U.S. DEPARTMENT OF THE INTERIOR

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OCCURRENCES OF ERIONITE IN SEDIMENTARY ROCKS OF THE WESTERN UNITED STATES

by

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ABSTRACT

Erionite has been reported from nonmarine tuffaceous rocks in all western states except Washington, but it is most common and abundant in southeastern California, northern and central Nevada, and eastern and southeastern Oregon. The host rocks are chiefly lacustrine and range in age from Eocene to Pleistocene, but most are Neogene. The thickness of the host rock commonly ranges from less than a centimeter to several meters, and the erionite content is a trace to nearly 100 percent of the rock. Erionite commonly coexists with other diagenetic zeolites, but the association with clinoptilolite seems most common. Unlike the type woolly erionite, most erionite in sedimentary rocks is acicular, prismatic, or rod-like, and it commonly occurs in bundles or radial aggregates. The individual crystals are about 2-200 μm long and 0.1-10 μm thick.

INTRODUCTION

Erionite, a zeolite, was originally described and named by Eakle (1898) who provided only a vague description of the type locality at the Durkee opal mine near Durkee, Baker County, Oregon. The name was derived from a Greek word that means wool because at the type locality the erionite occurs as white, wool-like fibers. The woolly fibers occur in veinlets of a gray, welded, ash-flow tuff and are readily recognized without the aid of a hand lens. For more than half a century, this zeolite was considered extremely rare, and no additional occurrences were found until Deffeyes (1959) described material from Nevada and Wyoming. Unlike the type erionite, these subsequent occurrences were microscopic, acicular to fibrous crystals in diagenetically altered, silicic, vitric tuffs of Cenozoic lacustrine deposits. Numerous additional discoveries of erionite have been reported in the last three decades from diverse rock types and geological environments throughout the world (Tschernich, 1992, p. 156-166); however, the most voluminous deposits seem to occur in continental Cenozoic silicic tuffs of the western United States.

In the late 1950s and early 1960s, the Linde Division of Union Carbide Corporation included erionite in their zeolite exploration program because it was viewed as a potentially valuable commercial adsorbent and molecular sieve (Mumpton, 1984). Numerous erionite deposits, as well as other zeolite deposits, were discovered in the western United States during this early exploration, but the results were not published until much later (Mumpton, 1984). Erionite was not mined by Union Carbide Corporation. Other companies subsequently explored for erionite, but only Mobil Oil Corporation produced a minor tonnage from their Jersey Valley, Nevada deposit (Papke, 1972) for internal use as a catalyst or catalyst support. Early settlers to parts of southeastern Oregon and northern Nevada found that erionite-rich tuff could be cut, sawed, and nailed, so the material was used as a local building stone, without the knowledge of the zeolite content. At the present time (1995), erionite is not being mined or utilized in the United States, although some deposits that are mined for other zeolites may contain trace to minor amounts of erionite as a contaminant.

Since the 1970s, epidemiological investigations in central Turkey and a variety of *in vitro* and *in vivo* experimental studies postulated a linkage between the exposure to erionite and malignant plural mesothelioma, a disease previously associated only with the inhalation of certain fibrous asbestos minerals (Baris, 1991; Coffin and Ghio, 1991). The apparent biological effects of erionite on humans still are not understood (Coffin and others, 1992; Eborn and Aust, 1995) and require continued study.

The intent of this compilation of erionite occurrences in sedimentary deposits of the western United States is to provide a basis for future studies by geological, mining, and medical investigators.

