UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PRELIMINARY REPORT ON THE GEOLOGY OF THE LAKEVIEW URANIUM AREA, LAKE COUNTY, OREGON

By George W. Walker

U.S. Geological Survey
Open-File Report 80-532
1980

This report is preliminary
and has not been edited or
reviewed for conformity with
Geological Survey standards.

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INTRODUCTION

The Lakeview uranium area, which to 1979 had yielded nearly 500,000 pounds (∿220 metric tons) of uranium oxide (U_3O_8) from the White King and Lucky Lass mines, is in southern Lake County, Oreg. (fig. 1), in mountainous terrane just north of the large valley that contains Goose Lake. Initial discoveries of uranium were on the White King and Lucky Lass claims in 1955, followed by discoveries of anomalous radioactivity and small occurrences of 6-valent uranium minerals in several adjoining areas. These early discoveries ultimately led to the mining of more than 145,000 tons of ore averaging about 0.17 percent uranium. Although no active mining has occurred since 1965, interest in the area has continued principally by companies and individuals attempting to ascertain whether the area contains additional buried deposits of relatively high-grade ore or very large tonnages of lower-grade rock associated with the rhyolite domes and intrusives or with other Cenozoic volcanic rocks that characterize the region.

Purpose and scope

This study was directed partly toward the same goals of determining uranium resources, but, more specifically toward establishing the geochemical relations of uranium and other metals with rhyolite bodies in the Lakeview uranium area and to compare these bodies with similar rhyolitic bodies outside the area. The ultimate goal of this work was to determine, if possible, the uranium resource potential of these kinds of rocks over an area of several thousand square kilometers and to apply knowledge gained from this resource assessment to similar terranes within the Northern Basin and Range Province. The regional evaluation is still in progress, and its results will be reported at some appropriate time in the future.

To these ends a review was made of previous geologic studies of the area and of the uranium deposits themselves, and some regional geologic mapping was done at a scale of 1:24,000. A geologic map was prepared of an area covering about 450 km^2 (∿170 mi^2), more or less centered on the White King and Lucky Lass mines and on the major cluster of uranium-bearing rhyolites, and some geologic reconnaissance and attendant sampling of rhyolite intrusives and extrusives well outside the Lakeview uranium area were completed. Isotopic dates were obtained on some units and magnetic polarity characteristics were determined on many units in order to more firmly establish age and stratigraphic relations of the diverse volcanic and volcaniclastic units of the region. Major oxide chemistry and selected trace-element chemistry were obtained on those rhyolitic units suitable for analysis in order to establish distribution patterns for uranium, as well as several other metals, in the rhyolitic rocks of the Lakeview uranium area and to make regional correlations with other analyzed rhyolitic rocks.

Very little effort was directed in this study toward an investigation of the detailed geology and ores at either the White King or Lucky Lass mines. This was mandated by lack of access due to flooding of both open pits and

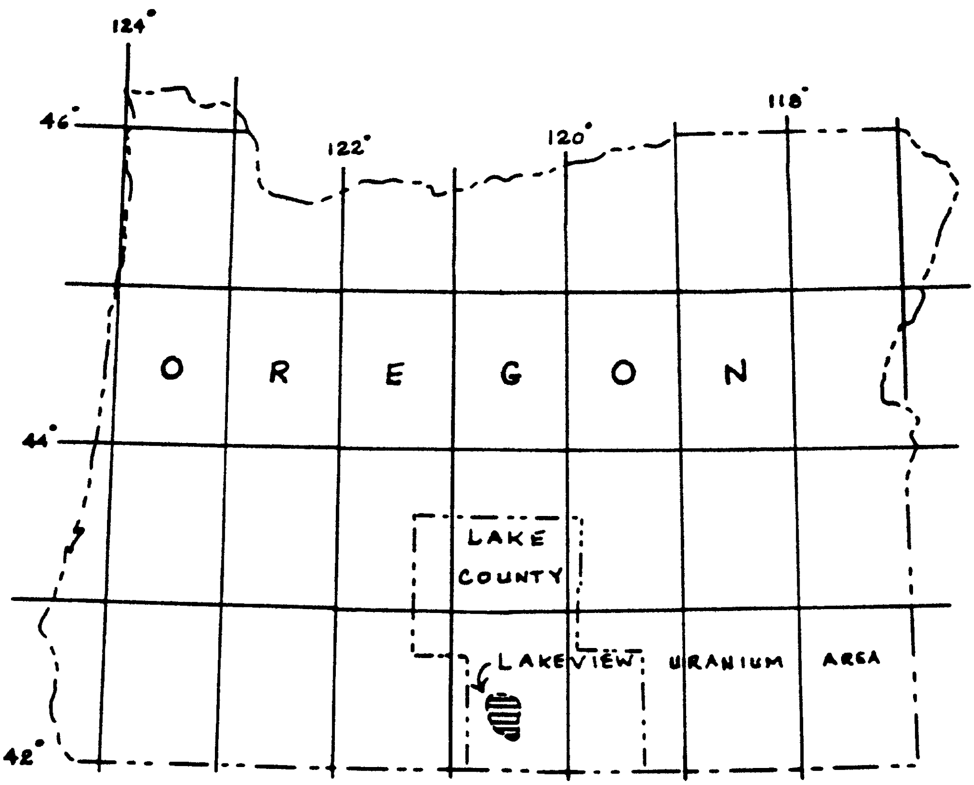


Figure 1.- Index map showing location of Lakeview uranium area.

underground workings at the time of the study and to the availability of published reports that covered at least parts of these topics. In 1977 and 1978, when this study was made, the only ore specimens available were those collected either from dumps or, at the White King mine, from small outcrops on the margin of the lake that filled the open pit.

Previous work

Knowledge of the geology of southern Lake County, Ore., and particularly of the area containing uranium deposits and uranium-bearing rhyolites, was of extremely limited scope prior to the 1950's and was based almost entirely on broad reconnaissance investigations designed to provide information on geography, broad regional geology, hydrology, topography, and botany. A few of the more noteworthy early regional studies include those by Russell (1884, 1905) and Waring (1908). Since the late 1940's several studies of specific small areas in and near the Lakeview uranium area were carried out by graduate students. A thesis by Johns (1949) describes the geology and mercury occurrences in rhyolite at Quartz Mountain (fig. 2), just west of the Lakeview uranium area, and a thesis by Appling (1950) discusses the economic geology of the Brattain mining area in the Paisley Hills. A thesis by Muntzert (1969) also discusses part of the geology of the Paisley Hills. Haddock (1959) prepared a geologic map and report of the Cougar Peak area, describing in detail the lithologic character of many of the rock units and preparing some regional correlations of selected units. Another thesis, dealing principally with the petrogenetics of rhyolitic and related rocks in the Drakes Peak volcanic complex, was prepared by Wells (1975).

A ground water study by the U.S. Geological Survey (Trauger, 1950) considered some aspects of the unconsolidated surficial units and provided a generalized geologic map of Lake County, but did not attempt to differentiate any of the volcanic bedrock units. Subsequent regional syntheses of geologic information, which incorporated much new reconnaissance mapping, were prepared by Walker (1963) and Peterson and McIntyre (1970).

Shortly after discovery of uranium in the area, several studies were initiated that dealt with the geology in and near the uranium occurrences leading to reports by Peterson (1958, 1959) and a report by Cohenour (1960). The latter report includes the most comprehensive published discussion of the geology of the ore deposits and their mineralogy and paragenesis.

Several specialized studies that bear on the geology of the region include that by Donath (1962) on interpretation of structural elements using principally geophysical and photogeologic techniques and that by MacLeod and others (1976) on the age and major oxide chemistry of rhyolites of southeast Oregon and their import on geothermal resource potential.

Figure 2. Index to geographic localities of region, sample localities for Which isotopic dates are available, and distribution of rhyolite intrusives and domes. (Folded copy in back.)

ACKNOWLEDGMENTS

The author was ably assisted in the field and briefly in the office by David Horley (summer 1978; spring 1979) and by James M. Baker (summer 1977).

Isotopic dating of several samples of rhyolite and basalt was provided by E. H. McKee, U.S. Geological Survey, Menlo Park, Calif. Considerable help was provided through numerous conversations with personnel of Western Nuclear, Inc., particularly with James A. McGlasson and Thomas H. Thomas, concerning the geology of the Lakeview uranium area. The investigation also was facilitated by the cooperation of local residents and landowners and by personnel of the U.S. Forest Service.

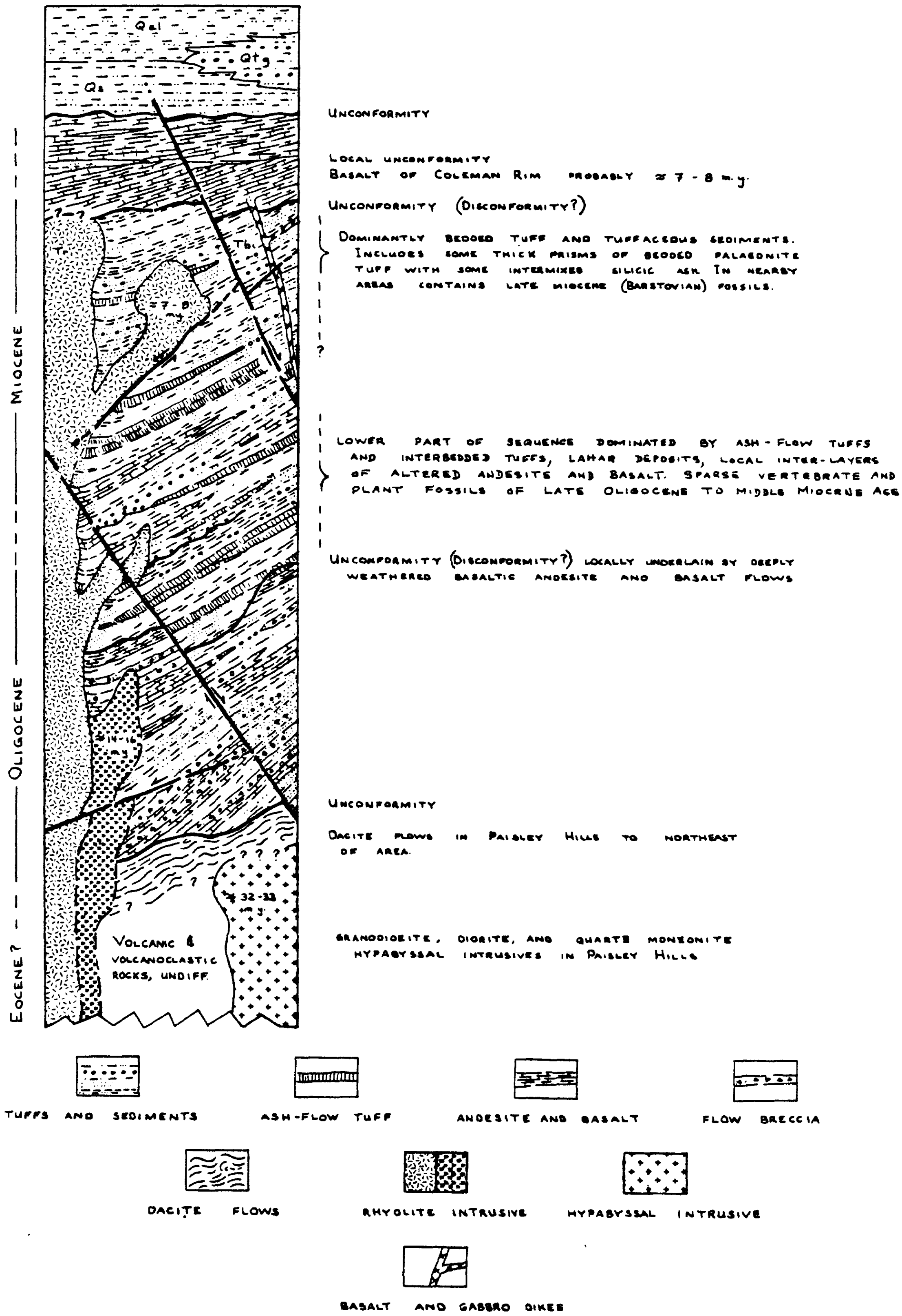
GEOLOGIC ENVIRONMENT OF URANIUM

Uranium associated with several other metals is confined principally to slightly peraluminous rhyolite domes and intrusives of Miocene age and to the adjacent upper(?) Oligocene or Miocene volcanic and volcaniclastic wallrocks. The domes and intrusives are localized by faults and fault intersections that apparently are concentrated along the axis of a complex northwest-trending broad structural warp, characterized by opposing tilted fault blocks; the apparent warp probably resulted from extensional rather than compressional forces. The most intensely mineralized areas, including the only uranium deposits heretofore exploited commercially, are spatially related to areas of extensive silicification and clay alteration, although unaltered fresh obsidian from the rhyolite domes and intrusives also contains more uranium, and several of them contain more thorium, arsenic, antimony, and molybdenum than the average crustal abundances for these kinds of rocks.

Stratigraphy

The stratigraphic column of the Lakeview uranium area, shown schematically in figure 3, is composed entirely of Eocene(?) and younger continental volcanic, volcaniclastic, and sedimentary rocks, including minor diatomaceous interbeds in some of the Pleistocene pluvial lake deposits. The pre-Pliocene part of this sequence is locally intruded by dikes and sills of basalt and gabbro and by numerous rhyolite masses that are mostly either domes or plugs; to the northeast in the Paisley Hills shallow (hypabyssal) stocks or large plugs of quartz monzonite, granodiorite, and diorite of Oligocene age also are present. The total thickness of the Cenozoic sequence appears to be in excess of 4,200 m, including approximately 600 to 800 m measured or estimated from surface exposures and about 3,400 to 3,600 m in the subsurface as determined from sparse well log data. Except for the test well (Leavitt No. 1) south of Lakeview (fig. 2), which encountered volcanic, volcaniclastic, and sedimentary rocks of late Cretaceous age, wells in the area have not reached "basement," and there are no inliers of pre-Cenozoic rocks in or near the area, so that essentially nothing is known of the rocks beneath the volcanic and sedimentary sequence.

FIGURE 3.- SCHEMATIC COMPOSITE STRATIGRAPHIC COLUMN



Older andesitic rocks

Probably the oldest rocks exposed at the surface within the map area (pl. 1) consist mostly of both altered and unaltered andesite and lesser basalt flows, flow breccias, and some interstratified tuffaceous sedimentary rocks and tuffs of late Eocene or early Oligocene age. Major exposures of these rocks are on Buck and Doe Mountains at the northern edge of the map area, where they consist dominantly of altered pyroxene, olivine-pyroxene, and hornblende-pyroxene andesite and some basaltic andesite and basalt flows, breccia and tuff breccia; the section also includes a few rhyodacite flows, some interlayered tuffaceous sedimentary rocks, and, at the top of this sequence, some rather deeply weathered, platy olivine-bearing basaltic andesite flows. Characteristically the andesitic rocks are porphyritic with groundmass textures either trachytic or pilotaxitic; the groundmass in some flows is composed of small, randomly oriented, nearly equidimensional andesite tablets engulfed in cryptofelsite. A few flows are aphyric and consist of flow-alined andesite microlites with some magnetite grains in rather sparse cryptofelsite. The phenocrysts and clots of phenocrysts are mostly plagioclase, generally sodic labradorite or calcic andesine, augite, olivine, and minor altered hornblende. In nearly all rocks the olivine is partly to completely altered to bright green, olive green, brown, or orange, iron- and magnesium-bearing smectite-type clays, generally referred to as nontronite, saponite, or vermiculite. Vesicles and pore spaces in these rocks are either filled with a fibrous zeolite, probably stilbite, or are coated with a bright green, low birefringent fibrous mineral that may also be smectite.

Rocks perhaps partly equivalent to these older altered rocks crop out to the northeast in the Paisley Hills (fig. 2) where they occur unconformably above dacite flows and have been intruded by small hypabyssal stocks or large plugs dated isotopically by potassium-argon methods at between 32.6 ± 0.7 m.y. (million years) and 33.6 ± 1.0 m.y. (Muntzert, 1969; Armstrong and others, 1976), an early to middle Oligocene age (Berggren and Van Couvering, 1974). The hypabyssal intrusives in the Paisley Hills appear to represent the deeply eroded cores of ancient volcanoes possibly representing the volcanic conduits for some of the early eruptive units present in the area. No more precise dating is currently available for the rocks exposed on Buck and Doe Mountains, but the lithologic character and apparent age and stratigraphic position suggests the upper part of this sequence may be correlative to the upper part of the Clarno Formation (Merriam, 1901) of central Oregon and possibly to the lower part of the Cedarville Series of Russell (1928), which has been isotopically dated at 32 to 33 m.y. (Duffield and McKee, 1974; E. H. McKee, oral commun., 1979).

A study of 12 core specimens and numerous cuttings from a test well drilled to a depth of over 3,600 m (12,093 ft) on Grasshopper Flat (lat 42°26′54" N., long 120°37′55" W.; fig. 2) by Humble Oil and Refining Company, indicates that rocks in the subsurface include lithologic types similar to those exposed on Buck and Doe Mountains and in the Paisley Hills to the northeast of the area, as well as several other lithologic types. The cores, which may or may not represent a typical section (or suite), are dominantly of flows, flow breccias, and agglomerates or volcanic conglomerates composed of basalt and andesite that are mostly porphyritic and exhibit either pilotaxitic or trachytic textures. Most abundant varietal types include olivine, olivine-pyroxene, pyroxene, and hornblende-pyroxene andesite and olivine-bearing basalt or basaltic andesite. Also present are tuffaceous sedimentary rocks and interbedded agglomerates (conglomerates?) of andesitic to dacitic composition, as well as fine-grained gray, grayish-red, reddish-brown, and purplish-gray mudstones and siltstones. The degree of alteration, particularly at deeper levels in the well, is more intense than is exhibited in most of the rocks exposed at the surface, and many fractures and voids are filled with calcite, secondary silica minerals, zeolites, or other alteration products. Some of the olivine is altered to iron- and magnesium-bearing smectite-type clays (saponite and nontronite) and, near the bottom of the well, some of the mafic minerals and interstitial glass is altered to chlorite.

Presumably most of the rocks encountered in the well are of early Oligocene or Eocene age, although those at and near the surface are of early Miocene or late Oligocene age and those at the bottom of the well may be as old as Cretaceous. Isotopic dates on basalt cuttings from the interval between 11,840 and 11,850 ft are 29.7±1.8 m.y. and 30.3±1.4 m.y. (Denison, 1970); however, alteration of rocks at this depth may have uniformly affected the content of potassium and argon and, hence, these dates should be accepted with some caution.

Tuffs, tuffaceous sedimentary rocks, and flows

Stratigraphically and unconformably (disconformably?) above this older sequence of andesite and basalt flows, breccias, and volcaniclastic rocks is a sequence of ash-flow tuffs, tuffs, and tuffaceous sedimentary rocks that is extremely varied in composition and textures and represents several different depositional environments. Some parts of the sequence are dominated by rhyolitic to rhyodacitic volcaniclastic materials, whereas others are composed of abundant palagonitic tuffs and breccias, and, locally, a few thin flows of basalt or andesite. In and near Buck and Doe Mountains a part of the sequence is clearly unconformable with the underlying Eocene or early Oligocene rocks, and similar relations can be demonstrated for areas at the south end of the Paisley Hills, 8.5 km east of Doe Mountain, and east of Coglan Butte (fig. 2), about 27 km northeast of Doe Mountain. The regional extent of this unconformity is unknown, although local relief of several hundred meters on the unconformity, as well as local weathering, suggests that a significant interval of time may be involved. The angular discordance of beds in the two units may result from differences in the degree of deformation, although they may only relate to differences in initial dip.

