GEOLOGIC REPORT 60

GEOLOGY OF THE CLEARWATER MOUNTAINS, SOUTH·CENTRAL ALASKA

By
Thomas E. Smith

Description of geologic structure, stratigraphy, and petrology of a zonal metamorphic terrane. Prepared in cooperation with the U.S. Geological Survey, with a chapter on the economic geology of the area by Thomas K. Bundtzen, of the Alaska Division of Geological and Geophysical Surveys.

COLLEGE, ALASKA
1981

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Cover photo: *View south toward headwaters of Eldorado Creek. Ditches in foreground brought water for hydraulic placer-mining operations in Lower Eldorado Creek. Photo by T.E. Smith.*

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GEOLOGY OF THE CLEARWATER MOUNTAINS, SOUTH-CENTRAL ALASKA

By Thomas E. Smith[1]

ABSTRACT

Metamorphosed bedrock forming the western Clearwater Mountains comprises two main rock sequences: 1) a thick section of low-grade metavolcanic rocks of Late Triassic age and 2) an overlying pelitic succession of pre-Upper Jurassic rocks that vary in metamorphic grade from argillite to layered gneiss. Combined, the sequences have an estimated thickness of about 25,000 feet and are exposed in a broad northeasterly trending belt extending about 70 miles along the south flank of the Alaska Range. The pelitic sediments were intruded by alkali gabbro in Late Jurassic time and by a magma series of intermediate composition during Cretaceous and early Tertiary time.

The north-dipping metavolcanic sequence consists mainly of thickly bedded tholeiitic basalts and basaltic andesites. Subordinate volcaniclastic, pelitic, and calcareous sediments are interstatified throughout the flow sequence, but are most abundant near the upper part of the section.

Folded pelitic strata north of the volcanic belt consist primarily of dark carbonaceous argillite, siltstone, and lighter graywacke, with minor layers of tuff and intraformational conglomerate. The pelitic rocks form a zonational metamorphic belt of the Barrovian facies series that grades northwestward from prehnite- or pumpellyite-bearing sedimentary rock near Windy Creek to sillimanite-bearing gneisses and schists north of Valdez Creek. A steep thermal and dynamic gradient during metamorphism-now recorded by index mineral assemblages and rotational microtextures such as rolled garnets and intrafolial folds-is attributed to penetrative shearing and thrusting, which brings the highest pressure-temperature assemblages on the north into the same tectonic level as lower grade rocks to the south.

Numerous plutonic and hypabyssal bodies of intermediate composition were emplaced during the regional metamorphic event. Most intrusives show secondary minerals and textures characteristic of the metamorphic zone in which they occur, and several have acted as hosts for gold-quartz-carbonate vein deposits.

Deformation of the region has progressed from 1) downwarp with coeval volcanism and sedimentation (Triassic-Jurassic) through 2) deep-seated overthrusting and strike-slip dislocation accompanied by recrystallization (Cretaceous) to 3) high-angle, brittle-fracture style of faulting characteristic of shallow environments (Tertiary). The high-angle faults of greatest continuity trend generally east-west or east-northeast, subparallel to major rock units.

The Valdez Creek mining camp, in the west-central part of the study area, historically has been a placer gold mining region. Gold production has been largely confined to bedrock depressions in abandoned Pleistocene outwash channels within the lower Valdez Creek drainage and in alluvial deposits of Holocene age. Bench gravels near Valdez Creek include at least 35 million cubic yards of potentially auriferous material. Two centers of structurally controlled auriferous sulfide-quartz-carbonate veins intrude altered quartz-diorite at Timberline and Gold Hill and are probably the source of the gold placers in the Valdez Creek drainage. Stream-sediment and bedrock geochemical analyses indicate a close association of gold and arsenic in the Timberline and Gold Hill mineralized areas. Anomalous mercury values are found between the two gold centers, which implies a crude hypogene zonation outward from the auriferous centers.

The well-known Denali stratiform copper-silver deposits are found along a zone of sedimentary-volcanic rock intercalation near the stratigraphic top of a thick metamorphosed basalt-andesite sequence in the Amphitheatre Group. Weak copper mineralization is common within the Amphitheatre Group and suggests a high copper content from Triassic rocks in the study area.

INTRODUCTION

LOCATION AND ACCESS

The Clearwater Mountains area considered in this report encompasses about 330 square miles of south-central Alaska and includes the Healy A-I Quadrangle and the southern part of the Healy B-1 Quadrangle. The region is located about 150 miles northeast of Anchorage, about midway between the towns of Paxson and Cantwell, Alaska; it can be reached via the Denali Highway, which crosses the southern part of the Healy A-I Quadrangle (fig. 1). Several unimproved airstrips and small lakes within the report area are accessible to light aircraft equipped with large tires or floats. Unimproved roads suitable for all-terrane vehicles traverse the main valleys of Valdez and Windy Creeks.

PURPOSE AND SCOPE OF REPORT

Geological investigations in the Clearwater Mountains were begun in 1968 while the author was employed by

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the U.S. Geological Survey. Initial objectives of the project were mainly economic in orientation; the region includes the Valdez Creek mining district, a gold placer belt that has been mined intermittently since its discovery in 1903 and which by 1936 had yielded about 36,000 ounces of gold. Interest in the area has been renewed with the discovery of important copper lodes, the 'Denali' deposits, near the headwaters of Windy Creek. As a by-product of the author's mineral resource studies, now released as separate reports of the USGS (Smith, 1970a-c), a considerable body of basic geological information has been obtained. Geologic mapping efforts during the investigation were expanded beyond initial objectives to provide a type section across the major lithologic belts that extend for many miles through the Clearwater and Talkeetna Mountains. It is the intent of this report to present general descriptive and interpretive aspects of bedrock geology in the Clearwater Mountains and to provide a brief and generalized discussion of the surficial geology. T.K. Bundtzen has provided an economic geology section for the report-derived from previous investigations of various government and industry geologists and published work by the author.

METHODS OF STUDY

Geologic mapping was done directly on topographic base maps enlarged to a scale of 1: 31,680. All stations were located by use of an aneroid altimeter, by resection with Brunton compass, or by proximity to readily locatable topographic features such as peaks or stream intersections. A cabin at the old mining town of Denali was used as a base camp through the courtesy of L.B. Kercher. Access to field camps was by weasel (a tracked vehicle), by light airplane, or by backpacking. Both helicopter and fixed-wing aircraft were used in aerial reconnaissance and geochemical sampling. Mapping was further facilitated by Kodachrome slides and aerial photographs with approximate scales of 1: 10,000 and 1:40,000. Total field work required 4 months in 1968, 4-1/2 months in 1969, and 3 weeks in 1971.

Laboratory studies of rock samples took about 18 months during the winters of 1968-69 and 1969-70. Studies of the rocks were augmented by examination of over 1,000 thin sections and by numerous chemical and spectrographic analyses. Universal stage methods were used in determining many of the mineralogical parameters. Potassium-argon isotope age determinations were made on pure mineral separates prepared by standard techniques.

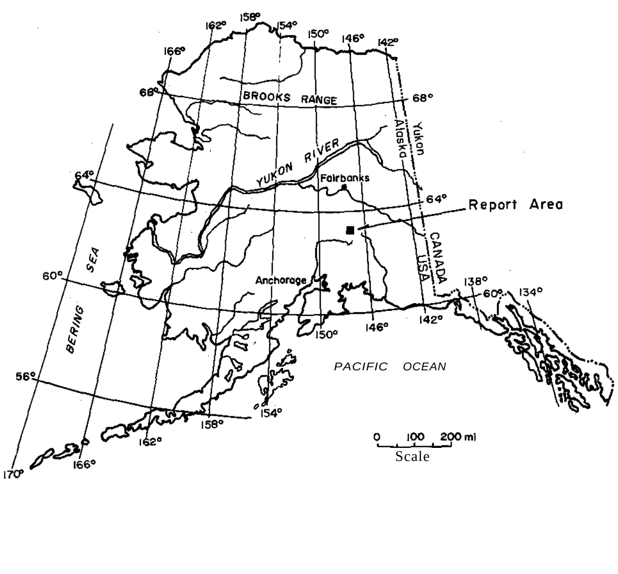

Figure 1. Index map of Alaska showing location of report area.

ACKNOWLEDGMENTS

The field and laboratory investigations discussed in this report and the results reported were greatly aided by the cooperation of numerous individuals and organizations. The investigation was undertaken at the suggestion of C.C. Hawley, then of the USGS, and George Gryc, former Chief, Branch of Alaska Mineral Re· sources, USGS. This organization sponsored earlier phases of the project through part-time employment, use of government vehicles, equipment, and charter aircraft, and by making available a variety of laboratory services and professional expertise.

A.L. Clark and S.H.B. Clark, C.C. Hawley, O.J. Ferrians, and Prof. D.B. Slemmons discussed various aspects of the project with the author in the field during 1968-69. During office preparation of the report the author benefitted from the interest, advice, and reviews of Profs. D.B. Slemmons, M.J. Hibbard, E.R. Larson, F.L. Humphrey, and A.L. Payne, all of the University of Nevada. The late C.E. Fritts, Gordon Herreid, Thomas K. Bundtzen, and Cheri Daniels (DGGS), and Thomas C. Mowatt (U.S. Bureau of Mines) reviewed the manuscript; their efforts in calling attention to errors of analysis and obscurities in the prose is sincerely appreciated. L.C. (Ann) Schell and Cheri Daniels drafted numerous figures and plates for the report. Bundtzen's efforts in compiling the economic geology section are gratefully acknowledged.

J.H. Schilling and J.B. Murphy generously offered the services of the Nevada Bureau of Mines in separating minerals and in other special preparations. Potassium-argon determinations on the mineral separates were made through the courtesy of M.A. Lanphere, Isotope Geology Branch, USGS; Prof. N.J. Silberling of Stanford University examined fossils collected by the writer and reexamined older collections from the area. D.M. Hopkins, Reuben Kachadoorian, and D.R. Nichols (USGS) allowed access to unpublished material on the surficial

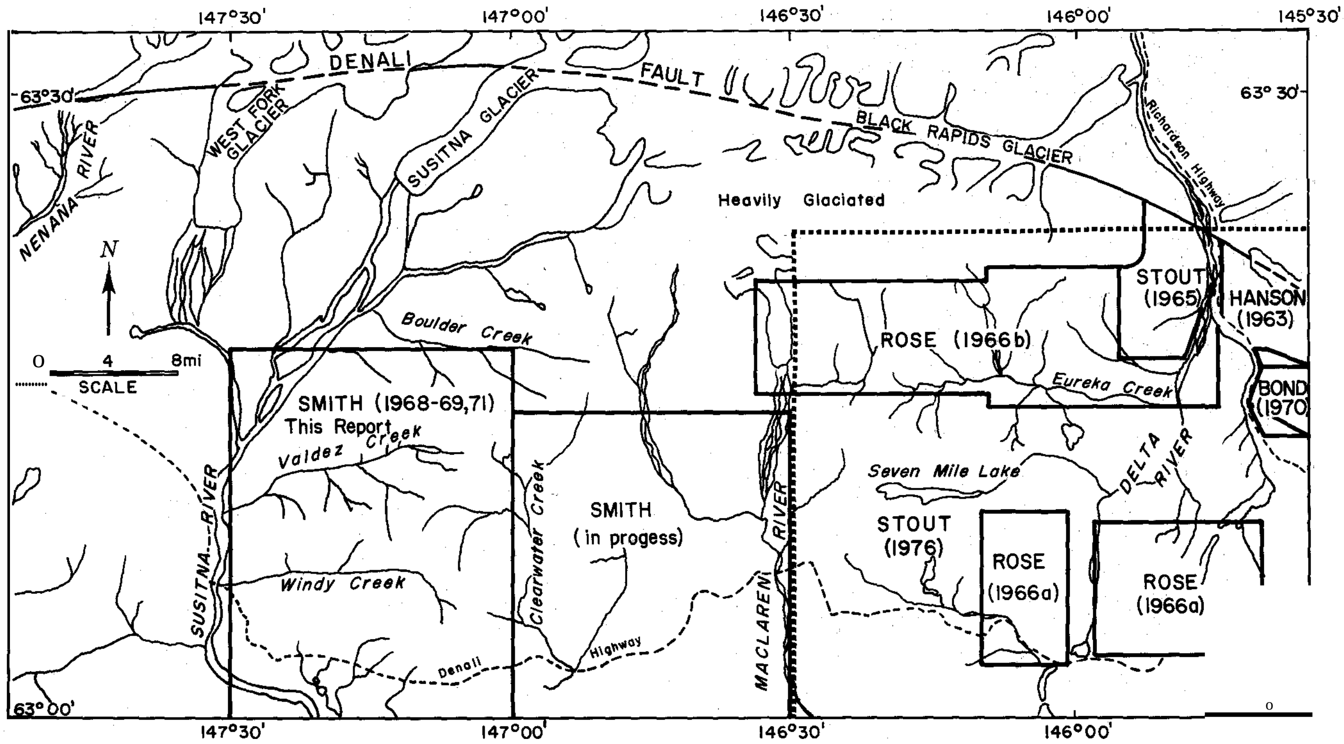

Figure 2. Index map of Clearwater Mountains region showing areas of recent geologic mapping. Early reconnaissance work of Moffit (1912) and Chapin (1918) covers entire region.

geology in the Healy A-1 and Mt. Hayes A-6 Quadrangles.

To individual claim holders in the Clearwater Mountains, especially L.B. Kercher, M.J. Wall, the late Earl Bott, Lyle Bott, M. Ringstad, C.S. Miller, and J. Barbeau, the author expresses gratitude for permission to publish data from their properties. The opportunity for discussion with Lawrence Coffield, who has explored and mined in the Clearwater Mountains since earlier USGS studies there in 1930 (Ross, 1933), is acknowedged with particular pleasure. Mr. and Mrs. D.E. Thompson of Susitna Lodge extended many favors to the author and his assistants as well as providing expert air support for the project.

The competent work of S.R. Bruff, S.W. Ivosevic and G.L. Kline, geologic field assistants in 1968, 1969, and 1971, respectively, is sincerely appreciated.

PREVIOUS WORK

The geologic mapping investigations reported here were stimulated to a great extent by the previous efforts of other geologists. Until recently, most of the knowledge of bedrock geology and mineral occurrences in the Clearwater Mountains was based on the work of Moffit (1912), Chapin (1918), Ross (1933), Tuck (1938), Capps (1940), Kaufman (1964), and Glavinovich (1967). StUdies of surficial deposits along the route of the Denali Highway, which crosses the present report area, were conducted by Kachadoorian, Hopkins, and Nichols (1954 and unpublished); only a generalized summary of this work is included here. Stevens (1971) and Seraphim (1975) completed detailed studies of the 'Denali' stratiform copper deposits. Extrapolation of major geologic elements outside of the present study area was facilitated by the recent detailed work (fig. 2) of Rose (1965, 1966a,b), Rose and Saunders (1965), Bond (1965, 1970), Hanson (1963), Stout (1965, 1976), and by the compilation of Capps (1940).

The studies summarized in previous reports have been invaluable to the present investigation, particularly in formulating initial objectives and regional concepts. Differences of interpretation existing between this and earlier reconnaissance work in the area reflect only an advancement of knowledge gained from detailed studies extending over several field seasons, an advantage not enjoyed by previous investigators.

OUTLINE OF GEOLOGY

Bedrock underlying the Clearwater Mountains comprises two primary rock sequences: 1) a thick succession of low-grade metavolcanic rocks and 2) an overlying pelitic sequence zonational from prehnite- and pumpellyite-bearing argillite in the south to sillimanite-bearing rocks on the ridge north of Valdez Creek. The latter sequence is subdivided into three metamorphic units on the generalized geologic map (fig. 3). Stratigraphic relationships between the sequences are shown by a composite geologic column in figure 4.

METAVOLCANIC ROCKS

The southern part of the Healy A-I Quadrangle is underlain by metavolcanic rocks of the Amphitheatre Group (TRab) consisting predominantly of dark-gray or greenish metabasalts and basaltic meta-andesites. These rocks crop out in a broad, northeasterly trending belt that extends east and west for many miles beyond the area of the report (Moffit, 1912; Moffit and Pogue, 1915; Chapin, 1918; and Rose, 1966a,b). Dips within this unit are generally northerly and average about 55^0.

In addition to the bedded flows, subordinate members of flow breccia, volcaniclastic debris, carbonaceous argillite, and discontinuous limestone lenses are locally present. Amygdaloidal flows are common throughout the volcanic succession. Individual amygdule fillings are most commonly epidote, quartz, chlorite, prehnite-pumpellyite, or calcite. In rare local occurrences, native copper or bornite coexists with the epidote.

Within the volcanic unit just south of Windy Creek, a prominent shear system trending N. 50^0 E. has produced zones of intensely brecciated and altered rock up to 100 feet wide. Veinlets of quartz, calcite, hematite, and bornite are pervasive in the shear zones, and secondary limonitic fracture fillings or malachite staining is locally abundant along weathered veinlets.

Fossils collected from a limestone lens near the top of this unit are mid-Late Triassic in age (Moffit, 1912; N.J. Silberling, written comm., 1969); thus the thick section of lavas lying stratigraphically beneath is assigned to the Triassic System.

PELITIC ROCKS

Conformably overlying the metavolcanic unit and bordering it on the north is a thick sequence of metamorphosed pelitic rocks (fig. 3) that grade from chlorite- and prehnite-bearing argillite and graywacke just north of Windy Creek through phyllite and biotite schist near Valdez Creek to garnetiferous, sillimanite-bearing schist and gneiss near the Susitna River (pJa, Kp, Ks, Kgn). These rocks are differentiated into separate map units on the basis of metamorphic grade. The argillites and metagraywackes include minor tuffaceous strata, limestone lenses, and conglomerates.

The argillite (pJa) is composed mainly of quartz, sericite, and biotite, with a dominant gray to black color being imparted by carbonaceous material in the matrix. Graded bedding, festooned cross-bedding, and load-cast structures are prevalent in this unit. Rhythmic bedding defined by 2- to 6-inch graded strata is locally present. Typically, very fine grained argillite grades vertically or laterally into fine- or medium-grained greenish metagraywacke. Numerous beds and lenses of the more persistent graywacke beds are shown with a dense stippled pattern on figure 3. The argillite unit grades into more intensely metamorphosed phyllites and spotted phyllites (Kp) near Valdez Creek. Northward from this contact is a prograde metamorphic assemblage of the Barrovian Series. Pelitic rocks near Valdez Creek are spotted with clots of poikiloblastic biotite, retain relict sedimentary structures, and contain abundant chlorite. North of Valdez Creek the phyllites grade into fine-grained biotite schists (Ks), which similarly grade northward into coarser grained biotite-garnet schists. A rehealed thrust fault marks a transition into sillimanite-muscovite gneisses and schists (Kgn). A large sill-like body of foliated quartz diorite occupies the center of the highest grade terrane. This body was probably emplaced between kinematic events during the regional metamorphism.

INTRUSIVE ROCKS

The northeasterly trending belt of phyllite, schist, and gneiss is truncated in the eastern part of the area by a large slightly foliated granodiorite pluton of Late Cretaceous or early Tertiary age (Smith and Lanphere, 1971, p. 17). Compositionally this rock is similar to the sill-like body farther west, but is much less foliated or gneissose. Margins of the pluton, where well exposed, are mildly foliated with attitudes closely paralleling those in adjoining schists and gneisses. Locally it is discordantly intrusive into the host rocks. Xenoliths of the metamorphics are abundant near these discordant contacts; elsewhere it is rare to find inclusions near the margin.

Several smaller plutons ranging in age and composition from alkali gabbro (Late Jurassic) to tonalite (Cretaceous?) have intruded rocks of the pelitic sequence. Hornfelsed contact zones and pyritic halos are developed where these stocks intrude lower grade metamorphic rocks, but seem not to be present where higher grade metamorphites are intruded.

STRUCTURE

The dominant structural grain in the western Clearwater Mountains strikes about N. 75^0 E. Attitudes of flows in the metavolcanic succession show dips prevailing to the northwest except in the southeasternmost part of the area. A consistent northwesterly dip of foliation is also present in the schists and gneisses north of Valdez Creek. In contrast, the area between Valdez and Windy Creeks is characterized by gentle folding and local overturning of argillite strata; along certain horizons, interbed slippage and adjustments during folding have transformed the argillites into foliated, fissile slates. Several folds, whose axes trend N. 70^0-80^0 E. and which are of regional extent, are decipherable in the pelitic strata south of Valdez Creek.

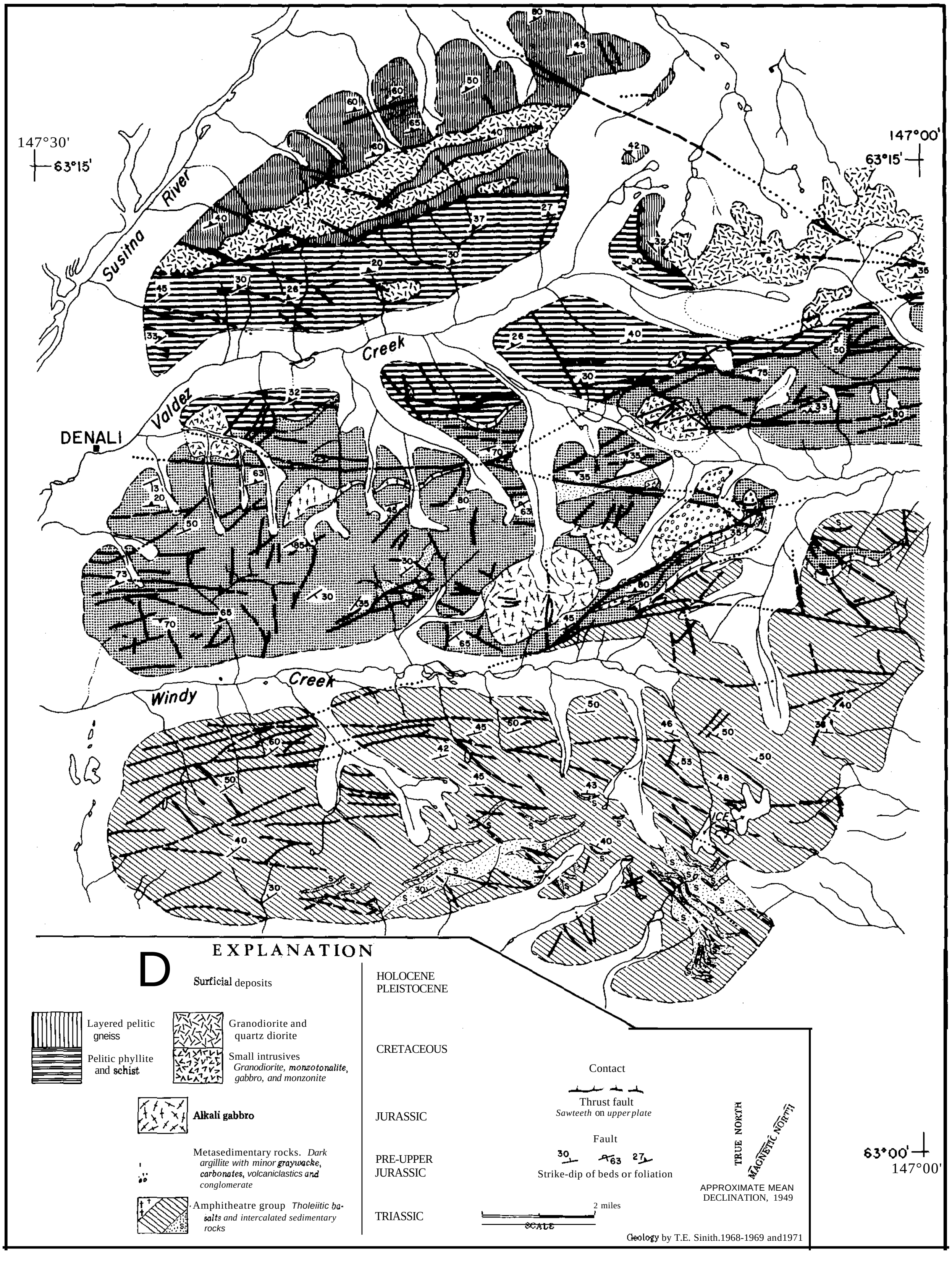

Figure 3. Generalized geologic map of western Clearwater Mountains.

Numerous high-angle faults cut older structural elements. Both strike-slip and vertical movements on these faults appear to have been recurrent throughout the Tertiary Period, though displacements are generally less than a few hundred feet. Several of the shear zones and faults are traceable for several miles. Structural intersections along the throughgoing east-west-trending fault south of Valdez Creek and the shear zone crossing Windy Creek (fig. 3) have been important in localizing gold lode deposits in the area. With the exception of penetrative shearing associated with metamorphism, thrust faults in this region are confined to local interbed slippages and within disharmonic folds. Few of the mapped thrusts have appreciable continuity, and their displacements are measurable in tens of feet.

SYSTEMATIC DESCRIPTIVE GEOLOGY

AMPHITHEATRE GROUP

INTRODUCTION

Metavolcanic rocks and interbedded sediments, tuffs, and flow breccias are exposed in a continuous mountain belt extending from Paxson Lake near the Richardson Highway (long. 145^0 15' W.) westward through the Amphitheatre' and Clearwater Mountains to about long. 148^0 W., near the confluence of Watana Creek and the Susitna River-a distance of over 85 miles. Within the present project area and to the east, the volcanic sequence underlies a craggy, N. 80^0 E.-trending range characterized by sharp narrow ridges, glacial valleys, and steeply walled cirques (fig. 5). Exposure width varies from about 6 miles in the area of plate 1 to over 15 miles near the Maclaren River to the east.

The name "Amphitheatre basalt" was first applied to exposures of the metavolcanic sequence on Paxson Mountain and nearby hills (Rose and Saunders, 1965, p. 4). The usage was later refined to "Amphitheatre Formation" which included subunits of "basalt and andesite," "silicic tuff and tuffaceous sediments," "diabase and tuffaceous sediments," and "andesite agglomerate" as mapped in the vicinity of Sugarloaf Mountain in the Amphitheatre Mountains (Rose, 1966a, p. 1, 2). In a subsequent report, Rose (1966b, p. 8) reverted to "Amphitheatre basalt" which included flows, layered tuff, and agglomerate. Mapping by the present author east of the Susitna River has demonstrated the impracticability of defining discrete members or subunits of unique character, except on a very local basis. Yet there appear to be recognizable changes of character across the sequence in the Clearwater Mountains as described in this report; these give promise of subdivision into formations as the unit is better understood. For these reasons, the author favors abandonment of lithologic designation "basalt" and formalization of the name Amphitheatre Group as does Stout (1976), who subdivided the group into three formations east of the

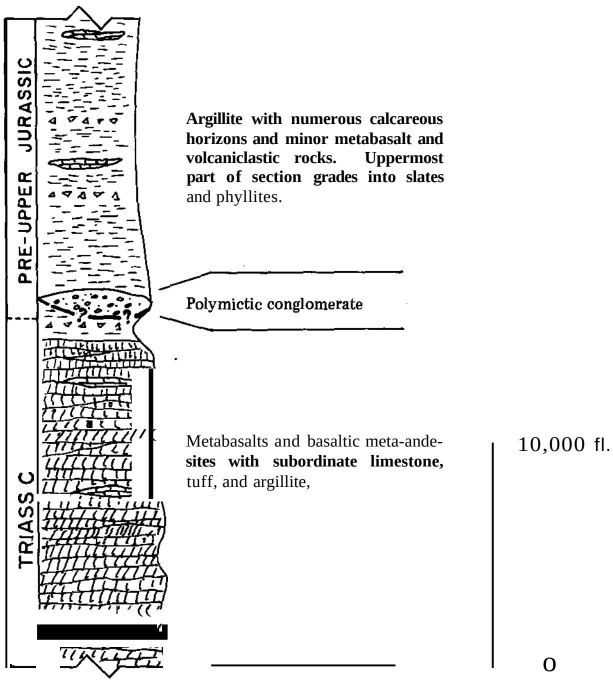

Figure 4. Composite columnar section for Clearwater Mountains rocks.

study area. Its type locality is herein designated as Paxson Mountain and nearby hills, at the eastern end of the Amphitheatre Mountains, as initially described by Rose and Saunders (1965, p. 4). Within the present map area, the group is SUbdivided into separate lithologies including tholeiitic metavolcanic rocks (TRab), limestone (TRal), argillite strata (TRaa), tuffaceous strata (TRat), and undifferentiated sedimentary strata (TRas).

The lowermost part of this unit is not exposed in the area of plate 1 and hence its total thickness is unknown. However, a cross section constructed northwestward from Nowater Creek (pI. 1) indicates that there may be over 15,000 feet of successive flows exposed between the Denali Highway and Windy Creek, although it is possible that part of this section may be repeated by the numerous high-angle faults which trend east-west through the unit. West of the map area, Moffit and Pogue (1915) estimated the thickness of the volcanic unit to be about 3,500 feet. An even greater thickness has been suggested for the lavas between Butte and Watana Creeks, still farther to the west of plate 1 (Chapin, 1918, p. 27).

On the basis of reconnaissance mapping, previous workers have disagreed as to the nature of the contact between the metavolcanic unit and the pelitic metasedimentary rocks bordering it on the north. Moffit (1912, p. 30) noted that the mountains south of Pass Creek (pI. 1) were "made up in part of lava flows and in part of sedimentary deposits which include a number of small limestone beds containing Upper Triassic fossils," but that the exact nature of the contact relations between the formations was in doubt. He tentatively concluded that the metasedimentary rocks were younger than the volcanics. Ross (1933) mapped an area on the west side of Pass Creek as "tuffaceous and related strata" and correlated the rocks with conglomerates and argillites south of Roosevelt Creek. This confusion of assignment for rocks in the upper part of the volcanic sequence was apparently caused by the complexity of contact and intrusive relations on the ridge west of Pass Creek.

Detailed mapping of the entire area south and west of Pass Creek during the present investigation suggests that the volcanic unit may be gradational into the metasedimentary unit above but that the contact has been faulted in many localities, including the area of this report. The uppermost flows of the sequence alternate with numerous interbeds of thinly stratified mudstone and siltstone, now metamorphosed to argillite and greenish water-laid tuff. At certain horizons in the upper part of the section, discontinuous limestone beds and lenses are present, and in the extreme western part of plate 1 they have yielded diagnostic index fossils.

A reexamination of Moffit's collection (USGS Mesozoic Loc. 6570) by N.J. Silberling, U.S. Geological Survey, has verified the identity of the ammonite *Tropites* sp. and the pelecypod *Halobia* cf. H. *"superba,"* indicating a late Karnian or mid-Late Triassic age for the upper part of the metavolcanic sequerrce (written comm., 1969). Previous workers have noted the resemblance and similarity of stratigraphic position between this unit and the Nikolai Greenstone of the Chitina Valley (Martin, 1926; Moffit, 1912), now considered to be late Middle or early Late Triassic (MacKevett, 1965). On these bases, the Amphitheatre Group is tentatively assigned to the Middle(?) and Upper Triassic Series.

Figure 5. Metavolcanic terrane (TRab); surface morphology modified by glacial and periglacial processes. View southeast across large tributary entering Windy Creek from south.

METAVOLCANIC ROCKS (TRab)

In the area of plate 1, the flow sequence generally crops out as grayish brown, craggy ridges and cliffs separated by U-shaped valleys and flanked by coalescing talus aprons or rock glaciers. The lower ridges and noses have typically been rounded and subdued by Pleistocene valley glaciation (fig. 5). Remnant morainal debris is common at elevations below 4,500 feet and, on the south side of the range, forms a continuous mantle over bedrock below the 3,500-foot elevation. Elsewhere in the range, extensive glacial deposits are confined to the valley floors or lowermost ridges and noses, and are usually brush covered.

The metavolcanic rocks comprise a thickly bedded sequence of grayish-olive or grayish-red metabasalts and basaltic andesites that dip generally northward. The thickness of individual flows varies from 2 to 50 feet, although locally very thin flows are present.

Bedding surfaces between flows are usually indistinct and, in most exposures, are more apparent from a distance than at the outcrop. In some parts of the section, however, the bedding is marked by the alternation of thin (2 feet) reddish flows with thick (10 feet) grayish-olive flows. Columnar jointing occurs in many of the thicker flows and, where present, often persists laterally for several hundred feet. Pillowed horizons are common near the center of the unit.

The most abundant rock type in the unit is grayish-olive metabasalt or basaltic andesite with a typically felsitic or porphyro-aphanitic texture in hand specimen. Similar-appearing flows whose grayish-olive groundmass is mottled with grayish-red patches are also abundant throughout the section; both types contain numerous amygdaloidal members interlayered with the most common massive or porphyritic flows. Phenocrysts are usually pale-green, albitized plagioclase or, less commonly, greenish-black chloritic aggregates, pseudomorphic after plagioclase or clinopyroxene. Plagioclase phenocrysts contain abundant inclusions of secondary epidote or chlorite and are rarely more than 4 mm long. Glomeroporphyritic clots of such plagioclase occur' locally in the greenish flows of the sequence (fig. 6).

In thin section, the volcanics consist primarily of plagioclase, clinopyroxene, and iron-titanium oxides or hematite, characteristically intergrown in a subophitic or intergranular fabric. In the finer grained rocks, groundmass minerals average about 0.1 to 0.2 mm in size with phenocrysts to 4 or 5 mm. The medium-grained equivalents show average grain sizes of about 1.5 to 2.0 mm, also dominantly in intergranular relation. Chlorite, chloritic phyllosilicates, epidote, clinozoisite, magnetite, hematite, carbonate, apatite, prehnite, pumpellyite, quartz, sericite, and albite are present in varying proportions as a result of the regional metamorphism and/or local superimposed hydrothermal alteration. All except sericite, apatite, and magnetite occur both in the groundmass and as amygdule fillings.

Plagioclase typically constitutes 50 to 60 percent of the rocks in both aphanitic and porphyritic varieties. Pronounced zoning is relatively rare in the plagioclases as a result of extensive albitization, although some of the larger crystals show a smooth or slightly oscillatory normal zoning from core to rim and often exhibit a slight dispersion. In a few specimens, these plagioclases have compositions in the range An_{40-57}. This is assumed to be representative of the original rocks before metamorphism and establishes their identity as basalts or basaltic andesites. A universal stage determination of one fresh-appearing but unzoned phenocryst (sample 68-ASb-177) showed it to be a slightly disordered albite of about composition An_5 (curves used from Slemmons, 1962). Cumulophyric groups of plagioclase phenocrysts are common in some horizons, either as monomineralic radial clusters (fig. 6) or intergrown with larger clinopyroxenes. Albite, carlsbad, and transverse twinning are ubiquitous in both microlithic and phenocrystic varieties of feldspar. In most sections examined, plagioclases are partially converted to secondary epidote, chlorite, sericite, clinozoisite, and minor clay minerals. It is rare to find crystals without abundant inclusions of one or more secondary minerals.

Colorless clinopyroxenes are the second most abundant minerals in the metavolcanic rocks, composing about 20 to 40 percent of the rock. They are present mainly as equidimensional crystals in intergranular or subophitic relation to the plagioclase laths. Larger subhedral phenocrysts are present locally as well, either as isolated individuals or in glomeroporphyritic aggregates with plagioclase phenocrysts. Subcalcic augite ($2V = 35^\circ$-40°) is the most abundant pyroxene; however, both pigeonite and diopsidic augite occur locally in subordinate quantities. Secondary metamorphic and alteration processes have had a less pronounced effect on the clinopyroxenes than on plagioclases, although to some degree they are replaced by magnetite, leucoxene,

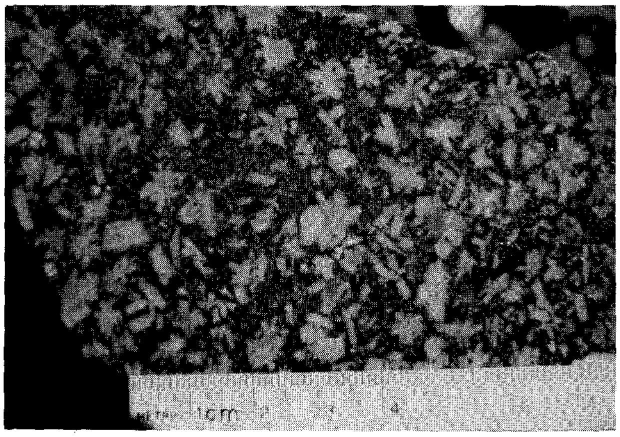

Figure 6. Glomeroporphyritic aggregates of albitized plagioclase in metabasalt (TRab, sample 68-ASb-1554).

or hematite, and less commonly by chloritic aggregates.

Iron or titanium oxides and their secondary products occur throughout all the volcanics in amounts of 5 to 10 percent. The titanium minerals are largely altered to murky-white, opaque leucoxene materials which, in some specimens, compose 60 percent of the total opaque constituents. Magnetite grains are generally subhedral and equidimensional, although locally they are skeletal and less commonly fringed with hematite. In the grayish-red flows, the leucoxene minerals are finely intergrown with red hematite. Leucoxene is often concentrated along borders of chlorite-filled amygdules, separated from the chlorite by narrow selvages of epidote. In another typical occurrence, the leucoxene-rich border is separated from a calcite-filled amygdule by linings of deep-green chlorite.

In addition to the more abundant grayish-olive volcanics, numerous relatively thin (2 to 8 feet) flows of grayish-red rocks occur throughout the metavolcanic sequence. They have nearly identical compositions, mineralogy, and textural variation as the greenish flows, except that opaque minerals are in large part converted to fine-grained red hematite. Similar thin-bedded hematitic flows have been described by Surdam (1968) in the Karmutsen Group of British Columbia. Most reddish flows in the present study area, like those described by Surdam, are amygdaloidal. Hematitic staining commonly rims the iron-titanium minerals or is disseminated throughout the secondary titanium minerals. Surdam's (1968) proposed mechanism for the hematite formation, a syngenetic devolatilization effect during cooling of the flows, is probably applicable to these Alaskan rocks as well. Hematitic coloration does not transect flow boundaries as would be expected if it resulted from metamorphism. In accordance with Surdam's interpretation, the hematite appears to represent a reaction between iron-titanium oxides and hot gases associated with a particular eruption enriched in oxygen through fractionation or contamination.

Many of the grayish-olive flows and most of the grayish-red flows contain abundant amygdules that constitute up to about 20 percent of the rock by volume. Most amygdules vary between 2 and 30 mm in diameter, though locally they attain several centimeters in diameter. Except for obviously deformed rocks along shear zones, most amygdules are rounded or irregular with little evidence of flattening or distortion. The most abundant minerals filling the amygdules are quartz, calcite, chlorite, prehnite, pumpellyite, epidote, and intergrowths of quartz-albite or chlorite-hematite. Clinozoisite is locally present as an amygdule mineral. Prehnite is often associated with deep-green pumpellyite. Common assemblages in the amygdules are:

- Quartz-albite-pumpellyite
- Quartz-chlorite-calcite
- Quartz-prehnite-epidote-pumpellyite
- Chlorite with hematite veinlets.

Green and yellow chlorite often form linings on amygdule walls with internal fillings of calcite or quartz. Pumpellyite locally projects into such quartz fillings in radial bundles (fig. 7).

Near fault zones or in sheared areas, the metavolcanics are characteristically transformed to dusky-brown equivalents penetrated by pervasive nonsystematic fractures, whose fresh surfaces are slickensided and coated with iridescent dark limonitic materials. Hairlike quartz veinlets and quartz-carbonate veinlets are also pervasive in the altered areas. Less prevalent but still abundant in the shear zones are light-olive rocks strongly tinted by high percentages of epidote and chlorite. Most of the groundmass of these rocks, except for relict pyroxenes and iron oxide, is replaced by yellow-green epidote. Quartz-carbonate veins pervasively cut these rocks also; locally the veins contain selvages of bornite and secondary copper minerals along the interior of the veinlets. Joint and fracture surfaces near the shear zones are often coated with limonite, milky quartz, and epidote. In and near these altered areas, amygdules often contain coexisting epidote and bornite or epidote and native copper.

