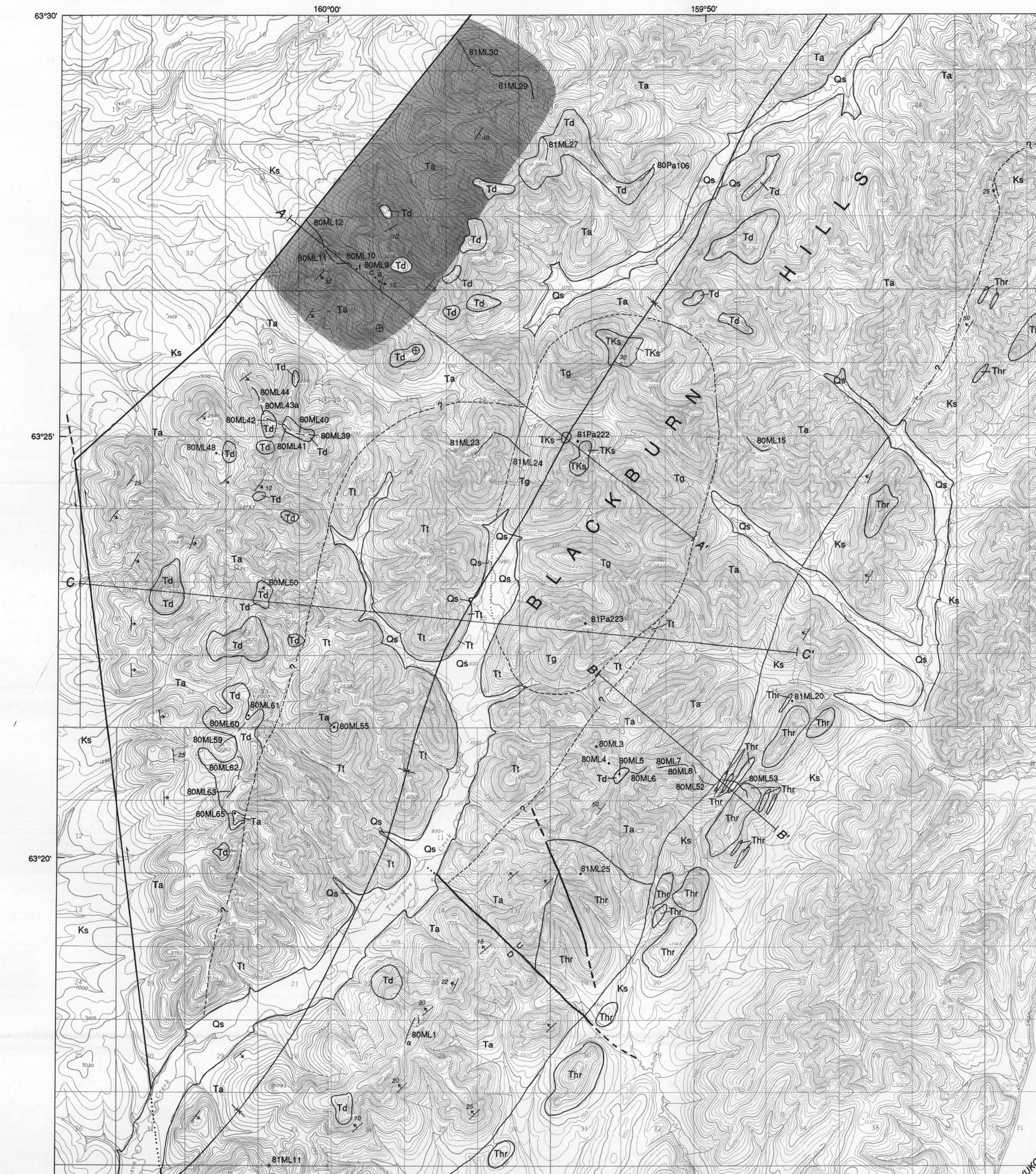
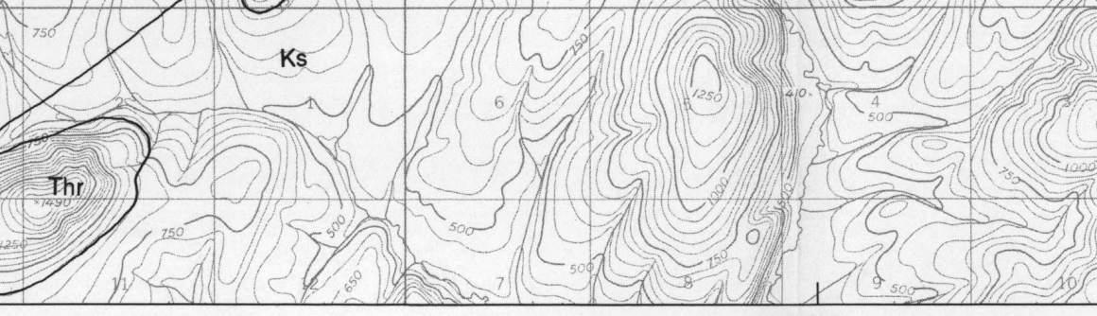
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF–2199



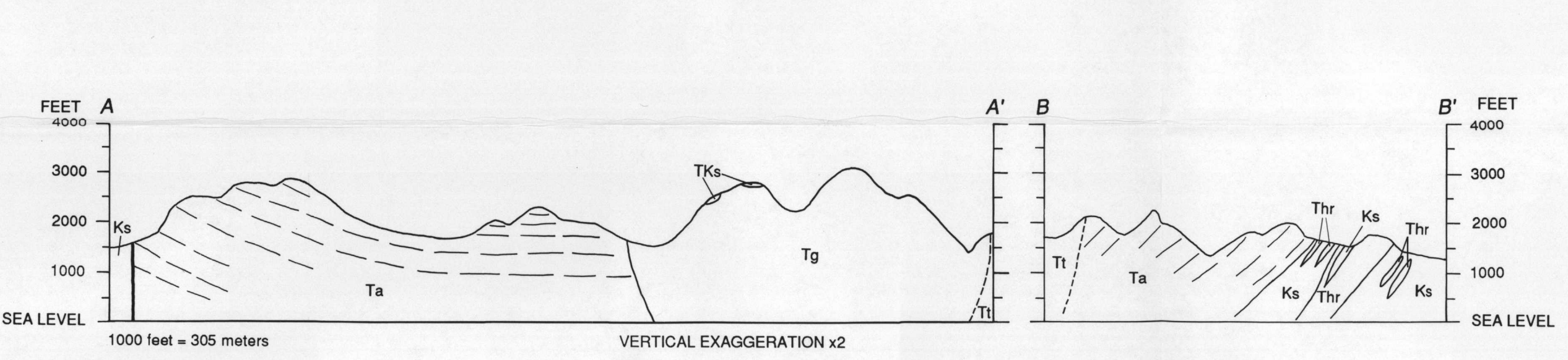
Base from U.S. Geological Survey, Unalakleet (B–2), 1952 (revised 1965); Unalakleet (B–3), 1952 (revised 1971)
Universal Transverse Mercator projection

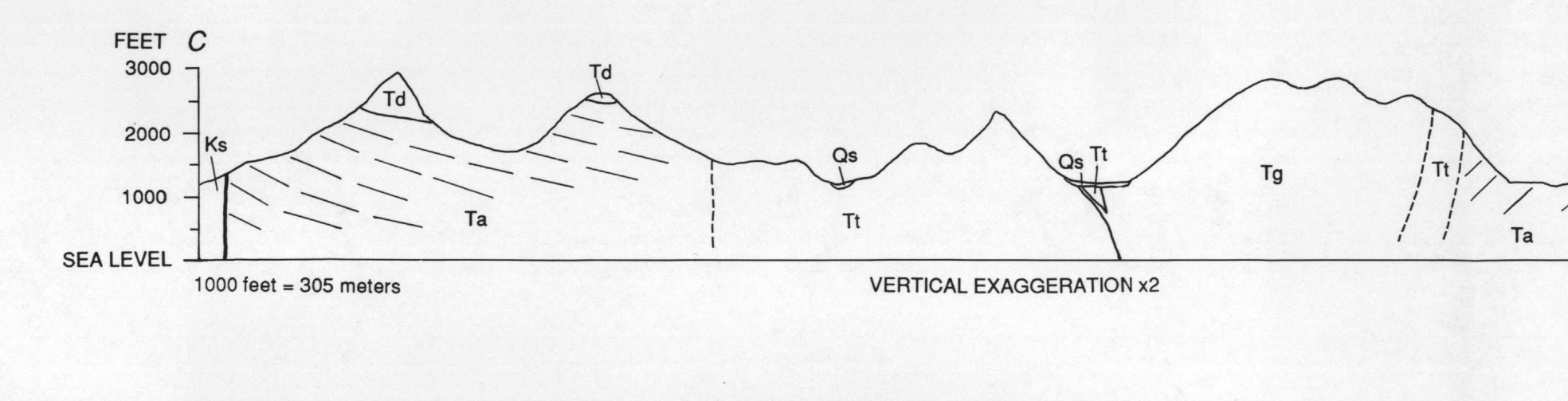


CONTOUR INTERVAL 50 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Geology by E.J. Moll-Stalcup and W.W. Patton, Jr., assisted by Carl Schwab, 1980–81
Edited by Taryn Lindquist; prepared by Carol Quesenberry
Manuscript approved for publication, March 13, 1992

QUADRANGLE LOCATION





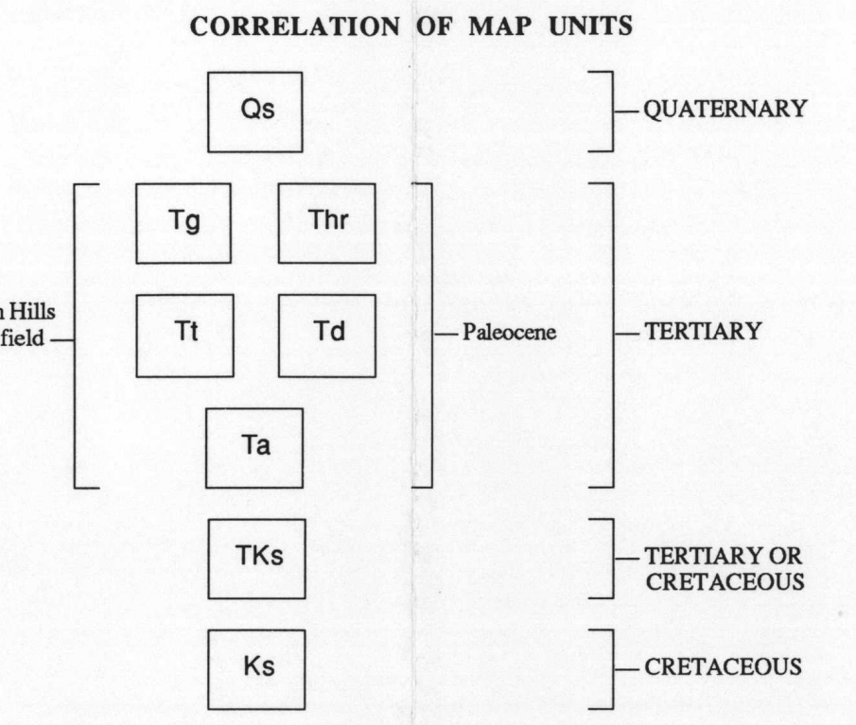
GEOLOGIC MAP OF THE BLACKBURN HILLS VOLCANIC FIELD, WESTERN ALASKA

By

Elizabeth J. Moll-Stalcup and William W. Patton, Jr.

