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Reconnaissance geology and resources of Miocene diatomite, Trinity Pass Area, Pershing County, Nevada

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ABSTRACT

Deposits of Miocene diatomite in the Trinity Range, west of Lovelock, have supported significant mining for more than 30 years. Gently dipping sequences of diatomite and tuff, comprising more than 100 m of high quality diatomite, are mass mined in four open-pit mines. The high quality diatomite is processed at Colado for filter aids and fillers. The diatomite formed at about 15 Ma in a freshwater lake created during the early stages of Basin-and-Range faulting and volcanism. The deposits were preserved by unusually gentle Tertiary tectonics. Technical properties of the diatomite were protected from destructive diagenesis by uplift shortly after deposition, and protected from erosion by cover afforded by rhyolite, basalt, and gravel. Geologic relations support a likely large inferred resource of diatomite, under less than 30 m of cover, that is favorable for future mining.

INTRODUCTION

Diatomite deposits in the Trinity Range, Pershing County, have been known since 1923 and have been mined by a major operation since 1958 (Johnson, 1977). Diatomite, also termed diatomaceous earth, is a low density, fine-grained, sedimentary rock composed of the siliceous shells (frustules) of microscopic plants called diatoms (forms of brown algae). Because of itsunusual properties--low density, high porosity and surface area, brightness, and inertness--diatomite has many industrial uses as filter aids, fillers, insulation, and absorbents. Diatomite may form in either fresh or salt water. The Trinity Range deposits formed in a Miocene freshwater lake, as did other Tertiary diatomite deposits in Nevada. Production and reserve data are not available, but geologic relations in the area indicate large undeveloped resources that could support mining for many years.

Four open-pit mines operated by Eagle Picher Minerals, Inc. develop diatomite in Miocene tuffaceous sedimentary rocks that are close to the surface over an area of about 40 sq. km.on the western slope of the Trinity Range, about 30 km west of Lovelock (fig. 1). The diatomite mines have been included in the Velvet mining district (Johnson, 1977), named for a group of gold-silver mines with modest production, but Trinity Pass is a more prominent location, and this locality name will be used in this report. Land status is a mix of private lands belonging to the Southern Pacific Railroad and public lands administered by Bureau of Land Management.

Preservation of diatomite will be mentioned frequently in this report, and this emphasis may puzzle some readers. Preservation is necessary for any ore deposit to be viable but is especially significant for commercial diatomite deposits that are easily eroded and ruined by diagenetic alteration. The technology of diatomite production (Lenz and Morris, 1993) focuses on classification for various commercial uses and on removing water that adds to weight and shipping expenses. Ore is stacked at the mine sites to allow solar drying, then transported 40 km in specially built 60-cubic-yard ore trailers to the Colado plant on the Southern Pacific Railroad and Interstate 80. At the plant, the ore is dried, calcined, or size classified according to the application (Lenz and Morris, 1993). The Trinity Pass deposits yield high quality