Where pyritization has accompanied hypogene alteration of the metavolcanics, light-brown and dark-yellowish-orange limonite[2] of supergene origin forms broad stained areas and float runs which contrast strongly with the darker host rocks. Pervasive hypogene silicification commonly accompanies the pyritic alteration in these rocks.

ROCKS OF SUBORDINATE OCCURRENCE WITHIN AMPHITHEATRE GROUP (TRaa, TRal, TRat, TRas)

The volcanic unit includes, at various horizons, thin beds or sequences of argillite, tuff, limestone, and flow breccia. The thickest members are interbedded with flow rocks in the lower part of the metavolcanic section, or occur at the very top of the sequence. A few diorite and gabbro dikes and sills have intruded the lowermost sedimentary lenses in the Raft Creek drainage.

Elsewhere, thinly stratified, discontinuous beds of pale-olive or greenish-gray tuffaceous argillite (TRaa) occur at several horizons in the volcanic pile, either isolated or associated with dark carbonaceous argillite and chert. Small-scale graded bedding, cross-bedding, laminations, and load casts are abundant in all metasedimentary rocks. In thin section the tuffaceous argillite consists of a very fine grained groundmass of chlorite and carbonaceous matter with sparse angular fragments of quartz, plagioclase, and chloritic aggregates whose outline is suggestive of altered lithic particles.

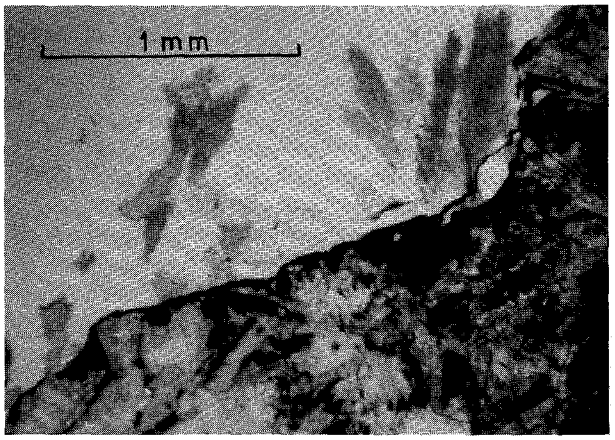

Figure 7. Photomicrograph of green and yellow pumpellyite projecting into quartz-filled amygdule (TRab, crossed nicols, sample 68-ASb-183).

Epidote, pumpellyite, and prehnite occur locally in the fine-grained matrix. Other clay-sized phyllosilicates, carbonates, and hematitic staining are present but are too fine grained for optical determination.

In many occurrences, the pale-olive tuffaceous argillite (TRat) grades into medium-gray or gray-black very fine grained argillite (TRaa), and in the larger sedimentary members (TRas), a lateral variation is present from dark carbonaceous argillite near the centers outward into thin fingers of greenish volcaniclastic material interlayered with flows. Silty and sandy laminae are common in the argillite and often are present as the lower extreme of graded cycles in "varved" rhythmites, whose individual cycles vary from 1 inch to about 4 inches. The clay-sized constituents illite(?), chlorite, and carbonaceous material make up 70 to 90 percent of the rocks with subordinate silt-sized angular quartz and feldspar. Carbonaceous material of organic origin is distributed in fine laminae and imparts a fissile quality to the rock. Primary pyrite is common along the organic layers.

In addition to the tuffaceous and pelitic sedimentary rocks, thin (2 feet or less) lenses and discontinuous beds of medium-gray to light-brownish-gray argillaceous limestone (TRal) occur in the metavolcanic unit. Bedding in these recrystallized, impure limestones is irnperfectly defined by irregular clayey brownish-gray layers that stand out in positive relief on otherwise hackly weathered surfaces. The presence of these limy horizons, the organic sediments, and widespread pillow structures and large amygdules in the volcanics suggests that the lavas were extruded into a subsiding near-shore environment, the buildup in general keeping pace with SUbsidence. The surface of the lavas was apparently occasionally depressed below sea level, allowing deposition of organic sediments and limy marine muds in low-energy reducing environments, probably in shallow semi-isolated near-shore basins (fig. 8).

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[2]The term 'limonite' is used in a nonrigorous manner for the megascopic descriptions in this report. It includes reddish-brown and black hydrous ferric oxides and other iron-bearing compounds as discussed by Blanchard (1968, P. 7).

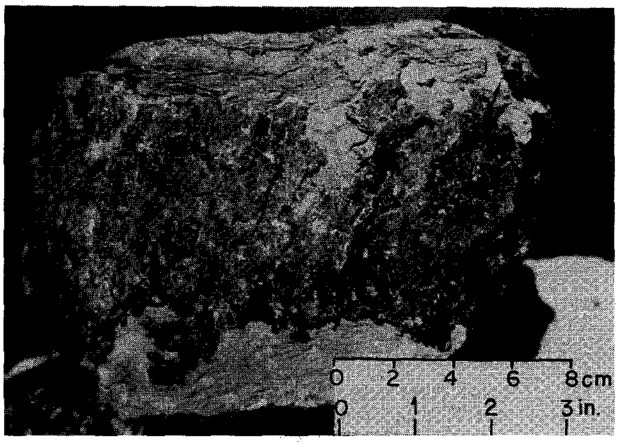


Figure 8. Thin tongue of vesicular metabasalt (TRab) enclosed in argillaceous limestone (TRal).

Outcrops of flow breccias in the unit are similar in appearance to enclosing flow rocks, except that differentially weathered surfaces reflect the presence of cognate inclusions and clasts. Intraclasts of composition similar to the matrix are discernible only on such weathered surfaces. A few breccia horizons contain inclusions of slightly different color or, texture, and these are evident on freshly broken surfaces as well. Both intraclasts and matrix are commonly amygdaloidal.

A few dikes and sills of intermediate to mafic composition have intruded the metavolcanic unit. The weathered, lichen-covered outcrops of these rocks cannot be distinguished from the intruded metavolcanics; consequently they are unmappable at 1:63,360 scale.

PETROCHEMICAL CLASSIFICATION OF METAVOLCANIC ROCKS IN THE AMPHITHEATRE GROUP

The metavolcanic rocks in the Clearwater Mountains have been variously classified as "diabase" (Moffit, 1912), "basalt and andesite flows" (Ross, 1933), and "andesite with subordinate basalt" (Glavinovich, 1967). The various assignments of names were apparently based either on megascopic appearance and color index or on averaged plagioclase composition-determined optically. In this study, the examination of over 80 thin sections has demonstrated that a classification by major-oxide chemistry is a more definitive method. Many of the plagioclases have reequilibrated during metamorphism to albite, whose optically determined composition is about An5-6 and, which typically have numerous inclusions-so abundant that the recognition of an albitic range of refraction index is not readily apparent. If structural ordering attended the widespread albitization and if determination curves for ordered or intermediate feldspars are applied with the usual assumptions to most of these rocks, compositions of An35-38 are obtained, incorrectly implying that the rocks are dominantly pyroxene andesites. A classification by optically determined plagioclase composition is further compilcated because some feldspars apparently have not completely inverted to a low structural state and their composition is An40-57 with curves for disordered volcanic feldspars. This compositional range would suggest the rocks should be considered metamorphosed basalts or basaltic andesites.

To assist in clarifying the classification, several bulk samples of unaltered metavolcanic rocks and one of tuff were collected for major-oxide analysis. Each was a composite sample of freshly broken rock and weighed 5 to 10 pounds. Major-oxide analyses were made by using the rapid rock method described by Shapiro and Brannock (1962), supplemented by atomic absorption spectrophotometry.

Analyses and normative minerals for these rocks are listed in table 1, together with average compositions for andesites, tholeiitic andesites, tholeiitic basalts, and tholeiitic olivine basalts taken from Nockolds (1954). An inspection of this table reveals that analyzed rocks from the map area have close affinities with average tholeiitic basalts, although they may be slightly subsilic. Sample 68-ASb-139 is apparently silica deficient;

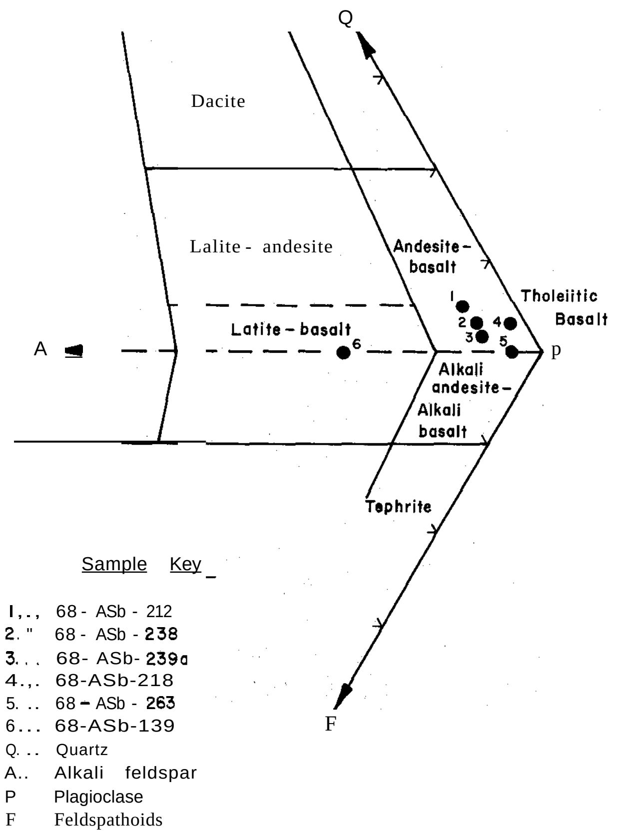


Figure 9. QAPF classification diagram for Clearwater Mountains metavolcanic rocks (modified from Streckeisen, 1967).

however, its normative content of olivine is still only 0.5 percent-not in the range of olivine basalt. These data support the assignment of the metavolcanics to a normal tholeiitic basalt association, one which displays a striking similarity to the basaltic lavas erupted into the subsiding Coast Range geosyncline during Tertiary time (Waters, 1955, p. 704). This resemblance is apparent in thickness, potential extent, constancy of composition throughout the sequence, and association with argillites, graywackes, and tuffaceous sedimentary rocks.

Figure 9 is a plot of normative feldspars and quartz on the QAPF classification diagram proposed by Streckeisen (1967) for volcanic rocks. Most Clearwater Mountains samples fall in the field of andesites and basalts. Sample 68-ASb-139 is an exception; by normative mineralogy. it would be termed a latite-basalt. Figure 10 shows the relationship of Clearwater Mountain samples to zonal tholeiite-high alumina-alkali basalt fields from island-arc settings.

CALCAREOUS AND TUFFACEOUS ROCKS ABOVE METAVOLCANIC ROCKS IN THE AMPHITHEATRE GROUP

DISTRIBUTION

Several discontinuous beds or lenses of limestone, calcareous argillites, and calcareous tuffs-a few of which have appreciable thickness and lateral extent (pl. 1)-occur along the contact between the meta-

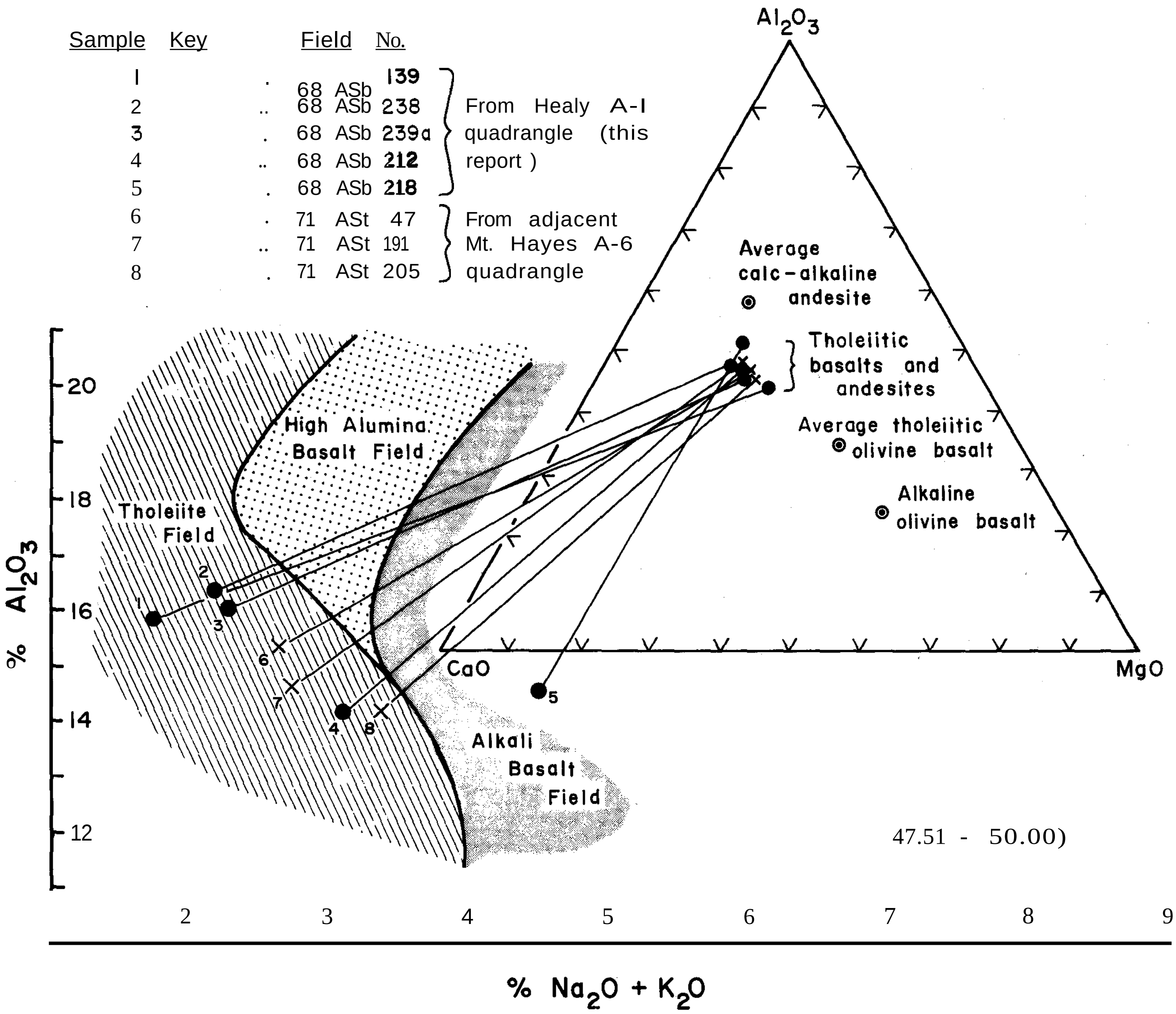


Figure 10. Major-element distribution of volcanic rocks from Clearwater Mountains showing variation within tholeiite field and comparison with other types of andesites and basalts; average compositions from Nockolds (1954).

Table 1. *Analytical and other data for metavolcanic rocks of Clearwater Mountains and for selected average volcanic rocks*[a]

	Avg andesite	Avg thoI andesite	Avg thol basalt	Avg thoI oliv bslt	68-ASb-139 th bslt	68-ASb-212 th bslt	68-ASb-218 alk bslt	68-ASb-238 th bslt	68-ASb-239a th bslt	68-ASb-263 (tuff)
Major-oxide analyses (weight percent)[b]										
SiO_2	54.20	51.43	50.83	47.90	47.4	49.3	49.3	50.0	50.0	52.8
Al_2O_3	17.17	13.05	14.07	11.84	15.8	14.2	14.6	16.3	16.1	14.8
Fe_2O_3	3.48	3.36	2.88	2.32	0.71	4.6	11.3	1.3	1.3	1.0
FeO	5.49	9.74	9.06	9.80	7.9	7.7	1.0	8.0	8.2	8.7
MgO	4.36	5.28	6.34	14.07	9.3	6.2	5.3	6.4	7.1	7.4
CaO	7.92	8.78	10.42	9.29	11.2	10.2	8.8	12.5	11.7	6.5
Na_2O	3.67	3.18	2.23	1.66	1.3	2.7	4.4	1.8	2.0	4.4
K_2O	1.11	1.04	0.82	0.54	0.47	0.45	0.11	0.42	0.34	0.18
H_2O^-	---	---	---	---	0.16	0.36	0.54	0.25	0.18	0.09
H_2O^+	0.86	0.87	0.91	0.59	3.30	1.8	2.3	1.7	1.6	2.9
TiO_2	1.31	2.60	2.03	1.65	0.51	1.8	1.7	1.0	0.95	0.86
P_2O_5	0.28	0.48	0.23	0.19	0.11	0.18	0.16	0.09	0.10	0.10
MnO	0.15	0.19	0.18	0.15	0.16	0.20	0.16	0.16	0.16	0.15
CO_2	---	---	---	---	0.78	0.05	0.09	$<$ 0.05	0.05	0.05
Sum	100.00	100.00	100.00	100.00	99	100	100	100	100	100
Semiquantitative spectrographic analyses (parts per million)[c]										
B					N	N	N	N	N	30
Ba					700	100	70	150	100	70
Co					50	70	70	50	50	50
Cr					700	150	200	300	700	500
Cu					150	150	200	200	200	150
Nb					N	15	15	N	N	N
Ni					500	200	150	150	200	100
Pb					N	N	7	N	N	N
Sc					50	70	70	70	70	70
Sr					300	300	200	200	200	100
V					300	500	500	500	500	300
Y					20	50	50	30	30	30
Zr					30	100	100	50	50	50
Oa					10	15	15	15	15	15
Yb					2	3	3	3	2	3

CIPW Norms

quartz	5.7	3.2	3.5			2.93	1.97	1.92	0.98	
orthoclase	6.7	6.1	5.0	2.8	2.88	2.77	0.68	2.55	2.06	1.08
albite	30.9	27.2	18.9	14.1	12.11	25.25	41.20	16.64	18.42	40.26
anorthite	27.2	18.1	25.9	23.4	37.23	26.35	20.61	36.20	34.83	20.49
wollastonite	4.2	9.2	10.3	9.1	5.30	9.92	8.72	10.69	9.49	4.56
enstatite	10.9	13.2	15.8	20.5	26.18	17.83	15.26	18.19	20.11	16.07
ferrosilite	5.3	11.1	11.2	7.9	11.5	6.80	- -	10.65	11.00	9.29
forsterite	- -	- -		10.3	0.34				- -	3.57
fayalite		-	- -	4.4	0.15				-	2.06
magnetite	5.1	4.9	4.2	3.3	0.77	5.°1	- -	1.40	1.39	1.07
ilmenite	2.4	5.0	3.8	3.2	0.74	2.61	1.89	1.43	1.36	1.22
apatite	0.7	1.1	0.5	0.4	0.24	0.39	0.35	0.19	0.21	0.21
calcite	- -			-	2.57	0.13	0.24	0.13	0.13	0.13
hematite		-	-	-			8.21	-	-	
sphene		- -	- -	- -			0.86			

[a]Compositions of average volcanic rocks and norms computed therefrom are taken from Nockolds (1954).
[b]Analyses of Clearwater Mountains rocks by P. Elmore, G. Chloe, L. Artis, S. Botts, H. Smith, J. Kelsey, J. Glenn of U.S Geological Survey using methods described by Shapiro and Brannock (1962). For sample locations see Appendix.
[c]Analyses by C. Heropoulos of U.S. Geological Survey. Elements looked for but not found: Ag, As, Au, Be Bi Cd, La, Mo, Pd, Pt, Sb, Sn, Te, U, W, Zn, Ce, Ge, Hf In, Li Re, Ta, Th, Tl, and Eu.

volcanic unit and the overlying pelitic sequence. Neither limestones nor tuffs are restricted to this horizon as noted earlier, but are present in minor quantities at discrete horizons interlayered with both the volcanics and the overlying pelitic sediments. Tuffaceous metasedimentary rocks, cherts, metabasaltic flows, and limy or carbonaceous argillite are intimately and complexly interfingered with the limestone beds in many occurrences, particularly on the ridge northeast of the pass between Windy and Pass Creeks (pi. 1).

Mappable units of tuffaceous strata, including associated flows, limestone, and limy argillite, are all similarly indicated on plate 1, although all do not necessarily occur at correlative horizons. The description of the two basic lithologies in this section emphasizes the steeply dipping rocks occurring near the basalt-argillite contact, but is applicable as well to similar rocks in other parts of the map area.

LIMESTONE AND CALCAREOUS ARGILLITE (TRal)

Calcareous rocks are exposed chiefly in the headwall along the ridge north of Windy Lake (pi. 1 and fig. 11) and consist dominantly of light-olive-gray argillaceous and silty limestone with subordinate lenses of more pure medium-gray limestone. Two such lensoid bodies of considerable size are shown on plate 1. The impure limestones are generally finely banded (less than 1 mm) with clayey and silty laminae. Deformation and recrystallization have distorted most primary structures, though in most exposures bedding is readily discernible. One of the less deformed limestone beds north of Windy Lake contains siliceous structures suggestive of scleractinian corals (e.g., *Thamnasteria?)* and spongiormorphid coelenterates (N.J. Silberling, written comm., 1969).

Well-preserved primary structures, either faunal or depositional, are rare exceptions in the calcareous units. Many of the outcrops and specimens examined show definite tectonite fabrics, and field occurrences are classified as calc-phyllites or calc-schists (fig. 12). The more calcareous beds have been transformed into impure banded marbles with smeared-out carbonaceous and silty laminae. These commonly weather out into rectangular blocky rubble with hackly surfaces. Silty and argillaceous members preserve a fine lamination, especially apparent on weathered surfaces. Locally massive undeformed beds of medium-gray microsparite from 4 inches to 1 foot thick alternate with silty interbeds, which weather in negative relief (fig. 13).

In thin section, the calcareous beds vary from carbonaceous siltstones or quartzites with microcrystalline sparry cement through finely laminated carbonaceous and pyritic microsparites to mylonitic sparites with tectonite fabrics. In the last named, smeared-out carbonaceous layers, lenticular structure, flaser textures, and augen consisting of resistant calcite grains bounded

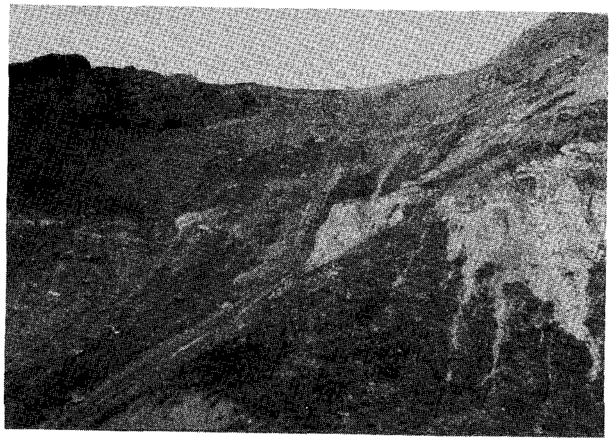


Figure 11. Interbedded limestone (light-colored rocks; TRal) and tuff (TRat) in headwall north of Windy Lake; view north.

by "pressure shadows" of finely crystalline carbonate are characteristic. In silty or quartzitic bands, quartz grains are present mainly in a granoblastic fabric with either sutured or polygonal intergrain relationships. Euhedral pyrite crystals are common along carbonaceous laminae. The majority of less deformed impure limestones falls in the classification of very finely crystalline carbonaceous microsparite, probably recrystallized from micrites or dismicrites (in the classification of Folk, 1959). This suggests that these rocks were deposited rather rapidly in shallow water as a microcrystalline ooze. In addition, the presence of ammonoids, pelecypods, and probable corals in the rocks further supports the interpretation of depositional environment as semi-isolated lagoons or shallow basins with marine connections, but without appreciable wave action or current activity.

TUFFACEOUS ROCKS, CHERTS, AND ARGILLITE (TRat, TRaa)

Metasedimentary rocks of tuffaceous composition occur more widely than do the limy strata discussed above. In the area north of Windy Lake, they form a unit about 400 feet thick, which is intertongued with limy argillites and which includes numerous pods and small lenses of impure carbonate. Elsewhere in the area of plate 1, magnesian metasedimentary rocks of volcanic origin are present at several horizons. Locally they are interbedded with or overlie flow rocks (pJb); however, they also crop out as isolated members interbedded with the argillite unit near the headwaters of Rusty Creek and on the slope west of upper Pass Creek (TRat).

In field exposure, the tuffs occur both as undeformed light-olive or grayish-green metasedimentary rocks with well-preserved primary depositional structures and as thoroughly recrystallized epidote-chlorite-muscovite schists or hornfelses with segregated pods of

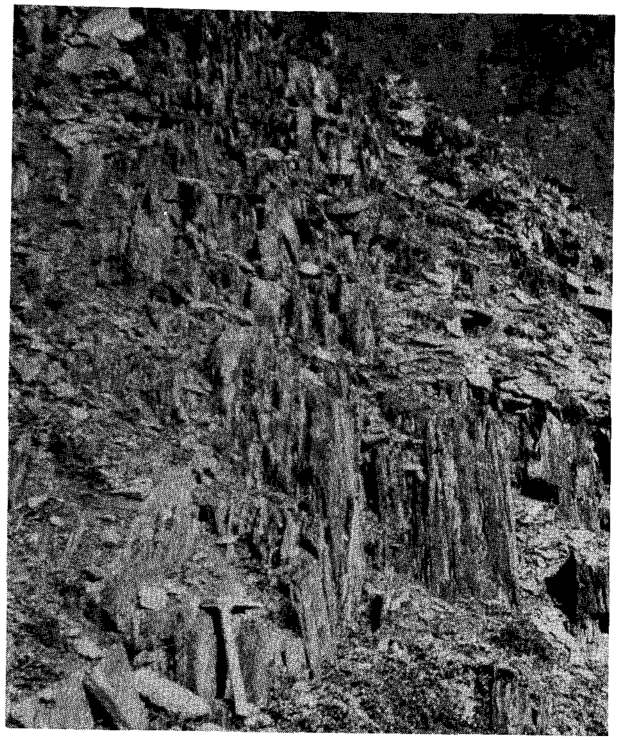


Figure 12. Calc-phyllites derived from limy argillite (TRal) along shear zone near headwaters of Pass Creek; view northeast.

carbonate. Schistose varieties of the tuffs are particularly extensive near the large limestone bodies north of Windy Lake, and weather with distinctive fluted surfaces. Less deformed equivalents contain fragments of pyroxene (in part replaced by chlorite-actinolite aggregates), quartz, and iron oxides-all embedded in a fine-grained epidote-chlorite, muscovite-quartz groundmass. This assemblage was probably recrystallized from volcaniclastic muds. Intraclasts of black carbonaceous mud derived from other parts of the depositional basin are locally abundant.

One major-oxide and trace-element analysis was made of the tuffaceous metasedimentary rocks west of upper Pass Creek (table 1, sample 68-ASb-263). A comparison of its major-oxide content with those of the volcanics substantiates its tholeiitic affinity. Only a slight increase in silica and loss of calcium have occurred during the cycle of weathering, erosion, and deposition, perhaps implying a nearby volcanic source area for the detritus.

PRE-UPPER JURASSIC SEDIMENTARY AND MINOR VOLCANIC ROCKS

DISTRIBUTION AND AGE

Argillite (pJa), boulder conglomerate (pJcg), volcaniclastic sedimentary and minor volcanic rocks (pJt), and metabasalt (pJb) compose a complex layered sequence of questionable age. The pJcg, pJt, and pJb units are thin beds and locally thickened wedges, interbedded within or in fault contact with the larger argillite unit (pJa), which forms a broad, folded belt across the north-central portion of plate 1 north of Windy Creek. As in the case of the metavolcanic and metasedimentary units of the Amphitheatre Group, the pJ units have eroded to a rugged mountain range about 5 miles wide and trending roughly N. 70^0 E. Sharp, narrow ridges flanked by talus aprons characterize the topography of the pJ units, particularly the argillite (pJa, fig. 14). In general, ridgelines are smoother and less craggy than those of the metavolcanic rocks in the Amphitheatre Group. Cliffs and near-vertical faces are common only where thick, massive graywacke, conglomerate, and metabasalt members of the pJcg, pJa, and pJb units are undergoing erosion. The pJ units are transitional between relatively unmetamorphosed sedimentary and volcanic rocks in the southern part to slates and semischists along the northern part of the outcrop exposures.

At the present time, no direct evidence of depositional age has been established for the pJa, pJcg, pJt, and pJb units. Contact relationships seem to suggest they may overlie the upper part of the Amphitheatre Group. By that interpretation, the older age limit for the pJ units would be established by Upper Triassic fossils recovered from limestone lenses in the uppermost part of the Amphitheatre Group discussed previously. No fossil evidence other than poorly preserved worm(?) trails observed in the argillite unit (pJa) has been found. Approximately 15 miles southwest of the study area in the Talkeetna Mountains D-1 Quadrangle, fossils collected by G.L. Kline during the 1972 season in cobble conglomerate and sandstone similar to the pJcg unit of the study area yield a Jurassic *Buchia* assemblage. Additionally, potassium-argon radiometric ages of 143 $\pm$ 4 and 130 $\pm$ 4 m.y. (pl. 1) were obtained on hornblende and biotite from the small stock that intrudes the argillite unit (pJa) in the headwaters of Eldorado Creek. Hence the depositional age of the pJa, pJcg, pJb, and pJt units would appear to be bracketed between middle Late Triassic and Late Jurassic time.

However, regional comparisons with similar units elsewhere in Alaska suggest the pJ units as well as pelitic phyllite, schist, and gneiss of the Maclaren metamorphic complex may also include rocks of upper Paleozoic to Cretaceous parentage.

CONGLOMERATE UNIT (pJcg)

Overlying the tuffaceous rocks and exposed on a prominent mountain about 1.5 miles southeast of Roosevelt Lake is a massive, wedge-shaped body of polymictic cobble and boulder conglomerate, whose aggregate thickness is at least 1,000 feet (pl. 1). Its total

Figure 13. Alternating beds of siltstone (negative relief) and gray limestone (TRal); view northeast near headwaters of Pass Creek.

Figure 14. Glaciated topography in argillite (pJa); view west from headwaters of Timberline Creek.

areal exposure is less than a square mile, and outcrops of the unit are confined to the area: near the mountain.

The conglomerate is composed of well-rounded elliptical pebbles, cobbles, and boulders of diverse origin embedded in a well-indurated but poorly sorted matrix of angular lithic and mineral fragments. Many of the cobbles are discontinuously coated with hematite. Detrital mineral components in the matrix are mainly albite, quartz, and altered ferromagnesians-all set in a recrystallized tuffaceous groundmass. The fine-grained matrix material has undergone extensive recrystallization during the regional metamorphism and now exhibits abundant secondary chlorite and prehnite. Most mafic detritus and mud clasts are similarly converted to chloritic aggregates.

Basalt, diorite, and graywacke are'the most abundant lithologies present as cobbles and boulders in the unit. The majority of volcanic cobbles examined could have been derived from the volcanic rocks underlying the conglomerate. Dioritic cobbles are probably intrusive equivalents of the volcanics. One cobble examined in thin section was apparently derived from a basalt or andesite with a glassy groundmass-now devitrified-and is unlike the volcanics in the map area. This and the graywacke pebbles and cobbles are the only constituents noted that are possibly exotic to the underlying units.

In view of its content of well-rounded components, thickness, and restricted lateral extent, this conglomeratic wedge is interpreted as a side-entry fan deposited at the margin of a subsiding trough, perhaps at the discharge point of a major stream. Laterally it grades into the basal part of a thick sequence of pelitic sedimentary rocks. By this interpretation the unit should not be considered a simple basal conglomerate and probably does not mark an interruption of regional sedimentation.

ARGILLITE (pJa)

The argillite unit (pJa) structurally overlies the metavolcanic rocks and limestones as discussed previously. Above that contact, it consists of a series of well-indurated mudstones, siltstones, and poorly sorted graywackes, all of which were mildly to moderately recrystallized by regional metamorphism but which retain undeformed primary sedimentary structures. Typically, fracture and joint faces show distinct banding between black carbonaceous mudstone and olive-gray silty or sandy layers (fig. 15). The graywacke beds weather to a light-olive gray in contrast to the mudstones, which retain a dark-gray or black color, thus accentuating the banding on exposed surfaces. All rock types of this unit appear to be less receptive to lichen growth than igneous rocks in the map area.

In the northern part of the unit, the character of the argillite unit is more nearly that of a metamorphic sequence. Mudstones are typically slaty, and massive graywacke beds exhibit a crude schistosity or ac-

Figure 15. Rhythmically banded argillite (pJa) near Eldorado Creek.

centuated bedding-plane foliation. Slaty cleavage usually is bedding-plane controlled but also transects bedding in areas of intense folding. Such discordant foliation is well exposed in the Dry Creek cut near Denali. Phyllites with subhorizontal lineations, produced by S planes intersecting at very low angles, occur along the northern edge of the unit near White Creek and Gold Hill. North of Timberline Creek the rocks are recrystallized to a very fine grained biotitic semischist.

The slates and phyllites weather into platy talus fragments with a distinct surface sheen. In debris fans and talus aprons the fragments commonly assume a subparallel orientation, prodUcing shiny reflective slopes visible for miles.

Rocks of the argillite unit consist dominantly of grayish-black mudstones, dark-gray siltstones, and medium-gray lithic graywackes. The graywacke members vary widely in grain size from silty through medium- and coarse-grained varieties. Coarser grained beds commonly attain thicknesses of more than 50 feet, particularly in the lower part of the section. Several of the more persistent graywacke beds are shown in a stippled pattern on plate 1. The graywacke strata are rarely traceable laterally for more than a few hundred feet, but rather grade into or intertongue with fine silts and mudstones that form the bulk 'of the unit. The coarser graywackes form massive blocky talus rubble with light-olive-gray or pale-brown weathered surfaces. Flattened or slightly rounded clasts of black mudstone are common in the coarser grained varieties (fig. 16).

Thin strata and laminae of silt interbedded with black

Figure 16. Flattened mudstone intraclasts in graywacke (pJa) from ridge north of mouth of Windy Creek.

mudstones are more common than the massive beds. These thinly bedded rocks show a variety of primary sedimentary structures, including rhythmic graded bedding on a 1/2- to 4-inch scale, festooned cross-bedding, wavy cross lamination, and numerous load casts. Olive-gray silty beds typically grade upward within inches into gray or black carbonaceous mudstone, which in turn is overlain by another silty layer-the interface often showing load casts or flame structures as a result of compaction. The aggregate thickness of these rhythmites is rarely more than 10 feet in anyone exposure. Evenly graded laminae such as those just described are locally present throughout the unit, but more commonly each cycle consists of silt in the lower part showing delicate wavy lamination or extensive festooned cross-bedding. The silty material grades imperfectly upward into the dark muds that form the upper part of each cycle (fig. 17). Observation of many such cross-bedded horizons in the unit suggests a general southerly transport of sediment in the basin. Few slump structures or convolute bedding forms were noted.

In addition to the graywackes and banded rocks, the argillite unit includes great thicknesses of well-indurated black mudstone, rather thinly bedded and uninterrupted for hundreds of feet. The black mudstones are very carbonaceous, weather into dark-gray or black slopes and soil, and commonly fracture with subconchoidal surfaces, whereas the siltier and banded members show planar and plumose fracture surfaces. Where the mudstones contain appreciable primary pyrite, weathered surfaces and talus take on a subdued reddish-tone-often visible from a distance.

Other minor constituents of the argillite unit are thin (4 inches to 1 foot) beds of intraformational stretched pebble conglomerate and lenses of impure limestone or calcareous siltstone. The conglomerates occur at several horizons throughout the unit. Debris within them consists mostly of stretched clasts of green or black mud with subordinate amounts of rounded volcanic or chert pebbles embedded in a poorly sorted matrix of angular quartz-feldspar and muddy groundmass (fig. 18). Limy beds in the argillite unit are platy impure microsparite or black carbonaceous lenses, usually no more than 2 feet thick.

Locally, volcanogenic metasedimentary rocks or greenish argillite are intercalated within the argillite unit, as for example near Timberline Creek and Black Creek, and are more magnesian, probably reflecting a temporary influx of debris from volcanic terrane.

PETROGRAPHY

In thin section the coarser graywackes, both massive and banded types, include subangular or angular fragments of quartz and plagioclase with subordinate quantities of brown hornblende and clinopyroxene-all embedded in a matrix of chlorite, carbonaceous mud,

Figure 17. Graded cycle in banded argillite (pJa). Note preserved load casts.

and calcite. Individual grains are seldom over 0.3 mm in diameter and grade down to submicroscopic fragments. Platy or lens-shaped mud clasts up to 1 or 2 mm are also common constituents. Thin, semiopaque carbonaceous layers are draped over and compressed around larger resistant mineral fragments and locally contain euhedral pyrite crystals. In the more reconstituted argillites, chlorite, muscovite, stilpnomelane(?), and biotite replace the finely laminated carbonaceous layers. Most of the silty detritus is less than 0.05 mm in diameter and occurs as uniform strata or graded beds, or is finely interlaminated with submicroscopic mudstone.

Prehnite is a common replacement mineral in the graywacke groundmass material across the southern part of the unit. Pumpellyite is also common, but is not developed everywhere in the prehnite zone. Along the northern part of the unit, incipient and well-developed cleavage often transects otherwise undisturbed bedding fabric. Where present, cleavage planes are generally about 0.05 to 0.1 mm apart. Various phyllosilicates in the slates and semischists of this zone are also aligned in a distinct foliation, but are essentially parallel to the bedding. Green and light-brown biotite are common in the argillites of higher metamorphic grade. Lensoid augen of polygonal quartz are intrafoliated in many of the slaty rocks.

Argillite near the large quartz-diorite pluton in the northwestern part of the map area shows a polymetamorphic fabric, with large unoriented clots of secondary muscovite and chlorite grown into a semischistose fabric. This observation agrees with field relations that the pluton is slightly younger than the regional metamorphism.

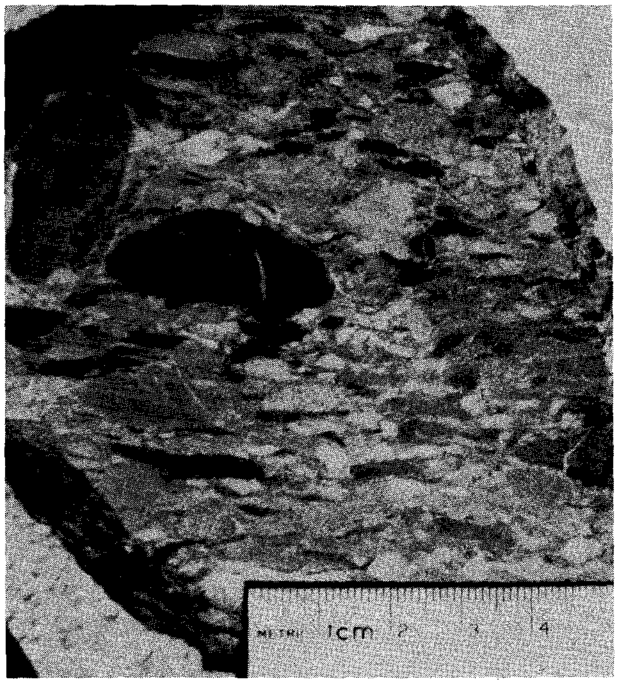


Figure 18. Intraformational conglomerate consisting chiefly of rounded and stretched mud clasts (pJa).

PETROCHEMISTRY

Table 2 lists major-oxide and trace-element analyses of seven argillite and graywacke samples from the Clearwater Mountains. The argillites are remarkably similar in composition to average shales as shown by comparison to composite data from Pettijohn (1957, p. 344). Trivalent iron is deficient at the expense of the divalent form, probably reflecting a reducing effect of abundant carbonaceous material in these sediments. Potassium is deficient over average shales by about 1.5 percent and magnesium is slightly higher. Both differences suggest the argillites were derived from a source area of intermediate composition. It is also possible that a mixing of detritus, the greater part from a felsic source, with basic debris from a nearby volcanic terrane, has produced the departure from a normal shale. Sample 68-ASb-266 has a composition more nearly like that of a subgraywacke. This is a matrix-poor quartzo-feldspathic sandstone and is not typical of the majority of graywackes in the area. Spectrographic analyses are provided as supplementary information on the sedimentary rocks so that they may be compared chemically with higher grade metamorphic rocks to the north.