1992

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

[Abbreviations used in this report—Minerals: An, anorthite; En, enstatite; Fo, forsterite; Fs, ferrosilite; Wo, wollastonite. Elements: Ba, barium; Be, beryllium; Ce, cerium; Co, cobalt; Cr, chromium; Cs, cesium; Eu, europium; F, fluorine; Fe, iron; Gd, gadolinium; Hf, hafnium; Ho, holmium; K, potassium; La, lanthanum; Lu, lutetium; Nb, niobium; Nd, neodymium; Rb, rubidium; Sb, antimony; Sc, scandium; Sm, samarium; Sn, tin; Sr, strontium; Ta, tantalum; Tb, terbium; Th, thorium; Tm, thulium; U, uranium; W, tungsten; Y, yttrium; Yb, ytterbium; Zn, zinc; Zr, zirconium]

Qs **Sand, silt, and gravel (Quaternary)**—Sand, silt, and gravel, mainly along Thompson and Blackburn Creeks

Tg **Granite (Paleocene)**—Pluton of pink to light-gray granite and quartz monzonite (63–72 percent SiO_2) that intrudes the central part of the Blackburn Hills volcanic field; found as small outcrop or rubble. Unit is composed of fine-grained, hypidiomorphic-granular or sparsely porphyritic granitic rocks that are characterized by plagioclase laths (An_{16-38}) mantled by orthoclase. Orthoclase usually is present as thick rims on plagioclase or, less commonly, as interstitial crystals. Quartz is usually interstitial but is present in some rocks as crystals that are optically but not physically continuous over large areas. Some rocks (for example, sample 81ML24; table 1) display graphic-textured intergrowths of quartz and potassium feldspar, either as small interstitial patches or as widespread intergrowths that replace original mineralogy. Most of the pluton has about 10 percent hornblende and biotite and 5 percent iron-titanium oxides; more mafic parts (63 percent SiO_2) have as much as 3 percent pyroxene. Pink granite dikes that are presumably from the pluton cut unit Tt near the contact between the two units (fig. 1A). A biotite mineral separate from sample 81Pa223 yielded a potassium-argon age of 56.2±1.7 Ma (Patton and Moll, 1985)

Thr **Hypabyssal rhyolite (Paleocene)**—Fine-grained, porphyritic hypabyssal rhyolite that intrudes units Ta and Ks along the southeastern flank of the Blackburn Hills volcanic field. Rocks of the hypabyssal rhyolite are texturally and mineralogically similar to the granitic pluton (Tg) in that they are characterized by fine- to medium-grained phenocrysts of plagioclase rimmed by orthoclase; they are therefore interpreted to be the differentiated hypabyssal equivalent of the granitic pluton. Most of the unit is porphyritic, although in places the groundmass is only slightly finer than the phenocrysts. The groundmass consists of fine- to medium-grained plagioclase, orthoclase, and quartz. Mafic minerals are usually altered. Rocks are commonly altered and locally contain calcite and zeolites.

Four samples from the porphyritic intrusive rhyolite were analyzed for major and trace elements (table 1; fig. 1B). The intrusive rhyolite is silicic, clustering at about 76 percent SiO_2, and is compositionally similar to the calc-alkalic rhyolite of unit Td in major and trace elements. Data from the hypabyssal rhyolite plot along a continuum with samples from the granitic pluton

Tt **Green tuff and tuff breccia (Paleocene)**—Green tuff and tuff breccia; white rhyolite breccia, domes, and ash; highly altered green dacite and andesite flows; and minor pink granite dikes. Unit consists of more than 1,000 m of green tuff and tuff breccia intercalated with highly altered andesite flows and cut by fine-grained white rhyolite domes or flows. Unit is confined to structureless rubble and small outcrops in the central part of the volcanic field. At least 500 m of this unit consists of green tuff and tuff breccia that varies from fine-grained, gray-green ash beds to coarse volcanic breccia that contains clasts as long as 25 cm. Tuff is composed of abundant lithic fragments of rhyolite, green partially welded pumice, and subordinate andesite lithic fragments, all in a groundmass of devitrified glass shards and crystals of altered plagioclase, quartz, and mafic minerals. Rhyolite lithic fragments consist of various lithologies of unit Td and include both devitrified and glassy fragments, some of which show remnant flow banding and perlitic cracks. Partially welded pumice is altered to chlorite and epidote. Mafic minerals are altered to chlorite and opaque oxides. Devitrified rhyolite glass is locally altered to zeolites.

Rhyolite consists of white, flow-banded, devitrified rhyolite that is often fractured and has quartz veins filling fractures. Rhyolite breccia consists of nearly monolithologic, angular clasts of white, flow-banded rhyolite, as well as rare andesite clasts and pumice, all in a matrix of polycrystalline quartz.

Dacite and andesite are highly altered and are composed of 15 to 25 percent phenocrysts of chiefly plagioclase and mafic minerals that are altered to chlorite and epidote. Dacite has groundmass composed of polycrystalline quartz and potassium feldspar. Andesite has highly altered groundmass composed of medium-grained plagioclase laths, chlorite, epidote, and opaque minerals.

Unit is locally cut by dikes of pink granite that is lithologically similar to that of the granitic pluton (Tg). Green tuff and breccia are interpreted to represent thick intracaldera tuff that is probably related to the eruption of large siliceous ash-flow tuffs late in the evolution of the volcanic field. Unit probably also contains some near-source outflow deposits consisting of altered flows and tuffs.

The contact with unit Ta is interpreted to mark the edge of the caldera rim, although the contact is obscured by alteration of both units along the contact, as well as poor exposures at the south and north ends of the contact. The unit may also be present in a poorly mapped area of the volcanic field northeast of the map area

Td **Rhyolite domes and flows (Paleocene)**—Well-exposed remnants of rhyolite domes and flows and associated basal breccia and tuff. Unit is exposed mainly along the axis and western flank of a large syncline, where it either overlies unit Ta or is interbedded with the uppermost part of unit Ta. Rhyolite consists of black hydrated glass and devitrified rhyolite. Glassy rocks are flow-banded and perlitic. Most devitrified rhyolite has groundmass of microcrystalline quartz and feldspar, and some samples display very fine grained needles of green pyroxene in the groundmass. Most glassy rocks contain 1 to 5 percent fine-grained phenocrysts of ferrohedenbergite and a single type of feldspar, either unzoned oligoclase, anorthoclase, or oligoclase rimmed by anorthoclase. One vitrophyre has phenocrysts of hypersthene ($Wo_{03}En_{51}Fs_{46}$) and zoned plagioclase (An_{24-52}). Most devitrified and partially devitrified rocks are calc-alkalic rhyolite that contains 3 to 20 percent phenocrysts of chiefly plagioclase, which exhibits either normal or oscillatory zoning from andesine to oligoclase and often shows zonal arrangement of melt inclusions. Mafic minerals in the devitrified calc-alkalic rocks are often altered, but the following mineral assemblages have been identified: plagioclase+biotite+ilmenite+magnetite; plagioclase+hornblende+ilmenite+magnetite; and plagioclase+hornblende+clinopyroxene+orthopyroxene+ilmenite+magnetite. Devitrified samples have abundant secondary chalcedony.

Two types of rhyolite, calc-alkalic (alkali-balanced) and sodic (soda-rich-potash-poor), have been distinguished on the basis of mineralogy and chemistry (table 2; figs. 1C, D). The sodic group has higher Na_2O and lower K_2O contents than the calc-alkalic group. The calc-alkalic rhyolite has K_2O/Na_2O ratios greater than 0.8 (usually greater than 1); MgO contents greater than 0.3 percent; and SiO_2 contents between 72.5 and 76.8 percent. The sodic rhyolite has K_2O/Na_2O ratios less than 0.5; MgO contents less than 0.1 percent; SiO_2 contents between 76 and 77 percent; and TiO_2, CaO, and Al_2O_3 contents that are lower than the calc-alkalic rhyolite. The sodic rocks also have higher Ta, Rb, Cs, Zn, and U contents; slightly higher Be, W, Sn, Th, Nb, Zr, Sb, Hf, and Y contents; and lower Co, Sc, Sr, Ba, and Eu contents than the calc-alkalic rocks. The calc-alkalic group has similar light rare-earth element (LREE) contents, lower heavy rare-earth element (HREE) contents, and smaller Eu anomalies than does the sodic group (figs. 1C, D).

A few samples (80ML39d, 40a, and 48a) appear to be transitional between the two rhyolite types (table 2; fig. 1E). Samples 39d and 40a have low Ba and Sr contents, like the sodic group, but have K_2O/Na_2O ratios greater than 0.9, like the calc-alkalic group. Conversely, sample 48a has a high Ba and Sr content, like the calc-alkalic group, but a low K_2O/Na_2O ratio, like the sodic group. Some of these distinctive "transitional" chemical features may be due to alteration. However, rare-earth element (REE) contents for samples 40a and 48a are distinct from either group (fig. 1E). The chondrite-normalized REE pattern for sample 39d is similar to patterns for the sodic rhyolites, but the concentrations are lower (figs. 1C, E), possibly owing to either dilution by SiO_2 (the rock has 79 percent SiO_2) or inclusions of mafic and intermediate-composition xenoliths. The three samples exhibit the following mineralogy: 39d, anorthoclase+altered mafic minerals; 40a, sanidine+needles of bright-green (iron-rich?) pyroxene; and 48a, oligoclase+orthopyroxene. The calc-alkalic rhyolite is chemically and mineralogically similar to rhyolite from orogenic zones, but the sodic rhyolite is similar to the soda-rich-potash-poor lavas erupted from Deception Island (South Shetland Group) and Fedarb Island (Papua New Guinea) (Ewart, 1979). Ewart (1979) states that the soda-rich-potash-poor magmas are found in regions where subduction has ceased in the relatively recent past.