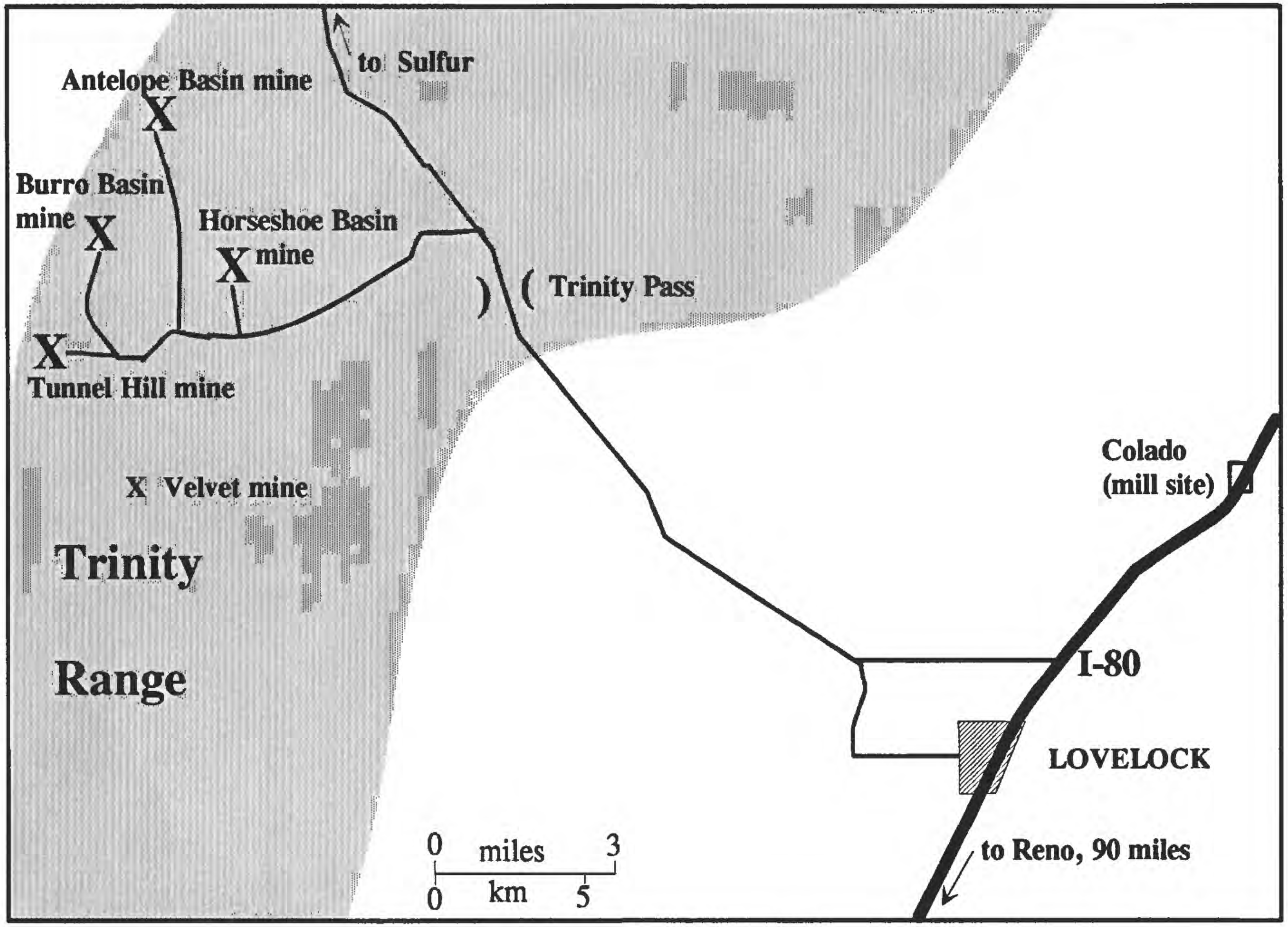

Fig. 1. Location of diatomite deposits near Trinity Pass, Pershing County, Nevada
The four mines of Eagle Picher Minerals, Inc., are shown by the large X's.

diatomite that is chiefly utilized as filter aids and functional fillers.

The general geology and technology of diatomite are reviewed elsewhere (Bates, 1960; Barron, 1987;

Lenz and Morris, 1993). This paper treats only geologic aspects of the Trinity Pass diatomite deposits and their geologic history in the Tertiary and Quaternary with the goal of assessing the magnitude of the diatomite resources. The discussions that follow and the geologic map are based on five days of reconnaissance fieldwork in June of 1994. This investigation was undertaken as part of the mineral resource assessment of the Winnemucca Resource District of the US Bureau of Land Management.

ACKNOWLEDGEMENTS

This study was made possible by the cooperation of Eagle Picher Minerals, Inc. M. M. Moezzi, chief mine geologist and engineer provided essential geologic information and a field tour of the mine area. My brief studies were greatly aided by Moezzi's 35 years of exploration and mining experience in the area. Errors in this report are those of the author and should not be attributed to Moezzi or to Eagle Picher Minerals, Inc. Tony Gibbons and Don Sawatzky, USGS, provided helpful comments on the manuscript.

PREVIOUS STUDIES

Relatively little information on the Trinity Pass diatomite deposits has been published. The deposits were briefly described in the Pershing County report (Johnson, 1977), including technical information from a communication by M. M. Moezzi. An excellent overview of diatomite in Nevada, and the deposits at Trinity Pass in particular, is provided by Lenz and Morris (1993). Geology of the Tertiary rocks in the area is described in Johnson (1977) and shown on the accompanying geologic map at a scale of 1:250,000. This map of Pershing County necessarily utilized generalized units having few age limitations; the diatomite-bearing "tuff and sedimentary rocks" unit (Pliocene-Miocene) appears to be younger than the "rhyolite" map unit (Miocene-Oligocene), but there was no definitive age data.

GEOLOGIC SETTING

Stratigraphy

The generalized stratigraphy of the Trinity Pass area is shown in figure 2. The sequence, from oldest to youngest, includes:

1. **Mesozoic metasedimetary rocks (Mzs)** exposed in the southwestern part of the study area. Typical lithologies are gray-green phyllite and gray quartzite. Thickness is not known because the base is not exposed. These rocks are probably part of the Auld Lang Syne Group (Burke and Silberling, 1973; Johnson, 1977).

