Open File Report No. 84-2

BEDROCK GEOLOGY OF THE RICHARDSON MINING DISTRICT, ALASKA

by

R.C. Swainbank, J.P. Burton and P.A. Metz

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OPEN FILE REPORT 84-2

Mineral Industry Research Laboratory
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June, 1984
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ABSTRACT

Placer gold, which has been worked in the Richardson district since the turn of the century, appears to be spatially associated with a rhyolite porphyry-dike dated at 86.942.6 m.y. The trend of the dike in the Tenderfoot Creek-Democrat Creek area appears to be related to the Richardson Lineament, one of several linear features with northwesterly trends in the district.

Gold was found in pan concentrate samples during this study several thousand feet upstream of the rhyolite dike in several tributaries of Banner Creek, and anomalous amounts of silver were found in stream sediment samples in the same area, but the source was not found.

The rhyolite dike in the Banner Creek area separates gneissic terrane and locally granofelsic variants to the northeast from schistose rocks to the southeast. Impure marble, amphibolite augen-gneiss and garnet-bearing quartzofeldspathic gneiss are commonly found to the northeast of the dike.

At the head of Junction Creek the dike appears to trend westerly towards the Birch Lake Pluton, and gneissic rocks, associated with small rhyolite dikes are known to the west and north of the pluton. The pluton and its margins are characterized by anomalous quantities of tin, tungsten and other metals in pan concentrate samples.

A small stock of similar composition was discovered during this program to the northwest of VABM Buck, but the subsurface extent is suspected to be much greater to the southeast. Like the Birch Lake Pluton the elements tin and tungsten occur in anomalous quantities in pan concentrate samples from many of the drainages off this area.
Introduction

The Richardson mining district is located in the central portion of the Yukon-Tanana Uplands (see Figure 1). Rock exposure is rare in the Richardson Mining District, however bedrock exposure is good in the roadcuts along the Richardson Highway, which is almost coincident with the southern limit of the project area between Shaw Creek and Harding Lake. Exposure is also adequate in the Banner Creek-Democrat Creek areas, where numerous exploration pits, open-cuts and a few ditch-lines provide an opportunity to examine rock in situ. Bedrock was seen in some stream valleys and in a few occasional isolated, residual, tor-like knobs on ridgelines. Residual rubble in trails on the ridgelines, supplemented by that in hand-dug pits along the lines of traverse, provided additional lithologic information. In many cases such pits, dug to depths of three or four feet, yielded few or no rock fragments.

Plates I and II shows the locations of the geologic stations occupied in the program, and Plates III thru IV are the geologic maps constructed from the information gained. Plates III thru IV show structural information, and Plates V and VI geochemical. Plates IIIa and IIIb contain sample location and geological data at a 1" = 1000' scale for the Banner Creek-Buckeye Creek part of the district.

The Richardson district is underlain by polymetamorphic crystalline rocks including schist, gneiss and granofels composed of varying proportions of quartz, plagioclase, potash feldspar, muscovite and biotite. Calcite, sphene and epidote are common in impure marbles or calc-silicate rocks, and in amphibolite units within the schist and gneiss.

Clinopyroxene is abundant in calc-silicate rocks which may be high-grade impure marbles. Andalusite is a constituent of many of the schists and
Figure 2. Location map of the Richardson Mining District and adjacent areas.
gneisses and cordierite occurs in schists near plutons. Sillimanite is present in many of the higher-grade gneisses, but no staurolite or kyanite was observed. In terms of metamorphic grade, the parageneses of the schists indicate upper greenschist to lower amphibolite, while the gneisses are mid to upper amphibolite facies.

These polymetamorphic crystalline rocks are intruded and thermally upgraded by at least two quartz monzonite porphyry plutons, one of which was identified in this program.

Biotite and hornblende-bearing variants of the plutons were recognized, and granophyric variants are locally common. Garnet-clinopyroxene skarn occurs in country rock of appropriate chemistry, and hornfels aureoles are variably developed.

Fine-grained rhyolite porphyry, sometimes accompanied by andesite porphyry, was found at widely scattered localities throughout the district. The disposition of most of the rubble crops suggests dike-like bodies. In the Banner Creek area the rhyolite porphyry is locally altered and contains sulphide-bearing quartz veins.

The Birch Lake pluton has previously been dated at 89.3 ± 2.7 my, and the rhyolite porphyry in Banner Creek at 86.9 ± 2.6 my (Bundtzen and Reger, 1977).

On the basis of field work, supplemented by petrographic study of 150 thin-sections in this project and restudy of about 100 thin sections kindly loaned by the U.S. Geological Survey, the Richardson district can be considered as two distinct terranes, the one composed predominantly of schist, the other of gneiss and granofels.

In only a few places do sufficient rock exposures exist to draw any conclusions regarding the relationships between the schist and gneiss
terranes. These include road cuts in the vicinity of MP309-MP312 on the Richardson Highway a few miles southeast of the Midway Lodge; in the vicinity of the Birch Lake Pluton; and in the Banner Creek-Buckeye Creek area.

Though no continuous geologic sections exist in any of these areas, there are sufficient natural and man-made exposures in the Banner-Buckeye region to recognize some mutual relationships between the schist terrane, the gneiss terrane and the rhyolite porphyry.

We believe that the information derived from the Banner-Buckeye area may have broader application within the Richardson district as a whole, particularly in regard to characteristic elemental and petrologic associations.

Previous Investigations

Recent publications with reference to the geology of the Richardson district include Saunders (1965), Bundtzen and Reger (1977), Weber, et al. (1978) and Foster et al. (1978).

Saunders (1969) presented a generalized geologic map of the Banner Creek and Tenderfoot areas, and analyzed sixty-six stream sediment samples for heavy metals using cold-extractable methods. He suggested that the North Fork of Banner Creek should be further prospected to determine the source of anomalous heavy metal concentrations in several of the tributaries.