DEPOSITIONAL ENVIRONMENT

Deposition of the pelitic sequence apparently proceeded without appreciable interruption from the shallow-water sedimentation pattern that produced the limestone and tuffaceous units discussed earlier. Continued subsidence and an influx of pelitic muds initiated accumulation of the carbonaceous muds, silts, and sands that eventually formed about 8,000 feet of section.

The prevalence of delicate cross laminations, thin graded strata, and abundant organic carbon with primary pyrite implies that much of the pJa unit may have been deposited in a low-energy, distal-marine environment, parts of which were qUite shallow. The thin limy interbeds and mudclast conglomerates also are consistent with this interpretation. The textures, composition, and structures are very similar to those described by Smith (1968) and Coleman and Gagliano (1965) for intertidal and deltaic environments.

The remarkable aspect of the pJa unit is its uniformity over thousands of feet of section, recording an even subsidence, balanced by deposition. An influx of magnesian tuffaceous debris occasionally interrupted the steady deposition of pelitic muds, suggesting that the volcanic source area was still mildly positive and undergoing erosion; thus a periodic alternation of source area is implied, as mentioned above.

Table 2. *Analytical data for argillites and graywackes from Clearwater Mountains and for average shale*[a]

	69-ASt-300 Green argillite	68-ASb-266 Metagraywacke	68-ASb-1048b Phyllitic argillite	68-ASb-550a Argillite	68-ASb-668 Metagraywacke	69-ASt-261 Composite argillite	69-ASt-261a Composite argillite	Avg shale
				Major-oxide analyses (weight percent)[b]				
SiO_2	58.3	72.9	56.1	57.3	57.3	59.6	58.5	58.19
Al_2O_3	16.4	11.4	14.0	15.2	14.3	16.6	16.4	15.40
Fe_2O_3	1.0	0.60	0.64	1.1	1.1	1.7	1.8	4.02
FeO	5.7	3.0	5.6	7.7	5.5	5.9	5.8	2.45
MgO	4.4	1.2	3.7	4.7	3.4	3.3	3.5	2.44
CaO	5.5	2.8	7.0	3.3	6.5	2.6	4.3	3.11
Na_2O	2.9	1.9	2.6	2.9	2.9	2.8	3.0	1.30
K_2O	1.4	1.2	1.3	1.6	1.5	1.8	1.4	3.24
H_2O+	3.0	0.33	3.3	3.7	2.8	3.3	3.0	5.00
H_2O-	0.05	1.8	0.09	0.33	0.05	0.21	0.19	
TiO_2	1.0	0.55	0.83	1.0	0.90	0.87	0.89	0.65
P_2O_5	0.23	0.10	0.35	0.22	0.17	0.21	0.30	0.17
MnO	0.06	0.16	0.11	0.13	0.10	0.09	0.10	---
CO_2	0.05	1.6	4.3	0.29	3.1	0.05	0.18	2.63
Sum	100	100	100	99	100	99	99	100
				Semiquantitative spectrographic analyses (parts per million)[c]				
B	N	50	50	20	20	20	15	
Ba	150	700	500	300	500	700	500	
Co	20	10	20	30	20	15	30	
Cr	200	70	100	100	70	100	150	
Cu	20	30	100	200	70	100	150	
Nb	N	N	10	7	15	7	10	
Ni	100	50	50	70	50	50	70	
Pb	N	10	7	N	7	7	10	
Sc	50	15	30	30	30	30	30	
Sr	500	300	300	300	500	300	500	
V	500	100	200	300	200	200	200	
Y	30	20	20	30	30	30	30	
Zr	100	100	100	100	100	100	100	
Ga	20	10	15	20	15	20	20	
Yb	3	2	2	3	3	3	3	

[a]Composition of average shale from Pettijohn (1957, p. 344).
[b]Analyses by P. Elmore, L. Artis, J. Kelsey, G. Chloe, H. Smith, and J. Glenn of the U.S. Geological Survey using methods described by Shapiro and Brannock (1962). For sample locations, refer to Appendix.
[c]Analyses by Chris Heropoulos of the U.S. Geological Survey. Elements looked for but not found: Ag, As, AU, Be, Bi, Cd, La, Mo, Pd, Pt, Sb, Sn, Te, U, W, Zn, Ce, Ge, Hf, In, Li, Re, Ta, Th, Tl, Eu.

VOLCANICLASTIC SEDIMENTARY ROCKS AND ARGILLITE (pJt)

Beds of olive to greenish-gray metatuffs and black banded argillite are exposed in two bands in the study area: 1) as a 4-mile-long, 300-foot-thick section interbedded within the argillite unit (pJa) at the headwaters of White Creek, and 2) as a thin, 2·1/2-mile-long band that forms the boundary between the argillite unit (pJa) on the south and the spotted phyllite unit (Kp) on the north between the White and Roosevelt Creek drainages (pl. 1). On Timberline and Black Creeks the tuffaceous rocks grade compositionally from pale-green argillites into gray or black argillite with a high carbonaceous content. The magnesian sediments there have apparently responded in much greater degree to the regional metamorphism than have the adjoining pelitic rocks (pJa); primary microtextures in the pJt unit are almost wholly obliterated by recrystallization, even in dynamically undeformed members. Overgrowths of quartz and albite over detrital grains and of actinolite over pyroxene fragments are common in the tuffs. In addition to the coarser varieties of metasedimentary rocks, minor quantities of green, white, and black chert occur locally and are composed chiefly of finely crystalline quartz with impurities of chlorite.

METABASALT, VOLCANICLASTIC SEDIMENTARY ROCKS, AND ARGILLITE (pJb)

Near the headwaters of the east fork of Roosevelt Creek is a complexly deformed wedge of weakly metamorphosed basalt and associated vplcaniclastic metasedimentary rocks and argillite. Rock types in this unit are almost identical with those found in the Amphitheatre Group, and the pJb unit is distinguished from the latter by its apparent stratigraphic position near the top of the argillite unit (pJa). Maximum thickness is estimated to be about 300 feet; however, the pJb unit thins rapidly along strike. A northeast-trending, high-angle fault offsets the pJb unit left laterally about 1/2 mile.

PHYLLITE, SCHIST, AND GNEISS OF THE MACLAREN METAMORPHIC BELT

SPOTTED PHYLLITE (Kp)

OCCURRENCE

Spotted phyllites and semischists (Kp) occur along the northern border of the argillites in the western part of plate 1. The phyllite is the first of three wholly metamorphic units to be described in this report. This unit and two others composed of schists and gneisses are differentiated on plate 1. All appear to have been derived from pelitic sediments and calcareous pelites like those described on preceding pages, and represent a response to a steep metamorphic gradient, increasing in intensity northward. The spotted phyllites form a gradational unit between the slaty argillites (pJa) on the south and the higher grade schists (Ks) that border the unit on the north.

Exposures of the phyllites are confined to a wedge-shaped zone extending into the area of plate 1 from the west and coinciding with the Valdez Creek basin, now mantled with extensive glacial deposits. Outcrops of the rocks are best exposed in the canyons and ravines that drain into Valdez Creek from the north. Caribou, Show Me, and Fox Creeks have cut through the morainal veneer, exposing the metamorphic bedrock. The spotted phyllites (Kp) also crop out along the south side of Gold Hill and in the Lucky Gulch drainage.

MEGASCOPIC CHARACTER

The phyllites form a north-dipping unit, medium to dark gray on freshly broken surfaces and strongly banded and foliated. Compositional laminations between fine- and coarser grained strata occur throughout these rocks as well as the argillites, and on the same scale (fig. 19). Delicate sedimentary structures are not present; rather, laminations are smooth and even as a result of the bedding-plane-controlled shearing that these rocks were subjected to during metamorphism. This is shown clearly in thin section.

Exposed surfaces crosscutting foliation are commonly fluted by differential weathering and range from dark-yellow brown to bone gray. Freshly broken rock is generally medium to dark gray and foliation surfaces show a distinct sheen produced by uniformly oriented muscovite and chlorite in the fine-grained matrix. Broken surfaces both in and across the foliation planes are spotted with porphyroblasts of bronze to black biotite. Individual porphyroblasts, usually randomly oriented with respect to foliation, range in diameter from 0.5 to 3 mm (fig. 20), and commonly show poikiloblastic internal textures. These biotites may have been the material identified as ottrelite during earlier reconnaissance work in the area (Moffit, 1912, p.63).

To some degree the character of spotting varies across the unit. In the south, large biotites cleave readily and form brilliantly shiny platelike areas throughout the rock. In the northern part of the unit, almandine and hornblende form subdued knots and lumps on otherwise smoothly foliated surfaces. Biotitic spotting in the north is also more subdued, and individual crystals tend to be smeared out in a well-defined lineation parallel to dip direction. In actinolitic horizons of the unit, particularly in the north, amphibole prisms and needles are also strongly lineated in the direction of dip, and more weakly so in the direction of strike.

PETROGRAPHIC DESCRIPTION

Microscopically the phyllites are seen to consist dominantly of two assemblages:

1) Quartz-albite-chlorite-muscovite-(graphite) ± dolomite or calcite
2) Quartz-albite-biotite-muscovite-(graphite) ± dolomite or calcite.

Chlorite-bearing assemblages are common except along the northern part of the unit, where clinozoisite or epidote and garnet or actinolite are commonly developed. The most usual assemblage in the northern part of the unit is:

.quartz-albite-muscovite or biotite-epidote-almandine-(graphite) ± dolomite or calcite,

but in more basic horizons is replaced by

.quartz-albite-biotite-amphibole-epidote-(graphite).

The latter is interpreted as recrystallized tuffaceous sedimentary beds and appears to be intercalated or lenticulated in the metamorphic rocks in much the same manner as are tuffs in the argillitic rocks.

Biotite porphyroblasts crosscut the fabric of mildly foliated rocks in the southern part of the unit. Most are poikiloblastic with inclusions of quartz and graphite preserved as helicitic remnants of the replaced fabric. Grain borders of the biotites are usually serrated or irregular and rarely idioblastic. More strongly foliated rocks of the unit farther north have similar biotites, but there they often show spiral or snowball inclusions, attesting to their dynamothermal growth under shearing stress. Garnets exhibiting these stmctures are also present with the rotated biotites. A consistency of attitude of spirals in anyone thin section demonstrates that they are not merely helicitic textures developed over previous folds, but truly record a period of shearing parallel to the pronounced foliation. Nearly all such spiral grains examined show an apparent rotation of 70 to 90 degrees. Graphite is generally in idioblastic plates coexisting with chlorite and quartz, both of which are more coarsely crystallized than the average matrix minerals from which they were reconstituted.

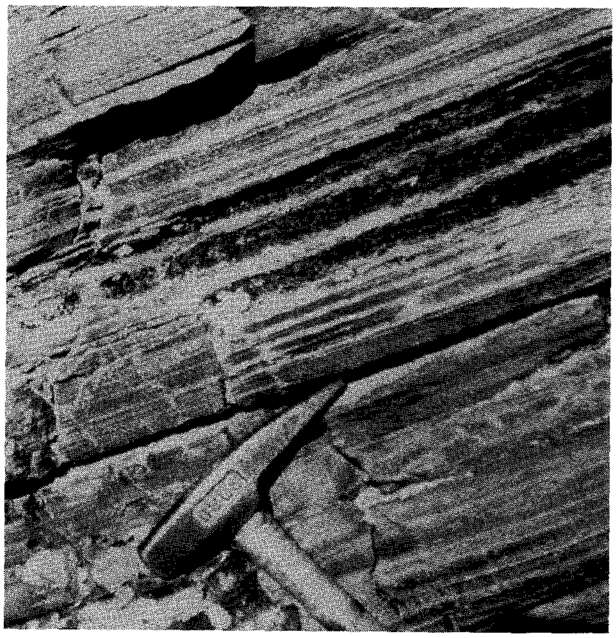


Figure 19. Compositional laminations in phyllite (Kp) similar to those in argillite (pJa). These are probably original sedimentary laminae slightly smoothed by dynamothermal metamorphism.

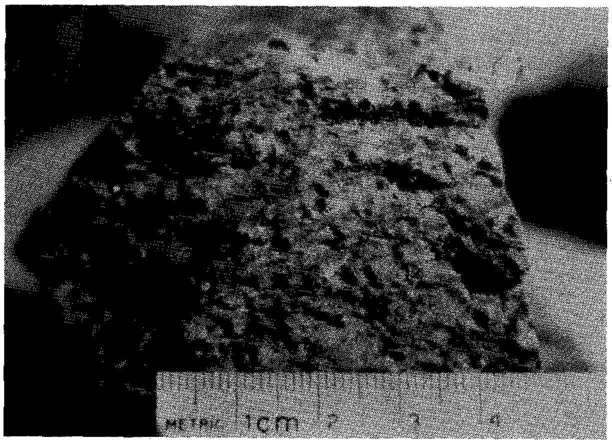


Figure 20. Biotite porphyroblasts in phyllite (Kp). Note spotted texture and diverse orientation of biotite crystals with respect to foliation.

PETROCHEMISTRY

The major oxide and trace-element content of one spotted phyllite sample (68-ASb-417a) is given in table 3. A comparison of these data with analyses of argillites in table 2 illustrates the chemical identity of the two rock types and also the apparent retention of all elements through the onset of dynamothermal recrystallization. Similar isochemical behavior during the regional metamorphism has been reported by Shaw (1954) for pelitic rocks of various grades in New Hampshire.

SCHIST (Ks)

DISTRIBUTION

With the disappearance of obvious spotting on foliation surfaces,the pelitic sequence grades northward from spotted phyllites to semischists and schists. An abundance of oriented biotite flakes gives these rocks a subdued brownish or bronzish sheen on freshly broken surfaces, as contrasted with the silvery grays of chloritic rocks to the south; this color difference and lack of spotting form the basis of distinction between this unit and the phyllites along the southern border.

The schist unit occupies a broad area of the upper

Table 3. *Major-oxide[a] and trace-element[b] content of spotted phyllite sample 68-ASb-417a*

Major oxide[a] (percent)		Trace element[b] (ppm)	
SiO_2	58.0	B	10
Al_2O_3	15.6	Ba	500
Fe_2O_3	1.2	Co	50
FeO	7.8	Cr	100
MgO	5.0	Cu	150
CaO	2.2	Nb	10
Na_2O	2.5	Ni	100
K_2O	1.6	Pb	7
H_2O-	0.08	Sc	30
H_2O+	3.8	Sr	300
TiO_2	1.0	V	300
P_2O_5	0.22	Y	30
MnO	0.13	Zr	100
CO_2	0.82	Ga	15
		Yb	2
Sum	100		

aMajor-oxide analyses by P. Elmore, G. Chloe, L. Artis, H. Smith, J. Kelsey, and J. Glenn of U.S. Geological Survey using method described by Shapiro and Brannock (1962).

bSix-step spectrographic analysis by C. Heropoulos of U.S. Geological Survey. Elements looked for but not found: Ag, As, Au, Be, Bi, Cd, La, Mo, Pd, Pt, Sb, Sn, Te, V, W, Zn, Ce, Ge, Hf, In, Li, Re, Ta, Th, Tl, Eu. For sample location, see Appendix.

Valdez Creek drainage between Roosevelt and Grogg Creeks and underlies the elevated bench north of Valdez Creek (pi. 1). The Ks unit is truncated by a large granodiorite pluton in the eastern part of the area, but along the southern margin of the pluton it forms a narrow selvage between the intrusive and argillitic country rock. The schist, like other rock units in the pelitic sequence, is transitional and grades continuously up to the gneisses and high-grade schists that make up the northernmost unit mapped. This northern contact of the schist lies along the base of the cuestalike ridge north of Valdez Creek and can be traced around the hill north of Grogg Creek (pi. 1).

MEGASCOPIC CHARACTER

Rocks of the schist unit preserve many features of the spotted phyllites, especially across the southern part of the unit. The fine, even laminations persist into the schists and most freshly broken specimens are medium to dark gray on the edges, reflecting an abundance of chlorite and graphite (fig. 21). On foliation surfaces, most of the rocks display a brownish.gray hue. Oriented phyllosilicates forming the planar fabric in the semischists are generally less than 0.1 mm thick and do not form continuous micaceous surfaces. As a result, the cross·foliation fracture habit of these rocks is subconchoidal to irregular. A pronounced fissility or fluted breakage habit becomes apparent only in more highly schistose rocks to the north, where micaceous surfaces are essentially continuous. This unit has numerous thin laminae and horizons that contain green amphiboles and pinkish garnets similar to those in the upper part of the phyllites. These interlaminations are commonly lighter in color than the enclosing pelites. Most of these grayish rocks weather into blocky or flat rubble with abundant lichens.

The fine-grained grayish rocks grade northward into distinctly biotitic or garnetiferous schists that make up the bulk of the unit. The increased size of oriented biotites and their greater degree of planar continuity are evident. Compositional laminations tend to be less prominent than in the lower grade rocks. Incipient segregation layering of quartzo-feldspathic components from schistose biotitic laminae is prevalent along the northern part of the unit; such segregation layers are generally less than 2 mm thick. The higher grade schists of the unit weather out as large flaggy plates with smooth planar foliation surfaces (fig. 22), disrupted only by occasional porphyroblasts of garnet or locally by staurolite and hornblende. Biotite and muscovite are the essential phyllosilicates in this part of the unit and lend a brownish or reddish-brown tone to most outcrops.

Limonite-stained quartz veins are present throughout the higher grade schists, occurring most commonly as pods and discontinuous veinlets parallel to foliation. Several of those examined contain small quantities of

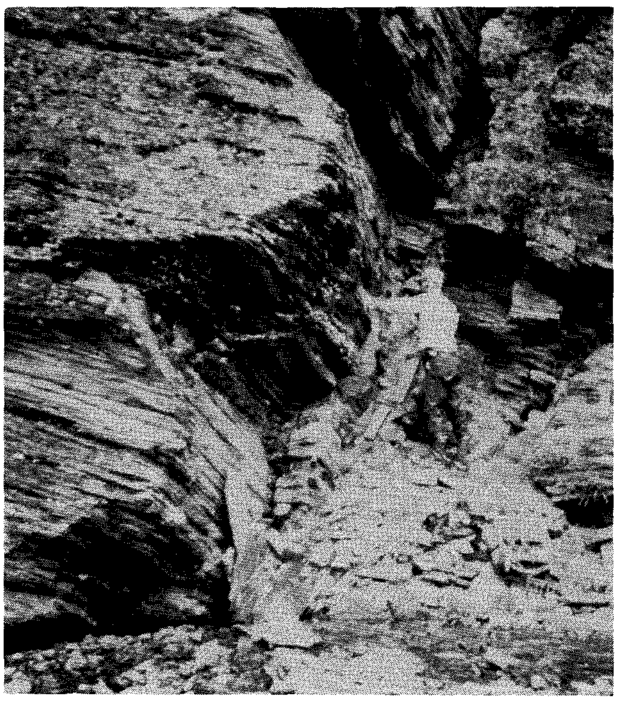


Figure 21. Outcrop of fine-grained schist with thin, even compositional laminations (Ks). View west in drainage east of Craig Creek.

pyrite or pyrrhotite(?).

Basic horizons throughout the unit contain porphyroblastic hornblende and actinolitic hornblende. As in the case of the phyllites, the amphiboles are usually aligned downdip and more weakly so along strike. Within the higher grade part of the unit, however, hornblende needles in random orientation are locally seen on weathered foliation surfaces.

PETROGRAPHIC DESCRIPTION

For the most part, rocks of the schist unit display predictable mineralogies, well established by numerous workers for pelitic, psammitic, and basic source rocks. The most common mineral assemblages observed are:

1) Quartz-plagioclase-biotite-chlorite-(graphite)
2) Quartz-plagioclase-biotite-muscovite-(graphite)
3) Quartz - plagioclase - biotite -muscovite- almandine-clinozoisite or epidote-(graphite)
4) Quartz-plagioclase - biotite - muscovite - almandine-staurolite-(graphite) ± kyanite or sillimanite (in extreme western part of area).

Basic horizons are characterized by the assemblages:

1) Quartz-plagioclase-biotite-calcite-hornblende-almandine
2) Quartz-plagioclase-chlorite-biotite-calcite-hornblende.

Apatite, zircon, sphene, and magnetite or hematite are common accessories throughout the unit. Albitic plagioclase and actinolitic hornblende are present in the lower grade part of the unit instead of plagioclase and hornblende.

The distribution of index minerals denoting specific pressure-temperature regions is discussed in the section

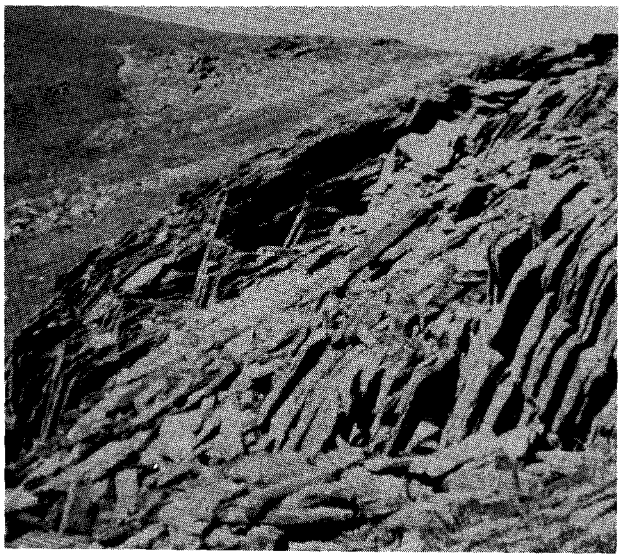


Figure 22. Strongly foliated pelites (Ks) showing flaggy weathering habit. View northwest in headwaters of Fox Creek.

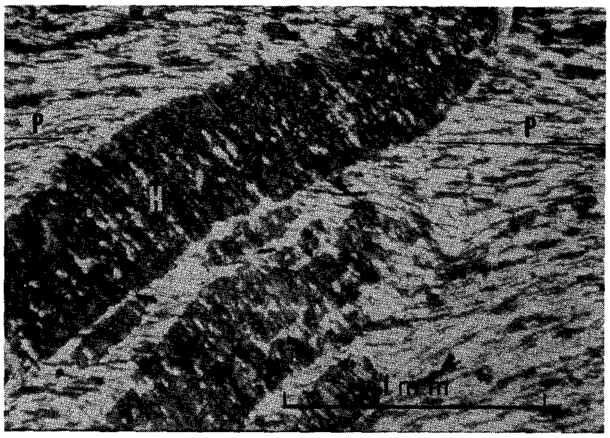


Figure 23. Photomicrograph of helicitic textures in hornblende (H) from schist (Ks) illustrating post-growth rotation. Plane of dominant schistosity (P). (Plane light, sample 68-ASb-422-2).

on metamorphism. However, the mineral assemblages above are indicative of both the greenschist and the almandine-amphibolite metamorphic facies, illustrating that map contacts, based on the megascopic appearance of the rocks, are not precisely coincident with isograd surfaces in the rocks.

Hornblende porphyroblasts are generally xenoblastic or lens shaped and many include helicitic remnants of the planar fabric. In most sections examined they are rotated from their original orientation (fig. 23). Inclusions consist mainly of flat or elongate quartz grains and graphite, although some hornblendes include plagioclase as well. Garnets generally are rounded or idioblastic in outline but often show an internal zone with numerous inclusions and some suggestion of poorly preserved spirals. The outer zone is clear gamet, probably accretionary in a late, static thermal phase of metamorphism. Atoll structures are locally present in the garnets, with circular rims of almandine, around cores of chlorite or biotite (fig. 24). Secondary chlorite after both biotite and almandine is present throughout most of the unit.

Staurolite, kyanite, and sillimanite occur in the highest grade rocks of the unit near a large quartz diorite intrusive (Kgd, pI. 1) and appear to have crystallized largely in a postkinematic environment. Metacrysts of the two former minerals lie in foliation planes, but are often idioblastic and elongate in random directions. Staurolite porphyroblasts are without exception poikiloblastic or sieved with abundant quartz and feldspar inclusions. Fibrolitic sillimanite is characteristically intergrown with or in felted aggregates along borders of biotite and muscovite crystals. Fascicular bundles of sillimanite needles also are found within quartz crystals in the highest grade rocks.

The quartzo-feldspathic components of the schists commonly display a granoblastic-elongate texture with generally straight grain boundaries, separated by trains

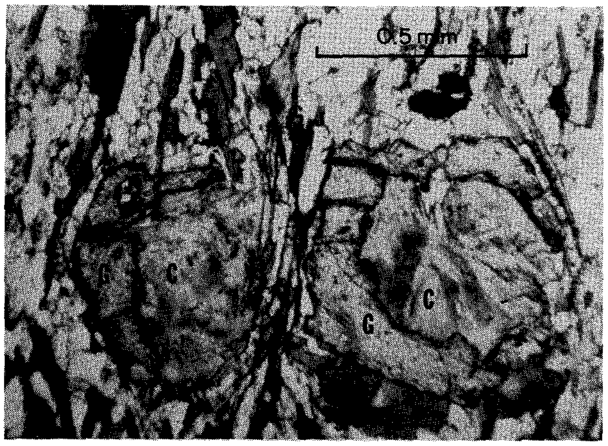


Figure 24. Photomicrpgraph of retrograde atoll structures in garnet (G) from schist (Ks); centers of atolls replaced by chlorite (C). (Plane light, sample 68-ASb-644).

of uniformly oriented micas that impart the prominent schistosity. In numerous horizons, however, the leucocratic constituents are present in ribbon or "sliced" structure (Spry, 1969) with layers of mica between individual ribbons. This mixture is interpreted as indicative of extensive intrafolial shearing.

PETROCHEMISTRY

A listed summary of major oxides and trace elements for five schist samples is provided in table 4. An inspection of these data and comparison to tables 2 and 3 again verify the chemical equivalence of the metamorphites to the argillitic rocks discussed previously. There is little question that the schists were derived from pelitic rocks identical with those exposed south of Valdez Creek. This concept of origin for the metamorphic rocks was suggested by Ross (1933, p. 438) and Kaufman (1964, p. 3), though not verified by analysis.

GNEISS AND HIGH·GRADE SCHIST (Kgn)

DISTRIBUTION

The most northerly unit mapped in the present study consists of a thick sequence of layered gneisses and schists, essentially of pelitic composition, which contain abundant kyanite, staurolite, and sillimanite. Layered, migmatitic, and augen gneisses are common in the extreme eastern part of the unit near its contact with the large quartz diorite pluton that truncates the metamorphic belt. In a very general way the unit grades northward from rocks of gneissic character in the southern part to more evenly foliated high-grade schists in the northernmost exposures.

The gneiss unit and a foliated sill-like body that intrudes it underlie most of the long ridge trending N. 70^0 E. between Valdez Creek and the Susitna River. The unit extends eastward under extensive glacial deposits along Boulder Creek to the margin of the large pluton. A reconnaissance north of the map area by light aircraft indicates that massive intrusive rock, probably granodiorite, forms many of the highland exposures north of Boulder Creek. The highest grade metamorphic terrane thus extends along strike into an embayment of a large postkinematic pluton-possibly of batholithic dimension. The contact relations of intrusive rocks adjoining the gneiss unit are discussed in the section on intrusive rocks (p. 31).

The southern contact between the gneiss and biotite-garnet schists, interpreted as a ductile thrust fault produced during metamorphism, lies generally along the base of the ridge north of Valdez Creek. In the west it crosses the ridge at a low angle and intersects the large sill that occupies the crest (pI. 1). The schist-gneiss contact is also well exposed on the ridge north of Grogg Creek. The entire length of the contact marks a discontinuity in the metamorphic pelites, both texturally and mineralogically, from fine-grained, smoothly weathering schists to coarse-grained competent gneisses which contain high-grade polymorphs of Al_2SiO_5, apparent wherever the contact is crossed.

MEGASCOPIC CHARACTER

Just above the southern contact the unit consists dominantly of evenly layered gneiss in which coarsely crystalline layers of quartz-feldspar alternate with micaceous laminae. The overall color of the rock from a distance is brownish gray or brownish black. Component layers range from 1/8 to 1 inch in thickness, although the quartzo-feldspathic bands are generally somewhat thicker than the intervening micaceous layers (fig. 26). There is a tendency for leucocratic horizons to be thicker and more massive in the eastern part of the unit. In this area, the strike of foliation swings from a prevailing N. $60\text{-}80^0$ E. direction to about N. 40^0 W., maintaining a consistent northerly dip. Concordant pegmatitic pods of quartz-plagioclase with occasional tourmaline or muscovite and quartzose rods are prevalent in the gneisses as well as small, concordant bodies of highly foliated quartz diorite, some of which are garnetiferous and scarcely distinguishable from adjoining paragneisses.

Foliation surfaces of the gneisses and high-grade schists are much more maculose and undulatory than those of the schist unit. Abundant stubby books of biotite and muscovite to 1/4 inch or more in size are crudely oriented in the plane of foliation, lending a submetallic glistening appearance to the rocks, in contrast to the smooth sheen of the lower grade schists.

Megascopic porphyroblasts of pink almandine, kyanite, and locally staurolite are present on many weathered foliation surfaces. Garnets commonly weather in bold relief either as rounded and idioblastic forms or as

Table 4. *Analytical data for schists of Clearwater Mountains*

	68-ASb-392 Semischist	68-ASb-455 Biotite schist	68-ASb-464 Biotite schist	68-ASb-467 Biotite schist	68-ASb-1591b Biotite schist
	Major-oxide analyses (weight percent)[a]				
SiO_2	58.7	60.6	62.5	56.8	58.9
Al_2O_3	16.0	15.9	14.9	15.6	15.7
Fe_2O_3	1.1	0.80	0.89	1.3	0.68
FeO	7.2	6.0	5.1	5.4	8.2
MgO	4.3	3.4	3.3	3.8	5.2
CaO	2.7	4.6	5.4	9.3	2.3
Na_2O	2.0	3.1	2.8	2.4	2.7
K_2O	2.0	2.1	1.6	1.6	1.5
H_2O-	0.05	0.03	0.05	0.06	0.04
H_2O+	3.5	1.4	1.3	1.1	3.2
TiO_2	0.93	0.81	0.69	0.83	0.21
P_2O_5	0.20	0.24	0.14	0.20	0.20
MnO	0.09	0.14	0.13	0.21	0.24
CO_2	0.95	0.51	1.1	1.2	0.09
Sum	100	100	100	100	99
	Semiquantitative spectrographic analyses (parts per million)[b]				
B	20				20
Ba	500	1000	700	700	500
Co	30	20	30	20	30
Cr	100	70	100	100	150
Cu	100	100	70	70	100
Nb	10			10	10
Ni	70	50	70	70	70
Pb	7	7	10	7	
Sc	30	20	30	20	30
Sr	300	1000	700	700	300
V	300	200	150	200	300
Y	30	30	30	30	30
Zr	100	100	70	100	100
Ga	20	15	15	15	20
Yb	3	3	3	3	3

[a]Analyses by P. Elmore, G. Chloe, L. Artis, S. Botts, H. Smith, J. Kelsey, and J. Glenn of U.S. Geological Survey using methods described by Shapiro and Brannock (1962).

[b]Analyses by C. Herapoulos of U.S. Geological Survey. Elements looked for but not found: Ag, As, Au, Be, Bi, Cd, La, Mo, Pd, Pt, Sb, Sn, Te, V, W, Zn, Ce, Ge, Hf, In, Li, Re, Ta, Th, Tl, Eu.

polycrystalline aggregates, attaining an inch or more in diameter. Bluish-white or grayish kyanite blades are observable on many partings along micaceous layers of the gneisses; many of the blades are 2 or 3 inches long. Garnet porphyroblasts are present in both leucocratic and micaceous layers, and locally small prisms of black tourmaline may be seen as well. Staurolite is generally apparent only in thin section, but on rare occasion occurs as idioblastic prisms or displays cruciform twinning.

The higher grade schists along the northern extremity of the unit typically exhibit coppery-bronze glistening surfaces, somewhat less irregular than schistose layers in the gneisses, Parts of the unit consisting dominantly of schist also include minor horizons of highly contorted migmatitic gneiss, many of which are only a few inches or at most 2 feet thick (fig. 27). These horizons in the schist were apparently zones of high shear mobility and display numerous intrafolial folds, both rooted and rootless, with amplitudes of several inches. Axial planes of most such folds are parallel and steeply dipping, and lie mainly in the plane of dominant foliation. Attitudes of these structures, suggestive of drag folds, indicate a high degree of penetrative shear strain on the rocks, with relative uplift on the north together with left-lateral displacement; all movement occurred parallel to foliation planes.

The plane of dominant schistosity follows original bedding, whether upright or overturned, in the gneisses as well as in the schist and phyllite units, as is shown clearly on the northerly trending noses extending down from the ridge east of the Susitna River in sections 14 and 23. There, a thin horizon of impure blue-gray marble and an amphibole-rich basic horizon are laterally continuous for thousands of feet within the plane of

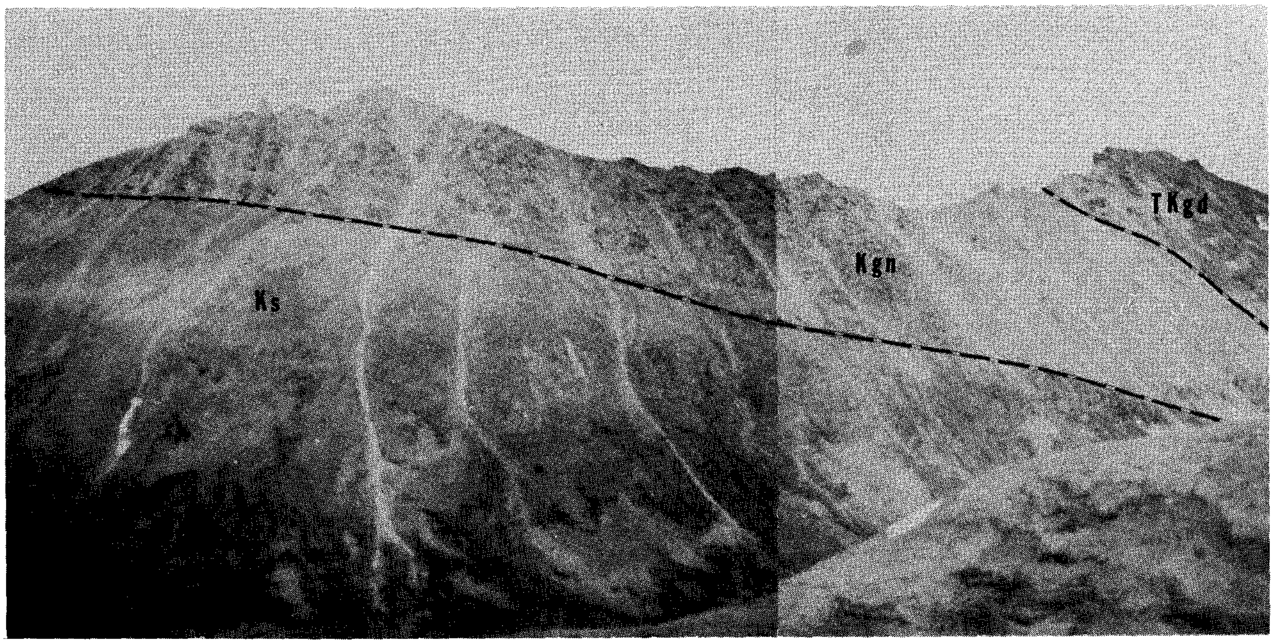


Figure 25. Thrust contact between lower, smoothly weathering schists (Ks) and upper, craggy-weathering gneiss (Kgn). Granodiorite pluton (TKgd) discordantly intrudes metamorphites. View north across mouth of Grogg Creek.

metamorphic foliation. This part of the unit, consisting mostly of schist, is not as extensively recrystallized as the gneissic portions. The calcareous horizon preserves some textures suggestive of cross-bedding, indicating a possible upright position for the beds. Biotite spotting and even laminations about 1/2 to 1 inch thick between dark graphitic bands of lighter quartzo-feldspathic layers are common near the limy bed, approximately at the same scale as those found in the sediments to the south. Crenulated lineations in the foliation, plunging downdip, are present in several pelitic horizons near the marble.

PETROGRAPHIC DESCRIPTION

Texturally the gneisses represent a considerable departure from the schist unit to the south. Predominant quartzo-feldspathic constituents are present in essentially pure segregations in granoblastic polygonal relation to adjacent grains. Grain sizes average from 1 to 2 mm and most grains join at equal or subequal angles in the triple points, implying a close attainment of chemical equilibrium. Micaceous components comprise imperfectly oriented subidioblastic and tabular blocks of biotite and muscovite. The latter appears in many sections to be later than the biotites and is present in more widely diverse orientations.

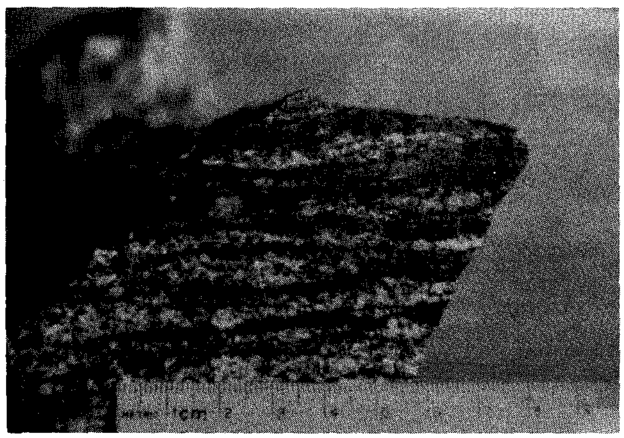


Figure 26. Pronounced layering in gneiss (Kgn).

Figure 27. Migmatitic horizon in gneiss (Kgn) south of Boulder Creek

Plagioclases are restricted to the narrow compositional range from An34 to An45' well within andesine brackets. Zoning, if present, is smoothly normal or, more rarely, slightly patchy, possibly as a result of partial granulation and rehealing. Myrmekitic intergrowths are locally present along grain boundaries, especially in very coarse-grained rocks with abundant sutured mineral boundaries; these are, however, of comparatively rare occurrence.

Both biotite and muscovite crystals commonly include trains of finely crystalline graphite assumed to be inherited from the sedimentary fabric. Many of these document a rotation of host grain during or after growth, illustrating further the pervasive shearing that the rocks have undergone.

In thin section, kyanite and staurolite are without exception porphyroblastic or poikiloblastic. Grains are often elongate but are mainly subidioblastic or xenoblastic, crosscut other fabric elements, and contain inclusions of most other minerals except for the micas and garnet. Sillimanite occurs as slender needles, as fascicular bundles, or in fibrous aggregates as a replacement of muscovite and biotite. Less commonly it is present within quartz grains or associated with kyanite.

Almandine garnets, like those described in the schist unit, are dominantly subidioblastic or idioblastic, pink, and transect most other minerals in both micaceous and quartzo-feldspathic laminae. Inclusions of quartz are commonly present in the inner zones of the garnets. However, inclusion trains here show no suggestion of apparent structure such as spiral or foliate orientation. Retrograde replacement of certain zones by biotite quartz, and chlorite is shown by well-developed atoll structures in some specimens (Rast, 1965). Secondary chlorite in random orientation is widely developed after biotite and almandine.

The most common mineral assemblages in the paragneisses are:

1) Quartz- plagioclase - biotite -muscovite -almandine-(kyanite, sillimanite)-(graphite)
2) Quartz -plagioclase - biotite - muscovite - (kyanite, sillimanite)-(graphite)
3) Quartz-plagioclase-biotite-muscovite-(kyanite, sillimanite, staurolite)-(graphite)
4) Quartz-plagioclase-biotite-muscovite-(kyanite, staurolite)-(graphite).

Clinozoisite, sphene, magnetite, zircon, and tourmaline are widely distributed as accessory constituents in most of the pelitic rocks. Basic horizons of the unit display somewhat simpler assemblages such as the following:

1) Quartz-plagioclase-hornblende-(graphite)
2) Quartz-plagioclase-hornblende·caldte
3) Quartz-plagioclase-hornblende-biotite-(graphite) ± minor almandine, kyanite, or clinozoisite.