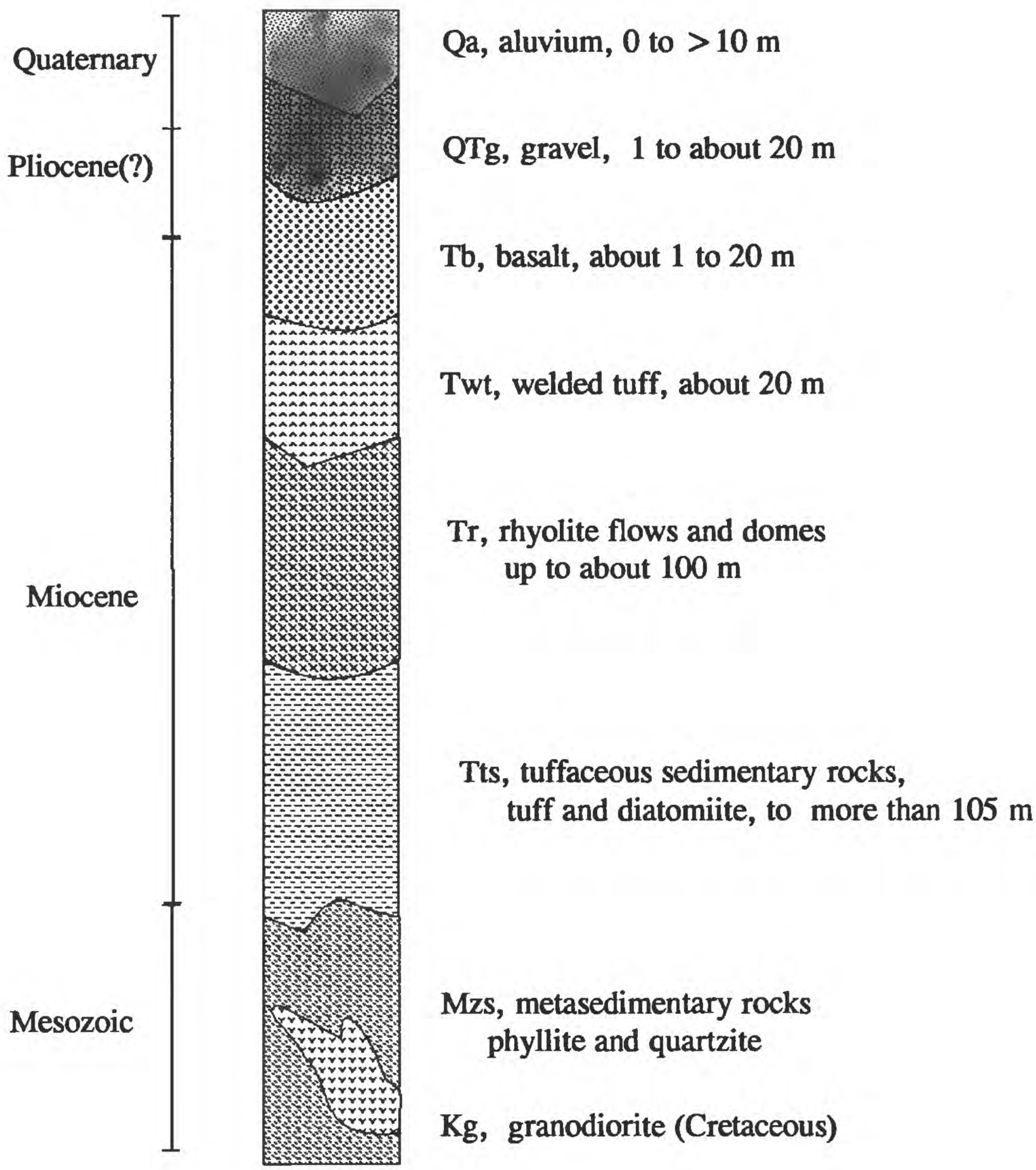

Figure 2. Stratigraphic column for the Trinity Pass area, Pershing County, Nevada

2. **Cretaceous granodiorite (Kg)** intrudes the metasedimentary rocks at Trinity Pass and is part of a large pluton that crops out in the Trinity Range (Johnson, 1977).

3. **Miocene tuffaceous sedimentary rocks (Tts)** including diatomite, tuff, and tuffaceous sandstone. Lavas of intermediate composition are present locally. This unit comprises rocks similar to those in the "Tuff and sedimentary rocks" unit of Johnson (1977).

4. **Miocene rhyolite** lavas and domes **(Tr)** overlie and intrude unit 3. Although compositions probably range from dacite to rhyolite, for simplicity the unit will be called rhyolite. There are many similar-appearing felsic flows and intrusions in the region, with possible ages of Oligocene to Miocene (Johnson, 1977), and probably are of several ages in the study area. Available physical evidence suggests that all rhyolites in the Trinity Pass area are younger than the diatomite-bearing unit.

5. **Miocene welded tuff (Twt)** overlies rhyolite flows in the northern part of the area. A bed of air-fall crystal tuff underlies the welded tuff. Biotite from a latite dike in this unit yielded an age of 12.7 Ma (McKee and Marvin, 1974).

6. **Miocene to Pliocene(?) basalt** flows **(Tb)** that overlie rhyolite and welded tuff are of more than one age. Flows that follow drainages that are nearly the same as modern ones appear to be very young (Pliocene?). A local unit of basaltic debris flow, exposed only in the Antelope Basin open pit (fig. 2), is apparently related to relatively recent basaltic volcanism and normal faulting on the western margin of the Trinity range.

7. **Pliocene to Quaternary gravel (QTg)** comprised chiefly of metasedimentary rock clasts overlies Tertiary units on the west side of the range. Age of the gravel is not well defined but is estimated to be Pliocene because the deposits are not related to modern drainages, are cut by younger alluvial channels and by range-bounding normal faults, and are weakly lithified.

8. **Quaternary alluvium (Qa)** fills modern drainages and overlies Pliocene gravel on the west side of the range. Composition of clasts in these alluvial deposits of silt, sand, and gravel generally reflects that of rocks cropping out nearby.

