GEOLOGIC REPORT

ALUM Prospect

Esmeralda County, Nevada

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Summary

The Alum and Fish Lake geothermal prospects are located in Esmeralda County, Nevada. Both prospects are near trunk lines of the Nevada power grid and in environmentally insensitive areas with easy access. Basin and Range Front type faulting is prevalent in both areas providing deep circulation conduits for hydrothermal circulation.

The Alum prospect lies in the center of a triangular basin. Cambrian and Ordovician carbonate rocks are exposed south and east of the Alum sulfur mine. The remainder of the prospect lies in Tertiary sedimentary rocks of the Esmeralda Formation. A silicic tuff is interbedded with these sediments in the upper portion of the formation. Holocene basalt overlies the Esmeralda south of the prospect area.

The Fish Lake prospect is located at the southern end of the Volcanic Hills. The prospect is within two silicic tuff units of Early Pliocene age. An olivine basalt of Quaternary age intrudes Quaternary alluvium southwest of the prospect. Extensive small displacement normal faulting has occurred throughout the prospect.

ALUM PROSPECT

Introduction

The Alum Prospect is located at the Alum Sulfur mine, Section 29, T1N, R39E Esmeralda County, Nevada. The prospect may be reached from Blair Junction on Highway 50 by traveling south on Highway 47 for a distance of 8.7 miles. At this point an unmaintained dirt road leads northeast and then east for two miles to the prospect site.

The prospect lies at an elevation of 4900 to 5300 feet at the western extremity of the Weepah Hills and the southwestern terminus of the Big Smoky Valley. Isolated and prominently uplifted blocks of the Tertiary Esmeralda Formation form the western boundary of the prospect. Eastward from the sulfur mine site, the Weepah Hills rise slowly in highly dissected west-trending ridges to an elevation of 7700 feet, ten miles to the east. The Alum prospect lies at the drainage divide between the Big Smoky Valley to the north and the Clayton Valley to the south. The valleys, both of which are closed basins, contain large supplies of brackish water at shallow depths.

The climate is extremely arid and supports only sparse and patchy growths of sage and grass which are confined to stream bottoms of the lower western area. No permanent human habitation or other cultural activities exist in the vicinity of the prospect at this time. A main trunk line of the Nevada power grid passes within five miles of the prospect site.

A general geologic description of the Alum district and Weepah Hills is found in Albers and Stewart (1972). Detailed stratigraphy of the Tertiary sedimentary-pyroclastic section is given by Robinson and others (1968).

Regional Geology

The Alum Prospect lies at the center of a triangular basin bounded by three mountain ranges: the Monte Cristo Range to the north, the Silver Peak Range to the southwest, and the Weepah Hills and Lone Mountain to the east. The three ranges contain rocks ranging in age from Precambrian to Quaternary.

The Precambrian-Paleozoic rocks consist of fine-grained clastic and carbonate facies. They exhibit extensive low angle thrust faulting of large horizontal displacement. The pre-Mesozoic section is intruded by monzonite of Mesozoic age. The Lone Mountain Batholith is the largest exposure of the intrusives, while much smaller stocks occur in the Monte Cristo and Silver Peak Ranges. The intruded sedimentary rocks are deformed in conformance with the dome-shaped intrusive bodies. Tactites, marbles and hornfels are common at the monzonite-sedimentary contacts.

Large volumes of Tertiary intermediate to silicic pyroclastic and flow units overlie much of the Paleozoic and Mesozoic rocks of the Monte Cristo and Silver Peak Ranges but are absent in the Weepah Hills-Lone Mountain region.

Fluviatile and lacustrine deposition in basins roughly paralleling present topography took place during the Upper Miocene and Lower Pliocene. Silicic and intermediate pyroclastic and flow units are interbedded with these sediments. The youngest volcanic events in the region are represented by very late Pleistocene and Recent basalt flows and cinder cones which occur in the southern part of the map area.

Basin and Range faulting with up to 10,000 feet of vertical displacement began in the early Tertiary and continues to the present. Fault scarps in Quaternary alluvial fans along the northern boundary of the Weepah Hills and Lone Mountain indicate currently active faulting. This faulting is the primary factor in the formation of major topographic features in the region (Albers and Stewart, 1972).

Rock Units

The Alum prospect lies entirely within the Esmeralda Formation which is exposed throughout the western half of the Weepah Hills and Southern Great Smoky Valley (Figure 1). The basement is composed of Cambrian and Ordovician fine grained lacustrine and carbonate rocks (€Ols). These rocks are overlain by carbonate breccias derived from Cambrian and Ordivician rocks to the east. The Esmeralda Formation uncomformably overlies these breccias and consists of lacustrine and fluviatile deposits of sandstone, shale and siltstones interfingered with conglomerates and pyroclastic units. A tuff unit in the upper part of the formation has a K-Ar date of 6.9 m.y. The unit is locally covered by Quaternary alluvium. More than 9,000 feet of strata are exposed in the map area, though some of the apparent thickness may be due to faulting. The bottom of the formation is not exposed in the map area. The very poorly bedded, tan to black, well indurated carbonate breccias overlying the basement are Paleozoic in age. They are composed of limestone, silty limestone, limey siltstone, siltstone shale and sandstone which form angular to subangular clasts up to 30cm in diameter.

The Esmeralda Formation in the mapped area generally strikes northeast and dips 25^{o} to the southeast. The predominate lithology is an alternating sequence of well bedded siltstone, shale and sandstone (Tes). This sequence is interbedded with a pyroclastic unit and in turn is unconformably overlain by conglomerates. The well bedded clastic sequence is dominated by well indurated tan to buff siliceous siltstone with minor sandy horizons. The siliceous unit alternates with argillaceous, poorly indurated, green brown siltstone which weathers to rounded soil covered slopes. The siliceous and argillaceous beds form alternating sequences 30 to 50 meters thick. Thinner beds of fine to medium grained sandstone ranging from 0.2 to 1.0 meters thick occur within the siltstone sequence. These sandstone beds contain siliceous cement, are very hard, and form prominent ridges in the map area. Conglomerate lenses up to two meters thick are interbedded with the sandstone beds. One to five meter thick beds of light brown, highly fissle shale are common throughout the sequence. Occasional chert beds 2 to 5cm thick occur in the siltstone dominated parts of the section.

The upper part of the fine grained clastic section contains a lithic and crystal tuff (Tef) which varies in thickness from 3 to 10 meters. The tuff unit contains pumice and siliceous volcanic rock fragments in addition to the abundant euhedral quartz and feldspar crystals indicating a rhyolitic or dacitic composition. This unit is very well indurated and forms resistant cappings on the most prominent ridges in the central portion of the map area.

A conglomerate and coarse sandstone unit 10 to 30 meters thick overlies the fine grained clastic sequence. The contact is an angular unconformity with underlying truncated siltstones dipping 20° to 30° more steeply than the overlying conglomerates and sandstone. The lower part of the coarse grained clastic unit consists of poorly sorted pebbly arkosic sandstone. The sandstone exhibits current cross bedding and cut and fill structures. The sandstone grades upward into a poorly bedded conglomerate containing sand lenses.

The conglomerate and coarse sandstone unit (Tec) grade upward into a sequence of thinly interbedded, tan to buff, calcareous siltstones, sandy siltstones and fine to medium grain sandstones. Minor calcite veining 1 to 10mm thick is evident in the upper sections of the Esmeralda Formation along with lenses of poorly sorted conglomerate up to two meters thick and chert lenses up to 10cm thick. The conglomerate lenses are not evident in the upper portion of the Esmeralda along the eastern border of the map area.

Several outcrops of poorly bedded limestone and silty limestone breccia (Tls) uncomformably overlie the Esmeralda east and north of the Alum Mine. These outcrops of limestone breccia appear to be similar to the limestone breccia which underlies the Esmeralda and is observed on the Monocline Peak and the horst blocks east of the Monocline Peak. The Esmeralda pinches out to the east and south of the map area.

Overlying the Esmeralda in the southern portion of the map area are viscular olivine basalt flows (Qb). These flows are Holocene in age and conformably overlie the Esmeralda. The basalt ranges from 10 to 30 meters in thickness, with the thickest exposures on The Monocline, at the southern boundary of the mapped area.