Associated volcanic breccia and tuff are composed of medium- to coarse-grained perlitic rhyolite clasts, green-to-brown altered pumice, glass shards, feldspar and quartz crystals, and andesite lithic clasts.

A sanidine mineral separate from a rhyolite dome sample (80ML39d) yielded a potassium-argon age of 56.0±1.7 Ma (Patton and Moll, 1985)

Ta **Andesite and basalt flows (Paleocene)**—Well-exposed sequence more than 1,500 m thick of subaerial, columnar-jointed andesite and basalt flows. Most common rock types are one- and two-pyroxene andesites; high-silica (greater than 60 percent SiO_2) hornblende andesite and olivine-bearing basaltic andesite (less than 55 percent SiO_2) are much less common. Basalt is restricted to the uppermost part of the stratigraphic section, where it is locally intercalated with rhyolite of unit Td. Pyroxene andesite has 1 to 2 percent phenocrysts of plagioclase, clinopyroxene and (or) orthopyroxene, plus or minus altered olivine. Plagioclase phenocrysts show oscillatory zoning, which varies from An_{57-88} in the basaltic andesite to An_{48-68} in the high-silica andesite, and frequently show zonal arrangement of melt inclusions. Orthopyroxene varies from bronzite to hypersthene (En_{70-88}). Clinopyroxene displays a narrow compositional range in the augite field ($Wo_{43}En_{43}Fs_{14}$). Groundmass in the andesites is usually hyaloophitic or intersertal and is composed of subparallel plagioclase microlites, pyroxene, ilmenite, and magnetite, all in a dark glass. Hornblende-bearing, high-silica andesite contains 15 to 20 percent phenocrysts of plagioclase, gold-brown hornblende, and clinopyroxene. The groundmass consists of fine-grained plagioclase laths and opaque oxides, in a pale, devitrified glass.

Two basalt flows (less than 53 percent SiO_2) from the upper part of the stratigraphic section have been analyzed. Sample 80ML9f (table 3; fig. 1F) is a porphyritic basalt that contains 3 to 15 percent phenocrysts of plagioclase, clinopyroxene, magnetite, and altered olivine, in a holocrystalline groundmass of plagioclase, clinopyroxene, and magnetite. Sample 80ML65 (table 3; fig. 1E) is a diabasic basalt that consists of fine-grained labradorite laths, altered olivine (about Fo_{70}), subophitic brown clinopyroxene ($Wo_{46}En_{35}Fs_{19}$), ilmenite, and magnetite. A similar, unanalyzed basalt from station 81ML11 in the southern part of the volcanic field contains 5 percent olivine and pinkish-brown clinopyroxene. Basalts have small Nb–Ta anomalies and relatively small enrichments in K, Ba, Sr, Th, and U contents relative to La contents compared with andesites from the Blackburn Hills and other arc basalts, which indicates little or no arc affinity.

The andesites (53–63 percent SiO_2) are classified as orogenic andesites as defined by Gill (1981), because most have low TiO_2 contents (less than 1.75 percent) and moderate K_2O contents (table 3). Most of samples plot in the medium-potassium field of Gill (1981) on a K_2O–SiO_2 diagram, though a few plot in the low- and high-potassium fields. The andesite samples also plot in the orogenic-andesite field on La–Ba and La–Th discrimination diagrams of Gill (1981), whereas the basalt samples plot in the field for enriched midoceanic-ridge basalt (MORB) (fig. 2). All rocks have relatively high incompatible-element contents compared with most orogenic andesites; however, the andesites are depleted in Nb and Ta and enriched in K, Rb, Cs, Ba, Sr, Th, and U contents relative to La content, a characteristics of arc volcanic rocks. Average trace-element ratios for K/Cs, K/Ba, Ba/La, and K/Sr are similar to those in Aleutian arc volcanic rocks and indicate an affinity with arc volcanic rocks.

The andesites and basalts are herein divided into two compositional groups. Group 1 consists of andesites and basalts (48–61 percent SiO_2) that have moderate LREE and HREE contents (table 3; figs. 1F, G); group 2 consists of andesites (58–62 percent SiO_2) that have lower FeO* (total Fe) and TiO_2 contents, higher MgO contents, and more steeply sloping REE patterns (higher LREE and lower HREE contents) than group 1 (table 3; fig. 1H). The two groups are also geographically distinct. Group 1 rocks are mapped throughout the volcanic field, whereas group 2 rocks are found only on two ridges in the northwestern part of the volcanic field (shaded area).

A hornblende mineral separate from an andesite flow from near the base of the unit yields a potassium-argon age of 65.2±3.9 Ma (Patton and Moll, 1985)

TKs **Sandstone (Tertiary or Cretaceous)**—Fine-grained, dark-banded volcanic sandstone metamorphosed to hornfels. Unit is restricted to three roof pendants in the granitic pluton (Tg). Fine-grained detrital quartz grains make up 30 to 40 percent of the rock; much of the quartz is polycrystalline or has undulatory extinction, which may indicate a metamorphic-rock source. Remaining 60 to 70 percent of rock is composed of feldspar grains and lithic fragments, both of which are almost completely replaced by white mica and chlorite. Unit may be correlative with unit Ks or, alternatively, may be younger than unit Ks and derived in part from rocks underlying the Blackburn Hills volcanic field. Rocks are intruded by, and altered to hornfels by, granitic pluton (Tg) (56 Ma). Unit is tentatively assigned a Cretaceous or Tertiary age

Ks **Sandstone, shale, conglomerate, and coal (Cretaceous)**—Chiefly fluvial and shallow-marine deposits of well-sorted, medium- to coarse-grained, light-gray to olive, crossbedded sandstone; fine- to medium-grained, dark-gray to green, silty sandstone; dark-gray micaceous shale; quartz-chert pebble conglomerate; and thin seams of bituminous coal. Unit is best exposed in cutbanks along the Yukon River. Sandstones are composed chiefly of grains of quartz, chert, and metamorphic-rock detritus, as well as subordinate amounts of volcanic-rock fragments and plagioclase grains (Patton and Moll, 1985). Fresh- and brackish-water mollusk fossils are common; plant fossils of probable Cenomanian age (R.A. Spicer, written commun., 1984) are also abundant. Unit is assigned a late Early (Albian) and early Late (Cenomanian) Cretaceous age.

Unit is in fault contact with unit Ta along the west and northwest boundaries of the volcanic field. The contact with unit Ta along the east flank of syncline is poorly exposed in a series of brush-covered saddles; however, the conformable dips of both units suggest that unit Ta conformably overlies unit Ks

Approximate contact—Dashed where uncertain; dotted where concealed; queried where doubtful

U D **Fault**—Dashed where approximately located; dotted where concealed. U, upthrown block; D, downthrown block. Arrows indicate direction of relative movement

Syncline

Strike and dip of bedding or flows

10 **Inclined**

⊕ **Horizontal**

15 **Attitude of bedding or flows based on aerial photography or distant observation**—Showing dip where estimated

Field station and sample locality—Analyses of selected samples given in tables 1–3; data plotted in figures 1, 2. See section entitled "Description of Samples" for detailed lithologic descriptions

a 80ML1 j **Traverse**—Letters indicate specific sample localities. Traverse direction from uphill to downhill unless otherwise indicated by ascending order of sample locality letters

• 81ML20 **Spot locality**

Measured and projected orientation of bedding or flows—Shown in cross section only

▨ **Area of group 2 rocks**

DISCUSSION

The Blackburn Hills volcanic field is one of a number of Late Cretaceous and early Tertiary (75–50 Ma) volcanic fields in western Alaska that make up a vast magmatic province, which stretches from the Arctic Circle to Bristol Bay. Most of the volcanic field consists of calc-alkalic andesite, rhyolite, and granite, which were generated in response to subduction of the Kula plate along the southern continental margin of Alaska in the Late Cretaceous and early Tertiary. Small volumes of basalt and sodic rhyolite are interbedded with the calc-alkalic rocks near the top of the stratigraphic section. Eruptions of these basalts and sodic rhyolites mark the end of subduction and the transition to postsubduction magmatism. A hornblende separate of a calc-alkalic andesite from the base of the Blackburn Hills volcanic field was dated by potassium-argon method at 65.2±3.9 Ma (Patton and Moll, 1985); sanidine separated from a rhyolite dome at the top of the volcanic field yielded a potassium-argon age of 56.0±1.7 Ma (Patton and Moll, 1985); and biotite separated from the granite yielded a potassium-argon age of 56.2±1.7 Ma (Patton and Moll, 1985).

Most of the mapping was done during two-week periods in both 1980 and 1981, accomplished chiefly by helicopter-aided foot traverses down ridges and supplemented by spot landing at isolated localities. Cross sections show the relation between the various volcanic and plutonic units in the Blackburn Hills volcanic field and the surrounding Cretaceous sedimentary rocks. Generalized stratigraphic columns (figs. 3, 4), showing typical rock types and lithologic variations within volcanic units, were constructed using field notes and altimeter measurements.

The age, field, and compositional data suggest the following geologic history. Volcanism in the Blackburn Hills began with the eruption of dominantly andesitic lava flows about 65 Ma. These eruptions may have built stratovolcanoes, although the original topography of the postulated cones is now obscured by later faulting, folding, and erosion. About 56 Ma, rhyolite domes and basalt flows were erupted in addition to andesite as volcanism waned. After some of the rhyolite domes were erupted, the green tuff and tuff breccia unit was deposited in the center of the volcanic field. We interpret the thick (at least 1000 m) section of green tuff, tuff breccia, rhyolite, and altered andesite rubble to be an intracaldera deposit probably related to the eruption of silicic ash-flow tuff. We believe this is the most likely explanation for the presence of a minimum volume of 2 to 3 km³ of green, propylitically altered tuff and tuff breccia in the center of the volcanic field. In the map area, outflow sheets of ash-flow tuffs probably produced by this postulated eruption have been stripped away by erosion during the last 56 m.y., but they may be preserved about 25 km southeast of the map area where five ash-flow tuff cooling units are mapped east of the Yukon River.

Eruptions that produced the thick section of the green tuff and tuff breccia unit were quickly followed by intrusion of the central granitic pluton and the smaller rhyolite domes, sills, and intrusions along the eastern part of the volcanic field. Potassium-argon ages on the granitic pluton, which cuts the green tuff and tuff breccia unit, and on the rhyolite domes, which make up fragments in the green tuff and tuff breccia unit, are the same within analytical uncertainty; this suggests that dome formation, pyroclastic eruption, and stock intrusion occurred in rapid succession.