STRUCTURE

Tertiary structure of the Trinity Range is seemingly like that of most of western Nevada, yet there are differences that are important for the diatomite deposits. The range is an uplifted block, bounded by north-trending normal faults that are typical of the Basin-and-Range province, which became active about 16 m. y. ago (Christiansen and McKee, 1978; Johnson, 1977). Processes in the earliest stages of Basin-and-Range extensional tectonism created volcanic rocks and the basin that hosted a Miocene lake, both essential for development of diatomite. Later (post-diatomite) structural activity uplifted the range. However, structure within the uplifted block (Trinity Range) appears to be simpler than in most of the region. Normal faults with north-south as well as east-west strike cut the Tertiary rocks but produce only minor amounts of tilt. The low dip of most diatomite strata is an important factor in their economic viability as it allows efficient bulk mining by scrapers.

Tertiary structures are generally not well exposed in the soft tuffaceous sedimentary rocks but are clear in the diatomite mines. High-angle faults with a few meters of displacement are exposed in the Tunnel Hill and Horseshoe Basin pits, and several faults with 10 to 20 m of displacement are exposed in the Antelope Basin pit (pl. 1). Displacements of up to 40 m are known in the Antelope Basin pit area (Lenz and Morris, 1993). Sedimentary rocks are locally arched adjacent to rhyolite domes. Compared to others parts of the Basin-and-Range Province, the magnitude of Tertiary deformation in the area is only moderate, suggested by the generally low dips of less than 10 degrees for most Tertiary units. The major faults are along the margin of the range. The modern surface in the Trinity Pass area appears to be similar to that at about 15 Ma.

Structural geometry of the Miocene lake is presumed more complex than evident in the area of the mines. The nature and location of the bounding faults are not known. The style of sedimentation at the basin margins would be of scientific interest, but economic deposits of diatomite would not be expected at those locations. Internal facies changes are not evident in my reconnaissance observations. However, more detailed geologic mapping and drill cutting logs indicate there are stratigraphic changes in the commercial diatomite zone such as would be created in sub-basins (M. M. Moezzi; oral commun., 1994; Lenz and Morris, 1993). The deeper portion of the basin favorable for significant diatomite deposition must have exceeded 15 km (SW-NE) by 20 km (NW-SE) in width and length.

Rhyolite flow-dome complexes erupted along fault or fracture zones and indicate the general locations of Miocene faults in the Trinity Pass area as they do elsewhere in northwestern Nevada (Nash and others, 1995). Steeply dipping flow foliation is observed in the vicinity of feeder zones. The dip of flow foliation fans out from the feeders and is generally less than 10 degrees in the distal flows.

COMMENTS on GEOLOGIC UNITS

Tertiary rocks that underlie the diatomite-bearing tuffaceous sedimentary rock unit (Tts) are not well exposed in the central part of the study area and were not studied. The stratigraphy and lithology of pre-diatomite, Miocene sedimentary and volcanic rocks of the Velvet area, about 3 km south of the Tunnel Hill mine, were briefly described by Masterson and Kyle (1984). The pre-diatomite rhyolite flows, tuffs, and volcaniclastic sedimentary rocks of the Velvet area (Masterson and Kyle, 1984) are lithologically similar to units in the Trinity Pass area that I interpret to be younger than diatomite. More geologic mapping and geochronologic studies are needed on to better define age relations and possible multiple cycles of rocks having similar features.

The Tertiary tuffaceous sedimentary rock unit (Tts) is highly variable in composition within the study area. Outcrops, trenches, and mine exposures suggest it is chiefly a mixture of two end-members, air-fall tuff and diatomite, deposited in a lacustrine environment. A third variant, volcaniclastic sandstone, occurs high in the section and appears to be fluvial in origin. Lava flows of intermediate composition are present in areas distant from the mines and were not studied; these rocks may have been deposited on the margins of the lacustrine basin and certainly are not typical of the part of the basin that accumulated the thickest and best deposits of diatomite.

The tuffs--often referred to as ash in the literature--are rich in pumice, glass shards, and crystals of feldspar. Beds are compositionally uniform across several meters, and their thickness is remarkably consistent for hundreds of meters laterally in the pits. The beds show almost no internal structures, but the base or top may show some minor scouring and sorting. Rip-up clasts of diatomite enclosed in tuff are present in a few exposures. Petrographic studies reveal that clasts of pumice and glass, generally 0.2 to 1 mm in size, are fresh and uncompacted. Chemical analyses of two typical pumice tuffs show 70.4 to 71.6 wt percent SiO_2 (anhydrous basis). A tan tuff below diatomite has 62.3 wt percent SiO_2.

Diatomite beds are massive in color, texture, and density across thicknesses of up to several meters, but also display millimeter-scale lamination or varves. A diatomite specialist presumably would point out numerous features that are more diagnostic of depositional conditions or technical properties. Soft-sediment structures are fairly common in tuff-diatomite sequences exposed in trenches and pits. Load structures in which gray tuff displace and deform white diatomite are spectacular in several pit faces. Dikes of tuff injected into overlying diatomite strata also are fairly common. The thick sequences of tuff and diatomite show delicate bedding features (exposed in the pits) that suggest they accumulated under very stable subaqueous conditions; input of terrigenous clastic material was minor in the commercial zones of diatomite. Interbeds of lacustrine limestone and animal or plant fossils, common in lacustrine diatomite sequences elsewhere, are not present.