PROPERTIES OF ERIONITE

Chemical Composition

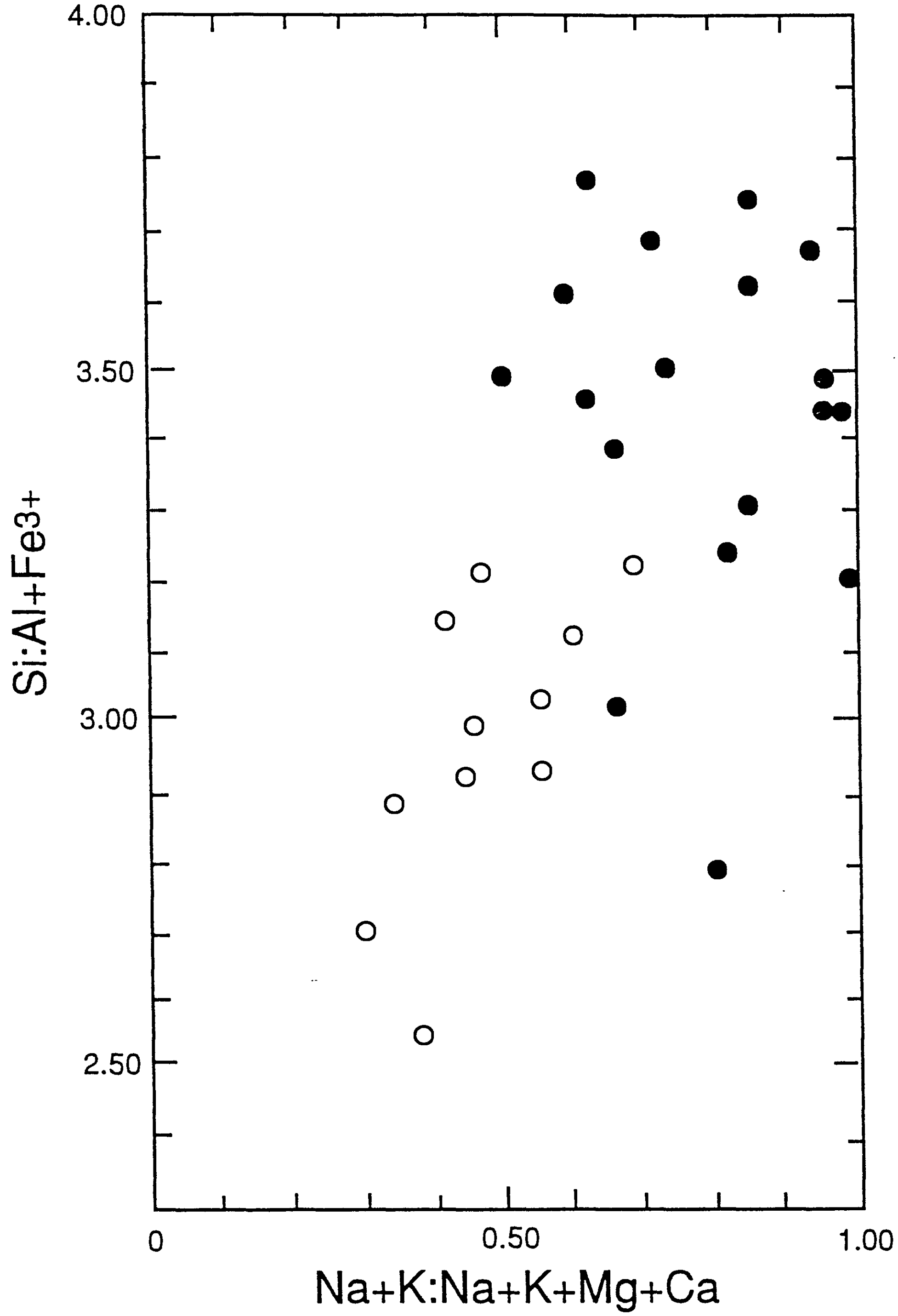

Figure 1. Erionite compositional variations shown by the ratios Si:(Al+Fe^{3+}) and (Na+K):(Na+K+Mg+Ca). Solid circles are erionites from sedimentary rocks; open circles are erionites from mafic lavas. Modified from Gude and Sheppard (1981).

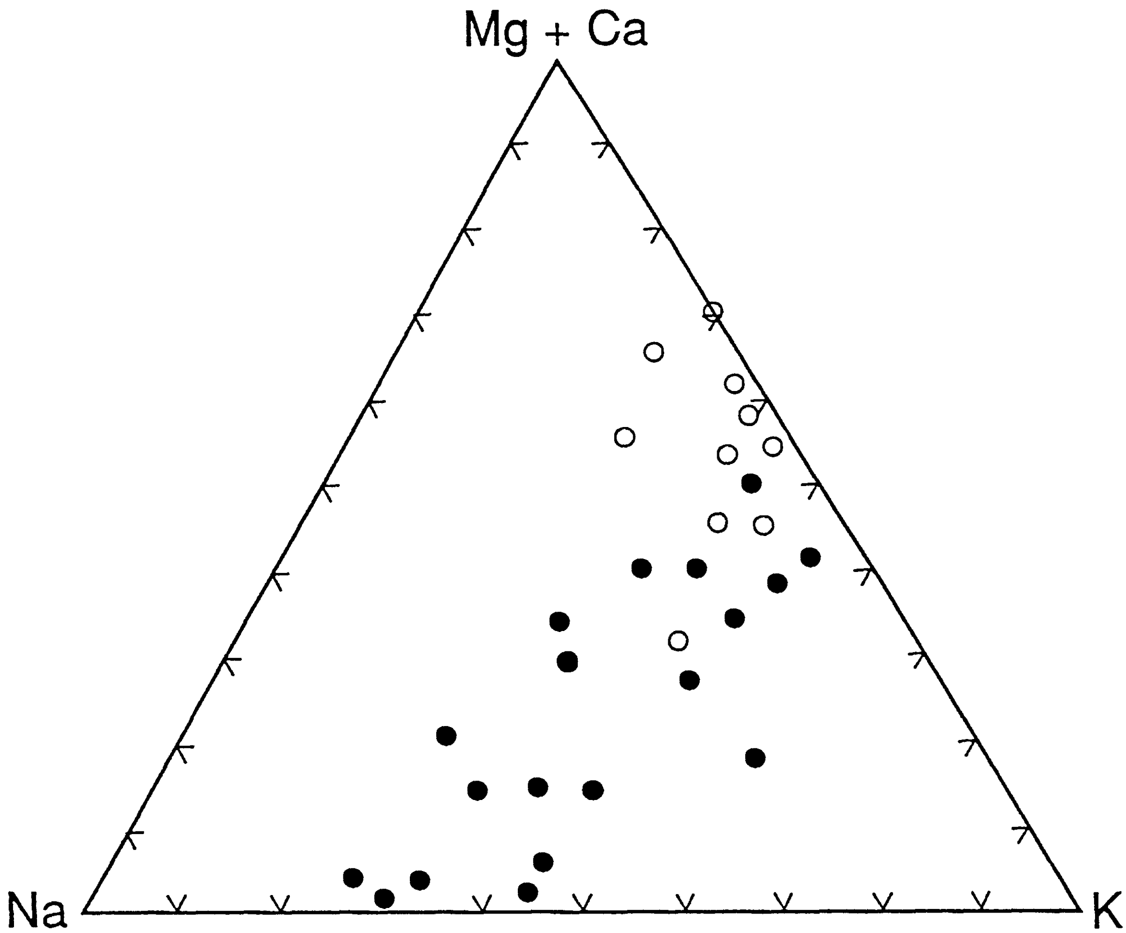

Figure 2. Erionite composition in atomic percentages for (Mg+Ca), Na, and K. Solid circles are erionites from sedimentary rocks; open circles are erionites from mafic lavas. Modified from Gude and Sheppard (1981).

The chemical composition of erionite is variable, but most have Si:(Al+Fe^{3+}) ratios greater than 3.0, and monovalent exchangeable cations generally exceed divalent ones. Si:(Al+Fe^{3+}) ratios of about 2.6-3.8 have been determined (Sheppard and Gude, 1969a; Gude and Sheppard, 1981) for erionite from a variety of rock types and geological environments (fig. 1). Varieties with dominant Na, K, and (Ca+Mg) are known (fig. 2). K shows a relatively narrow range of about 25-60 percent of the exchangeable cations. Generally, erionite from silicic, vitric tuff is relatively siliceous and alkalic, but erionite in mafic lava is relatively aluminous and rich in alkaline earths.

Physical Properties

Erionite is uniaxial positive and length slow. The indices of refraction are in the range of about 1.46-1.48. Hexagonal cell parameters are a=13.19-13.34 Å and c=15.04-15.17 Å. Siliceous varieties generally have a smaller unit cell than aluminous varieties.

