UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

URANIUM, THORIUM, AND MERCURY DISTRIBUTION THROUGH THE EVOLUTION OF THE MCDERMITT CALDERA COMPLEX

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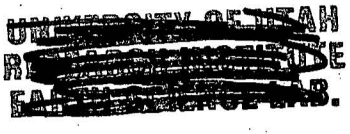
U.S. Geological Survey
Open-file Report 79-541
1979



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ABSTRACT

The McDermitt caldera complex developed over a period of 5 m.y. years during which ash-flow tuff sheets anomalous in mercury, uranium, and thorium were emplaced. The moat portions of the caldera complex were subsequently filled with tuffaceous sediments. Late in the caldera development near-surface intrusives and domes were emplaced along the margins of the complex and mineralized with uranium. Seven large hydrotherml systems developed at this time and formed large areas of alteration within the caldera-fill volcanics and sediments. Five of the altered zones are associated with economic concentrations of uranium, and or mercury.

INTRODUCTION

The McDermitt caldera complex is a large Miocene collapse structure consisting of nested and overlapping calderas. The calderas occur along the Nevada-Oregon border (fig. 1) and occupy the Trout Creek, Double H, and Montana Mountains. Ore deposits of mercury with appreciable concentrations of uranium (Rytuba, 1977) and uranium ore deposits which include a recently discovered ore body in caldera-fill volcanics occur within the complex. Potentially economic concentrations of lithium also occur within the caldera-fill sediments and constitute a major lithium resource within the

United States (Glanzman, Rytuba, and McCarthy, 1978; Rytuba and Glanzman, 1978).

CALDERA EVOLUTION

The caldera complex developed over an interval of 5 million years during which large volumes of peralkaline rhyolitic magma were erupted. Five large-volume (greater than 100 km^3) ash-flow tuffs were vented during this interval resulting in the formation of five calderas (fig. 2). The initial ash-flow tuff (unit 1) is a simple cooling unit with a maximum thickness of 230 m. It occurs to the south and east of the complex (fig. 3). Following eruption of unit 1, small-volume ash-flow tuffs with a combined thickness of 9 m were erupted. The second large-volume ash-flow tuff, unit 2, is present in the same area as unit 1 and has a maximum thickness of 210 m. One of the vent areas for this tuff is located in the northeastern part of the Double-H Mountains (fig. 4). Shortly after the cooling of unit 2, ash-flow tuff 3 was erupted at 17.5±0.3 m.y. It is present in the southern and eastern part of the complex and has a minimum thickness of 65 m (fig. 5).

Large-volume explosive volcanic activity then ceased for a period of 2 m.y. Volcanic activity during this interval consisted of small-volume air-fall tuffs and ash-flow tuffs of limited extent. The resumption of large-volume explosive volcanism began at 15.8±0.3 m.y. with the eruption of two ash-flow tuff sheets, 4 and 5, with a combined thickness in excess of 120 m. Although the units were emplaced in a short time interval, they cooled separately and are simple cooling units. Units 4 and 5 are present principally in the north part of the complex (fig. 6), but a small stratigraphic section of both units occurs in a fault block along the caldera wall in the south part of the complex.

The last major volcanic event in the complex consisted of the emplacement of near-surface rhyolitic intrusives and exogenous domes from 14.9 to 13.7 m.y. These were emplaced in the arc extending from the southwest to the central part of the complex (fig. 7).

HG, U, AND TH CONTENT OF THE VOLCANIC ROCKS

The progressive change in mercury, uranium, and thorium content of rhyolite glasses, representing each of the major volcanic events in the caldera development, are shown in figure 8. Since the ash-flow tuffs, intrusives, and exogenous domes are believed to be erupted from the upper part of a magma chamber, the chemical analyses of the rhyolite glasses from these units show the trace-element content of the magmas present during the formation of the complex. All samples analyzed were nonhydrated glasses from either the ash-flow tuff sheets or from the chilled margin of the intrusives and flow domes.

The mercury content of the magmas which erupted as ash-flow tuff sheets 1, 2, and 3 are all 20 ppb. After a 2 million year hiatus in volcanic activity, the mercury content of the magma emplaced at 15.8 m.y. was 50 ppb during the initial phase of the eruption of unit 4, then increased to 70 ppb during the middle part of the eruption and then fell to 30 ppb at the end of the eruption. During eruption of ash-flow sheet 5, the mercury content of the magma was identical to the last phase of the eruption of unit 4. With the change over to less explosive volcanic activity late in the caldera history, the mercury of the magmas which formed near-surface intrusives and flow domes varied from 10 to 70 ppb. Intrusives spatially associated with the uranium deposits contain the most mercury of the flow domes and intrusives emplaced during the last volcanic event in the caldera.

The uranium in the magma varied considerably during the eruption of ash-flow sheets 1, 2, and 3. The initial uranium content was 8.5 ppm, fell to 5.5 ppm during the early eruption of unit 2 and later rose to 9.4 ppm during the eruption. The uranium content decreased again to 6.5 ppm during the eruption of unit 3.

With the resumption of volcanic activity at 15.8 m.y., the uranium content was the same as in the first magma erupted. It then decreased to 5.2 ppm during the middle and late part of the eruption of unit 4.

With the eruption of unit 5, the uranium content of the magma was 9.4 ppm, again equal to the content of the first magma erupted. The four peralkaline magmas which erupted the early parts of ash-flow sheets 1, 2, 4, and 5 all have similar uranium contents. The later ash flows vented during the later part of the eruption of unit 4 are lower in uranium and indicate that uranium concentration was highest at the top of the magma chamber. Similar relations have been observed in the Bishop tuff (Hildreth, 1978).

Thorium contents of the first magmas erupted from the complex paralleled the trend for uranium. During the early phase of the eruption of unit 4, the thorium content was 19.9 ppm. It then decreased to 12.3 ppm during the later part of the eruption. This trend of high thorium early in the eruption and lower content late in the eruption of the ash-flow sheet 4 parallels the trend for uranium. During the emplacement of intrusives and flow domes the thorium content returned to concentrations characterizing the beginning of each of the ash-flow tuff eruptions.