These assemblages are characteristic of the amphibolite facies, although the respective index minerals to the various subfacies are not distributed in well-defined zones. Instead, all appear simultaneously at the lower contact; that is, the staurolite, kyanite, and sillimanite isograds are superimposed, lending support to the interpretation of this contact as a deep-seated thrust surface.

PETROCHEMISTRY

As implicitly outlined in the previous pages of this section, the bulk of the gneisses are rather heterogeneous in any single outcrop, and owing to their large grain size and permeability, are deeply weathered in most exposures. Because of the sensitivity of the major-oxide content to slight textural and mineralogical inhomogeneities, a number of samples were analyzed for trace elements only. These data, along with averages of trace-element content for the gneisses, schists, and argillites, are provided in table 5. There IS a considerable fluctuation of element content between various gneiss samples, a much wider spread than has been noted for the lower grade metamorphites. This is most likely related to the more extensive recrystallizing and segregative processes that have operated on these rocks and possibly to a metasomatic effect on both the large pluton and the numerous sills or minor intrusives found throughout the unit. Most of the latter are highly foliated and were probably emplaced prior to the last dynamothermal episode.

Figure 28 shows trace-element profiles of the compositional averages listed in table 5. The profile for an average gneiss is broadly correlative with those of the lower grade rocks, but also displays some significant

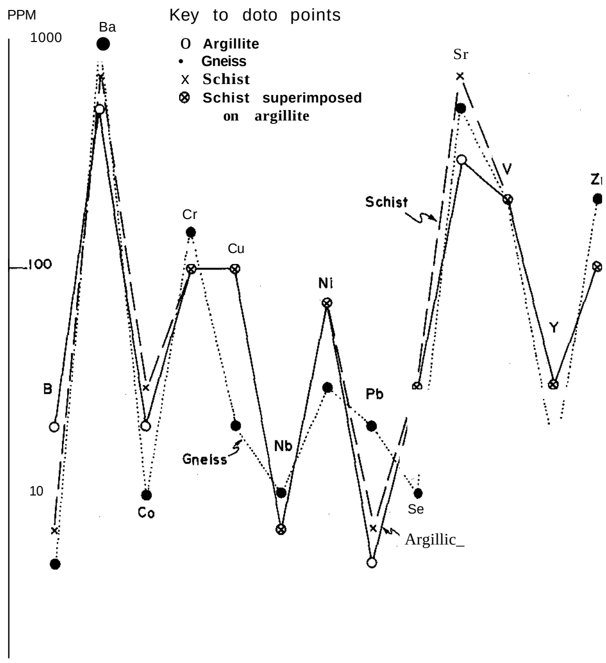


Figure 28. Trace-element profiles in average argillite (pJa), schist (Ks), and gneiss (Kgn) from text tables.

Table 5. *Semiquantitative spectrographic analyses of gneiss samples and average values for metamorphites from the western Clearwater Mountains.*[a] *All values in ppm.*

	69-ASt-132 Gneiss	69-ASt-150 Gneiss	69-ASt-172 Leuco gneiss	69-ASt-172a Mica gneiss	69-ASt-190 Gneiss	69-ASt-190a Co-gr gneiss	Avg gneiss (6)	Avg schist (5)	Avg argillite (7)
Ag					7				
B				15	10		5	7	20
Ba	700	1500	500	1500	1500	1500	1000	700	500
Be		1.5					0.2		
Co	10	15		10	10	10	10	30	20
Cr	150	300	30	300	70	70	150	100	100
Cu	30	30	5	70	5	7	200	100	100
Nb	10	10	10	10	10	10	10	7	7
Ni	30	100	15	70	30	30	30	70	70
Pb	10	15	30	15	30	20	20	7	5
Sc	20	20	5	15	10	7	10	30	30
Sr	300	300	700	150	700	700	500	700	300
V	300	300	30	300	70	100	200	200	200
y	15	15	10	20	15	10	15	30	30
Zn				200		200	70		
Zr	70	150	150	150	500	300	200	100	100

[a]Gneiss samples analyzed by K.J. Curry of U.S. Geological Survey. Averages for schist and argillite from previous text tables. Elements looked for but not found: As, Au, Bi, La, Mo, Sb, Sn, W. Numbers in parentheses indicate number of samples averaged.

differences. Scandium and yttrium are deficient by a factor of 2 or 3, perhaps reflecting their tendency to concentrate in late-stage magmatic fluids (Vlasov, 1966) and possibly in near-anatectic metamorphic fluids such as would be present in these rocks. Metamorphic dispersion near the melting point provides a plausible mechanism to explain deficiencies of these elements and of copper, which is low by a factor of 5. A slight paucity of cobalt and nickel is also apparent but is less readily explained in terms of classical geochemistry. Both elements should be stably bound in the mafic silicates of these rocks, the last phases to undergo partial melting. The presence of excess lead, zinc, and silver in the gneiss over lower grade metamorphites may be explained as simple metasomatic effects of the numerous intrusions, not wholly removed by metamorphic dispersion.

SURFICIAL DEPOSITS

ACKNOWLEDGMENT

Much of the lowland area in the western Clearwater Mountains is mantled by a variety of surficial deposits. Studies of the distribution and lithology of these deposits were made prior to 1960 by Kachadoorian, Hopkins, and Nichols (1954 and other unpublished reports) in preparation for construction of the Denali Highway. Their investigations form the basis for this section and for most surficial map units shown on plate 1.

The author accepts full responsibility for differences in interpretation, modifications, and additions to the earlier work.

GENERAL DISCUSSION

Most valleys in the Clearwater Mountains contain drift deposited by glaciers that originated in those mountains and in the Alaska Range to the north. Glacial drift of five ages is distinguished on the unpublished compilation, although equivalent forms of different ages are not differentiated on plate 1. Five stages of advance are recognized, each succeeding stage of which was generally of lesser extent and of higher elevation than its predecessors. Tentative inferred ages of the five advances are as follows: a) pre-Wisconsinan(?), termed pre-Denali glaciation; b) Early Wisconsinan(?) or Denali; c) Late Wisconsinan(?) or Hatchet Lake; d) early Holocene(?) or Alpine Creek; e) and an unnamed Holocene advance culminating in the last century or two (all names informal and subject to revision). Wind-blown silt a few inches thick mantles most of the drift except that deposited by the recent advance. The inferred distribution of glacial ice and moraines developed during the various advances is shown on figure 29, modified slightly from a compilation by D.R. Nichols.

Evidence of an extensive Late Wisconsinan lake is present at several locations in the Copper River basin and near the Tangle Lakes south and east of the project area (Nichols, 1956; written comm., 1971; Ferrians and Schmoll, 1957; Ferrians, 1963a,b). Silty and pebbly materials along the southeastern part of plate 1 may

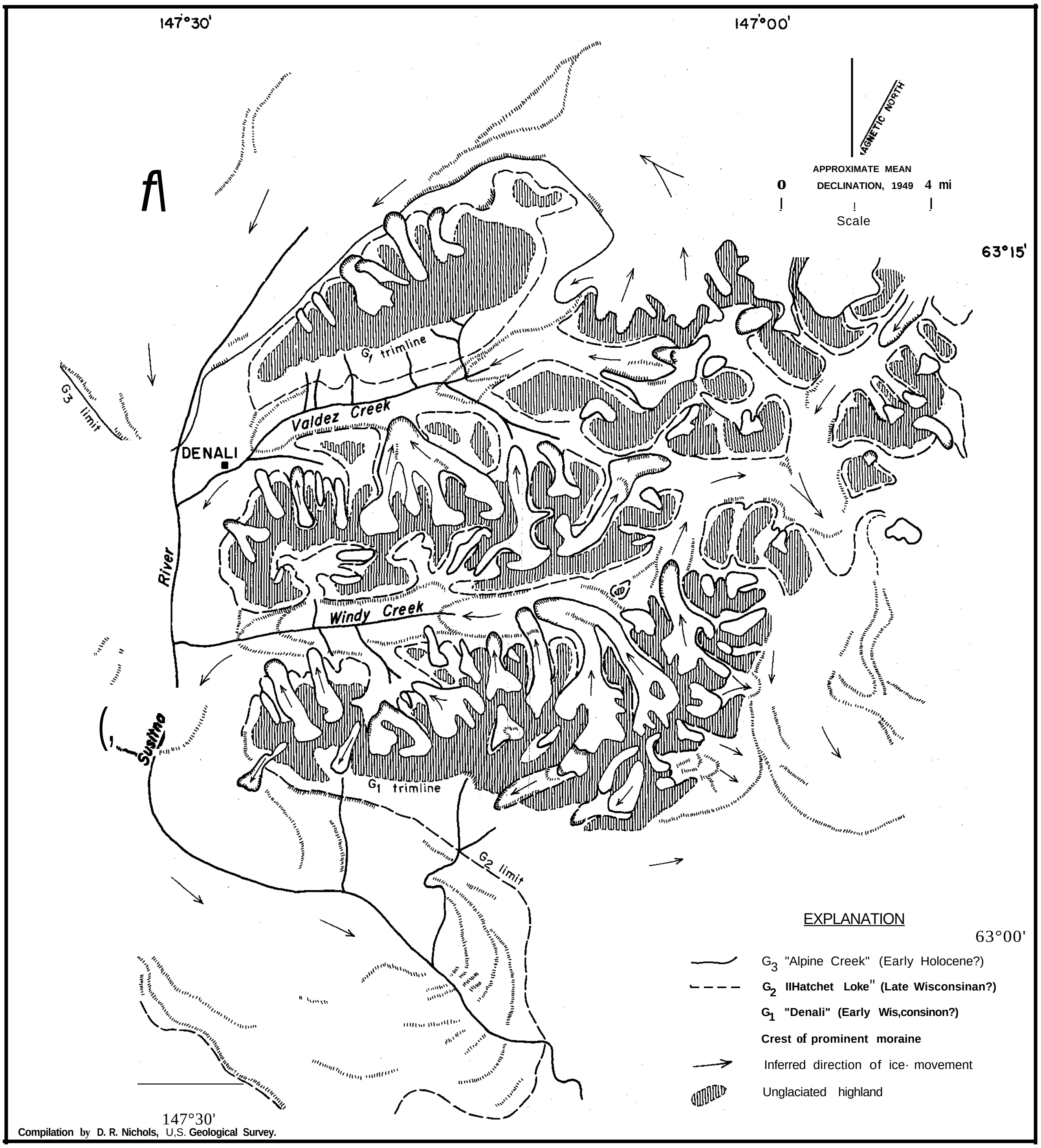


Figure 29. Map showing extent of glacial ice and prominent moraines in Clearwater Mountains.

represent lacustrine deposits formed in an arm of this large proglacial lake; these materials are indicated as undifferentiated glacial and lacustrine(?) deposits (Qu). In addition, some of the material shown on plate 1 as swamp deposits (Qs) may consist largely of lacustrine sediments that accumulated in small depressions on original drift surfaces and are now overlain by peat and organic silt of Holocene age.

The glacial deposits have been extensively reworked, particularly in broader valleys, and redeposited as alluvium along most of the streams. Talus cones and compound aprons cover the lower walls of most mountain valleys. With accumulation of interstitial ice, debris flowed to form prominent rock glaciers that are lobate, tongue-shaped, and spatulate (fig. 30). The morphology of several rock glaciers is indicative of current activity, namely steep, bare fronts and sharp angles between the front and upper surfaces (Wahrhaftig and Cox, 1959, p.392).

Vegetated colluvial slopes are common in the area, especially on older erosion surfaces (fig. 31); many slopes show advanced development of solifluction lobes and terraces (fig. 32), illustrative of the periglacial conditions existing since withdrawal of the glaciers. Nivation processes have locally accelerated terrace development.

The following abbreviated lithologic descriptions have been closely paraphrased from the legend of an unpublished preliminary map compiled by Hopkins, Kachadoorian, and Nichols (1953). Inasmuch as their investigation is peripheral to the intent of the present study, only a summary of the descriptions is reported here.

Other deposits, in addition to those listed below, mantle valley sides and cirque walls of the region. Steeper slopes are flanked by coalescing talus cones or aprons of rubbly, angular deposits of shattered, loose bedrock debris carried downslope by gravity. Colluvial materials composed of heterogeneous mixtures of frost-derived materials from upslope cover many slopes of the region. Inasmuch as both types of deposits are of local derivation and merely reflect underlying bedrock lithology, they are not differentiated from bedrock on plate 1.

Figure 30. Active(?) rock glacier in upper White Creek drainage.

Figure 31. Former erosion surface in Clearwater Mountains.

DEPOSITS OF EARLY WISCONSINAN(?) TO EARLY HOLOCENE AGE

GROUND MORAINE COMPLEX (Qg)

This unit includes till and minor amounts of washed material. Surface topography varies from irregular in the youngest deposits in upland valleys to subdued older forms in major valley bottoms. Well-defined channels from 5 to more than 50 feet deep are locally incised into the till surface. This unit also includes sharp-crested eskers and kames formed under glaciers of various ages (fig. 33).

Occasionally bedrock on high upland surfaces is sporadically mantled with till from the pre-Wisconsinan 'pre-Denali' glaciation. These areas are not differentiated from younger deposits on plate 1.

MORAINAL DEPOSITS (Qm)

Lateral, medial, and terminal moraines form ridges and irregular topography in valley bottoms and sides; kettles and lakes often dot the morainal surface. The moraines are composed mainly of coarse rubbly till, except in larger valleys where a sandy and silty matrix is more common. Numerous pockets of well-washed sand and gravel are common.

OUTWASH DEPOSITS (Qo)

These deposits consist of sorted and bedded sands and gravels lying generally in front of synchronous

Figure 32. Solifluction lobes and terraces on slope east of Lucky Gulch.

moraines. Some were deposited on stagnant ice which has since melted, deforming or destroying bedding and resulting in pitted deposits.

DEPOSITS OF HOLOCENE AGE

ALLUVIAL FANS (Qaf)

Fans include poorly sorted gravels and sands ranging from coarse, bouldery gravel at the apex to sand and silt at the toes. Many contain varying amounts of wood and peaty organic material.

ALLUVIAL PLAINS (Qas)

Alluvium includes bedded and sorted river and stream deposits ranging from clean, medium gravel near glaciers and in high valleys to fine sand and silt in the lower reaches of large rivers.

SWAMP DEPOSITS (Qs)

Swamp deposits consist of thick accumulations of silt and sand with large amounts of intermixed vegetative matter in areas of poor drainage. Standing water may be present during wet summers, after winters of heavy snowfall, or near rivers that periodically flood. Away from rivers, swamps are probably old drained lake basins.

ROCK GLACIER DEPOSITS (Qr)

Rock glaciers form in cirques and protected mountain valleys by accumulation of shattered bedrock rubble and downslope movement. They contain varying amounts of silt and interstitial ice. Only a few are considered active.

INTRUSIVE ROCKS

INTRODUCTION

Plutonic and hypabyssal rocks of the western Clearwater Mountains show a wide compositional range from alkalic pyroxenites to tonalites and quartz monzonites. The largest bodies are principally of granodioritic and quartz-dioritic composition and form much of the bedrock in the northern part of plate 1. Numerous small stocks and dikes of slightly more diverse compositions have intruded the pelitic and volcanic sequence south of the larger granodiorite bodies. In the following discussion, the intrusive rocks are considered as individual entities, though in part series-related; they are indexed by location in figure 34. Available radiometric ages determined for this study are also shown. Figure 35 shows a classification of many such intrusions in the map area by normative feldspar content. This classification establishes a basis for the assignment of rock names in the following discussions of individual bodies.

The various igneous rocks exposed in the Clearwater Mountains may be conveniently divided by chronology and chemistry into three main groups. The first and oldest consists of tholeiitic lavas of the Amphitheatre Group, now metamorphosed, which form the long east-west-trending volcanic belt through this part of Alaska. A second group is represented by the alkalic gabbro of Eldorado Creek (Jag), Late Jurassic in age, which exhibits a wide fractionation range. The large granodiorite and quartz diorite bodies in the northern map area and satellitic offshoots of the same magmatic series (TKgd, Kqd, d, s, Ki, pl. 1) constitute the third and youngest group of Cretaceous and earliest Tertiary age. A diagrammatic representation of the three groups is provided by smoothed Alk-F-M trends in figure 36.

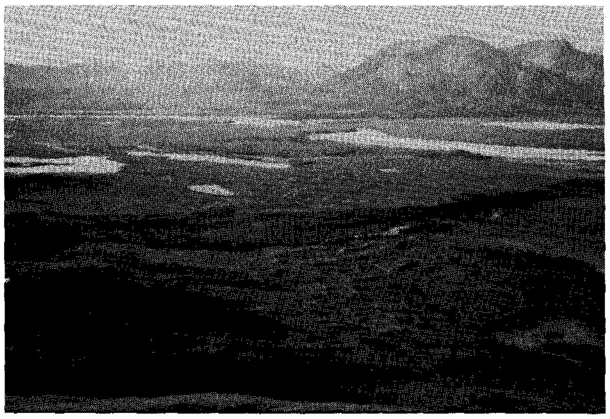


Figure 33. Kame-esker complex near mouth of Windy Creek.

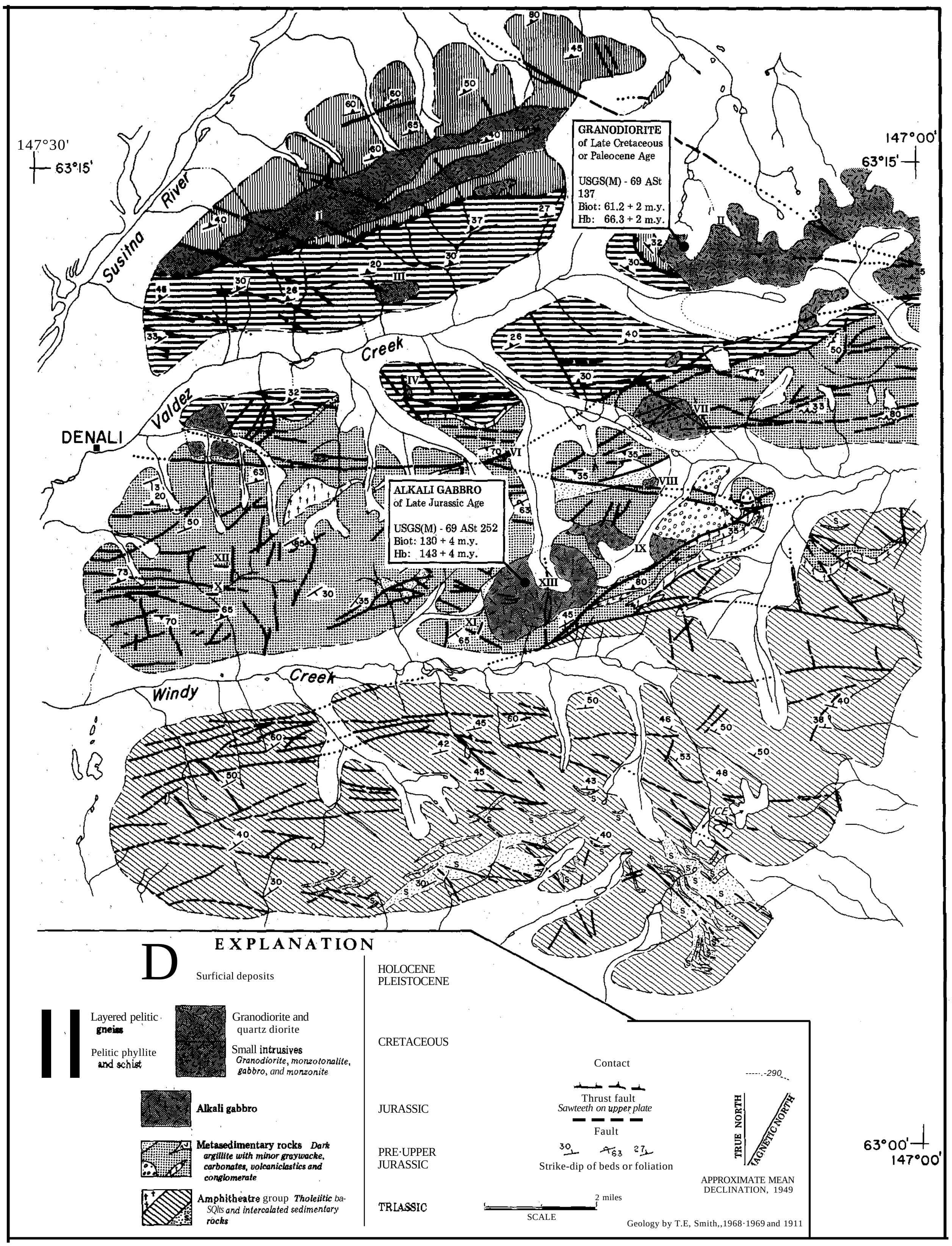


Figure 34. Index map and. ages of intrusive bodies.

FOLIATED QUARTZ DIORITE (Kqd) (INTRUSIVE BODY I)

The ridgeline north of Valdez Creek is underlain by a foliated sill-like intrusive body about 3/4 mile wide' and 7 miles long. It is dominantly quartz diorite, but locally it grades into areas of mafic quartz diorite and, less commonly, into felsic variants with only 10 or 15 percent mafic components. Foliation in this body is parallel to that of adjacent metamorphites, which it intrudes. The planar texture is the result of a very slight granulation and metamorphic recrystallization of an original igneous texture with concurrent growth of subparallel biotites.

Numerous xenolithic slivers and lenses of gneiss and high-grade schist are preserved within the sill, some of which are shown on plate 1. In the eastern part of the unit the sill is divided by a large septum of paragneiss that is about 1,000 feet thick and at least 3 miles long.

All such inclusions of metamorphic country rock closely parallel the prevailing foliation attitudes and preserve their high-grade mineral assemblages, including some relict sedimentary structures such as delicate helicitic trains of graphite through porphyroblastic minerals. The fact that these metamorphic inclusions persisted within the igneous body, either stably or metastably, implies that the quartz dioritic magma was intruded between kinematic events along the schistosity

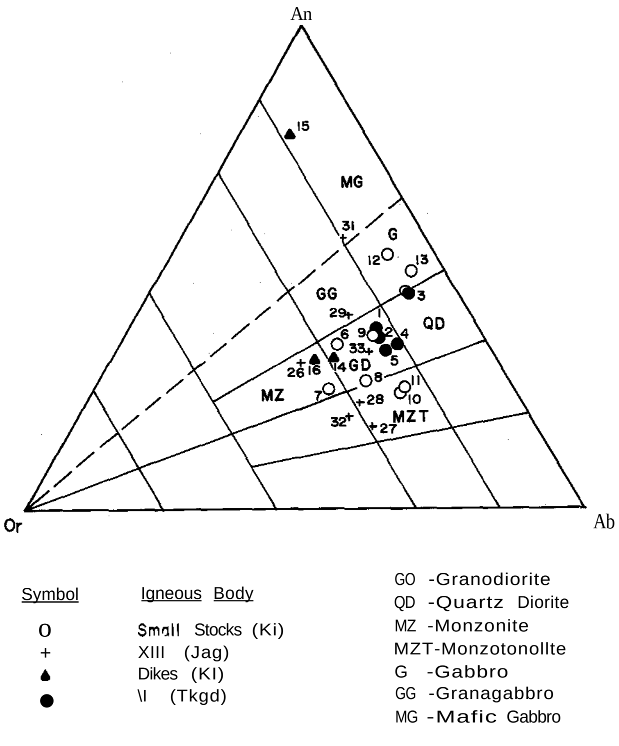


Figure 35. Classification diagram for intrusive rocks of Clearwater Mountains using normative feldspars.

of previously existing high-grade metamorphites, solidified, and was sheared and annealed by continued metamorphism.

The gneissose fabric of the quartz diorite and its inclusions was reported in earlier work in the region. Ross (1933, p. 440) notes that much of the intrusive body appeared almost as schistose as the schist it intruded. Both he and Moffit (1912) mistakenly considered the southern contact of the quartz diorite to be the edge of a large batholith extending to the north, and attributed the entire metamorphic belt to contact effects along its margin.

The body and its inclusions as well as nearby country rock were invaded later by granodiorite and quartz-diorite magma, forming small veins, dikes, and sills. Most of these are fine grained, equigranular, nonfoliated, and more leucocratic than the main quartz-diorite body.

Less weathered outcrops in the quartz diorite are generally light or medium gray and commonly show the platy fracture habit of the crudely foliated rocks. In most exposures the rocks show medium- or coarse-grained phanerocrystalline textures with average grain sizes between 1 and 3 mm, but with mildly lenticular feldspar porphyroclasts to 5 mm. Granulation and recrystallization effects have not been extreme in these rocks; consequently, their megascopic appearance is more that of an equigranular, granitoidal rock than that of a metamorphite. Little or no compositional banding is evident in the unit, in contrast to the distinct segregation layering in adjoining paragneisses.

The modal composition of the unit, estimated in numerous hand specimens and several thin sections, is approximately 45 percent plagioclase, 25 percent quartz, 25 percent biotite, and 4 percent hornblende with minor sphene, muscovite, apatite, clinozoisite, magnetite, graphite, and chlorite as accessories. Sparsely distributed almandine garnets are present in some of the rocks.

Slightly cataclastic textural elements occur throughout most of the unit, illustrating the penetrative deformation during metamorphism. Larger porphyroclastic igneous plagioclases of composition An32-An39 are broken and show deformation twinning, ragged borders, relict euhedral oscillatory zoning, and patchy mottling. Adjacent recrystallized grains of smaller size are generally unstrained and unzoned. Most of the larger quartz crystals exhibit strain lamallae and sometimes minor mortar structure; most grain boundaries are sutured or irregular. Biotite is present as crudely oriented, stubby subhedral or anhedral crystals, many of which include thin graphite plates roughly parallel to (001).

The similarity of trace-element content between the igneous rocks and adjacent gneisses is shown in tables 5 and 6 and in figure 37. The quartz diorite sample shows a slight deficiency of boron, lead, and yttrium and an excess of lanthanum compared with the paragneisses, but is otherwise essentially identical. These data are not sufficient to prove an anatectic origin for the original magma; however, they encourage such an interpretation.

GRANODIORITE PLUTON (TKgd) (INTRUSIVE BODY II)

The largest single exposure of intrusive rock mapped in the present study is in the northeastern part of the map area. The highlands and most of the surficial cover in that area are underlain by homogeneous granodiorite and quartz diorite. The bulk of the unit, represented by the samples plotted as solid circles on figure 35, has normative Or-Ab-An ratios in the granodiorite field, though near the composition of quartz diorite and less commonly trondhjemitic phases with a low mafic content.

Most of the rocks of intrusive body II (TKgd) are medium-light gray and form blocky or rectangular talus with blocks several feet in size. The craggy ridges and debris slopes underlain by these rocks support no vegetation other than scattered lichens and show a characteristic mottled gray tone from a distance (fig. 38).

The contacts of the unit are concordant to discordant with respect to attitudes in surrounding metamorphic rocks. Along the southeastern margin of the pluton the body is moderately to strongly foliated parallel to the adjoining schists. In thin section, this foliation is marked by moderate protoclasis along the border zone. Plagioclases are bent or broken, quartz grains are strained, and biotite and hornblende tend to be crudely aligned, producing the somewhat gneissic texture. The western border of the granodiorite pluton,

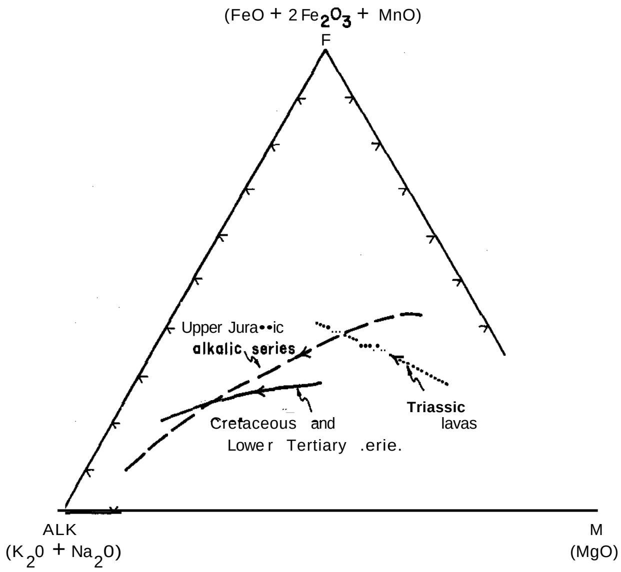


Figure 36. Alk-F-M trend diagram summarizing three main groups of igneous rocks in Clearwater Mountains. Trends drawn by inspection.

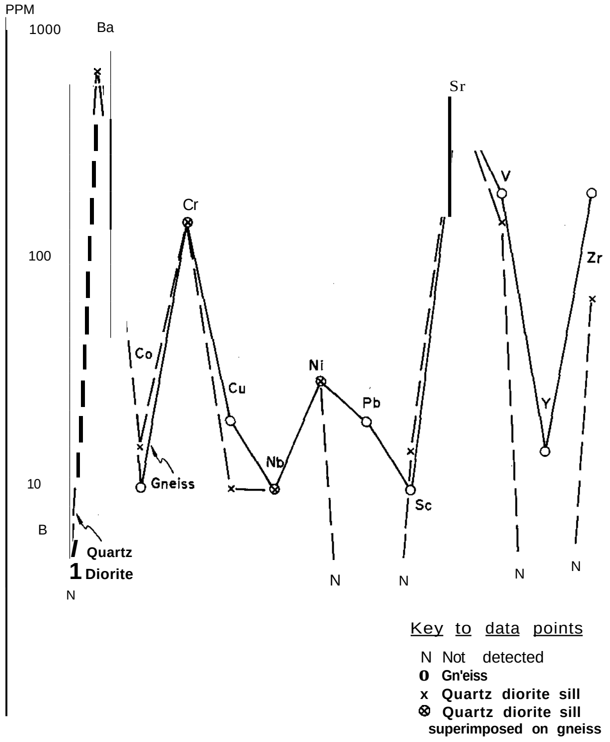


Figure 37. Comparison of trace-element profiles for quartz diorite sill and adjacent average gneiss.

exposed on the ridge north of Grogg Creek, is discordant at a low angle in relation to the gneisses and schists that make up the country rock in that area. In the host, slivers of schist, stretched or rounded xenoliths, and dikes are common along the western margin. The plutonic matrix shows little preferred orientation other than a faint foliation, probably attributable to differential flowage in the liquid state.

Estimated modal compositions of the intrusive body are variable with quartz varying from 8 to 16 percent, plagioclase from 50 to 65 percent, subequal amounts of hornblende and biotite from 20 to 35 percent, and orthoclase from 2 to 20 percent. Sphene, apatite, magnetite, and graphite are typical accessories in most of the rocks examined.

In the interior of the pluton, away from protoclastic or contaminated border zones, textures are mainly allotriomorphic-granular or hypidiomorphic-granular with grain sizes from 1 to 4 mm. Hornblendes are green and spongy or, more rarely, prismatic. Anhedral brown biotites occur interstitially as a replacement of hornblende or less commonly as euhedral books within large plagioclases. Plagioclase crystals in the compositional range An28-33 show a slight normal zoning or in large crystals, a diffuse, shadowy oscillatory zoning. Patchy twinned areas or areas of patchy zoning are also common in many of the plagioclases. Small quantities of interstitial orthoclase, some of which is perthitic, are present in most of the rocks, increasing to 15 per-

Table 6. *Semiquantitative spectrographic analysis of foliated sill, sample 68-ASb-515.*[a] *All values in ppm.*

Ba	700
Co	15
Cr	150
Cu	10
La	30
Nb	10
Ni	30
Sc	15
Sr	500
V	150
Zr	70

[a]Analyst: K.J. Curry of U.S. Geological Survey. Elements looked for but not found: Ag, As, Au, B, Be, Bi, Cd, Mo, Pb, Sb, Sn, W, Y, Zn.

cent or more in the trondhjemitic phases.

The major-oxide and trace-element chemistry and norms of five samples from this unit are provided in table 7. The positions of Alk-F-M ratios for these samples and other bodies in the study area are shown in figure 39. All the rocks from this pluton are slightly to the alkaline side of center on the Alk-F-M plot; their·positions relative to those of other small bodies in the area suggest that many of the smaller stocks may be differentiates of the same magmatic series.

Potassium-argon radiometric ages of biotite and hornblende separated from sample 69-ASt-137 in this body are 61.2 ± 2 and 66.3 ± 2 m.y., respectively (Smith and Lanphere, 1971, p.17). Inasmuch as this body is compositionally and texturally very similar to igneous body I, its emplacement is interpreted to be nearly contemporaneous, the foliated sill being emplaced only slightly earlier. The sill has clearly been involved in the latest episode of dynamothermal activity, and hence the date of igneous body II provides a younger limit of age for intense effects of the regional metamorphic event.

SMALL STOCKS, DIKES, AND SILLS (Ki, d, s) (INTRUSIVE BODIES III-XII)

In addition to the large plutons discussed above, several smaller stocks and hypabyssal bodies have intruded the area of plate 1. The majority of the small bodies examined were emplaced prior to the final stages of the metamorphic event; these show secondary textures and mineral assemblages characteristic of the metamorphic zones in which they are found. By normative feldspar content, the small stocks vary widely in classification from gabbros to granodiorites or monzotonalites as shown in figure 35.

Most of the small stocks (Ki, pI. 1) display medium-grained phanerocrystalline-equigranular or phaneroporphyritic textures, modified to some extent by secondary metamorphic and alteration processes. Widespread development of epidote and chlorite has produced grayish-green colors in most of the rocks. Those emplaced in higher grade metamorphites have slightly cataclastic textures with consequent foliation, and they locally contain secondary pink garnets, some of which are euhedrai. Between the biotite and almandine isograds, intrusive rocks show abundant fine-grained secondary biotite. Within the biotite and lower grade zones, plagioclases are albitized with attendant development of epidote, clinozoisite, sericite, and, in the lowest grade zones, chlorite and prehnite.

Numerous minor hypabyssal intrusives, dikes and sills (d, s, pI. 1) were mapped in this study, chiefly in the area north of Windy Creek. The majority are grayish green, and in the pelitic hosts they weather in positive relief. Like the small stocks, these bodies have been involved in the regional metamorphism and display mineral assemblages characteristic of the various metamorphic zones. Thus, where the dikes have intruded metamorphosed volcanic hosts, the two are virtually indistinguishable.

Numerous samples from the dikes and sills contain essentially unaltered augite phenocrysts, embedded in a pilotaxitic or intergranular matrix now almost wholly recrystallized. Plagioclase phenocrysts and microlites are albitized or sericitized. Abundant clinozoisite and epidote are present throughout the groundmass. Prehnite and chlorite are common components in the lower grade metamorphic zones.

Several of the dikes and small stocks have been important host rocks for small gold-quartz-carbonate vein deposits. These particular bodies show a superimposed hydrothermal-alteration suite consisting mainly of silica, carbonates, chlorite, and pyrite. The role of the intrusives was dominantly passive; they apparently acted as permeable pipelike avenues of entry for mineralizing solutions.

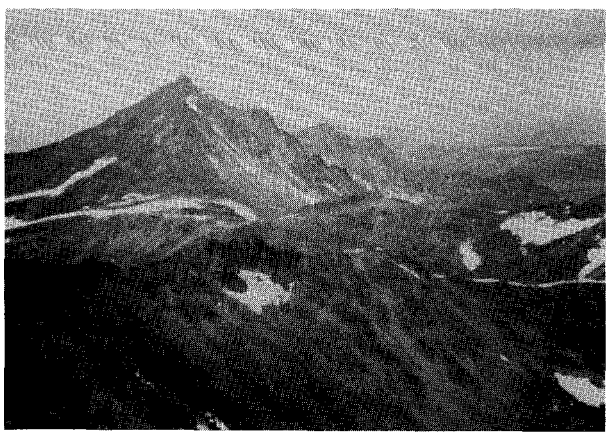


Figure 38. Mottled-gray talus slopes over granodiorite pluton (TKgd). View north from ridge west of Clearwater Creek, in extreme northeastern part of map area.

Table 7. *Analytical and other data from intrusive body II (TKgd) in Clearwater Mountains*

Sample No.	1	2	3	4	5
Field No.	68-ASb-306	68-ASb-312	68-ASb-451	68-ASb-455a	68-ASb-l048c
Igneous body	II	II	II	II	II
Rock type[a]	GD	GD	QD	GD	GD
			Major-oxide analyses (weight percent)[b]		
SiO_2	56.2	58.9	52.5	61.6	60.1
Al_2O_3	17.2	17.0	19.2	17.0	16.6
Fe_2O_3	1.1	1.0	0.65	1.1	1.2
FeO	6.1	5.3	6.5	4.3	4.8
MgO	4.6	4.0	5.0	2.9	3.5
CaO	6.1	5.5	7.6	5.1	5.3
Na_2O	3.3	3.4	3.7	3.7	3.6
K_2O	2.0	2.0	1.0	1.8	2.1
H_2O-	0.18	0.10	0.05	0.05	0.08
H_2O+	1.1	1.1	1.0	1.0	1.2
TiO_2	1.1	0.88	1.4	0.93	0.88
P_2O_5	0.44	0.35	0.46	0.31	0.34
MnO	0.14	0.12	0.13	0.11	0.13
CO_2	0.08	0.05	0.05	0.05	0.08
Sum	100	100	99	100	100
			Semiquantitative spectrographic analyses (parts per million)[c]		
Ba	2000	1500	1500	1500	1500
Co	50	30	30	20	30
Cr	200	200	200	100	150
Cu	50	70	50	20	50
La			30		
Nb	10		15	15	15
Ni	70	70	70	50	50
Pb			7	7	10
Sc	20	20	30	15	20
Sr	1500	1000	1500	1500	1000
V	200	200	200	150	150
Y	20	20	30	15	20
Zr	100	150	100	100	150
Ga	20	20	20	20	30
Yb	2	2	2	1.5	2
			Barth catanorms		
quartz	6.64	10.68	0.88	15.38	12.09
orthoclase	12.02	12.01	5.98	10.79	12.60
albite	30.13	31.02	33.61	33.70	32.83
anorthite	26.66	25.08	33.22	23.29	23.29
corundum		0.22		0.61	
nepheline					
wollastonite	0.27		0.63		0.26
enstatite	12.92	11.22	13.97	8.12	9.81
ferrosilite	7.49	6.58	7.96	4.84	5.66
forsterite					
fayalite					
magnetite	1.17	1.06	0.69	1.17	1.27
ilmenite	1.56	1.25	1.97	1.31	1.25
apatite	0.94	0.74	0.97	0.66	0.72
calcite	0.21	0.13	0.13	0.13	0.21

[a]GD - granodiorite, QD- quartz diorite
[b]Analyses by P. Elmore, G. Chloe, L. Artis. S. Botts, H. Smith, J. Kelsey of U.S. Geological Survey using methods described by Shapiro and Brannock (1962). For location of samples. refer to Appendix.
[c]Analyses by C. Heropoulos of U.S. Geological Survey. Elements looked for but not found: Ag, As, AU, B, Be, Bi, Cd, Pd, Pt, Sb, Sn, Te, U, W, Zn, Ce, Ge, Hf, In, Li, Re, Ta, Th, Tl, and Eu.

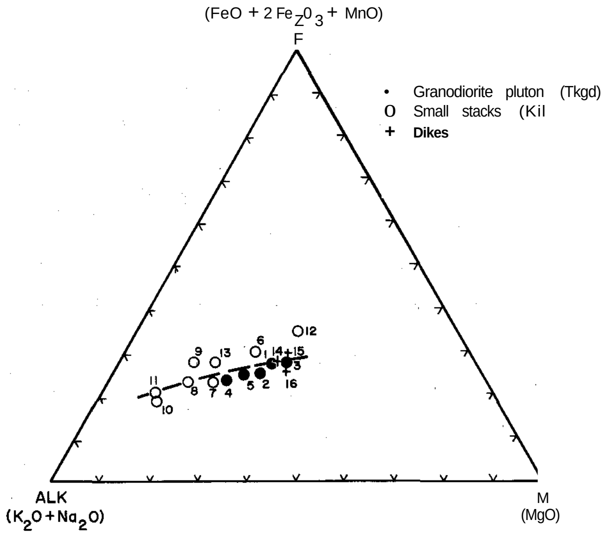


Figure 39. Alk-F-M variation diagram for igneous rocks of Cretaceous and early Tertiary age. Note that small stocks and dikes may be derived from same magma series as large granodiorite body.