Bundtzen and Reger (1977) identified lineaments extending from Tenderfoot Creek northwest to Shamrock Creek, which apparently control the distribution of bodies of porphyro-aphanitic quartz-orthoclase porphyry. The minimum age of the porphyry was reported at 86.9 ± 2.6 my, as determined by K/Ar dating. Their mapping in Buckeye Creek north of the porphyry disclosed outcrops of
epidote-actinolite hornfels proximal to coarse-grained K-feldspar-quartz-muscovite metagranite. The porphyry at the Democrat Mine was reported as being locally gossanized, containing disseminated sulphide pseudomorphs and quartz veins.

Geologic mapping by Weber et al. (1978) and Foster et al. (1978) was more regional in scope, covering the Big Delta quadrangle. A number of reports companion to the map describe the geochemistry, geophysics and photointerpretation of the quadrangle as part of the Alaskan Mineral Resource Assessment Program (AMRAP). This work provides the information discussed in the introduction. Dusel-Bacon and Foster (1983) describe the rocks in a proposed gneiss dome some centered approximately 24 miles northeast of the Richardson area. Approximately 100 thin sections from the Richardson district were loaned to the project by Cynthia Dusel-Bacon of the U.S. Geological Survey as a supplement to the 150 cut from rocks collected in this project.

**Regional Geology**

The Richardson mining district is located near the southern margin of the Yukon Crystalline Terrain which underlays much of the Yukon-Tanana Upland east of Fairbanks (see Figure 2).

Paleozoic or older quartzites, pelitic or calcareous schists of epidote-amphibolite metamorphic grade are locally upgraded in this portion of the Uplands to rocks with parageneses indicative of temperatures and pressures compatible with the kyanite-sillimanite-andalusite triple point.

The spatial distribution of these gneissic and granofelsic rocks, the geothermometry based on garnet-biotite pairs, and the structural attitudes suggest that classic gneiss domes may exist. Dusel-Bacon and Foster (1983)
Fig. 3. Generalized bedrock geology of the Yukon-Tanana Uplands (after Foster and others, 1973).
have proposed that one such dome is centered approximately 24 miles northeast of the Richardson district.

In addition to the granofelsic rocks, which despite their granoblastic texture contain evidence of their metamorphic origin, large areas of the Yukon Crystalline Terrain are underlain by obviously intrusive igneous rocks, and thermal aureoles are mappable in the surrounding schists. All gradations from phyllitic schists through gneiss and granofels to undoubted plutonic and hypabyssal intrusives have been recognized in the Richardson District.

Plates I through VI show the sample locations and local nomenclature, structural information, actual geology, geochemistry, and interpretative geology of the project area. An enlarged photomylar copy of the U.S. Geological Survey 1:63,000 topographic map was provided by Mr. Gil Monroe, miner, for use as a base map of the Buckeye-Banner Creek area, and his enthusiastic cooperation is gratefully acknowledged.

As noted in the introduction, the Richardson district is underlain by igneous, schist and gneiss terrane. Some gradation is evident from the field classifications such as "schistose gneiss", "gneissic schist", and "granofels".

In the Buckeye-Banner Creek area most variants seen elsewhere in the district were examined, with the exception of andesite porphyry, true granites or quartz monzonites, and the concommitant thermal aureoles.

All localities will be referred to the appropriate geologic station in parentheses, eg. (B120).

It is convenient to consider the rocks observed in the Richardson district in three groups. Rocks of undoubted igneous origin, including both
plutonic and hypabyssal variants, were relatively easily recognizable, and also readily traceable in rubble and outcrop.

The second group, -regionally metamorphosed rocks, -includes schists, quartzites, calcareous rocks, schistose gneiss, gneiss and granofels. The granofelsic rocks frequently have a granoblastic texture without even subtle gneissic layering, but usually have obvious metamorphic textures when examined under the microscope.

The third group consists of metamorphic rocks which have been altered by dynamic, thermal or hydrothermal agencies, usually on a purely local scale. Study of the 250 sections provided information contained in the following descriptions of the various rock types.

Igneous Rocks

Plutonic and hypabyssal igneous rocks occur in the Richardson district, and it is possible that some rubble crops may be remnants of extrusive igneous rocks. Though they are undoubtedly younger than the schist, gneiss and granofels which they intrude, the igneous rocks provide readily identifiable geographic references for the more complex metamorphic associates.

a) Plutonic Rocks

Three areas of plutonic rocks are present in the Richardson district, the largest of which is the Birch Lake Pluton. In this pluton the rock is coarse-grained porphyritic granite and quartz monzonite, with numerous xenoliths in the area east of Birch Lake close to the Highway, but with no evident foliation. In the western part of the pluton, the lower portion of VABM Hill, to an elevation of about 1250 feet, is composed of similar porphyritic, strongly jointed rock, and is well exposed in the borrow-pit at Station S55, (M14).
Vein quartz up to 2" thick fills two of the six joint sets, but no mineralization was noted. A dike of fine-grained quartz monzonite was noted at Station (B17), and along the northern margin of Canyon Creek, (Sta S231), pegmatitic veining was observed in the schist. Coarse granophyric textures were present in samples collected by the U.S. Geological Survey from this same area.

Massive quartz boulders were observed at Station (S154) on Gunnysack Creek northwest of Birch Lake, marking the approximate contact of the intrusive at 1100' OD. To the north of Birch Lake the contact is uncertain, but at 1250' OD at Station (B125) schistose rubble is mixed with fine grained igneous rocks. Northeast of the lake, granitic rubble appears to a extend to an elevation of about 1250 feet O.D. East-southeast of Birch Lake the contact occurs at an elevation of about 1300 feet, but drops rather steeply to below 1250 feet on the road leading to the tower marked on the map. The highest elevation of which the granite was noted is 1400 feet near station (B15).

Granite rubble was noted at an elevation of 1350 feet at station (B68) north of Junction Creek, suggesting that the granite may extend considerably further north than previously thought.

Coarse-grained, porphyritic quartz monzonite occurs on the ridges to the north of VABM Buck at stations (B90) to (B94). Similar rubble was found in the creeks to the west-northwest, northwest and east of these rubble crops, but ridge traverses indicate that the areal extent is limited at higher elevations.

Most of the ridges to the east of Gold Run Creek are composed of gneiss and granofels, generally of a felsic type. Even such apparently igneous rocks
such as those at (S111) near Rosa Pass can be seen to have developed from a gneissic protolith.