Structure

The map area has three structural zones. The structural zone west of the Alum Mine consists of northeast striking beds which have been gently folded to form southeasterly dipping anticlines and synclines. The folds are truncated in the north and east by northeast trending normal faults (Figure 2).

Surrounding the mine is a highly faulted and deformed area approximately three kilometers in length. It is characterized by small scale (5 to 10 meters) folding, high angle faulting and fracturing and a prominent topographic discontinuity. The sulfur mine workings and associated alteration zone is entirely located within this structurally disturbed zone. Beds of the Esmeralda Formation outside the zone do not show any deformation or faulting aside from the regional tilting of 20° to 30° to the southeast. The deformation zone may be explained as a partially ruptured, plunging fold with dimensions of approximately two kilometers on each limb. Exposures of the fault zone in the mine pits indicate a nearly vertical orientation. Flexure of the bedding in the vicinity of the faulting indicate right lateral strike slip movement with a cumulative offset of tens of meters. The topographic step within the fault zone in the otherwise uniform western slope of the Weepah Hills indicates a dipslip component of fault movement with the uplifted block to the east.

The third major structural feature is the Monocline Peak and associated horst blocks to the east. All three of these areas appear to be uplifted blocks of Paleozoic basement. The Esmeralda Formation has been tilted due to emplacement of these blocks. The limestone breccias which unconformably overlie the Esmeralda in the northeastern portion of the map area dip less steeply to the east than the underlying Esmeralda Formation.

The folds in the area represent a series of southeast dipping anticlines and synclines with the limbs varying from less than one kilometer to more than two kilometers. Basin and Range type faulting truncates the structure to the northwest and south. The Esmeralda Formation has been tilted to the west in the vicinity of The Monocline and as a result of the emplacement of these blocks, the horst block east of The Monocline.

Alteration and Hydrothermal Activity

Alteration in the map area is confined to the zone of strongest deformation where fault brecciation and intense fracturing are present. The alteration consists of argilliza- tion resulting in a friable, highly bleached, very low density rock. Accicular clumps of sulfur crystals fill cracks and joints, while coarsely crystalline sulfur fills vugs and larger cracks. White opalite is a minor constituent of the altered zone. The sulfur mineralization is confined to the intensely argillized zones within three to ten meters of brecciated faults. Alunite is abundant in the fractures, appearing as dense, translucent replacement veins up to 10cm thick. Examination of cuttings from drill hole number A3A show a disseminated pyrite horizon at a depth of 160 to 175 feet. The pyrite appears as 1 to 2mm stringers in the siltstone and as individual 2 to 3mm euhedral crystals.

Scarcity of siliceous deposits, such as sinter or opalite, indicate that near surface alteration is primarily fumarolic with little or no hydrothermal activity involved. The occurrence of alunite and elemental sulfur at the surface indicates that the fumarolic activity has ceased only very recently. The fumoralic activity may be related to the late Pleistocene, to Holocene basalt flows and eruptive centers south of Monocline Peak. Gaseous emanation from the basalt source at depth may have penetrated the thick sedimentary blanket of the Esmeralda Formation by way of the localized faulting within the map area. It is most likely that the northeast trending faults in the map area and the faults associated with the horst blocks southeast of the mine are deep circulation conduits of a convective hydrothermal system. This is borne out by the high heat flow values observed in the syncline northeast of Monocline Peak and around the Alum Mine site. This model accounts for both the recent age and distribution of fumoralic activity, the recent tetonic activity in the area and the observed high heat flow.

ALUM PROSPECT

By Bill Teplow and Gary Maranth
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Geology

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The prospect lies at an elevation of 4900 to 5300 feet at the western extremity of the Weepah Hills and the southwestern terminus of the Big Smoky Valley. The western half of the prospect consists of elongated ridges of Quaternary alluvium which have been partially dissected and removed, exposing Tertiary lake beds beneath. Isolated and prominently uplifted blocks of the Tertiary Esmeralda Formation form the western boundary of the prospect. Eastward from the sulfur mine site, the Weepah Hills rise slowly in highly dissected west-trending ridges to an elevation of 7700 feet, ten miles to the east. The Alum prospect lies at the drainage divide between the Big Smoky Valley to the north and the Clayton Valley to the south. The valleys, both of which are closed basins, contain large supplies of brackish water at shallow depths.

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Rock Units

The Alum Prospect lies entirely within the Esmeralda Formation which is exposed throughout the western half of the Weepah Hills and southern Great Smoky Valley (Figure 4). The unit is locally covered by Quaternary alluvium. The Esmeralda Formation consists of lacustrine and fluviatile deposits of sandstone, shale and siltstones interfingered with conglomerates and pyroclastic units. A tuff unit in the upper part of the formation has a K-Ar date of 6.9my. More than nine thousand feet of strata are exposed in the map area, though some of the apparent thickness may be due to faulting. The top and bottom of the formation are not exposed in the map area. A generalized stratigraphic column of the Alum area by Robinson and others (1968) appears in Figure 5.

The section of the Esmeralda Formation in the vicinity of the Alum Sulfur Mine strikes east-west and dips steeply (30°-60°) to the south. Three distinct lithologies characterize this 5000 foot thick section. The predominate lithology is an alternating sequence of well-bedded siltstone, shale and sandstone. This sequence is interbedded with a pyroclastic unit and, in turn, is unconformably overlain by conglomerates.

The well-bedded clastic sequence is dominated by well-indurated tan to buff siliceous siltstone with minor sandy horizons. This siliceous unit alternates with argillaceous, poorly indurated green-brown siltstone which weathers to rounded, soil-covered slopes. The siliceous and argillaceous beds form alternating sequences thirty to fifty meters thick. Thinner beds of fine to medium-grained sandstone, ranging from 0.2-1.0 meters thick, occur within the siltstone sequence. These sandstone beds contain siliceous cement, are very hard, and form prominent ridges in the map area. One to five meter thick beds of light brown highly fissile shale are common throughout the sequence. Occasional chert beds two to five centimeters thick occur in the siltstone dominated parts of the section.

The upper part of the fine-grained clastic section contains a lithic and crystal tuff which varies in thickness from three to ten meters. The tuff contains pumice and silicic volcanic rock fragments in addition to abundant euhedral quartz and feldspar crystals indicating a rhyolitic or dacitic composition. This unit is very well indurated and forms resistant cappings on the most prominent ridges and nobs along the southern boundary of the map area.

A conglomerate and coarse sandstone unit ten to thirty meters thick overlies the fine-grained clastic sequence. The contact is an angular unconformity with the underlying truncated siltstones dipping 20°-30° more steeply than the overlying conglomerates and sandstone. The lower part of the coarse-grained clastic unit consists of a poorly sorted pebbly arkosic sandstone. The sandstone exhibits current crossbedding and cut and fill structures. The sandstone grades into a poorly bedded conglomerate containing sand lenses. The siliceous siltstone clasts may be derived from the underlying fine-grained clastic sequence.

Structure

The map area may be divided into two distinct structural zones along a north-trending line passing through the Alum Sulfur Mine site (Figure 6). West of the dividing line the structure consists of moderately dipping beds striking northeast, while east of the line the beds dip steeply and strike east-west. The transition zone between the two regions is approximately 200-300 meters wide in the east-west direction and 1200 meters long in the north-south direction. It is characterized by small scale (five to ten meter) foldind, high angle faulting and fracturing and a prominent topographic discontinuity. The sulfur mine workings and associated alteration zone is entirely located within this structurally disturbed zone. Beds of the Esmeralda Formation outside the zone do not show any deformation or faulting aside from the regional tilting of 20°-30° to the southeast. The deformation zone may be explained as a partially ruptured plunging fold with dimensions of approximately two kilometers on each limb (Figure 6). Exposures of the fault zone in the mine pits indicate a nearly vertical orientation. Flexure of the bedding in the vicinity of the fault indicate right lateral strike slip movement with a cumulative offset of tens of meters. The topographic step within the fault zone in the otherwise uniform western slope of the Weebah Hills indicates a dip slip component of fault movement with the uplifted block to the east. Small sliver faults stepped down to the west support this model.