ALKALI GABBRO PLUTON (Jag) (INTRUSIVE BODY XIII)

The oldest intrusive rock in the Clearwater Mountains underlies approximately 2 square miles of the upper drainage basin of Eldorado Creek (pl. 1). K-Ar ages of hornblende from monzonite and of biotite from theralite in the stock are 143 ± 4 and 130 ± 4 m.y., respectively (Smith and Lanphere, 1971, p. 17). Hence its emplacement antedates the main regional metamorphic event by some 50-70 m.y. Static thermal metamorphism of the stock in the pumpellyite-prehnite-quartz facies has blurred original plutonic textures, has thoroughly redistributed its elemental components, and has resulted in the discordance between biotite and hornblende ages.

Rock types in the pluton compose an extremely heterogeneous, subsilicic series of alkali gabbros, ranging from mafic theralites through essexites and monzogabbros into monzodiorites and monzonites. Because of the mineralogical reconstitution during metamorphism, particularly of leucocratic components, all classifications are based on normative mineralogy, shown diagrammatically in figure 40.

Mafitic end members of the series consist dominantly of augitic pyroxene (2V = 45-50^0) with interstitial hornblende, biotite, and nepheline. Titanium-iron oxides

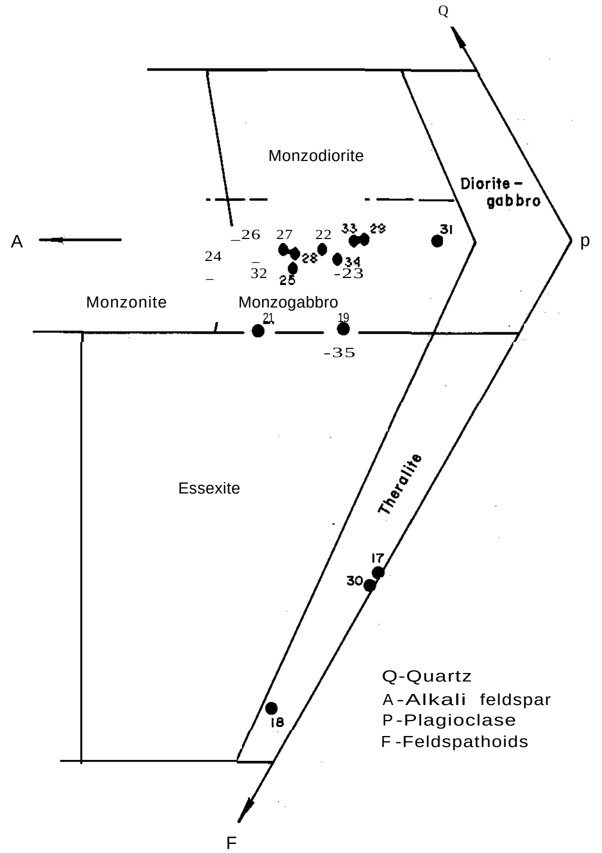


Figure 40. QAPF classification diagram of rocks from alkali gabbro pluton (Jag). Normative mineralogy from Streckeisen (1967, p. 172). Sample numbers correspond to analyses in table 9.

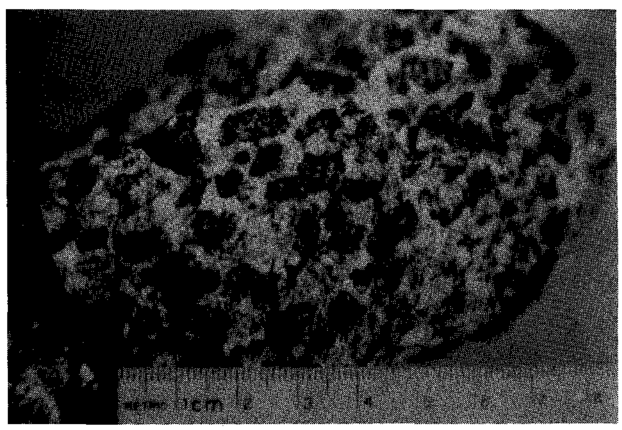


Figure 41. Hornblende-rich monzogabbro (Jag). Leucocratic phases are nepheline and K-feldspar. Pale-gray areas are altered plagioclase; sample 69-ASt-236.

Figure 42. Pyroxene-rich theralite (T) veined by light monzonite (M). Note dark hornblende reaction rims on theralite inclusion.

vary in abundance to about 10 percent. Strongly biotitic variants of the theralite (for example, sample 18 of fig. 40) probably represent contaminated theralites otherwise compositionally similar to samples 17 and 30.

The bulk of the unit consists of hornblendic monzogabbro (fig. 41) as classified in figure 40. The monzogabbro and the theralitic forerunners of the series are both strongly diked and veined by monzodiorite and monzonite (fig. 42) which, on one 1,200-foot-Iong exposed cliff face, make up approximately 8 percent of the total volume. The nonsystematic fractures into which this late phase was intruded are interpreted as shrinkage voids produced during freezing of the gabbroic magma, perhaps in a hood zone.

Remnant igneous textures illustrate a classical reaction series from the mafic end members to rocks composed mainly of orthoclase and altered plagioclase. Mantling of pyroxene-bearing host rocks by hornblende is common where it is intruded by monzonitic phases (fig. 42). Low-grade metamorphism of the original igneous assemblages has produced the expected suite of secondary minerals; plagioclases are replaced by sericite, muscovite, epidote, clinozoisite, and quartz, though some albite persists locally. Clinopyroxene and hornblende are partially converted to actinolite, sodic hornblende or chlorite. Murky, dense patches of inclusions are present in most primary orthoclases.

PETROCHEMISTRY

Chemical analyses and norms of plutons and dikes are listed in table 8. Alk-F-M ratios for these bodies are plotted in the variation diagram (fig. 39) along with those from the large granodiorite and quartz diorite bodies exposed in the northern part of the map area. Most of the plots for stocks, dikes, and large bodies form a comparatively smooth trend, suggesting they may be related as a simple magmatic series. Slight departures of several samples toward the 'F' end member could be explained by superimposed pyritization following an essentially isochemical metamorphism. An inspection of figure 39 shows that the pyroxene-bearing dikes in the area represent the mafic end of the series and are compositionally similar to parts of intrusive body II. The small stocks in the region occupy points along the entire range in the series, forming its most felsic extreme.

Assuming these small intrusives are related in a single series as figure 39 would imply, a simple sequence of intrusive activity might be tentatively inferred, with an early intrusion of dikes followed by injection of the larger bodies and felsic stocks. This simple sequence is partially inconsistent with field or textural relations and the age of intrusive body II (61-66 m.y., pl. 1). All intrusive rocks except the large granodiorite pluton (TKgd) were affected by the latest episode of metamorphism. Dynamic activity during the episode deformed all minor intrusives in the northern part of the area, including the quartz diorite sill (Kqd). If a simple fractionation series determined the intrusive sequence, igneous body II would also have undergone metamorphism in the latest event. Its field and textural relations, however, seem to preclude that interpretation. Rather, it seems reasonable to conclude that most of the igneous bodies in the study area are series-related but that their emplacement sequence is moderately complex, probably extending throughout Late Cretaceous and earliest Tertiary time. The polyphase metamorphic event occurred during the same time interval and was periodically punctuated by intrusion from the same series. Reconnaissance mapping reveals that much of the terrain north of the map area is underlain by intrusive rocks that also appear unmetamorphosed and megascopically similar to intrusive body II. It is likely that the intrusive rocks of the map area were derived by fractionation, emplaced and cooled during an interkinematic phase, and sheared and recrystallized shortly thereafter; the degree varied with the regional gradient. Intrusion of similar magma continued after the latest dynamic episode and is represented in the map area by intrusive body II, which discordantly intrudes the schists and gneisses. Freezing of this body approximately 61-66 m.y. ago recorded the end of progressive metamorphic and intrusive activity in the area.

A classical scheme of magmatic evolution in the Jag pluton is illustrated by chemical data and textural information. Table 9 (in pocket) provides chemical analyses and Barth catanorms on which variation diagrams for the unit are based. The entire rock series plots as smooth curves on an alkali-lime versus silica variation diagram (fig. 43) and shows a Peacock index of 52.5, well within the alkali-calcic range of composition. Rock analyses plotted on an Alk-F-M variation

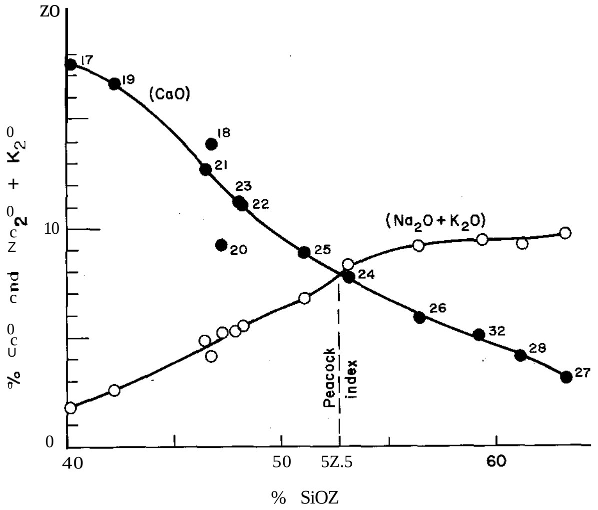


Figure 43. Alkali-lime vs silica variation diagram of rocks from alkali gabbro pluton (Jag). Peacock index for this body is within alkali-calcic range.

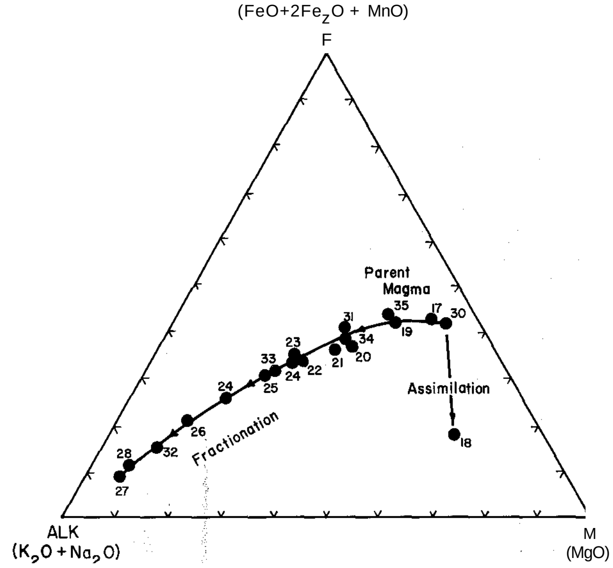


Figure 44. Alk-F-M diagram of rocks from alkali gabbro pluton (Jag). Points correspond to analyses in table 9. Curve shows smooth differentiation from theralite to monzonite veins and dikelets.

diagram show a continuous fractionation from theralitic parent magma to the monzonitic end members (fig. 44). Despite the altered appearances of these rocks, the consistency and continuity of their variation diagrams suggest that metamorphic reconstitution of the stock was essentially isochemicai. Sample 18 is a mafic variant exceptionally rich in biotite; its origin may be ascribed to assimilation of pelitic country rock by theralitic magma. This concept of origin is supported by figure 45, which indicates that a linear mixing of theralite with argillite could produce the bulk chemistry of the biotitic variants.

METAMORPHISM

INTRODUCTION

The systematic, descriptive sections of this report have implicitly considered the various stratigraphic units in a progressive order of deposition and also as products of systematically progressive metamorphism. The oldest and least metamorphosed rocks occupy the southern portions of the map area, whereas younger, more highly metamorphosed rocks constitute most of the bedrock in the northern part of the area. A discussion of the inferred genesis for the inverted metamorphic succession, in terms of mineral zonation and textural evolution, is the central topic of this section. The various charts and diagrams serve also to amplify and synthesize descriptive and chemical aspects of the rocks presented in earlier parts of the report.

ZONATION OF INDEX MINERALS

Gradational aspects of the metamorphic event, increasing in intensity northward, have been mentioned repeatedly in preceding descriptive sections. Each rock unit within the mapped contacts shows the gradation, and succeeding units to the north are, in general, metamorphosed to higher grades, culminating finally in the near-anatectic gneisses and sillimanite-bearing schists south of Boulder Creek and the Susitna River (pi. 1).

Evidence of the steep metamorphic gradient, both mineralogical and textural, suggests a gradation of dynamic as well as thermal components of metamorphism. The metavolcanic unit and southernmost part of the argillite unit contain abundant prehnite and/or pumpellyite and are thus assigned to alteration

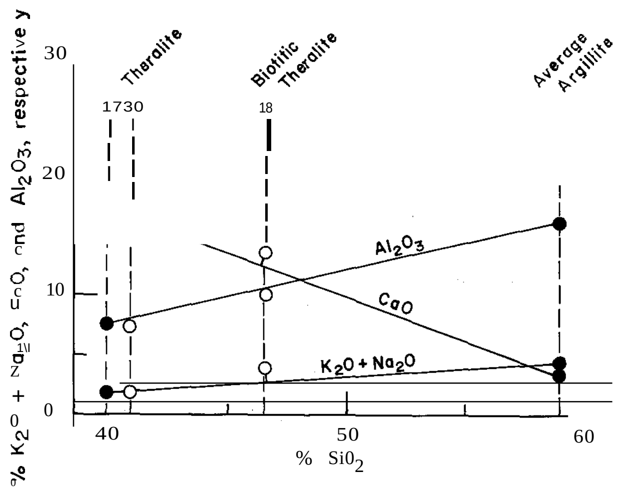


Figure 45. Linear mlxmg diagram showing possible origin of high biotite content in theralite by assimilation of pelitic country rock.

Table 8. *Analytical and other data for small stocks and dikes in Clearwater Mountains*

Sample *No.*	6	7	8	9	10
Field No.	68-ASb-339	68-ASb-343a	68-ASb-386	68-ASb-414	68-ASb-592
Igneous body	VII	VIII	IX	IV	V
Rock type[a]	GD	MZ	GD	GD	MZT
Major-oxide analyses (weight percent)[b]					
SiO_2	53.6	56.8	60.0	56.8	60.4
Al_2O_3	17.0	17.2	17.0	18.8	18.5
Fe_2O_3	2.4	2.0	2.2	2.8	2.1
FeO	5.8	4.5	3.2	3.6	2.5
MgO	4.0	3.1	2.1	1.7	1.4
CaO	7.0	5.8	5.0	6.7	5.1
Na_2O	3.0	3.5	3.8	3.7	5.0
K_2O	3.1	4.3	3.1	2.4	2.8
H_2O-	0.14	0.15	0.06	0.14	0.07
H_2O+	1.9	1.5	1.7	1.1	0.93
TiO_2	0.95	0.71	0.67	0.83	0.55
P_2O_5	0.44	0.36	0.32	0.30	0.23
MnO	0.18	0.14	0.14	0.16	0.15
CO_2	0.18	0.05	0.59	0.36	0.16
Sum	100	100	100	99	100
Semiquantitative spectrographic analyses (parts per million)[c]					
B	N	30	50	10	N
Ba	700	700	700	700	300
Be	N	N	2	N	2
Co	30	20	10	15	10
Cr	30	50	15	2	5
Cu	150	100	50	20	7
La	N	N	N	N	N
Nb	N	N	10	20	50
Ni	20	20	7	1	2
Pb	7	15	10	N	10
Sc	30	20	15	10	7
Sr	1500	1500	1500	1500	1000
V	300	200	150	100	100
Y	30	20	30	30	20
Zr	70	100	150	100	300
Ga	15	15	15	15	20
Yb	3	2	2	2	2
Barth catanorms					
quartz	3.02	2.94	12.50	9.35	7.72
orthoclase	18.83	25.76	18.68	14.51	16.59
albite	27.70	31.87	34.79	33.99	45.03
anorthite	24.44	18.78	19.36	28.24	19.83
corundum			0.48		
nepheline					
wollastanite	2.86	3.08		0.27	1.21
enstatite	11.36	8.68	5.91	4.80	3.88
ferrosilite	6.45	4.88	2.78	2.78	1.88
forsterite					
fayalite					
magnetite	2.58	2.12	2.35	2.99	2.20
ilmenite	1.36	1.00	0.95	1.18	0.77
apatite	0.95	0.76	0.68	0.64	0.48
calcite	0.47	0.13	1.52	0.93	0.41

[a]G _gabbro, GD - granodiorite, MG - mafic gabbro, MZ - monzonite, MZT - monzotonalite.

[b]Analyses by P. Elmore, G. Chloe, L. Artis, S. Botts, H. Smith, J. Kelsey of U.S. Geological Survey using methods described by Shapiro and Brannock (1962).

11	12	13	14	15	16
68-Asb-593	68-ASb-483a	68-ASb-483	68-ASb-44	68-ASb-56a	68-ASb-126c
V	III	III	XII	X	XI
MZT	G	G	GD	MG	MZ
Major.oxide analyses (weight percent)b					
59.2	53.2	58.0	51.2	52.6	53.4
18.7	18.5	20.5	16.0	15".6	15.5
2.1	1.2	1.4	1.8	0.84	2.3
2.9	7.4	3.8	6.4	7.6	5.6
1.4	4.5	2.0	5.2	6.8	5.3
5.8	7.9	8.0	9.1	8.1	7.6
5.0	2.8	3.7	2.9	2.8	2.5
2.6	0.86	0.81	3.1	0.44	3.5
0.03	0.13	0.03	0.11	0.14	0.32
0.91	0.66	0.92	2.5	3.2	2.2
0.51	1.2	0.51	0.93	0.79	0.83
0.24	0.32	0.19	0.56	0.44	0.42
0.14	0.15	0.13	0.15	0.16	0.13
0.18	0.40	0.05	0.10	0.14	0.08
100	99	100	100	100	100
Semiquantitative spectrographic analyses (parts per million)C					
7	N	N	N	7	30
300	500	300	700	150	700
3	N	N	N	N	N
10	30	15	30	30	50
5	30	7	150	200	200
5	15	5	200	150	200
30	N	N	N	N	N
50	15	7	N	N	N
2	2	7	70	150	100
7	N	N	7	10	N
7	30	10	30	20	30
1000	700	500	1500	1000	1000
100	150	100	200	200	200
30	30	15	30	20	30
300	100	70	100	70	100
20	20	15	15	15	15
3	2	1.5	3	2	3
Barth catanorms					
6.11	6.64	11.05		4.66	2.24
15.43	5.19	4.83	18.78	2.70	21.34
45.09	25.70	33.56	26.70	26.08	23.16
20.99	35.34	37.32	22.04	29.78	21.40
	0.33				
2.08		0.48	7.95	3.21	5.66
3.88	12.70	5.58	7.65	19.48	15.10
2.55	9.39	4.45	4.05	10.73	6.31
			5.31		
			2.81		
2.20	1.28	1.48	1.93	0.91	2.48
0.71	1.71	0.72	1.33	1.14	1.19
0.50	0.68	0.40	1.20	0.95	0.91
0.46	1.03	0.13	0.26	0.37	0.21

CAnalyses by C. Heropoulos, U.S. Geological Survey. Elements looked for but not found: Ag, As, Au, Bi, Cd, Pd, Pt, Sb, Sn, Te, U, W, Zn, Ce, Ge, Hf, In, Li, Re, Ta, Th, TI, and Eu.

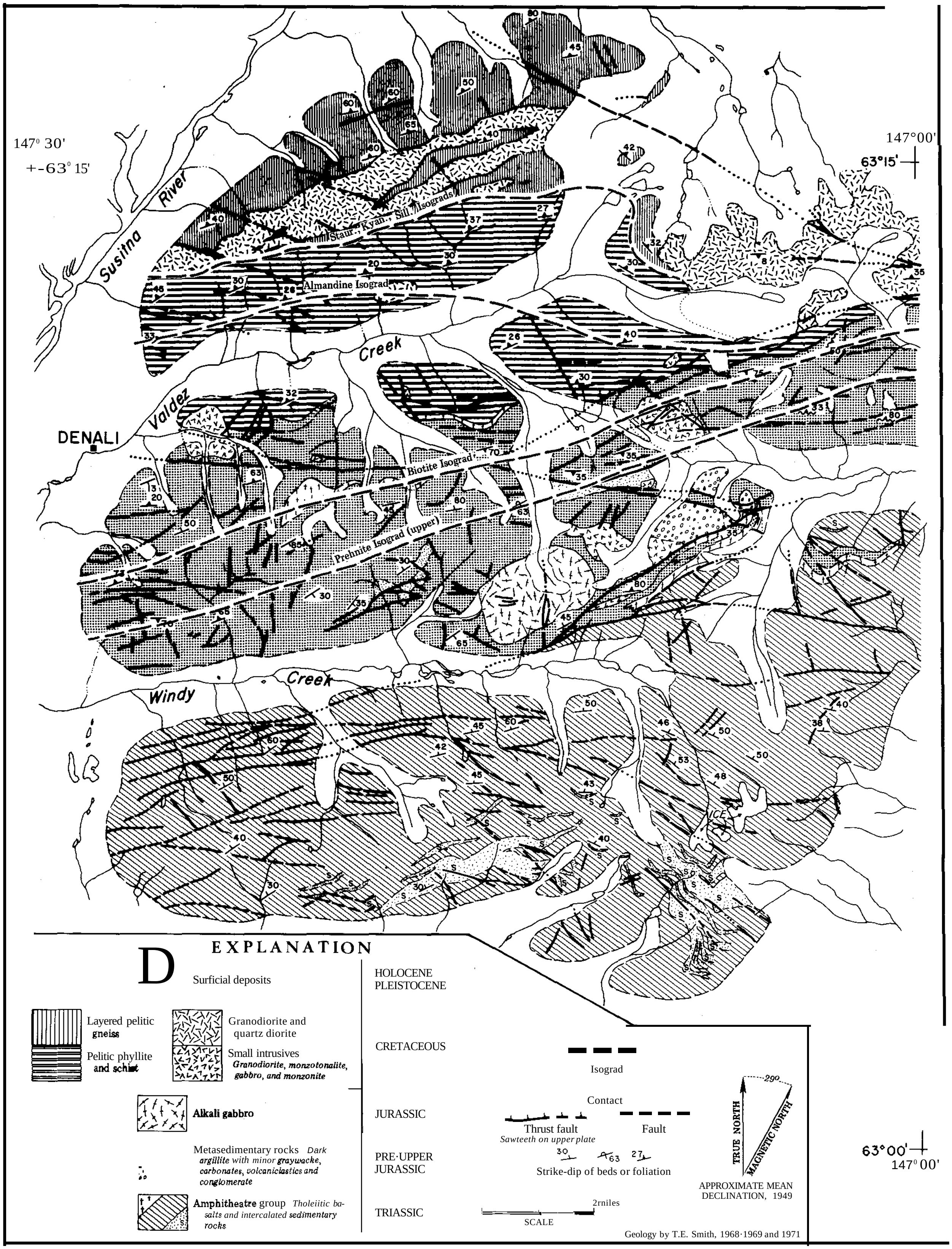


Figure 46. Isograds of index minerals in Clearwater Mountains.

in the pumpellyite-prehnite-quartz facies. With the disappearance of prehnite, the chlorite zone or chlorite-muscovite subfacies of the greenschist facies is attained; this particular subfacies in the map area is confined to the central part of the argillite unit. Occurrence of biotite porphyroblasts along the northern side of the chlorite zone and of almandine north of the biotite zone completes the transitional picture through the three zones of the greenschist facies. The relationship of index isograds to the various map units is plotted on figure 46. Similarly,' the distribution of metamorphic facies inferred from observed mineral assemblages is summarized in figure 47; each zone is mapped on the basis of the highest grade assemblage preserved in the

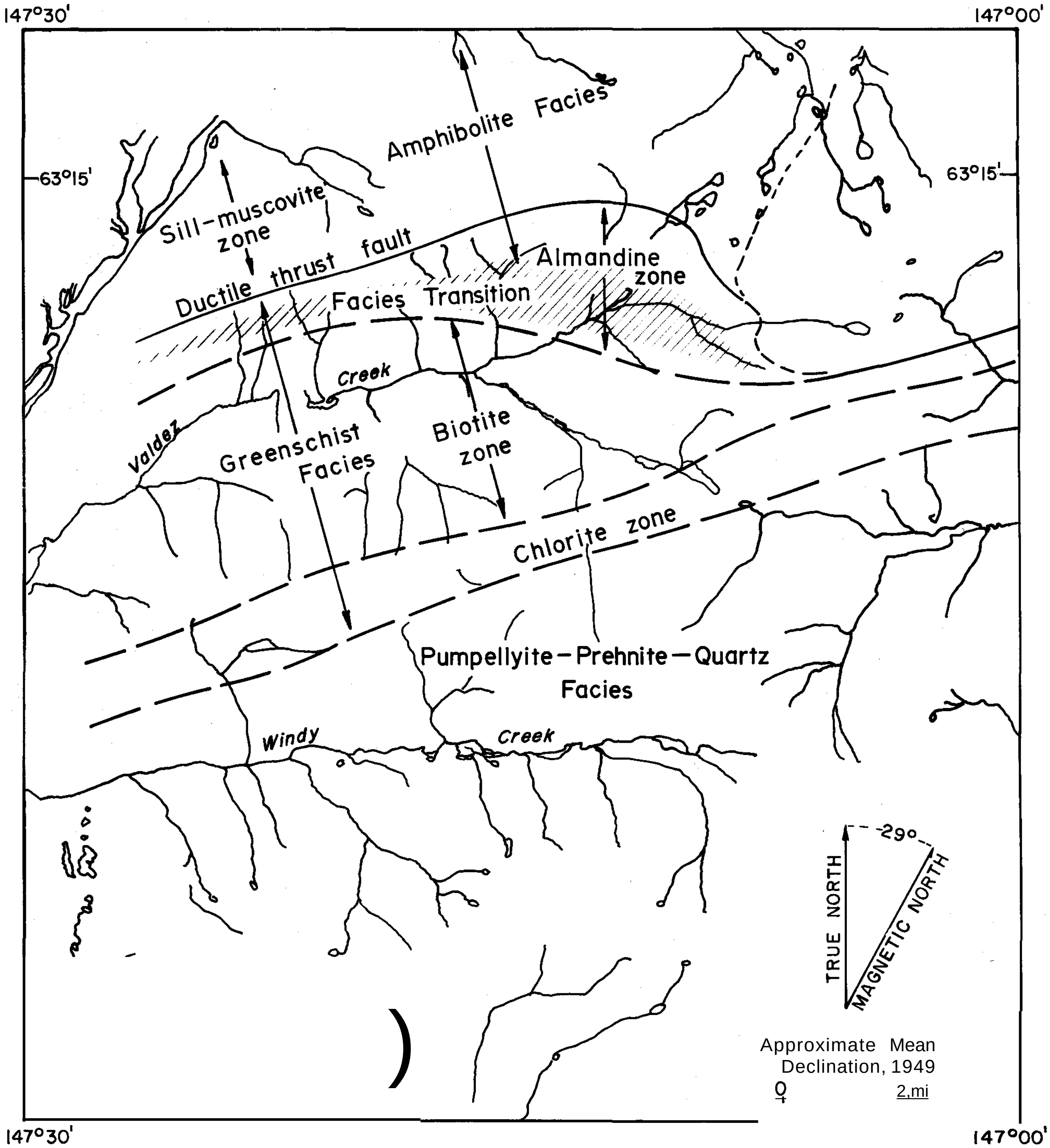


Figure 47. Map showing distribution of inferred facies and mineral zones during peak of metamorphism.

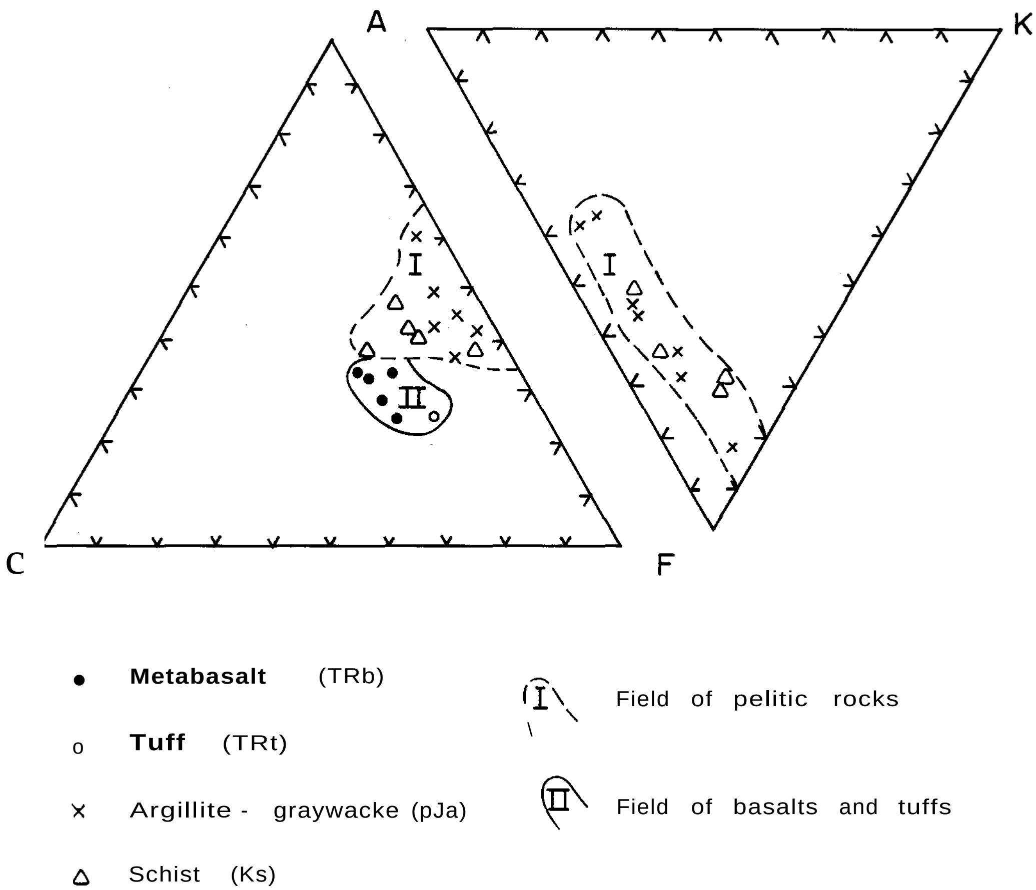


Figure 48. ACF and AKF ratios of regionally metamorphosed lavas, tuffs, and pelitic rocks, Clearwater Mountains.

rocks, neglecting lower grade minerals formed by retrogression of the primary assemblages.

Through the almandine zone of the greenschist facies and lower amphibolite facies, the gradational scheme is one of smooth progression. Rocks recording a transition beyond the almandine-amphibolite subfacies, however, do not preserve a continuous progression; instead they show an abrupt discontinuity into assemblages characteristic of the highest zones in the amphibolite facies, namely, a sillimanite-muscovite zone similar to that described by Lyons (1955) in New Hampshire. Distinguishable staurolite and kyanite zones are missing in the otherwise continuous Barrovian Series. Along the upper part of the almandine zone, sillimanite, kyanite, and staurolite appear simultaneously, often in coexistence. This is represented on figures 46 and 47 as a superimposed isograd or polyisograd.

Figure 48 summarizes major-oxide data in terms of ACF and AKF ternary ratios given previously for rocks of the various map units. Compositions of pelitic rocks (I) from the Clearwater Mountains are bounded by dashed lines, whereas tuffaceous and volcanic rocks (II) are enclosed by a solid boundary. The respective compositional areas are also shown in figures 49a-f, which graphically illustrate mineralogical assemblages for all facies and subfacies in conventional ACF and AKF formats.

TEXTURAL ZONATION AND EVOLUTION

Metamorphic bedrock underlying the Clearwater Mountains, particularly the Valdez Creek drainage area, may be subdivided on the basis of textural development as well as on the basis of diagnostic mineral assemblages. Textural advancement, a result of progressive dynamothermal metamorphism, is an attribute readily apparent in hand specimen and outcrop, and was used as the dominant criterion in selecting map units within the metamorphites. The metavolcanic and argillite units in the southern part of the area preserve primary depositional structures as outlined in previous sections, with little evidence of penetrative deformation except in the immediate vicinity of faults and dislocative zones.

More intense recrystallization of the pelites, with attendant growth of biotite poikiloblasts and simultaneous penetrative shear, produced the spotted phyllites. Primary sedimentary textures in the phyllites are blurred or streaked out into smooth laminations by pervasive deformation. Spiral inclusions of graphite in the biotites indicate a growth rotation of 70^0 to 90^0 (fig. 50a), suggesting a shear strain of about 1.3:1 across the surface intercepted by the porphyroblast. North of the phyllites in the schist unit, a record of increasing shear, essentially parallel to original bedding, is shown by spiral inclusions in almandine, quartz, and biotite in ribbon or "sliced" structure (Spry, 1969, p. 294), by rotated hornblendes with foliate helicitic inclusions, and by essentially continuous micaceous surfaces passing

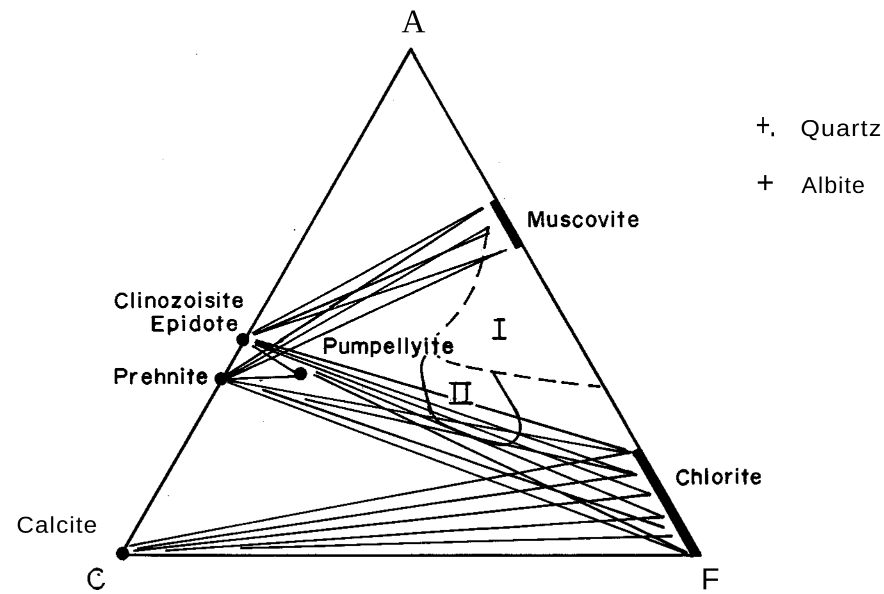


Figure 49a. Pumpellyite-prehnite-quartz facies, including metavolcanic and metapelitic rocks.

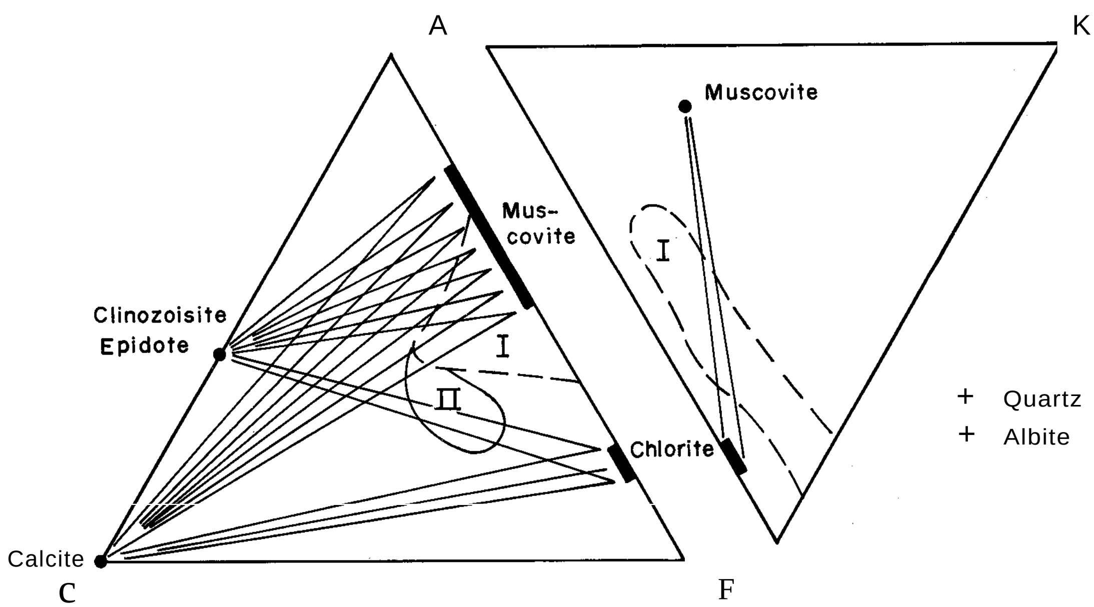


Figure 49b. Chlorite zone, greenschist facies.

Figure 49. ACF-AKF diagrams showing most typical mineral assemblages in various zones and subzones of metamorphic belt. Compositional ranges of minerals after Turner (1968). Dashed tie lines are calc-magnesian assemblages recrystallized from former tuffaceous horizons. Fields of analyzed rocks (I and II) keyed to figure 48.

around resistant, lenticular fabric elements (figs. 50a-d).

At the northern margin of the schist unit, corresponding to the upper limit of the almandine amphibolite subfacies, the rocks display a distinct textural discontinuity as they pass into the gneiss unit, the transition occurring over about 300 feet and paralleling the schistosity. This textural break coincides with the transition into sillimanite-bearing assemblages. Smoothly weathering homogeneous schists below and south of the transitional zone give way to craggy-weathering layered and migmatitic gneisses above and north of the poly-isograd. The differing physical character of the rocks across the zone is well shown on the ridge north of Grogg Creek (fig. 25). This contact is interpreted as a ductile thrust zone developed during metamorphism along which the northern rocks have been uplifted, thus placing the highest temperature assemblages against the lower grade rocks of the amphibolite facies.

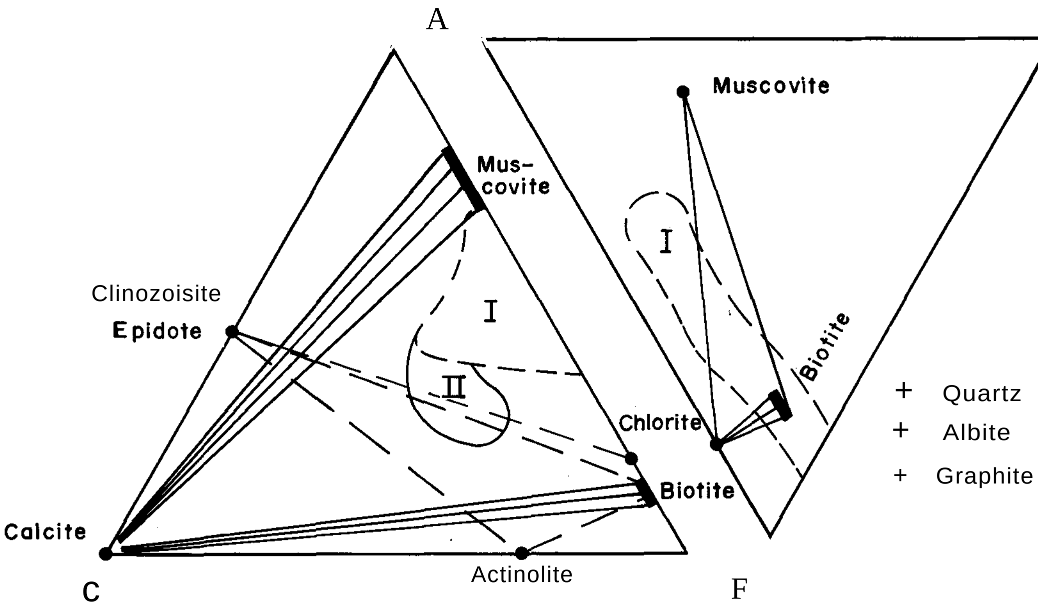


Figure 49c. Biotite zone, greenschist facies.