The plutonic rocks on Flag Hill west of Harding Lake are more calcic than those at Birch Lake. Labradorite plagioclase and relict, unstressed clinopyroxene constitute the bulk of the rock, with minor annealed quartz and abundant sphene. Both tremolite and chlorite are present as alteration products of the diopsidic pyroxene.

b)  **Rhyolite Intrusives**

1.  **Rhyolite Porphyry**

This rock type is the same as the porphyro-aphanitic quartz-orthoclase porphyry of Buntzen and Reger (1977), from which a Cretaceous age date of 86.9 ± 2.6 my was obtained.

As shown on Plate III rhyolite porphyry or quartz feldspar porphyry occurs in rubble crops, trenches and outcrop in the Banner Creek area from the head of Junction Creek (S215) to Tenderfoot Creek (B123a). Although not observed during this study, rhyolite porphyry has been reliably reported as occurring in the immediate vicinity of (S202) above Prosperity Gulch and (S180) above Dublin Gulch.

These exposures have a distinct linear trend from Tenderfoot Creek to Democrat Creek, with a westward flexure at the head of Junction Creek. It should be noted, however that many trenches did not penetrate bedrock, and that trenches on hill slopes could expose rubble displaced from outcrop.

In thin section the rhyolite porphyry consists of phenocrysts of fresh rounded subhedral quartz and one or more generations of altered potash feldspar, usually subhedral to euhedral, in an aphanitic groundmass of quartz,
potash feldspar and occasional biotite or muscovite. Glomeroporphyritic texture is common.

Frequently one generation of potash feldspar phenocryst is euhedral, highly sericitized, perhaps poikilitic, extensively haematized, while the second generation is euhedral and almost free of alteration. Alteration is generally to sericite and clay minerals, and haematization, if present, is pervasive.

Quartz veins are common in rhyolite porphyry in the vicinity of the Democrat Mine, usually associated with muscovite and adularia. The muscovite is frequently in the form of rosettes, suggesting annealing of the ground mass.

No fresh and unaltered examples of rhyolite porphyry were seen in this area or any other part of the Richardson District.

Only at station (S57), near the Democrat Mine, was a contact of the rhyolite porphyry observed. The strike is the same as the overall rubble crop distribution, and the dip is steep to the northeast. Phenocrysts are absent within one foot of the contact, and increase in size to the normal 1/2 cm within three feet. There is no sign of any amygdule development, though elsewhere erosion of the K-spar phenocrysts imparts a distinctly amygdular aspect. From the evidence available at (S57), the rhyolite porphyry appears to be intrusive, probably dike-like, dipping steeply to the northeast.

The spatial distribution of most known subcrops of rhyolite porphyry in the Buckeye-Banner area also suggests a dike-like form for the body. Apparent variations in width may be due to swelling with depth (e.g. at the confluence of Banner and Democrat Creeks), to less steep dips (e.g. the head of Junction Creek) or to solifluction (e.g. the head of Democrat Creek).
At the Democrat Mine (S56) and at the head of Junction Creek (S215) the rhyolite porphyry is stained pink by haematitic alteration. Petrographic examination of S56 indicates two generations of phenocrysts, where the earlier generation is extremely altered and haematite-stained, and the later generation of both quartz and orthoclase is clear, though poikilitic. The groundmass appears metamorphic rather than igneous, and may be recrystallized.

Greenish epidote-sericite alteration of the rhyolite porphyry of the Democrat Mine (S58) is common where mineralized quartz veins, frequently drusey or vuggy, cut the porphyry. The veins are apparently infrequent, and occasionally contain sulphides.

In the vicinity of Buckeye Creek, loess and retransported silt cover the hill slopes and valley, and the lack of subcrop or rubble of rhyolite porphyry between the reported occurrences near (S202) and (S180) is not remarkable, except that along the left bank of Buckeye Creek, between Dublin and Hinkley Gulches, rhyolite porphyry outcrops along a trend almost perpendicular to the overall trend of the proposed major dike.

In Hinkley Gulch, on the right bank, a vent-breccia or agglomerate of rhyolite porphyry contains rounded to subangular clasts of schist, quartzite and gneissic schist in an amygdular rhyolite porphyry matrix. Rounded, non-amygdular clasts of altered rhyolite porphyry are also present in the matrix. The clasts are generally one or two inches in size, and are rather fresh and unaltered. It is significant that many of the distinctive rock-types which outcrop only a few hundred feet up the Gulch were sought assiduously, but not found, as clasts in the agglomerate.
Tracing the outcrop to the northeast, the rhyolite porphyry forms a rubble apron on the steep hill slope, but the agglomeratic amygdular variant is confined to Hinkley Gulch proper. The upper limit of rubble trends quite steeply upslope, perpendicular to the local tectonic grain, and no rubble could be found to the southwest, northeast or at comparable elevations on the northwest side of Buckeye Creek. These factors combine to suggest a purely local dike feeding a vent with access to the surface.

Rhyolite porphyry rubble was sought, unsuccessfully, in the abundant rubble at the placer operation in, and at the head of, Hinkley Gulch.

An isolated rubble crop of rhyolite porphyry was found at station (B124), northeast of Birch Lake. As mentioned in the section describing the schist terrane, the sequence of impure marble, bleached and altered schist, garnet-bearing and amphibole-bearing quartzofeldspathic gneiss between stations (S136) and (S143) near the forks of Junction Creek is very similar to the rock association in the vicinity of the rhyolite porphyry dike in the Buckeye-Banner Creek area. No rhyolite porphyry was found in the area however.

A 10 foot wide dike of altered rhyolite porphyry intrudes gneisses in a road cut at (S87) south of the Silver Fox Lodge. This dike is associated with an andesite porphyry dike and has a slightly sinuous trend due to post emplacement shearing. Wall rock alteration is limited to minor development of muscovite.

Two small dikes of altered rhyolite porphyry at (S82, S83) about a mile to the east cause a slight increase in the muscovite content of the folded schist wallrock. A rubble crop of rhyolite porphyry at (S78) on the power line above (B80) coincides with a narrow, elevated ridge with a trend slightly west of north. Andesite porphyry rubble is present in the powerline
immediately to the west, also associated with a north-northwest trending ridge.

