrine grise, probablement d'âge pliocène, dans une zone d'épaisseur d' environ 1 m, sous un tuff gris vitrique remarquable. Des masses compactes de longues fibres bouclées, et laineuses sont dans le plan du joint et sont localement associeés avec de l'opal. Les indices de réfraction sont $\omega = 1{,}468$ et $\epsilon = 1{,}472$, les paramètres hexagonaux de maille sont $a = 13{,}186(2)$ Å, $c = 15{,}055(1)$ Å, et $V = 2267{,}1(0{,}9)$ Å^3. Une analyse chimique de l'érionite laineuse a rendu une composition de maille de: $Na_{1,01}K_{2,84}Mg_{0,3}Ca_{1,69}Al_{8,18}Si_{27,84}O_{72} \cdot 28{,}51H_2O$. [D.J.]