Peterson (1958) separated these tuffaceous sedimentary rocks in the vicinity of the White King and Lucky Lass mines into two groups, designated by him as the "Older" tuffs of early Miocene age and the "Younger" tuffs of late Miocene or possibly earliest Pliocene age. In current age terminology (Berggren and Van Couvering, 1974), the "Older" tuffs would probably be considered late Oligocene or early Miocene and the "Younger" tuffs as middle or late Miocene. The two units were considered by him to be conformable.

The age designations are based on small and widely distributed collections of both plant and vertebrate fossils from several different localities in the region and on stratigraphic relations with several radiometrically dated units. A fossil tooth found by N. V. Peterson in tuffaceous sedimentary beds on the southwest wall of Thomas Creek (lat

$42^{o}19'36''$ N.; long $120^{o}35'15''$ W.) was identified by J. Arnold Shotwell (see Peterson, 1959) as Diceratherium of probable early Miocene (Arikerean) age. Fossil leaves from the same beds were identified by J. A. Wolfe and compared to species in a flora of middle Miocene (Hemingfordian) or possibly even late Miocene (Barstovian) age. Other fossils found in nearby areas (Walker, 1963; Peterson and McIntyre, 1970) within the same sequence of tuffs and tuffaceous sedimentary rocks indicate an age range from late(?) Oligocene to middle Miocene and indicate equivalence with the John Day Formation, part of the Columbia River Basalt Group, and probably the Mascall Formation of central Oregon and with middle and upper parts of the Cedarville Series of Russell (1928) of northeastern California. Beds in the Warner Range containing the upper Cedarville flora were isotopically dated at 19.8 m.y. (Evernden and James, 1964), and several isotopic dates on middle and upper Cedarville Series rocks from northeastern California range from about 25 to 15 m.y. (E. H. McKee, oral commun., 1978). An upper age limit is placed on the tuffaceous sedimentary sequence by the late Miocene age (∿7-8 m.y.) of the numerous rhyolite plugs and domes that intrude the tuffaceous sedimentary sequence and by the middle to late Miocene age of the disconformably overlying basalt flows of Coleman Rim (∿8.5 m.y.). The hypabyssal intrusives in the Paisley Hills that are isotopically dated at about 33 m.y. may place a lower age limit on the sequence, inasmuch as they intrude the underlying Eocene and early Oligocene sequence of andesite and basalt flows and breccias, but apparently not the unconformably overlying tuffs and tuffaceous sedimentary rocks.

Subdivision of this late(?) Oligocene and Miocene sequence into an older unit dominated by ash-flow tuffs, tuffs, and a few interstratified flows and a younger unit dominated by tuffaceous sedimentary rocks and palagonite tuffs and tuff breccias, as suggested by Peterson (1959), is generally recognizable on a regional basis, although a contact between units exhibiting these lithologic types can be established only in a few places. There is no assurance, however, that the change in dominant lithologic types represents the same horizon throughout the region. Furthermore, the rapid and drastic facies changes, local disconformities, complex pattern of faulting, and lack of critical exposures in many areas, prevent such a subdivision from being mapped, so that the sequence is considered as a single gradational and interfingering unit on plate 1 and in the following lithologic descriptions.

The lower part of the sequence is dominated by a series of ash-flow tuffs composed of different amounts of glass shards, pumice and lithic fragments, and crystals, principally oligoclase, sanidine, and soda sanidine, and dark reddish-brown iron-rich biotite. Crystals and crystal fragments of quartz occur sparsely in several of the ash-flow tuffs, but appear to be lacking or only a minor constituent of most of the silicic volcanic and volcaniclastic rocks of this part of the section. In most ash-flow tuffs the glass shards and pumice lapilli are compressed and welded and exhibit a moderately well- to well-defined eutaxitic texture. Proportions of glass shards, crystals, and lithic fragments vary, but most ash-flow tuffs would be classed either as vitric or vitric-crystal tuffs, with lithic fragments mostly subordinate. Rock fragments are somewhat more abundant in ash-flow tuffs near the bottom of this sequence and in one or two ash-flow tuffs at the top of the sequence. The intermediate ash-flow tuffs tend to be more crystal rich and are commonly characterized by fairly abundant pleochroic yellowish-brown to red-brown biotite. Relatively little vapor-phase alteration is present in these tuffs, although most of the glass is partly to strongly devitrified and a patchy spherulitic texture is present locally, particularly in larger flattened crystallized pumice fragments.

The degree of compaction and welding of the ash-flow tuffs is highly variable from the bottom to the top and along strike of each cooling unit so that the outcrop pattern is erratic and is further complicated by numerous faults. Generally the tuffs crop out as discontinuous ledges (fig. 4) that in places exhibit crude columnar jointing and in some outcrops extensive, close-spaced platy jointing. None of the ash-flow tuff ledges can be traced for more than a few hundred meters along strike, in part because of numerous faults, and none has been related to a vent.

Interbedded with the ash-flow tuffs are thick, poorly bedded to nonbedded layers of ash and fine pumice lapilli (fig. 5) and poorly bedded tuff and some tuff breccia layers, presumably mostly representing air-fall deposits, although some of the thicker and coarser deposits are probably pumiceous mudflow (lahar) deposits. Bedded tuffaceous sedimentary rocks, probably representing both fluviatile and air-fall deposition locally occur between some of the ash-flow tuffs. In a few places, flows of olivine andesite or basaltic andesite with pilotaxitic to trachytic textures are interbedded in the sequence. Most of the olivine in these rocks is altered to smectite-type clays (nontronite or saponite), and vesicles and fractures are commonly filled with celadonite and fibrous zeolites, in a few places identified by X-ray diffraction as stilbite.

The younger part of the sequence contains relatively few ash-flow tuffs and is dominated by thinly layered tuffs and tuffaceous sedimentary rocks (fig. 6) that locally show graded bedding, extensive channel scours, and small-scale crossbedding. Some thin beds of nearly pure white air-fall rhyolite ash are present, as well as some beds and lenses of pebble conglomerate in which all clasts are of volcanic derivation. Much of the younger part of the sequence in areas south and southwest of Drum Hill and in the hills both north and south of upper South Creek is dominated by both thin- and thick-bedded palagonite tuff and tuff breccia, presumably of basaltic composition.

Basalt of Coleman Rim

Disconformably above the late(?) Oligocene and Miocene tuffs and tuffaceous sedimentary rocks is a sequence of basalt and minor andesite flows and flow breccias, here informally referred to as the basalt of Coleman Rim for exposures along that prominent north-northwest-trending escarpment at the west margin of the area (fig. 2). Extensive exposures of the basalts and andesites also are present from Shoestring Butte south and southeastward to the margin of Goose Lake Valley, where they are lapped by pluvial lake sediments. Small, partly downfaulted and landslide blocks and extensive basalt rubble and lag deposits of this unit occur at lower elevations between Coleman Rim and Shoestring Butte. Locally the unit is composed of only a few thin flows and is no more than 10 or 15 m thick, but on Coleman Rim it is 100 to 150 m thick and on the rim at Shoestring Butte is about 70 m. It thickens rapidly southeastward and in the Camp Creek drainage is made up of many thin flows and interfingering basalt flow breccia layers totaling 300 to 400 m. It is about 180 m thick on Grizzly Peak, 6 km south of Cougar Peak (Haddock, 1959).

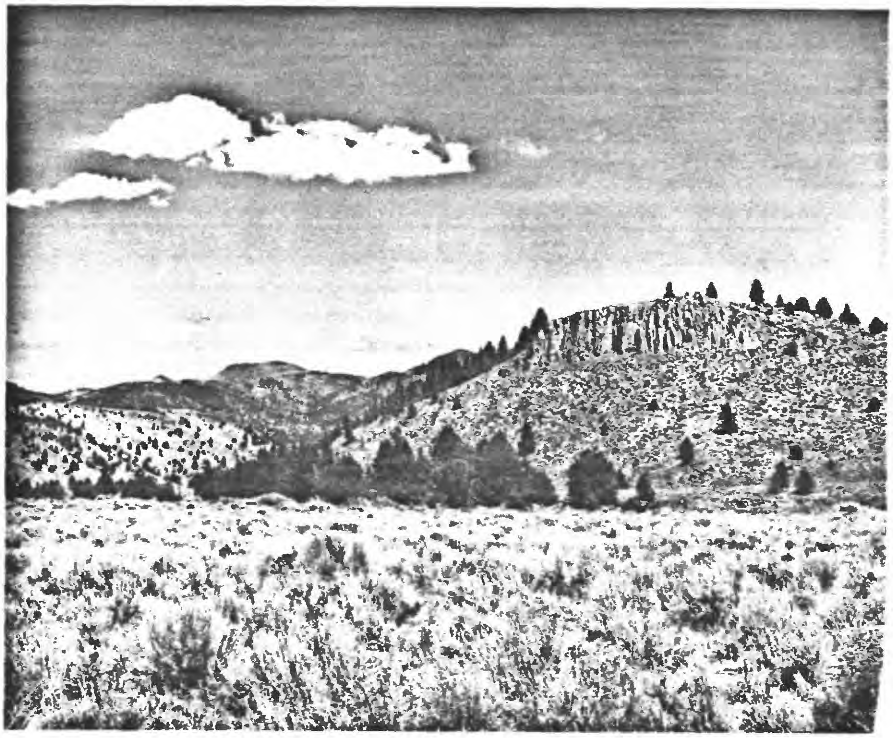


Figure 4. Photograph of some of best exposures of columnar ash-flow tuff on wall of Chewaucan River north of Doe Mountain. Paisley Hills in background.

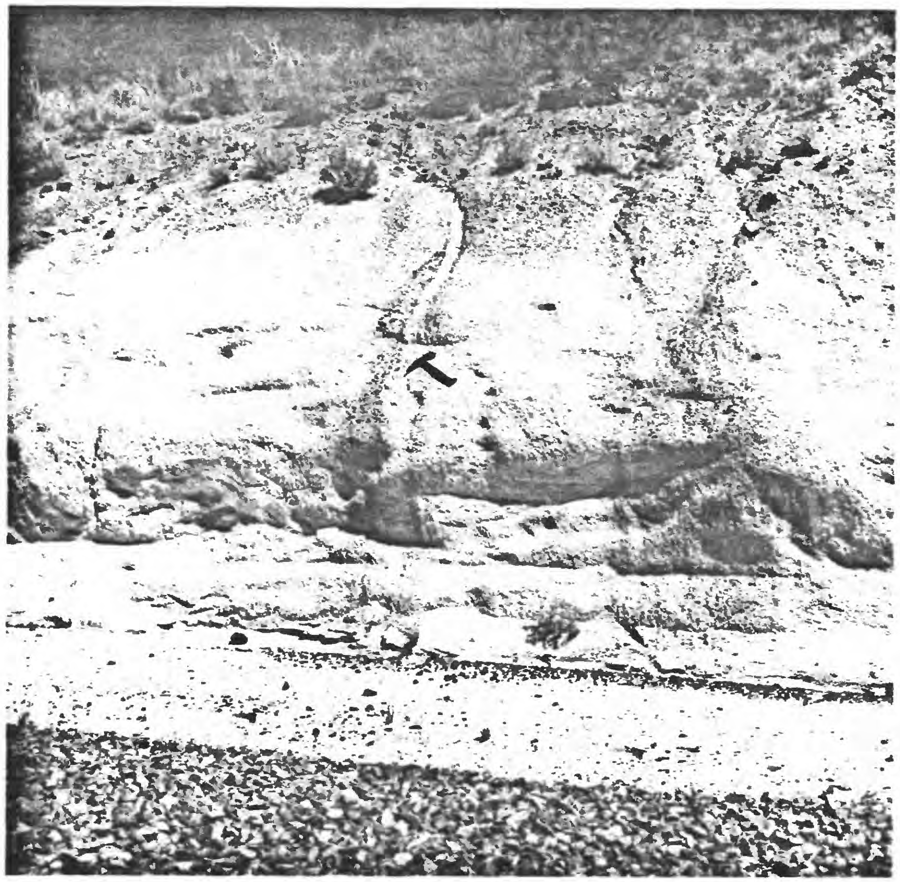


Figure 5. Photograph of air-fall pumice lapilli tuff that shows essentially no bedding over a thickness of several meters. East side of Ben Young Creek.

Figure 6. Photograph of bedded tuffaceous sedimentary rocks characteristic of upper part of the Oligocene and Miocene volcaniclastic and sedimentary sequence. Exposures on unnamed tributary on west side of Ben Young Creek.

Several names have been applied to these basalt and andesite flows and breccias, including Warner Basalt (Peterson, 1959; Cohenour, 1960) and Steens Basalt. For several reasons neither of these names is appropriate, and for the present it seems more suitable to use the informal name of basalt of Coleman Rim. The Warner Basalt, originally named by Russell (1928) for flow sequences exposed many tens of kilometers south of the Lakeview uranium area in the Warner Range of northeastern Modoc County, Calif., is lithologically much like the basalt of Coleman Rim. Gay and Aune (1958), in preparing a geologic map of the Alturas, 2° quadrangle, determined, however, that Russell's Warner Basalt actually includes flows of such diverse ages as Miocene, Pliocene, and Pleistocene and that these units of different age were in places separated by thick sequences of volcaniclastic and sedimentary rocks. The Steens Basalt, named by Fuller (1931) for a thick sequence of flows exposed on Steens Mountain 140 km to the northeast, is of middle Miocene age--about 15 m.y. according to Baksi and others (1967)--and is notable for the numerous thin flows characterized by abundant large phenocrysts of labradorite and by distinctive glomeroporphyritic clots of labradorite; this distinctive lithology is rare in the sequence of flows identified here as basalt of Coleman Rim but is clearly recognizable on Abert Rim and in several areas between Abert Lake and Coglan Butte about 25 km northeast of the Lakeview uranium area. A few isotopic dates have been obtained on some flows high in the basalt and andesite flow sequence mostly outside the Lakeview uranium area and indicate ages in the range of 6.8 to 10.5 m.y.; also some similarities in magnetic polarity characteristics exist among the geographically widely separated flow sequences. There is insufficient evidence, however, to establish complete or even partial equivalence and, hence, it seems premature to apply these earlier names to the basalt and andesite flows and breccias of the Lakeview area.

Stratigraphic relations indicate that the basalt and andesite sequence of the Lakeview uranium area is middle and late Miocene in age, probably mostly late Miocene. The unit, which is both faulted and tilted, locally occurs above tuffaceous sedimentary rocks that contain a middle Miocene (Barstovian) fauna and west of Coleman Rim it is lapped by a thick sequence of undated basalt flows which are in turn lapped by largely unfaulted, nearly flat lying Pliocene and Pleistocene(?) tuffaceous sedimentary rocks and basalt flows (Walker, 1963; Peterson and McIntyre, 1970). In a few places between Coleman Rim and Drum Hill some of the uppermost palagonitic tuffs and tuff breccias of the late(?) Oligocene and Miocene volcaniclastic and sedimentary sequence appear to interfinger with lower parts of the basalt sequence, suggesting contemporaneity. Basalt flows that are thought to be partly equivalent to the basalt of Coleman Rim are exposed on fault scarps in the vicinity of Picture Rock Pass, about 50-60 km north of the area, and cap table lands near Dry Creek, about 30 km south of the area. The flows in these two areas, one north and one south of the Lakeview uranium area, have been isotopically dated at about 6 to 8 m.y. (E. H. McKee, oral commun., 1978). A fresh, diktytaxitic, olivine basalt with normal magnetic polarity from the west top of Coleman Rim was dated by E. H. McKee (oral commun., 1979) at 8.5 m.y. and an olivine andesite or basaltic andesite flow from Shoestring Butte at 10.5 m.y. Whatever the age of this basalt and andesite unit, stratigraphic relations within the basalt sequence suggest that parts of the sequence were erupted over relatively brief periods of time but that the age of flow sequences in one area may be different from that in other areas.

Table 1. Chemical analyses of basalt of Coleman Rim
[N.R., not reported. Analysts of samples 2, 3, 4, and 5: P. L. D. Elmore, S. D. Botts, I. H. Barlow, G. Chloe]

Sample number	1	2	3	4	5
SiO_2 ----------	48.16	48.0	50.2	47.8	47.1
Al_2O_3 ----------	20.93	18.4	18.1	18.1	18.2
Fe_2O_3 ----------	8.45	2.1	2.7	4.2	3.8
FeO ----------		7.7	7.2	5.6	7.6
MgO ----------	9.43	9.3	6.2	8.0	6.0
CaO ----------	11.43	10.9	9.4	11.2	8.2
Na_2O ----------	1.47	2.6	3.2	2.3	3.7
K_2O ----------	.28	.24	.79	.22	.58
H_2O ----------	0	.50	.57	1.2	2.5
TiO_2 ----------	.43	.82	1.2	.86	1.6
P_2O_5 ----------	N.R.	.14	.32	.13	.47
MnO ----------	.16	.23	.18	.20	.22
CO_2 ----------	--	<.05	<.05	.06	<.05

1. West slope Coleman Rim, lat. 42°21′ N.; long. 120°44′ W. All Fe calculated as Fe_2O_3; H_2O as "loss on ignition (from Peterson and McIntyre, 1970).
2. West slope Coleman Rim, lat. 42°21′ N.; long. 120°42.6′ W.
3. West slope of Winter Ridge, lat. 42°46′ N., long. 120° 55.8′ W.
4. West bank of Elder Creek, 13 km north-northwest of Drum Hill, lat. 42°34′ N., long. 120°42.3′ W.
5. West slope of Coleman Rim, lat. 42°19.7′ N.; long. 120°44.3′ W.

Dominant among the different flows that make up the unit are ophitic, subophitic, intergranular, and, locally, diktytaxitic olivine-bearing basalt, in which labradorite occurs both as phenocrysts or clots of phenocrysts and as laths or microlites in the groundmass and olivine occurs as large phenocrysts, clots of smaller phenocrysts, and as interstitial grains. The olivine is commonly "iddingsitized" both along fractures and on peripheries of grains. Typical clinopyroxene, as large poikilitic crystals in ophititic flows, as nearly equidimensional phenocrysts, and as interstitial grains and thin-bladed crystals, is augite or subcalcic augite, commonly with an estimated 2V (+) of about 45^{o}. Many of the flows are plagioclase rich, which is reflected in the relatively high Al_2O_3 contents of the several analyzed samples of this unit (table 1) collected from the top and just west of Coleman Rim and from outcrops of the unit north of the Lakeview uranium area. An olivine andesite flow on the south end of Shoestring Butte contains sparse sodic labradorite phenocrysts in a pilotaxitic groundmass composed of stubby andesine microlites in cryptofelsite.

The question of how these basalt and minor andesite flows relate to the thick (>600 m) section of basalt and flow breccia exposed on major fault scarps northeast and east of the area, is, as yet, not fully resolved. Apparently the section of basalt and breccia on Coleman Rim and near Shoestring Butte is younger than most and perhaps all of the section of flows and flow breccias exposed about 36 km to the northeast on the 690-m fault scarp at Abert Rim, a section of basalt which also occurs stratigraphically above the late(?) Oligocene and Miocene sedimentary rocks. Near the top of the section on Abert Rim is a discontinuous and thin unit of sedimentary rocks that in areas a few kilometers east of the rim on Snyder and Honey Creeks (fig. 2) contains a middle Miocene (Barstovian) fauna (Walker, 1960; 1963). An ophitic and diktytaxitic olivine basalt flow, in which the olivine is only slightly "iddingsitized", collected near the top of Abert Rim and just beneath the sedimentary interlayer, was dated by E. H. McKee (oral commun., 1979) at just over 15 m.y. Above the sedimentary interlayer is an unconformable (disconformable?) sequence composed of a few thin flows of basalt that are at least partly similar in lithology to the basalt flows of Coleman Rim. On Abert Rim flows below the sedimentary interlayer exhibit reversed magnetic polarity (Watkins, 1963; 1965), whereas those above the sedimentary interlayer apparently are normally polarized although greatly affected by lightening strikes (N. D. Watkins, oral commun., 1962). The reverse-normal pattern of natural remanent magnetism is similar to that found in the thick section of basalt on Steens Mountain, 130 km east of Abert Rim, the upper (normal) part of which has been dated at about 15 m.y. (Baksi and others, 1967).