Projection of this trend to the northwest towards Harding Lake intercepts a ridgeline where rhyolite porphyry and andesite porphyry rubble is quite widespread in the logging trails. The apparent amygduular nature of the andesite porphyry appears to be due to weathering of the feldspar phenocrysts. Schistose gneiss or gneissic schist and quartzite to the northeast is prevalent, particularly in susceptible units, eg. (S63).

An isolated rubble crop of rhyolite porphyry at (S70) occurs within rubble of light colored quartzofeldspathic gneiss. At nearby stations (S73) (B71), about three miles east of Harding Lake, light colored, muscovite-rich quartzofeldspathic gneiss and intensely sheared gneiss rubble are present with rhyolite porphyry rubble in the ridge. A distinctive amphibole-bearing quartzofeldspathic augen gneiss similar to that associated with the rhyolite porphyry in the Banner-Buckeye area is present nearby at (B72).

An highly-altered rhyolite porphyry with glomerophyric quartz and potash feldspar was found at an isolated rubble crop north of Rosa Pass on the pipeline haul road.

Although all the rhyolite porphyry and other hypabyssal intrusives in the Richardson District are more or less highly altered, there is no apparent preferred orientation of the micaceous alteration products. Apart from a little displacement by shearing or jointing at (S87), and a possible westward warp of the main dike in the Junction Creek area of the Banner-Tenderfoot dike, they are almost undeformed, and appear to post-date most of the metamorphic events.
Quartz veins in the rhyolite dike at the Democrat Mine, some of which bear arsenopyrite and stibnite, testify to some post-emplacement hydrothermal activity, which could be deuteric.

2. Andesite Porphyry

Small dikes of altered andesite outcrop in the bluffs and roadcuts at station S87 on the Richardson Highway, and rubble of very similar rocks was found at S63 in a logging road. In both cases the rock consisted of altered andesine plagioclase laths in an highly altered matrix of fine grained clinopyroxene, plagioclase and quartz. Much of the pyroxene has been altered to chlorite with a little biotite and exsolved opaques.

In the rubble at S63 in particular, the andesite porphyry has an amygdular or scoriaceous appearance due to selective weathering of the feldspar phenocrysts.

An isolated occurrence of andesite porphyry was noted on the ridgeline south of Harding Lake by the U.S. Geological Survey, but was not observed in this study.

3. Basalt

A narrow dike of fine grained basalt with a fresh appearance forms an almost vertical rib in the biotite gneiss bluff at station S88 on the Richardson Highway. No other similar dikes were seen.

Regionally Metamorphosed Rocks

For convenience the metamorphic rocks in the Richardson District can be considered in three groups; schist, gneiss and granofels. Protoliths of the schists include shales, sandstones and calcareous rocks, and the demarcation
between schistose, gneissic and granofelsic variants is seldom clear-cut, and in many cases is clearly transitional.

Thermal effects, as might be expected, are more evident in the schist terrane than in the gneiss or granofels.

In the schistose rocks an early cataclastic event can usually be identified, more or less annealed into a later, planar, synkinematic fabric. Garnet is uncommon in this foliation which consists of quartzo-feldspathic and biotite-(epidote)-rich units. This fabric is locally modified by a generally weak thermal overprint, except in the near vicinity of the larger plutonic intrusives. There hornfels and skarn are present, and the synkinematic fabric is reduced to fine-grained hypidomorphic granular texture.

In the gneissic rocks, less intense but more widespread thermal overprinting is evident by the generally granoblastic texture, by random orientation of large, fresh biotite, feldspar and quartz crystals, and by variably well developed symplectic intergrowths of quartz and feldspar at grain boundaries. Sillimanite is common in the gneissic rocks, and garnet is sometimes present. The examples of gneiss studied petrographically still show evidence of a synkinematic foliation and of an even earlier cataclastic event, and at least some of the schistose gneiss has undulose planar structures caused by late shearing of the gneiss.

The general lack of garnet in both the schist and gneiss terrane is enigmatic, particularly considering that the chemical composition of many rocks studied appears to be appropriate for garnet formation.

a) Schistose Rocks

Most of the schistose rocks contain varying proportions of quartz, twinned potash feldspar and plagioclase, which ranges in composition from
albite to andesine. The whole range of composition from mica schist through quartz-mica schist to micaceous quartzite is known to be present in the district, though no distinctive mappable units could be identified. Both muscovite and biotite occur in many rocks, but as has been discussed in the section on igneous rocks, the proportion of muscovite appears to increase in the vicinity of hypabyssal intrusives. Epidote is occasionally present, and a little sphene, chlorite and relic amphibole are sometimes present.

Petrologic examination of about 30 thin-sections of schist shows the wide variation in proportion of the major components, quartz, plagioclase and potash feldspar. In most cases the earliest textures indicate intense dynamic metamorphism, with cataclastic or mylonitic fabrics. Some porphyroclasts, particularly of plagioclase and orthoclase, have survived the later overprinting, and occasionally the cores of the porphyroclasts are clear and zoned, though more often saussuritization and sericitization have to a greater or lesser extent clouded the porphyroclasts. The plagioclase is usually albite-oligoclase or oligoclase, and the potash feldspar is usually orthoclase and is generally twinned.

A later synkinematic overprint is almost without exception present in the schist. Quartz with polygonal crystal boundaries can be seen to be formed by annealing of the preexisting cataclastic quartz, and generally the orientation of the fabric is at a moderate to high angle to the earlier cataclastic fabric. Preferred lattice orientation of the quartz aggregates is not common. Muscovite, biotite and sphene are commonly aligned parallel to the elongation of quartz aggregates, and large sub- to euhedral poikiloblastic plagioclase and orthoclase porphyroblast generally show similar alignment. The feldspar
frequently has altered anhedral to subhedral cores, sometimes zoned, and clear, though poikiloblastic, margins.