The amounts of uranium and thorium in intrusives and flow domes associated with uranium deposits are similar to concentrations observed in the large-volume ash-flow tuffs, and no increase in the uranium and thorium content of the magmas during the evolution of the complex is apparent.

URANIUM ORE DEPOSITS AND OCCURRENCES

The uranium ore deposits occur in tuffaceous caldera-fill sediments and volcanics, and in intrusives and flow domes. Those in caldera-fill volcanics and sediments are closely associated with deposits of mercury and deposits previously exploited for mercury locally contain ore-grade concentrations of uranium.

In the vicinity of the mercury and uranium deposits the sediments are altered to zeolites, cristobalite, and clay minerals, while in and near the ore zones potassium feldspar is the dominant alteration product. Five areas of potassium-feldspar alteration occur within the caldera complex (fig. 9). Three areas of potassium-feldspar alteration are associated with ore deposits of mercury containing appreciable concentrations of uranium, and one area of potassium-feldspar and clinoptilolite alteration is associated with a uranium deposit near Cottonwood Creek. The fifth large area of potassium-feldspar alteration extends along the southwestern side of the complex. It is closely associated with intrusives and flow domes which are host rocks for uranium deposits at the Moonlight mine and Horse Creek occurrences.

Each area of potassium feldspar is believed to define the central part of a fossil hydrothermal system. The size of each of the four zones in the northern part of the complex is relatively small, about 1-2 km in diameter when compared to the large area of potassium feldspar in the southwestern part of the complex. Each of the five indicated hydrothermal systems have either large concentrations of uranium and mercury associated with them or contain

ore concentrations of one or both of these elements. Two additional hydrothermal alteration zones associated with anomalous concentrations of uranium and mercury occur at Crowley Creek and Rock Creek. In both areas the dominant alteration product is clinoptilolite but potassium feldspar is also present locally. The alteration assemblage and geochemical anomalies suggest the possibility of a larger zone of potassium-feldspar alteration at depth.

The uranium and thorium content of the seven areas of hydrothermal alteration varies considerably. In the McDermitt zone of alteration (fig. 9) uranium concentrations up to 192 ppm occur in the ore zone where the sediments are altered to potassium feldspar. The thorium content is low within the ore zone, less than 35 ppm, but increases to 150 ppm outside the ore zone. The distribution of uranium and thorium in a linear section through the McDermitt alteration zone are shown in figure 10. Proceeding inward to the deposit from the southwest the thorium content outside the ore zone is initially high, 92 ppm, and then drops to 20 ppm within the ore zone. Uranium shows a reverse trend being 10 ppm outside the ore zone, and 20 ppm in this part of the ore zone. Moving outward from the deposit to the northeast, the uranium content decreases to less than 10 ppm and the thorium content begins to rise again.

The relation of uranium, thorium, and mercury with depth in and outside the ore zone are shown in figures 11 and 12. Outside the ore zone, uranium content is nearly constant throughout the stratigraphic interval, but thorium increases with depth from 30 to 150 ppm. In the ore zone uranium increases in the mercury ore zone interval but is also high in stratigraphic intervals low in mercury. Thorium is low where uranium and mercury content are high.

In the Bretz and Cottonwood zones of hydrothermal alteration the central parts are altered to potassium feldspar and potassium feldspar and clinoptilolite respectively (fig. 9). Surrounding the central zone are a clinoptilolite zone and an outer zone of clinoptilolite with mordenite. At greater distances from the deposit relict glass is present with varying amounts of clinoptilolite and erionite. At the surface the two zones of alteration are separated by 1 km. The Bretz alteration zone has been mined for mercury but also contains significant amounts of uranium. The Cottonwood zone is associated with a uranium deposit reported to contain 13 million tons of 0.5 to 0.6 percent uranium.

Alteration minerals characterizing the sedimentary section exposed along Cottonwood Creek, at the extreme west end of the uranium ore deposit, are shown in figure 13. Clinoptilolite and erionite occur sporadically through the stratigraphic section and are more abundant in beds of tuffaceous sandstones. Feldspar occurs throughout the section.

Uranium occurs at several stratigraphic intervals in the Cottonwood section. Uranium in the basal 20 m of section occurs in the opaline silica-rich, thinly-laminated, ferric hydroxide stained layers. The uranium is closely associated with mercury, lithium, arsenic and antimony, strongly reflecting a common presence in the altering hydrothermal solutions. This is strikingly shown by the uranium and arsenic-rich calcite layer at approximately 26 m. The variability of the interval is obscured by a composite sampling in the 4 to 14 m, i.e. individual layers and beds were sampled only in the lower and upper parts of the interval. Above 20 m the elements separate. Lithium is less than 50 ppm in the calcite layer at 26 m and it is inversely related to uranium, arsenic, and mercury content. Carbonaceous debris is plentiful in the 28 to 37 m interval. Both lithium and

particularly uranium are enriched in the 37 to 42 m interval of organic-rich (ostracods and carbonaceous debris) lacustrine mudstones that alternate with black opaline-silica layers. A very coarse textured gray, pumiceous tuff interrupted the lacustrine sequence between 42 and 45 m in the section. The lower coarse-textured tuff grades upward into a finer air-fall tuff. The tuff is little altered, contains the highest thorium content in the section, and is low in uranium, lithium, arsenic, and mercury. The lacustrine sequence resumes at about 47 m with an enrichment in lithium, uranium, and arsenic in an organic-rich claystone. This sequence was interrupted at about 50 m by a gray air-fall tuff indicated by the thin bed enriched in thorium in the section. Above this bed, lacustrine claystones are enriched in lithium, arsenic, and mercury. This is the thickest section of lithium enrichment in the section. Above the claystones, at about 61 m, the section becomes a very coarse textured tuffaceous sandstone partially covered by slumping.