Alteration and Mineralization

Alteration in the map area is confined to the zone of strongest deformation where fault brecciation and intense fracturing are present. The alteration consists of argillization resulting in a friable, highly bleached, very low density rock. Accicular clumps of sulfur crystal fill cracks and joints, while coarsely crystalline sulfur fills vugs and larger cracks. White opalite is a minor constituent of the altered zone. The sulfur mineralization is confined to the intensely argillized zones within three to ten meters of brecciated faults. Alunite is abundant in the fractures, appearing as dense, translucent replacement veins up to 10cm thick. Examination of cuttings from drill hole number two (Figure 4) show a disseminated pyrite horizon at a depth of 160 to 175 feet. The pyrite appears as 1 to 2mm stringers in the siltstone and as individual 2 to 3mm euhedral crystals. Scarcity of siliceous deposits, such as sinter or opalite, indicate that near surface alteration is primarily fumarolic with little or no hydrothermal activity involved. The occurrence of alunite and elemental sulfur at the surface indicates that the fumarolic activity has ceased only very recently. The fumarolic activity may be related to the Late Pleistocene to Recent basaltic flows and eruptive centers within five miles of the mine site. Gaseous emanation from the basalt source at depth may have penetrated the thick sedimentary blanket of the Esmeralda Formation by way of the localized faulting within the map area. This model would account for both the apparent recent age and distribution of the fumarolic alteration.

Mercury Soil Survey

The mercury soil survey consisted of three sample lines with a very high sample density (Figures 8 and 9). The correlation between mercury anomalies and fault traces (Figure 2) indicates that mercury deposition is controlled by ascension of mercury rich thermal vapors along these faults.

The mercury soil survey does not indicate any abnormal regional heat flow. The mercury anomaly identified at the north end of line C-C' is probably due to analytical error.

Heat Flow

Extremely high heat flows, greater than twenty HFU's, were observed in two of the four gradient holes drilled in January, 1981. The remaining two gradient holes had heat flows in excess of twelve HFU's (Figures 10 to 14). Gradients from 205° C/km to 490° C/km were measured, mostly in siltstone. A maximum bottom hole temperature of 64.5° C at 100 meters was measured in drill hole number three.

Summary

The high density mercury soil survey is useful in delineating faults associated with ascension of hydrothermal fluids and/or vapors. No correlation between conductive heat flow and mercury soil deposits are apparent for this prospect, indicating that the anomaly may be strictly of convective origin.

The observed heat flow indicates that although the anomaly may be of convective origin, it is much more widespread than the mercury survey would indicate. The high bottom hole temperatures associated with uniform gradients and intense fumoralic alteration indicate that this prospect is a prime target for further assessment.

Figure 3. Alum-Location Map

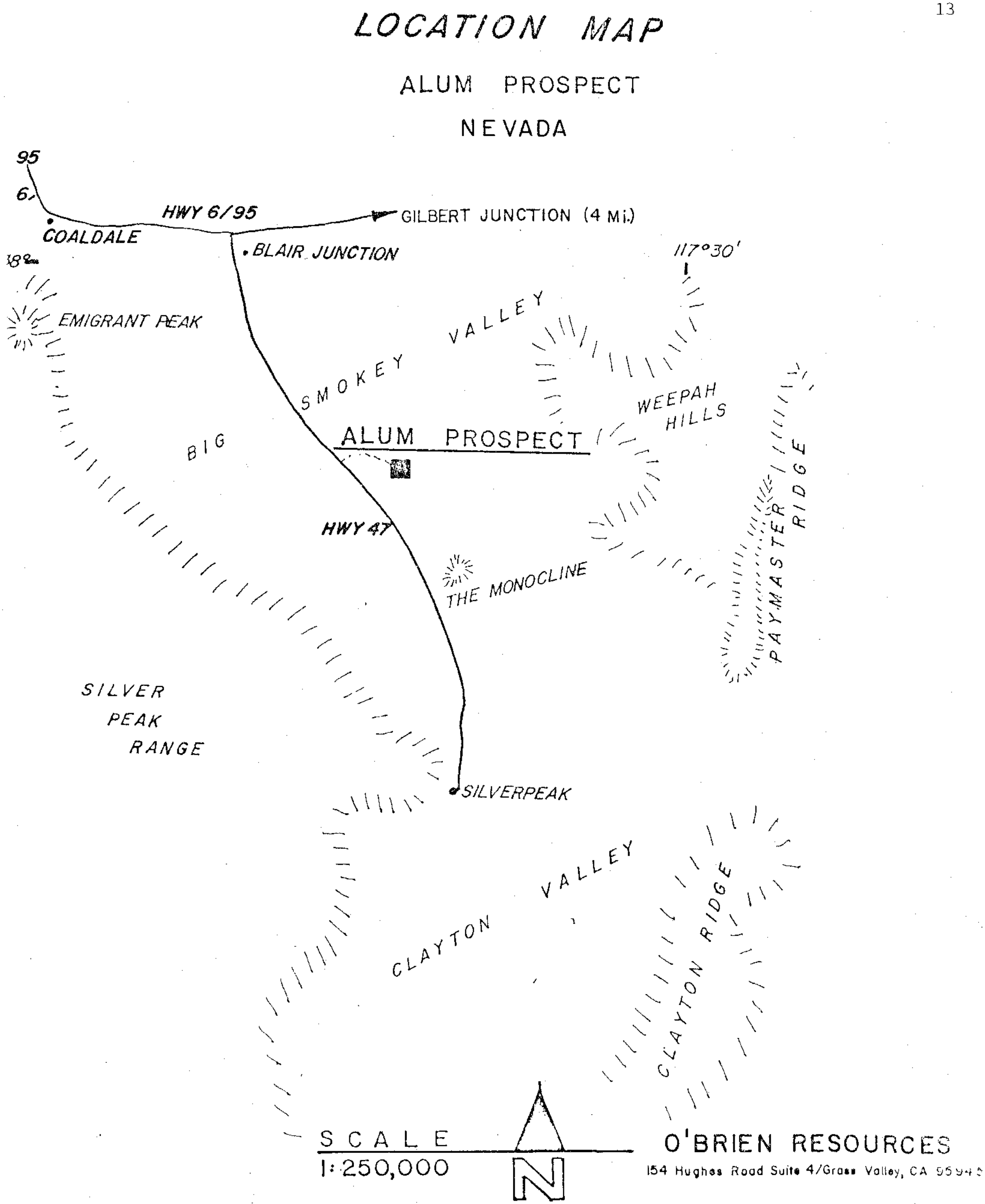
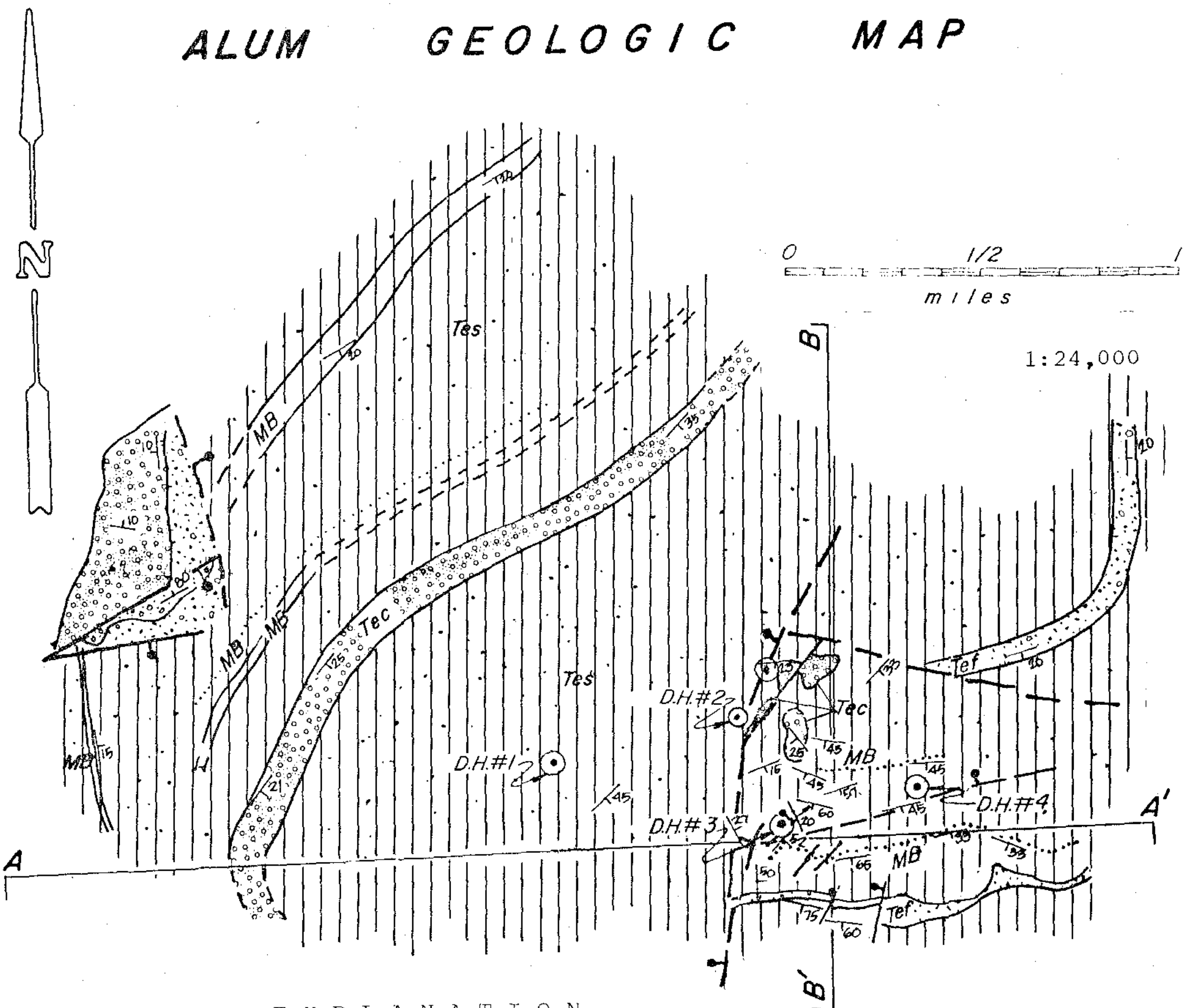