Intrafolial folds are sometimes present and are usually defined by sinuous muscovite or biotite layers within quartzofeldspathic layers. Twin planes in poikiloblastic plagioclase are generally somewhat bent proximal to such folds, which probably indicate post-synkinematic shearing. Other indications of at least local later shearing are narrow transverse slip planes defined by fine-grained muscovite, biotite or chlorite transverse to the better defined, coarse foliation composed of muscovite, biotite and quartzofeldspathic minerals.

Quartz, orthoclase, albite-oligoclase and biotite in varying proportions also constitute the bulk of the pelitic schist and mica-quartzite in the Buckeye-Banner area. The best exposures are in the drainage ditch from above Hinkley Gulch to Grizzly Gulch (S186-S188), and in the road cuts on the Richardson Highway. All rubble or outcrop which was observed southwest of the rhyolite dike, with the exception of the impure marble at (B122), the skarn at (S203), and possibly the 'white gneiss' would be classified as schist or quartzite. Very thin bleached and altered zones were noted at (B4, S4) on the highway in normal, unaltered biotite-quartz-feldspar schist. Three fold episodes can be discerned, on east-southeast, northeast and south-southeast axes, as in more fully discussed in the 'structure' section.

In the Hinkley-Grizzly drainage-ditch, crenulate fold axes, minor folds and boudinage indicate that folding was predominant about east-southeast axes which plunge about 20°-30° to the southeast. Intense shearing, brecciation and gouge in zones up to a few feet wide also appears to be controlled by east-southeast trending fractures. Small- to moderate-sized quartz segrega-
tions concordant with the foliation are common, and potash feldspar with the quartz imparts a pegmatoid appearance to some of the segregations.

A garnet-bearing unit about three feet thick was noted in association with a muscovite-rich quartz-feldspar schist within a few tens of feet of the contact of the schist with the aforementioned 'white gneiss' near (S186).

On the north side of Hinkley Gulch, (S204, S205, S206), north of the fault bounding the skarn and 'white gneiss' (S165), normal biotite- (muscovite)-quartz-feldspar schist is well exposed in several trenches, and exhibits few signs of alteration or thermal upgrading other than a little iron-staining.

Quite commonly schistose rocks collected far from known bodies of igneous rocks have large crystals of a deep brown pleochroic biotite or iron-rich chlorite with little or no preferred orientation. This type of growth is distinct from the decussate rosettes of fine-grained biotite which are common in the hornfels aureols of the plutons, but could indicate a late episode of weak thermal activity.

Within the schist terrane amphibole schist and amphibolites contain early hornblende which is granulated, leaving only remnants of the original crystals. The plagioclase is generally andesine or andesine-labradorite, and porphyroclasts are common, frequently with bent twin lamellae. Annealed granular quartz, fresh subhedral actinolite, clinozoisite epidote and euhedral andesine plagioclase form good synkinematic fabric. The associated quartz shows annealing of earlier cataclastic quartz. Larger plagioclase crystals are polkiloblastic and chlorite is ubiquitous, both as alteration along
cleavage of the early hornblende, and as a component of the synkinematic fabric. A few late shears contain fine-grained chlorite and opaques.

In thin section the impure marble within the schist terrane consists predominantly of calcite with a little quartz, plagioclase (albite-oligoclase), chlorite, sphene and clinozoisite. In one thin section studied calcite constitutes about 80% of the rock, but variants with much less recognizable calcite were present. Mortar texture, indicative of dynamic metamorphism, is common.

Augen schist was observed in several of the road cuts on the Richardson Highway, particularly between Canyon Creek and Banner Creek, intercalated without any apparent discontinuity with more normal, and much more abundant, pelitic schist and micaceous quartzites. The large clots and nodules in these schists are generally composed of a mixture of feldspar and quartz, with the long axes at an acute angle to the main fabric. Twin planes in the feldspar are generally bent or broken, and there is usually at least some alteration. Relic granulated quartz and feldspar, frequently with well-oriented biotite and muscovite, occurs in layers which wrap around the porphyroclasts. To a greater or lesser extent later recrystallization, including annealing of the quartz, has modified the protomylonite texture, and in some cases, (e.g. (S36) east of Birch Lake), recrystallization of the matrix and porphyroblastic growth of untwinned K-spar generates hartschiefer or blastomylonites. This locality is, however, near the north margin of the pluton.

Impure marbles were observed near the mouth of Canyon Creek in a road cut at (B76), associated with phyllite or phyllonite.
b) **Gneissic Rocks**

Just as the schistose rocks range from phyllic to gneissic in texture, the gneissic rocks contain schistose and almost granoblastic variants. Lithologic variations include impure marbles or calcareous gneiss, amphibole-bearing gneiss and amphibolite, and more normal quartzofeldspathic gneiss. Large plates of biotite are common in the gneiss, so that layering is generally poorly developed.

Augen-gneiss is not uncommon, and porphyroclastic or porphyroblastic textures can generally be discerned.

Petrographic examination of the gneisses indicates that all were affected by an early cataclastic event, a later synkinematic event and, to a greater or lesser degree, a late thermal event.

The gneissic rocks are generally composed of varying proportions of quartz, albite-oligoclase plagioclase, biotite, muscovite and untwinned orthoclase or microcline. Amphibole, variably altered to chlorite, is common only in a few of the gneissic rocks, and epidote, sphene, calcite and vesuvianite (?) occasionally accompany the amphibole but are more commonly associated with diopsidic pyroxene in the impure marbles. The plagioclase can be as calcic as labradorite in the impure marbles, and is of oligoclase-andesine composition in the amphibole-rich variants.

Though more common in the gneissic rocks than in the schist, garnet is present in relatively few of the gneissic rock. Considering the abundance of biotite, from which the garnet is generated in at least some gneissic rocks (eg. S.69), the general lack of garnet is surprising. Sillimanite, on the other hand, is almost ubiquitous in the gneissic rocks, and very rare in the schist terrane. Andalusite was recognized only in a massive pegmatitic rock
at Sl12, on the pipeline haul road near Redmond Creek. Apatite, zircon, corundum and vesuvianite were recognized in only a few thin sections, and are considered to be rare minor accessory minerals.