A distinctive unit of volcaniclastic sandstone having green-gray color and medium grain size is well exposed in parts of the west wall of the Antelope Basin pit. It was deposited on an irregular, erosional surface into diatomite, and contains more sorting and bedding variability than the tuffs. A section about 30 m thick is exposed in the west wall of the pit; thicknesses up to 50 m in drill holes are reported for the Antelope Basin area (Lenz and Morris, 1993). This sandstone appears to reflect a change in environment from lacustrine to fluvial, and possibly could be substantially younger in age. The sandstone protected the diatomite from erosion (Lenz and Morris, 1993).

Rhyolite flows and domes are a prominent feature of the Trinity Pass area. Excellent exposures reveal systematic changes in flow foliation from near vertical at intrusive vents to low angles on the flanks of domes. Fabrics in the flows and domes indicate the magma was viscous, typical of silicic compositions (Williams and McBirney, 1979). Thicknesses are variable, in the range of tens to hundreds of meters. The lavas appear to have flowed over a landscape of sedimentary rocks with low relief. Intrusive and extrusive contacts with diatomite and tuff are passive and barely altered, consistent with observations elsewhere in Nevada and Idaho (R.F. Hardyman, USGS, oral commun., 1995). The most dramatic activity is local arching of strata by about ten degrees near domal intrusions. The lack of hydrothermal brecciation and alteration along contacts suggests that the rhyolite bodies were emplaced subaerially rather than into the diatomite-forming lake. Extrusion or intrusion of rhyolite into a lake would have caused phreatic explosions, brecciation of rhyolite, and widespread hydrothermal alteration (Williams and McBirney, 1979).

The rhyolites contain 20 to 30 percent phenocrysts in an aphanitic to vitreous groundmass that is highly flow banded. Sanidine and plagioclase are approximately equal in abundance and 1 to 2 mm in size; quartz and biotite phenocrysts are sparse (0 to 2 percent each). The rhyolites are fresh to devitrified in the study area; the originally glassy groundmass is variably recrystallized (the cause of color variation), but feldspars are invariably unaltered. Chemical analyses of two fresh samples show 70.4 and 74.6 wt percent SiO_2 (anhydrous basis). Lithologically similar rhyolite flow-domes in the Seven Troughs and Velvet mining districts are pervasively altered. Hydrothermal alteration was expected where the rhyolites intrude diatomite, but the lack of alteration at these eruption centers in the Trinity Pass area is noteworthy.

The welded tuff unit is a distinctive fragmental rock containing clasts of pumice up to 2 cm in size, fragments of volcanic and basement rocks, and abundant coarse crystals of plagioclase, sanidine, and hornblende or biotite. The degree of welding is moderate; pumice clasts were compacted about 50 percent, and there was some flow around clasts. The welding and vapor-phase alteration impart a platy fabric. A poorly exposed bed of white, soft, air-fall crystal tuff about 3 m thick underlies the well-exposed brown welded tuff, which is about 20 m thick. The welded tuff is not exposed in the vicinity of the diatomite mines but must have formerly covered the deposits because the tuff is present 10 to 30 km away in the Trinity Range and in Blue Wing Mountains to the west (Johnson, 1977).

The basalts are indistinctive dark green to black lavas containing sparse olivine and plagioclase phenocrysts. Textures are variably aphanitic to vesicular depending upon position in the flow. Feeder dikes have similar compositions and aphanitic texture. No attempt was made to distinguish sub-units based on composition or age, although a range in ages is likely as previously discussed. Most of the flows in the central part of the study area are relatively thin and aggregate less than 20 m and commonly is a veneer of talus or strath boulders.

DIATOMITE DEPOSITS

The geology and distribution of diatomite in the Trinity Range is well known from mapping, exploration drilling and trenching, and mining by the Southern Pacific Co. and by Eagle Picher Minerals, Inc. since 1958. M.M.Moezzi, involved as geologist and mining engineer since the outset, is the chief source of information on the diatomite deposits, but only short excerpts of the geologic information is published (Johnson, 1977; Lenz and Morris, 1993). Most information is for diatomite that is close to the surface and accessible by shallow mining operations, thus does not characterize the sub-economic parts of the diatomite-bearing basin. There has been no economic incentive to drill into deeper or thinner beds of diatomite or to define in detail the likely facies changes within the lacustrine basin.

Diatomite is currently (1995) mined from four large open-pit mines: Horseshoe Basin, Antelope Basin, Tunnel Hill, and Burro Basin (fig. 1). Size of the pits ranges from about 300 to 2,000 m long, 200 to 600 m wide, and 30 to 80 m deep. Stripping ratios appear to be very low; to the eye, approximately equal amounts of waste (covering alluvium or basalt, tuff, and low quality diatomite) and ore-grade diatomite are mined. Numerous exploration pits and trenches, made chiefly in the 1960's, provide geologic and technical information on diatomite beds. Diatomite from these localities is generally similar in appearance but differs in technical properties that affect applications and value (M.M. Moezzi, personal communication, 1994). Mining engineering attributes, such as strip ratio, also are a prime determinant of mine location (the diatomite beds clearly extend beyond the open cuts. Information to estimate where commercial grade diatomite might occur below the current mining level and which might constitute ore under appropriate economic scenarios in not available. Geologic relations indicate large resources of diatomite between and beyond the mined zones, and future mining operations probably will focus on these near-surface zones rather than extensions at depth.