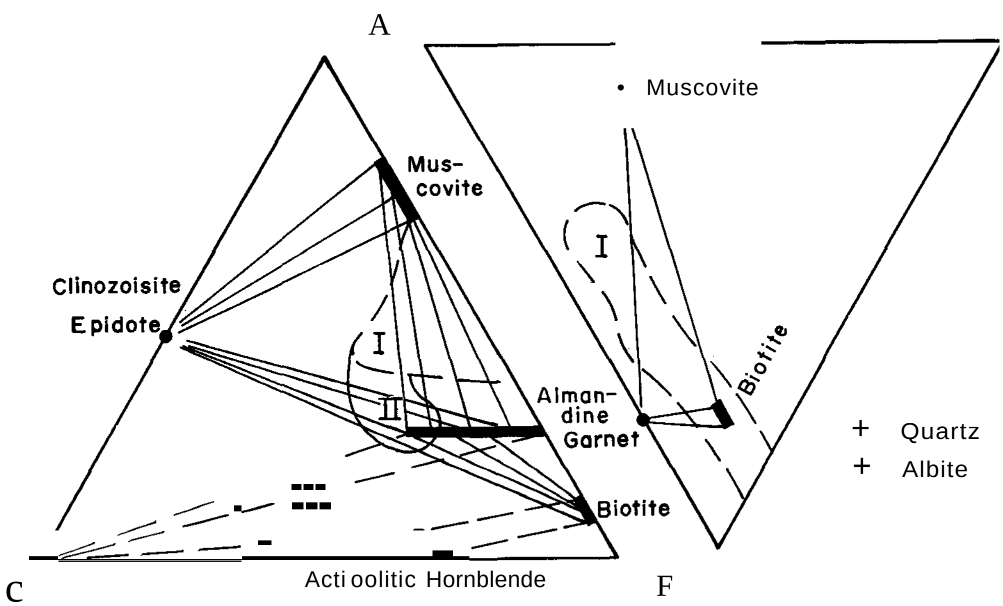


Figure 49d. Almandine zone, greenschist facies.

Textures of the gneisses are indicative of extensive dynamothermal crystallization. as well as mechanical and chemical segregation into quartzo-feldspathic and micaceous layers, lending a maculose appearance to foliation surfaces. The gneiss unit was apparently an elongate zone of high shear mobility during an early kinematic episode of the polymetamorphic event and preserves numerous intrafolial 'drag' folds, thus documenting a reverse movement in the rocks (fig. 51). The large foliated sill (Kqd, igneous body I) is thought to have been intruded into this mobile zone toward the end of early shearing or perhaps interkinematically before a final episode of shearing, which is now decipherable in the distorted igneous textures of the sill and other closely synchronous intrusive bodies across the area. Had the period of shearing been simply one extended episode, with synkinematic intrusion of molten material into the sill zone, subsequent shear dislocation should

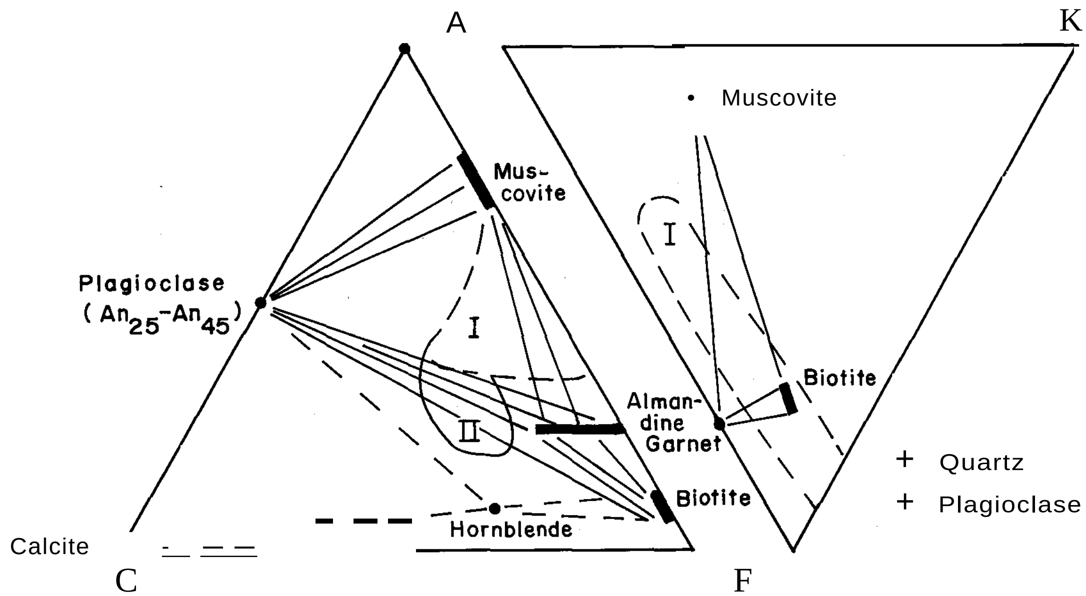


Figure 4ge. Almandine zone, amphibolite facies.

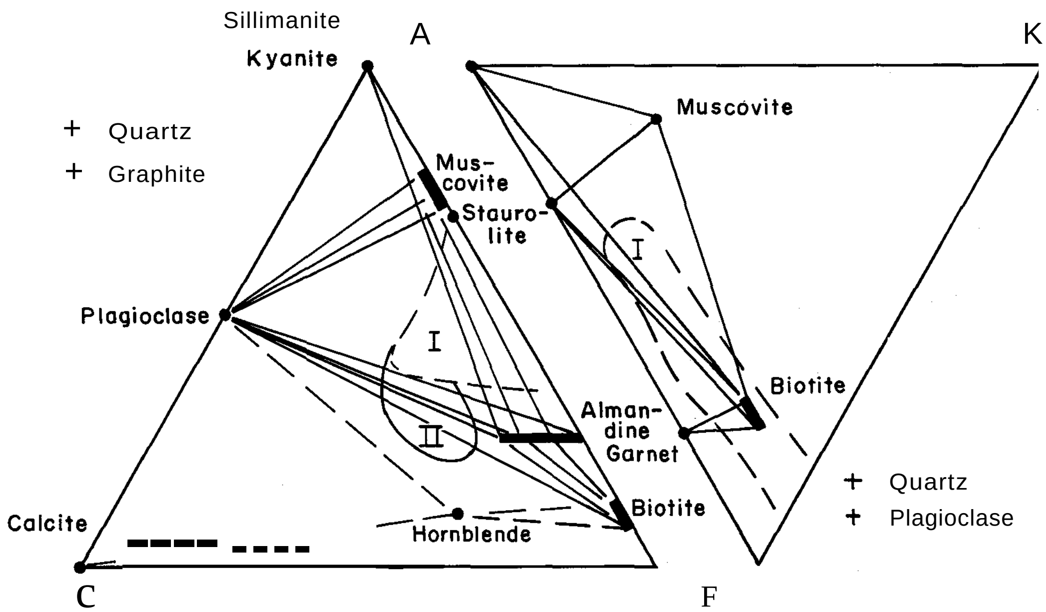


Figure 49f. Sillimanite zone, amphibolite facies.

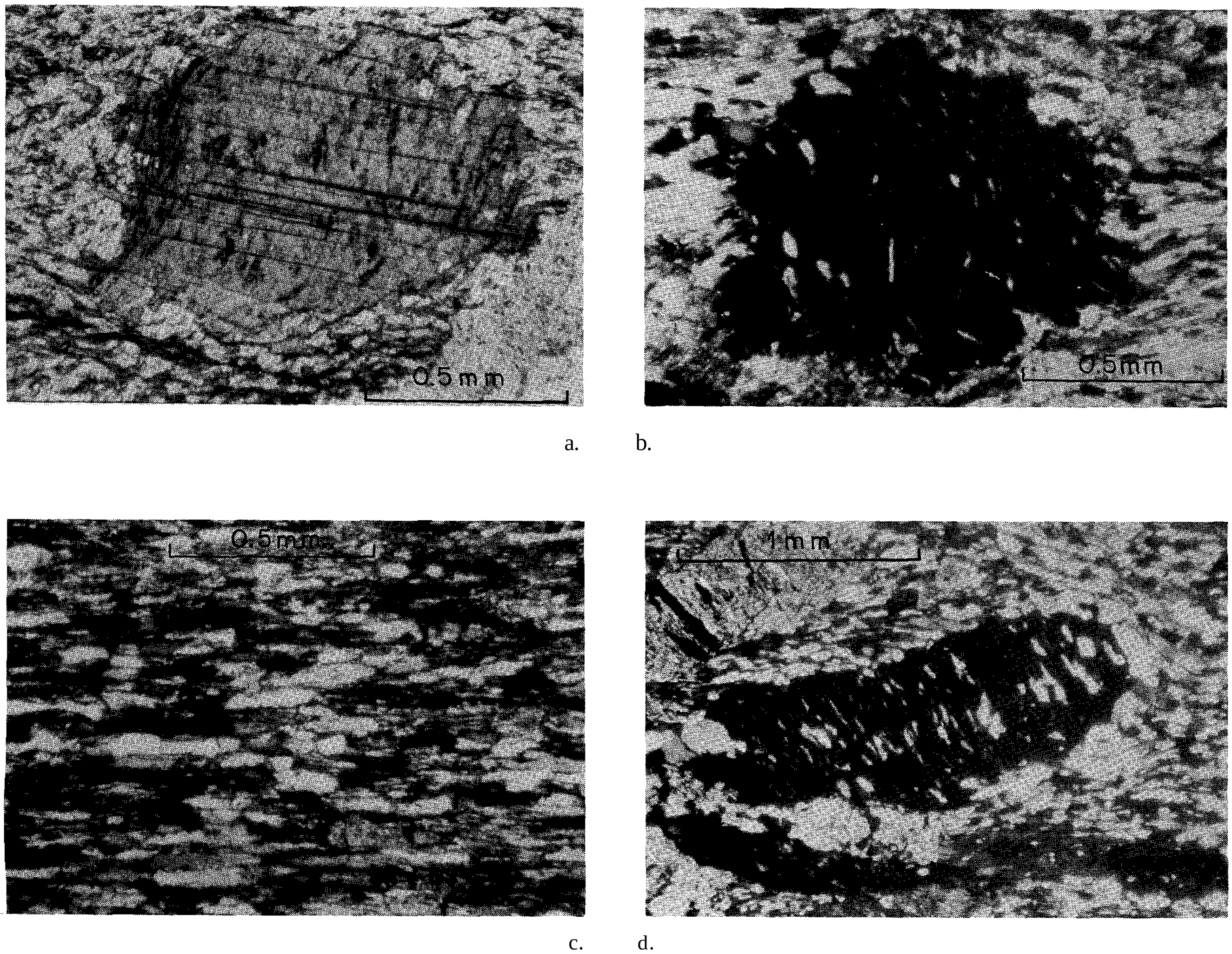


Figure 50a-d. Photomicrographs illustrating microtextural evidence for intrafolial shearing in metamorphites. Planes of schistocity are horizontal. (a) Spiral inclusions of graphite in biotite from phyllite (Kp); plane light; sample 68-ASb-633. (b) Spiral inclusions of quartz in almandine garnet from schist unit (Ks); crossed nicols; garnet in extinction; sample 68-ASb-640. (c) Ribbon-structured quartz (light mineral) in schist (Ks); crossed nicols; sample 68-ASb-514. (d) Helicitic textures in amphibole porphyroblasts showing postgrowth rotation; crossed nicols; amphibole inextinction and in pale gray; sample 68-ASb-632.

have been confined to the fluid magma. In such a situation, appreciable shear stresses could not have been transmitted to the adjoining metamorphites.

The numerous disoriented hornblendes and garnets, which preserve helicitic remnants of older foliation, are interpreted to have grown during a dynamically quiescent period and later rotated by shearing. For these reasons, the metamorphic event is assumed to include at least two dynamic episodes, as summarized schematically in figure 52.

With the cessation of dynamic components, the metamorphism was transformed into an extended thermal event, during which micas were polygonized and dynamothermal garnets were mantled with idioblastic rims and to some degree homogenized internally. Static thermal crystallization during this period gave rise to the postkinematic staurolites and kyanites, now observable as idioblastic forms in the rocks. Many of these, like the garnets, may have nucleated dynamothermally and developed their final outlines in the thermal phase.

Most of the rocks show an overprint of retrogressive thermal metamorphism. Almandine locally exhibits well-developed atoll structures (figs. 24 and 53) that are interpreted as selective replacement of internal zones by biotite, quartz, and chlorite (Rast, 1965). Porphyroblasts of chlorite crosscut primary metamorphic fabrics and further attest to mild retrograding, probably during waning stages of the main

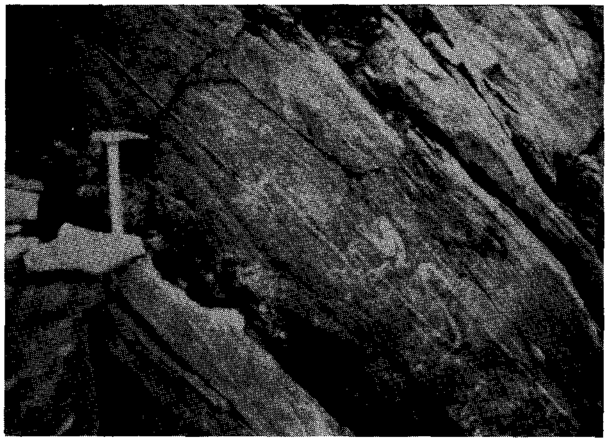


Figure 51. Intrafolial folds in gneiss (Kgn) showing reverse displacement. View west on hill VABM "Teddy" 6092 south of Susitna River.

event. A potassium-argon age determination of fine-grained biotite separated from the almandine zone of the schists suggests that metamorphism concluded duro ing the Paleocene Epoch, about 57 ± 2 m.y. ago (Smith and Lanphere, 1971, p. 20), when the biotites became a closed chemical system to radiogenic argon.

A summary of microtextures illustrating the progressive textural evolution of the pelites from undeformed argillite to sillimanite.bearing paragneisses is provided in figure 54. Microtextures interpreted as indicative of extensive shear in the rocks are shown in figure 50a-d. Intrafolial folds documenting uplift on the north are shown in figure 51. Measuring dislocation by using displacements of folded layers alone suggests a minimum shear strain of 1:1 in the area of figure 51. In a very general way, the sequence of textures across the region, shown by photomicrographs, may be envisioned also as the time sequence of textures and minerals that appeared during development of the higher grade rocks; the highest grade gneisses probably closely resembled the argillites and intermediate metamorphites at earlier stages of their evolution.

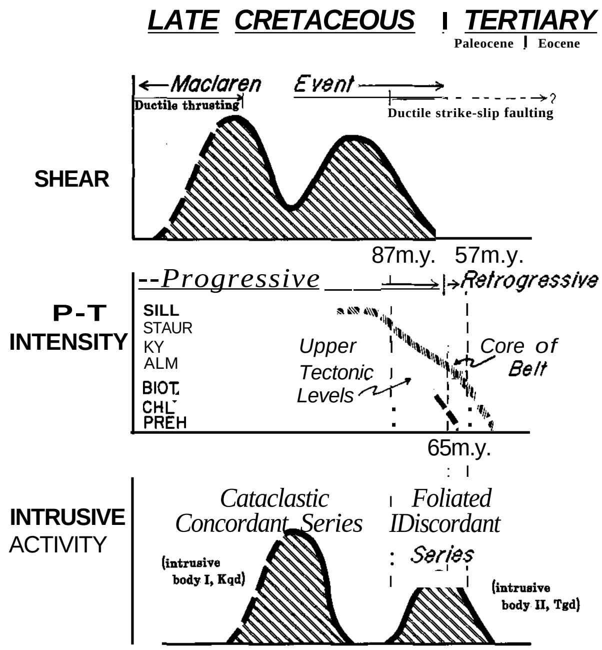
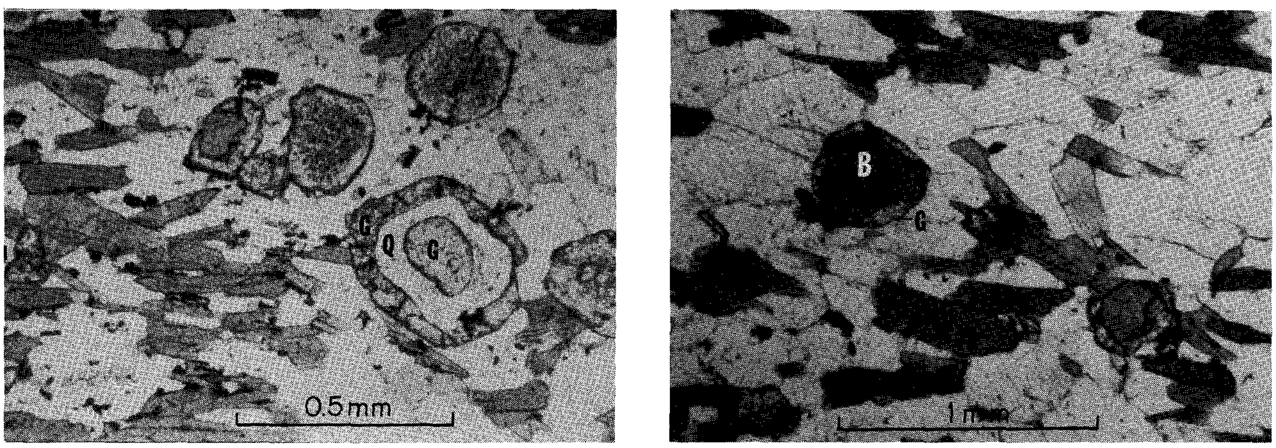


Figure 52. Inferred time relationships of metamorphism, intrusive activity, and ductile faulting. Calibration of diagram by K-Ar radiometric dates; magnitudes qualitative. Time scale is diagrammatic and non-linear. Very low grade burial metamorphism preceding main dynamothermal event; may be as old as Late Jurassic.



a. b.

Figure 53a,b. Photomicrographs of retrograde atoll microstructures in garnet (G) from schist (Ks) unit; selective zones replaced by quartz (Q) and biotite (B). (Plane light, sample 68-ASb-466).

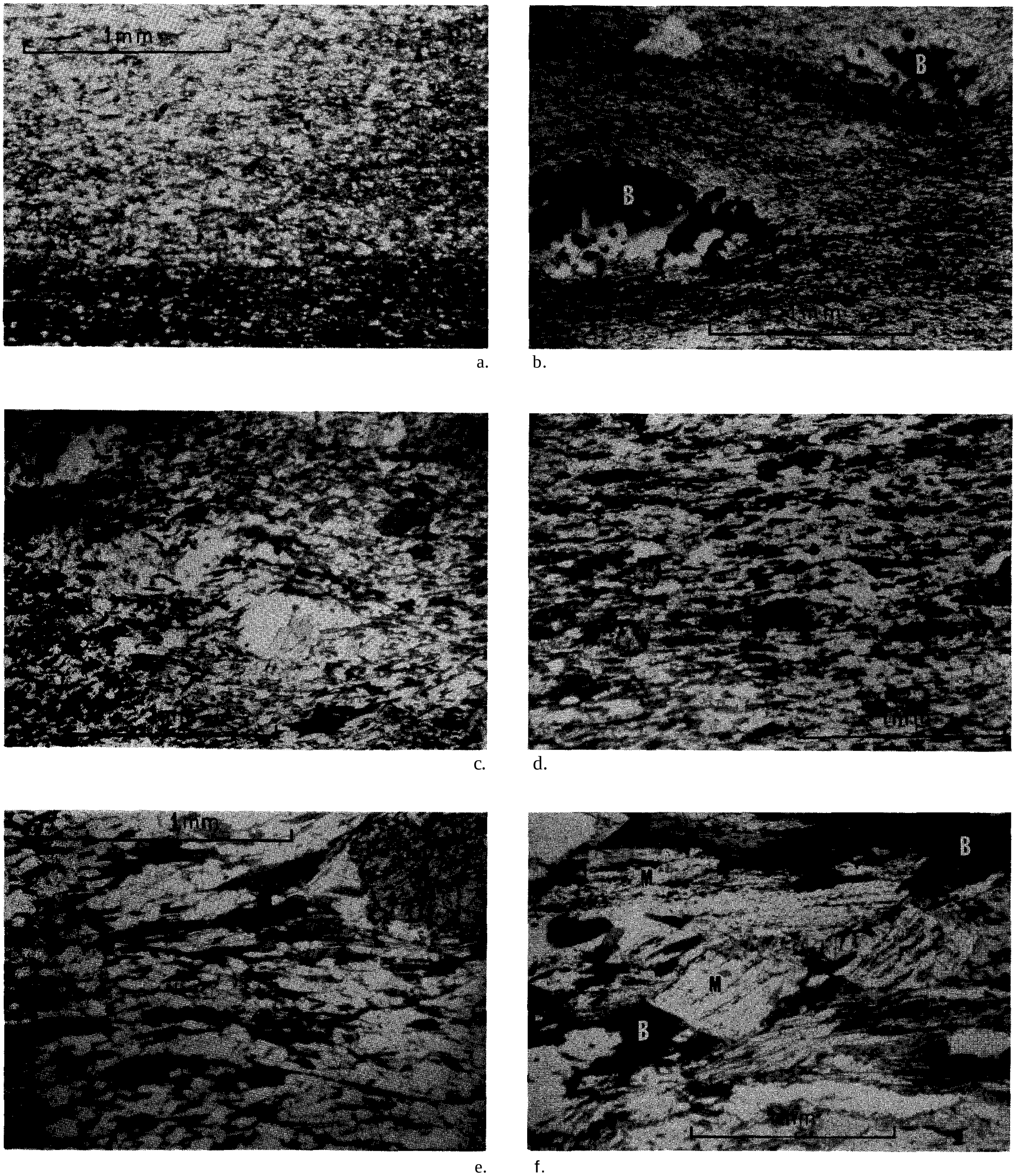


Figure 54a-f. Sequential photomicrographs illustrating textural evolution of metamorphic succession. (a) Argillite with sedimentary fabric; plane light, sample 68-ASb-287. (b) Spotted phyllite with biotite porphyroblasts (B); plane light, sample 68-ASb-507. (c) Destruction of biotite porphyroblasts by shearing; development of schistosity; plane light, sample 68-ASb-422. (d) Fine-grained schist with small garnets; plane light, sample 68-ASb-462. (e) Coarse-grained schist, plane light, sample 68-ASb-632B. (f) Schistose layer in gneiss showing coarsely crystalline biotite and muscovite in crude foliation. Muscovite (M) and biotite (B) include dark trains of graphite inherited from carbonaceous sediment; plane light, sample 69-ASt-172.

ORIGIN OF THE METAMORPHIC BELT

A discussion of a regional metamorphic succession such as that exposed in the Clearwater Mountains is incomplete without a statement of inferred genesis, especially when the isograds are seemingly inverted as they appear to be in this area. In general, schistosity parallels former bedding planes throughout most of the sequence; chloritic strata, now only compositional laminations with appreciable lateral continuity, are interlaminated with all pelitic rocks. Whether the former sediments were upright or overturned is not so readily apparent, however, because fold hinges are now transposed and obliterated. In lower grade rocks where sedimentary structures are preserved, the evidence is conflicting. Folding in the argillite unit varies in character from open to steeply isoclinal (see structure sections on pI. 1). Along the transitional zone between argillites and phyllites, cleavage is occasionally found transecting compositional laminae. These are the only indications in the map area suggestive of a transition also into isoclinally folded rocks north of the argillite unit, with axial planes paralleling schistosity. The relationship is much more clear in the Mt. Hayes A-6 Quadrangle to the east, where continued mapping has conclusively shown that deformation in the sediments steepens into isoclinal folds as they grade into phyllites or semischists. Compositional laminations in the tectonites are therefore correctly interpreted as former sedimentary horizons, but probably occur on various limbs of closely spaced isoclinal folds, now indistinguishable as a result of metamorphic processes.

As deformation progressed to the threshold of metamorphism, the northerly parts of the mobile belt were apparently uplifted differentially, resulting in the zonal tectonic belt and numerous local features illustrative of extensive intrafolial shearing. By this mode of genesis, summarized in figure 55, the metamorphic belt may be visualized as a northeasterly trending zone of overthrusting occurring differentially and penetratively across the sequence of phyllites, schists, and gneisses. The textural and mineralogical break at the sillimanite isograd is probably a surface of greater dislocation and thus should be considered a ductile thrust surface, along which highest grade metamorphites were uplifted into juxtaposition with rocks of the lowest amphibolite facies. Dislocation on this local structure was probably minor compared to the total displacement across the belt. This general mechanism of overthrusting as a control of metamorphism is similar to that described by Blake and others (1967) for blueschist-facies rocks in California and Oregon.

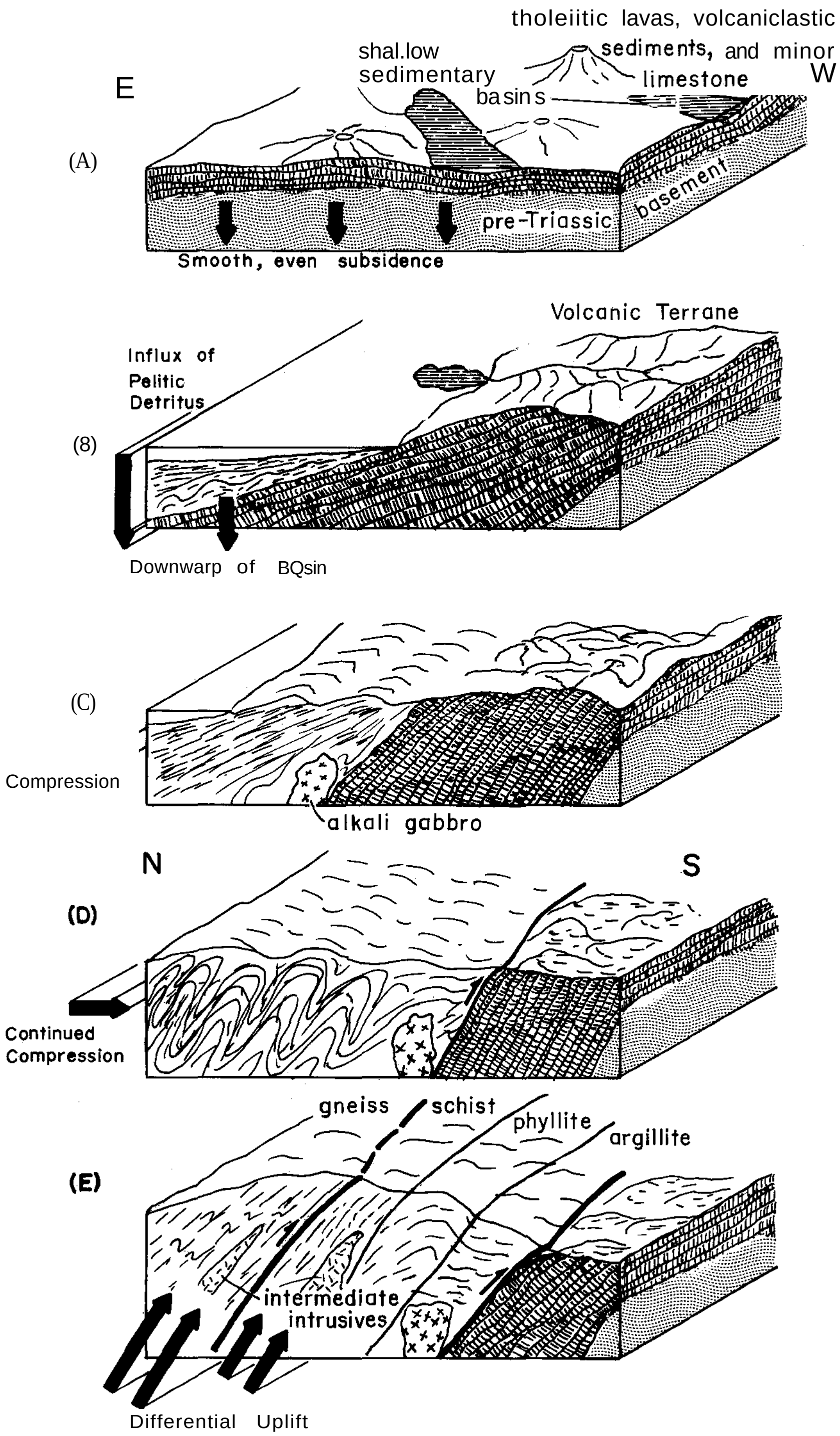
A less plausible alternative for producing the poly-isograd relationship has been considered by the author, in which intrusion of the foliated sill, with accompanying increase of heat flow, may have steepened the thermal gradient, resulting in the development of sillimanite near rocks of the lowest amphibolite facies. This may provide an alternative explanation for the mineralogical discontinuity, but it neither effectively accounts for the pronounced textural break between the schists and gneisses nor explains the presence of sjllimanite everywhere in the gneisses, even at some distance from the igneous body.

Rotational microtextures and displacement measured on intrafolial folds indicate that local shear components varied from about 1.3:1 in the phyllites to 1:1 or more in the gneisses. If this range may be extrapolated to the entire succession, a differential uplift of 6-8 miles is implied across the belt, neglecting offsets on the ductile thrust or other discrete surfaces. A reverse displacement of this order of magnitude is supported additionally by the pressure-temperature gradient inferred from assemblages of index minerals (fig. 56). Only slight latitude is allowable in the gradient for the Clearwater Mountains rocks without entering the stability fields of andalusite or glaucophane-lawsonite. It appears necessary, therefore, to infer a pressure differential of at least 2 kb in the progression of assemblages, and this may be tentatively translated as a differential uplift of 4-6 miles.

REGIONAL SIGNIFICANCE

The proposed mechanism of origin outlined in previous paragraphs of this section is consistent with data collected by the writer in the Clearwater Mountains and may also be applicable to an extensive belt along the south front of the Alaska Range. Integration of the present work with mapping by other workers suggests that these rocks are correlative with metamorphites exposed near the Richardson Highway, 40 miles to the east, and extending westward toward the map area (Bond, 1965; Hanson, 1963; Moffit, 1912; Stout, 1965; 1976; and Rose, 1966b; see fig. 2). Several of these authors have recognized an increasing grade of metamorphism northward and locally have mapped north-dipping thrust faults that separate high-grade metamorphites from less foliated rocks on the south. Most previous workers assigned the schists and gneisses a pre-Mississippian or possibly Precambrian age, largely on the basis of their advanced crystallinity and similarity to the Birch Creek schist (Moffit, 1912; Ragan and Hawkins, 1964). Rose (1966b, p. 7) acknowledged that they might represent metamorphosed equivalents of Mesozoic sedimentary rocks in the Clearwater Mountains and suggested that metamorphism occurred in Late Mesozoic or early Tertiary time. Evidence from the Clearwater Mountains, discussed in this report, conclusively validates this suggestion and brackets the age of intense metamorphism between Late Jurassic (143 m.y.) and Paleocene (57 m.y. ago). The onset of regional dynamothermal metamorphism is not precisely determinable, but probably began during the Cretaceous Period, after the intrusion of the Eldorado Creek pluton into pelitic sediments (143 m.y.). The pluton was later metamorphosed. It is possible that the pelitic sediments were altered by very low grade thermal metamorphism during Late Jurassic time, before the onset of dynamothermal activity.

More recent geologic mapping and geochronological studies by Turner and Smith (1974) and the reconnaissance work of Moffit and Pogue (1915) and Chapin (1918, p. 43) verifies that the belt of gneisses extends 15 or more miles to the west of the study area (fig. 2). Correlation of all mapping efforts in this part of Alaska



Triassic: *Low-latitude volcanic arc with numerous vents and centers erupting tholeiitic lava onto lowland area with shallow seaways. Limy marine muds deposited in shallow water. Eventual accumulation of over 15,000 feet of flows and sediment.*

Early and Middle Jurassic: *Continued downwarp and cessation of volcanism. Possible tectonic transport to higher latitudes. Deposition of distal pelitic muds balanced by subsidence so that basin remained shallow. Main source of detritus from present-day north although volcanic area still mildly positive, shedding some volcaniclastic materials to basin. Slumping in deepest horizons.*

Late Jurassic: *Compressive stress initiates folding in deepest parts of pelitic section. Intrusion of Eldorado Creek pluton into pelitic muds at* 143 *m.y.*

Early Cretaceous: *Continued stresses deforming pelitic strata against volcanic buttress. Northernmost strata compressed into closely spaced isoclinal folds. Slippage along mechanical discontinuity at contact with volcanics. Northern part of section becomes area of high heat flow.*

Late Cretaceous-Paleocene: *Onset of differential uplift along sedimentary laminae in isoclinal folds. Penetrative shearing at depth accompanied by recrystallization resulting in obliteration of sedimentary character as rocks become tectonites. Emplacement of interkinematic intru,sives during quiescent phases of tectonism. Total differential uplift about 7-10 km, bringing sillimanite-bearing rocks onto same level as lowest grade rocks to south. Cessation of dynamic activity in latest Cretaceous followed by waning thermal activity into mid-Paleocene.*

Figure 55. Sequential block diagrams illustrating development of Clearwater Mountains region through Paleocene time and evolution of metamorphic belt as a CUlminating phase.

indicates the metamorphic belt is over 70 miles long, extending westward from the Richardson Highway along the south flank of the Alaska Range, through the Clearwater Mountains, and into the northern Talkeetna Mountains.

This linear zone has been named the Maclaren metamorphic belt (Smith, 1970d) and appears to be the south flank of a symmetrical metamorphic belt formed over the end of a deep-seated batholith. Corroboration of this hypothesis must await further detailed mapping efforts along the belt. The concept is for the most part consistent with data now available, and the general age of metamorphism and intrusion inferred from independent evidence similarly accords with the proposed mechanism (Gates and Gryc, 1963).

Because of its apparent angularity with the Denali Fault, the possibility exists as well that this linear zone of crystalline schists may in fact be truncated by the fault and may correlate with equivalent metamorphites in other parts of Alaska or Canada.

On the basis of petrographic, structural, and geochronological similarities, the author and other colleagues (Forbes and others, 1973; Smith and others, 1974) have suggested that the Maclaren metamorphic belt has been offset right laterally 250 miles from the Kluane metamorphic-plutonic complex in the Yukon Territory, which is in turn contiguous with the Coast Range metamorphic-plutonic complex in southeastern Alaska and British Columbia (Forbes and Engels, 1970).

STRUCTURE

Structural elements in the western Clearwater Mountains may be described as the sequential products of recurrent tectonism. The rocks record a varying mode of deformation, corresponding to their position in the cycle of downwarp, metamorphism, compression, and uplift. Hence, structures may be classified in terms of simple chronology, progressing from folding through ductile distributive thrusting to ductile strike-dip dislocation, and finally to high-angle, brittle-fracture-style faulting, which now dominates the structural framework in this part of Alaska.

FOLDS

Mappable folds are, for the most part, restricted to the southern part of the pelitic sequence, where undistorted sedimentary textures allow resolution of the fold pattern. Axes of major folds mapped in the present study are shown on figure 57. The structures indicated thereon represent a slight divergence of opinion from that presented by earlier workers in the area. Previous investigators have variously concluded that "the Valdez Creek district is underlain by part of the north flank of a large fold...." (Ross, 1933, p. 442), or that "the lava flows exposed south of Windy Creek appear to dip beneath the Triassic sediments, and these, in turn, to pass beneath the schists and the great diorite mass between Valdez and Boulder Creeks, but that...a fault may exist between the slates and schists" (Moffit, 1912, p. 47). Detailed and closely spaced traverses made during the present study allowed delineation of the fold pattern shown in figure 57. Individual structures in the argillite unit are mainly open and upright. Only locally do they tighten into steeply dipping isoclinal folds (for example, near the mouth of Windy Creek) or into mildly overturned isoclinal folds such as those along the ridge south of Black Creek.

The dominant trend of most fold axes is about N. $70^0.80^0$ E., essentially the same as the prevailing strike in the volcanic and schist belts. This parallelism implies related mechanisms for producing the spectrum of deformational styles shown in the sediments and metamorphites. Compressive stresses oriented about N. 20^0-30^0 W. apparently were responsible for major folding of the pelitic rocks. Continued stresses from the northwest with an increasing vertical component have resulted in the differential uplift discussed earlier (fig. 55). The tightly folded sediments exposed in the north were, at that time, in a higher pressure-temperature environment and have reacted to regional stress by recrystallization and consequent rheid behavior, whereas the marginal parts of the mobil zone, represented by the argillite belt, have responded mainly by folding. Interbed slippage during folding, accompanied by minor recrystallization, has produced sporadic slaty horizons throughout the argillite unit. The mechanically competent lavas south of the argillite were essentially undisturbed by the deformation, except for early tilting and folding. The earliest stages of intense folding, before the metamorphism, are tentatively considered to be Late Jurassic in age, closely coincident with the intrusion of the alkali 'gabbro pluton at 143 m.y.

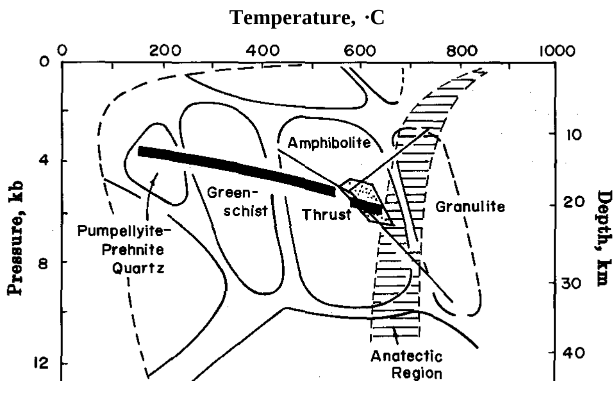


Figure 56. Indicated poT gradient involved in development of Clearwater Mountains metamorphites (heavy line). Facies fields after Turner (1968). Stippled areas shown Al_2SiO_5 triple point data from Richardson and others (1969). Anatectic region from Winkler (1967).