In tuffaceous sedimentary rocks, the erionite commonly occurs as prismatic, acicular, or fibrous crystals that are about 2-200 μm long and 0.1-10 μm thick. Scanning electron microscopy shows that some well-formed hexagonal prisms are terminated by pinacoidal faces. Much of the erionite occurs in stubby bundles that are 5-80 μm long, and each bundle consists of tens to hundreds of individual crystals. More rarely, the erionite occurs in radial aggregates or spherulites. Where erionite coexists with other zeolites, such as clinoptilolite or chabazite, it postdates these zeolites and commonly is draped across them.

The detection of trace amounts of erionite in tuffaceous rocks can be made by X-ray powder diffraction techniques. Bish and Chipera (1991) cautioned, however, that the recognition of erionite can be complicated by its coexistence with smectite or clinoptilolite. Even the weak and broad smectite 001 reflection can mask the erionite 100 reflection. Also, the clinoptilolite 110 reflection near 7.48° 2θ (CuKα) can mask the erionite 100 reflection near 7.67° 2θ. Identifications of trace amounts of erionite in clinoptilolite-bearing rocks should be considered suspect if based solely on a reflection near 7.5° 2θ. Bish and Chipera (1991) described a method using automated X-ray powder diffraction instrumentation that resulted in a lower limit of detection of 100-500 ppm erionite in tuffaceous rocks. A scanning electron microscope equipped with an energy-dispersive X-ray analyzer commonly can be used to discriminate fibrous erionite from mordenite in zeolitic rocks. If the zeolite morphology is not distinctive, the significantly lower Si:Al ratio for erionite should be adequate for identification (Sheppard, 1991, p. 12-13).

OCCURRENCES OF ERIONITE IN THE WESTERN UNITED STATES

In the western United States, erionite has been reported from nonmarine tuffaceous rocks that are chiefly lacustrine. Erionite has been reported in all western states except Washington, but it is most common and abundant in southeastern California, northern and central Nevada, and southeastern Oregon. The host rocks range in age from Eocene to Pleistocene, but most are Neogene. Erionite-bearing tuffaceous rocks are yellow, orange, or green and rarely white. The thickness ranges from less than a centimeter to several meters. The erionite content is a trace to nearly 100 percent of the rock. Coexisting diagenetic minerals in erionite-bearing tuffaceous rocks are other zeolites, smectite, opal-CT, quartz, potassium feldspar, calcite, searlesite, and fluorite. Associated zeolites are chabazite, clinoptilolite, mordenite, phillipsite, and analcime, but the association with clinoptilolite seems most common. Except for analcime, the erionite generally postdates the other zeolites. Analcime, as well as potassium feldspar, searlesite, and calcite, locally have replaced erionite.

The occurrences of erionite in tuffaceous sedimentary rocks of the western United States are briefly described in table 1 and are shown in figure 3. In addition to the locality

Table 1.--Occurrences of erionite in sedimentary rocks of the western United States.

[Locality numbers are shown in figure 3. Abundance of erionite indicated as: trace (less than 1%), minor (1-10 %), moderate (11-50 %), major (greater than 50%). Frequency of erionite-bearing rocks at localities indicated as rare or common. Remarks: Xo, confirmed by X-ray diffraction by original investigator; Xp, confirmed by X-ray diffraction by R.A. Sheppard; So, confirmed by scanning electron microscopy by original investigator; Sp, confirmed by scanning electron microscopy by R.A. Sheppard]

Locality	Occurrence	Abundance of erionite in zeolite-bearing rocks	Frequency of erionite-bearing rocks at locality	Erionite habit	Remarks	References
			Arizona			
1. Along the San Simon River, north of Bowie, Graham and Cochise Counties (NW1/4SE1/4 sec. 27, T. 11 N., R. 29 E.)	Tuff in the Gila Conglomerate that may be equivalent to the Pliocene lacustrine and fluvial beds of 111 (one-eleven) Ranch	Trace to major	Common	Bundles	Xo; Xp; So; Sp	Edson (1977); Eyde (1978, 1982); Mumpton and Ormsby (1976); Sheppard and others (1978; 1987); Welton (1984, p. 110-111, 122-123)
2. Near Bear Springs, Graham County (NW1/4SE1/4 sec. 4, T. 7 S., R. 23 E.)	Tuff in the Pliocene 111 (one-eleven) Ranch beds	Trace to major	Common	Unknown	Xo; Xp	(F.A. Mumpton, written commun., 1995); Eyde (1982)
3. Along Dripping Spring Wash, north of Christmas, Gila County (NW1/4 sec. 1, T. 4 S., R. 15 E.)	Tuff in upper Cenozoic lacustrine rocks	Trace	Rare	Unknown	Xo; So	Eyde (1982); Bowie and others (1987)
4. Near Kearny, Pinal County (NW1/4NW1/4 sec. 11, T. 5 S., R. 14 E.	Tuff in the Miocene San Manuel Formation	Moderate to major	Rare	Unknown	Xo; Xp	Krieger (1979)

5. Horseshoe Reservoir, Maricopa County (Unsurveyed, about 1 km west of the Horseshoe Dam)	Tuff in upper Cenozoic lacustrine rocks	Trace to moderate	Unknown	Unknown	Xp	(R.A. Sheppard, unpub. data, 1995)
6. Near Kirkland Junction, Yavapai County (NE1/4SW1/4 sec. 5, T. 11 N., R. 4 W.)	Tuff in upper Cenozoic lacustrine rocks	Trace to moderate	Unknown	Unknown	Xp	Eyde and Irvin (1979, p. 31); Sheppard and Gude (1983)
7. Near Wikieup, Mohave County (NE1/4SE1/4 sec. 7, T. 15 N., R. 12 W.)	Tuff in the upper Miocene and lower Pliocene Big Sandy Formation	Trace to major	Common	Prismatic and acicular individual crystals, bundles, and rare spherulites	Xp	Sheppard and Gude (1973)
			California			
8. Drill hole (Hector 3, about 4.7-5.4 m and 10.7 m depths) near the Hector hectorite mine, San Bernardino County (NW1/4SW1/4 sec. 25, T. 8 N., R. 5 E.)	Tuff in unnamed upper Cenozoic lacustrine rocks	Trace to moderate	Unknown	Unknown	Xo; Xp	Madsen (1970); Sweet (1985)
9. Southern flank of the Cady Mountains, San Bernardino County (NW1/4SW1/4 sec. 6, T. 8 N., R. 5 E.)	Tuff in unnamed upper Cenozoic lacustrine rocks	Major	Unknown	Bundles of acicular crystals	Xo; Xp; So	Mumpton and Ormsby (1976); Sheppard and others (1965); Stinson (1988, p. 52-53)