In the Coleman Rim section there are slightly altered basalt flows with reverse magnetic polarity that are exposed in several places in road cuts in upper Drews Creek. Capping Coleman Rim in this area are fresh to slightly altered basalt flows with normal magnetic polarity that are stratigraphically higher and apparently separated from the reversely polarized flows below by interlayered tuffaceous sedimentary rocks. Whether the similarities in remanent magnetism between Coleman Rim and Abert Rim really denotes partial temporal equivalence of the basalt sections is uncertain, but some field evidence and the lithologic character of the flows themselves supplies a few clues. Field relations in the area between Coglan Butte and Abert Rim indicate that the thick Abert Rim section of basalt flows and flow breccias thins rapidly westward and wedges out on a pre-existing high in and near the

Paisley Hills. Highly porphyritic, plagioclase-rich flows characteristic of the Abert Rim section and sections farther east on Poker Jim Ridge and Steens Mountain (fig. 2) do not occur in the Coleman Rim section, nor do the middle Miocene tuffaceous sedimentary rocks that occur between the normal and reversely polarized flow sequences at Abert Rim. The lithologic character of other flows in each section shows considerable variation in textures and mineral content and cannot be used as a basis of correlation.

Mafic intrusives and vents

Mafic intrusives and related near vent accumulations of agglutinate and thin flows in the Lakeview uranium area are mostly steeply inclined tabular dikes that strike northwest or, locally, northeast parallel with the general structural grain of the region (pl. 1). A few are sills parallel to bedding and a few are pluglike masses, such as the small elliptical vent area on the ridge about 2 km southeast of Cox Flat (lat 42°99.7 N., long 120°36.4′ W.). Presumably most and perhaps all of these vents are temporally and genetically related to the basalts of Coleman Rim, although physical connections between vents and flows have been destroyed by erosion. In several places, the tuffaceous sedimentary rocks adjacent to larger intrusives are baked and, locally, fused into a dark-gray to nearly black, highly coherent glassy, hornfels-like rock (buchite). Zones of baked sedimentary rocks are generally only a few tens of a centimeter but, locally as much as several meters thick.

The largest dike, which transects upper Thomas Creek 5 km west of Cox Flat, is about 2.5 km long and over 50 m wide, with several irregular off-shoots that make it appear even thicker. The dike consists of both olivine gabbro and olivine diabase with hypidiomorphic-granular textures as well as diabasic textures and is composed of coarse-grained augite, altered olivine, labradorite, and magnetite crystals. Pegmatitic inclusions and veinlets are present locally, and some of the larger augite crystals are poikilitic and contain laths of labradorite. Large labradorite crystals are commonly fractured and broken and exhibit incipient alteration along fractures probably related to deuteric processes. The alteration has converted much of the olivine to a fibrous, pleochroic brown mineral with parallel extinction, probably an Fe-rich smectite; both aragonite and a fibrous zeolite (stilbite?) are present on fractures and in pore spaces, probably derived from the alteration of the calcic plagioclase.

Most of the smaller dikes and sills are composed of plagioclase phyric basalt that is mineralogically and texturally much like the basalt flows of Coleman Rim; the only significant differences are that the olivine is somewhat more altered in the intrusives and the flows exhibit a higher degree of exsolution of volatiles, as exemplified by abundant vesicles and porous diktytaxitic texture.

East of Shoestring Creek mafic vent areas are characterized by linear outcrops of red, scoriaceous, and partly agglutinated basaltic tephra that probably represents the surface or near-surface expression of basaltic feeder systems. The oxidized cindery material is in an area of Oligocene or Miocene tuffaceous sedimentary rocks and its possible relation to younger basaltic flows is indeterminate.

Surficial deposits

Poorly consolidated surficial deposits of Pleistocene and Holocene age are present throughout much of the Lakeview uranium area. Pleistocene pluvial lake beds are localized in the southern part of the area in and along the margins of Goose Lake Valley. Landslides, probably mostly Pleistocene in age, occur in the steeper, more mountainous parts of the region. Several ages of late Pleistocene and Holocene alluvium is present along stream valleys. All of these deposits, except for a few diatomaceous layers in the lake beds and airborne volcanic ash and pumice lapilli erupted from young volcanoes in neighboring regions to the west, are composed of volcanic and volcaniclastic debris derived by erosion from adjoining bluffs and highlands.

The lake beds are commonly thinly laminated and mostly fine to medium grained in central parts of the pluvial lake basin but are coarser grained and poorly sorted near the margins of the basin. The near-shore deposits commonly consist of unconsolidated to poorly consolidated pebble conglomerate along old shoreline bars and beaches and occur as high as about 5,100 ft (1,554 m) on the walls of Goose Lake Valley. Similar gravelly deposits occur in paleo-deltaic deposits built at the time of high still stands of the pluvial lakes.

Both older and younger alluvium are present in the area. The older alluvium occurs as gravel and poorly consolidated sandstone beds capping terraces 10 m or less above present stream drainages, particularly around the margins of Cox Flat and in erosional remnants of terraces centrally located in the flat. Younger alluvium of unconsolidated sand and gravel covers the bottoms of most stream valleys of the area and is present in thin discontinuous patches along the smaller drainages.

Landslide deposits, which consist almost entirely of disaggregated blocks and rubble of the basalt of Coleman Rim intermixed with material from the underlying tuffs and tuffaceous sedimentary rocks, are mostly on or below steep bluffs and escarpments capped by relatively thick sections of basalt. Faulting, slumping, and erosion of massive basalt sequences and subsequent slumping and erosion of the disaggregated landslide material has spread basalt blocks and rubble widely over much of the area, particularly below (east) of Coleman Rim and between Augur Meadow and Thomas Creek. The widespread basaltic debris gives the erroneous impression that many areas are underlain by fairly continuous basalt when, in fact, they are underlain by the late(?) Oligocene and Miocene clastic rocks capped by landslide and lag debris.

Rhyolite

By far the most important rocks in terms of uranium mineralization and potential uranium source rocks are intrusive and extrusive rhyolites in the form of bulbous domelike masses, plugs, dikes, and extrusive flows. Most of these rocks occur in an indistinct northwest-trending belt (or belts) in the central part of the Lakeview uranium area (pl. 1). Many additional silicic intrusive and extrusive masses of several different ages occur in the region (fig. 2); some of these contain anomalous amounts of uranium, but, as yet, no economic deposits of uranium have been found associated with them. Some of the rhyolite masses in the Lakeview uranium area occur as separate small domes or plugs, whereas others represent clusters of several domes or plugs that apparently are connected at depth or, in a few places, by thick dikelike bodies that are now exposed at the surface. Good outcrops of the domes and plugs are rare except in a few manmade cuts and in steep canyon walls, in large part because of thick mantles of talus (fig. 7) that result from the disaggregation of the strongly flow banded and flow jointed rhyolite, aided in a few places by the intense hydration and alteration along the peripheries of the masses. Most of the rhyolite bodies erode to rounded or locally steep-sided hills (figs. 8 and 9) with only a few massive outcrops projecting through the talus. In several road cuts and borrow (or prospect) pits the domes and intrusives are shown to have chilled marginal facies composed of gray to black, mostly flow banded, perlitic glass or, more commonly, of silvery gray, throughly hydrated granular glass containing sparse to abundant obsidian spheres or blebs (apache tears) that are dense and unaltered. Where visible, the cores of the rhyolite bodies are composed of either partly to thoroughly devitrified, commonly spherulitic perlitic glass or flow-banded felsite largely derived from the devitrification and alteration of flow-banded perlitic glass.

The presence of rhyolite flows associated with a dome or intrusive south of Bear Flat probably indicates near-surface emplacement for the rhyolite body in that area, but elsewhere diagnostic criteria to establish depth of emplacement are lacking. Presumably all of the intrusives and domelike masses in the Lakeview uranium area were emplaced either at the surface or within a few hundred meters of the surface based on their structures and on the textures of the rhyolite, including the presence of abundant perlitic glass, obsidian breccias, and, locally, fairly abundant miarolitic cavities. Silicic intrusives of Oligocene age in the Paisley Hills, about 20 km to the northeast, exhibit hypidiomorphic granular and porphyritic textures that are quite different from those in the rhyolites in the Lakeview uranium area and probably denote crystallization under several hundred meters or more of cover.

Much of the rhyolite in the region is aphanitic or glassy, locally autobrecciated, and moderately to strongly flow banded, commonly with many of the bands manifested by perlitic texture. The flows are partly inflated, in contrast with the domes and intrusives, showing abundant miarolitic cavities that are lined with vapor-phase alkali feldspar, cristobalite, opal, and, in places, iron-stained material that may be finely divided hematite. Both the flows and intrusives are micro- to macroporphyritic with rare to fairly abundant phenocrysts mostly of alkali feldspar (soda sanidine and sanidine), oligoclase, some iron-rich dark-brown biotite, and minor iron oxides, some of which appears on morphologic grounds to be derived from the oxidation of pyrite. In a few rhyolites, there are rare elongate prisms of what originally was probably basaltic hornblende but is now largely iron oxides. Seen in thin section, the groundmass is glassy or cryptocrystalline and where crystallized commonly shows a well-defined spherulitic texture. Where the glass is fresh, crystallites and fine microlites are visible in thin section and perlitic texture common. The crystallites and microlites are mostly alined and, where identifiable under oil immersion microscopy, consist of feldspar, rare prisms of clinopyroxene or hypersthene, rare pleochroic brown hornblende and dark pleochroic brown, probably iron-rich biotite, and minor apatite. Microscopic opaque grains probably are mostly magnetite or ilmenite and the reddish to reddish-brown color of some fresh glass suggests submicroscopic dusting of hematite. Microphenocrysts of alkali feldspar are randomly distributed in some of the obsidian and are generally less than 0.01 mm in maximum dimension. A few obsidians contain small clots of plagioclase and

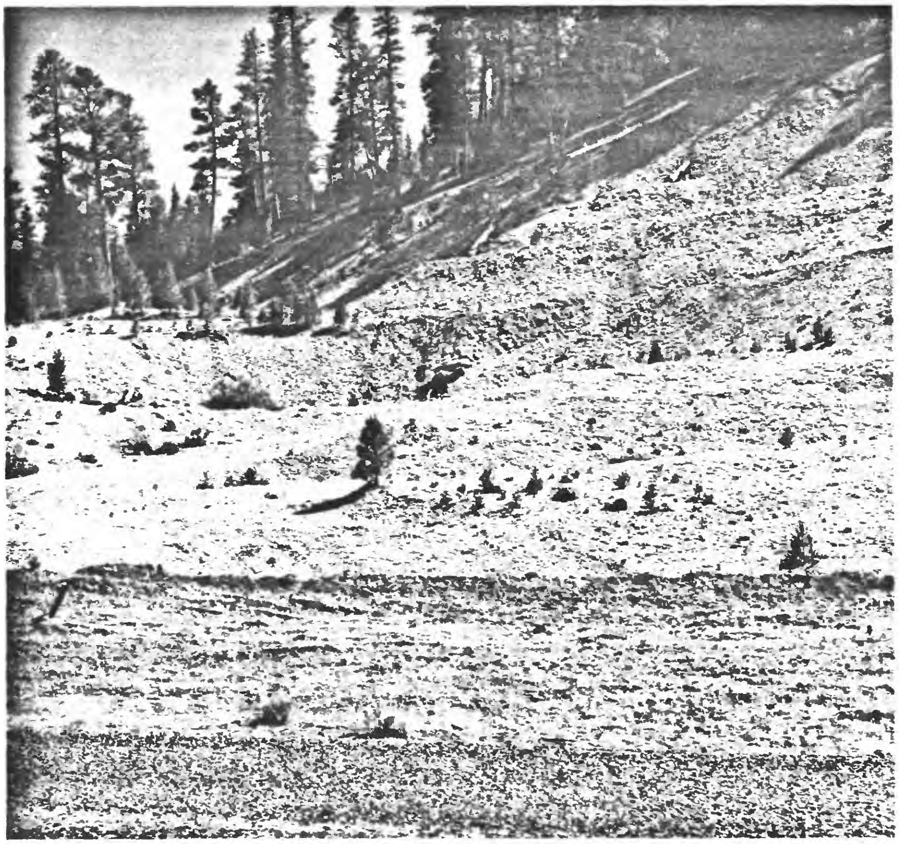


Figure 7. Photograph of borrow pit in rhyolite debris on west side of large, flow-banded and flow-jointed dome on Thomas Creek. Outcrops of perlitic and flow-banded hydrated glass are in central part of photograph above and to the right of small centrally located conifer.

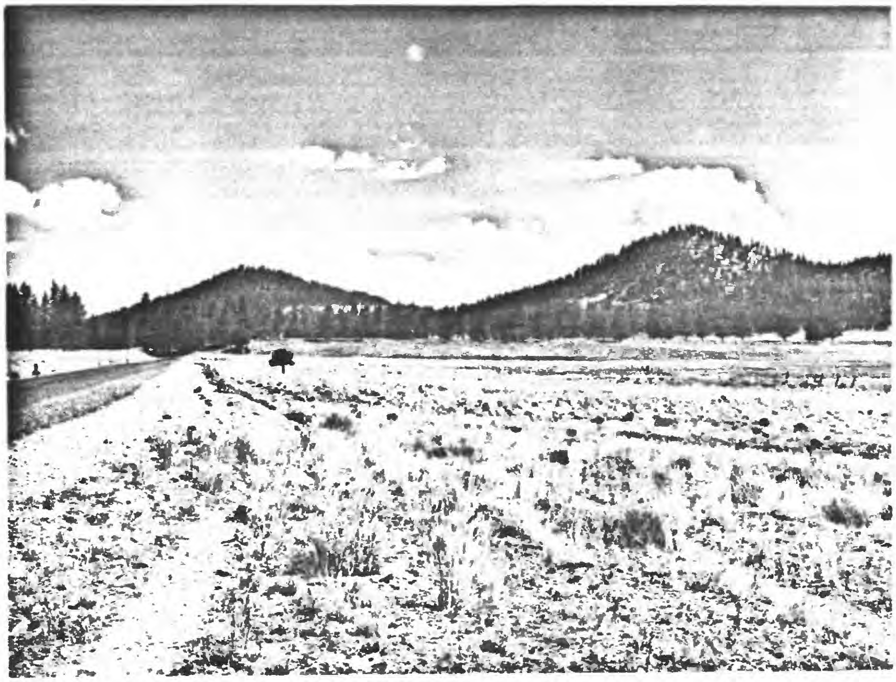


Figure 8. Photograph looking northeast across Cox Flat to rhyolite domes (conical hills) on northeast margin of the flat.

Figure 9. Photograph looking south-southeast across Cox Flat to large rounded dome on Thomas Creek. Borrow pit, shown in figure 7, is out of view on west (right) side of dome.

clinopyroxene. Most of the domes and intrusives exhibit extensive hydration of glass and some devitrification and vapor-phase crystallization, but only the intrusive mass at the White King mine and marginal parts of the intrusive at the southwest edge of Cox Flat (lat 42°20'10" N., long 120°35'53" W.) show extensive alteration and silicification.

The alteration and silicification show some vague spatial relation with the margins of the rhyolitic bodies but apparently a more direct relation with the current ground surface, which probably means that the present surface and that at the time of emplacement were more or less coincident. Study of cores from drill holes in the rhyolite intrusive at the White King mine suggests that the kind and degree of alteration changes with depth. At and near the surface the rhyolite is altered to kaolinite and is intensely silicified with opal, quartz, and lesser chalcedony(?). Argillic alteration persists with depth, perhaps with some slight decrease in intensity, but the intensity of silicification decreases noticeably even though the rhyolite at depth also is composed partly of silica minerals, mostly quartz and minor opal. In places, a few tens of meters beneath the surface, the silica minerals appear to be residual, following hydrothermal acid leach of the rhyolite, whereas at and near the surface silica has been introduced. A silicic opaline and chalcedonic(?) cap on the rhyolite intrusive at the White King mine and on the uranium deposit itself is nearly identical with the many opalite deposits of mercury characteristic of nearby areas in the northern Basin and Range. Good examples of this type of deposit are found at Quartz Mountain (Johns, 1949; Brooks, 1963), Opalite (Yates, 1942), and Glass Buttes (Brooks, 1963).

Most of the rhyolite intrusives and domes in the Lakeview uranium area appear to be part of a single, short-lived volcanic episode that took place slightly more than 7 m.y. ago. Rhyolites of this same episode are found over a much larger area (fig. 2) and include those at Owen Butte and Drews Ranch, located west of the Lakeview area, at McComb Butte and Tucker Hills, to the north and northeast of the area, and in the area near Fandango Pass, in northeastern Modoc County, Calif. Rhyolitic volcanism of this same type and age may extend further north, west, and south of the Lakeview uranium area, but there is no evidence of late Miocene silicic volcanism to the east (MacLeod and others, 1976). Exceptions to this late Miocene age assignment are found in the rhyolite at Drum Hill, which is 16 m.y. old, several rhyolites in the Warner Range, northeast of Lakeview, and probably in the intrusives on Morgan Creek, which are undated, but seem to be geologically more closely allied to Drum Hill than to the rhyolites near Cox Flat. Also exceptions to this age assignment are the Oligocene hypabyssal and near-surface intrusives in the Paisley Hills.

Field relations among rhyolite domes and intrusives and other bedrock units indicate that (1) a few rhyolites only intrude older parts of the late(?) Oligocene and Miocene sequence of tuffs and tuffaceous sedimentary rocks and perhaps are local vents for some of these volcaniclastic units, (2) a few have erupted rhyolite flows that lap onto upper parts of the tuffaceous sedimentary section, and (3) in those few places where basalt of Coleman Rim impinges on rhyolite bodies, all appear to be lapped by the basalt. This stratigraphic relation of rhyolite to capping basalt appears to be in contradiction to the few available potassium-argon dates for the basalts, although the dates indicate that the youngest basalt and the young rhyolites are very close in time and both of late Miocene age. The age range on the youngest group of rhyolites is about 7-8 m.y. and on the youngest basalt flows apparently about 6-8.5 m.y., based mostly on age determinations of flows in nearby areas. The apparent lapping of basalt on rhyolite in a few places is contrary to the age relations among rhyolites and basalt flows established by Peterson and McIntyre (1970, p. 22 and 26), so that rhyolites both younger and older than young parts of the basalt section are possible.