Figure 4. Alum-Geologic Map



EXPLANATION

Esmeralda Formation

Tef — Lithic and crystal tuff

Tec — Sandy Conglomerate

Tes — Interbedded siliceous siltstone, shale, sandstone, occasional chert lenses

Normal fault

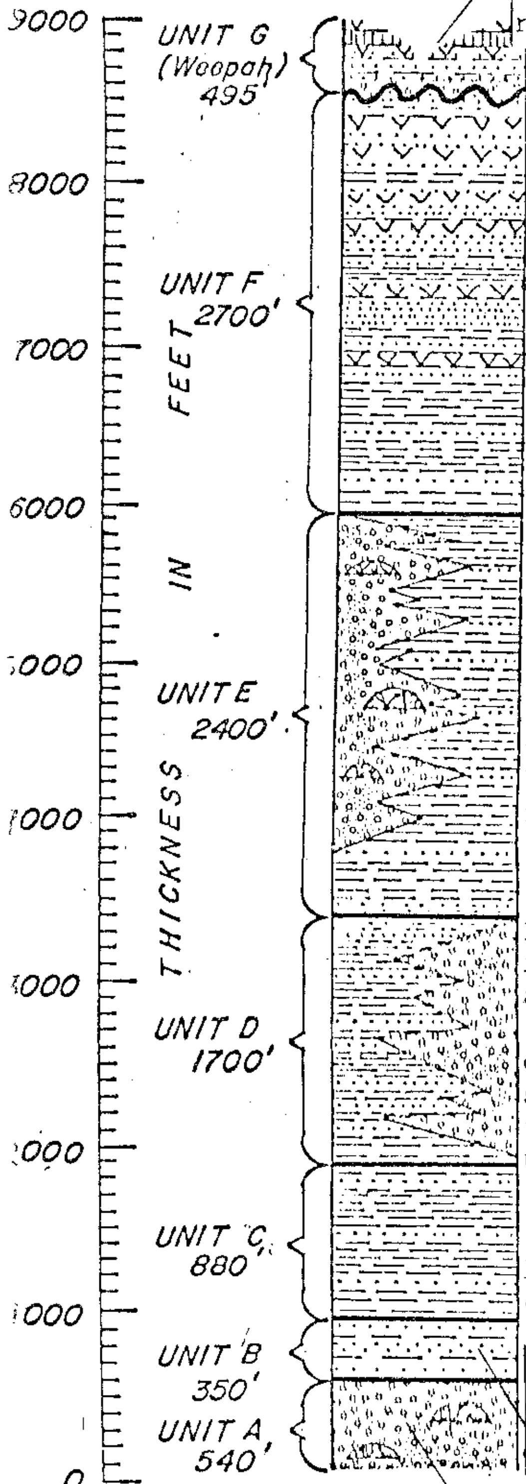
Strike slip fault

Strike and dip

Contact between units

MB — Marker bed

Figure 5. Stratigraphic Column, Alum District from Robinson P.T., etal (1968)



Gray generally poorly bedded friable, poorly sorted sandstones, siltstones, and conglomerates, white thick-bedded friable vitric tuffs and lapilli tuffs, grayish-black basalt flow; basal yellowish brown, crudely bedded tuff breccia. Unit characterized by pumicious nature of rocks.

Interbedded generally friable, pale-orange to light gray, laminate to thin-bedded siltstones, pale-orange to light-gray, papery shale yellowish-tray to light-olive-gray, thin to thick-bedded, poorly sorted claystones, light-gray to grayish-orange, thin to very thic bedded, fine to medium-grained, moderately sorted sandstones and very light gray to medium-light gray vitric tuffs. Siltstones and shales predominate in the lower part of the unit, sandstones and vitric tuffs predominate in the upper part of the unit.

Grayish-orange to grayish-yellow, thin-bedded siltstones, white to olive-gray, thin-bedded, poorly sorted, medium-grained sandstones and yellowish-gray to pale-yellowish-orange, poorly sorted shales and claystones which intertongue with gray to grayish-orange, thick to very thick bedded, lenticular, poorly sorted precambrian and paleozoic-pebble conglomerates with intercoated lenses of grayish-blue Paleozoic-limestone breccia and interbeds of poorly sorted medium to coarse-grained sandstone.

Light-gray to grayish-orange, thin-to very thick bedded, well-indurated, moderately to poorly sorted, volcanic-pebble conglomerates and light-gray to grayish-orange, thin-to thick-bedded, fine to coarse-grained volcanic sandstones which grade laterally into grayish-orange to grayish-yellow, laminated to thin-bedded, poorly sorted, fine-to medium-grained sandstones. Thin interbeds of white to pale-green tuff and reworked tuff occur in the lower part of the unit

White to very pale orange, laminated to very thin bedded tuffaceous and siliceous siltstones and grayish-orange to very pale orange papery shales: thin interbeds of pale-orange to yellowish-brown sandstone.

Pale-yellowish-orange to grayish-yellow, thin-to thick-bedded, moderately indurated, moderately to poorly sorted, fine to coarse-grained, feldspathic lithic sandstones and grayish-orange to yellowish-brown, laminated to thin-bedded siltstones.

Light-brown to greenish-gray thin-to very thick-bedded, well-indurated, poorly sorted pebble conglomerate composed of Paleozoic clasts. Large intercalated lenses of grayish-blue Paleozoic-limestone breccia and thin interbeds of sandstone, siltstone and limestone.