10. Near Mule Canyon, Calico Mountains, San Bernardino County (NE1/4SW1/4 sec. 24, T. 10 N., R. 1 E.)	Lacustrine mudstone and calcareous concretions in the Miocene Barstow Formation	Trace to minor	Unknown	Unknown	Xo	Park (1995)
11. Near Coon Canyon, Mud Hills, San Bernardino County (NW1/4NE1/4 sec. 23, T. 11 N., R. 2 W.)	Tuff in lacustrine rocks of the Miocene Barstow Formation	Trace to minor	Common	Individual acicular and prismatic crystals and rare bundles or clusters of radiating crystals	Xo; Xp; So	Coffman (1983); Gude (1985); Sheppard and Gude (1969b)
12. Kramer borate mine at Boron, Kern County	Tuff in the Miocene lacustrine Kramer beds	Minor to moderate	Unknown	Unknown	Xo; Xp	(F.A. Mumpton, written commun., 1979); Stinson (1988); Williamson (1987)
13. Drill hole at China Lake, San Bernardino County	Pleistocene tuff and claystone	Minor	Unknown	Unknown	Xo	Hay (1964, 1966)
14. Near Shoshone, Inyo County (NE1/4 sec. 12, T. 21 N., R. 6 E.)	Tuff from upper Cenozoic Lake Tecopa	Trace to major	Common	Individual acicular and rod-like crystals, bundles of acicular crystals, and clusters of radiating crystals	Xp; So; Sp	Mumpton and Ormsby (1976); Shedd and others (1982); Sheppard (1985); Sheppard and Gude (1968)
15. Drill hole at Owens Lake, Inyo County	Pleistocene tuff and claystone	Minor	Unknown	Unknown	Xo	Hay (1964, 1966)
Colorado						

16. Near the Rio Grande, south of Creede, Mineral County	Tuff in the Oligocene Creede Formation	Trace	Common	Individual acicular crystals	Xo; So	Bodine and others (1987); Larsen and Crossey (1994); (Daniel Larsen, written commun., 1995)
			Idaho			
17. Along Browns Creek, south of Oreana, Owyhee County (NE1/4NE1/4 sec. 24, T. 5 S., R. 1 W.)	Tuff in the Miocene Chalk Hills Formation	Trace to minor	Rare	Threadlike fibers	Xp; Sp	Sheppard (1991)
			Montana			
18. Hepburn's Mesa in Yellowstone Valley, Park County	Unnamed Miocene lacustrine tuffaceous rocks	Minor	Unknown	Unknown	Xo	Barnosky and others (1988)
			Nevada			
19. Near Beatty, Nye County	Tertiary tuff	Moderate	Unknown	Unknown	Xo	(F.A. Mumpton, written commun., 1995)
20. Drill holes (UE-25a#1, about 395.1 m depth; J-12, about 189.0-192.0 m depth; USW G-4, about 400.5 m depth; USW GU-3, about 362.5 m depth) at Yucca Mountain, Nye County	Tuff of the Miocene Topopah Spring Member of the Paintbrush Tuff	Trace	Rare	Hairlike fibers	Xo; So	Bish and Chipera (1991); Chipera and Bish (1989)
21. Gabbs Valley, northwest of Gabbs, Nye County	Tertiary tuff	Moderate to major	Unknown	Unknown	Xo	(F.A.Mumpton, written commun., 1995)

22. Southern Desatoya Mountains, Churchill County	Miocene volcaniclastic rocks	Trace to minor	Rare	Unknown	Xo	Barrows (1980)
23. Near Eastgate, Churchill County (sec. 28, T. 17 N., R. 36 E.)	Tuff in the Pliocene Monarch Mill Formation	Trace to major	Common	Individual acicular crystals	Xo; Xp; So	Mumpton and Ormsby (1976); Papke (1972); Shedd and others (1982); Sheppard and Gude (1980)
24. Trinity Range, Churchill County (northeast part of T. 24 N., R. 28 E.)	Unnamed upper Tertiary tuff	Minor	Common	Unknown	Xo	Holmes (1994)
25. Near Hungary Valley, Washoe County (SW1/4NW1/4 sec. 22, T. 22 N., R. 20 E.)	Tuff in unamed upper Tertiary lacustrine rocks	Trace	Unknown	Individual acicular to fibrous crystals	Xo; So	Holmes (1994); (F.A. Mumpton, written commun., 1995)
26. Near Windy Basin, east of Gerlach, Pershing County	Tertiary lacustrine tuffaceous rocks	Moderate	Unknown	Unknown	Xo	(F.A. Mumpton, written commun., 1995)
27. Jersey Valley, Pershing County (sec. 8, T. 27 N., R. 40 E.)	Tuff in unnamed upper Tertiary lacustrine rocks	Minor to major	Common	Individual acicular crystals and rare bundles	Xo; Xp; So	Deffeyes (1959); Mumpton and Ormsby (1976); Papke (1971); Shedd and others (1982)
28. Near Fish Creek, Lander County (NW1/4NW1/4 sec. 10, T. 27 N., R. 41 E.)	Unnamed upper Tertiary lapilli tuff	Trace to minor	Rare	Individual acicular crystals	Xp; Sp	(R.A. Sheppard, unpub. data, 1995)
29. Near Reese River, Lander County (sec. 26 and 35, T. 24 N., R. 43 E.)	Tuff in unnamed upper Tertiary lacustrine rocks	Trace to major	Common	Individual acicular crystals and rare woolly fibers	Xo; Xp; So; Sp	Deffeyes (1959); Gude and Sheppard (1981); Papke (1972); Shedd and others (1982)