Except for the older intrusives in the Paisley Hills, the rhyolite intrusive at the White King mine is the most altered and exhibits not only intense silicification, but also extensive evidence of hydrothermal alteration of feldspar and glass to kaolinite. A similar, but much less intense, alteration occurs in a part of the intrusive on the southwest side of Cox Flat. Neither of these intrusives has been dated, although a dated fragment of perlite from brecciated material above and probably related to the White King intrusive suggests a 7 m.y. age for the intrusive. Also their textural characteristics and relations to impinging stratigraphic units suggest that they both belong to the younger, 7 to 8 m.y. episode of silicic volcanism. If the intrusive at the White King mine is part of this late Miocene episode, why is it so thoroughly altered, silicified, and mineralized, whereas the other intrusives and domes of the episode are manifested by only slight alteration and little or no mineralization? A possible explanation is that the White King rhyolite intrusive was emplaced at deeper levels than the other intrusives and domes, the thicker section of cover trapping associated volatiles that altered both the rhyolite and the adjacent wallrocks. An alternate explanation is that the intrusive invaded water-saturated rocks or a water-saturated fault zone, creating a hydrothermal system that was effective in altering and mineralizing the rocks. Available data permit either or both alternatives, although the latter is favored because of a complete lack of textural or stratigraphic data to suggest different levels of emplacement and because the White King intrusive is localized in a complex fault zone.

Isotopic ages of units

Isotopic ages of a number of intrusive and extrusive volcanic units exposed in the region, as well as several from deep drill holes, supplement very meager dating of these units by paleontological methods (see p. 9-10). These isotopic ages, mostly from published references, are listed in table 2 and approximate locations of dated samples are shown in figure 2. Ages range from about 80 m.y. (late Cretaceous) on andesite from cores taken at over 2,918 m (9,576-9,579 ft) in a test well (Leavitt No. 1) a few miles south of Lakeview (Denison, 1970) to 6.8$\pm$0.90 m.y. on a basalt flow exposed in Picture Rock Pass, 50 to 60 km north of the Lakeview uranium area. A few isotopic ages on units identified as correlative in the field are not precisely the same, but are not sufficiently different to significantly change any of the stratigraphic or temporal relations. No attempt is made here to rationalize these isotopic age differences, except to indicate that they were done at different times in different laboratories and perhaps on material collected from different outcrops manifested by slight differences in alteration.

Andesites as old as those from deep in the Leavitt No. 1 well (fig. 2) have no surface counterparts in the Lakeview uranium area. Isotopic ages on basalt from deep in the Thomas Creek No. 1 well (fig. 2), within the Lakeview uranium area, are about 30 m.y. (table 2), which make it highly unlikely that rocks at the bottom of the well, only about 75 m ($\sim$240 ft) deeper, are as old

Table 2. Potassium-argon dates of volcanic rock units in and near the Lakeview uranium area, Lake County, Oregon

Age	Unit or rock type		Sample number	Location (lat. N., long., W.)	Reference
6.8 ±0.90	Basalt	(flow)	PRP-1-70	Picture Rock Pass; 43°04.0', 120°48.4'	E. H. McKee, oral commun., 1979
7.0 ±0.4	Perlite		69-78	White King mine; 42°20', 120°31.3'	do.
7.11±0.94	Rhyolite	(dome)	Mo73-35	Owen Butte; 42°19.7', 120°51.9'	McKee and others, 1976
7.13±0.34	Obsidian	(dome?)	Mo73-34	Drews Ranch; 42°16.1', 120°43.8'	do.
7.19±0.32	Rhyolite	(dome)	Mo-73-37	Thomas Creek; [1]42°19.9', 120°35.2'	do.
7.27±0.50	Rhyolite	(dome)	Mo73-36	Cougar Peak; 42°18.3', 120°37.9'	do.
7.41±0.19	Obsidian	(dome?)	Mo73-40	Tucker Hill; 42°36.0', 120°25.3'	do.
7.6 ±0.4	Rhyolite vitrophyre	(dome)	--	Quartz Butte; 42°21.0', 120°47.6'	Peterson and McIntyre, 1970
7.70±0.09	Obsidian	(dome)	Mo73-39	McComb Butte; 42°34.6', 120°37.1'	McKee and others, 1976
8.1 ±0.5	Rhyolite	(dome)	--	Thomas Creek; 42°19.9', 120°35.2'	Peterson and McIntyre, 1970
8.5±1.3	Basalt	(flow)	7-78	Coleman Rim; 42°20.2', 120°41'	E. H. McKee, oral commun., 1979
10.5 ±0.03	Basaltic andesite	(flow)	10-78	Shoestring Butte; 42°22.9', 120°31.7'	do.
14.3±1.5	Rhyolite	(flow)	DP-108	Drake Peak Complex. Sample from Light Peak; 42°18', 120°08.2'	do. (sample collected by R. W. Wells)
15.1 ±0.8	Basalt	(flow)	39-78	Abert Rim; 42°28', 120°13.5'	E. H. McKee, oral commun., 1979
16.0 ±0.4	Rhyolite	(dome)	GWW-33-77	Drum Hill; 42°27.5', 120°39.4'	E. H. McKee, written commun., 1978
29.7 ±1.8 30.3 ±1.4	Basalt	(flow?)	--	Well cuttings (11,840-11,850 ft) Thomas Creek No. 1; 42°26.9'; 120°37.9'	Denison, 1970
32.6 ±0.7 33.6 ±1.5	Quartz monzonite		JM-291	Paisley Hills; 42°37.7', 120°32'	Muntzert, 1969
32.6 ±1.0 33.6 ±1.0	Biotite Hornblende	from adamellite	--	East Flank Paisley Hills; 42°37.7', 120°32'	Armstrong, Taubeneck, and Hales, 1976
79.8 ±4 83.4±2	Andesite	(flow?)	--	Core (9,576-9,579 ft) from Lesvitt No. 1; 42°05', 120°19.6'	Denison, 1970

[1]Latitude and longitude location given in McKee and others (1976), is for another undated rhyolite sample.

as those in the Leavitt well. Nor is there any evidence that rocks as old as 80 m.y. are exposed anywhere in the Paisley Hills, although the only isotopic dating there is on 32- to 33-m.y.-old intrusives that invade a sequence of flows, breccias, and tuffs thought to be of late Eocene or early Oligocene age.

The dated domes and intrusives, some of which are genetically related to the uranium mineralization, appear to be separable into three age groups, the oldest represented by the hypabyssal granitoid intrusives in the Paisley Hills at about 32 to 33 m.y., an intermediate age group about 14 to 16 m.y. that includes two widely separated complexes at Drakes Peak in the Warner Range and at Drum Hill, and the youngest at about 7 to 8 m.y. The youngest group, whose ages are so close that they suggest essentially a single period of rhyolitic magmatism, is spread over a rather large geographic area and represents a significant part of the pattern of decreasing age progression in silicic volcanism extending through southeast Oregon from the vicinity of Harney Basin westward toward the Cascade Range (Walker, 1974; MacLeod and others, 1976). Most and perhaps all of the domes and intrusives clustered in the vicinity of the White King mine, including those on Thomas Creek and on Shoestring Creek, as well as those peripheral to Cox Flat, are thought to represent parts of this younger group. The rhyolitic masses on Morgan Creek and near Paxton Meadow have not been dated; on geologic relations it appears likely that the rhyolite on Morgan Creek is part of the intermediate age group and that near Paxton Meadow either part of the intermediate or younger group.

The rhyolite intrusive at the White King mine is so thoroughly altered that no material has yet been found within the intrusive that is suitable for isotopic dating. Above the intrusive, however, is highly brecciated rock that contains numerous angular fragments and chunks of slightly hydrated but otherwise unaltered perlitic obsidian, as well as other volcanic rock types. The obsidian fragments are thought to represent part of the same rhyolite found in the intrusive but in the form of an overlying explosion breccia; the larger angular perlite fragments are fragile so that normal stream or lahar transport probably would destroy them and, hence, it is unlikely that they were derived from other rhyolite bodies. A potassium-argon date on one of the larger fragments of perlite from this breccia is 7.0 ± 0.4 m.y., which is corrobrative evidence in support of temporal equivalence of the White King intrusive with other intrusives of the younger group in and near the margins of Cox Flat.

Structure

Many of the uranium-bearing rhyolite intrusives and domes of the Lakeview uranium area are localized in highly faulted and complex volcanic terrane related to a regional northwest-trending structure or set of structures defined by some workers as a broad anticlinal warp (or anticlinorium) probably developed during compression and by others as a series of opposing and outward dipping fault blocks (or antiform) that resulted from tensional rather than compressive forces. An extensional stress regime oriented generally east-west, or perhaps west-northwest and east-southeast, is consistent with regional structures throughout the northern Basin and Range, but this does not eliminate the possibility of some squeezing and compression of crustal blocks between regionally extensive transverse faults that have been recognized or suspected by several workers (Walker, 1963, 1969, p. 79; Walker and others, 1967; Lawrence, 1976). A combination of east-west extension and northwest-and southeast-trending couples that are related to these suspected transverse faults may explain the rhombic fracture system delineated by Donath (1962) for similar terrane near Summer Lake (fig. 2), about 50 km north of the Lakeview uranium area. Because of the uncertainty of the mechanism or mechanisms that formed this broad and faulted regional warp (fig. 10), it is referred to here as an antiform.

The axis of the antiform trends N. 20^{o}-25^{o} W. approximately through the middle of the Lakeview uranium area (fig. 2). The antiform can be recognized for several tens of kilometers both north and south of the area, and its width is on the order of 30 km. On the west, at Coleman Rim, flows dip gently westward and ultimately are lapped by younger flows and tuffaceous sedimentary rocks (Walker, 1963; Peterson and McIntyre, 1970). A major northward extension of this west limb includes the westward-dipping flows and underlying tuffaceous sedimentary rocks on Winter Ridge. The eastern limb of the antiform is more complex and difficult to delineate as a result of disruption by several major northwest-trending faults and several areas of probable volcanic-tectonic collapse near Summer Lake and Chewaucan Marsh. The eastern limb includes the eastward-dipping flows and sedimentary rocks of the large Warner Mountains fault block, bounded on the west by Abert Rim and its southern extension on the east side of Goose Lake Valley and by northeast-dipping flows, tuffs, and tuffaceous sedimentary rocks northeast of the Paisley Hills and Chewaucan Marsh in the vicinity of Coglan Butte. Older rocks in the Paisley Hills, on Buck and Doe Mountains, and near the axis of the antiform are more steeply inclined than the younger basaltic rocks away from the axial region.

Structural details within this broad antiform are obscured by lack of critical outcrops and by the extensive cover of poorly exposed basaltic flow breccias, extensive basalt talus and lag deposits, and numerous large and small slide blocks of basalt and breccia. The bedrock geology in many areas also is obscured by dense vegetation cover. Numerous unconformities between volcanic units, some with several tens of meters of gentle or locally abrupt relief, complicate the recognition and unravelling of fault structures. Geologic maps that cover all or parts of the antiform (Haddock, 1959; Cohenour, 1960; Walker, 1963; Peterson and McIntyre, 1970; pl. 1) show a large number of northwest-trending and a few northeast-trending faults most of which are thought to exhibit normal displacements. The precise location and character of many of these faults are poorly documented and based on physiography and the recognition of slightly eroded fault scarps, on apparent discontinuity of units, on obvious linear stream drainages commonly separating structural blocks with beds inclined in different directions, and seldom on observed and measured displacements. The amount of displacement on most faults is probably only a few tens of meters at most, but on the large faults, such as those at Abert Rim and Winter Ridge, displacements greater than 600-700 m can be demonstrated. In the few places where faults can be traced across stratigraphic sections, the inclination of the fault planes is generally moderate to steep, mostly in the range of 60-80^{o}. On the geologic map (pl. 1) only the more prominent and well-documented faults are shown; they probably represent less than 10 percent of the total number of faults present in the area.

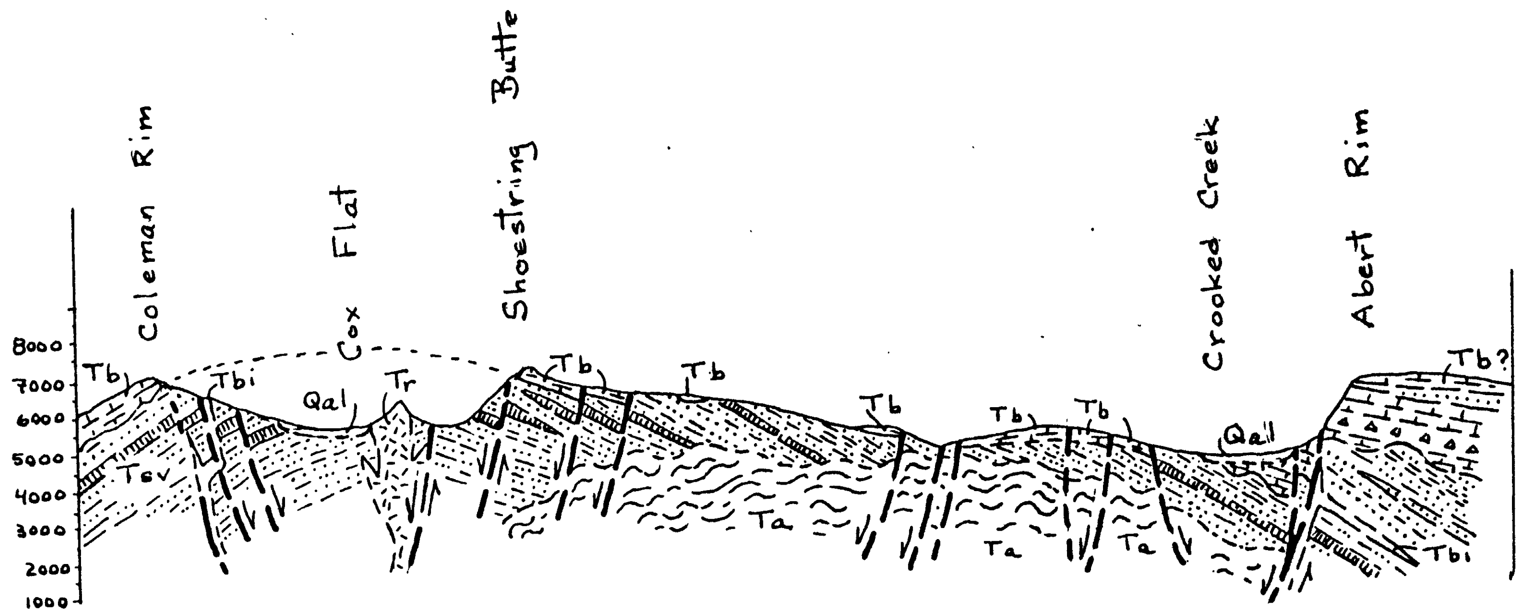


Figure 10. Sketch section of antiform from Coleman Rim northeastward to Abert Rim. Vertical exaggeration, 4X.

Where exposures are good, as for example on the walls of the open pits at the White King and Lucky Lass mines, it is obvious that, in addition to the large through-going faults, there are myriad small faults with displacements of a few meters or less and with both normal and reverse displacements. Most of the small faults strike northwest parallel with the larger faults and a few strike northeast. Inclinations are both steep and, for a few small faults, relatively gentle; a few of the small reverse faults that probably represent local adjustments to movements on larger nearby normal faults, the dip is only a few tens of degrees.

The White King and Lucky Lass mines, as well as several of the rhyolite domes and intrusives northwest of these mines, are in a northwest-trending steeply inclined fault zone in which the major block northeast of the fault zone is depressed relative to the block southwest of the fault (fig. 11). The zone is made up of several more or less parallel strands. Within this zone are numerous disrupted blocks of the basalt of Coleman Rim that in part have slid on the incompetent underlying altered tuffs and tuffaceous sedimentary rocks. A prominent northeast-trending linear feature, evident on aerial photographs, projects across Thomas Creek from just southeast of Cougar Peak into the area near the Lucky Lass and White King mines (pl. 1). On the ground the linear feature can be recognized only by a narrow zone or band of alined drainages. Inasmuch as inclined ash-flow tuffs can be traced without apparent offset across the linear feature, in areas south of Thomas Creek, the zone probably represents en echelon fractures perhaps reflecting some underlying older structure. Several short parallel linear features manifested by straight drainages are present a kilometer or so south of the prominent linear feature.

Regional aeromagnetic data

An airborne magnetometer survey was made of the Klamath Falls 1^{o} by 2^{o} quadrangle (U.S. Geol. Survey, 1972) as a part of the evaluation of the geothermal potential of southeast Oregon. This survey, which covers the Lakeview uranium area as well as adjacent regions, is of a reconnaissance nature, with east-west flight lines spaced at approximately 3 km (2 mi) intervals and at an average barometric elevation of 9,000 ft above sea level. The magnetic data were compiled relative to an arbitrary datum at a scale of 1:250,000 and were contoured mostly at an interval of 100 gammas but locally at 20 gammas.

A small part of this regional survey covering the Lakeview uranium area and some adjacent terrane is shown in figure 12 and the position of individual rhyolite domes and intrusives indicated. No clearly defined regional gradients can be recognized on the aeromagnetic map, although most of the uranium-bearing domes and intrusives occur in and on the southern flanks of a broad, northeast-trending elliptical magnetic high more or less centered on rhyolite bodies north of Cox Flat. The positive anomaly has a relative magnitude of about 400 gammas; it lies athwart the northwest-trending antiform and may represent an up-doming of normally polarized late(?) Oligocene and Miocene volcaniclastic rocks or, more likely, a reflection of higher average elevation and some hills capped with normally polarized late Miocene basalt near the center of the high. The greater abundance of rhyolite domes and intrusives in and near this anomaly may only be a fortuitous result of erosion and exposure; they also may be weakly normally polarized. No other surfical

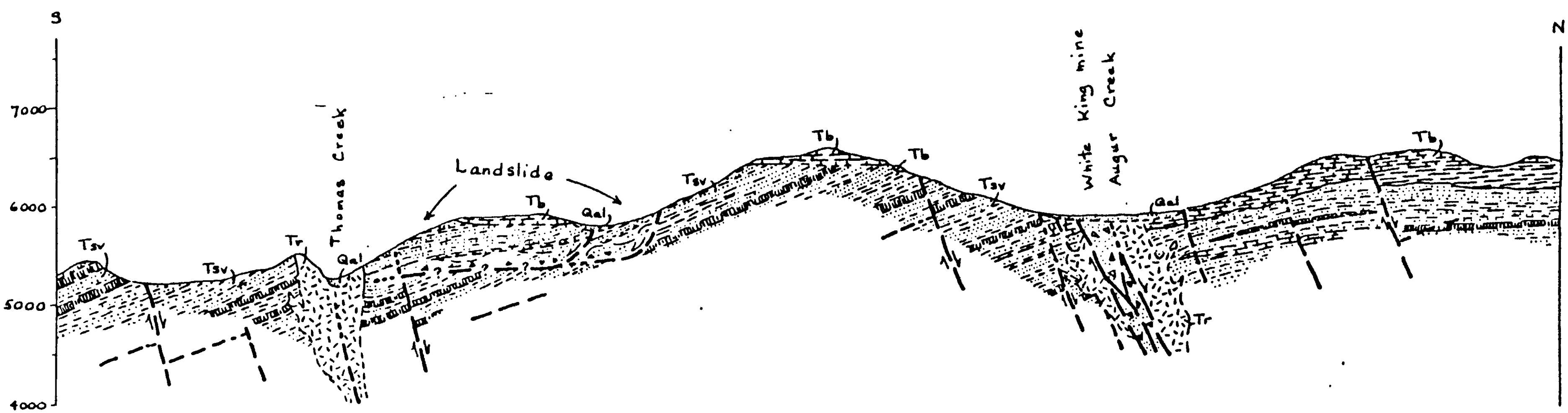


Figure 11.--Sketch section, approximately north-south, through White King mine area. Shows landslide block on south slope between Thomas and Augur Creeks. Vertical exaggeration, 2X.