In the Opalite hydrothermal alteration zone a large area of potassium feldspar extends outward for 0.75 km from the deposit. Peripheral to the potassium-feldspar zone is a zeolite zone consisting of clinoptilolite, erionite, and potassium feldspar. Around the Opalite mine anomalously high uranium values are restricted to the zone of potassium-felspar alteration. Local areas within the Opalite mercury mine contain up to 265 ppm uranium. These areas contain pyrite and are intensely silicified. Other elements which are present in anomalous concentrations in the ore zone are As, Sb, Mo, Zr, and Be.

In the Montana Mountains a large zone of potassium-feldspar alteration extends along the margin of the caldera (fig. 9). The alteration zone is spatially related to intrusives and flow domes which were emplaced in the period between 14.9 to 13.7 m.y. Hydrothermal systems developed at the end of this volcanic episode resulted in the intense alteration of sediments and volcanic rocks for distances up to 5 km from the intrusives.

Uranium occurrences within this altered zone occur at the base of the stratigraphic section (fig. 14). The lower part of the section consists of coarse sandstone and pebble conglomerate resting on a friable ash-flow tuff. The beds have been altered to an assemblage of potassium feldspar, quartz, calcite, and dolomite. Only minor amounts of dioctahedral smectite clay are present. Beds containing anomalous uranium extend from the base of the section upward to 13 m and another concentration occurs higher in the section where trioctahedral smectite first becomes the dominant clay mineral.

Alteration of the sediments and trace-element chemistry indicate the presence of another hydrothermal system along Crowley Creek which parallels the northeast ring-fracture zone of the Calavera caldera (figs. 8 and 2). The sediments are altered to clinoptilolite and smectite clays but local beds of potassium feldspar are also present. The zeolitized sediments are bounded on the north and south by unaltered sediments. Geochemical anomalies of As, Sb, U, Be, and Hg associated with this zone of alteration indicate that this area is similar to the Opalite and McDermitt hydrothermal alteration zones.

Other uranium deposits and occurrences are located in and adjacent to rhyolite domes and near-surface intrusives which were emplaced along the western part of the complex in the period from 14.9 to 13.7 m.y. (fig. 7). These intrusives and flow domes are associated with strong positive magnetic anomalies (fig. 15) (U.S. Geol. Survey, 1972a, b), the largest of which

parallels the entire length of the intrusive trend extending from south of the Moonlight mine to the eastern part of Horse Creek where it terminates against the projected trace of the Longridge caldera. Other magnetic highs are associated with the young flow domes of Round Mountain and Black Mountain in the central part of the complex.

Several intrusives, apparently emplaced along the projected trace of the Calavera caldera in the vicinity of the Moonlight mine, reached the surface and vented small-volume ash-flow tuff sheets. One of these tuff sheets is altered to potassium feldspar and quartz and contains up to 0.1 percent uranium. Potassium feldspar replaced analcime grains and some remnant analcime is present.

In the Moonlight uranium mine and associated deposits the veins of uraninite occur along the brecciated contact of a near-surface intrusive. The rhyolite is altered to potassium feldspar, quartz, and pyrite, and calcite and fluorite are locally abundant as gangue minerals. Anomalous amounts of zirconium, arsenic, antimony, silver, barium, molybdenum, and mercury are associated with the ore.

CONCLUSION

The McDermitt caldera complex is unique among calderas in that it contains anomalous amounts of many metals including major deposits of uranium, mercury, and lithium. Geologic factors that are special to the McDermitt caldera complex that may have contributed to the formation of the ore deposits are: (1) Volcanic activity extended for a long time span in a restricted area. The transfer of heat to shallow levels in the crust during the long evolution of the complex would contribute to the development of near-surface hydrothermal systems. (2) Rhyolites erupted within the caldera complex are anomalously high in the elements which are concentrated in the ore deposits.

This initial magmatic concentration of the elements provides a source from which the elements could be leached by hydrothermal fluids (Rytuba and Glanzman, 1978). (3) The closed basins created by the collapse events were not breached. These basins provided a stable physical and chemical environment in which the more mobile elements Hg, U, Li, B, and As could be concentrated from the several hydrothermal systems which were active in the caldera complex.

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_____1972b, Aeromagnetic map of the Adel and parts of the Burns, Boise, and Jordan Valley 1° by 2° quadrangle, Oregon: U.S. Geological Survey Open-File Map, scale 1:250,000.

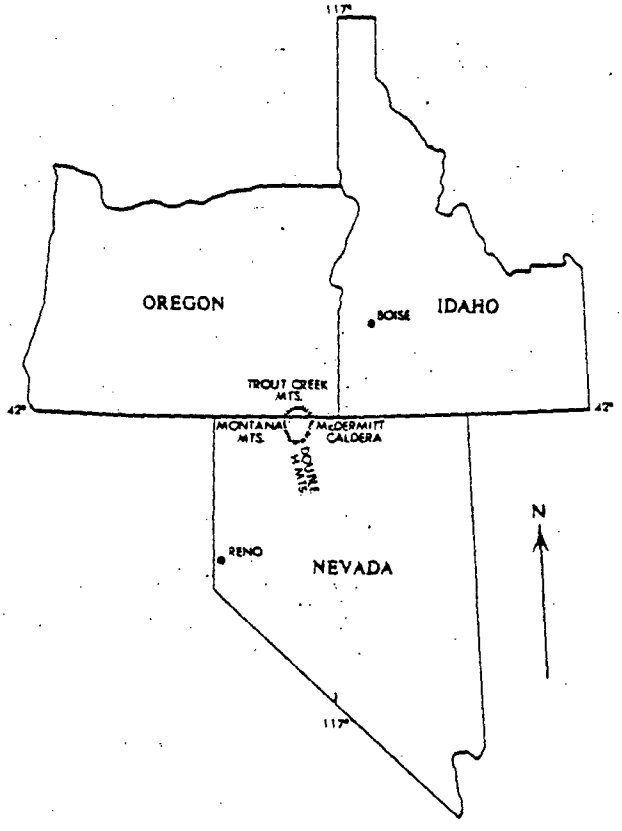

Figure 1.--Location of McDermitt caldera.