30. Pine Valley, Eureka County (NW1/4 sec. 20 T. 28 N., R. 52 E.)	Tuff in the Pliocene Hay Ranch Formation	Trace to major	Common	Bundles and aggregates of radiating prismatic crystals	Xo; Xp; So	Deffeyes (1959); Papke (1972); Regnier (1960; Shedd and others (1982)
31. Along Spring Creek, Humboldt County (NW1/4NE1/4 sec. 21, T. 41 N., R. 41 E.)	Tuff in unnamed Miocene lacustrine rocks	Trace to minor	Unknown	Unknown	Xp	Sheppard and Gude (1983)
32. Eastern fork of Chimney Reservoir, Humboldt County (NW1/4SE1/4 sec. 17, T. 41 N., R. 43 E.)	Tuff in unnamed Miocene lacustrine rocks	Trace to major	Common	Unknown	Xp	Sheppard and Gude (1983)
33. Along South Fork Little Humboldt River, Elko County (NW1/4NE1/4 sec. 1, T. 41 N., R. 44 E.)	Tuff in unnamed Miocene lacustrine rocks	Trace to moderate	Unknown	Unknown	Xp	Sheppard and Gude (1983)
34. Near Susie Creek, Elko County (sec. 6, T. 35 N., R. 54 E.)	Tertiary tuffaceous sandstone	Trace	Unknown	Unknown	Xo	(F.A. Mumpton, written commun., 1995)
New Mexico						
35. Near Buckhorn, Grant County (NE1/4SW1/4 sec. 10, T. 15 S., R. 18 W.)	Tuff in a lacustrine facies in the Pliocene (?) upper part of the Gila Conglomerate	Trace to major	Common	Chiefly bundles but rare acicular individual crystals	Xo; Xp; So; Sp	Bowie and others (1987); Eyde (1982); Gude and Sheppard (1988); Olander (1979); Sheppard and Gude (1987)

36. Drill hole (Oberlin No. 2, about 445-564 m depth) in the Plains of San Augustin, Catron County (center of sec. 28, T. 5 S., R. 13 W.)	Volcaniclastic sandstone in Pleistocene sediments	Trace	Unknown	Acicular and rod-like individuals crystals	Xo; So	Sedenquist (1986)
North Dakota						
37. Little Badlands of western Stark County (sec. 7, T. 137 N., R. 97 W.)	Claystone and sandstone in the Oligocene Dickinson Member of the Brule Formation	Unknown	Unknown	Acicular individual crystals	Xo	Stone (1972)
Oregon						
38. Near the Bretz mine, along the northern rim of the McDermitt caldera, Malheur County	Unnamed Miocene tuffaceous sediments	Trace to moderate	Unknown	Unknown	Xo	Glanzman and others (1978); Rytuba (1976)
39. Near Rome, Malheur County (NW1/4NE1/4 sec. 22 T. 31 S., R. 41 E.)	Tuff and tuffaceous sandstone in the Miocene Rome beds	Trace to major	Common	Individual acicular or rod-like crystals and clusters of acicular crystals	Xo; Xp; So; Sp	Campion (1979); Holmes (1990; 1994); Sheppard and Gude (1969c, 1993); Wolf and Ellison (1971)
40. Along Ryegrass Creek, Malheur County (SW1/4 sec. 23, T. 29 S., R. 40 E.)	Tuff in unnamed Miocene lacustrine rocks, possibly equivalent to the Rome beds	Moderate	Unknown	Unknown	Xp	Ferns (1992); Ferns and others (1993); (R.A. Sheppard, unpub. data, 1992)
41. Near Round Mountains, Malheur County (sec. 8 and 17, T. 25 S., R. 46 E.)	Tuff in the Miocene Sucker Creek Formation	Trace	Rare	Unknown	Xo	Holmes (1990); (D.A. Holmes, written commun., 1994)

42. Near Harney Lake, Harney County (NW1/4 sec. 18, T. 28 S., R. 31 E.)	Tuff and tuffaceous sandstone in unnamed Miocene lacustrine rocks	Trace to moderate	Common	Individual acicular or prismatic crystals, bundles, and radial aggregates	Xo; Xp; Sp	Sheppard (1993, 1994); Walker and Swanson (1968)
43. Wrights Point, Harney County (SW1/4SE1/4 sec. 34, T. 24 S., R. 31 E.)	Tuffaceous rocks in the Pliocene Harney Formation	Minor to moderate	Unknown	Unknown	Xo; Xp	(F.A. Mumpton, written commun., 1995); (R.A. Sheppard, unpub. data, 1992)
44. Near Durkee, Baker County (SW1/4SW1/4 sec. 36, T. 11 S., R. 43 E.)	Tuff in unnamed Miocene lacustrine rocks	Trace to major	Common	Individual acicular and rod-like crystals, bundles of hexagonal rods, and rare woolly fibers	Xo; Xp; So; Sp	Eakle (1898); Gude and Sheppard (1986, 1993); Mumpton and Ormsby (1976); Sheppard (1976); Staples (1957); Staples and Gard (1959)
South Dakota						
45. Sheep Mountain Table, Shannon County (NE1/4 sec. 32, T. 4 S., R. 44 W.)	Tuff in the Miocene Sharps Formation	Trace	Rare	Individual fibrous and acicular crystals and clusters of radiating fibers	Xo; Xp; So; Sp	Deffeyes (1959); Raymond (1986); Raymond and others (1982)
Utah						