ACKNOWLEDGMENTS

We are grateful to Marvin Lanphere and Bill Silberman for providing the potassium-argon ages used in this report. We thank Jim McGee for help with the microprobe and Mike Clynne and Steve Box for their helpful reviews. Karen Wheeler provided drafting and layout support, and Judy Weathers typed the final version of the manuscript.

REFERENCES CITED

Ewart, A., 1979, A review of the mineralogy and chemistry of Tertiary-Recent dacitic, latitic, rhyolitic, and related salic volcanic rocks, *in* Barker, F., ed.,Trondhjemites, dacites and related rocks: Amsterdam, Elsevier, p. 13–121.

Gill, J.B., 1981, Orogenic andesites and plate tectonics: New York, Springer-Verlag, 390 p.

Moll-Stalcup, E.J., 1990, Latest Cretaceous and Cenozoic magmatism in mainland Alaska: U.S. Geological Survey Open-File Report 90–84, 80 p.

Moll-Stalcup, E.J., and Arth, J.G., 1991, Isotopic and chemical constraints on the petrogenesis of the Blackburn Hills volcanic field, western Alaska: Geochimica et Cosmochimica Acta, v. 55, no. 12, p. 3753–76.

Patton, W.W., Jr., and Moll, E.J., 1985, Geologic map of the northern and central part of the Unalakleet quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–1749, scale 1:250,000.

Wheatley, M.R., and Rock, N.M.S., 1988, Spider: a Macintosh program to generate normalized multi-element "spidergrams": American Mineralogist, v. 73, p. 919–21.

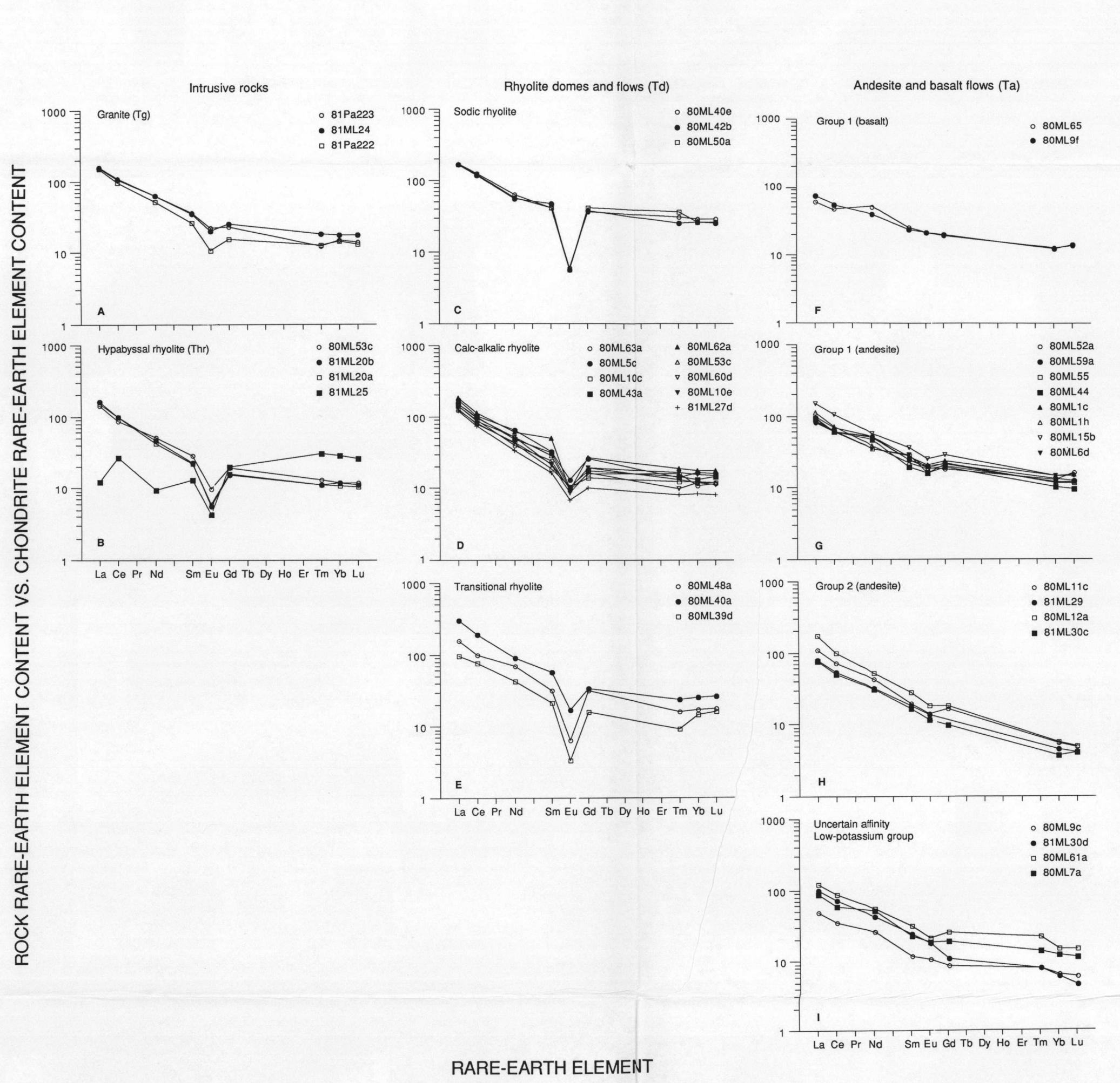


Figure 1. Plots of rare-earth element (REE) contents of rocks of Blackburn Hills volcanic field normalized with REE contents of chondrite meteorites. Plotting program from Wheatley and Rock (1988). Analyses given in tables 1–3. See section entitled "Description of Samples" for lithology of rocks. Intrusive rocks: A, granite (Tg); B, hypabyssal rhyolite (Thr). Rhyolite domes and flows (Td): C, sodic rhyolite; D, calc-alkalic rhyolite; E, transitional rhyolite. Andesite and basalt flows (Ta): F, basaltic rocks of group 1; G, andesitic rocks of group 1; H, andesitic rocks of group 2; I, rocks of uncertain affinity and of low-potassium group.

DESCRIPTION OF SAMPLES

Granite (Tg)

81Pa223: Fine- to medium-grained plagioclase laths rimmed by potassium feldspar. Interstitial potassium feldspar and quartz. Mafic minerals consist of clinopyroxene, pale-green amphibole, biotite, magnetite, and ilmenite. Minor chlorite replacing amphibole and biotite. Accessory apatite and zircon.

81ML24: Fine-grained equigranular microgranite composed of euhedral plagioclase laths that have thick mantles of potassium feldspar, anhedral and sometimes graphic quartz, opaque oxides, green amphibole, and apatite. Minor secondary chlorite. Visual estimate is 40 percent plagioclase, 35 percent potassium feldspar, and 25 percent quartz.

81Pa222: Fine- to medium-grained, porphyritic intrusive rock that contains 15 percent phenocrysts of plagioclase rimmed by potassium feldspar, in very fine grained groundmass of quartz, potassium feldspar, and plagioclase. Mafic minerals are pale-greenish-brown amphibole, biotite, and magnetite. Accessory zircon and apatite.

Hypabyssal rhyolite (Thr)

80ML53c: 15 percent phenocrysts of altered plagioclase, ilmenite, and magnetite (some secondary alteration replacing mafic minerals), in groundmass of devitrified glass (microfelsite).

81ML20b: 10 percent small phenocrysts of altered plagioclase rimmed by potassium feldspar. Slightly finer groundmass of plagioclase, potassium feldspar, and quartz. Abundant fine-grained quartz and potassium-feldspar graphic intergrowths. Mafic minerals (2–3 percent) replaced by muscovite, sphene, and secondary biotite. Accessory apatite and zircon.

81ML20a: 10 percent fine- to medium-grained phenocrysts of altered plagioclase rimmed by potassium feldspar, in fine-grained groundmass of plagioclase, potassium feldspar, and quartz. Some potassium feldspar and quartz are found as graphic intergrowths. Mafic minerals are replaced by muscovite, oxides, and sphene. Accessory apatite. Radial fibrous minerals in groundmass may be chalcedony or zeolites.

81ML25: Highly porphyritic; 5 percent medium-grained plagioclase phenocrysts that have thick mantles of potassium feldspar, in groundmass of very fine grained quartz, feldspar, and opaque minerals. Mafic minerals altered to small patches of brown oxides.

Rhyolite domes and flows (Td)

Sodic rhyolite

80ML40e: 1 percent phenocrysts consisting of stubby prisms of anorthoclase and subordinate grains of bright-green ferrohedenbergite, in pale-brown, perlitic glass.

80ML42b: Less than 1 percent phenocrysts of homogeneous anorthoclase (one crystal has faint albite twinning in core) and bright-green ferrohedenbergite, in pale-brown, perlitic glass.

80ML50a: Less than 1 percent phenocrysts of fresh anorthoclase and bright-green ferrohedenbergite, in pale-brown, perlitic glass.

80ML41d: 5 percent oscillatory-zoned plagioclase phenocrysts that have rims of potassium feldspar(?). Feldspars are found both in single crystals and in crystal clusters. Minor opaque minerals, altered mafic minerals, and apatite. Highly altered groundmass of devitrified glass and zeolites. One thin section contains an andesite xenolith.

Calc-alkalic rhyolite

80ML63a: 10 percent phenocrysts of fresh plagioclase, brown hornblende, orthopyroxene (bronzite and hypersthene, En_{55-76}), trace augite, zircon, apatite, and opaque oxides, all in pale-brown, slightly devitrified glass. Microphenocrysts of biotite. Relatively fresh in thin section.

80ML5c: 10 percent phenocrysts of altered plagioclase, opaque oxides, rusty-brown altered mafic minerals (biotite? hornblende?), in groundmass of partially devitrified glass.

80ML10c: 10 percent phenocrysts of altered and resorbed plagioclase. Vesicles filled with calcite and polycrystalline quartz. Calcite replacing crystals also. Mafic minerals altered to opaque oxides. Accessory apatite.

80ML43a: 20 percent phenocrysts of slightly altered plagioclase and rusty-weathered mafic minerals (biotite?), opaque oxides, apatite, and zircon, all in groundmass of devitrified glass and fine-grained biotite.

80ML62a: 10 percent phenocrysts of altered plagioclase and green alteration minerals replacing mafic minerals (biotite?). Opaque oxides and apatite. Groundmass of partially devitrified glass.