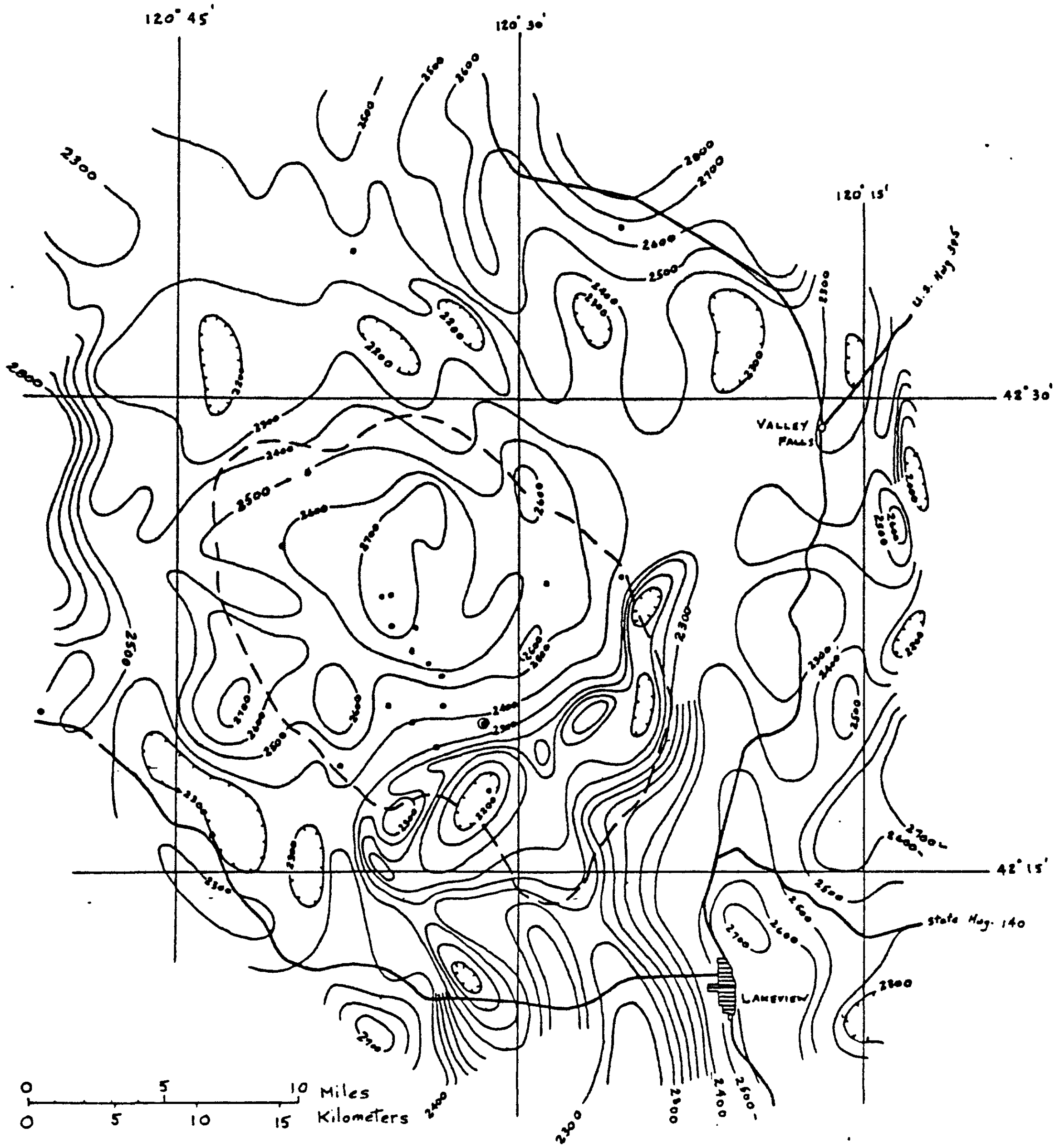


Figure 12.--Regional aeromagnetic map of the Lakeview area, Oregon. (Modified from U.S. Geol. Survey, 1972). Outline of area covered on geologic map (Plate 1) — — . Location of domes and intrusives • and of White King mine ⊗ .

geologic phenomena that would explain this broad elliptical magnetic high have been recognized.

CHEMICAL COMPOSITION OF RHYOLITES

In order to more completely understand the petrochemical nature of the rhyolites in the Lakeview region and to ascertain the content and distribution of selected trace elements, chemical analyses were made of representative samples of intrusive and extrusive rocks collected from the uranium-bearing area and of some similar rocks in adjoining areas. Where possible, fresh undevitrified and nonhydrated obsidian from chilled marginal facies of the intrusives and domes was selected for analysis, although for the altered and silicified rhyolite at the White King mine no such material has yet been found. A few samples of partly hydrated and thoroughly devitrified rhyolite also were analyzed for comparison with the analyses of unaltered obsidian. Many of the samples are obsidian blebs (apache tears) collected from zones of hydrated glass on the margins of the rhyolite masses; larger blebs from these zones were crushed, and only the nonhydrated fresh glass from the cores of the apache tears was analyzed.

Chemically most of the domes and intrusives in the Lakeview uranium area are surprisingly similar (table 3, col. 1 through 12), particularly if analyses from chilled marginal facies are compared; they also are much like other Miocene rhyolites exposed in nearby areas (table 3, col. 13 through 20). In most volcanic rock classifications (Rittmann, 1952; Nockolds, 1954; Wahlstrom, 1955; O'Connor, 1965) all of these intrusive and extrusive rocks are within the range of rhyolite to soda rhyolite, although those at Owen Butte, at Cougar Peak, Morgan Creek, northeast of Paxton Meadow, and several from the Drake Peak complex (Wells, 1975) are slightly more mafic than the other rhyolites. The unaltered glassy rhyolites are all slightly peraluminous, with $Al_2O_3 > Na_2O + K_2O + CaO$, and in most rocks some corundum is present in the norm. Normatively the rocks are composed of more or less equal amounts of quartz, orthoclase, and albite; they contain only minor amounts of other constituents. A normative Q-Or-Ab plot (fig. 13) shows a close grouping of all analyzed rhyolite and only a slight and probably nondiagnostic tendency for rhyolites of the younger age group to be slightly enriched in quartz and perhaps in orthoclase over those in the 14-16-m.y. age groups and in the undated group of rhyolites.

The one analysis of altered and silicified rhyolite from the White King mine (table 3, col. 1) shows some leaching of Al_2O_3, total Fe, Na_2O, and CaO and some addition of silica. Apparently the processes that altered the rhyolite had relatively little affect on the content of K_2O, TiO_2, and P_2O_5, although K_2O may be slightly depleted and P_2O_5 slightly enriched. Rhyolite at the White King mine is too altered to permit meaningful comparisons with the unaltered glassy rhyolites and obsidians, although the ratio of one oxide to another seems to follow a pattern similar to that in the other analyzed rocks. It seems likely that prior to silicification and alteration the White King intrusive was similar to, if not identical with, the other young rhyolites exposed adjacent to Cox Flat and on Thomas Creek.

Differentiation indexes of all the rhyolitic rocks that have been analyzed, except for the altered intrusive at the White King mine, are in the range of 90 to 98 (see table 3), the most highly differentiated rocks are

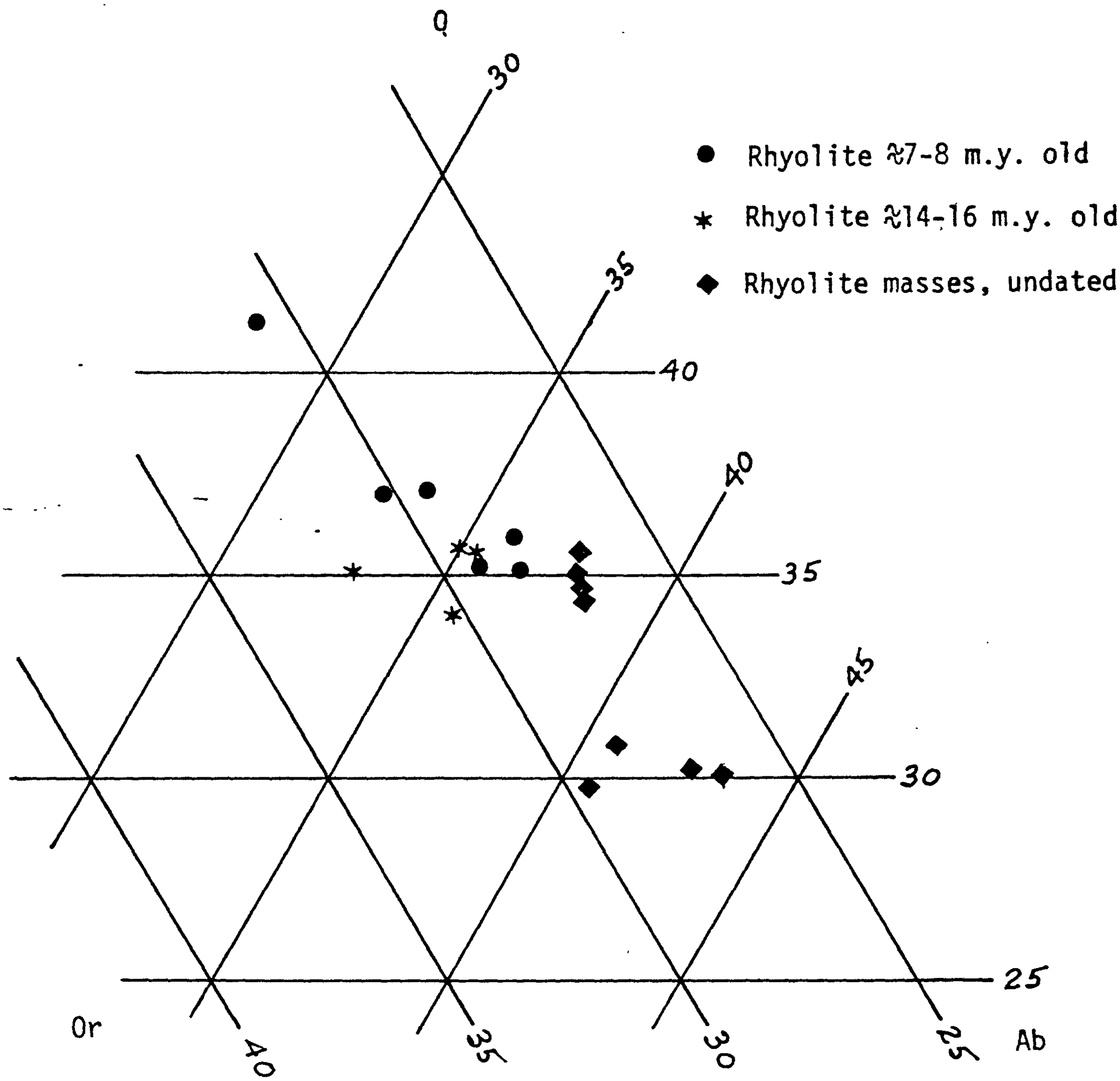


Figure 13.--Normative Q-Or-Ab plot of analyzed rhyolites.

Table 3. Chemical analyses, including analysis of selected minor elements, and norms of rhyolite domes and flows from southern Lake and Klamath Counties, Oregon

[N, not detected at limit of detection, or at value shown. L, detected, but below limit of determination, or below value shown. --, not determined. Includes conventional and rapid-rock analyses. Trace elements by spectrographic and INAA methods. Analysts: N. Skinner, Edytha Engleman, H. T. Millard, Jr., C. McFee, C. H. Ellis, V. C. Smith, R. B. Vaughn, M. F. Caughlin, H. N., Schneider, W. R. Steng, C. Bliss, J. C. Crock, Joseph Maffty, A. Haubert, L. J. Schwarz, J. Budinsky, E. Campbell, R. Moore, W. D'Angelo, Wayne Mountjoy, P. A. Baedecker]

	Lakeview uranium area												Adjacent areas							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
K-Ar age	7.0±0.4	7.19±0.32					7.27±0.50			16.0±0.4			7.70±0.09	7.41±0.19	7.13±0.34	7.11±0.94	(14 m.y.)			
SiO_2	81.4	76.27	76.9	76.8	75.7	76.68	74.73	74.6	75.1	76.1	75.2	74.7	75.87	76.06	76.75	72.28	74.67	75.53	76.53	74.3
Al_2O_3	10.5	13.48	13.4	13.4	13.0	12.95	13.41	13.4	13.3	13.1	13.2	13.0	13.33	13.21	12.56	13.06	13.47	13.44	13.58	12.9
Fe_2O_3	.03	.00	.17	.20	.13	.30	1.22	.89	.60	.86	.78	.77	.15	.19	.28	.90	[1]1.62	[1].51	[1].38	.65
FeO	.01	.25	.25	.20	.24	.31	.25	.51	.76	.24	.78	.72	.45	.49	.45	.63	—	—	—	.77
MgO	.00	.08	.01	.00	.00	.04	.19	.04	.05	.01	.07	.06	.06	.06	.03	.38	.52	.29	.21	.04
CaO	.05	.56	.30	.26	.28	.49	1.06	.46	.47	.10	.48	.42	.89	.80	.51	1.25	1.23	.85	.81	.55
Na_2O	2.6	3.09	4.4	4.3	4.3	4.29	3.62	4.8	4.9	4.1	4.6	4.6	3.92	4.05	4.07	3.38	3.53	3.90	3.92	4.7
K_2O	4.2	4.83	4.5	4.4	4.4	4.40	4.54	4.4	4.3	5.0	4.6	4.8	4.61	4.52	4.53	4.48	4.91	4.64	4.70	4.5
H_2O+	.53	.98	.47	.65	1.4	.13	.37	.32	.12	.51	.27	.26	.21	.16	.28	2.28	.52	.56	.56	.28
H_2O-	.67	.15	.05	.05	.05	.03	.06	.02	.08	.31	.12	.16	.05	.04	.06	.08				
TiO_2	.07	.06	.07	.07	.08	.06	.18	.06	.06	.19	.08	.08	.05	.05	.06	.19	.28	.08	.10	.06
P_2O_5	.11	.01	.10	.05	.03	.00	.04	.04	.04	.10	.04	.04	.00	.00	.01	.05	.08	.03	.00	.10
MnO	.01	.02	.09	.09	.09	.10	.05	.05	.05	.02	.05	.05	.06	.07	.07	.06	.05	.02	.04	.00
CO_2	.00	—	.01	.01	.00	—	—	.01	.02	—	.00	.02	—	—	—	—	—	—	—	.01
NORMS (WATER-FREE)																				
Q	—	39.03	33.75	34.59	33.75	33.69	34.09	29.84	28.94	33.31	29.55	28.88	33.25	33.23	34.47	33.27	32.09	33.19	33.85	29.14
Or	—	28.95	26.71	26.00	26.47	26.12	27.00	26.18	25.53	29.55	27.24	28.60	27.42	26.83	26.89	27.30	29.19	27.36	27.95	26.95
Ab	—	26.23	37.40	36.38	37.06	36.47	30.88	40.95	41.63	34.69	39.01	39.17	33.42	34.44	34.52	29.44	30.04	33.17	33.34	40.36
An	—	2.76	.84	.97	1.19	2.43	5.05	2.02	1.58	.15	1.76	.67	4.46	3.97	2.47	6.08	5.63	4.02	4.02	.87
C	—	2.28	1.00	1.21	.74	.23	.70	—	—	1.00	—	—	.26	.22	.06	.51	.29	.59	.59	—
Ac	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ns	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Wo	—	—	—	—	—	—	—	—	.20	—	.15	.48	—	—	—	—	—	—	—	.53
En	—	.20	.02	—	—	.10	.47	.10	.12	.2	.17	.15	.15	.15	.07	.97	1.30	.72	.52	.10
Fs	—	.40	.37	.25	.37	.41	—	.19	.89	—	.75	.66	.81	.79	.63	.21	.47	.18	.10	.79
Mt	—	—	.25	.29	.19	.43	.45	1.30	.87	.29	1.13	1.13	.22	.28	.41	1.33	1.17	.36	.28	.96
Il	—	.11	.13	.13	.15	.11	.34	.11	.11	.36	.15	.15	—	.09	.11	.38	.53	.15	.19	.11
Ap	—	.02	.24	.12	.07	—	.09	.09	.09	.24	.09	.09	—	—	.02	.12	.19	.07	—	.24
Hm	—	—	—	—	—	—	.92	—	—	.66	—	—	—	—	—	—	—	—	—	—
Q	—	41.42	34.49	35.67	34.69	35.00	37.06	30.20	30.12	34.15	30.85	29.88	35.34	35.17	35.95	36.96	35.14	35.42	35.58	30.21
Or	—	30.73	27.29	26.81	27.21	27.13	29.36	27.22	26.56	30.29	28.44	29.59	29.14	28.39	28.04	30.33	31.97	29.19	29.38	27.94
Ab	—	27.84	38.22	37.52	38.10	37.88	33.58	42.58	43.32	35.56	40.72	40.53	35.52	36.44	36.00	32.71	32.89	35.39	35.04	41.85
D.I.	—	94.	98.	97.	97.	96.	92.	97.	96.	98.	96.	97.	94.	95.	96.	90.	91.	94.	95.	96.