The Tunnel Hill mine, developed near the original outcrop of diatomite discovered by a local rancher and named for a small exploration adit dug into diatomite, is relatively small. There was a thin veneer of basalt above the deposit, thus very little stripping was required. Two dikes of basalt intrude diatomite and must be avoided in mining. Only a small amount of tuff is present, and the mined diatomite zone was about 40 m thick (Lenz and Morris, 1993). Massive to thin beds of diatomite dip less than 10°E except near the dike in the west wall of the pit.

The Horseshoe Basin mine is a larger, deeper cut into a section of diatomite and tuff that is about 105 m thick. A thick bed of tuff (36 m) is near the top of the section; it displays remarkable loading structures into diatomite at its base. Other thin tuff beds a few meters thick occur lower in the section. The base of the deposit is a tan tuff of intermediate composition. I do not have information on the section below the tan tuff. Dips in the Horseshoe Basin pit range from 5 to about 20° NW.

The Burro Basin mine is relatively small but developed nearly pure diatomite below a thin cap of tuffaceous sandstone and cover of gravel. Diatomite beds are gently draped, changing from flat to 10° W dip across the pit. Basalt caps the hill adjacent to the pit and has protected the diatomite from erosion.

The Antelope Basin open pit is long and narrow, trending down a graben between north-striking normal faults (Lenz and Morris, 1993) that displace gravel deposits. On the east wall of the pit, truncated by a normal fault, is a debris flow containing boulders of basalt up to a meter in diameter. The basaltic debris flow is in fault contact with Pliocene(?) gravel that contains only quartzite and phyllite clasts. The section mined, nearly pure diatomite, ranges from 20 to 50 m thick over the 2 km length of the mine and dips less than 10° W except where dragged along the bounding normal faults. A massive tuffaceous sandstone as much as 50 m thick covers the diatomite zone.

Diatomite exposed in test pits and trenches generally resembles that in the larger mines. To the eye, diatomite in test cuts between the Tunnel Hill and Burro Basin pits (section 25, pl. 1) is not altered in color or hardness within tens of meters of the large rhyolite dome in that area. Diatomite, being very soft, is rarely present in natural exposures, thus it is difficult to make even qualitative estimates of amounts of diatomite relative to tuff or sandstone in the sedimentary sections. No limestone beds were noted in the field, and none have been identified by M. Moezzi (Oral commun., 1994). Limestone or course-grained clastic lithologies may exist at the margins of the Miocene basin but have not been identified.

DISCUSSION

Diatom paleobiology

Concepts of diatom growth (Barron, 1987; Lenz and Morris, 1993;) provide a framework for understanding the Trinity Pass deposits. Diatoms are microscopic, single-cell plants (brown algae). They live by photosynthesis and require chiefly sunlight, carbon dioxide, and silica. Seasonal temperature changes in bodies of water can cause turnover and input of nutrients such as nitrate and phosphate from cooler, deeper zones to the surface, which can cause very rapid growth (bloom) of diatoms. Diatoms secrete siliceous material to form ornate shells (frustules) that have consistent form related to species. It is these frustules, with their unique and complex shapes, that accumulate as the siliceous sediment. The deposits in Nevada, all lacustrine, are characterized by two genera of diatoms, along with lesser amounts of siliceous sponge and flagellaria (Lenz and Morris, 1993). These biota suggest the lacustrine environment was deep water, seasonally eutrophic, temperate, and alkaline.

Several geochemical conditions are required for the robust growth of diatoms needed to produce economic deposits: (1) high concentrations of soluble silica, generally related to volcanism; (2) pH in the range of 6 to 8; (3) low ratios of Na:K and Ca:Mg (ie relatively high K and Mg); (4) high boron; (5) high phosphate and nitrate, generally in upwelling currents. Geochemical factors are reviewed by Barron (1987) and by Lenz and Morris (1993).

Climate in the middle Miocene can be extrapolated from that deduced for the Pyramid Lake area (Axelrod, 1992), 75 km to the southwest. At Pyramid Lake, fossil flora in diatomite, estimated to be 15.6 Ma, indicate a mean annual temperature of about 13.5 °C, and annual precipitation of about 900 mm. The forest environment near Pyramid Lake resembled that now in northwestern California. Axelrod (1992) inferred that the deciduous hardwoods of the Pyramid flora reflected a climate indicating that the Sierra Nevada were present but relatively low in elevation to the west. Plant fossils have not been found in the Trinity Pass diatomite to corroborate the evidence for the Pyramid area, but the relative proximity of the two areas suggests that the Pyramid model can be applied to the Trinity diatomite.

DIATOMITE FORMATION and PRESERVATION

Economic viability of the Trinity Pass diatomite is related to the approximately 15 million years of Tertiary history of the area. Formation and subsequent preservation of these delicate materials was a delicate balance of constructive and destructive processes related to Basin-and-Range extension. Based on my brief studies, I concur with Lenz and Morris (1993) regarding the importance of preserving the diatomite strata by Tertiary faulting and by younger covering rocks.