80ML60d: 20 percent phenocrysts of slightly altered plagioclase (single crystals and clusters), fresh biotite, and opaque oxides. Accessory zircon and apatite. Groundmass of microcrystalline quartz and feldspar, biotite (+chlorite), and opaque oxides. Some phenocryst-size clear patches of polycrystalline quartz.

80ML10e: 15 percent phenocrysts of hydrothermally altered plagioclase (andesine and oligoclase), fresh hornblende, opaque minerals, apatite, and zircon, in groundmass of devitrified glass.

81ML27d: 5 percent phenocrysts of plagioclase, fresh biotite, opaque oxides, and zircon, in altered groundmass of devitrified glass and zeolites.

80Pa106a: 5 to 7 percent fine- to medium-grained phenocrysts of altered feldspar that are partially replaced by calcite. Groundmass consists of devitrified glass, fine-grained biotite, and opaque oxides.

80Pa106b: Altered dacite; 5 to 7 percent fine- to medium-grained phenocrysts of altered feldspar that are partially replaced by calcite. Mafic minerals are completely altered. Groundmass of devitrified glass, fine-grained opaque oxides, and fine-grained biotite.

Transitional rhyolite

80ML48a: Less than 1 percent phenocrysts of homogeneous oligoclase, which have clear albite twins, and of orthopyroxene, in groundmass of flow-banded glass. Banding is defined by concentrations of pale-green pyroxene and dark-brown allanite(?) needles.

80ML40a: 3 percent feldspar (sanidine?) phenocrysts that have sharp carlsbad twins, in groundmass of felted plagioclase laths, devitrified glass, minor zeolites (or chalcedony), and needles of bright-green (iron-rich?) pyroxene. May be a densely welded tuff; in some places texture looks like collapsed pumice.

80ML39d: 5 percent phenocrysts of feldspar, some of which have faint albite twins in cores but most of which are anorthoclase (3.75 percent K_2O). Many inclusions of mafic and intermediate-composition volcanic rocks that are rich in dark opaque oxides replacing mafic minerals.

Andesite and basalt flows (Ta)

Group 1

80ML65: Basalt; fine-grained equigranular diabasic rock having fresh labradorite laths, subophitic pinkish-brown clinopyroxene ($Wo_{46}En_{35}Fs_{18}$), ilmenite, magnetite, and olivine (Fo_{66-71}) that is almost completely replaced by calcite and green secondary minerals.

80ML9f: Basalt; 5 percent small phenocrysts of very fresh, oscillatory-zoned plagioclase. Plagioclase phenocrysts contain very fine inclusions of pyroxene and opaque oxides. Groundmass of plagioclase laths, granular pyroxene, magnetite, and interstitial feldspar. Sparse green alteration mineral has replaced about 1 percent of groundmass grains and phenocrysts and appears to be replacing olivine.

80ML52a: Andesite; 25 percent phenocrysts of plagioclase (chiefly labradorite to bytownite, some andesine), olivine replaced by calcite, and clinopyroxene ($Wo_{43}En_{43}Fs_{14}$), all in groundmass of plagioclase laths, granular pyroxene, and magnetite. Texture is chiefly intergranular; sparsely intersertal.

80ML59a: Andesite; 10 percent phenocrysts of zoned and resorbed plagioclase, clinopyroxene, magnetite, and altered mafic minerals (olivine? orthopyroxene?), in groundmass of plagioclase laths, pyroxene, and opaque oxides, all in black, opaque glass. Texture is intersertal to hyaloophitic.

80ML55: Andesite; 35 percent phenocrysts of plagioclase, clinopyroxene, magnetite, and green secondary minerals replacing hornblende(?) or orthopyroxene(?). Groundmass consists of plagioclase, opaque oxides, altered feldspars, and devitrified glass.

80ML44b: Andesite; 15 percent phenocrysts of plagioclase and minor orthopyroxene, in groundmass of granular pyroxene, plagioclase laths, ilmenite, and magnetite, all in interstitial glass. Small patches of secondary biotite replacing mafic minerals are present in groundmass. Some altered phenocrysts may be olivine.

80ML1c: Andesite; 2 percent small phenocrysts of plagioclase, clinopyroxene, and magnetite, all in groundmass of subparallel plagioclase laths, granular pyroxene, and magnetite. Some lenses of brown sideromelane glass are present in groundmass.

80ML1h: Andesite; less than 1 percent small phenocrysts of inclusion-filled plagioclase, in groundmass of subparallel plagioclase laths, magnetite, pyroxene, and interstitial glass. Rock has a few percent vesicles.

80ML15a: Highly altered andesite; 15 to 20 percent phenocrysts of plagioclase and altered mafic minerals. Plagioclase replaced by calcite and sericite. Mafic phenocrysts replaced by calcite, serpentine, and opaque oxides. Groundmass of very fine grained plagioclase needles in dark, partially devitrified glass.

80ML15b: Andesite; 20 percent phenocrysts of plagioclase, clinopyroxene, and magnetite. About 10 percent of phenocrysts are brownish-green alteration minerals, which are probably replacing hornblende. Phenocrysts commonly are found in large glomeroporphyritic clots. Medium-grained groundmass consists of felted plagioclase laths, opaque oxides, and brown secondary minerals. Minor interstitial glass and apatite.

80ML6b: Andesite; less than 1 percent phenocrysts of plagioclase and microphenocrysts of clinopyroxene and altered hornblende(?), in groundmass of aligned plagioclase laths and opaque oxides. Minor interstitial glass.

Group 2

81ML23: Altered andesite; 15 percent coarse-grained plagioclase phenocrysts and altered mafic minerals. Devitrified groundmass of potassium feldspar, quartz, and altered mafic minerals.

80ML11b: 20 percent medium-grained phenocrysts of plagioclase and clinopyroxene. Hornblende pseudomorphs. Glomeroporphyritic.

80ML11c: 10 percent phenocrysts of plagioclase, orthopyroxene, clinopyroxene, ilmenite, and magnetite. Some pyroxene is found in glomeroporphyritic clots. Minor secondary biotite replacing some mafic minerals. Groundmass consists of felted plagioclase laths, opaque oxides, and sparse pyroxene.

81ML29b: 20 percent phenocrysts of altered plagioclase and green to pale-yellow amphibole rimmed by dark oxides. Microphenocrysts of amphibole and orthopyroxene. Groundmass of very fine grained plagioclase laths, opaque oxides, and partially devitrified glass. Patches of secondary alteration minerals are present throughout groundmass and may be filling original pore space.

80ML12a: 15 percent phenocrysts of altered plagioclase (An_{48-68}), gold-brown amphibole, and pale-green clinopyroxene. Groundmass of very fine grained plagioclase laths, opaque oxides, secondary(?) biotite, and partially devitrified glass. Less than 2 percent magnesium-rich (En_{85-88}) orthopyroxene xenocrysts.

80ML12b: Similar to 80ML12a; 15 to 20 percent phenocrysts of hornblende, plagioclase, pale-green clinopyroxene, and opaque oxides. Groundmass of very fine grained plagioclase microlites, secondary biotite, and partially devitrified glass.

81ML30c: 25 percent phenocrysts of plagioclase, orthopyroxene, and clinopyroxene, in fine-grained groundmass of plagioclase laths, pyroxenes, and opaque oxides, all in partially devitrified glass. Intersertal texture.

Uncertain affinity

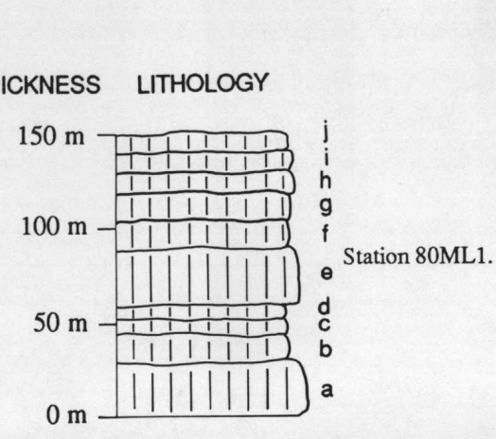
81ML30d: 30 percent phenocrysts of plagioclase, clinopyroxene, and altered olivine. Much of clinopyroxene, olivine, and minor plagioclase are found in clusters of as many as 30 crystals. Groundmass of plagioclase, pyroxene, ilmenite, and magnetite.

80ML9c: 10 percent phenocrysts of plagioclase and clinopyroxene. Less than 1 percent of phenocrysts are olivine pseudomorphs replaced by calcite and greenish-gold alteration minerals. Groundmass consists of microphenocrysts of plagioclase, orthopyroxene, clinopyroxene, and sparse opaque oxides. Holocrystalline and intersertal. Very fresh except for alteration of olivine.

Low-potassium group

80ML7a: 5 percent phenocrysts of plagioclase and clinopyroxene, in groundmass of plagioclase laths, granular pyroxene, and opaque oxides. Minor biotite microphenocrysts (may be secondary). Mineralogy is fresh but rock has abundant (5–10 percent) lenses and pore space filled with radial spherulites of chalcedony and gold fibrous secondary minerals.

80ML61a: 15 percent very fresh phenocrysts of plagioclase, clinopyroxene, and magnetite, in groundmass of plagioclase laths, opaque oxides, pyroxene(?), and pale-brown glass.



Station 80ML1. Chiefly fine-grained, blue-black andesite. 1–5 percent fine-grained phenocrysts of plagioclase and pyroxene.

Figure 3. Stratigraphic section of andesite and basalt flows (Ta) in southeastern part of Blackburn Hills volcanic field. Letters a–j refer to specific sample localities. Chemical analysis of selected samples given in table 3; see section entitled "Description of Samples" for more detailed lithologic descriptions.