IDEALIZED STRUCTURAL MAP OF ALUM SULFUR MINE SITE

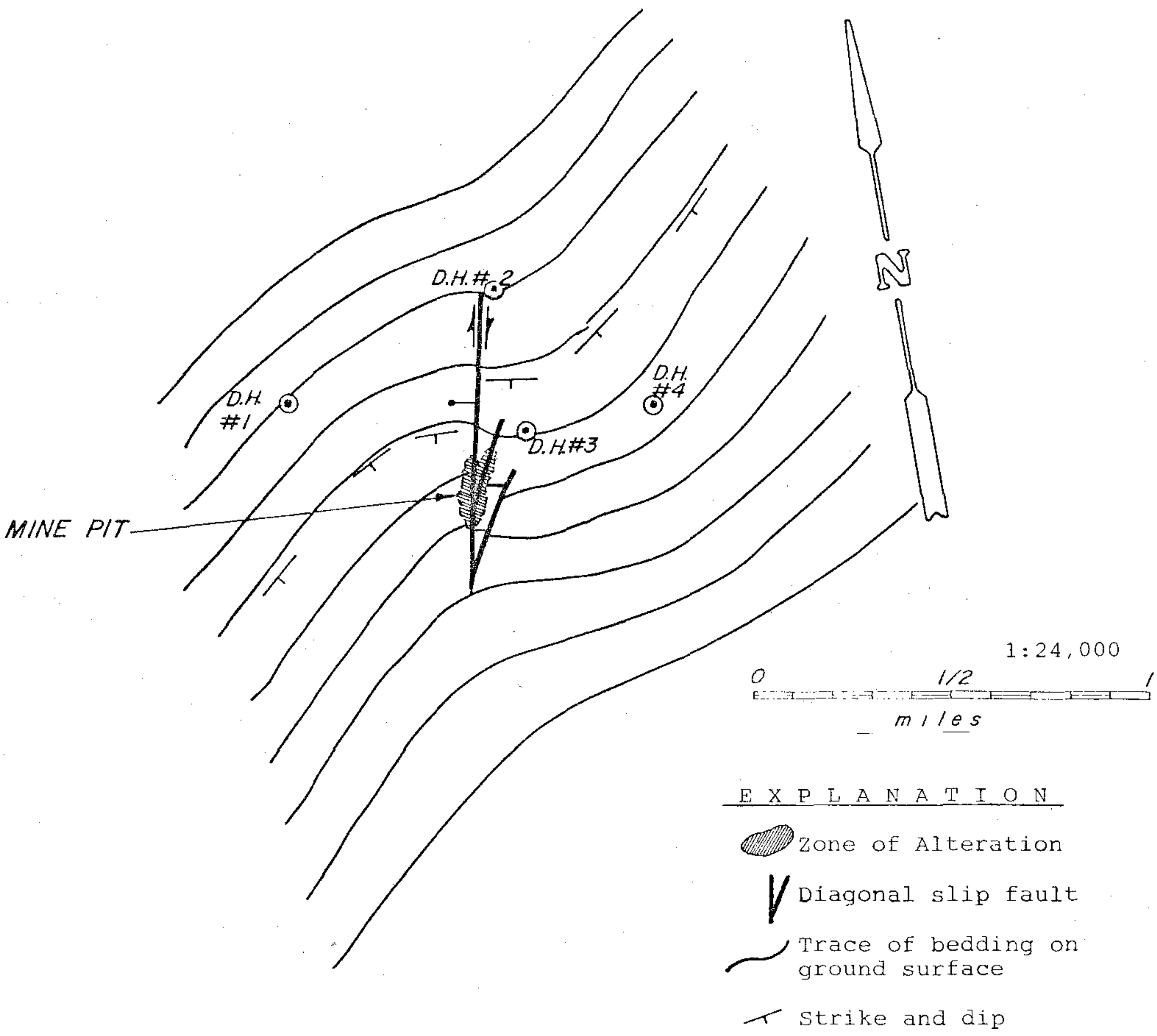
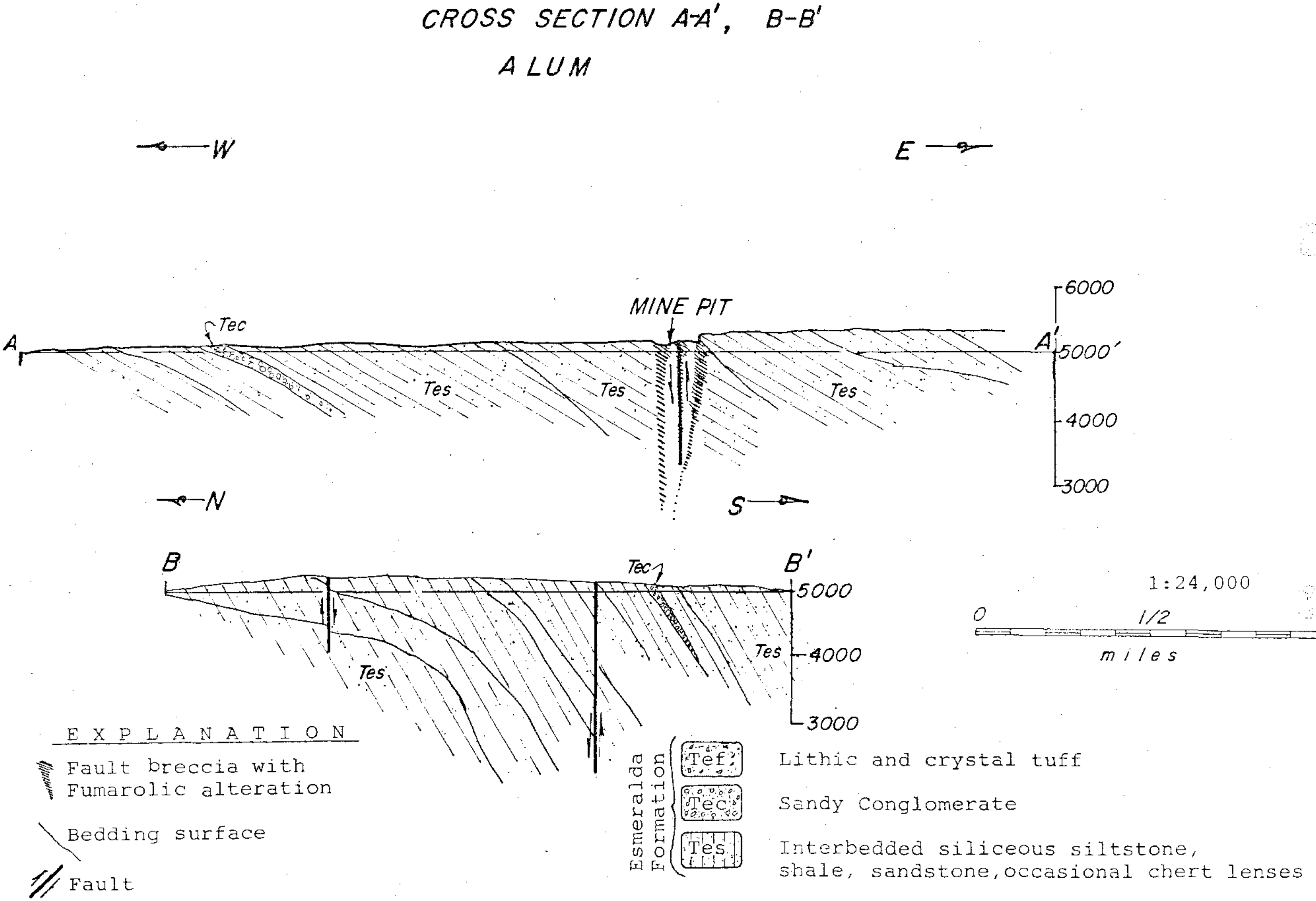


Figure 7. Alum-Cross Sections A-A', B-B'