46. Drill hole (Phillips Sunnyside No. 2) near Sunnyside, Carbon County (sec. 15, T. 13 S., R. 14 E.)	Bitumen-bearing sandstone in the Eocene part of the Colton Formation	Trace	Unknown	Bundles in the sandstone cement	Xo; So	Schenk and Pollastro (1987); (R.M. Pollastro, written commun., 1995)
			Wyoming			
47. Near Fort LaClede, Sweetwater County (SE1/4SE1/4 sec. 1, T. 16 N., R. 98 W.)	Tuff in the Eocene Adobe Town Member of the Washakie Formation	Trace	Rare	Unknown	Xo	Harris and King (1990, p. 31); Roehler (1985)
48. Beaver Rim (northeastward from the SW1/4 sec. 3, T. 30 N., R. 96 W. to the NE1/4 sec. 34, T. 32 N., R. 95 W.), Fremont County	Tuff in the Eocene Wagon Bed Formation	Trace to moderate	Common	Acicular individual crystals	Xo; Xp	Boles and Surdam (1979); Van Houten (1964)
49. Near Moonstone, Natrona County (NE1/4 sec. 17, T. 30 N., R. 89 W.)	Tuff in the Pliocene Moonstone Formation	Trace to moderate	Common	Acicular individual crystals and clusters of rod-like and acicular crystals	Xo; Xp	Mariner (1971)
50. Near Hawks Butte, Hot Springs County (NW1/4 sec. 36, T. 42 N., R. 90 W.)	Volcaniclastic sandstone and tuff in the Eocene Tepee Trail Formation	Minor to moderate	Rare	Clusters of radiating crystals	Xo	Bay (1969)

51. Several drill holes in Lower and Upper Geyser Basins, Yellowstone National Park	Pleistocene volcaniclastic sandstone and conglomerate and volcanic breccia	Trace	Rare	Bundles and individual fibrous to rod-like crystals	Xo; So	Bargar and others (1981); Honda and Muffler (1970); Honda and Sasaki (1977); Keith and Muffler (1978); Keith and others (1978)

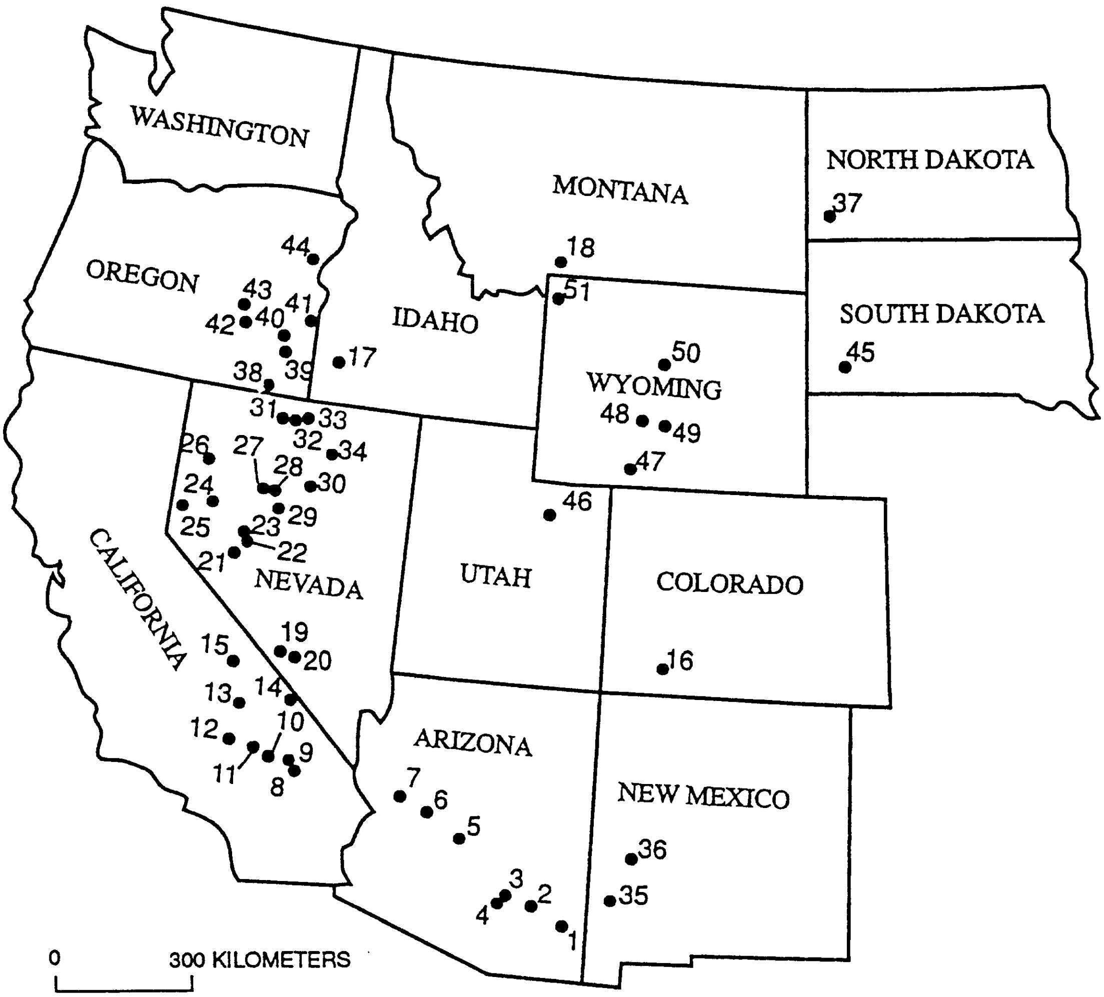

Figure 3. Map showing occurrences of erionite in sedimentary rocks of the western United States. Data for numbered localities are given in table 1.

number, the locality column of table 1 includes a nearby geographic feature, county name, and generally location to the nearest 1/41/4 section. The host rock type and stratigraphic information are given in the occurrence column. The content of erionite in the zeolite-bearing rocks is listed as trace (less than 1 percent), minor (1-10 percent), moderate (11-50 percent), and major (greater than 50 percent). Frequency of occurrence of erionite-bearing rocks at the locality is listed as rare or common.

Arizona

Occurrences of erionite in Arizona seem confined to a northwest-trending band that extends from near Bowie (fig. 3, locality 1) to near Wikieup (locality 7). The frequency of occurrence of erionite-bearing rocks at or near the localities is mostly rare or unknown in Arizona, except near Bowie (locality 1), Bear Springs (locality 2), and Wikieup (locality 7).