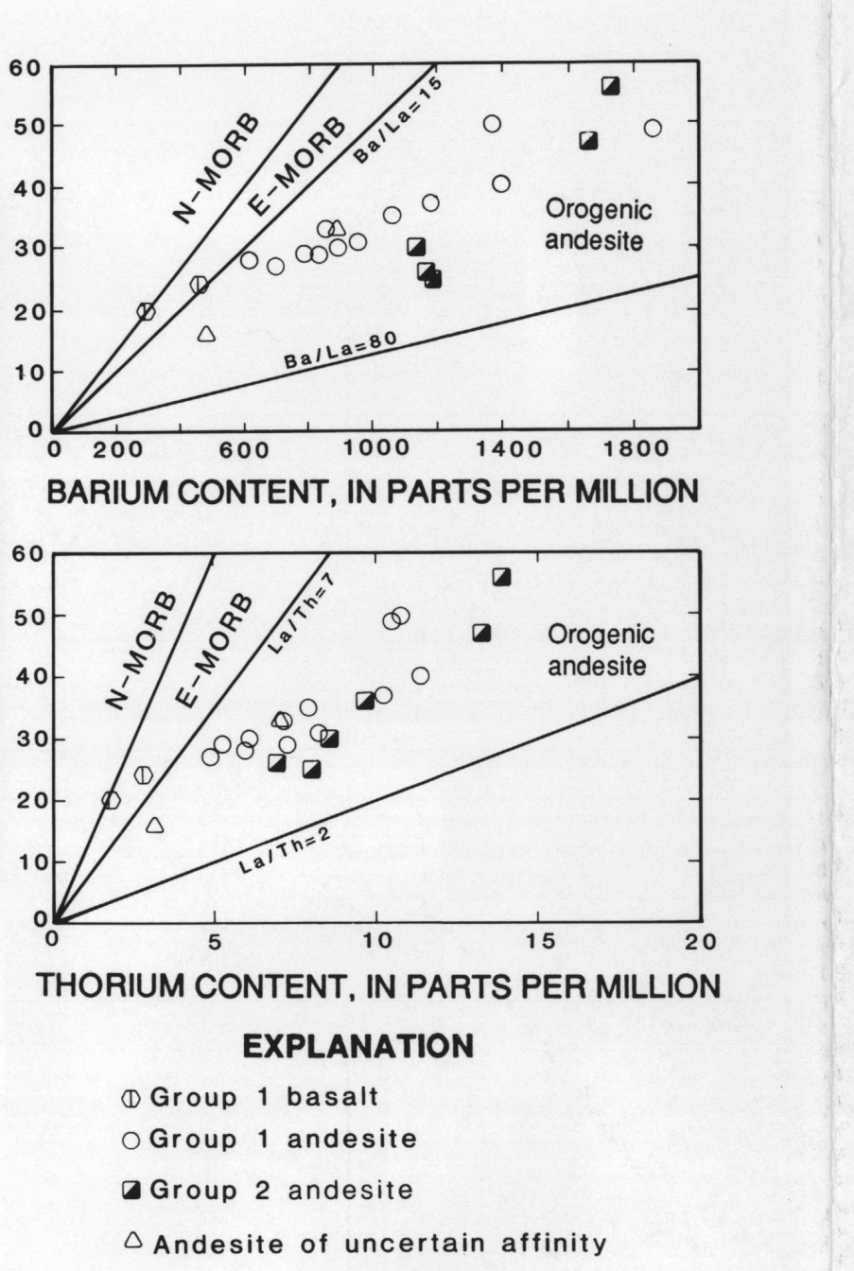
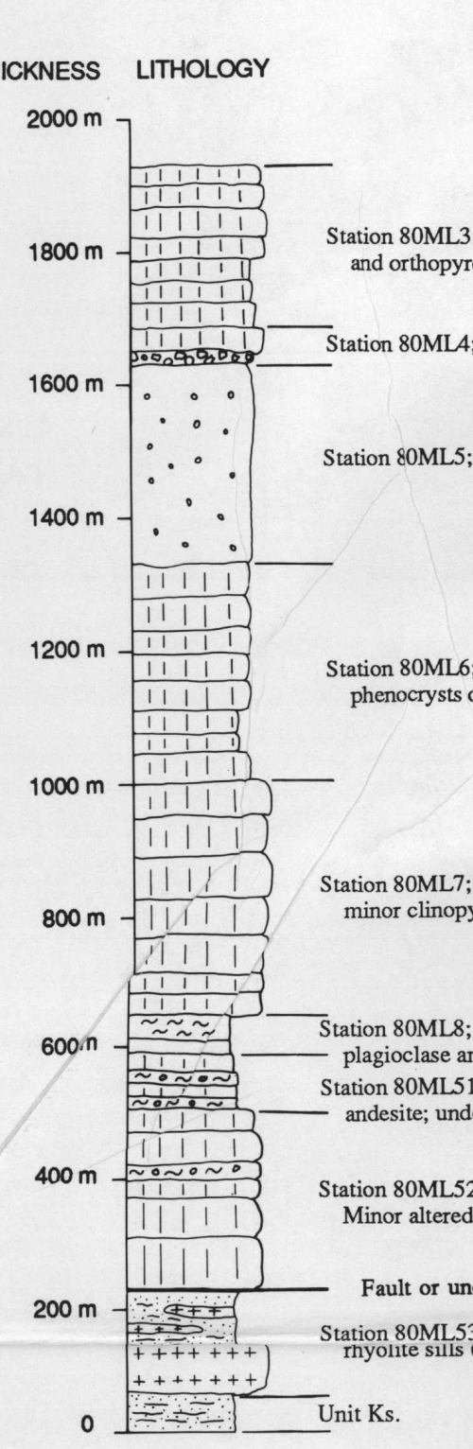


Figure 2. Discrimination diagrams for rocks of Blackburn Hills volcanic field, showing compositional fields for normal midocean-ridge basalt (N–MORB), enriched midocean-ridge basalt (E–MORB), and orogenic andesite from Gill (1981). Analyses given in table 3.



Station 80ML3; unit Ta. Gray to black andesite and basalt(?) flows, typically 5–7 m thick. Sparse phenocrysts of plagioclase and orthopyroxene, plus or minus clinopyroxene. Red oxidized flow tops.

Station 80ML4; unit Ta. Reddish-brown andesite flow, typically 5–7 m thick. Underlain by andesite breccia.

Station 80ML5; unit Td. Brick-red, partially devitrified rhyolite. 5 percent fine-grained plagioclase phenocrysts.

Station 80ML6; unit Ta. Fine-grained andesite flows. Columnar jointing and platy fracture. Less than 1 percent fine-grained phenocrysts of plagioclase and pyroxene.

Station 80ML7; unit Ta. Medium- to coarse-grained, dark-gray andesite. 5 percent phenocrysts of chiefly plagioclase and minor clinopyroxene.

Station 80ML8; unit Ta. Devitrified and partially welded, white ash-flow tuff having 10 percent phenocrysts of chiefly plagioclase and containing lithic clasts of graywacke and basalt. Underlain by altered green and pink rhyolite.

Station 80ML51; unit Ta. Fine-grained andesite flow; underlain by lithic crystal tuff; underlain by altered coarse-grained andesite; underlain by felsic lithic tuff that has green clasts in reddish matrix.

Station 80ML52; unit Ta. Olivine andesite flows having 15 percent phenocrysts of plagioclase, clinopyroxene, and olivine. Minor altered rhyolite, including some altered glass.

Fault or unconformity (covered).

Station 80ML53; units Ks and Thr. Upper part: fine-grained, micaceous sandstone rubble (unit Ks), cut by 3 or 4 hypabyssal rhyolite sills (unit Thr) in low saddle on map. Lower part: hypabyssal rhyolite sill (unit Thr) intruding sedimentary rocks.

Unit Ks.

Figure 4. Stratigraphic section of units Ks, Ta, Td, and Thr along eastern flank of Blackburn Hills volcanic field. Chemical analyses of selected samples given in table 3; see section entitled "Description of Samples" for more detailed lithologic descriptions.

Table 1. *Whole-rock chemical analyses of intrusive rocks from Blackburn Hills volcanic field*

[n.d., not accurately detected. Major elements in weight percent; trace elements in parts per million. Actual CaO values reported herein; CaO values of samples that have high CO_2 contents were corrected for secondary calcite. Analyses performed: FeO, CO_2, and H_2O by wet chemistry; all other major elements by wavelength dispersive X-ray fluorescence; Rb, Sr, Ba, Nb, Zr, and Y by X-ray fluorescence; all other trace elements by instrumental neutron activation, except Th and U values in italics, which were by delayed neutron activation. Analysts: J.W. Baker, M. Coughlin, S. Danahey, R.G. Johnson, J.S. Kane, B.S. King, D. Kobilas, J.R. Linsey, B. McCall, H.J. Rose, L.F. Schwarz, G. Sellers, J. Storey, J.E. Taggert, Jr., B. Vaugh, and J.S. Wahlberg]

	Granite (Tg)			Hypabyssal rhyolite (Thr)			
Sample number	81Pa223	81ML24	81Pa222	80ML53c	81ML20b	81ML20a	81ML25
Major element							
SiO_2	62.60	67.30	70.80	73.00	74.80	74.80	75.10
Al_2O_3	16.00	15.40	14.50	13.90	13.40	13.40	13.30
Fe_2O_3	3.12	2.02	1.46	1.15	0.95	1.13	1.31
FeO	2.13	1.60	0.80	0.54	0.24	0.24	0.08
MgO	1.84	0.84	0.50	0.20	0.18	0.21	<0.10
CaO	3.57	1.94	1.33	[1]0.69	0.06	0.06	0.09
Na_2O	4.82	4.99	4.60	4.00	3.76	3.97	3.95
K_2O	2.79	3.51	4.04	3.20	4.71	4.20	4.59
TiO_2	1.10	0.65	0.38	0.28	0.18	0.18	0.05
P_2O_5	0.42	0.17	0.08	<0.1	<0.05	<0.05	<0.05
MnO	0.15	0.09	0.05	0.03	<0.02	<0.02	<0.02
CO_2	0.13	0.02	0.03	0.49	0.03	0.02	0.01
H_2O+	0.70	0.69	0.20	1.14	0.83	0.77	0.62
H_2O-	0.42	0.20	0.28	0.41	0.22	0.39	0.28
Total	99.79	99.42	99.05	99.03	99.36	99.37	99.38
SiO_2 (anhydrous)	63.53	68.32	71.85	73.72	75.28	75.27	75.57
FeO* (total Fe)	4.93	3.41	2.11	1.57	1.09	1.25	1.26
Trace element							
Rb	79	107	146	89	147	137	182
Cs	3.6	4.2	3.7	2.3	1.2	1.1	6.4
Sr	458	261	189	91	57	73	10
Ba	1340	1460	1340	1217	1510	1440	145
La	53	51	50	46	53	50	4
Ce	94	92	82.5	76	85	85	23
Nd	39	39	32	33	29	27	6
Sm	7.2	7.1	5.3	5.9	4.6	4.5	2.7
Eu	1.68	1.55	0.83	0.75	0.43	0.46	0.33
Gd	6.3	6.9	4.25	5.4	4.2	4.4	5.6
Tb	0.89	1.08	0.66	0.4	n.d.	0.52	1.18
Tm	0.38	0.57	0.399	0.41	0.34	0.34	0.96
Yb	3.3	3.9	3.15	2.6	2.65	2.4	6.3
Lu	0.47	0.59	0.44	0.41	0.38	0.36	0.88
Y	31	38	32	30	32	29	55
Zr	256	392	318	250	224	224	223
Hf	6.6	9.5	7.3	6.3	5.5	5.4	8
Nb	18	19	16	21	24	25	45
Ta	1.55	1.77	1.77	1.67	1.89	1.82	3.18
Th	11.3	15.1	19.9	*22.3*	22.8	22.7	24.4
U	3.1	4.2	4	*6.55*	5.25	5	5.4
Sc	10.7	8.21	4.54	3.16	2.86	2.88	0.54
Cr	3.5	6.5	4.9	2.1	3.9	2.9	3.3
Co	8.7	4.7	2.1	1.5	0.7	0.8	<0.02
Zn	115	80	42.5	33	41	22	114
Sb	2.1	2.1	0.4	2.2	1	0.3	1.2