Fi[illegible]e 8. Alum-Mercury Concentratio[illegible] ap

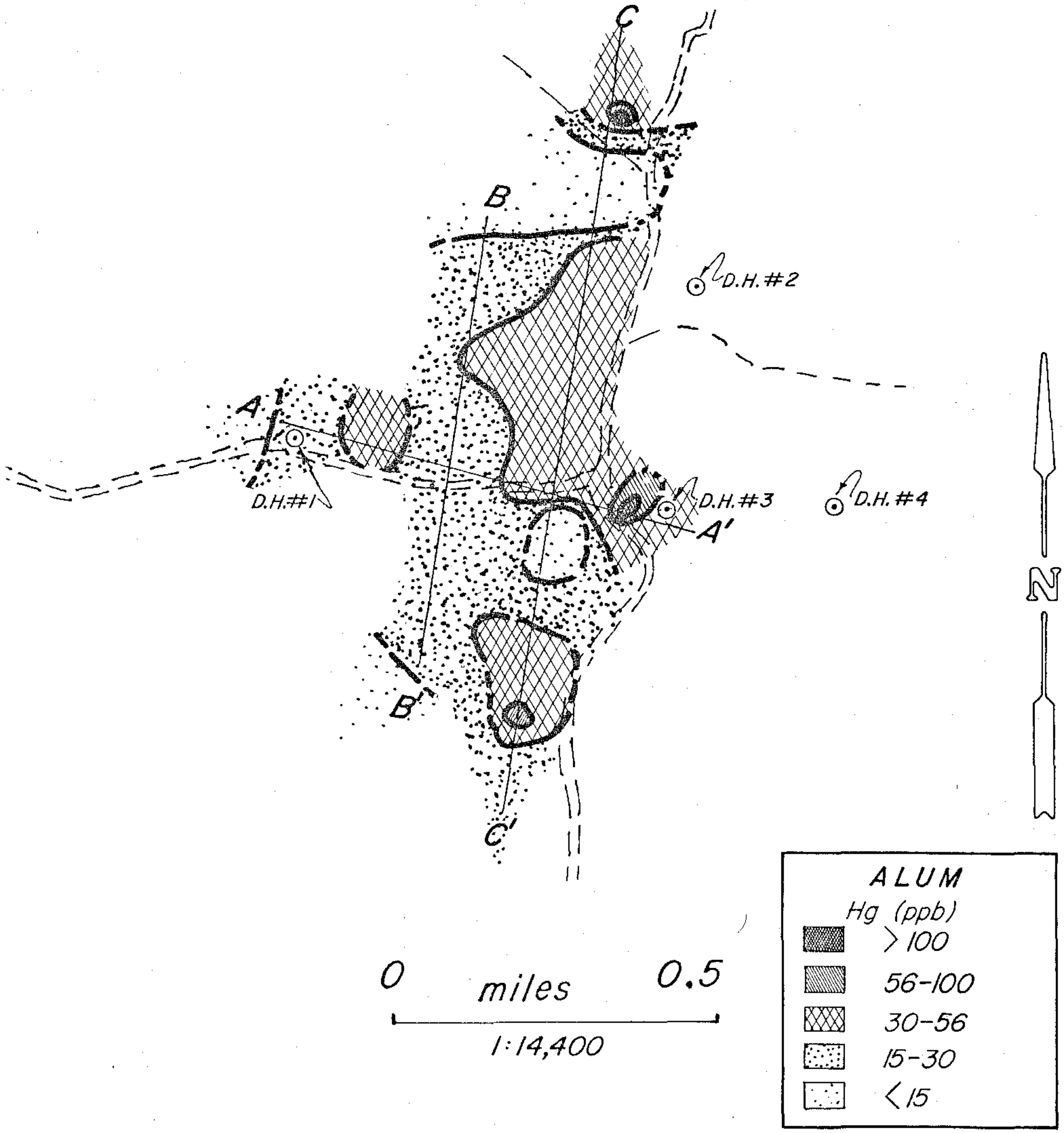


Figure 9. Alum-Mercury Profiles A-A', B-B', C-C'

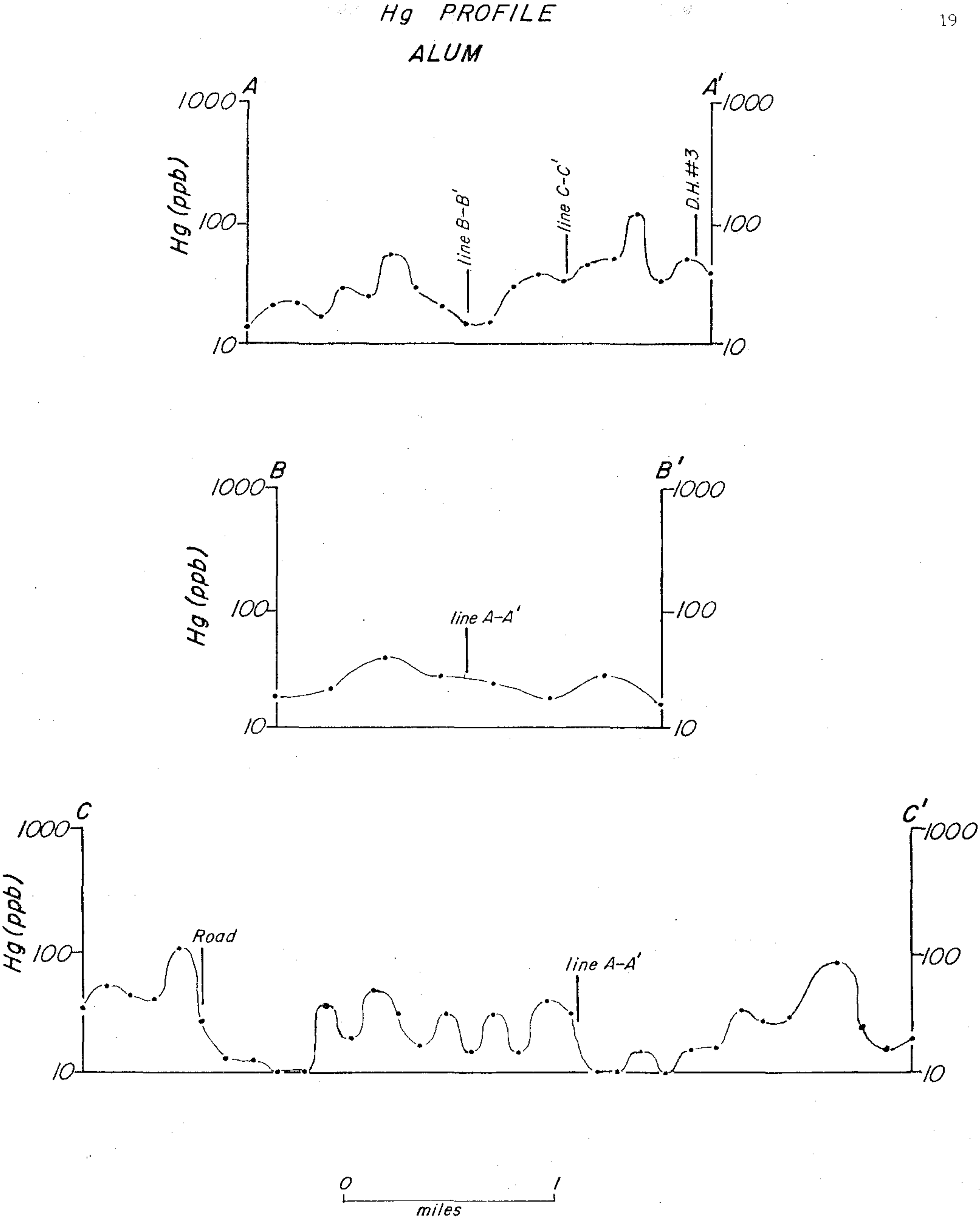
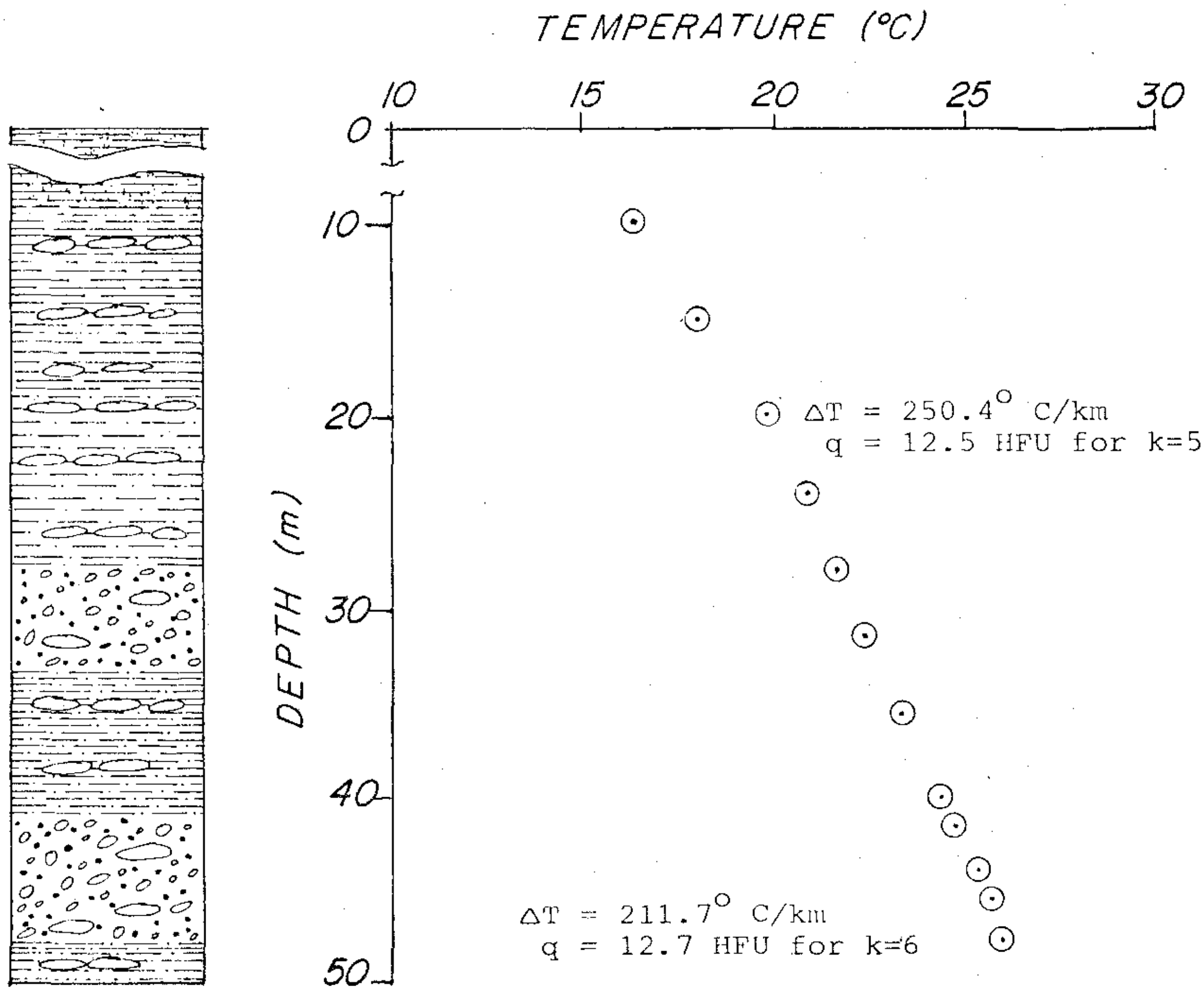