Table 3 (continued)

QUANTITATIVE SPECTROGRAPHIC AND INAA TRACE-ELEMENT DETERMINATIONS ON CHEMICALLY ANALYZED SAMPLES

Cl[2]	39.	190.	180.	180.	190.	80.	230.	1100.	1200.	1000.	2500.	2800.	470.	390.	510.	610.	--	--	--	1100.
F[3]	18.	50.	460.	500.	730.	69.	240.	1400.	1400.	170.	2500.	700.	830.	750.	490.	170.	--	--	--	--
Ag	<20.	.05	<20.	<20.	<20.	<.05	<.05	<20.	<20.	<20.	<20.	<20.	.06	<.05	.04	.05	--	--	--	.07
As	160.	1.7	1.2	4.0	1.6	5.4	2.1	1.1	1.4	1.9	2.1	2.1	2.1	2.0	2.8	2.8	--	--	--	4.0
Au	<.05	<.1	<.05	<.05	<.05	<.1	<.1	<.05	<.05	<.05	<.05	<.05	<.1	<.1	<.1	<.1	--	--	--	<.05
B	31.	20.	110.	95.	100.	70.	20.	130.	120.	55.	180.	110.	30.	30.	72.	20.	--	--	--	--
Ba	25.	96.	10.	4.	6.	77.	899.	20.	24.	120.	11.	16.	382.	313.	51.	1046.	--	--	--	--
Be	1.5	3.	.6	<.6	<.6	6.	N2	3.	2.	3.	4.	3.	4.	2.	4.	N2	--	--	--	--
Bi	<6.	--	<6.	<6.	<6.	--	--	<14.	<14.	<6.	<14.	<14.	--	--	--	--	--	--	--	--
Cd	<14.	N50	<14.	<14.	<14.	N50	N50	<14.	<14.	<14.	<14.	<14.	--	N50	N50	N50	--	--	--	--
Co	<2.	<2.	<2.	<2.	<2.	.1	1.8	<2.	<2.	<2.	<2.	<2.	.2	.2	<.3	2.1	--	--	--	--
Cr	5.	<.5	7.	7.	8.	.6	2.2	<1.5	4.	6.	<1.5	<1.5	<1.3	.7	<.8	2.4	--	--	--	--
Cu	<9.	1.	12.	12.	62.	2.	8.	11.	10.	13.	25.	85.	2.	1.	3.	10.	--	--	--	--
Hg	.46	.38	.022	.03	.065	.050	.050	.02	.035	.022	.038	<.01	.058	.065	.045	.01	--	--	--	<.01
La	<15.	11.5	<15.	<14.	<14.	12.	33.5	<14.	<14.	43.	53.	53.	31.8	45.5	19.	29.5	--	--	--	--
Mo	5.	N3	3.	3.	3.	N3	L3	<4.	<4.	7.	11.	7.	4.	L3	L3	L3	--	--	--	--
Nb	26.	L10	41.	37.	41.	20.	L10	14.	14.	35.	24.	20.	L10	L10	L10	L10	--	--	--	--
Ni	1.5	L5	2.	2.	1.5	N5	L5	2.	3.	<1.5	<1.5	<1.5	N5	N5	N5	L5	-	--	--	--
Pb	30.	50.	35.	32.	49.	50.	40.	12.	10.	27.	10.	8.	40.	40.	40.	30.	--	--	--	--
Sb	43.1	.8	.9	.9	1.0	1.0	.4	.4	.4	.8	.8	.8	.4	<.6	.6	.5	--	--	--	--
Sc	1.	3.07	4.	3.	2.	4.73	2.79	<1.5	<1.5	1.	<1.5	<1.5	2.2	2.49	3.16	2.90	--	--	--	--
Sn	<4.	N10	<4.	<4.	20.	N10	N10	<4.	<4.	7.	<4.	<4.	N10	N10	N10	N10	--	--	--	--
Sr	10.	49.	4.	2.	3.	5.	190.	<2.	<2.	36.	<2.	<2.	85.	68.	8.	190.	166.	26.	57.	--
V	<2.	L7	<2.	<2.	<2.	N7	20.	<2.	<2.	<2.	<2.	<2.	N7	N7	N7	30.	--	--	--	--
W[2]	.80	1.2	.66	.86	.50	.76	.76	1.2	1.1	2.0	2.2	2.2	.88	.90	1.1	.92	--	--	--	--
Y	29.	20.	52.	43.	44.	60.	20.	120.	140.	31.	49.	45.	30.	30.	40.	20.	--	--	19.	--
Zn	<30.	15.	<30.	<30.	70.	33.	34.	150.	120.	<30.	160.	63.	28.	30.	34.	32.	--	--	--	--
Zr	53.	108.	100.	90.	110.	138.	154.	120.	110.	210.	120.	110.	74.	76.	88.	128.	86.	37.	60.	--
Ce	<100.	19.5	<100.	<100.	<100.	24.5	53.5	<100.	<100.	<100.	<100.	<100.	19.	27.	37.	46.	--	--	--	--
Ga	14.	17.	20.	19.	19.	20.	14.	23.	23.	21.	22.	19.	15.	14.	15.	16.	--	--	--	--
Ge	<14.	N10	<14.	<14.	<14.	N10	N10	<10.	<10.	<14.	<10.	<10.	N10	N10	N10	N10	--	--	--	--
In	<3.	--	<3.	<3.	<3.	--	--	<3.	<3.	<3.	<3.	<3.	--	--	--	--	--	--	--	--
Re	<14.	--	<14.	<14.	<14.	--	--	<14.	<14.	<14.	<14.	<14.	--	--	--	--	--	--	--	--
Tl	<6.	--	<6.	<6.	<6.	--	--	<6.	<6.	<6.	<6.	<6.	--	--	--	--	--	--	--	--
Yb	1.	2.4	5.	3.	2.	5.3	2.0	8.	7.	3.	4.	3.	2.7	2.9	3.35	2.0	--	--	--	--
Th	12.1	9.1	15.2	16.1	15.2	16.1	11.1	10.3	11.0	19.3	19.3	19.1	6.8	8.4	11.95	9.6	--	--	--	11.2
U	9.7	6.5	9.7	9.4	8.3	8.8	4.5	3.3	3.4	6.6	6.6	6.6	4.8	4.7	8.2	6.05	--	--	--	3.7
Th/U	1.25	1.40	1.57	1.71	1.71	1.83	2.47	3.12	3.24	2.92	2.92	2.89	1.42	1.79	1.46	1.59	--	--	--	3.02

[1] All iron as Fe_2O_3.

[2] W and Cl determined spectrophotometrically.

[3] F determined with specific-ion electrode.

1. Flow-banded and silicified rhyolite collected from outcrop just above water level at west end of open pit, White King mine. Lat 42°19.9' N., long 120°31.3'W. (Sample GW-26-77).
2. Flow-banded perlitic obsidian collected from borrow pit on west side of large dome on Thomas Creek. Lat 42°19.8'N., long 120°36.0'W. (Sample Mo73-37).
3. Rhyolite collected from dome northeast of Cox Flat. Lat. 42°22.7'N., long 120°34.3'W. (Sample GW-9-77).
4. Obsidian (apache tears) collected from marginal facies of dome west of Lucky Lass mine. Lat 42°20.3'N., long 120°33.5'W. (Sample GW-68-77).
5. Obsidian (apache tears) collected from marginal facies of dome east of Cox Flat. Lat 42°21.8'N., long 120°34.0'W. (Sample GW-74-77).
6. Glassy rhyolite from borrow pit on east side of small dome north of U.S. Forest Service Worker Center. Lat 42°23.8'N., long 120°36.0'W. (Sample Mo73-38).
7. Glassy rhyolite from southwest top of Cougar Peak. Lat 42°18.3'N, long 120°37.9'W. (Sample Mo73-36).

Table 3 (continued)

8. Obsidian (apache tears) from marginal facies of dome northeast of Paxton Meadow. Lat 42°24.2'N., long 120°28.7'W. (Sample GW-107-77).
9. Obsidian (apache tears) from marginal facies of rhyolite flow(?) exposed on Cox Creek road. Lat 42°23.7'N., long 120°25.8'W. (Sample GW-126-77).
10. Glassy rhyolite from top of Drum Hill. Lat 42°27.6'N., long 120°39.4'W. (Sample GW-33-77.
11. Obsidian (apache tears) from marginal facies of dome on Morgan Creek. Lat 42°25.6'N., long 120°40.7'W. (Sample GW-80-77).
12. Obsidian (apache tears) from marginal facies of dome on upper Morgan Creek. Lat 42°25.2'N., long 120°41.5'W. (Sample GW-89-77).
13. Obsidian (apache tears) collected on south slope of McComb Butte fro marginal facies of dome. Lat 42°34.6'N., long 120°37.1'W. (Sample Mo73-39).
14. Obsidian (apache tears) from marginal facies of dome(s) at Tucker Hill. Lat 42°36.0'N., long 120°25.3'W. (Sample Mo73-40).
15. Obsidian (apache tears) from marginal facies of rhyolite mass at Drews Ranch. Lat 42°16.1'N., long 120°43.8'W. (Sample Mo73-34).
16. Perlitic rhyolite from south flank of Owen Butte. Lat 42°19.7'N., long 120°51.9'W. (Sample Mo73-35).
17. Rhyolite from Drake Peak area (see Wells, 1975). (Sample 134-D).
18. Rhyolite from Drake Peak area (see Wells, 1975). (Sample 144-D).
19. Rhyolite from Drake Peak area (see Wells, 1975). (Sample 149-D).
20. Obsidian (apache tears) from marginal facies of dome north of Camas Prairie. Lat 42°15.5'N., long 120°17.9'W. (Sample GW-35-78).

those at Drum Hill (D.I.=98) and the dome northeast of Cox Flat (D.I.=97) and the least differentiated at Drake Peak (D.I.=91) and Owen Butte (D.I.=90). Comparisons of these differentiation indexes with those published by Thornton and Tuttle (1960) for Daly's averages of several major igneous rock types show (1) the high degree of differentiation in all of the Lakeview area rhyolites and (2) that they are most like Daly's alkali rhyolites. Examples of both the youngest and intermediate age groups of rhyolites are included in both the most highly and least differentiated material. Whether any of the rhyolites are comagmatic remains to be proved. The only suggestion of consanguinity is the similarity in chemistry and close age grouping of the youngest rhyolites.

Selected minor element chemistry (table 3) shows expectable patterns of abundance and distribution not unlike those found in other silicic crustal rocks (Turekian and Wedepohl, 1961; Deffeyes and MacGregor, 1978, p. 17), particularly rhyolitic rocks of the western United States (Coats, 1956; Zielinski, 1978).

The content of F and Cl in the rhyolites of the Lakeview uranium area is highly variable. The variations are somewhat comparable to those found throughout middle and upper Cenozoic rhyolite domes of southeast Oregon (MacLeod and others, 1976) and perhaps reflect mainly the depth of emplacement and the effect this has on exsolution and escape of volatiles. Fluorine ranges from 18 ppm (parts per million) at the White King mine and 50 ppm in the large dome on Thomas Creek to 1,400 ppm in the rhyolites near Paxton Meadow and Cox Creek. Chlorine ranges from 39 ppm in rhyolite from the White King mine to 2,800 ppm in the intrusive on upper Morgan Creek. Note that the lowest contents of both F and Cl occur in the altered rock from the White King mine, showing that the alteration leached rather than deposited halogens.

The presence of minor amounts of cinnabar (HgS) and stibnite (Sb_2S_3) and substantial amounts of realgar (AsS), orpiment (As_2S_2), jordisite (amorphous MoS_2), and ilsemannite ($Mo_3O_8 \cdot N\ H_2O$?) in the White King mine indicates probable enrichment in the metallic elements that comprise these minerals, although it may only demonstrate redistribution of elements within a large body of rock to form local concentrations. Geochemical data suggest that mercury is enriched in the rhyolite at the White King mine and in the large dome on Thomas Creek, but show no correlation with differentiation index (fig. 14) or with feldspar fractionation, as indicated by the content of Ba and Sr (fig. 15). Arsenic, which is a major constituent of the ores at the White King mine, is abundant (160 ppm) in the White King rhyolite and slightly enriched in the dome or intrusive west of the Lucky Lass mine and in the rhyolite northeast of the U.S. Forest Service Thomas Creek Work Camp (table 3); it also shows little, if any, correlation with the degree of differentiation (fig. 16) and questionable correlation with total Ba and Sr (fig. 17). In the White King mine some jordisite and its widespread alteration product ilsemannite indicates at least local enrichment of molybdenum and analyses for Mo in some of the rhyolite obsidians of the Lakeview uranium area indicate several times normal crustal abundances. Analyses of rhyolites of the younger age group in and near the White King and Lucky Lass mines indicate a molybdenum content of about 3 ppm or less, whereas the intermediate-age rhyolite at Drum Hill contains 7 ppm and the two nearby rhyolite masses on Morgan Creek, both of which are thought to represent the intermediate age group, contain 11 and 7 ppm. Whether the high values in these geographically closely grouped rhyolite masses is provincial, age

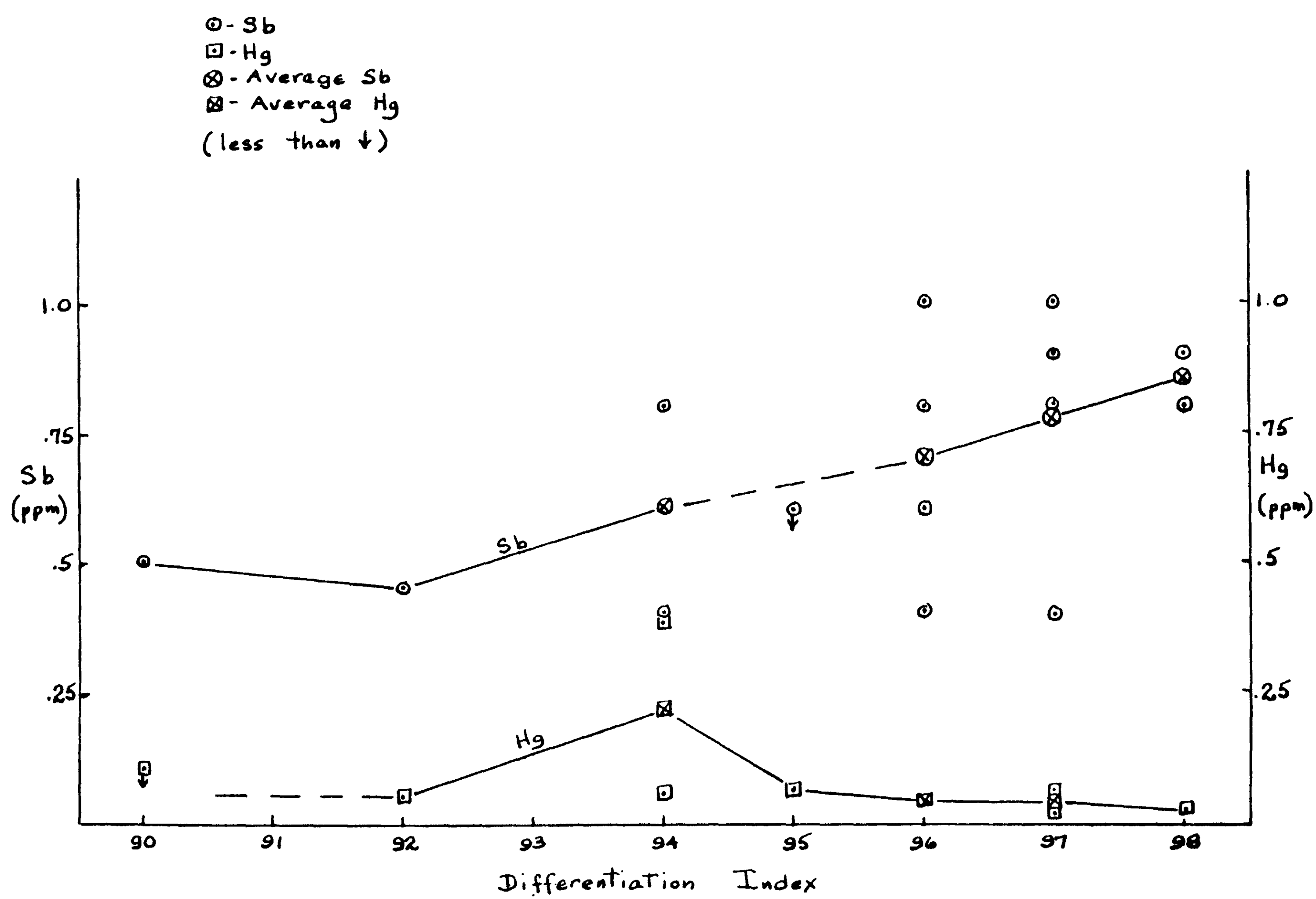


Figure 14. Mercury- and antimony-differentiation index diagram.

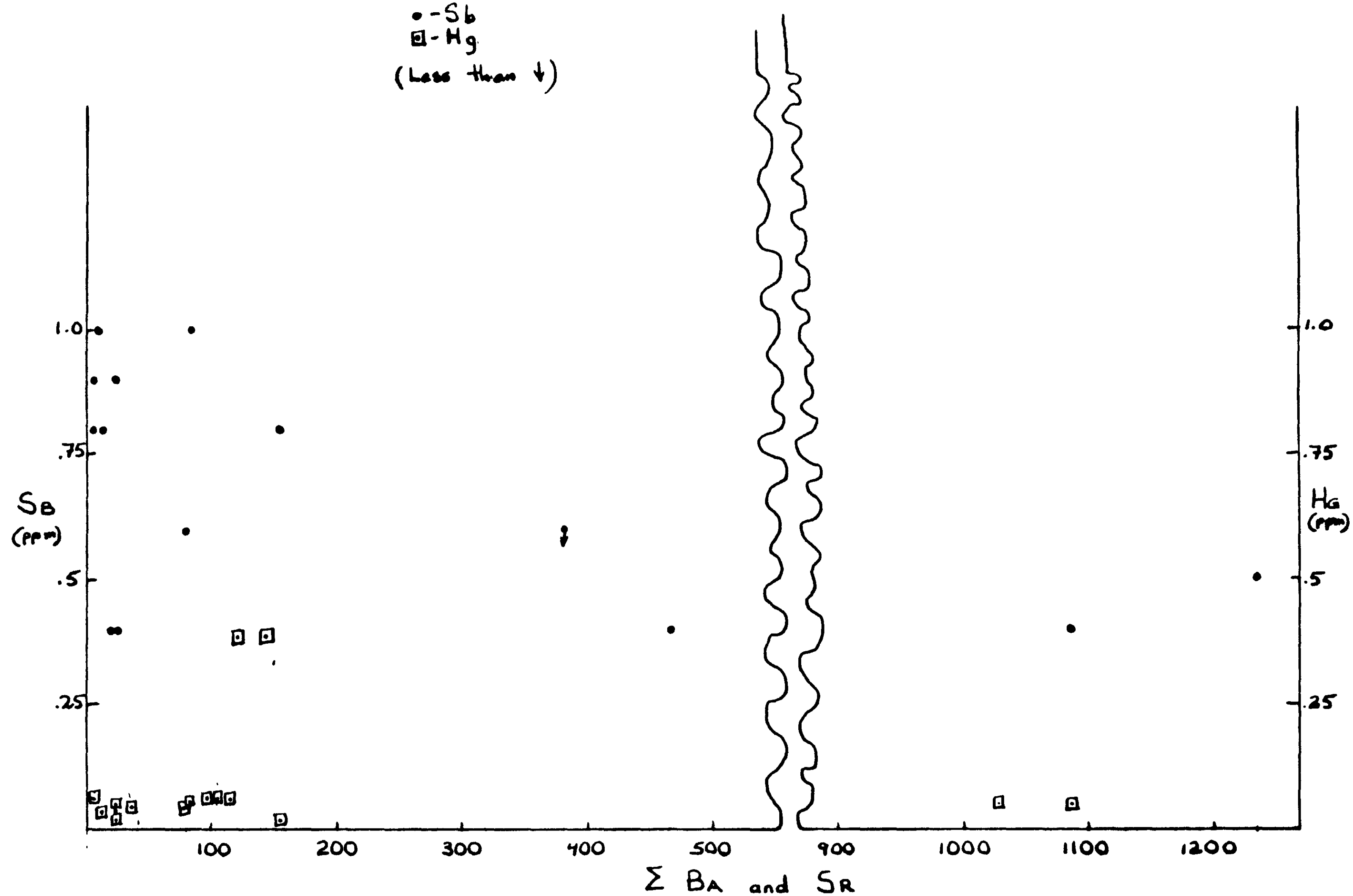


Figure 15. Variation of mercury and antimony with total barium and strontium.