[1] 0.38% CaO in calcite; 0.31% CaO in other minerals

Table 2. *Whole-rock chemical analyses of rhyolitic rocks from Blackburn Hills volcanic field*

[n.a., not analyzed; n.d., not accurately detected. Major elements in weight percent; trace elements in parts per million. Actual CaO values reported herein; CaO values of samples that have high CO_2 contents were corrected for secondary calcite. Analyses performed: F by specific ion electrode; FeO, CO_2, and H_2O by wet chemistry; all other major elements by wavelength dispersive X-ray fluorescence; Rb, Sr, Ba, Nb, Zr, and Y by X-ray fluorescence, except Rb and Sr values in italics, which were by isotope dilution mass spectrometry; Be by induction coupled plasma; Sn by heated graphite atomizer-atomic absorption spectrometry; W by ion exchange induction coupled plasma; all other trace elements by instrumental neutron activation, except Th and U values in italics, which were by delayed neutron activation. Analysts: J.W. Baker, M. Coughlin, S. Danahey, R.G. Johnson, J.S. Kane, B.S. King, D. Kobilas, J.R. Linsey, B. McCall, H.J. Rose, L.F. Schwarz, G. Sellers, J. Storey, J.E. Taggert, Jr., B. Vaugh, and J.S. Wahlberg]

	Rhyolite domes and flows (Td)																
	Sodic rhyolite				Calc-alkalic rhyolite										Transitional rhyolite		
Sample number	80ML40e	80ML42b	80ML50a	80ML41d	80ML63a	80ML5c	80ML10c	80ML43a	80ML62a	80ML60d	80ML10e	81ML27d	80Pa106a	80Pa106b	80ML48a	80ML40a	80ML39d
Major element																	
SiO_2	72.00	72.00	72.30	71.00	66.10	70.40	71.3	71.30	72.70	73.10	75.7	79.50	77.4	74.5	71.80	75.10	79.40
Al_2O_3	11.80	11.80	11.80	11.70	13.20	14.50	12.60	14.40	14.20	13.90	12.10	10.90	11.6	12.8	13.30	11.00	10.80
Fe_2O_3	0.92	1.00	1.11	1.04	0.56	2.61	0.62	1.72	1.08	1.44	0.97	0.39	0.69	1.19	0.76	3.39	1.22
FeO	0.85	0.76	0.63	0.69	1.16	0.40	0.66	0.50	1.00	0.58	0.56	0.08	0.21	0.38	0.79	0.22	0.13
MgO	0.10	<0.10	0.10	0.10	0.30	0.40	0.20	0.50	0.40	0.51	0.30	<0.10	0.3	0.49	0.30	<0.1	0.1
CaO	0.34	0.40	0.44	0.55	3.45	0.89	[1]3.35	0.96	0.58	0.14	[2]1.31	0.54	0.36	0.84	0.82	0.39	0.09
Na_2O	5.20	5.40	4.60	4.70	3.00	3.90	3.50	4.20	3.80	3.90	3.10	2.98	3.4	3.2	5.30	4.60	3.60
K_2O	2.24	1.95	2.64	2.73	1.44	3.77	3.87	4.26	4.89	4.37	4.25	4.14	4.52	3.5	2.05	4.22	4.15
TiO_2	0.10	0.09	0.10	0.10	0.24	0.34	0.40	0.35	0.27	0.33	0.22	0.18	0.15	0.29	0.20	0.25	0.08
P_2O_5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	<0.05	0.09	<0.1	<0.1	<0.1
MnO	0.03	0.04	0.04	0.04	0.04	<0.02	0.12	0.03	0.04	0.02	0.03	<0.02	<0.02	<0.02	0.03	0.07	<0.02
CO_2	<0.01	0.02	<0.01	0.06	0.06	<0.01	1.75	0.01	0.09	<0.01	0.26	0.01	<0.01	0.13	0.01	<0.01	<0.01
H_2O+	4.84	5.26	5.13	5.33	5.84	0.91	0.60	0.62	0.66	0.81	0.68	0.65	0.47	1.15	4.17	0.24	0.48
H_2O-	0.43	0.23	0.54	1.08	4.54	1.15	0.05	0.26	0.25	0.39	0.17	0.19	0.12	0.75	0.21	0.05	0.07
F	0.01	0.04	0.02	0.04	0.02	0.05	0.02	0.02	0.02	0.03	0.01	0.05	0.02	0.03	0.02	0.01	0.01
Total	98.85	98.99	99.45	99.16	99.94	99.32	99.04	99.13	99.98	99.54	99.66	99.61	99.24	99.34	99.76	99.54	100.33
SiO_2 (anhydrous)	76.94	77.05	77.11	76.63	73.87	72.42	73.79	72.59	73.46	74.36	76.82	80.54	78.48	76.58	75.30	75.68	79.58
FeO* (total Fe)	1.68	1.66	1.63	1.63	1.66	2.74	1.22	2.04	1.97	1.87	1.43	0.43	0.92	1.61	1.47	3.26	1.23
Trace element																	
Rb	*205.5*	198	227	220	57	120	95	126	156	125	92	118	142	114	*218.2*	*89.7*	*143.5*
Cs	13.1	11.6	12.4	76.4	53.9	2.4	1.05	2.4	2.6	1.2	0.65	1.1	n.a.	n.a.	18	1	3
Sr	*27.5*	19	76	115	938	111	168	121	135	92	122	98	50	94	*76.8*	*9*	*7.25*
Ba	403	320	1123	661	1039	1313	1321	1495	1732	1874	4600	1400	1055	1193	1084	399	246
La	57	55	55	55	47	56	41.5	50	60	50	42	39	n.a.	n.a.	51	98	31
Ce	107	101	103	101	78	89	70.5	85	97	83	68	63	n.a.	n.a.	85	165	65
Nd	40	35	36	33	25	41	26.5	30	38	32	27.5	21	n.a.	n.a.	43	57	27
Sm	8.2	9.4	8.2	8	5	6.65	3.8	6.5	10.1	4.3	4.5	3.4	n.a.	n.a.	6.4	11.7	4.3
Eu	0.46	0.43	0.44	0.44	0.74	1.01	0.8	0.81	0.74	0.67	0.76	0.53	n.a.	n.a.	0.5	1.29	0.26
Gd	9.8	10.4	11.4	10.1	4.4	7.2	3.9	4.8	7.5	4.5	5.3	2.8	n.a.	n.a.	8.7	9.4	4.4
Tb	1.02	1.05	0.97	0.99	0.41	0.67	0.46	0.51	0.69	0.4	0.52	0.37	n.a.	n.a.	0.55	1.01	0.43
Ho	2.3	2.6	3.7	3	1.3	1.5	0.7	1.3	2.4	1.1	0.8	1.9	n.a.	n.a.	1.5	1.9	1.2
Tm	0.96	0.79	1.1	0.94	0.49	0.43	0.38	0.45	0.59	0.3	0.51	0.25	n.a.	n.a.	0.5	0.74	0.28
Yb	6.3	5.7	5.7	6.1	2.4	3.6	2.7	2.9	3.9	2.6	3.45	1.8	n.a.	n.a.	3.8	5.6	3.2
Lu	0.98	0.86	0.89	0.87	0.39	0.55	0.4	0.49	0.59	0.38	0.51	0.27	n.a.	n.a.	0.6	0.89	0.54
Y	55	50	40	55	23	41	29	33	39	25	36	21	20	26	38	50	31
Zr	380	384	241	377	248	303	249	273	300	231	279	159	118	178	236	579	259
Hf	9.9	9.7	9.9	9.6	6	7.7	5.95	7.2	8	5.9	7.7	3.8	n.a.	n.a.	6.7	13.6	7.4
Nb	27	31	22	32	20	21	18	24	26	22	17	18	21	21	24	21	24
Ta	2.33	2.47	2.44	2.31	1.55	1.8	1.51	1.87	2.04	1.93	1.47	1.56	n.a.	n.a.	1.88	1.96	2.17
Th	*25.4*	*30.9*	*22.4*	*22.1*	18.5	*22.5*	*15.9*	*21.1*	*25.4*	*22.2*	*17.8*	17.7	*20.2*	*19.0*	*26.3*	*20.1*	*19.2*
U	*8.67*	*8.8*	*8.91*	*9.24*	9.5	*7.51*	*6.16*	*6.64*	*8.27*	*6.75*	*6.63*	6.4	*4.69*	*5.39*	*9.47*	*3.77*	*7.39*
Sc	1.81	1.83	1.69	1.78	3.35	5.1	5.41	5	5.49	3.83	2.62	1.82	n.a.	n.a.	4.49	3.09	1.57
Cr	n.d.	3.4	n.d.	n.d.	n.d.	1.3	2.5	1	0.2	3	1.35	4.9	n.a.	n.a.	3.1	0.1	1.4
Co	0.2	0.2	0.2	0.4	1.3	0.7	1.9	2.4	1.4	2.1	1.35	0.2	n.a.	n.a.	1.2	0.5	0.7
Zn	75	72	72	69	39	62	36.5	37	47	38	43	14	n.a.	n.a.	39	55	45
Be	3.3	3.2	3.4	3.3	n.d.	2.2	1.6	2.1	2.5	2.1	2	n.d.	2	1.9	2.6	1.3	3.2
Sn	4.2	4	3.6	2.9	n.d.	2.5	2.3	1.7	2.7	2.7	2.1	n.d.	1.4	1.3	3.3	1.7	3.1
Sb	4.8	2.2	1.5	1.5	1.2	1.8	1.7	3.5	1.2	0.9	1.3	0.9	n.a.	n.a.	1.4	1.9	3.2
W	3	3.1	2.7	3.4	n.d.	4.8	2.2	1.1	1.4	1.1	1.9	n.d.	2.2	2	2.7	0.4	2.3