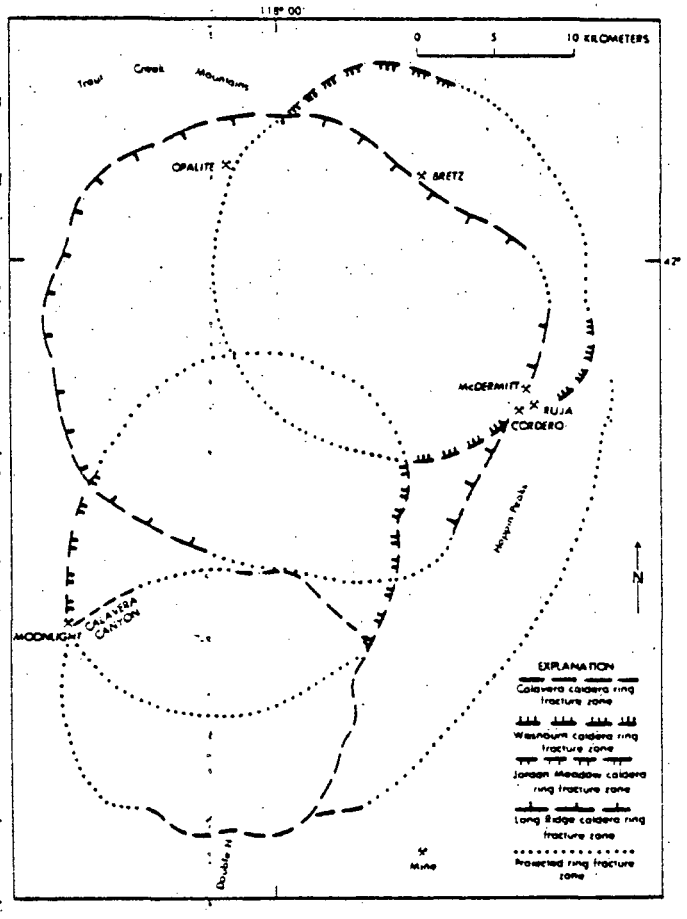

Figure 2.--Location of calderas within the McDermitt caldera complex.

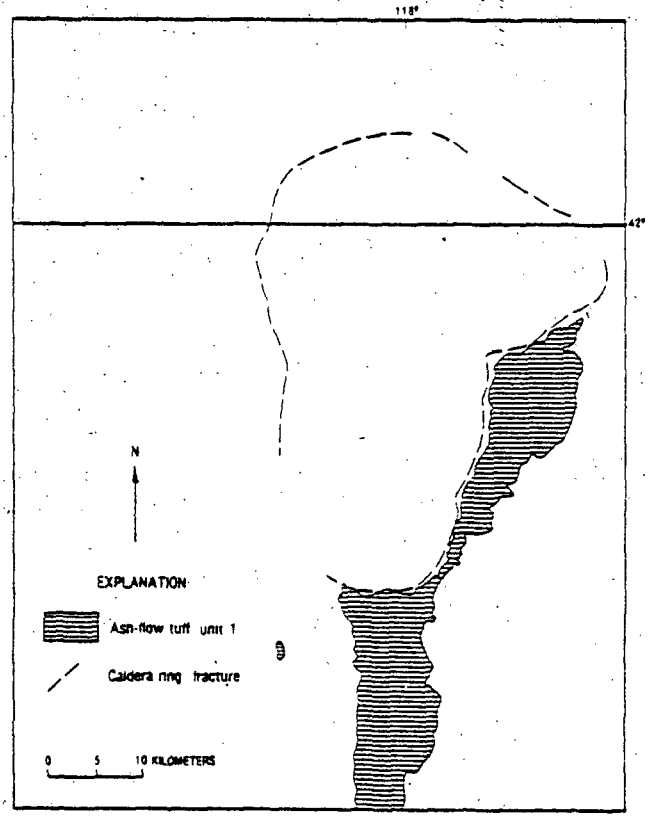

Figure 3.--Distribution of ash-flow tuff unit 1.

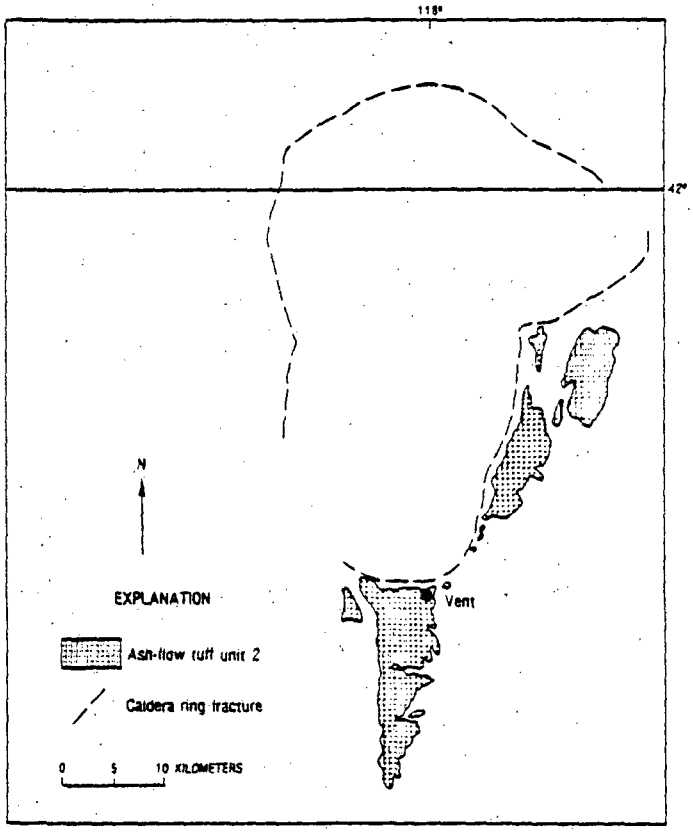

Figure 4.--Distribution of ash-flow tuff unit 2.