Figure 10. Alum ill Hole No. 1, Temperature and thology Log

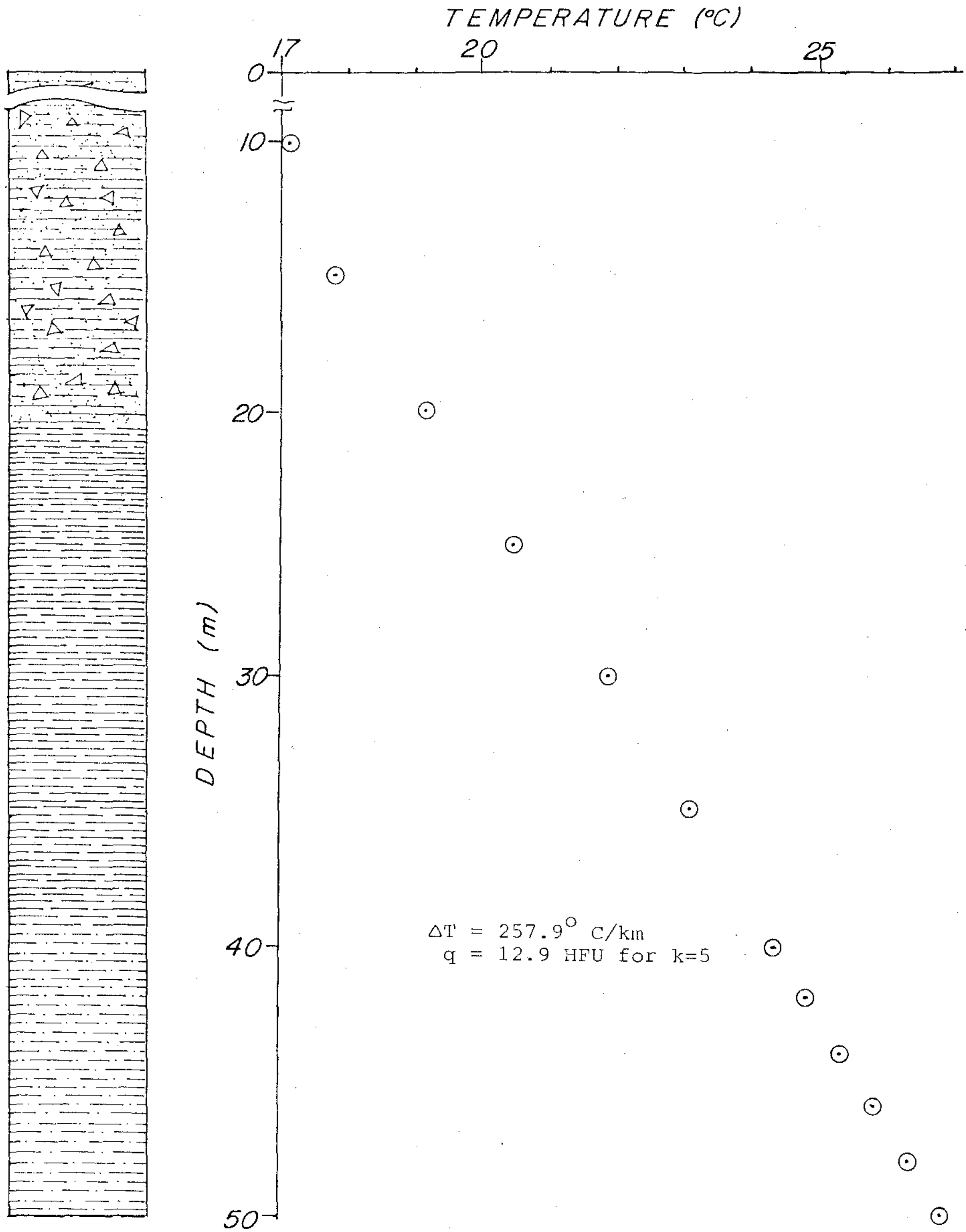
ALUM # 1



0-9	buff sandy claystone
9-18	greenish buff claystone with cherty layers 2-5mm thick
18-27	greenish buff poorly sorted, sandy siltstone with cherty layers subrounded redish gray chert clasts
33.5-41	buff siltstone with cherty layers
41-47	coarse grained, subrounded, pebbly lithic quartz sandstone
47-49	buff siltstone with cherty layers