Petrographic study of the texture of the gneissic rocks indicates an early phase of dynamic metamorphism with development of a granular cataclastic or mortar texture, often preserved only in the 'strain shadow' areas of rounded porphyroclasts or early porphyroblasts of potash feldspar and plagioclase. The feldspar is generally intensely altered and the potash feldspar is sometimes twinned. Bent and strained twin lamellae are common.

The long axes of the rounded porphyroclasts make an acute angle with coarser more typical dynamothermal layering in most examples studied. Mafic and quartzofeldspathic components are more or less segregated, and oriented biotite and muscovite are aligned parallel to patches of annealed granular quartz with poorly-developed preferred lattice orientation, and to untwinned orthoclase and small twinned albite-oligoclase. Sillimanite is commonly associated with the mica, particularly the muscovite, as oriented aggregates of minute acicular crystals, and rarely as larger euhedral laths. Garnet, if present, appears to be generated from biotite in this synkinematic fabric.

Evidence of later, thermal overprinting is developed to a variable extent in the gneissic rocks, ultimately resulting in a granoblastic mosaic with only rare, obscure remnants of oriented fabric elements. Large subhedral to euhedral plates of biotite with random orientation of the c-axes disrupt biotite and muscovite rich bands, and clots of subhedral to anhedral muscovite are scattered throughout the rock in some places. Thin veinlets of felty quartz feldspar cut across earlier layering in several localities. Large
subhedral or anhedral patches of poikiloblastic potash feldspar include rounded remnants of earlier quartz feldspar fabric, and crosshatch twinning is developed in many examples. Lobate or rounded patches of graphic or granophyric texture are present to some extent at quartz-orthoclase (or microcline) grain boundaries, and occasional examples of myrmekitic textures were observed. Large patches of quartz develop preferred lattice orientation, and a mottled or undulose extinction is all that indicates the origin from annealing of granular material.

Some of these indications of a thermal episode are present in many of the gneissic rocks studied, and most are present in the rocks described in the field as granofels. On the geologic maps the granofels is indicated as 'FGf' or 'MGf', indicating the felsic or mafic aspect, in order to differentiate them from 'FGn' or 'MGn', their apparent gneissic equivalent, which in hand specimen still retain a recognizable layering, or at least some planar fabric elements.

In the Banner Creek area, (Plate III), gneissic rocks appear to be restricted to the area northeast of the northwest-trending rhyolite dike. A possible exception is a highly distinctive 'white gneiss', but this unit is thought to be a product of local alteration, and is discussed in some detail in the section on "altered metamorphic rocks".

Outcrops and subcrops are more abundant in the Banner Creek area than in most places in the Richardson District, and the relationships between the various components of the gneiss terrane are more readily observed.

Several distinctive, and possibly mappable, rock-types could be discerned. These include:
i) Amphibole-bearing gneiss

At station (S124A) at the head of Tenderfoot Creek, a coarse, unaltered amphibole gneiss with a somewhat granoblastic texture outcrops in trenches immediately to the northeast of rhyolite porphyry rubble. Coarse-grained, chloritic, hornblende-quartz-feldspar augen gneiss is exposed in trenches three hundred feet to the northeast.

Coarse-grained schistose chlorite (hornblende)-quartz-feldspar augen-gneiss rubble is exposed in trenches at (B120) at the head of Junction Creek some five miles to the northwest of Tenderfoot Creek. Hornblende exists only in the finely granulated matrix, with chlorite the most abundant and freshest mineral at (S45) and (S177) above Prosperity Gulch.

Similar rocks were noted in similar spatial relationships with rhyolite porphyry dikes elsewhere in the Richardson District. A bluff of sheared amphibole gneiss at (S143) on Junction Creek is associated with garnet-bearing bleached gneiss and schist, though the nearest rhyolite porphyry known is some three miles to the west. Amphibolite gneiss, intensely sheared and contorted, outcrops in the bluffs above the Tanana River at (S75, S76, and S77), about a mile east of the Silver Fox Lodge, and both rhyolite porphyry and andesite porphyry are found at (S78) a few hundred feet to the west. Amphibole-rich quartzofeldspathic augen-gneiss of a very similar appearance to that near Banner Creek occurs near rhyolite porphyry rubble on the ridge east of Harding
Lake at station (B72), and a rather fresh, well banded, amphibole quartzofeldspathic gneiss occurs in rubble on the trail west of VABM Red at S59. Schistose rock occurs in rubble to the west of this station, and gneissic rocks to the east, but the nearest known rhyolite porphyry rubble is at (S70), a mile to the northwest.

One other occurrence of amphibole-bearing gneiss was observed at (S120) in the upper reach of Banner Creek, and is of interest because it is sulphide-bearing and because a few weak silver anomalies and a gold anomaly occur in the near vicinity. This amphibole-gneiss is only about 1 foot thick, and is associated with a pink biotite-quartz-feldspar gneiss which displays strong evidence of late thermal overprint on a synkinematic fabric derived from an early cataclastic event. Shears and veins of quartz and potash feldspar crosscut the layering of the quartzofeldspathic gneiss. Petrographic study of the amphibolite indicates no thermal episode, but two well oriented fabric elements are evident with the sulphides entrained in the later synkinematic fabric along with abundant biotite, approximately perpendicular to the early, porphyroclastic, plagioclase-quartz-amphibole fabric. The later fabric is subparallel to the shears and veinlets in the country gneiss. Subcrops are relatively common in the area, but no more amphibolite-rich rubble was found.

ii) Garnet-bearing quartzofeldspathic gneiss

White, medium- to fine-grained quartzofeldspathic gneiss containing euhedral mauve-pink garnets up to 2mm in diameter was first noted in a rubble crop at (S43) north of Prosperity Gulch.

Similar rock exposed in the ditch above Banner Creek at (S126) forms a bold outcrop approximately 100 feet wide, and is composed of quartz,
poikiloblastic microcline with minor sericitic alteration, and oligoclase plagioclase. The slight anisotropism of the garnet may indicate an early synkinematic origin rather than a thermal origin. Adjacent biotite-quartz-feldspar gneiss more clearly indicates an early cataclastic fabric annealed in a later synkinematic event, with good preferred orientation of biotite. A later thermal event is indicated by fresh, decussate, (unoriented), biotite flakes in the mesocratic gneiss. Graphic and myrmekitic intergrowths of quartz, microcline and plagioclase at some grain boundaries are further evidence of a late thermal upgrading. No garnet is present in the biotite-bearing gneiss.