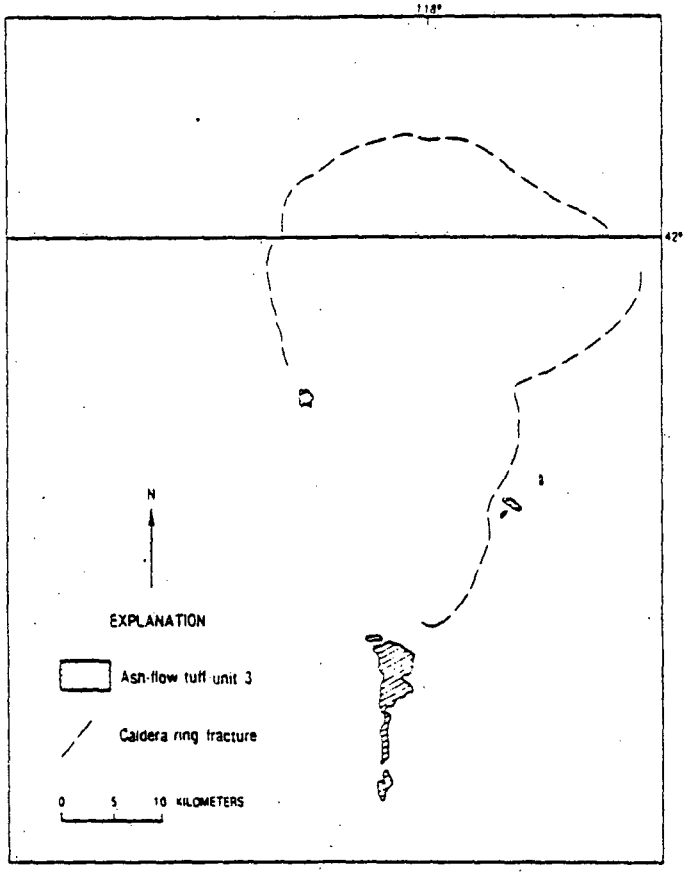

Figure 5.--Distribution of ash-flow tuff unit 3.

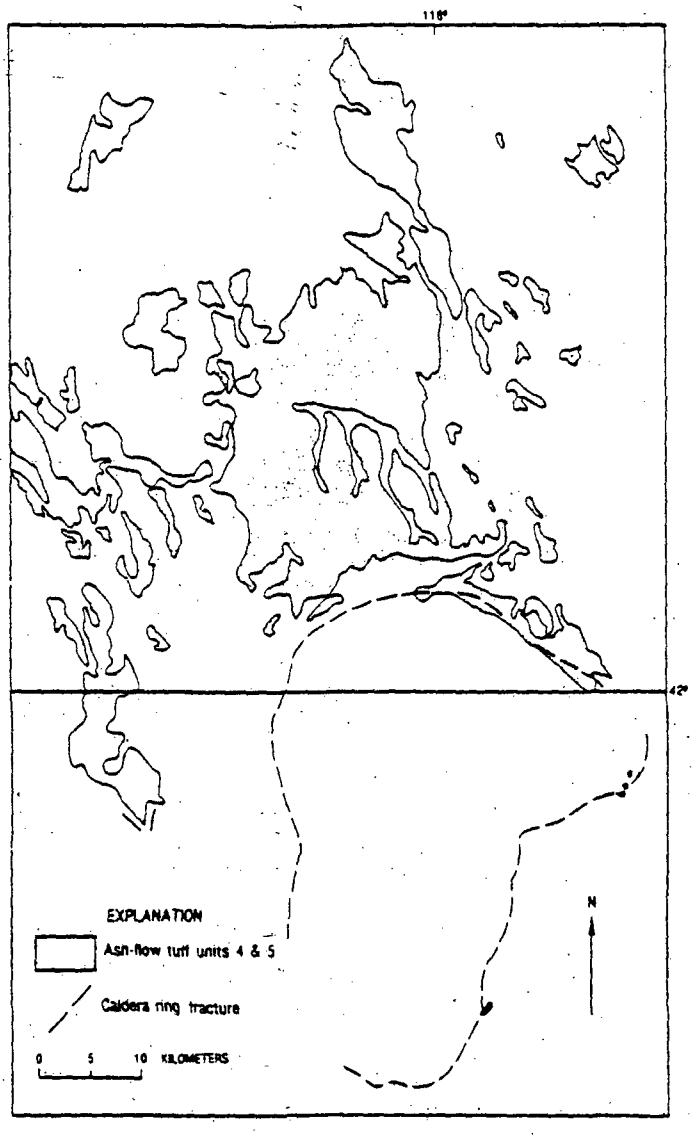

Figure 6.--Distribution of ash flow tuff units 4 and 5.

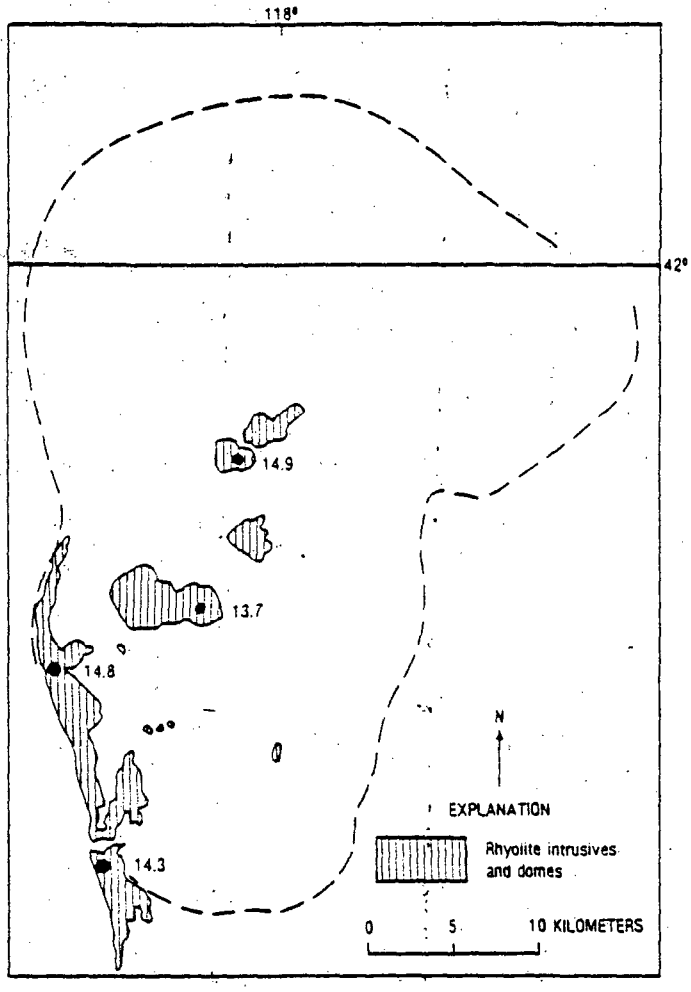

Figure 7.--Distribution and K-Ar ages of intrusives and rhyolite domes.