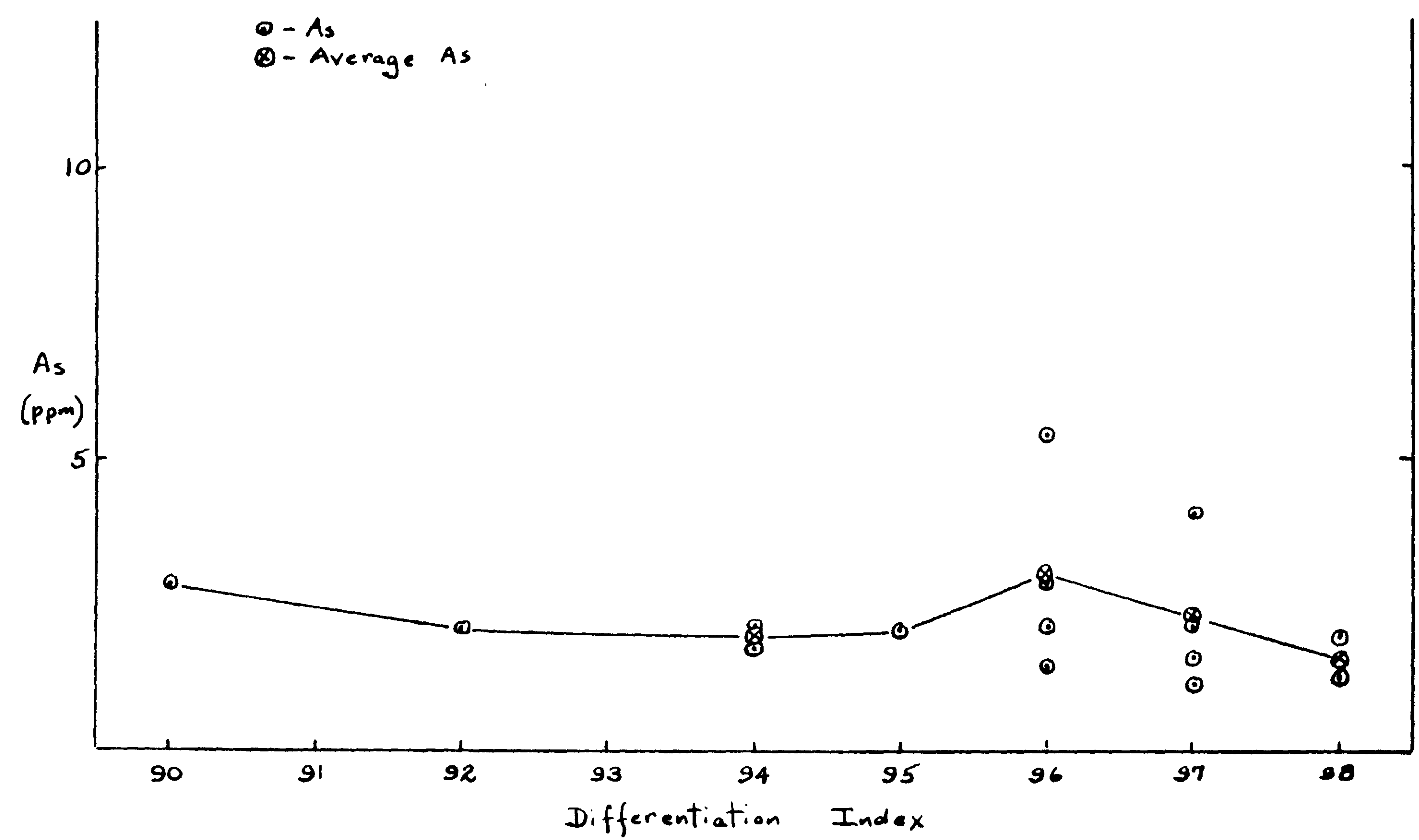


Figure 16. Arsenic-differentiation index diagram.

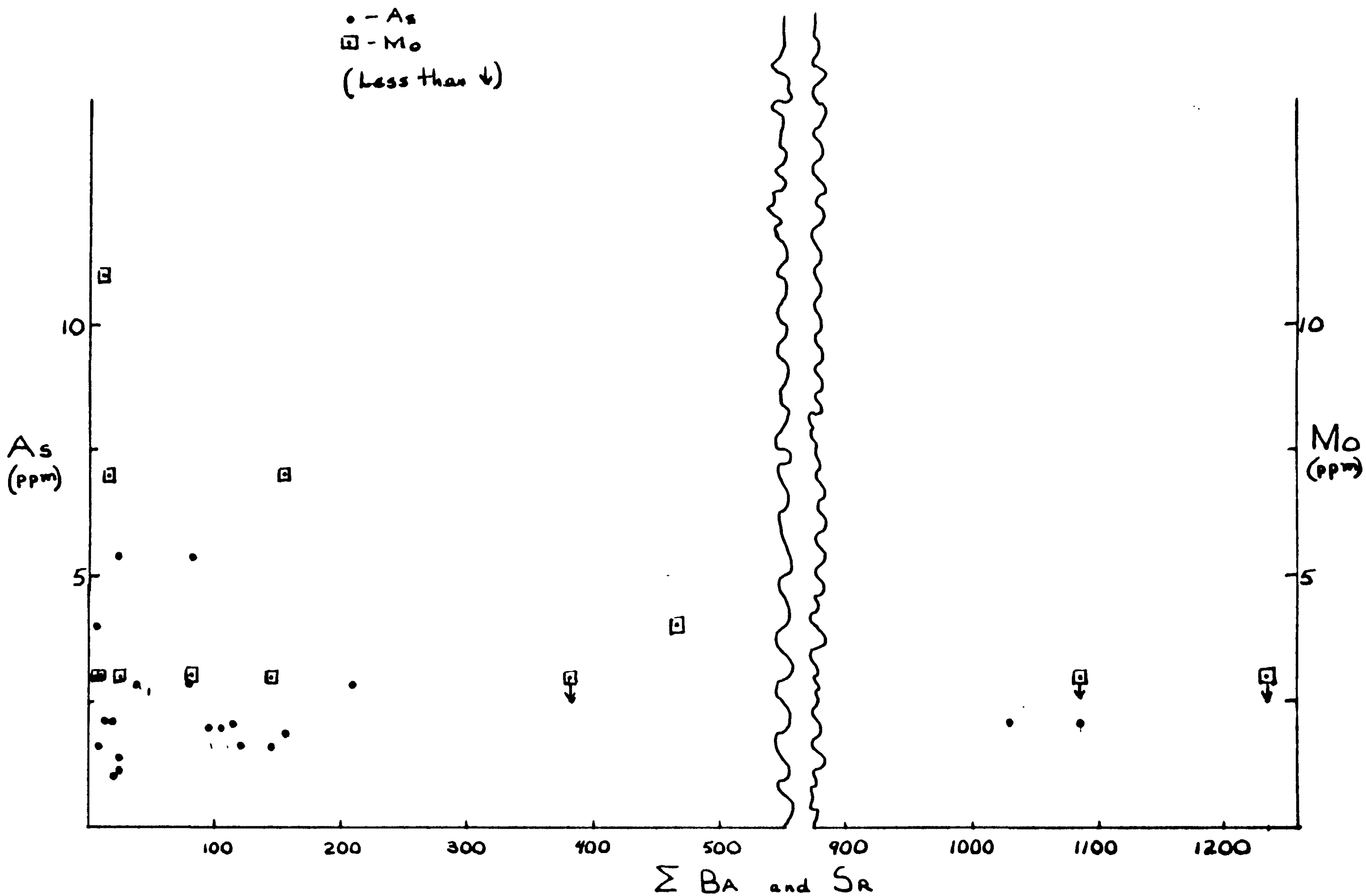


Figure 17. Variation of arsenic and molybdenum with total barium and strontium.

related, or fortuitous is, as yet, unresolved. Little, if any, correlation can be demonstrated between molybdenum content and differentiation index (fig. 18) or with depletion of barium and strontium (fig. 17).

None of the rhyolites shows any appreciable enrichment in either Au or Ag. Slight enrichment of Cu characterizes the rhyolite mass northeast of Cox Flat and on upper Morgan Creek and Zn may be slightly enriched in rhyolite exposed lower on Morgan Creek and near Paxton Meadow.

Invariably the rhyolite domes and intrusives are several times more radioactive than any of the wallrocks and analyses for uranium and thorium indicate some enrichment in these elements. Chilled glass from the margins of the domes and intrusives contains from 3.3 to 9.4 ppm uranium, as determined by instrumental neutron activation analyses (INAA), and from 6.8 to 21.4 ppm thorium, whereas the somewhat more crystalline core facies generally contain a little less uranium and thorium. Uranium contents similar to those presented here were found in samples from several domes in the region using fluorometric analytical techniques (Erikson and Curry, 1977). The single analysis of altered rhyolite from the White King mine shows about the same amount of thorium as found in other rhyolite bodies in the area. The abundance and distribution pattern for uranium is comparable to that in most calc-alkaline rhyolites of the western United States and matches a few of the peralkaline rhyolites (Zielinski, 1978), although the peralkaline rhyolites of the central and northern Basin and Range tend to be richer in uranium, reaching levels of 9 to 10 ppm in ash-flow tuffs and even higher values in the middle Miocene peralkaline rhyolite domes of the McDermitt caldera area (Zielinski, 1978; J. J. Rytuba, oral commun., 1978; Rytuba and others, 1979).

The abundance of uranium and thorium in the Lakeview uranium area tends to increase with differentiation index (fig. 19), although among those peraluminous rhyolites of both middle and late Miocene age increases are nonlinear and the highest values occur between differentiation indexes of 96 and 97. Differences in barium and strontium abundances suggest that some feldspar fractionation may have occurred and that this fractionation also affected the uranium and thorium abundances (fig. 20), the high values being associated with rhyolites depleted in Ba and Sr, and hence, feldspar. Because rhyolites of both middle and late Miocene age are involved, the fractionation patterns are tenuous at best, however.

If one assumes that rhyolites of the younger age group are all part of a single episode of volcanism and in some way genetically related to a common body of differentiating magma at depth, the chemistry indicates not only a high degree of differentiation but also suggests some feldspar fractionation. Spectrographic analyses of samples of the younger rhyolites mostly show low barium and strontium values (table 3), except for samples of the rhyolite at Cougar Peak (840 ppm Ba; 190 ppm Sr) and Owen Butte (920 ppm Ba; 190 ppm Sr). Further, comparisons of the abundances of uranium and thorium in all of the younger group of rhyolites with the total content of Ba and Sr (fig. 21), suggests an enrichment in both uranium and thorium in the residual melt as a result of the crystallization and fractionation of feldspar. These data also show a strong tendency for all the young domes and intrusives within a kilometer or two of the White King mine to be characterized by high differentiation indexes, low total Ba and Sr, and high uranium and thorium values. This may imply a significant geographic separation of those rhyolites of potential economic interest from those of little or no interest.

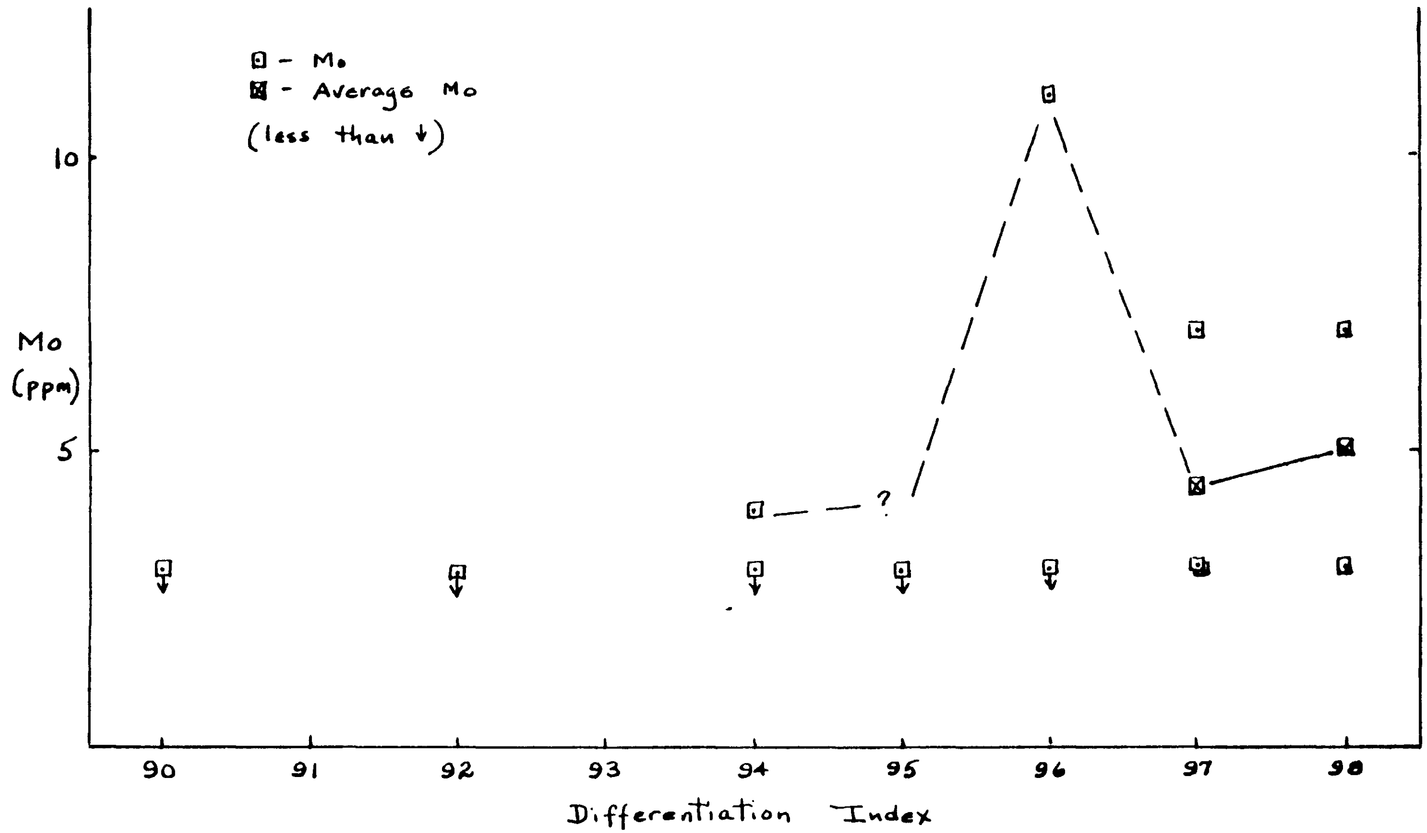


Figure 18. Molybdenum-differentiation index diagram.

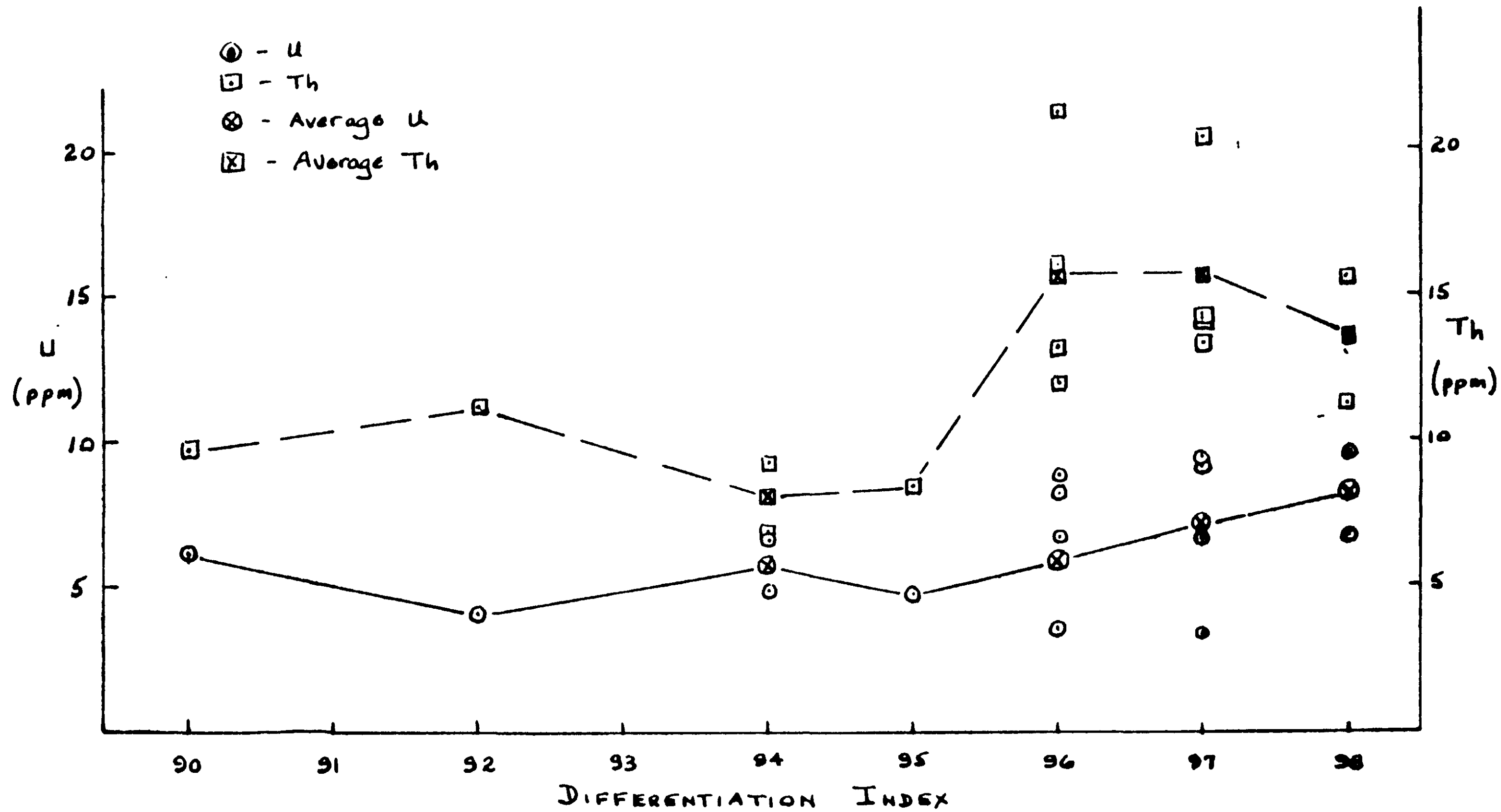


Figure 19. Variation of uranium and thorium with differentiation index.

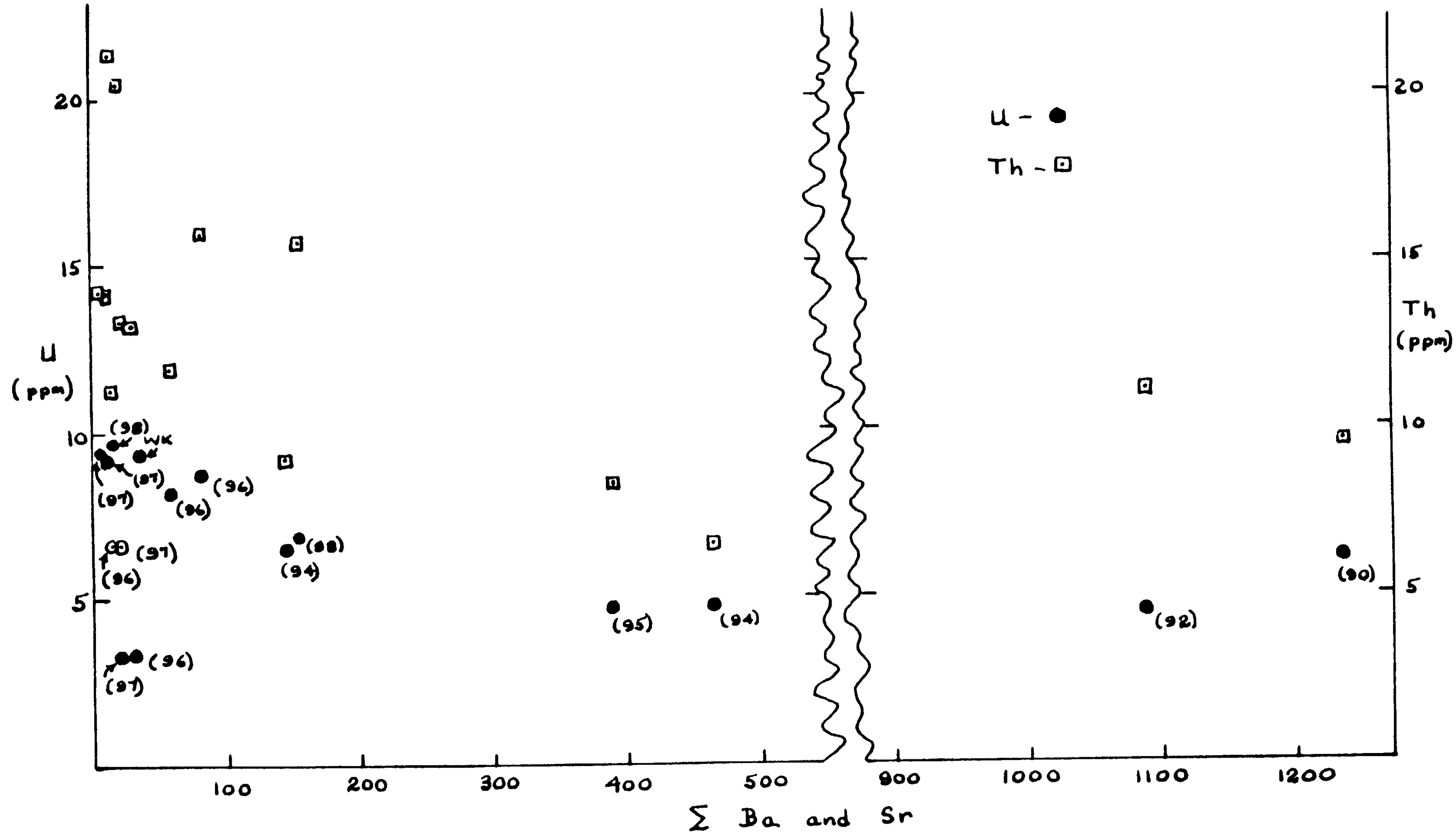


Figure 20. Variation in uranium and thorium content of all analyzed rhyolites (except for rhyolite at White King and Drake Peak) with total barium plus strontium content. Numbers in parentheses represent differentiation indexes (D.I.) of individual rhyolites.