Garnet-bearing rocks were sought near (S218) and (S196) based on the trend extrapolated between (S126) and (S43). Garnets similar to those at S43 and S126, though larger and subhedral to euhedral, occur in a quartz-oligoclase-calcite-sphene rock at (S196), and in a similar rock at (S199). At both places the rock forms bold outcrops, and at (S196) the metamorphic history includes a late thermal event after a synkinematic event, itself preceded by an early cataclastic event. At (S218) the textures and field relations suggest that the garnets occur in a coarse-grained to pegmatitic granitic rock composed mainly of quartz and microcline with some graphic intergrowth.

Garnets occur in an ironstained micaceous quartzite at (B120) at the head of Junction creek, and the metamorphic history again includes an early, intense cataclastic episode, a later moderate regional metamorphic event and a late thermal episode.

A similar rock with garnets of identical appearance is associated with amphibole-bearing gneiss and bleached gneiss at station S141 on Junction Creek.
While garnet in quartzofeldspathic schists and gneiss is not found only at the above localities, the frequency and somewhat predictable nature of these occurrences suggests a genetic association, and their spatial distribution in relation to the main rhyolite porphyry dike, and to the impure marble described in the following section, is intriguing.

iii) Impure marble

Impure marble was found at (S41) south of and near the head of Dublin Gulch; at (S198) and (S200) on Buckeye Creek near the mouth of Moore Gulch; at (S78) and (S41) north of Prosperity Gulch; at (S171) near the mouth of O'Brien Creek; and at (S220) at the confluence of Democrat and Banner Creeks. Only at the latter occurrence could the impure marble be seen in apparent conformable contact with gneissic rocks to the southwest; elsewhere only rubble or isolated outcrops were observed.

These rocks are composed of varying proportions of quartz, andesine to labradorite plagioclase, microcline or untwinned orthoclase, calcite, sphene, epidote, tremolite and diopside. No garnet was observed.

To some degree all exhibit a late thermal event which has modified a well developed synkinematic fabric, itself superimposed upon an earlier cataclastic, granulated fabric.

At Banner Creek, Prosperity Gulch and Buckeye Creek the impure marble appears juxtaposed between a garnet-bearing quartzofeldspathic gneiss and amphibole-bearing gneiss or the rhyolite dike.

The northwestward continuity of the impure marble "unit" was tested up Democrat Creek to Junction Creek but was not found, but a fine-grained garnet-diopside-quartz "skarn" southwest of the Democrat Mine, at B122, on the
southwest side of the rhyolite dike may represent a westward continuation of the trend.

Very similar rocks were found on two ridges north of the quartz monzonite porphyry about two miles north of VABM Buck, at stations S97, S98, B95, B96. Mortar texture in quartz and calcite, and relict patches of intensely granulated quartz, calcite, diopside (?), orthoclase and calcic plagioclase testify to at least two metamorphic pulses. Epidote, sphene, iron oxides and (?) zircon occur in well-defined bands at (B95), and coarse poikiloblastic calcite and quartz at (B96) indicate a later thermal overprint. Fresh marble was found associated with gneiss and quartz monzonite at (S115) on the projected eastward trend. Calc-silicate rocks found by the U.S. Geological Survey on Redmond Creek contain calcite, feldspar, sphene and randomly oriented diopside, and the outcrop is on the projected westward trend of the occurrences of impure marbles north of VABM Buck. Impure marble was also found on the trail between Canyon Creek and Junction Creek (S136), and consists of quartz, diopside (?), epidote and sphene. The fabric is dominantly synkinematic, though veinlets of potash feldspar occur in the marble, and the associated rocks a few hundred feet to the north have some gneissic characteristics such as weak development of cross hatch twinning in the orthoclase, and trace garnet and sillimanite.

iv) Schistose gneiss.

Rocks designated in the field as 'schistose gneiss' ("ScGn") were found, when examined in thin section, to be intensely sheared on undulose planes, with development of oriented mica along the planes. In some rocks the microshears are so numerous that the earlier history is almost obliterated.
Schistose gneiss was noted in Banner, O'Brien and Buckeye Creeks about a mile northeast of the rhyolite dike at (SL21, 122, BL13, SL32). These rocks have been extensively sheared, with development of chlorite, biotite and muscovite oriented along the undulose shear planes, but the shearing is the latest event, and thermal, synkinematic and cataclastic textures are readily discernable in the less altered, lensoid gneiss remnants between the shears.

Structures in the gneiss are complicated, as shown by the disparate dips of the foliation at numerous places, particularly on the Democrat Ditch.

c) Granofels

This term was used in the field for rocks without obvious planar structure such as layering or foliation, but which had no clearly igneous texture either. Textures are commonly hypidiomorphic granular or granoblastic, and grain size is generally medium, occasionally coarse. Color of the granofels ranges from very light to almost black, and petrographic analysis shows a range in composition from quartz monzonitic, with oligoclase-andesine plagioclase, to a dark quartz diorite type with andesine or even labradorite plagioclase. While the proportions of feldspar vary widely, in general the darker the color, the less potash feldspar and quartz, and the greater the proportion of plagioclase, and of course biotite. Amphibole, probably tremolite, occurs in a few samples as remnant porphyroclasts, much altered to chlorite, biotite and opaques. Sphene is present in the amphibole-bearing granofels, indicating the more calcic whole-rock composition.

These rocks are designated felsic or mafic granofels, FGf and MGf respectively, as distinct from gneissic rocks designated Gn on the geologic map.
Textures in these rocks are indicative of at least three distinct episodes of metamorphism. An early, dominantly dynamic episode is indicated by a granular mortar texture of quartz, feldspar and sometimes a ferromagnesian mineral, probably amphibole. Because of the subsequent metamorphism, the early fabric elements are commonly almost obliterated, but fine-grained, granular quartz + feldic minerals can usually be discerned in the strain shadows of larger, rounded, highly-altered, feldspar porphyroclasts which exhibit a weak preferred orientation of the long axes.