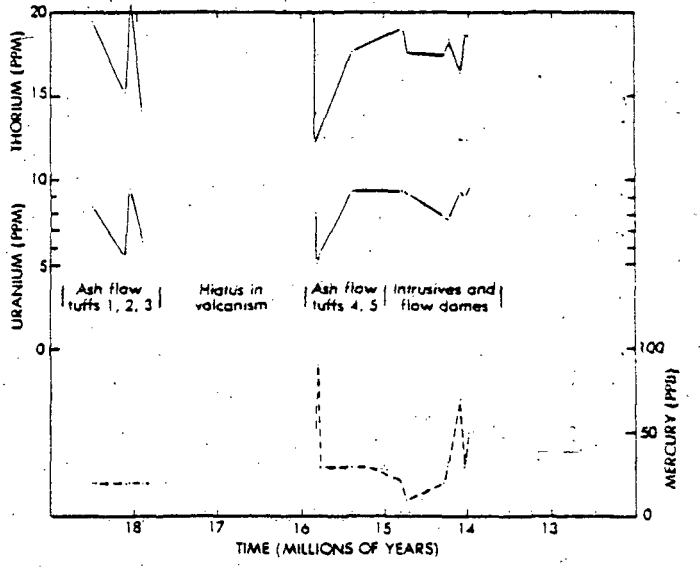

Figure 8.--U, Th, Hg distribution with time.

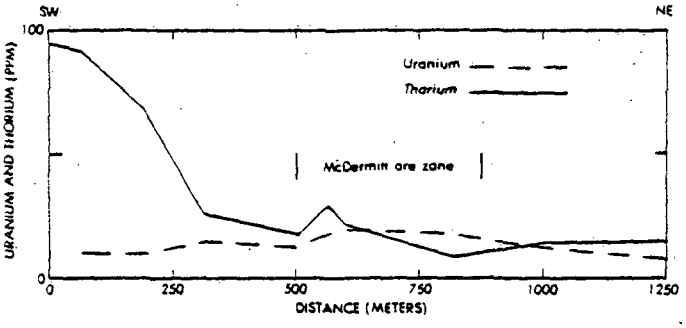

Figure 10.--Uranium and thorium content along a linear section through the McDermitt alteration zone and ore deposit.

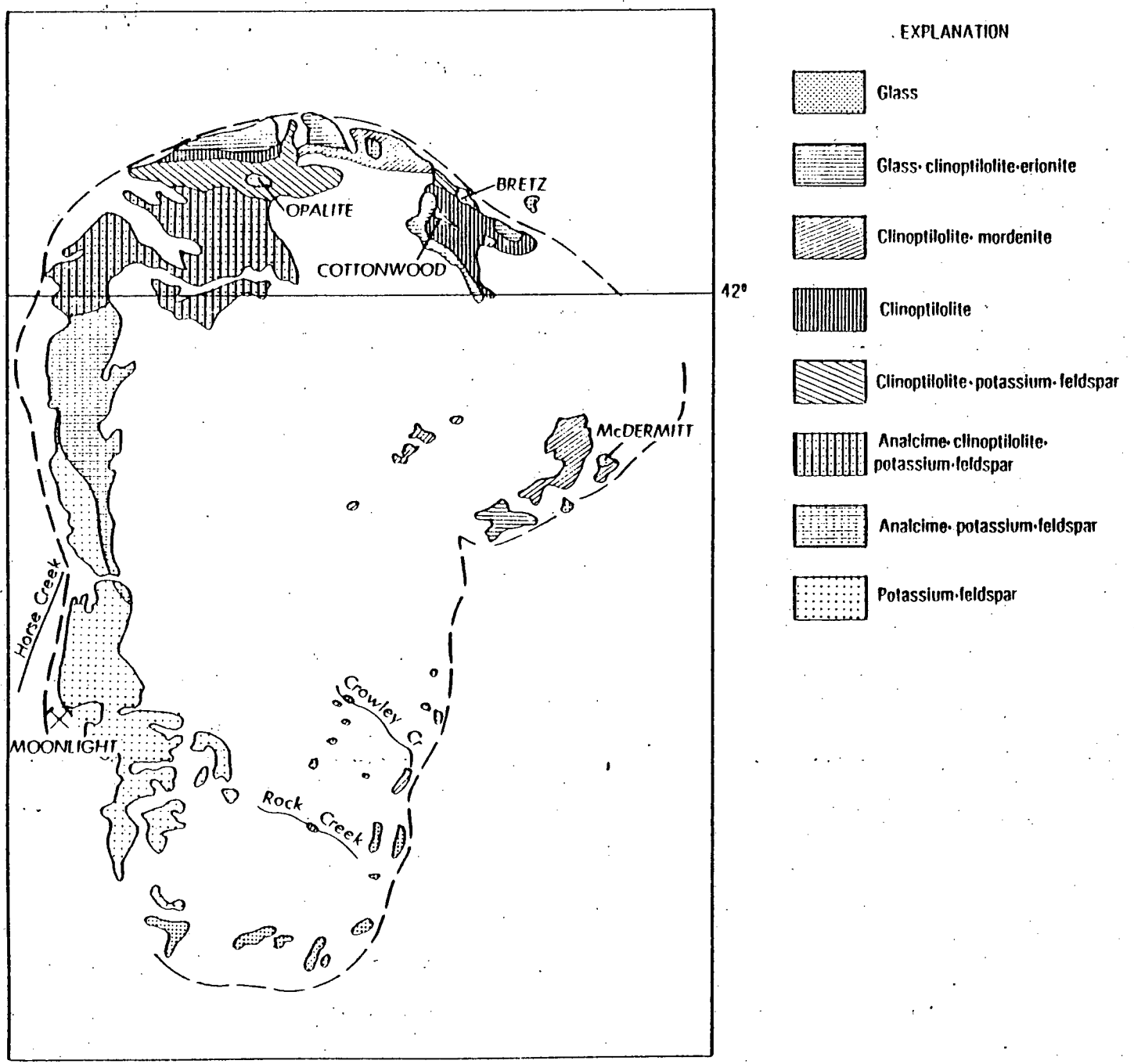

Figure 9.--Alteration zones in tuffaceous sediments.