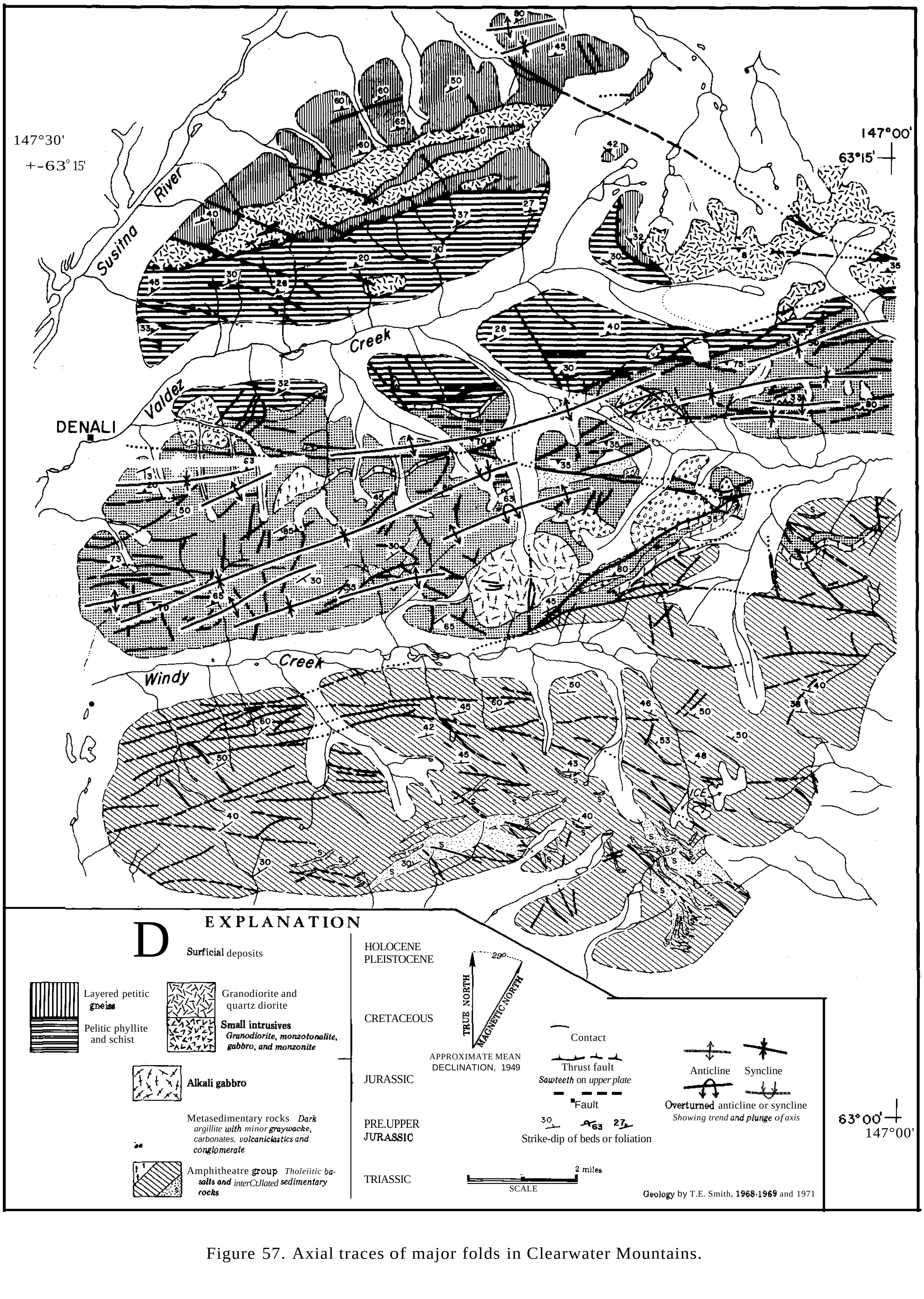


Figure 57. Axial traces of major folds in Clearwater Mountains.

FAULTS

In addition to the synkinematic overthrust, two distinct sets of high-angle faults trending N. 70^0-80^0 E. and N. 70^0-80^0 W. (fig. 58) cut older structural elements in the Clearwater Mountains. Movement along these features, of varying sense, has been recurrent since the waning stages of metamorphism in Paleocene time, proceeding from early deep-seated, ductile dislocation to later shallow, brittle fracturing.

The concept of ductile overthrusting, induced by N. 20^0 W.-trending compression and accompanied by dynamothermal activity, has been covered in the section on metamorphism. These effects and the folding, probably confined to Late Jurassic and Cretaceous time, record the earliest recognizable stresses affecting these rocks. High-angle dislocation of both major sets is present; however, these dislocations also show evidence of extensive rehealing and recrystallization, but only immediately bordering the fault zone (fig. 58). Dislocation mylonites, slates, and schists commonly parallel these features, and most show a strong subhorizontal lineation, implying that early movements were mainly strike-slips. The development of these incipient structures probably reflects a significant shift in regional stress during early Tertiary time.

Well-developed slates and phyllites border the shear zone trending up Windy Creek near its mouth. Where it leaves the creek near its headwaters, the same fault is marked by a zone of calc-phyllites with local, vertically plunging drag folds, indicating right-lateral displacement. A number of high-angle faults similarly cut the small intrusive at Timberline Creek. Weathered traces of these faults show fault-zone rock with horizontal lineations preserved as well-recrystallized dislocation schists. Underground in the Timberline Creek adit, however, the same faults include much clayey gouge with vertical slickensides, probably developed by normal movement in a later shallow. environment that was less conducive to recrystallization. Offsets in the contact of the pluton north of Timberline Creek suggest a left-lateral displacement, although this apparent effect may be partly due to vertical offsets of the contact where it plunges northwest.

Recurrent movement has persisted throughout Tertiary time on many of the major faults. With continued uplift and erosion, this has given way to a less systematic, brittle-fracture style of deformation characteristic of shallow environments. Cumulative displacement on most of the faults is probably measurable in tens or hundreds of feet, although the faults of greatest continuity juxtapose similar lithologies or parallel regional contacts, which may well disguise greater displacements.

ECONOMIC GEOLOGY

(Compiled by T.K. Bundtzen)

The Valdez Creek mining camp, in the west-central part of the study area, historically has been a placer mining region, which is the source of most of the known mineral production in the western Clearwater Mountains. Production has been largely confined to rich pockets in abandoned Pleistocene outwash channels and alluvial deposits of Holocene age. Recent investigations of bench gravels (including seismic refraction measurements) have defined a deposit of more than 35 million cubic yards of auriferous gravels.

Two centers of structurally controlled auriferous sulfide-quartz-carbonate veins within altered quartz diorite at Timberline and Eldorado Creeks (Gold Hill-Lucky Hill area) have been explored with underground workings and are probably the source of the placers in the Valdez Creek drainage. A small amount of gold has been extracted from these deposits.

The well-known Denali stratiform chalcopyrite-pyrite deposits are found along a zone of sedimentary-volcanic rock intercalation near the stratigraphic top of a thick Triassic basalt-andesite sequence. They have been extensively explored with both surface and subsurface diamond-drilling programs, but their origin remains somewhat contoversial (Stevens, 1971; Seraphim, 1975).

Previously reported geochemical results of stream-sediment and bedrock samples (Smith, 1970b) indicate a close association of gold and arsenic in the Timberline and Gold Hill mineralized areas. Mercury is concentrated along the same general trend as the gold-quartz-sulfide vein systems, but occurs between the two gold centers, which implies a crude hypogene zonation outward from the auriferous centers along the trend of mineralization. Copper anomalies are confined to the head of Windy Creek, to the area draining the Denali copper deposits, and to an area south of Windy Creek; all are believed to be associated with a major east-west-trending shear zone in the mafic metavolcanic rocks.

Kame and esker complexes and bench gravels in the southern part of the study area could provide millions of cubic yards of high-quality sand and gravel aggregate.

PLACER GOLD DEPOSITS

Gold was discovered on Valdez Creek on August 15, 1903 by a party consisting of Peter Monahan, J.S. Smith, J.M. Johnson, and J_C. Clarkson, who with others, had ventured from the coastal town of Valdez on a prospecting expedition (Moffit, 1912, p. 53-54). The discovery was made at the mouth of Valdez Creek canyon (pI. 1, fig. 59), and further prospecting revealed that gold values suddenly dropped off after ascending the stream above an old incised drainage system. The aerial extent of this buried, gravel-filled canyon was prospected and later mined by open-cut

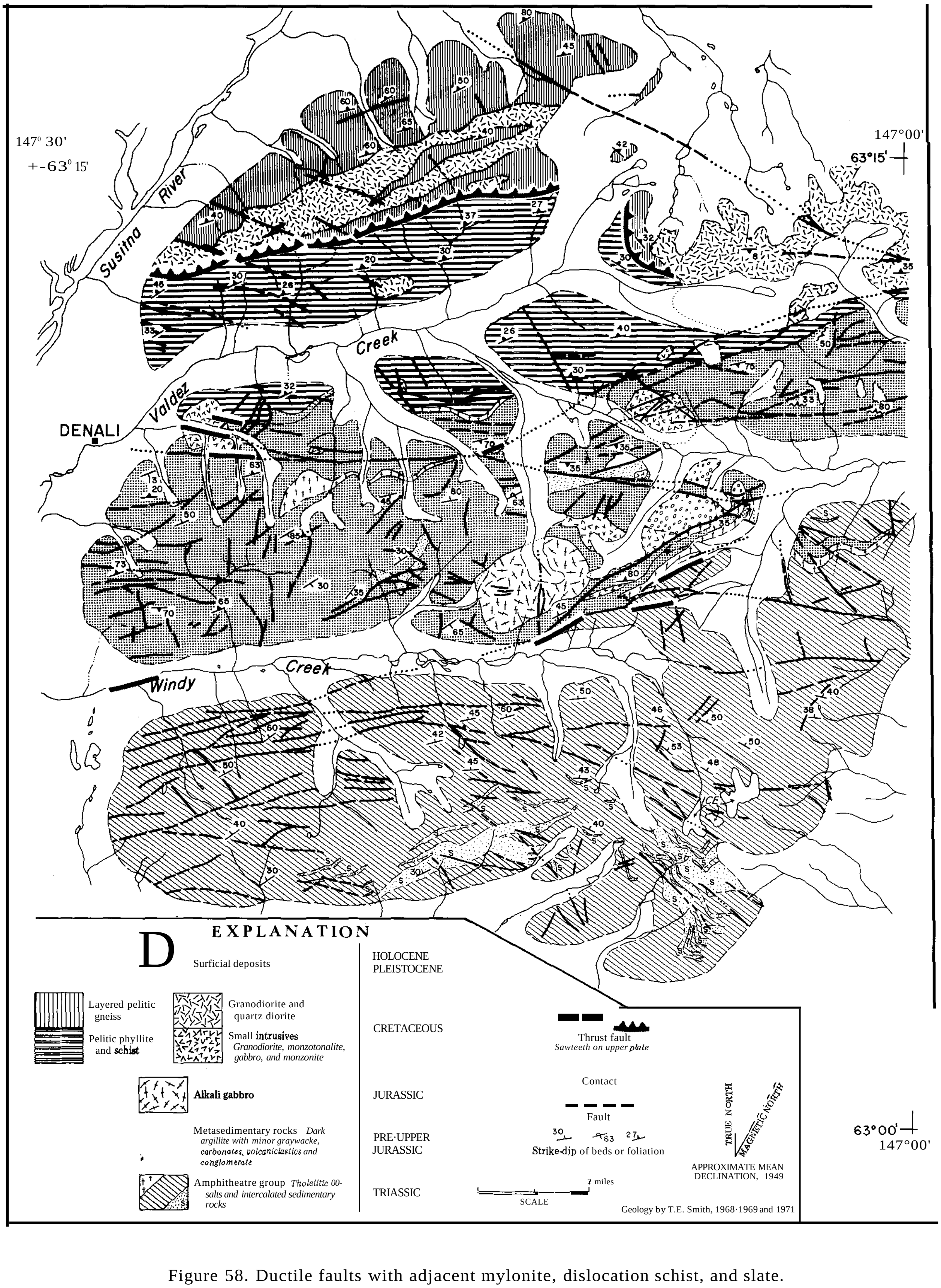


Figure 58. Ductile faults with adjacent mylonite, dislocation schist, and slate.

hydraulic and underground-drift mmmg methods. This ancient stream deposit, which became known as the Tammany Channel, accounted for a large part of the gold production of the district. Valdez Creek and nearby bench gravels, the Tammany Channel, Lucky Gulch, and White, Roosevelt, Eldorado, and Surprise Creeks produced about 35,000 ounces of gold through 1936 (Tuck, 1938); subsequent production records are not

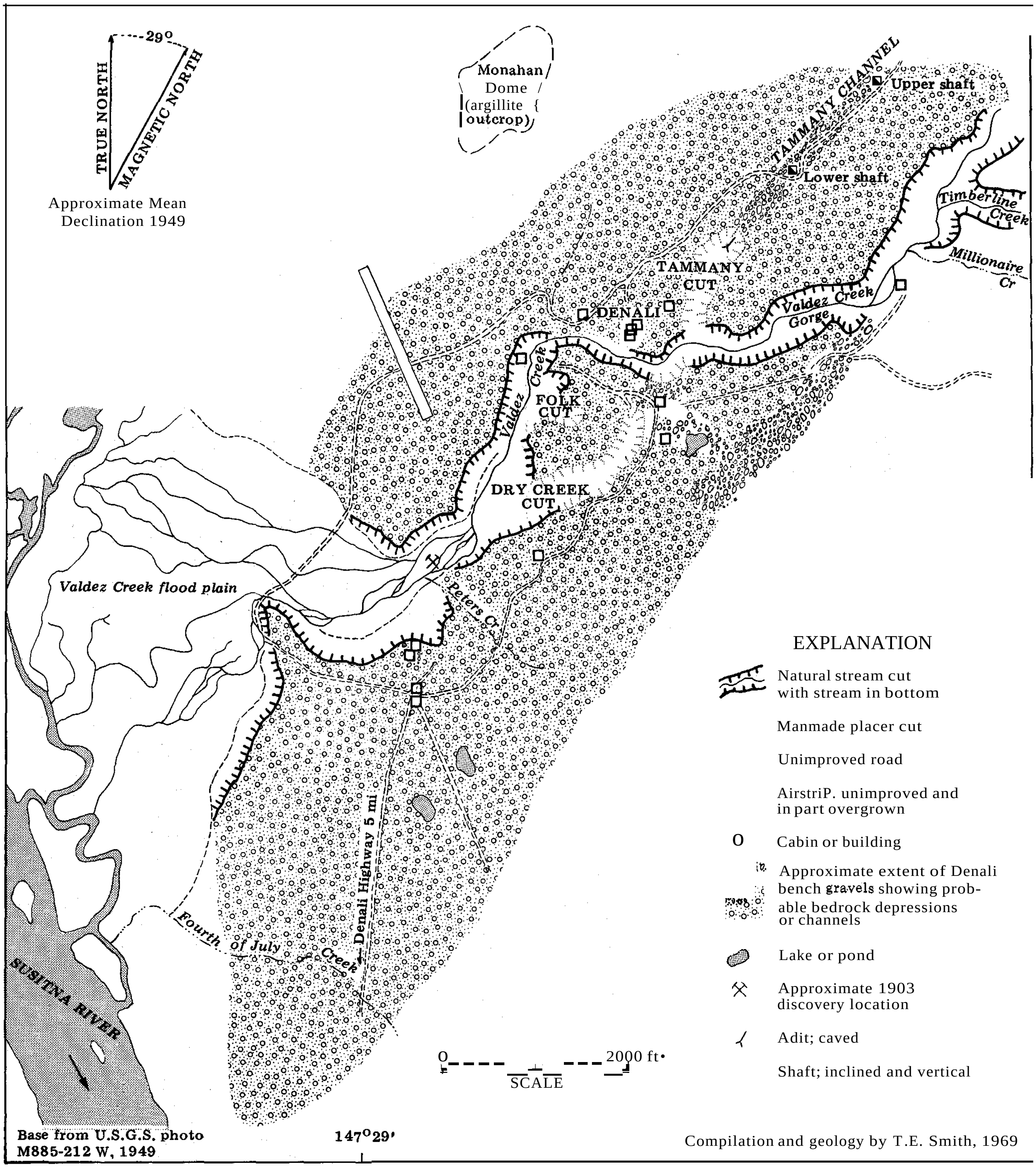


Figure 59. Denali placer area, northwestern Healy *A-l* Quadrangle, Alaska; modified from Smith (1970a).

well known, but no more than 30 percent of this figure is believed to have been produced since. The rise in the price of gold beginning in the early 1970s has stimulated renewed small-scale placer gold mining in the region. According to Smith (1941, p. 177), "all records of gold fineness from the Valdez Creek district show with remarkable uninformity a fineness of 852, with a single exception from Lucky Gulch, which has 828."

TAMMANY CHANNEL AND ADJACENT BENCH GRAVELS

The Tammany Channel (pI. 1, loco 3; fig. 59) is a deeply incised bedrock canyon cut by the ancestral Valdez Creek. This buried canyon and its probable downstream extension, 'the Dry Creek cut,' were filled by beds of moderately sorted fluvial gravel, much of which has since been removed by hydraulic mining. Subrounded boulders are usually concentrated near the channel bottom, and quartz, diorite, schist, and argillite represent the most abundant lithologies in the gravels. Scour-and-fill structures are prevalent in the lower part of the channel but give way to more evenly bedded material near the top. Numerous discontinuous layers of rounded to subrounded cobbles are present throughout the gravels. All detritus appears to be derived from the Valdez Creek drainage; there are no exotic lithologies to suggest that glacial debris from other drainages has been incorporated in the deposits. The V-shaped cross section and large rounded boulders in the buried channel record an interval of vigorous erosion, perhaps during an early Pleistocene interglaciation. Downcutting during this time was apparently to a level near the present floor of the Susitna valley. A subsequent local advance of the Susitna Glacier initiated aggradation that buried the canyons with fluvial gravels. Within the gravels, such characteristics as a general absence of scour-and-fill structures except in the deeper channels, the presence of distinct bedding and dips lower than 2^0, and the lack of a bedding relation to the irregular bedrock surface all suggest moderate-energy deposition on a gentle alluvial plain. Because of their areal configuration parallel to the Valdez Creek valley and their internal character, the gravels are interpreted as a broad proglacial outwash deposit or valley train that formed below the stationary or retreating terminus of the glacier. The western side of the aggradational outwash plain was apparently bounded and obstructed by the Susitna Glacier, which deflected the proglacial deposits southward along the mountain front.

A final advance and rapid retreat of the Valdez Creek Glacier mantled the outwash plain with thin, irregular ground moraine containing abundant angular boulders of lithologies indigenouS' to the Valdez Creek basin. The moraine is rarely more than 10 feet thick; locally its surface is irregular and marked by numerous low ridges and potholes.

Valdez Creek was rejuvenated when the Susitna Glacier withdrew. It has cut its present incised course to a depth of about 20 feet below the floor of the ancestral channel, which is exposed in the Tammany cut.

Quaternary deposits with a similar depositional history occur in the Kumara area, Westland district, New Zealand, where glaciofluvial outwash gravels deposited by rivers immediately in front of terminal ice positions 'of Late Quaternary age host rich placer-gold deposits (Williams, 1965, p. 74-77).

A thin layer of decomposed slate bedrock at the base of the Tammany Channel yielded most of the gold values (S. Herman, oral comm., 1969), although all the fill reportedly contained fine gold. According to Moffit (1912, p. 60), the gold in the Valdez Creek drainage varies from well worn to angular and rough. A decrease in surface roughness is noted below the intersection of the present creek and the Tammany Channel. Thus, the more coarse gold is probably coming from an upstream source, whereas the more rounded gold is emanating from the Tammany Channel. Heavy minerals in the concentrate include large quantities of 'ruby sand' or red garnet and minor magnetite. Tammany Channel gold is not known for its coarseness; for example, Moffit (1912) reported the largest nuggets through 1911 averaged 0.1 oz, which is typical of gold worked by glaciofluvial processes.

From 1904·13, a tunnel about 1,450 feet long was driven into the northern part of the Tammany Channel, where several hundred thousand yards of gravel yielded 9,500 ounces of gold.[3] Much of this same ground was removed by open-cut hydraulic mining by McKinley Placer Mining Company from 1913-24. Saunders (1953, p. 8) reported that an additional 3,600 feet of tunneling and shafts had been driven beyond the end of the open cut since 1924. Total known gold production in the Tammany Channel north of Valdez Creek is estimated to be 27,000 ounces. Between 1935 and the end of World War II an extension of the channel south of Valdez Creek or the 'Dry Creek cut' was hydraulically worked; production is not known but the cut is about as large as the Tammany Channel hydraulic pit (fig. 59).

There have been several attempts to mine bench gravels on both sides of Valdez Creek near the old town of Denali. Between 1928 and 1930, about 100,000 cubic yards of gravel were removed from the 'Folk cut' downstream from the Denali townsite, yielding 2,850 ounces of gold, comparable to the amount found in the Tammany Channel (Ross, 1933, p. 451). Since 1940, the bench gravels have been mined inter-

aBecause previous workers almost universally reported gold production in dollar value, gold figures have been computed from either 1) $20.67/ounce if production was prior to 1934 or 2) $35/ounce for the period 1934-72. Production after 1972 is unknown and jewelry-gold value was not taken into account.

mittently along the south wall of Valdez Creek across from Denali and near Peters Creek (fig. 59). More recent exploration efforts in the 1960s indicate 0.014 to 0.036 ounce/cubic yard gold uniformly distributed throughout the bench gravels near Peters Creek (M.J. Wall, written comm., 1969; L.B. Kercher, oral comm., 1969). Smith (1970a, p. 150-151) ran seismic refraction surveys to estimate the total volume of the Denali bench gravels and to locate any additional unknown incised channels. His inferred geologic sections show that the Denali Bench is a relatively smooth bedrock surface marked by gentle undulations and depressions and covered by a gravel blanket 45 to 75 feet thick. The blanket covers a minimum area of 3,000 by 7,000 feet with a minimum average depth of 45 feet. Thus, at least 35 million cubic yards of auriferous detritus cover the Denali Bench.

VALDEZ CREEK PROPER

Mining of the creek placers has been generally restricted to a few claims above the 'discovery bar' at the mouth of Valdez Creek (Moffit, 1912); the best ground is immediately below the intersection of modern Valdez Creek with the ancestral Tammany Channel (pl. 1, loc. 1). Here, gravels originally 3 to 12 feet thick overlie the dark-gray slate bedrock on whose surfaces the best values were found. (Clastic compositions of the fluvial gravels are the same as those in the Tammany Channel.) Large boulders of glaciofluvial origin are abundant in thepaystreaks' and caused problems with the pick-and-shovel mining methods practiced in the early days (Moffit, 1912). Hydraulic mining operations in the Tammany Channel flushed large volumes of gravel out over the top of the creek gravels, which further complicated mining prospects on this ground.

Isolated benches and inside meanders in the narrow Valdez Creek canyon above the Tammany Channel have been worked by individuals (pI. 1, loco 4; fig. 59). Mechanized small-scale mining operations on Valdez Creek above the Tammany Channel during the 1977 season apparently yielded encouraging amounts of placer gold concentrated in sporadic paystreaks (P. Herzberg, oral comm., 1979).

LUCKY GULCH

Lucky Gulch (pl. 1, loco 17), about 9 miles upstream from Denali, is a small incised stream that is seasonally fed by snowbanks; by fall, it contains little or no water. Most of the fluvially transported material in the gulch is angular slate derived from nearby bedrock, but the lower end of the gulch contains glacially derived(?) subangular cobbles of intrusive rock, greenschist, conglomerate, and other exotic materials (Ross, 1933, p. 454). Gold values are erratically distributed throughout the gulch because of, mass movement of talus into the stream cut, glacial dilution near the base, and wide fluctuations in stream hydraulics during the spring and summer. Total production through 1925 was estimated at 3,000 ounces (Wimmler, 1925a, p. 72). The gulch is well known for coarse, angular nuggets; two taken in 1907 and 1910 weighed 52 and 32 ounces, respectively (Moffit, 1912).

WHITE CREEK AND TRIBUTARIES

White Creek and its tributaries, Big Rusty, Little Rusty, and Rusty Creeks (pI. 1, loco 12-16), have yielded an estimated 500-600 ounces of gold. Most originated from small hydraulic cuts in two main areas 1 to 4 miles above the mouth of where the fluvial deposits are from 6 to 20 feet below the present valley floor. In other areas, the gravel deposits can exceed 60 feet in thickness and pay has not been found (Wimmler, 1925a, p. 69). A boom dam-hydraulic operation recovered a few ounces of gold from Rusty Creek in the 1920s. The entire White Creek valley was glaciated in late Wisconsinan time and gold and heavy-mineral placers were probably diluted and buried by glaciofluvial deposits. Foliation in the dark-gray slate and bedrock, strikes east-west to northeast, dips shallowly to the north, and is locally intruded by Tertiary(?) mafic dikes. Gold-bearing quartz-sulfide vein mineralization is associated with these dikes and Ross (1933, p. 454) believes these veins are, in part, the source of the placer gold.

Concentrates collected by Wimmler (1925a, p. 70-71) from the hydraulic operation on White Creek in 1925 contained magnetite, garnet, rutile, pyrite, native copper" chalcopyrite, galena, native bismuth, native arsenic, and hessite, a silver telluride. An assay of the hessite yielded 61 percent silver and 1 ounce/ton gold, Galena and bismuth in the concentrates contained 1.90 ounces/ton gold and 283.6 ounces/ton silver. The hessite was later confirmed by Ross (1933, p. 454), who also identified pyrrhotite, realgar, and orpiment in the concentrates.

OTHER PLACERS

Minor amounts of gold have been recovered on Timberline, Roosevelt, Eldorado, and Surprise Creeks (pl. 1, locs. 5, 20b, 20a, 22, respectively). A rich pocket discovered in 1924 on a bench overlooking Timberline Creek yielded 10 ounces of coarse gold; this discovery caused 40 to 50 men to explore the district in 1925, but to no avail. Most of the ground on Roosevelt, Eldorado, and Surprise Creeks occupies glacial troughs, and any economic placers may have been diluted or removed during the last glacial advance in late Wisconsinan time.

LODE GOLD DEPOSITS

The early Valdez Creek placer miners found lode-gold veins cutting igneous and metamorphic rocks in the Timberline Creek, Gold Hill, and Lucky Hill areas (pl. 1, locs. 6-10, 18, 19, 21), but little attention was paid to the exposures for many years. Several of the deposits were trenched and sampled with mixed results. In the 1930s over 1,000 feet of underground development work was conducted on the Timberline Creek and Lucky Hill prospects and a small ball mill was put into operation on the Timberline property for a short time; however, production is unknown (I. Bott, oral comm., 1979). Smith (1970b) has mapped available underground workings and collected surface rock samples in the Timberline-White Creek area that contained anomalous amounts of gold, arsenic, and mercury. This previously reported work has defined an east-west-trending mineral belt about 1 mile wide and 6 miles long that has a crude hypogene zonation with mercury enrichment between the centers of gold concentration (pls. 2 and 3). The mineral belt roughly coincides with a complex system of shears and fractures approximately parallel to and south of Valdez Creek. In addition to the obvious association of the mineral belt with fault structures, it is nearly coincident with the core of a large antiform whose axis trends eastward from the abandoned town of Denali (pl. 1).

A further relationship of potential exploration significance is the coincidence of the mineral belt with the gradational boundary between strongly recrystallized schists to the north and weakly metamorphosed argillites to the south. The spatial relationship between the lode gold occurrences and gold placer deposits suggests the former was the source of the latter.

Known gold-bearing lodes show a wide variety of characteristics. They occur in both metasedimentary and intrusive rocks, but the most continuous and potentially largest are hosted in the igneous rock bodies. Some of the better gold-assay values, however, have come from discontinuous zones in the metasedimentary rock units. Chlorite selvages on veins are ubiquitous in the Timberline Creek deposits, whereas yellowish ankeritic carbonate is particularly abundant in the Gold Hill-Lucky Hill vein systems. In addition to the free gold, almost all the lodes in the belt contain trace to minor amounts of pyrite, pyrrhotite, galena, sphalerite, and arsenopyrite. Hessite identified from placers in White Creek is presumably derived from the Gold Hill area; Herzberg (oral comm., 1979) tentatively identified goldfieldite rimming free gold in bedrock specimens from the Timberline Creek area.

TIMBERLINE CREEK PROSPECTS

Several quartz-carbonate-gold-bearing vein systems on the north hillside above Timberline Creek were explored and trenched prior to World War II by Lawrence Coffield, Clark Duff, and J.M. Olson (figs. 60,61). They recognized five veins-the Big Water Hole, Freda G, Valdez Creek 6, Little Caribou, and Big Caribou lodes (pl. 1, locs. 6-10; fig. 60) that generally trended east-west to N. 70° W. and dipped steeply to vertical.

According to Ross (1933, p. 460-461):

> "The Big Caribou vein has been traced for fully 1,000 feet and doubtless extends further. Its trend is somewhat curved but averages N. 80° W. and its dip is steep to the north. Various cuts expose a lode 8 feet wide consisting of sheared and chloritized diorite with disseminated pyrite and other sulfides and white quartz kidneys and lenses containing arsenopyrite, pyrite, pyrrhotite, and a little chalcopyrite. A solid band of white vein quartz 2 feet wide occupies the footwall side of the lode. On the basis of its known extension and on the assumption that it persists downward at least 100 feet, this lode is estimated to contain fully 100,000 tons.
>
> The Little Caribou vein is developed only by small cuts, all so badly slumped that no sampling could be done at the time of the writer's visit. It trends about N. 65° E., has a width of several feet, and is surely 200 feet long and probably much longer.
>
> The Big Water Hole or Valdez Creek no. 5 vein is definitely exposed only in two pits close together, but float suggests that it extends some distance to the east. It strikes east and dips steeply north. The pits show sheared and much altered diorite with quartz lenses. Both the altered rock and the quartz contain sulphides. The more easterly of the two pits was cleaned out by Lawrence Coffield and sampled by the writer. The sheared material of the lode here is 7 feet wide.
>
> Shallow cuts near the crest of the ridge exposed two vein segments. One known as the Freda G strikes about N. 75° E., dips 83°-90° SE., and cuts somewhat sheared diorite. The lower of the two cuts was about east, dips 70° N., and consists of 2 feet of quartz."

In 1933 Coffield and Associates leased the Timberline properties to Alaska Exploration and Mining of Spokane, Washington, which began both surface and underground exploration work on the mineralized veins. By 1934, a small mill equipped with jaw crusher, ball mill, classifier, and amalgamating plates was installed on Timberline Creek and "a few tons of ore were milled" (Tuck, 1938, p. 115). A 60-foot-long tunnel was driven to explore the Freda G vein and some of the mill ore came from this property. The Big Water Hole vein was explored on the surface and a few tons of it were also milled (Tuck, 1938, p. 117). By the end of 1936 a tunnel had been driven over 600 feet to intersect the Caribou veins about 200 vertical feet below their outcrops. The Big Caribou 'vein fault' was intersected 385 feet from the portal and about 150 feet of lateral drifting explored both sides of the vein. The Little Caribou vein-fault was intersected about 500 feet from the portal and explored westward with a drift for about 125 feet. Except for a company that reportedly performed some development work in 1979 (I. Bott, oral comm., March 1979) no records of further activity or development are known.

Figure 60 shows the geologic relationships to known lode mineralization in the general Timberline Creek area. The Little Caribou and Big Caribou lode systems are shown accurately, but the Freda G, Valdez 6, Campbell and Boedeker, and Big Water Hole veins are only approximately located. The most obvious mineralization control is the N. 80° W. to east-west and conjugate N. 50° E. high-angle fractures prevalent throughout the Timberline Creek area. Offsets of a plutonic body on the north side of Timberline Creek imply a left-lateral strike-slip displacement along the major east-west- to N. 80° W.-trending faults. This sense of movement is indirectly supported by the prevalence of discontinuous quartz lodes in N. 55° E.-trending fractures conjugate to the main east-west-trending faults; fractures and joints of this trend would be dilated on left-lateral movement along the main faults. The main host of the known gold mineralization has been the altered quartz diorite stock of Cretaceous(?) age (Ki unit, pl. 1; fig. 60). Also on the figure are the bedrock sample localities reported previously by the author (Smith, 1970b, p. 37-48) and gold and arsenic values above 0.18 and 60 ppm, respectively, which were determined to be anomalous (Smith, 1970b, p. 18).

The Timberline adit (fig. 61) was mapped by the author in 1969; the portal has since caved (P. Herzberg, oral comm., 1979). The relationships between the Big Caribou and Little Caribou lode systems and gold anomalies are illustrated by the sample results. The most conspicuous gold anomalies are associated with the Big Caribou fault zone, which apparently has a fairly continuous downdip extension of over 200 feet from the known surface exposures.

The results of sampling the Timberline Creek vein faults have been mixed. Ross (1933, p. 462-473) reported that Coffield's assays of the Little Caribou. Big Caribou, Freda G, and Valdez Creek 5 and 6 veins varied from 0.24 to 3.96 ounces/ton gold, whereas his own varied from trace to 0.33 ounce/ton. Tuck (1938)

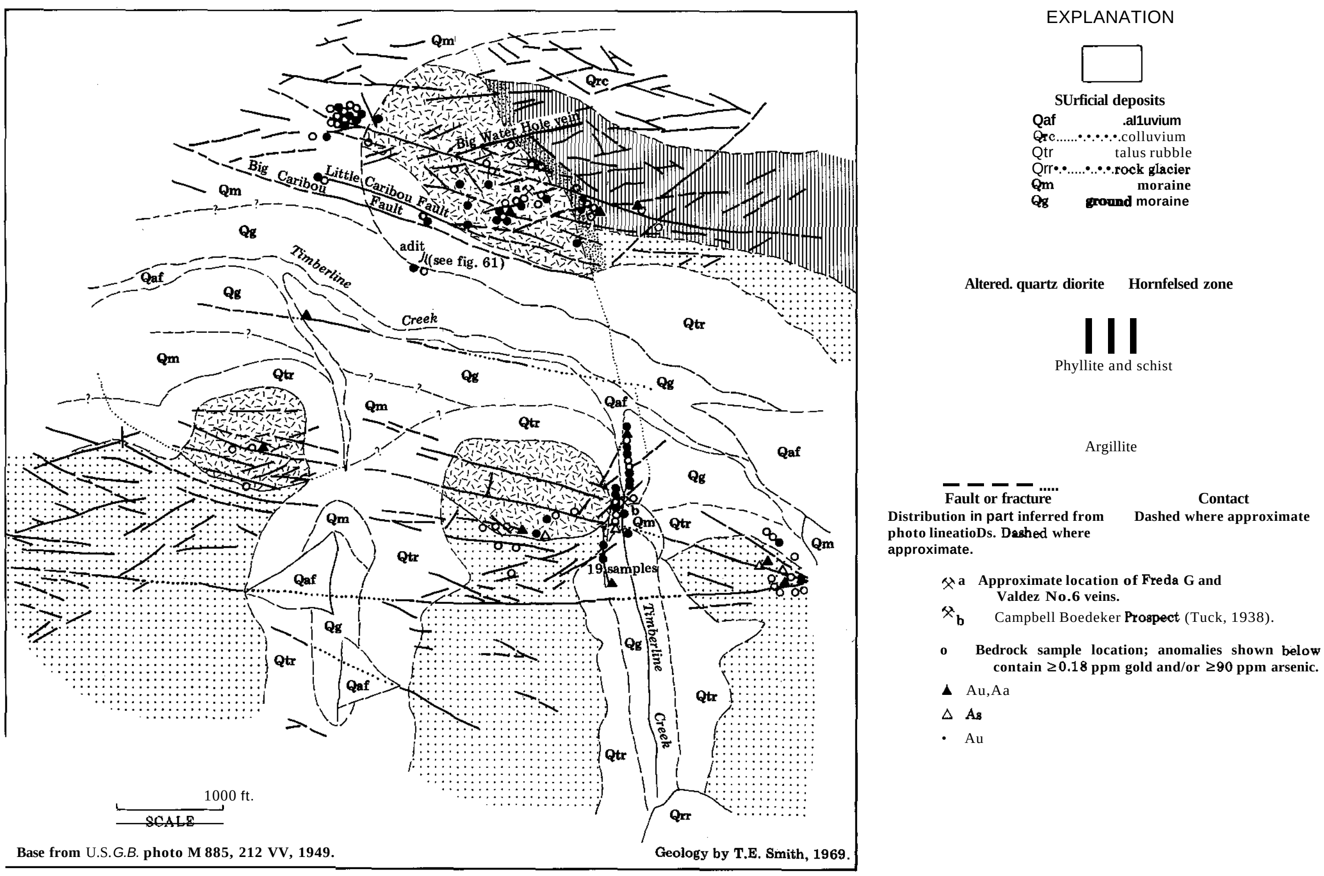


Figure 60. Geologic map of Timberline Creek area showing bedrock sample locations, and gold and arsenic geochemical anomalies; modified from Smith (1970b, p. 36-45).

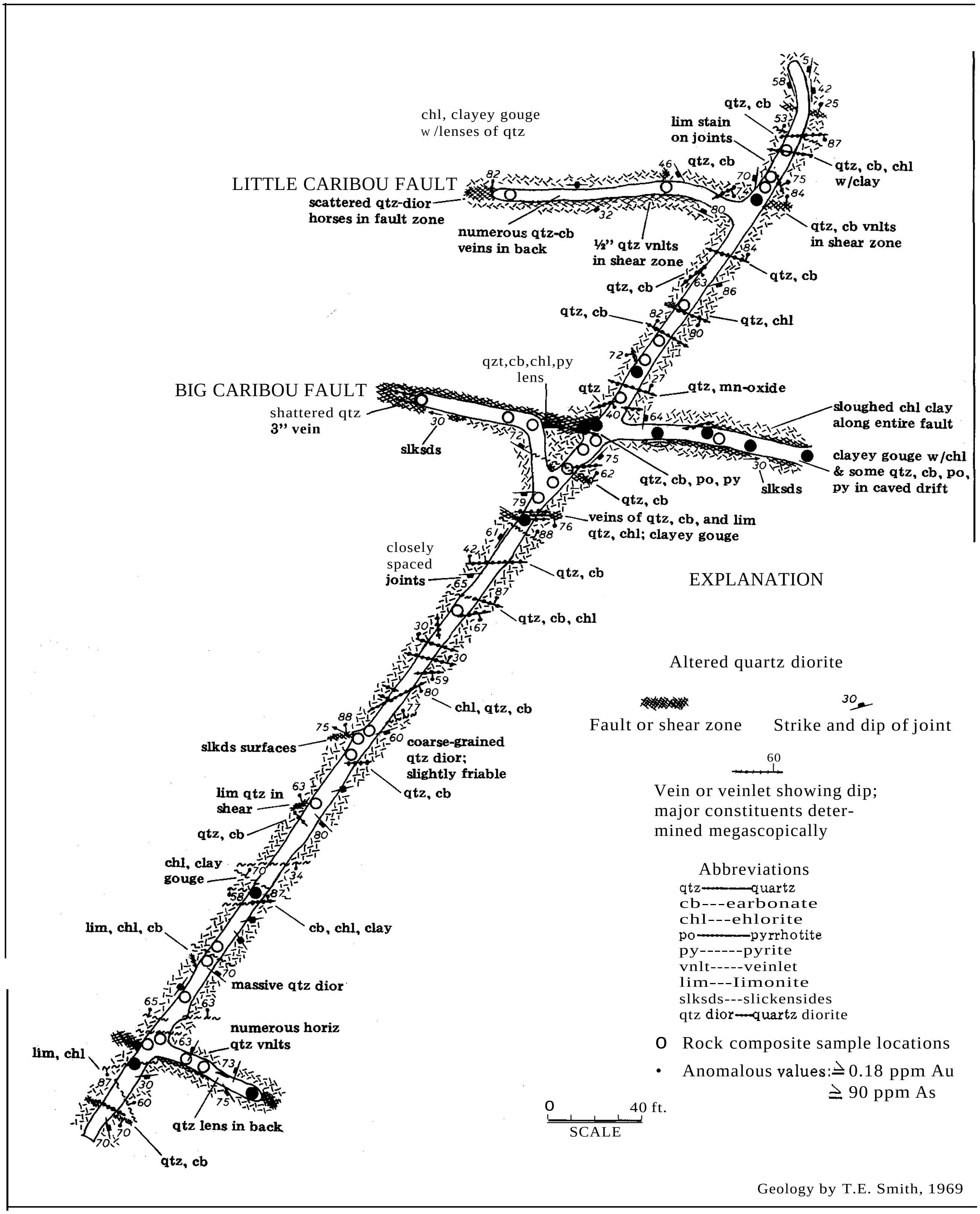


Figure 61. Geologic mine map of Timberline adit showing location of geochemical and composite chip samples. For location of adit, see figure 60.

reported low values similar to those reported by Smith (1970b). With the exception of a sample collected near the lower portal containing 35 ppm gold, Smith's values ranged from 0.18 to 1.8 ppm gold.

GOLD HILL-LUCKY HILL AREA

Several lode discoveries were made on the north slope of Gold Hill between Lucky Gulch and White Creek ('Lucky Hill') shortly after the 1903 placer discoveries (Wimmler, 1925b). The Yellowhorn and Accident prospects (pI. 1, locs. 18a, 18b), on the north slope of Gold Hill at an elevation of 3,950 feet, were probably the first lodes discovered in the district. They are part of a discontinuous lode system striking approximately N. 75^0 E. and dipping shallowly to the north. By 1936 at least two short tunnels (now caved) were driven into the lode, which consisted of a 4-foot-wide zone of quartz and mineralized schist. According to Tuck (1938, p. 118), "the quartz veins and lenses parallel the schistosity of the country rock, and the whole mineralized zone appears to have the same strike and dip as is shown by the metamorphosed sediments." Channel samples from the Yellowhom Prospect yielded 0.01 to 0.04 ounce/ton gold (Tuck, 1938). Fine gold can be panned from soil and weathered rock across the north slope of Gold Hill.