At least four geologic stages of formation and preservation are evident in the Trinity Pass area. (1) Early Basin-and-Range extension that created the basin, freshwater lake, and siliceous volcanism at about 15 Ma to make the environment for diatom growth. (2) Rhyolitic volcanism at about 14 Ma created flow-domes that covered the soft sediments and protected them from erosion. Volcanic features suggest that the lake was dry by this time. Diagenetic reactions in the diatomite were minor; whether related to the drying of the lake, lack of deep burial, or other reasons. (3) Basaltic volcanism in late Miocene to Pliocene also provided protection for the easily eroded diatomite that was exposed in this period. (4) Pliocene to Quaternary faulting helped protect deposits from erosion in two ways: by downdropping along range-front faults at the west side of the range (Antelope Basin mine area), and by creating conglomerate that was deposited on the diatomite-bearing rocks. The magnitude of the fault displacements, up or down, was relatively small compared to many ranges in Nevada: the topography of the area was maintained like that of today for nearly 15 Ma. Diatomite beds were only gently arched. Steep tilting, as seen in Tertiary rocks in many parts of Nevada, would have adversely impacted the economics of bulk mining.

Preservation of diatomite qualities that make them commercial also requires isolation from diagenetic conditions, such as deep burial, elevated temperatures, and alkaline pore waters (Barron, 1987) that destroy delicate frustules. Research on the diagenesis of opal, in the form of diatoms, radiolaria, and chert (reviewed by Knauth, 1994) indicates these materials are extremely reactive and readily compact and recrystallize to other forms that do not have the desired properties of unaltered diatomite. Temperatures of less than 30° C cause significant recrystallization. Considering the evidence for volcanism during and after diatomite deposition, it is remarkable that the Trinity Pass deposits escaped diagenetic alteration. The most likely explanation is that the diatomite-bearing sediments were uplifted shortly after deposition, the lake eliminated, and pore fluids drained before diagenesis could proceed very far. This scenario is supported by the evidence mentioned earlier for the subaerial emplacement of rhyolite flows and domes but requires very specific timing and styles of faulting at about 14-15 Ma.

The age of the diatomite is not known in detail. No fossils have been found in the sedimentary rocks. The overlying rhyolite flows have not yet been dated. Similar rhyolite on the east side of the Trinity Range, about 15 km away, yielded a K/Ar age of 14.4 Ma (McKee and Marvin, 1974). A minimum age of 13.7 Ma is inferred from adularia in gold-bearing veins (Silberman and others, 1973) in post-diatomite rhyolite, Seven Troughs district, 20 km to the west. Samples of rhyolite from the area are being analyzed by K/Ar methods, and if a date on that unit is reliable it will provide a limit on the age of the diatomite. Regional studies of Miocene tuffs by W. P. Nash, University of Utah (written commun. to M. M. Moezzi, 1994) include samples from the Trinity Pass diatomite mines and may yield a more direct age. Available information suggests that the age of the diatomite is about 15 Ma.

DIATOMITE RESOURCES

The bedded character of the diatomite deposits, lack of evidence for rapid lateral facies changes, and minor structural complexity, permit relatively reliable geologic assessment of resources (nomenclature defined in Appendix I) adjacent to current mining reserves. The reserves (measured resources), as defined by Eagle Picher Minerals, Inc. are proprietary. Two types of inferred resources are evident from geology: (1) *highly prospective*, generally below shallow cover; and (2) *moderately prospective,* generally below cover that is more than 30 m thick and probably too thick to allow open-pit mining.

Areas of inferred diatomite resources are shown on figure 3. Geologic relations indicate that strata likely to contain diatomite underlie most of the study area. The diatomite-bearing tuffaceous sedimentary unit (Tts) has been eroded in places, and the effects of erosion are possibly most significant in the eastern part of the area such as east of the Horseshoe Basin deposit where erosion seems to have removed much of the diatomite-bearing part of the section. Limited information suggests that in the eastern and northern parts of the study area the sedimentary section contains more tuffaceous rocks than to the southwest. Also, the lack of substantial prospects in the eastern and northern areas implies that the quality or thickness of diatomite is not as good as to the northwest. Geology suggests that diatomite is thicker and relatively close to the surface in the zone termed highly prospective on figure 3. The low dip of strata, and the good continuity of diatomite beds support extrapolation of information from the mines into the highly prospective resource area. A substantial part of this area is covered by less than about 30 m of younger rocks and alluvium, thus probably is appropriate for surface mining. Diatomite in the zone of moderately prospective resources (fig. 3) is generally less known than in the highly favorable zone and tends to have thicker cover. Diatomite covered by more than about 50 m of rhyolite, basalt, and gravel will be sub-economic unless there are large changes in mining technology or greatly increased values for special grades of diatomite, as yet not defined.