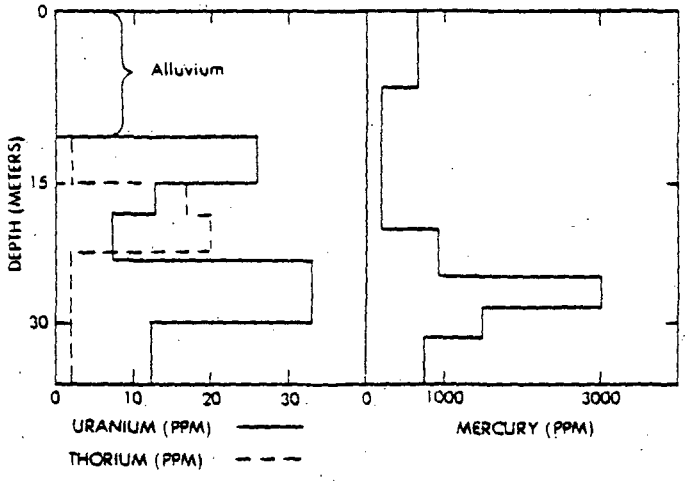

Figure 12.--Uranium and thorium concentration with depth in the McDermitt ore zone.

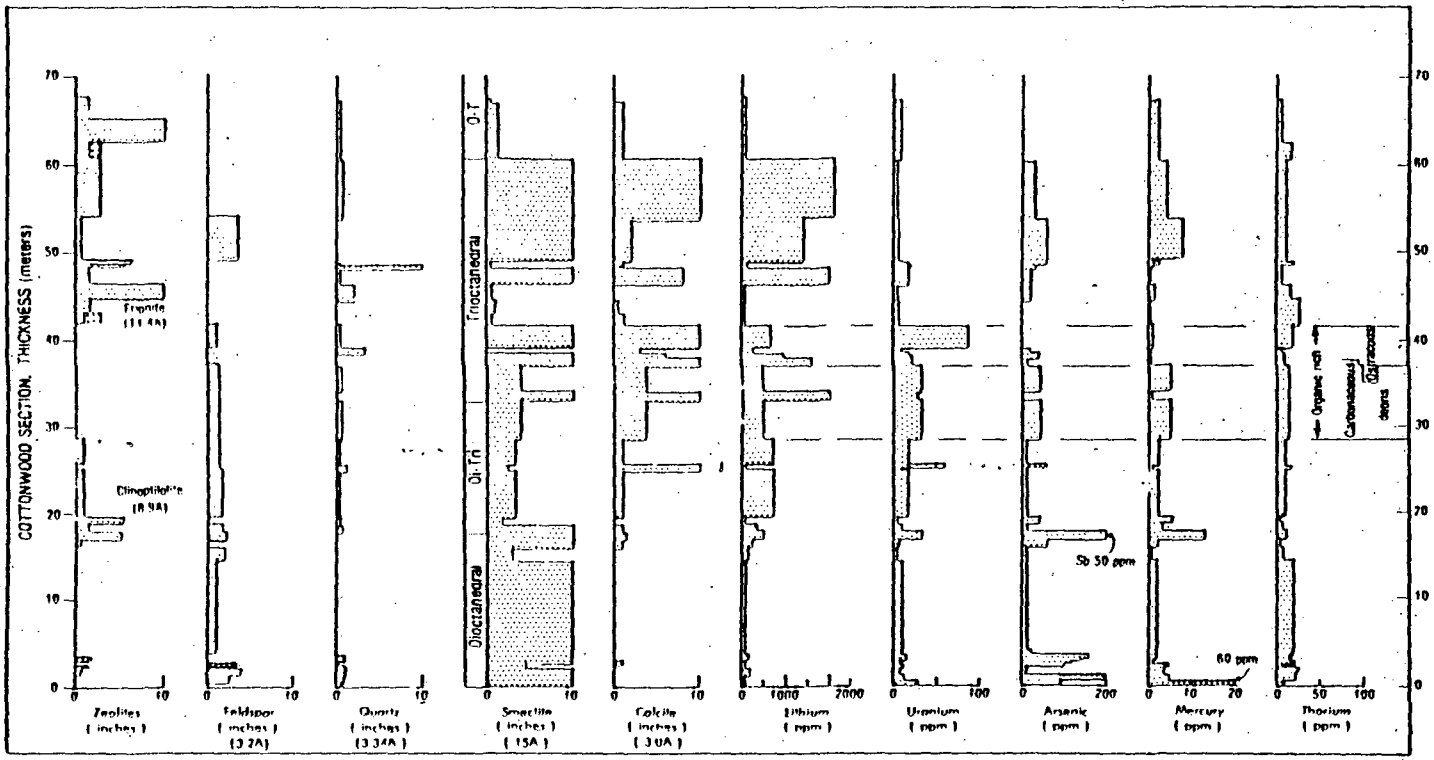

Figure 13.--Uranium and thorium content in a stratigraphic section along Cottonwood Creek.