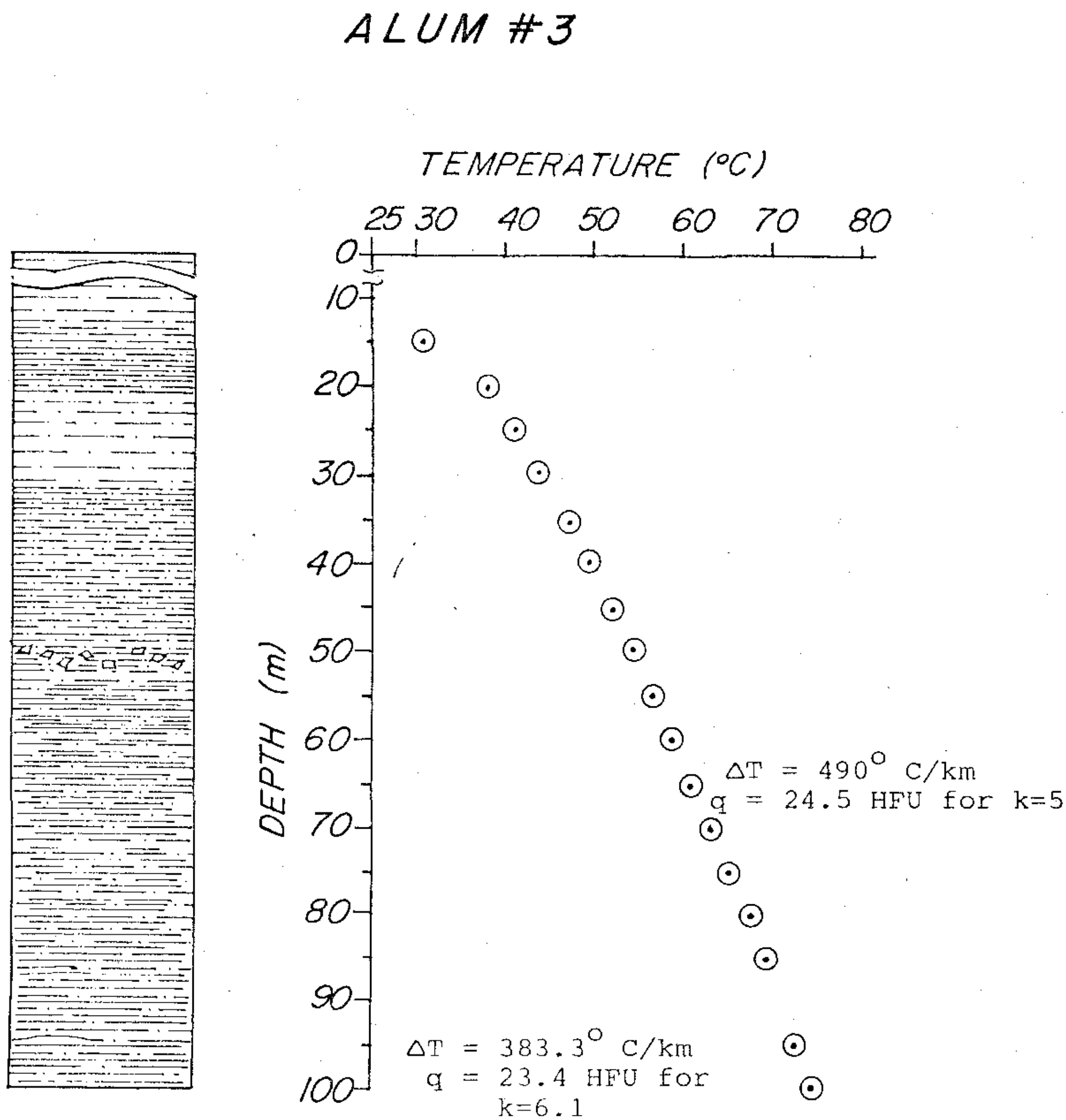
Figure 11. Alum Drill Hole No. 2, Temperature and Lithology Log

ALUM # 2



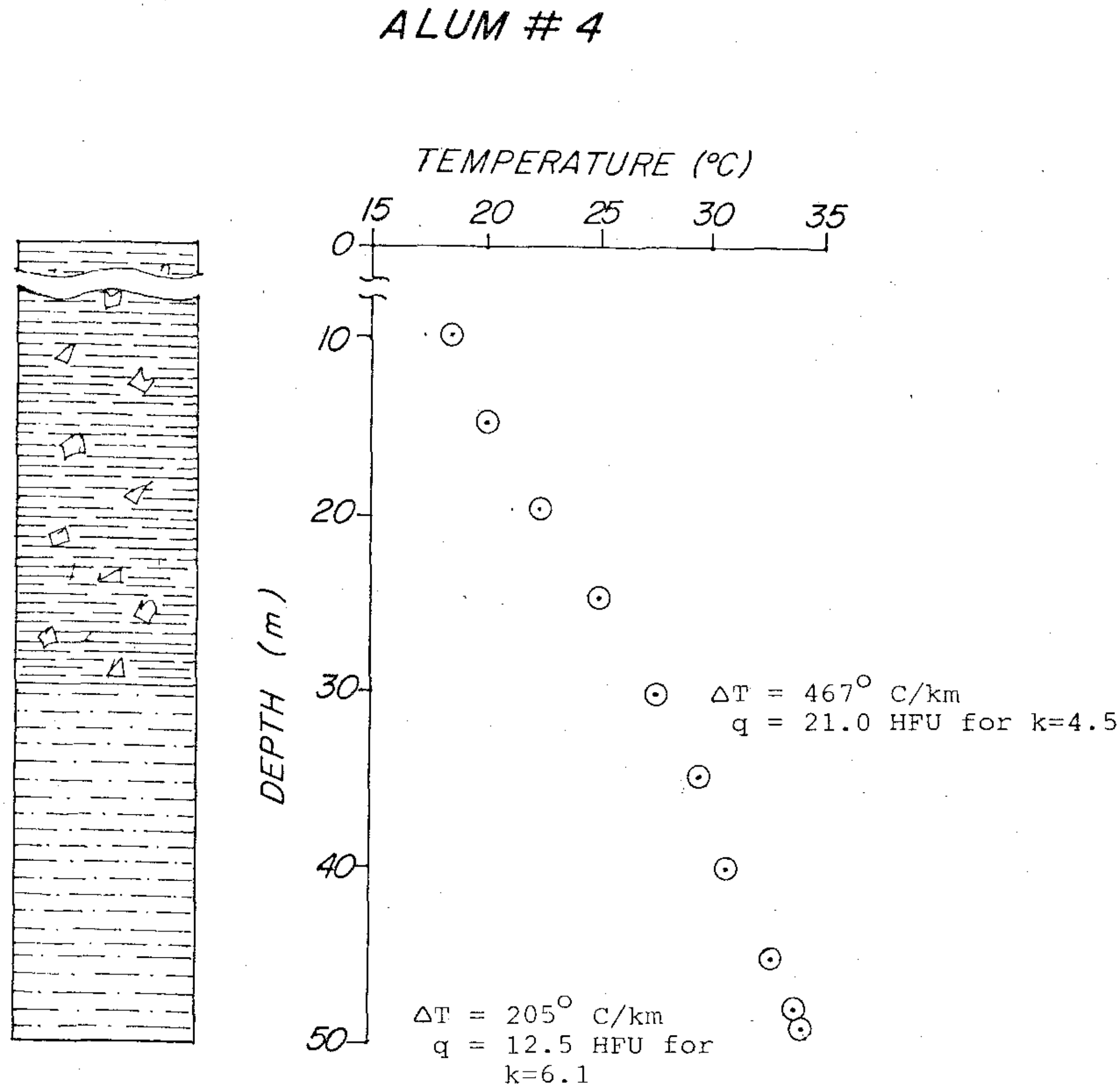
0-21 tuffaceous, medium grained, subrounded sandstone with high clay content
21-39.5 light green-gray claystone
39.5-49 gray sandy siltstone

Figure 12. Alum Drill Hole No.3, Temperature and Lithology Log



0-12	white-very light buff siltstone
12-21	very light gray siliceous siltstone
21-32	light gray siliceous siltstone with iron staining
32-49	medium gray non-siliceous siltstone
49-53	medium gray non-siliceous siltstone with pyrite crystals
53-100	medium gray siliceous siltstone

Figure 13. Alum-...ll Hole No.4, Temperature and ...thology Log



0-27 very light gray argillite with 2-5mm quartz fragments

27-50 medium green gray siltstone (argillic ?) interbedded with dark green-gray medium grained graywacke with green glauconite (?) cement

Figure 14. Alum-Heat Flow Coutour Map