The so-called "marker tuff" at the Bowie zeolite deposit has been mined intermittently for chabazite since 1962 (Sheppard and others, 1987). The marker tuff is 22-155 cm thick and crops out discontinuously for about 15 km along the southwestern side of San Simon Valley. Only the basal 10-20 cm of the tuff are mined for chabazite. Erionite commonly makes up a trace of this basal part but makes up as much as 70 percent of the overlying, thin-bedded part that is not processed. The erionite commonly occurs in stubby bundles in both parts of the tuff.

Several zeolitic tuffs crop out discontinuously over a distance of about 12 km north of Cottonwood Creek, near Bear Springs (locality 2). The tuffs are 15-45 cm thick and contain a trace to moderate amounts of erionite in addition to the predominate chabazite (Eyde, 1982; Eyde and Irvin, 1979).

Erionite is common in tuffaceous lacustrine rocks of the Big Sandy Formation near Wikieup (locality 7). At least 13 tuffs, 1 cm to about 1 m thick, crop out for a distance of about 12 km chiefly along the eastern side of the Big Sandy River (Sheppard and Gude, 1973). Although some tuffs, particularly those in the central part of the ancient lake deposit, lack erionite, many contain a trace to nearly 100 percent erionite. The erionite occurs as prismatic or acicular individual crystals or occurs in bundles but rarely in spherulites.

California

Occurrences of erionite are known only from upper Cenozoic lacustrine rocks in southeastern California, chiefly San Bernardino County (fig. 3, table 1). The frequency of occurrence of erionite-bearing rocks at the localities is mostly unknown, except in the Mud Hills (locality 11) and at Lake Tecopa (locality 14) where erionite is common. The abundance of erionite at the localities is mainly in trace to minor amounts, except along the southern flank of the Cady Mountains (locality 9) and at Lake Tecopa (locality 14) where erionite locally makes up nearly 100 percent of certain tuffs (Sheppard and others, 1965; Sheppard and Gude, 1968). At Lake Tecopa, erionite is especially abundant in a conspicuous tuff (tuff A) that crops out along the Amargosa River just south of Shoshone to near Tecopa, a distance of about 14 km.

In addition to erionite occurrences in shallow parts of a drill hole near the Hector hectorite mine (locality 8), erionite-rich tuffs crop out just beneath a Pleistocene basalt flow close to the mine (Sweet, 1985). Correlation of these tuffs with those along the southern flank of the Cady Mountains to the north remains uncertain, but they may be parts of the same stratigraphic unit.

Colorado

The only reported occurrence of erionite in Colorado is in the tuffaceous Oligocene Creede Formation (locality 16), which is the sedimentary moat fill of the Creede caldera (Larsen and Crossey, 1994). According to Daniel Larsen (written commun., 1995), erionite commonly occurs throughout the depositional basin in trace amounts in the upper

400 m of the formation. Although it is most common in basinal lacustrine deposits, it also has been recognized in lake-margin alluvial deposits.

Idaho

Occurrences of erionite in Idaho are restricted to tuffs in the Miocene Chalk Hills Formation along Browns Creek (locality 17) south of Oreana and about 2 km to the east. Chiefly trace amounts of erionite were recognized only rarely, even though most tuffs in this area are zeolitic and consist mainly of clinoptilolite, smectite, and opal-CT (Sheppard, 1991). The erionite occurs as threadlike fibers or clusters of threadlike fibers. Where associated with clinoptilolite, the erionite commonly formed later than the clinoptilolite and is draped across the blocky to platy clinoptilolite.

Montana

The only reported occurrence of erionite in Montana is about 25 km north of Gardiner (locality 18). Barnosky and others (1988) recognized small amounts of erionite in Miocene lacustrine rocks at Hepburn's Mesa in the Yellowstone Valley where about 150 m of tuffaceous sediments contain major amounts of clinoptilolite.

Nevada

Except for two localities (fig. 3, localities 19 and 20) near Beatty, the occurrences of erionite are in the northern and central parts of Nevada. Deffeyes (1959) was first to report that erionite was not as rare as had been previously believed. He documented the common and abundant occurrence of erionite in silicic, vitric tuffs that had been deposited in Cenozoic lakes of central Nevada. Papke (1972) mapped and studied in detail four of the erionite deposits (localities 23, 27, 29, and 30) that had been prospected by several companies, including Union Carbide Corporation, Shell Development Company, and Mobil Oil Corporation. Of all the high-grade erionite deposits in Nevada, only several hundred tons of erionite-rich tuff were mined from Jersey Valley (locality 27) by Mobil Oil Corporation.

Most erionite occurrences in Nevada are in upper Cenozoic tuffaceous, lacustrine rocks. The thickness of the erionite-bearing tuff is less than 1 cm to more than 1 m, and the erionite content ranges from a trace to nearly 100 percent. At Jersey Valley (locality 27), two erionite-rich beds can be traced along strike for about 5.5 km. Most erionite-rich tuff is yellow or light orange. Erionite coexists with analcime, chabazite, clinoptilolite, mordenite, and phillipsite, but the association with clinoptilolite is most common. At the Reese River occurrence (locality 29), some erionite has a woolly appearance (Gude and Sheppard, 1981) and resembles the type erionite from Durkee, Oregon (locality 44). Most erionite from the lacustrine deposits occurs as acicular or prismatic crystals or as bundles or aggregates of radiating acicular crystals.

Ash-flow tuffs at Yucca Mountain (locality 20) and near Fish Creek (locality 28) rarely contain trace amounts of erionite. Erionite has been recognized only in the subsurface at Yucca Mountain. At both localities, the erionite coexists with clinoptilolite.

New Mexico

Erionite has been reported only from southwestern New Mexico where it occurs in a lacustrine facies of the Gila Conglomerate near Buckhorn (locality 35) and in a drill hole that penetrated Pleistocene sediments on the Plains of San Augustin (locality 36). Trace to major amounts of erionite are common in a conspicuous marker tuff in the upper part of the Gila Conglomerate (Gude and Sheppard, 1988). This tuff is about 0.5-2.7 m thick and crops out along the southwest side of Duck Creek for a distance of about 6 km. The erionite occurs chiefly in bundles and coexists with clinoptilolite and analcime. Finnell (1987) described an erionite-bearing tuff in the Gila Conglomerate about 4.5 km southeast of Gila. The tuff contains trace to minor amounts of erionite that coexist with chabazite and phillipsite. Although this site is near the Duck Creek occurrences, correlation with the tuff near Buckhorn was not possible.