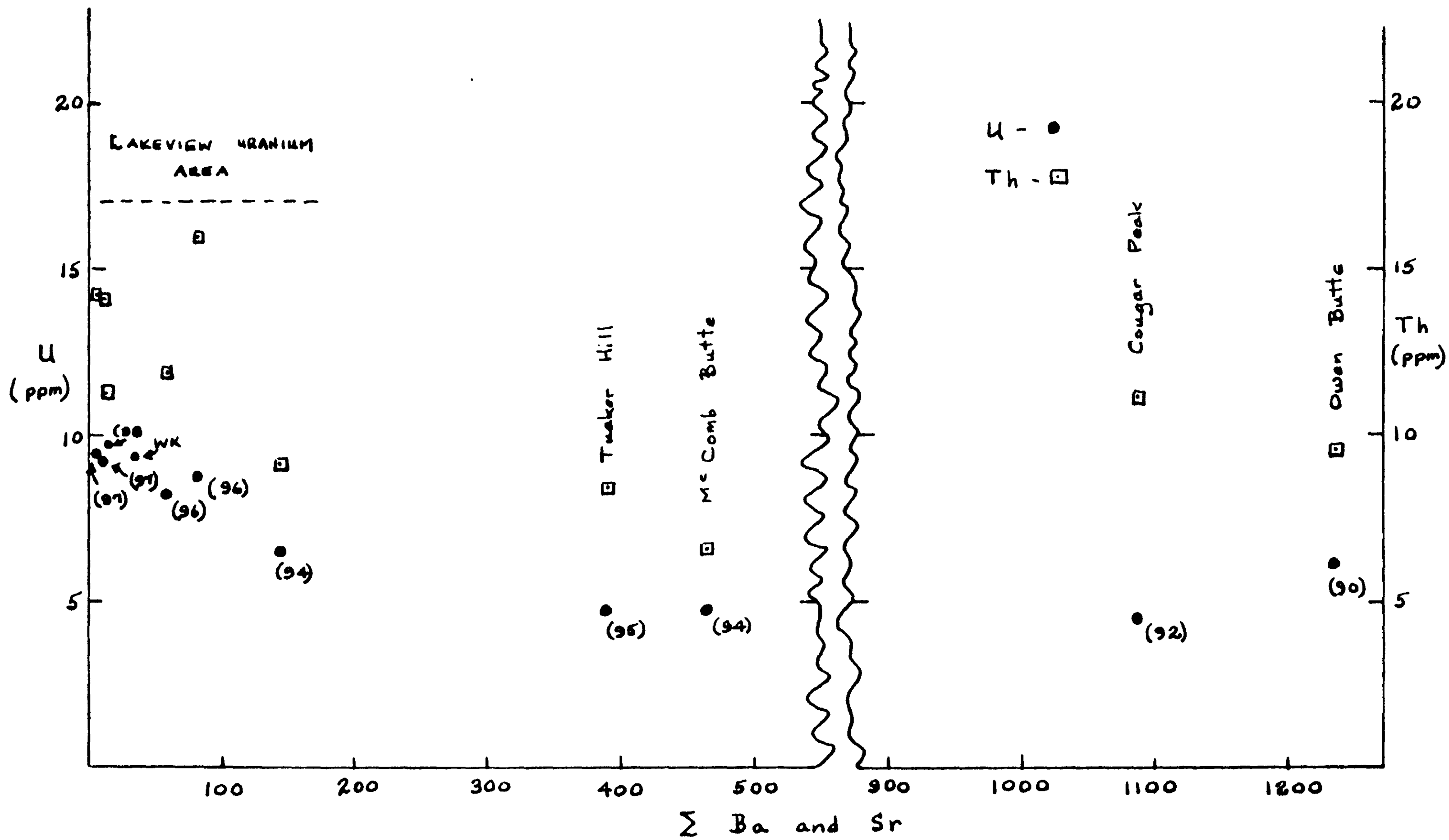


Figure 21. Variation in uranium and thorium content of younger group of rhyolites (only) with total barium plus strontium. WK, identifies intrusive at White King mine. Numbers in parentheses represent differentiation indexes (D.I.) of individual rhyolites.

Among the dated rhyolites with ages between 7 and 8 m.y., there seems to be no recognizable correlation of feldspar fractionation, as indicated by abundances of Ba and Sr, or of the degree of differentiation with age. The youngest of these rhyolite bodies (7.11 m.y.) contains the highest value of combined Ba and Sr and the lowest differentiation index. This would imply that no systematic differentiation trend can be established with available data for the young group of rhyolites.

URANIUM ORE DEPOSITS AND URANIUM POTENTIAL

The only deposits that have yielded significant tonnages of uranium ore in the Lakeview uranium area are at the White King and Lucky Lass mines, both located on upper Augur Creek about 1.5 km apart. Neither of these properties have been actively mined since the mid-1960's, although study and exploration of these and other nearby uranium-bearing areas have continued intermittently and recently (1977 and 1978) have been at a relatively high level. Workings at both properties are largely inaccessible, owing to extensive flooding of open pits and all underground workings connected to them. Descriptions of these workings and the geology exposed in them, as well as documentation of the early history of uranium discovery and exploitation in the region, is covered in several reports (Peterson, 1959; Cohenour, 1960; Peterson and MacIntyre, 1970) and will not be repeated here. The following discussion is based on new data obtained by the author and on older information that bears on the genesis of the ore bodies and on an evaluation of the uranium potential of the region.

By far the larger of these two deposits is the White King mine (fig. 22), located at the west end of the meadow on upper Augur Creek, where mineralization is associated with a silicified and altered rhyolite intrusive and with the altered tuffs and tuffaceous sedimentary wallrocks. Introduced metallic minerals in veinlets, fracture coatings, and disseminations include pyrite and marcasite, jordisite, uraninite and coffinite, galena, realgar, orpiment, stibnite, and cinnabar; orpiment probably is derived from the hydrothermal alteration of realgar. A variety of secondary minerals has resulted from the oxidation and hydration of the primary assemblage, including hydrated iron oxides, ilsemannite, heinrichite, metaheinrichite, and possibly autunite, tobernite, abernathyite, uranospinite, and novacekite (Cohenour, 1960, p. 21).

The rhyolite intrusive at the White King mine is pluglike with irregular apophyses, and it intrudes a complex northwest-trending fault zone characterized by several en echelon shears and much brecciation that separates a down-dropped fault block north of the fault zone relative to the block south of the fault zone (Cohenour, 1960, fig. 2; pl. 1, and fig. 11). Postintrusive and postmineralization faulting has disrupted ore bodies and locally has brecciated mineralized ground.

The Lucky Lass mine is entirely within a southward dipping, faulted, and locally brecciated and sheared sequence of upper(?) Oligocene to Miocene bedded tuffaceous sedimentary rocks (fig. 23) identified by some workers (Peterson, 1959; Cohenour, 1960) as part of the uppermost Cedarville Formation. No rhyolite is present in surface exposures and apparently none has been encountered in drill holes on the property, several of which have reached depths of over 500 ft ($\sim$152 m). Most of the ore appears to be

Figure 22. Photograph of water-filled open pit at the White King mine. Wall, at west end of pit, exposes a variety of highly faulted and broken volcanic and volcaniclastic rocks that are locally altered and silicified. A few small outcrops of the altered, silicified, and mineralized flow-banded rhyolite are exposed for about 2 m above water level in the left center part of the wall.

Figure 23. Photograph of water-filled open pit at the Lucky Lass mine. Southward-dipping bedded tuffaceous sedimentary rocks of late(?) Oligocene or Miocene age are cut by northward-dipping faults and by some small south-dipping faults (not shown). Ridge to the south (left) is capped by faulted and locally landslid masses of basalt of Coleman Rim.

localized in a steeply inclined pipelike body of sheared and argillized tuffaceous rock between steeply dipping faults. The nearest exposed rhyolite body, which exhibits little or no hydrothermal alteration, is located about 1 km west-northwest of the mine and the next nearest, at the surface, is the altered intrusive at the White King mine, about 1.5 km to the east. Rocks exposed in the open pit at the Lucky Lass are not as silicified or altered as those at the White King mine; most of the ore that was shipped contained secondary uranium minerals and some iron oxides, but apparently none of the other metallic minerals found at the White King mine. Some sooty black to gray pitchblende or coffinite present in the subsurface probably denotes primary mineralization, however.

Other small prospects in the Lakeview uranium area, including the Marty K, Lucky Day and Topper claims, Los Oros and B.V.D. groups, S & M claims, and Hope claims (fig. 2), are characterized principally by secondary uranium minerals occuring on fractures and in gouge and breccia along faults that cut bedded tuffaceous sedimentary rocks, referred to as uppermost Cedarville by Cohenour (1960). A large number of additional claims, both old and recently located, cover much of the intervening areas. Although a small amount of ore-grade material was mined at the Marty K property, there is no record of any production from any of these prospects.

Secondary uranium minerals also have been reported to occur in vesicles in basalt flows both in drill cores and in shallow prospects in the northern part of sec. 35 (lat 42°19′ N., long 120°33.2′ W.) on the northeast wall of Thomas Creek Canyon. These occurrences of secondary uranium minerals in vesicles have not been substantiated by this study nor is their identity known, but, because of the mobility of 6-valent uranyl compounds, redistribution of uranium in the zone of oxidation is to be expected. Whether this association has any bearing on the age relations of primary uranium mineralization and the emplacement of basalt flows and rhyolite intrusives remains to be established; no primary uranium minerals have been found in basalts exposed at the surface and presumably representing part of the isotopically dated Coleman Rim sequence.

Information in reports prepared during the period when the mines were active and some additional geologic and geochemical data collected during this investigation bear on the genesis of the ore bodies and on an evaluation of the uranium potential of the region. With the possible exception of the rhyolite intrusive northeast of Paxton Meadow, which contains about 3 ppm uranium (table 3), all of the unaltered rhyolites and associated obsidians of the Lakeview uranium area contain several times the amount of uranium normally found in silicic crustal rocks (Turekian and Wedepohl, 1961; Clark and others, 1966). They tend to follow the abundance pattern demonstrated by Coats (1956) for silicic volcanic rocks of his Shoshone comagmatic province of northern Nevada and adjacent parts of Oregon and Idaho. From analyses of samples of obsidian and rhyolite (table 3) and from the uniformly high radiation measurements throughout most of the unaltered domes and intrusives, it would appear that the uranium (and probably thorium) is more or less uniformly distributed and that most of the unaltered material contains in the range of 6.5 to about 9.5 ppm uranium. Presumably the uranium in these unaltered rocks originally was enriched both by differentiation and feldspar fractionation, as indicated by comparing uranium contents with differentiation index (fig. 19) and with total barium plus strontium (fig. 20); uranium is obviously enriched in those highly differentiated rocks depleted in barium and strontium.

If one assumes that the distribution of uranium is more or less uniform and that the surface area of the rhyolite masses is an indication of the shape of the body with depth, some impressive volumes of uranium can be calculated for the Lakeview uranium area. For example, the total uranium content of the large dome on Thomas Creek to a depth of 1 km, assuming a cylindrical shape 1.3 km in diameter, an average uranium content of 6.5 ppm, and a specific gravity of 2.5, is:

$$\text{Volume of rock} = (3.14)(0.65\ \text{km})^2 \times 1\ \text{km} = 1.33\ \text{km}^3$$

$$\text{Total uranium} = \frac{6.5(\text{ppm}) \times 2.5(\text{S.G.}) \times 1.33(\text{km}^3) \times 10^9}{10^6} = 21.6 \times 10^3 \text{ metric tons}$$

For unaltered rhyolite masses in the area with 9 ppm or more uranium, such as the bodies northeast of Cox Flat (9.7 ppm), west of the Lucky mine (9.4 ppm), and east of Cox Flat (9.2 ppm), the tons of uranium in each cubic kilometer is proportionately larger. Just how much total uranium is present in the many unaltered silicic domes and intrusives is impossible to calculate, but it assuredly is large and has represented a readily available source for the uranium found in ore-grade deposits.

Availability of this uranium is dependent on how it is fixed in the unaltered obsidian and rhyolite and whether its release and redistribution is possible through normal geologic, hydrologic, and weathering processes. A small amount of the uranium appears to be fixed in rare and minute refractory accessory minerals, such as apatite and zircon, and also is associated with opaque grains, mostly Fe and Ti oxides. However, most of the uranium in the unaltered obsidian appears to be in a dispersed state in some form as yet unrecognized, but probably not as submicroscopic discrete mineral grains. Such a dispersed and homogeneous distribution was obtained on both synthetic and natural uranium-bearing glasses (Zielinski, 1978, p. 411), and it indicates that the uranium is highly soluable in silicate melts.

Leaching of the uranium from the refractory accessory minerals is accomplished with difficulty, but the dispersed uranium in the meta-stable glass is readily available through devitrification or alteration of the glass. Conditions of uranium depletion in crystalline felsites over that in obsidian have been demonstrated by Zielinski (1978), and these conditions seem applicable to the uranium occurrences in the Lakeview area.

In most glassy rhyolite bodies in the Lakeview uranium area that are neither altered nor silicified, both uranium and thorium appear to be more or less uniformly distributed and at abundance levels in the range of 3 to nearly 10 ppm for uranium and 9 to 19 ppm for thorium. Hydration of the glass with little or no accompanying crystallization, alteration, or silicification appears to have little affect on the redistribution of the uranium and thorium, which is in accord with the results of investigations of hydrated and nonhydrated glasses by Rosholt and others (1971). Where devitrification and subsequent crystallization of the glassy phases has occurred, however, the pattern of uranium and thorium distribution is more erratic and, further, where argillic alteration and silicification are more pervasive, such as found at the White King mine, uranium has been redistributed to form local ore-grade concentrations (>1,000 ppm).

Alteration of the White King intrusive and adjoining wallrocks most likely resulted from the development of a low- to moderate-temperature, near-surface hydrothermal system in which argillic alteration occurred both at or near the surface and downward for at least several hundred meters--currently the depth of exploration--and silica was leached from lower parts of the system and deposited at or near the surface to form a silicic cap. Because uranium abundances in amounts significantly greater than that found in the unaltered rhyolites appear to be largely, if not wholly, dependent on the development of a hydrothermal system and the resultant redistribution of uranium and other metallic elements and concentration into deposits. The question arises as to what unique geologic conditions prevailed during emplacement and subsequent alteration of the rhyolite intrusive at the White King mine, in contrast with other nearly identical rhyolite bodies intruding similar rocks in adjacent areas. A further question arises as to the relation, if any, of the Lucky Lass mine to the intrusive at the White King mine, inasmuch as there is no known intrusive in or near the Lucky Lass mine.

It is reasonable to assume that the unique characteristics of the alteration and associated mineralization at the White King mine are the result of the rhyolite body (1) being emplaced at depths greater than other rhyolite bodies in the area, the thicker section of roof rocks forming a cap or mantle that prevented escape of exsolving volatiles, (2) intruding into water-saturated tuffs and tuffaceous sedimentary rocks or, more likely, into water-saturated fault breccia along the northwest-trending fault zone that localized the intrusive, or (3) a combination of emplacement both at greater depth and in water-saturated rocks. Textural and structural characteristics of the rhyolite bodies suggest that they all were emplaced at or just below the surface, so that it seems more likely that the hydrothermal system (or cell) resulted from intrusion of a dry rhyolitic melt into water-saturated rocks. Uranium-bearing fluids generated from the hydrothermal system at the site of the White King mine may have migrated laterally along the fault zone to the vicinity of the Lucky Lass mine, depositing uranium in a structurally and probably stratigraphically defined trap in essentially unaltered tuffs and tuffaceous sedimentary rocks. Faults that displace ore and rhyolite, including silicified parts of it, may, in part, be concurrent with the hydrothermal system, inasmuch as some silicified breccia is recemented by a later stage of silicification. Some faults appear to postdate all of the silicification and primary mineralization.

PRELIMINARY EVALUATION OF AREA

From what is known of the surface geology and from subsurface drilling and mining operations, the rhyolite domes of the Lakeview uranium area are commonly hydrated, particularly on and near contacts with wallrocks, and locally devitrified, but are intensely kaolinized, silicified, and mineralized only in and near the White King mine. At the Lucky Lass mine, 1.5 km west of the White King mine, there is no evidence of a separate buried rhyolite intrusive nor is there extensive silicification or kaolinization of the mineralized tuffs and tuffaceous sedimentary rocks. Both mines are located in the same regionally extensive fault zone, but not on the same shear or shears within this zone. If the hydrothermal model for the formation of the White

King and Lucky Lass ore bodies is correct, in which crystallization, alteration, and leaching of rhyolite at depth has provided metals and silica for deposition at and near the surface, it would appear that these favorable geologic conditions are not repeated elsewhere in the region, at least not close enough to the present ground surface to be recognizable. Currently available geologic, geochemical, and geophysical data have not, as yet, identified areas in which highly favorable geologic conditions might have existed at depth.

The lack of kaolinitic alteration and extensive silicification in the domes away from the White King mine and in their wallrocks suggests that no comparable hydrothermal systems developed, either because the rhyolite bodies reached the surface and vented volatiles or because the rhyolites and the invaded wallrocks were comparatively dry. Without a suitable hydrothermal system it seems unlikely that large, high-grade concentrations of uranium and other metals comparable to that at the White King mine were formed, although smaller deposits or deposits with much lower concentrations of metals may be present beneath cover that is sufficiently thick to hinder recognition at the surface. Lack of a suitable hydrothermal system probably also would preclude formation of deposits comparable to the Lucky Lass ore body.

At both the White King and Lucky Lass mines there are still substantial quantities of uranium, some of it in local concentrations with grades comparable to the ores mined prior to the mid-1960's (grades up to several tenths of a percent) and in very large tonnages, both underground and in dumps, with grades in the range of a few hundredths to a few tenths of a percent uranium.

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