[1] 1.37% CaO in calcite; 1.98% CaO in other minerals
[2] 0.20% CaO in calcite; 1.11% CaO in other minerals

Table 3. *Whole-rock chemical analyses of andesites and basalts from Blackburn Hills volcanic field*

[n.a., not analyzed; n.d., not accurately detected. Major elements in weight percent; trace elements in parts per million. Analyses performed: FeO, CO_2, H_2O by wet chemistry; all other elements by wavelength dispersive X-ray florescence; Rb, Sr, Ba, Nb, Zr, and Y by X-ray florescence, except Ba and Zr values in italics, which were by instrumental neutron activation; all other trace elements by instrumental neutron activation, except Th and U values in italics, which were by delayed neutron activation. Analysts: J.W. Baker, M. Coughlin, S. Danahey, R.G. Johnson, J.S. Kane, B.S. King, D. Kobilas, J.R. Linsey, B. McCall, H.J. Rose, L.F. Schwarz, G. Sellers, J. Storey, J.E. Taggert, Jr., B. Vaugh, and J.S. Wahlberg]

	Andesite and basalt flows (Ta)																					
	Group 1											Group 2							Uncertain affinity		Low-K group	
Sample number	80ML65	80ML9f	80ML52a	80ML59a	80ML55	80ML44b	80ML1c	80ML1h	80ML15a	80ML15b	80ML6d	81ML23	80ML11b	80ML11c	81ML29b	80ML12a	80ML12b	81ML30c	81ML30d	80ML9c	80ML7a	80ML61a
Major element																						
SiO_2	46.80	51.60	52.10	52.50	55.30	55.50	55.60	58.50	58.90	59.40	59.50	56.50	57.70	58.70	59.80	60.40	61.70	61.00	53.40	55.20	56.80	60.20
Al_2O_3	16.40	17.00	17.30	16.00	16.70	18.20	16.00	16.50	16.20	16.60	16.60	16.40	16.60	16.50	16.60	16.70	16.60	15.90	16.60	18.50	16.20	15.50
Fe_2O_3	4.40	3.20	3.18	2.67	3.04	3.47	4.23	4.61	3.62	4.45	4.21	2.42	3.67	3.36	3.36	4.55	3.56	2.64	4.01	1.90	5.42	1.91
FeO	7.08	6.31	5.65	6.29	4.65	3.16	4.01	1.91	3.58	2.66	2.07	4.20	2.06	1.94	2.20	0.98	1.34	2.10	2.80	3.36	2.19	4.19
MgO	6.51	4.90	4.30	5.27	3.60	3.40	3.30	2.60	1.80	2.10	2.30	4.96	2.60	3.70	3.81	2.20	2.20	4.71	4.08	5.55	3.40	2.00
CaO	9.00	8.86	8.79	7.79	7.52	8.35	6.99	5.62	4.74	5.26	4.71	6.93	7.12	6.56	5.89	4.03	4.04	5.43	9.24	9.36	6.92	4.78
Na_2O	2.90	3.60	3.20	3.50	3.10	3.30	3.70	3.80	3.50	3.80	3.90	3.02	3.40	3.60	3.73	4.60	4.10	3.59	3.58	2.90	3.20	4.80
K_2O	0.55	1.05	1.10	1.13	1.01	1.26	1.42	1.93	2.12	2.07	1.49	1.10	2.01	1.95	1.73	2.40	2.55	1.95	1.31	0.86	0.43	1.12
TiO_2	2.39	1.89	1.63	1.84	1.54	0.98	1.71	1.15	1.22	1.30	0.97	1.04	1.00	0.95	0.89	0.92	0.92	0.66	1.25	0.63	1.50	1.28
P_2O_5	0.40	0.50	0.30	0.40	0.30	0.20	0.52	0.30	0.40	0.40	0.30	0.31	0.30	0.30	0.28	0.40	0.30	0.22	0.36	0.20	0.30	0.40
MnO	0.20	0.16	0.16	0.15	0.13	0.10	0.14	0.09	0.10	0.11	0.07	0.07	0.08	0.08	0.06	0.04	0.04	0.06	0.08	0.07	0.08	0.12
CO_2	0.17	0.01	0.32	0.15	0.13	0.19	0.33	0.02	1.12	0.02	0.02	0.44	1.03	0.51	0.02	0.14	0.21	0.01	1.20	0.10	0.09	0.05
H_2O+	2.28	0.56	1.01	1.62	1.61	0.42	0.49	0.69	1.73	1.00	1.49	2.50	0.85	0.63	0.66	1.35	2.22	0.77	0.98	0.42	1.23	2.20
H_2O-	1.70	0.65	0.57	0.67	0.35	0.73	1.24	1.59	0.35	1.17	1.42	0.37	1.43	1.03	0.65	0.65	0.73	0.78	0.99	0.95	1.94	0.96
Total	100.78	100.29	99.61	99.98	98.98	99.26	99.68	99.31	99.38	100.34	99.05	100.26	99.85	99.81	99.68	99.36	100.51	99.82	99.88	100.00	99.70	99.51
SiO_2 (anhydrous)	48.43	52.08	53.32	53.82	57.08	56.68	56.96	60.30	61.24	60.52	61.90	58.28	59.77	60.12	60.80	62.13	63.38	62.08	55.22	56.02	58.90	62.51
FeO* (total Fe)	11.35	9.2	8.65	8.84	7.57	6.39	7.96	6.22	7.34	6.76	5.85	6.58	5.5	5.06	5.31	5.21	4.65	4.56	6.63	5.08	4.96	5.22
Trace element																						
Rb	18	20	28	41	53	35	50	57	51	59	43	32	66	62	68	76	73	72	48	29	14	67
Cs	n.d.	1.2	0.5	2.2	1.8	1.2	1.1	1.2	4.1	1.35	1.1	2.3	2.05	1.5	1.9	3.2	2.5	1.7	1.3	0.6	0.2	81.1
Sr	476	538	439	469	463	493	497	400	349	422	440	620	586	757	633	696	642	541	1010	535	430	558
Ba	294	458	696	614	833	891	*854*	*1180*	1859	1370	954	957	1138	1200	1170	1733	1668	1190	889	481	789	1400
La	20	24	27	28	29	30	33	37	49	50	31	27	30	36	26	56	47	25	33	16	29	40
Ce	40	48	52	52	53	52	60	62	89	90	53	48	52	61	46	85	78.5	43	61	30	50.5	75
Nd	32	25	31	32	22	29	33	24	51	36	22	23	25	27	20	33	30	19	27	16.5	32	35
Sm	5.1	4.75	4.9	5	5.6	4	5.5	4.5	6.5	7.4	5.9	4	3.9	3.95	3.7	5.55	5.65	3.3	4.9	2.45	4.6	6.4
Eu	1.67	1.63	1.46	1.55	1.45	1.22	1.62	1.38	1.89	1.96	1.22	1.12	1.09	1.08	1.05	1.41	1.27	0.88	1.39	0.83	1.44	1.65
Gd	5.3	5.6	5	5.9	6.1	5.3	6.5	5.6	6.4	7.8	6.00	2.3	4.3	4.6	n.d.	5	n.d.	2.7	3.1	2.45	5.3	7.2
Tb	0.52	0.54	0.63	0.58	0.52	0.44	0.64	0.53	0.64	0.72	0.58	0.42	0.34	0.305	0.38	0.42	0.33	0.29	0.46	0.3	0.55	7.1
Tm	0.47	0.41	0.39	0.7	0.5	0.37	0.55	0.42	0.49	0.58	0.38	0.09	0.26	0.28	0.16	0.25	0.23	0.1	0.26	0.26	0.45	0.60
Yb	2.8	2.7	2.8	2.9	2.5	2.2	3.15	2.65	3	3.2	2.5	1.1	1.25	1.2	1	1.25	1	0.8	1.4	1.5	2.8	3.4
Lu	0.46	0.48	0.54	0.42	0.39	0.32	0.5	0.4	0.47	0.49	0.41	0.15	0.195	0.16	0.14	0.17	0.15	0.14	0.17	0.22	0.41	0.52
Y	28.	25	39	26	25	21	n.a.	n.a.	33	35	28	14	17	14	16	16	14	13	15	13	27	30
Zr	181	200	176	207	190	169	*216*	*215*	266	267	192	144	177	170	152	198	198	133	163	112	179	290
Hf	3.8	4.1	4	4.3	4.4	3.5	4.4	4.6	6	6	4.7	3.2	3.7	3.7	3.2	4.4	4.1	2.9	3.3	2.4	4.1	6.6
Nb	15	19	11	20	16	11	n.a.	n.a.	18	19	9	12	18	19	12	24	23	9	16	7	10	23
Ta	1.00	1.45	0.91	1.24	1.18	0.70	1.10	1.13	1.19	1.28	0.96	0.83	1.11	1.09	0.81	1.53	1.45	0.65	1.01	0.48	0.9	1.72
Th	1.80	2.85	4.90	6.00	7.30	*6.12*	7.20	10.25	10.5	10.75	8.30	6.1	8.65	9.75	7	13.9	13.3	8.1	7.1	3.2	5.3	11.4
U	2.1	1	1.5	2.3	4.1	*2.21*	2.7	3.45	2.7	4.2	3.5	1.9	3.05	3.1	2.3	5.05	4.3	2.8	1.8	1.05	1.8	4.5
Sc	27	24.7	24.3	22.5	20.7	16.8	20.9	14.95	15.1	15.4	13.6	15.4	14.2	11.6	12	9.84	9.45	11.8	17.7	15.75	20.2	14.7
Cr	96.3	75.7	82.2	53.8	45.1	55.9	25.5	10.4	2.5	3.5	3.7	182	101	114	124	82.2	80.1	207	246	198	19.4	5.0
Co	40.1	29.8	28.8	29.1	24.1	19.8	21.5	19.3	12.5	13	18	23.8	15.9	19.4	18.3	15.4	13.3	21	25.9	24.2	20.4	12.4
Zn	84	81	81	73	75	55	75	61	80	92	79	67	63.5	55	60	64	94.5	52	83	52	64	67
Sb	0.6	1.2	1.9	1.2	3.4	1	0.8	1.3	2.8	1.3	1.05	1.91	1.5	2.05	0.3	1.1	0.95	0.4	0.4	1.05	n.d.	3.08

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1992

For sale by U.S. Geological Survey, Alaska Distribution Section, New Federal Bldg., Box 12, 101 Twelfth Avenue, Fairbanks, AK 99701, and U.S. Geological Survey, Map Distribution, Box 25286, Federal Center, Denver, CO 80225