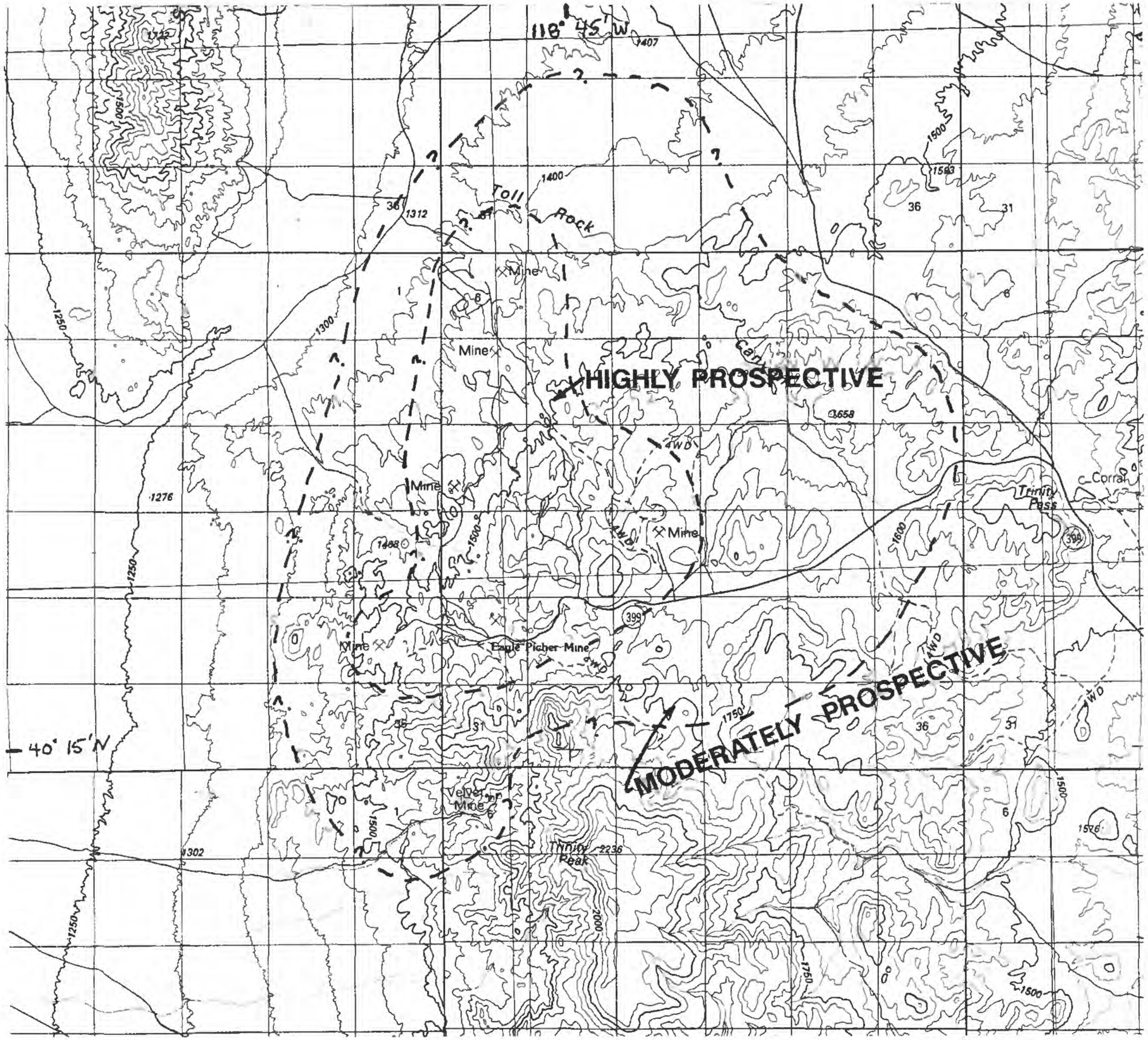

Figure 3. Map of geologically inferred diatomite resources in the Trinity Pass area, Pershing County, Nev. Boundaries are approximately located, and queried where information is lacking. Resource terms defined in text. Base from USGS Lovelock, NV, map (1984), scale 1:100,000; squares in land grid are 1 mile wide sections.

CONCLUSIONS

Thick deposits of diatomite formed in the early stages of Basin-and-Range extensional tectonism that produced siliceous volcanism and a freshwater lake at about 15 Ma. Gentle uplift protected the diatomite from destructive diagenetic alteration and burial by rhyolitic and basaltic lavas and Teriary conglomerate protected the diatomite from erosion. Mass mining is facilitated by the small amount of tectonic tilting of strata. High quality sequences of diatomite up to 100 m thick have been mined for the past 37 years and a large geologically indicated resource of diatomite, under less than 30 m of cover, is favorable for future development.

APPENDIX I. Resource terminology

Resource terminology for undiscovered resources that is normally used in USGS reports is not appropriate here because the diatomite under discussion is an identified resource. The following terms are adapted from the principles of a resource classification (U.S. Bureau of Mines-U.S. Geological Survey, 1980). Resources in areas in which the thickness and quality of diatomite have been measured in outcrop or trenches or by drilling, are ***measured*** **and** ***indicated resources*** and would be covered by ***ore reserves*** of industry (proprietary in this case). Resources estimated here, which are adjacent to those identified resources, are termed ***inferred resources*** because of geologic evidence for their existence and for their continuity with measured deposits. Two categories are recognized here, that I term ***highly prospective*** and ***moderately prospective***. Highly prospective resources of diatomite have geologic attributes (thickness, structure) that are similar to economic beds a few kilometers away and are estimated to be covered by less than about 30 m of non-ore rocks and alluvium. Moderately prospective resources are less demonstrably similar in their geologic attributes to economic deposits, are more distant from measured deposits than highly prospective resources, and generally are covered by more than 30 m of younger rocks and alluvium.

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