Pleistocene volcaniclastic sandstone in the subsurface on the Plains of San Augustin (locality 36) contains trace amounts of acicular to rod-like erionite (Sedenquist, 1986). The erionite coexists with clinoptilolite and analcime.

North Dakota

The only reported occurrence of erionite is in the Little Badlands of southwestern North Dakota (locality 37). Stone (1972) briefly described acicular erionite from claystone and sandstone in the Oligocene Dickinson Member of the Brule Formation. The erionite coexists with clinoptilolite, but its abundance was not reported.

Oregon

Occurrences of erionite are known only from upper Tertiary rocks in east-central and southeastern Oregon. The frequency of occurrence of erionite-bearing rocks at or near the localities is mostly unknown or rare except near Rome (locality 39), Harney Lake (locality 42), and Durkee (locality 44). The host rock for the erionite in Oregon is chiefly lacustrine tuff. Major amounts of erionite have been recognized at the Rome and Durkee localities.

Erionite-bearing rocks are especially common in the Miocene Rome beds over an elongated north-south area of about 550 km^2, chiefly between Rome and Crooked Creek to the west (Campion, 1979). The Rome beds are at least 100 m thick and consist of alluvial and lacustrine rocks that were rich in volcaniclastic material. Although erionite occurs in most rock types throughout the area, it is most abundant in two conspicuous tuffs (Sheppard and Gude, 1993). The lower marker tuff is light yellowish green, commonly 3-6 m thick, and commonly consists of major amounts of erionite, locally nearly 100 percent. This erionite-rich tuff has been the chief source of material used in biological experiments in the United States as well as overseas. The erionite occurs as individual acicular or rod-like crystals and as clusters of acicular crystals. The upper marker tuff is 6-7 m thick, but only a meter-thick orange unit near the middle of the tuff contains erionite. The upper part of the orange unit locally contains as much as 80 percent erionite which coexists with clinoptilolite.

Erionite is widespread in the unnamed Miocene tuffaceous, fluvial and lacustrine rocks near Harney Lake, but it is most common and abundant at the southern part of the area (Sheppard, 1994). The erionite content of the tuffaceous rocks ranges from a trace to about 50 percent. Erionite occurs as acicular, fibrous, or prismatic crystal that are 2-500 µm long. Locally, the acicular or prismatic crystals are in bundles or radial aggregates. Erionite coexists with analcime, chabazite, clinoptilolite, mordenite, and phillipsite, but it most commonly coexists with clinoptilolite. The erionite postdates all the above zeolites except analcime.

The opal mine just north of Swayze Creek near Durkee (locality 44) is the type area for erionite. Here, the woolly variety of erionite occurs in veinlets of a gray, silicic, welded ash-flow tuff which is at or near the base of an unnamed Miocene lacustrine sequence that is rich in volcaniclastic material (Gude and Sheppard, 1986; 1993). Although the type woolly erionite is difficult to find at the abandoned opal mine, small fragments were still recognizable there as recently as 1995. Woolly erionite was not recognized elsewhere near Durkee. An area of lacustrine rocks of about 18 km^2 near Durkee (Gude and Sheppard, 1986) is rich in zeolites, including erionite, chabazite, clinoptilolite, mordenite, phillipsite, and analcime. Most of the zeolites occur in lacustrine tuff that ranges in thickness from less than 1 cm to more than 1 m. Acicular to rod-like erionite makes up a trace to nearly 100 percent of the tuff and commonly is distributed throughout the zeolitic area.

South Dakota

Erionite is reported only from tuffaceous rocks in the Miocene Sharps Formation of southwestern South Dakota (Raymond, 1986; Raymond and others, 1982). The erionite has been rarely recognized, and it occurs only in trace amounts. At Sheep Mountain Table (locality 45), the erionite occurs as white, silky fibers as much as 200 μm long in irregular vugs of a clinoptilolite-rich tuff, just beneath the table surface.

Utah

The only occurrence of erionite in Utah is from a single drill hole that penetrated the Eocene part of the Colton Formation near Sunnyside (locality 46). Trace amounts of erionite were recognized by X-ray diffraction and scanning electron microscopy in alluvial, bitumen-bearing sandstone (R.M. Pollastro, written commun., 1995). The erionite occurs in stubby bundles (less than 10 μm long) of acicular crystals.

Wyoming

Erionite-bearing rocks are common at two sites in south-central Wyoming: along Beaver Rim in Fremont County (locality 48) and near Moonstone in Natrona County (locality 49). Elsewhere, erionite-bearing rocks are rare at the erionite occurrences. At Beaver Rim, lacustrine tuff in the Eocene Wagon Bed Formation contains trace to moderate amounts of erionite (Boles and Surdam, 1979). The erionite occurs chiefly as acicular crystals, and it commonly postdates the coexisting clinoptilolite. Near Moonstone, lacustrine tuffaceous sandstone and tuff in the Pliocene Moonstone Formation contain trace to moderate amounts of erionite (Mariner, 1971). The erionite occurs as acicular crystals and clusters of rod-like and acicular crystals, and it commonly coexists with clinoptilolite.

Tuff in the Eocene Adobe Town Member of the Washakie Formation near historic Fort LaClede (locality 47) contains a high-grade clinoptilolite deposit that has been commercially prospected and mined (Harris and King, 1990, p. 31). A trace amount of erionite has been reported from this deposit by Harris and King (1990). R.E. Harris (oral commun., 1995) confirmed to me that one sample of the clinoptilolite-rich tuff, collected from the deposit by the Wyoming Geological Survey, showed a trace amount of erionite as determined by X-ray diffraction. Inasmuch as numerous investigators, including me, have studied samples from this deposit by X-ray diffraction and scanning electron microscopy and could not confirm the presence of erionite, perhaps the reported trace of erionite should be regarded as equivocal.

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