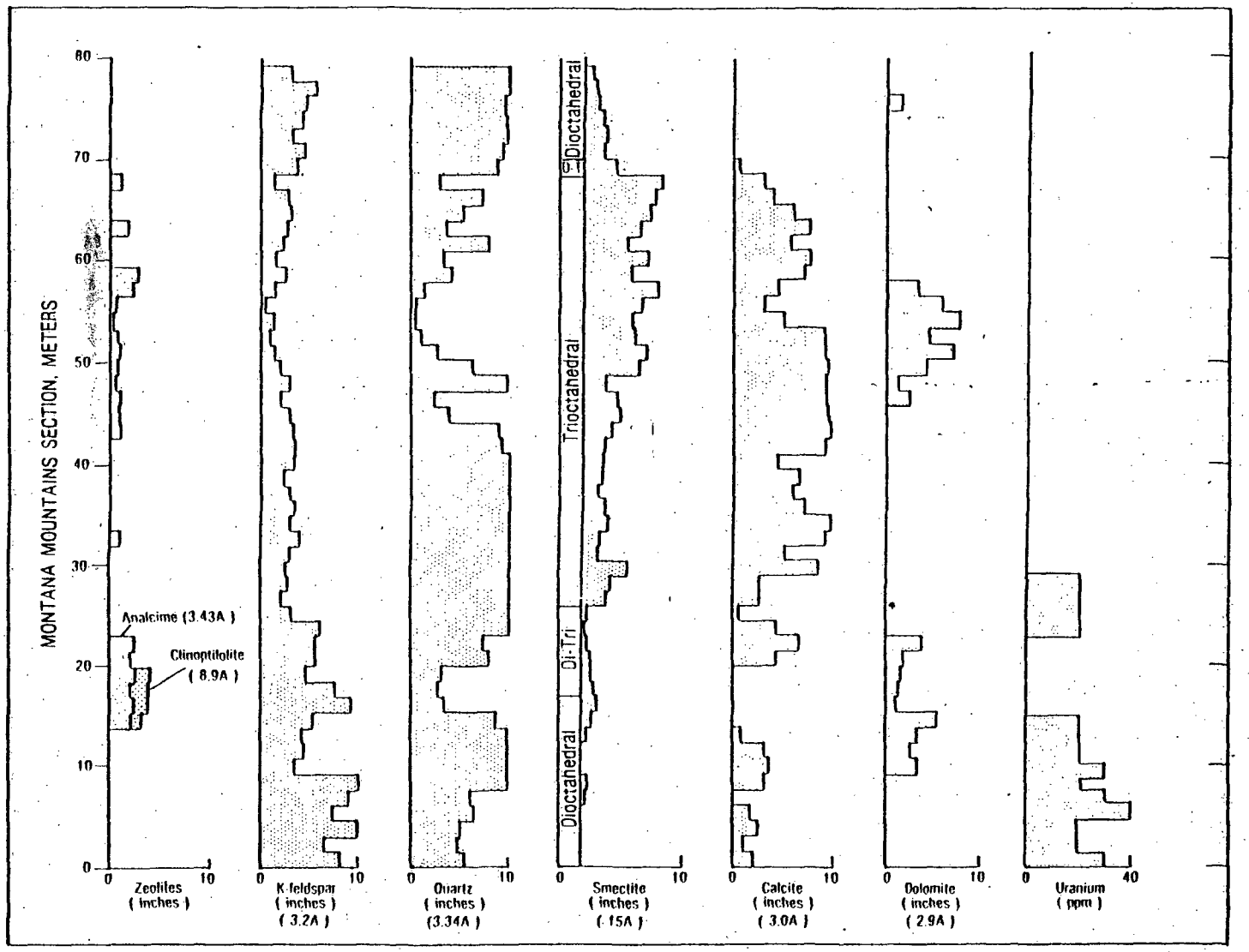

Figure 14.--Relationships between zeolites, K-feldspar, quartz, smectite, calcite, dolomite, and uranium in altered sediments in the Montana Mountains.

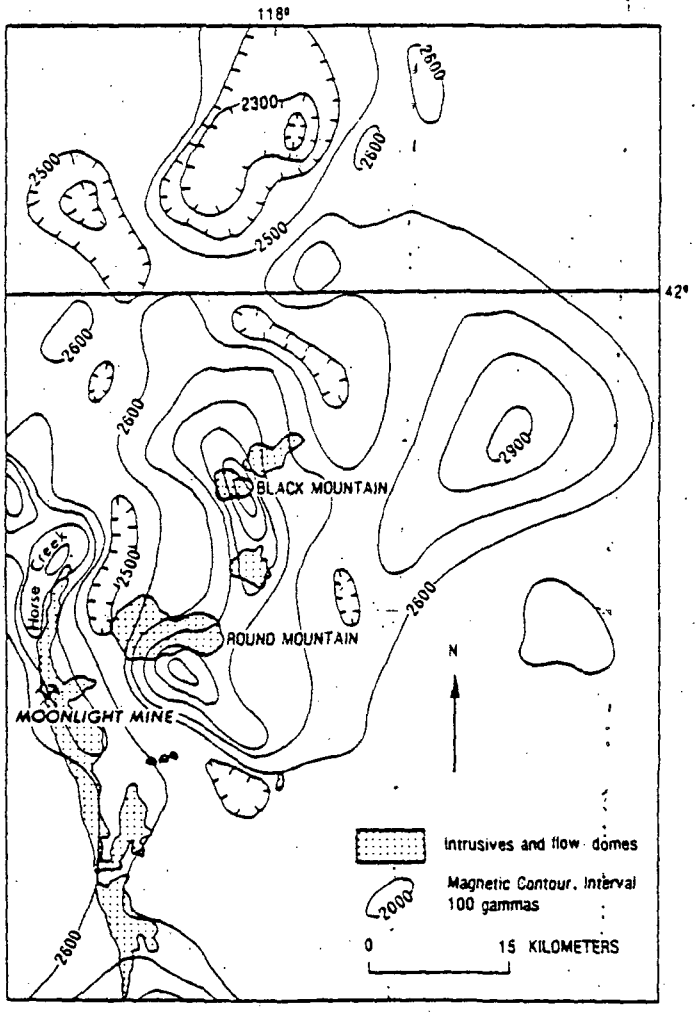

Figure 15.--Aeromagnetic anomalies associated with the intrusives and flow domes.