The Lucky Top prospect (pI. 1, loco 19) was found in 1936 as float on the east side of Lucky Gulch and finally traced eastward to the top of the ridge. The vein varies from a few inches to 1 foot wide and is composed of banded 'comb quartz' with sharp contacts in the enclosing slate bedrock (Tuck, 1938, p. 120). Gouge and slickenside indicate movement during and after vein formation. The poorly exposed discontinuous mineralized zone trends roughly east-west for several hundred feet and contains arsenopyrite, quartz, galena, and locally spectacular examples of free gold. Tuck (1938) reported that one hand specimen of quartz collected in the 1930s contained almost 2 ounces of gold. This gold-bearing vein system is found just above Lucky Gulch, which is well known for its extremely coarse placer gold.

The Black Creek Prospect or Wagner Lode (pI. 1, loco 21; figs. 62, 63), was discovered in the mid-1930s and underground development work was evidently completed prior to World War II (Saunders, 1953). The geologic relationships and geochemical sampling at the prospect are shown in figure 62. The prospect area is located at the intersection of two major faults and is underlain by the argillite sequence-differentiated into four members for the prospect study. Small, highly altered intrusives of intermediate composition were emplaced in the highly sheared hosts. Subsequent recurrent movement along the faults sheared and shattered the igneous rocks. Pyrite, pyrrhotite, and their alteration or weathering products are ubiquitous in the rocks underlying the prospect and have produced a reddish-stained area over the entire saddle. Most lode-mining efforts at the prospect have focused on the auriferous quartz veins in the shattered intrusive, although anomalous gold concentrations have been found nearby, as in the Timberline Creek area.

A mine map illustrating the geology and gold-arsenic anomalies in the Black Creek or Wagner adit is provided in figure 63. Very high concentrations of gold, ranging from 4 to 86 ppm in adit samples, are largely restricted to the small intrusive body near the portal. All of the samples yielding these high gold-arsenic values are composite chip samples, taken over 10-foot intervals; each contained an appreciable amount of vein material or limonitic residue found over the same interval. The larger intrusive, from which mineralized quartz veins were explored on the surface, was not penetrated by the exploration adit, but it may be similarly mineralized at depth.

COPPER LODES
DENALI DEPOSITS

A series of at least six stratiform chalcopyrite-pyrite deposits are intercalated with Upper Triassic metavolcanic and metasedimentary rocks in the divide between Windy Creek and the South Fork of Pass Creek (pI. 1, loco 34). These deposits are collectively known as the 'Denali Prospect' and have been discussed in some detail by Stevens (1971) and Seraphim (1975); they will be described here in a general way on the basis of their work. The significance of the mineralization was first recognized in 1963 by Kaufman ,(1964), but early Valdez Creek gold miners and prospectors such as George Fennimore, C.R. Greathouse, and Denny Thompson had been aware of copper mineralization both in outcrop within Pass Creek and as float along the hillside (Stevens, 1971). In 1964, the Alaska Syndicate began development work on the Denali deposits and by 1971, surface trenching, underground tunneling, and a substantial amount of diamond drilling had delineated a small but high-grade reserve of copper and by-product silver and gold.

The geology of part of the Denali Prospect shown in figure 64 has been adapted from Stevens (1971, figs. 4, 6). Rock types cropping out at the prospect include limestone, metavolcanic rocks, argillite, and carbonate-rich sulfide bands. On the basis of the degree of relict primary textures that can be recognized, metavolcanic rocks in the prospect area are tuff, gabbro, and greenstone, shown on plate 1 as the stratigraphic top of the Amphitheatre Group. The metasedimentary rocks range from very light gray bleached massive limestone through impure, well-banded limestone and argillaceous limestone to graphitic argillite. The pure and massive

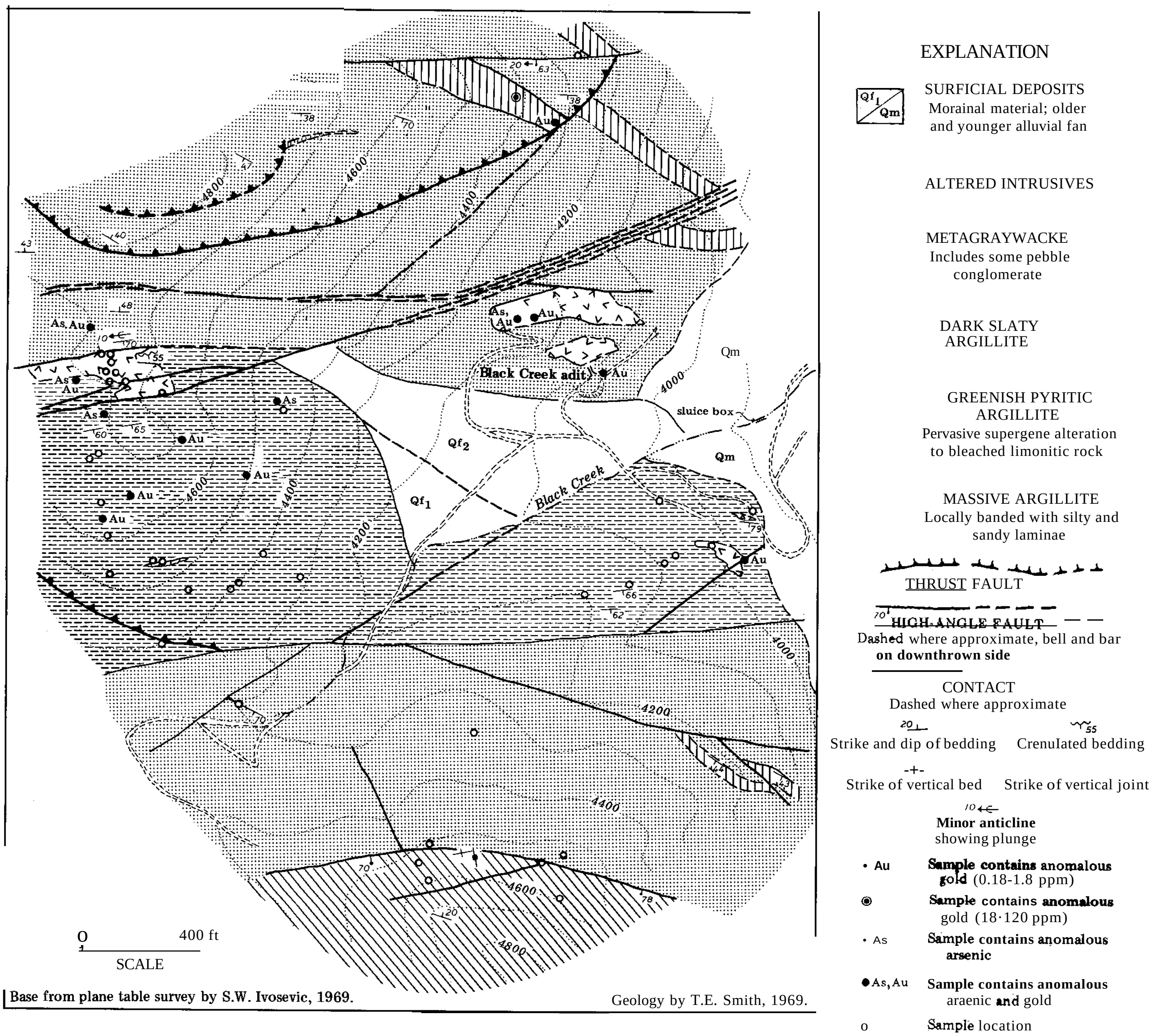


Figure 62. Geologic map of eastern Lucky Hill area showing location of Black Creek adit (prospect 19, pi. 1), geochemical bedrock samples, and gold-arsenic anomalies.

varieties of limestone are barren of sulfides (Seraphim, 1975).

The chalcopyrite and pyrite are hosted only in the impure and argillaceous limestone in the zone of intercalated metasedimentary and metavolcanic rocks. In the metavolcanic rocks underlying the ore zone, scattered chalcopyrite, bo.rnite, chalcocite, native copper, and very minor pyrite are present in sporadic amounts_ Within the ore zone, chalcopyrite and pyrite amount to an average 30 percent of the host rock and are present in a 1:1 ratio. Sphalerite and digenite are also found in minor amounts associated with the pyrite and chalcopyrite. The graphitic argillite unit above the ore zone uniformly contains 2 to 3 percent pyrite.

Both Stevens (1971, p. 33) and Seraphim (1975, p. 953) describe three major types of sulfide mineralization: 1) massive sulfide beds, 2) very finely laminated, rhythmically layered sulfides and carbonate detritus, or 'pajama rock,' and 3) homogeneous mixtures of sulfide and detritus, Le., 5- to 20-cm-thick bands of massive chalcopyrite-pyrite and argillaceous limestone. According to Stevens (1971, p. 33), the rhythmic layering sequences (type 2 above) reach maximum thicknesses of 10 feet and are remarkably similar to varves formed in a glaciofluvial environment. Seraphim (1975) has shown that the major ore zone (no. 6, fig. 64) contains

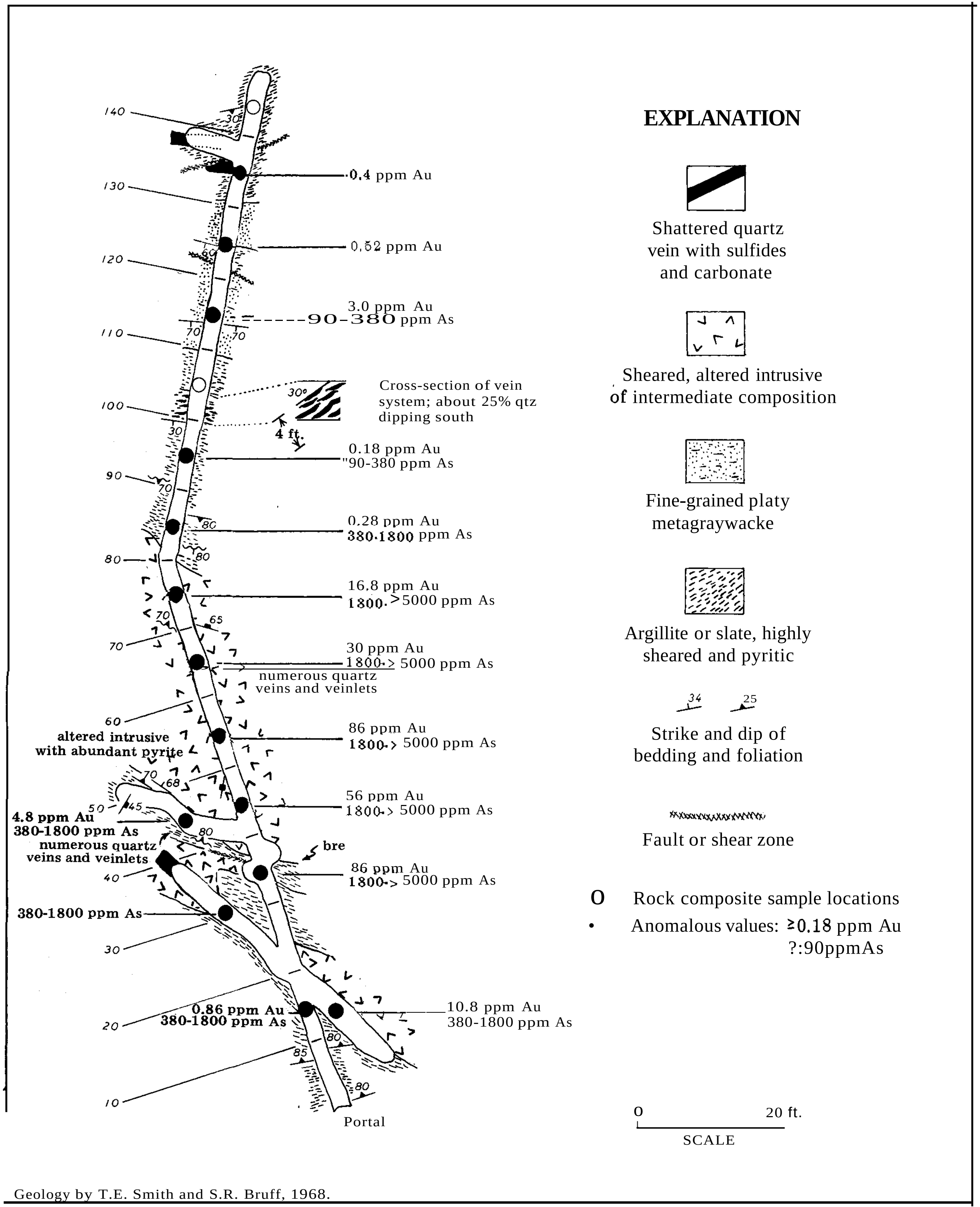


Figure 63. Geologic mine map of Black Creek prospect showing results of composite chip sampling. For location of adit, see figure 62.

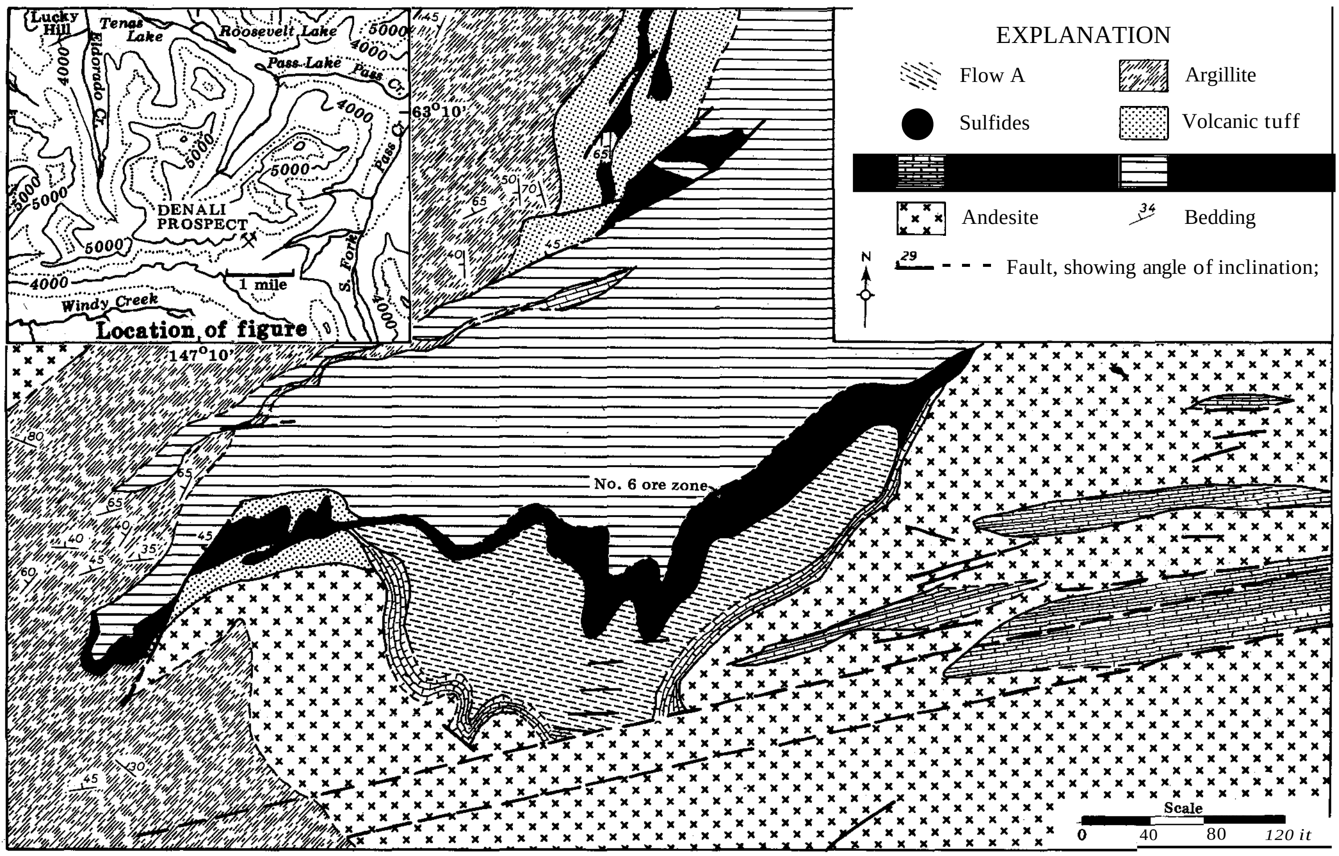


Figure 64. Surface bedrock geology of part of Denali prospect from Stevens (1971, fig. 4).

over 4,500 sulfide laminations.

Stevens (1971) believes that the Denali deposits formed in an euxinic marine basin, where abundant organic material and sulfate-reducing bacteria created a strongly reducing environment. He based this conclusion in part on 1) the sedimentary structures of the sulfides such as the rhythmic layering, presence of pyrite framboids, soft-sediment slumping, lack of cross-cutting sulfides, and microfaulting, 2) the lack of replacement textures, 3) the presence of black, sooty carbonaceous powder, a food source of sulphate-reducing bacteria, 4) the lack of hydrothermal wallrock alteration, 5) the simple elemental geochemistry of the deposits, that is, essentially copper, iron, and minor to trace silver, gold, zinc, and 6) sulfur isotopic analyses (S34 0/00) averaging -28.35, which suggest a biogenic origin.

Seraphim (1975) also believes the sulfides are syngenetic, but questions some of the features of the deposits such as 1) the change in the copper-iron ratio from the underlying volcanic rocks to the overlying sedimentary rocks, 2) the close relationship of Denali mineralization to andesite flow fronts, 3) the continuity of metasedimentary rocks to the west of the deposits, which would preclude the closed system usually needed for a biogenically derived deposit, 4) the change in sulfide content along the footwall of the No.6 zone, and 5) the presence of at least two hydrothermal or solfataric springs in the No.5 ore zone (not shown in fig. 64). Thus, Seraphim (1975, p. 958) concludes the Denali deposits were formed from copper·rich acidic(?) solutions derived from a volcanic source to the southeast. These solutions would react rapidly as they entered the reducing lime and carbonaceous marine environment, with subsequent rapid deposition of sulfides. He further suggests that the copper-rich solutions were formed from surface leaching of an abundant copper source found in the adjacent volcanic landmass or from copper originating from hydrothermal or solfataric springs related to volcanism. This alternate hypothesis can be described as the 'Bessi' type or 'cupreous-pyrite' massive-sulfide volcanogenic model (Hutchison, 1973), in which each sulfide layer represents a submarine volcanic exhalation and subsequent precipitation of copper and iron sulfides. Bessi-type deposits typically have simple elemental contents (major copper, minor zinc, gold credits), are restricted to mafic volcanic piles, and are usually smaller than other types of stratiform volcanogenic deposits. Volcanogenic massive sulfides, however, are typically enriched by 'heavy' sulfur isotopes during the metallic sulfide phase; thus, the very light sulfur isotopes reported by Stevens

(1971) do not support the Bessi model. The Denali deposits may represent distal rather than proximal precipitation of sulfides from a submarine volcanic vent system.

SMALL COPPER DEPOSITS SOUTH OF WINDY CREEK

Minor copper shows are common within the Amphitheatre Group in the study area. Glavinovich (1967, p. 29-34) describes about 10 copper occurrences in rock units south of Windy Creek (pl. 1, locs. 23-33). These small deposits usually occur as open-space fillings in amygdules, as quartz-epidote sulfide veins in fractures and joints, and as disseminated copper mineralization in shear zones. Copper minerals include major bornite and lesser amounts of chalcocite, native copper, chalcopyrite, covellite, malachite, and azurite. Many are found as mineralized rubble on the hillsides, but the float is believed to indicate that bedrock mineralization is in the immediate vicinity. All but one of the showings described by Glavinovich (1967) are hosted in intermediate or mafic metavolcanic rocks of the Amphitheatre Group.

The most well known of these occurrences is the Greathouse Prospect (pl. 1, loc. 28), which consists of bornite, chalcocite, and covellite with associated quartz, malachite, epidote, and calcite in a 3-foot-wide north-west-trending shear zone. The footwall and hanging wall of the shear zone are altered basalt. Fragmental country rock within the mineralized zone is strongly epidotized. A 4-foot-wide diorite dike is located near the zone. Glavinovich (1967, p. 33) has shown that chalcocite generally replaces bornite, covellite replaces chalcocite, and quartz and malachite crosscut the previous sulfides.

The Raft Creek Prospect (pl. 1, loc. 33) consists of chalcopyrite, pyrite, and malachite erratically distributed in quartz veins that cut a small diorite pluton. Vein widths range from 1/4 to 3 inches within a zone of numerous fractures several feet wide.

Most of these small copper shows occur in fractures formed contemporaneously with alteration of the host rocks and illustrate the high copper content of the Triassic Amphitheatre Group volcanics. Seraphim (1975) postulates this is the source of copper in the Denali deposits previously described. Similar copper occurrences have been reported by Stout (1976) in the Amphitheatre Group 60 miles to the east of the Clearwater Mountains. As suggested by Glavinovich (1967, p. 44), hydrothermal solutions passing through structural channels could produce sizable replacement bodies. Such a hypothesis has been used to explain the origin of the Kennecott deposits in the Chitina valley (Bateman and McLaughlin, 1920), where the original volcanic source of the copper is the Triassic Nikolai Greenstone, a unit virtually indistinguishable from the Amphitheatre Group. Such enriched solutions passing into reactive carbonate-rich rocks could produce commercial ore bodies.

ELEMENTAL GEOCHEMISTRY

Smith (1970b) collected 217 stream-sediment and several hundred bedrock-chip samples in the study area and analyzed them for 30 elements by the semiquantitative emission spectrographic technique. Additionally gold, silver, copper, and tellurium were analyzed by atomic-absorption spectrophotometry, and tungsten, arsenic, and mercury were delineated by colorimetric techniques. Some of these results are summarized below and shown on plates 2 and 3.

Background, threshold, and anomalous values of the samples were determined by using the method described by Lepeltier (1969); summary data for copper, silver, gold, arsenic, and mercury are shown in table 10. In the stream-sediment samples the mercury, gold, and copper formed complex populations, whereas silver and arsenic showed a simple log-normal distribution. In the rock samples the gold, copper, arsenic, and mercury all plotted as complex populations, with gold and copper in rock samples present in near-crustal average abundance (gold 0.007 ppm).

Standard product-moment correlation coefficients between all pairs were computed by Smith (1970b, p. 17-22) to determine the intrasample element associations using a method similar to that described by Davis (1973, p. 73-80). Bedrock sample data indicate that gold shows meaningful correlation with silver

Table 10. *Background (ppm), threshold (ppm), and enrichment values for geochemical samples, Clearwater Mountains, Alaska (from Smith, 1970b, p. 16).*

Stream-sediment samples

	Au	Ag	As	Cu	Hg
Background	0.007	0.9	9.0	90	0.16
Enrichment over crustal average*	1 X	13 X	5 X	1.6 X	2 X
Threshold	0.09	1.5	120	250	0.9

Bedrock geochemical samples

	Au	As	Cu	Hg
Background	0.008	10.0	40.0	0.2
Enrichment over crustal average*	1X	5.5 X	0.7 X	2.5 X
Threshold	0.18	90	300	0.6

*Crustal averages taken from Taylor (1964) and Jones (1968).

(0.67), arsenic (0.57), and mercury (0.43). Silver is correlative with cobalt (0.24) and arsenic (0.30). Copper shows no strong association with any trace element and has only a low correlation with silver. Stream-sediment-sample correlations show that gold is associated with boron (0.31) and arsenic (0.34). Silver shows definite mafic or ultramafic affiliations with cobalt (0.42), chromium (0.27), nickel (0.40), and copper (0.29).

Thus, arsenic and mercury could be valuable index elements of gold deposits in the study area, whereas mafic elements may be useful indicators for copper mineralization, particularly in streams draining the metavolcanic rocks.

REFERENCES CITED

Bateman, A.M., and McLaughlin, D.H., 1920, Geology of the ore deposits at Kennecott, Alaska: Econ. Geology, v. 15, p. 1-80.

Blake, M.C., Jr., Irwin, W.P., and Coleman, R.G., 1967, Upside-down metamorphic zonation, blueschist facies, along a regional thrust in California and Oregon, *in* Geological Survey Research, 1967: U.S. Geol. Survey Prof. Paper 575-C, p. Cl-9.

Blanchard, Roland, 1968, Interpretation of leached outcrops: Nevada Bur. Mines Bull. 66, 196 p.

Bond, G.C., 1965, Bedrock geology of the Gulkana glacier area, Alaska Range: Fairbanks, Univ. Alaska M.S. thesis, 45 p.

__________, 1970, Permian volcanics, volcaniclastics, and limestones in the Cordilleran Eugeosyncline, east-central Alaska Range, Alaska: Madison, Univ. Wis. Ph.D. dissertation, 144 p.

Capps, S.R., 1940, Geology of the Alaska Railroad region: U.S. Geol. Survey Bull. 907, 201 p.

Chapin, Theodore, 1918, The Nelchina-Susitna region, Alaska: U.S. Geol.Survey Bull. 668, 67 p.

Coleman, J.M., and Gagliano, S.M., 1965, Sedimentary structures, Mississippi River deltaic plain; Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p.133-48.

Davis, J.C., 1973, Statistics and data analysis in geology: New York, John Wiley and Sons, 550 p.

Ferrians, O.J., Jr., 1963a, Till-like glaciolacustrine deposits in the Copper River Basin [abs.]: Geol. Soc. America Spec. Paper 73, p. 151.

__________, 1963b, Glaciolacustrine diamicton deposits in the Copper River Basin, Alaska, *in* Geological Survey Research, 1963: U.S. Geol. Survey Prof. Paper 475-C, p. C121-25.

Ferrians, O.J., Jr., and Schmoll, H.R., 1957, Extensive proglacial lake of Wisconsin age in the Copper River Basin, Alaska [abs.]: Geol. Soc. America Bull., v. 68, no. 12, p. 1726.

Folk, R.L., 1959, Practical petrographic classification of limestone: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 1-38.

Forbes, R.B., and Engels, J.C., 1970, $^{40}K/^{40}Ar$ age relations of the Coast Range Batholith and related rocks of the Juneau Ice Field area: Geol. Soc. Amer. Bull., v. 81, p. 579-84.

Forbes, R.B., Turner, D.L., Stout, J.H., and Smith, T.E., 1973, Cenozoic offset along the Denali Fault, Alaskal' [abs.]: EOS (Am. Geophys. Union Trans.), v. 54, no. 4, p. 495.

Gates, G.O., and Gryc, George, 1963, Structure and tectonic history of Alaska, *in* Backbone of the Americas: Am. Assoc. Petroleum Geologists Mem. 2, p. 264-77.

Glavinovich, P.S., 1967, Trace element copper distribution and areal geology in a portion of the Clearwater Mountains, Alaska: Fairbanks, Univ. Alaska Minerals Industry Research Lab. Rept. 10, 55 p.

Hanson, L.G., 1963, Bedrock geology of the Rainbow Mountain area, Alaska Range, Alaska: Alaska Div. Mines and Minerals Geol. Rept. 2, 82 p.

Hietanen, Anna, 1963, Idaho Batholith near Pierce and Bungalow, Clearwater County, Idaho: U.S. Geol. Survey Prof. Paper 344-D, p. Dl-42.

Hopkins, D.M., Kachadoorian, Reuben, and Nichols, D.R., 1953, Unpublished map, legend, notes, and preliminary manuscript concerning surficial geology in the area between Susitna and Maclaren Rivers, Alaska.

Hutchinson, R.W., 1973, Volcanogenic sulfide deposits and their metallogenic significance: Econ. Geology, v. 68, no. 8, p. 1223-46.

Kachadoorian, Reuben, Hopkins, D.M., and Nichols, D.R., 1954, A preliminary report of geologic factors affecting highway construction in the area between the Susitna and Maclaren Rivers, Alaska: U.S. Geol. Survey open-file rept., 74 p.

Kaufman, M.A., 1964, Geology and mineral deposits of the Denali-Maclaren River area, Alaska: Alaska Div. Mines and Minerals Geol. Rept. 4, 15 p.

Jones, R.S., 1968, Gold in meteorites and in the Earth's crust: U.S. Geol. Surv. Circ. 603,4 p.

Lepeltier, Claude, 1969, A simplified statistical treatment of geochemical data by graphical representation: Econ. Geology, v. 64, no. 5, p. 538-50.

Lyons, J.B., 1955, Geology of the Hanover Quadrangle, New Hampshire-Vermont: Geol. Soc. America Bull., v. 66, no. 1, p. 105-46.

MacKevett, E.M., Jr., 1965, Preliminary geologic map of the McCarthy C-6 Quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map 1-406.

Martin, G.G., 1926, The Mesozoic stratigraphy of Alaska: U.S. Geol. Survey Bull. 776, 493 p.

Moffit, F.H., 1912, Headwater regions of Gulkana and Susitna Rivers, Alaska: U.S. Geol. Survey Bull. 498, 81 p.

Moffit, F.H., and Pogue, J.B., 1915, The Broad Pass region, Alaska: U.S. Geol. Survey Bull. 608,80 p.

Nichols, D.R., 1956, Permafrost and groundwater conditions in the Glennallen area, Alaska: U.S. Geol. Survey open-file rept., 18 p.

Nockolds, S.R., 1954, Average chemical composition of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007-32.

Pettijohn, F.J., 1957, Sedimentary rocks: New York, Harper Brothers, 718 p.

Ragan, D.M., and Hawkins, J.W., 1964, Relict charnockitic rocks, granulite facies gneisses and migmatites in a polymetamorphic complex, Gulkana Glacier region, eastern Alaska Range: Geol. Soc. America Abs. with Programs Cordilleran Section, p. 52.

Rast, Nicholas, 1965, Nucleation and growth of metamorphic minerals, *in* W.S. Pitcher and G.S. Flinn, eds., Controls of metamorphism: Edinburgh, Oliver and Boyd, p. 73-102.

Richardson, S.W., Gilbert, M.C., and Bell, P.M., 1969, Experimental determination of kyanite-andalusite and andalusite-sillimanite equilibria - The aluminum silicate triple point: Am. Jour. Sci., v. 267, no. 3, p. 259-70.

Rose, A.W., 1965, Geology and mineral deposits of the Rainy Creek area, Mt. Hayes Quadrangle, Alaska: Alaska Div. Mines and Minerals GeoL Rept. 14,51 p.

_____________, 1966a, Geology of a part of the Amphitheatre Mountains, Mt. Hayes Quadrangle, Alaska: Alaska Div. Mines and Minerals Geol. Rept. 19, 12 p.

_____________, 1966b, Geological and geochemical investigations in the Eureka Creek and Rainy Creek areas, Mt. Hayes Quadrangle, Alaska: Alaska Div. Mines and Minerals GeoL Rept. 20, 36 p.

Rose, A.W., and Saunders, R.H., 1965, Geology and geochemical investigations near Paxson, northern Copper River Basin, Alaska: Alaska Div. Mines and Minerals GeoL Rept. 13, 35 p.

Ross, C.P., 1933, The Valdez Creek mining district, Alaska: U.S. GeoL Survey Bull. 849-H, p. 435-67.

Saunders, R.M., 1953, Valdez Creek district: Alaska Terr. Dept. Mines unpub. paper MR 67-7, 10 p.

Seraphim, R.H., 1975, Denali - A nonmetamorphosed stratiform sulfide deposit: Econ. GeoL, v. 70, no. 5, p.949-60.

Shapiro, Lewis, and Brannock, W.W., 1962, Rapid analysis of silicate carbonate and phosphate rocks: U.S. GeoL Survey Bull. 1144-A,p. *AI-56.*

Shaw, D.M., 1954, Trace elements in pelitic rocks: GeoL Soc. America Bull., v. 65, no. 12, p. 1151-82.

Slemmons, D.B., 1962, Determination of volcanic and plutonic plagioclases using a three- or four-axis universal stage: Geol. Soc. America Spec. Paper 69, 64p.

Smith, N.D., 1968, Cyclic sedimentation in a Silurian intertidal sequence in eastern Pennsylvania: Jour. Sed. Petrology, v. 38, no. 4, p. 1301-14.

Smith, P.S., 1941, Fineness of gold from Alaska placers: U.S. Geol. Surv. Bull. 910-C, 272 p.

Smith, T.E., 1970a, Gold resource potential of the Denali bench gravels, Valdez Creek mining district, Alaska, *in* Geological Survey Research 1970: U.S. GeoL Survey Prof. Paper 700-D, p. D146-52.

_____________, 1970b, Results of geochemical sampling in the western Clearwater Mountains, Alaska: U.S. Geol. Survey open-file rept., 247 p.

_____________, 1970c, Lode gold occurrences in the western Clearwater Mountains [abs.], *in* Geological Survey Research 1970: U.S. GeoL Survey Prof. Paper 700-A, p. *A47.*

_____________, 1970d, Inverted metamorphic zonation in the northern Clearwater Mountains, Alaska [abs.], *in* Geological Survey Research 1970: U.S. Geol. Surv. Prof. Paper 700-A, p. *A47-48.*

_____________, 1971, Geology, economic geochemistry, and placer gold resources of the western Clearwater Mountains, east-central Alaska: Dissert. Abs., v. XXXII, no. 3, p. 1665-B.

Smith, T.E., and Lanphere, M.A., 1971, Age of the sedimentation, plutonism, and regional metamorphism in the Clearwater Mountains region, central Alaska: Isochron/West, no. 2, p. 17-20.

Smith, T.E., Forbes, R.B., and Turner, D.L., 1974, A solution to the Denali Fault offset problem: Alaska Div. Geol. and Geophys. Surv., 1973, Ann. Rept., p.25-27.

Spry, Alan, 1969, Metamorphic textures: New York, Pergamon Press, 350 p.

Stevens, D.L., 1971, Geology and geochemistry of the Denali Prospect, Clearwater Mountains, Alaska: Fairbanks, Univ. Alaska Ph.D. dissertation, 81 p.

Stout, J.H., 1965, Bedrock geology between Rainy Creek and the Denali Fault, eastern Alaska Range, Alaska: Fairbanks, Univ. Alaska M.S. thesis, 75 p.

_____________, 1976, Geology of the Eureka Creek area, east-central Alaska Range: Alaska Div. GeoL and Geophys. Surveys GeoL Rept. 45, 32 p.

Streckeisen, AL., 1967, Classification and nomenclature of igneous rocks: Neues Jahrb: Mineralogie Abh., B. 107, 2 u 3, p. 144-240.

Surdam, R.C., 1968, Origin of native copper and hematite in the Karmutsen Group, Vancouver Island, B.C.: Econ. Geology, v. 63, no. 8, p. 961-66.

Taylor, S.R., 1964, Abundance of chemical elements in the Earth's crust: Geochim. et Cosmochim. Acta, v. 28, p. 1280-81.

Tuck, Ralph, 1938, The Valdez Creek mining district, Alaska, in 1936: U.S. GeoL Survey Bull. 897-B, p.108-31.

Turner, F.J., 1968, Metamorphic petrology - Mineralogical and field aspects: New York, McGraw-Hill, 403 p.

Turner, D.L., and Smith, T.E., 1974, Geochronology and generalized geology of the central Alaska Range; Clearwater Mountains and northern Talkeetna Mountains: Alaska Div. Geol. and Geophys. Surv. Open-file Rept. AOF-72, 10 p., 1 pI.

Vlasov, K.A, ed., 1966, Geochemistry of rare elements and genetic types of their deposits, translated from Russian by Z. Lerman: Israel program for scientific translations, Jerusalem.

Wahrhaftig, Clyde, and Cox, Allen, 1959, Rock glaciers in the Alaska Range: GeoL Soc. America Bull., v. 70, no. 4, p. 346-83.

Waters, AC., 1955, Volcanic rocks and the tectonic cycle, *in* The crust of the Earth: Geol. Soc. America Spec. Paper 62, p. 704-22.

Williams, G.J., 1965, Economic geology of New Zealand: Commonwealth Mining and Metallurgical Cong., Australia and New Zealand, Melbourne, 8th, v. 4, p. 74-77.

Wimmler, N.L., 1925a, Placer mining in Alaska in 1925: Alaska Terr. Dept. Mines unpub. paper MR 195-8, p.58-72.

_____________, 1925b, Valdez Creek lode prospects: Alaska Terr. Dept. Mines unpub. paperMR 67-2, 5 p.

Winkler, H.G.F., 1967, Petrogenesis of metamorphic rocks: New York, Springer-Verlag, 237 p.

_____________, 1970, Permian volcanics, volcaniclastics, and limestones in the Cordilleran Eugeosyncline, east-central Alaska Range, Alaska: Madison, Univ. Wis. Ph.D. dissertation, 144 p.

APPENDIX

Location of rock samples analyzed for major oxides from western Clearwater Mountains.

Field No.	West Longitude	North Latitude
	Metavolcanics (TRb)	
68-ASb-139	147°13'25"	63°07'20"
68-ASb-212	147°05'00"	63°07'55"
68-ASb-218	147°02'55"	63°07'30"
68-ASb-238	147°01'40"	63°08'35"
68-ASb-239a	147°01'35"	63°08'40"
68-ASb-263	147°05'45"	63°09'40"
	Argillite (pJa)	
69-ASt-261	147°15'00"	63°10'00"
69-ASt-261a	147°15'00"	63°10'00"
68-ASb-266	147°06'05"	63°10'10"
68-ASb-550a	147°17'35"	63°09'45"
68-ASb-668	147°26'55"	63°08'50"
68-ASb-1048b	147°00'50"	63°12'40"
	Phyllite (TKp)	
68-ASb-417a	147°13'30"	63°12'15"
	Schist (TKs)	
68-ASb-392	147°15'00"	63°11'35"
68-ASb-455	147°09'50"	63°13'10"
68-ASb-464	147°12'50"	63°14'00"
68-ASb-467	147°12'10"	63°14'30"
68-ASb-1591b	147°12'35"	63°12'25"
	Granodiorite (Tgd)	
68-ASb-306	147°00'00"	63°13'25"
68-ASb-312	147°00'00"	63°14'00"
68-ASb-451	147°07'20"	63°14'15"
68-ASb-455a	147°09'50"	63°13'10"
68-ASb-1048c	147°00'50"	63°12'40"
	Small Stocks and Dikes (TKi)	
68-ASb-44	147°24'00"	63°08'55"
68-ASb-56a	147°22'05"	63°07'40"
68-ASb-126c	147°14'55"	63°08'00"
68-ASb-339	147°08'40"	63°11'10"
68-ASb-343a	147°09'10"	63°10'05"
68-ASb-386	147°11'35"	63°09'30"
68-ASb-414	147°17'30"	63°11'30"
68-ASb-483	147°18'30"	63°13'05"
68-ASb-483a	147°18'30"	63°13'05"
68-ASb-592	147°23'50"	63°11'10"
68-ASb-593	147°24'15"	63°11'20"

Field No.	West Longitude	North Latitude
	Alkali Gabbro (Jag)	
68-ASb-134	147°14'25"	63°08'25"
68-ASb-135b	147°14'25"	63°08'30"
68-ASb-136	147°14'35"	63°08'40"
68-ASb-153	147°13'10"	63°07'55"
68-ASb-160a	147°12'00"	63°08'20"
68-ASb-243	147°08'10"	63°09'15"
68-ASb-389	147°13'25"	63°08'55"
69-ASt-231	147°12'00"	63°09'00"
69-ASt-232	147°12'00"	63°09'00"
69-ASt-233	147°12'00"	63°09'00"
69-ASt-234	147°12'00"	63°09'00"
69-ASt-235	147°12'00"	63°09'00"
69-ASt-236	147°12'00"	63°09'00"
69-ASt-237	147°12'00"	63°09'00"
69-ASt-238	147°12'00"	63°09'00"
69-ASt-239	147°12'00"	63°09'00"
69-ASt-240	147°12'00"	63°09'00"
69-ASt-242	147°12'00"	63°09'00"

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