In most of the granofels studied, an episode of dynamothermal or regional metamorphism can be recognized by a variably developed preferred orientation of light to dark brown biotite, muscovite and occasionally sillimanite. Feldspars are generally fairly small, subhedral to anhedral, with bent twinning. Many of the feldspars are twinned and poikilitic, but appear fresher than the altered porphyroclasts, and the preferred orientation is generally at a rather large acute angle to the poorly developed orientation of the porphyroclasts. To a greater or lesser extent the quartz is composed of annealed granular quartz, and in some aggregate patches the individual granule boundaries are evident only by the flickering extinction upon rotation of the microscope stage. Preferred lattice orientation is usually weak within these annealed patches, which are elongate parallel to the preferred orientation of muscovite and biotite.

A later, thermal, event is generally the most apparent. Coarser-grained randomly-oriented biotite, untwinned potash feldspar or microcline, quartz and fresh plagioclase from a granoblastic matrix containing relics of the two earlier events. The biotite, and sometimes muscovite, appears fresh. The feldspars, particularly plagioclase, are commonly "zoned", with fresh, unal-
tered peripheral growth on poikilitic, and/or extremely altered cores. Clots and patches of sillimanite are present in the altered cores of untwinned potash feldspar in some rocks. Quartz, which is commonly interstitial, has a strong, preferred lattice orientation, and exhibits only a trace of the "stressed" origin. Characteristic of the thermal event are the grain-boundary reactions between quartz, plagioclase and potash feldspar. Rounded or lobate patches of myrmekitic or graphic intergrowths are common in the granofelsic rocks.

The relationship between the gneiss and granofels is nowhere directly exposed, but in the Democrat Ditch normal gneiss is exposed, (S123, S124, S125, S126, S127), while only 50 to 100 feet down slope abundant rubble of mafic granofels (S167, S168, S169) subcrops. Much of the granofels is somewhat gneissic, and the contact, though rather abrupt, appears transitional. In general more normal gneiss occurs at higher elevations, and granofelsic rocks at lower elevations, though the transition zone appears at higher elevations in the southeastern part of the map area.

Because only rubble crops or isolated outcrops of the granofelsic rocks were found, little can be said of the field relationships. At (S10) at the head of Tenderfoot Creek, rubble of both mafic and felsic variants was found. In some instances lensoid clots of mafic granofels up to six inches are enclosed within the felsic granofels, but the grain size of the felsic is coarser at the contact. At this locality, as near S198 on Buckeye Creek, (S173-4) on O'Brien Creek and (S167-169) on Banner Creek, quartzofeldspathic gneiss and biotite-quartz-feldspar gneiss occur in outcrop within a few feet of their apparent granofelsic equivalents.
Although one of about fifteen examples examined petrographically contains labradorite plagioclase, most have compositions in the quartz-monzonite to quartz-diorite range. Granofelsic rocks in the Banner-Buckeye area appear to have at least a spatial association with the impure marble and garnet-bearing quartzofeldspathic gneiss.

Granofelsic rocks are common within the gneissic rock along the north side of the Tanana River, west of Shaw Creek, where they are generally fractured and bleached, particularly along the joints, giving an appearance of being intruded by abundant, thin, felsic dikes. Granofelsic rocks are also common in a northeasterly-trending belt west of a line joining the head of Tenderfoot Creek and the head of Rosa Creek to the headwaters of Banner Creek. Schistose gneiss within this belt is generally demonstrably due to later shearing and attendant formation of mica.

Granofelsic rocks are also common to the south and east of the quartz monzonite porphyry north of VABM Buck, and appear to underlie a broad arcuate zone from Mosquito Creek in the west to Rosa Pass in the east. Within the area south of VABM Buck, intensely brecciated and haematized granofelsic rocks occur at (B65), and fine veinlets of felty quartz, potash feldspar and sericite cut across the breccia. Vermiform veinlets, pegmatoidal quartz and orthoclase traverse the well-developed granoblastic rocks elsewhere in the vicinity, and traces of arsenopyrite were observed in some of the more vuggy quartz veins.

Contact Metamorphic Rocks

a) Skarn

Massive skarn outcrops in Hinkley Gulch on Banner Creek at sta (S203) and about 200 feet east at (S165). At (S165) a two-foot thick exposure of
epidote-amphibole skarn occurs in a fault zone separating 'white gneiss' from gneissic schist to the north. The skarn is intensively fractured and chloritized, and is only present as a thin schlieren on the east wall of the ten-foot wide trench. At (S203), massive epidote-amphibole skarn is devoid of any obvious layering, and local pods and patches of garnet-amphibole skarn are surrounded by the more common epidote-amphibole variant. The ferromagnesian minerals are extensively chloritized.

The width of the skarn at (S203) is about 60 feet, and since it thins rapidly to the east, and no rubble was seen in the trail 200 feet to the west, the two dimensional form appears to be lensoid.

Rubble of garnet-diopside-quartz rock at (B122) west of the Democrat Mine is assigned to the impure marble category because of the evident synkinematic history.

Impure marbles at B76 near the mouth of Canyon Creek appear to be parental to the banded garnet-calcite-quartz-sphene-epidote skarn observed in a road leading to the Tower south of Canyon Creek (S24 S25). Intensely complicated folding of a ptygmatic nature was noted in the skarn at (S24).

Similar but more massive skarn near Flag Hill, west of Harding Lake (M18, M20, M24) consists of relict diopside, amphibole (?tremolite?), garnet, calcite, epidote, and quartz. A little feldspar, biotite and muscovite is sometimes present, generally associated with later shearing. Some thermal indications such as decussate patches and rosettes of epidote, and quartz-k-spar intergrowths are evident, but the dominant texture is synkinematic, with a few relics or an earlier cataclastic event indicated by granular, quartz and mortar texture in calcite.
Massive garnet-diopside skarn was also found at M26, on the Tanana River south of Birch Lake, and at M44, in the Tanana River Bluffs south of Tenderfoot-Creek.

b) Hornfels

Thermal upgrading of the schist around the tower south of Canyon Creek is widespread, and causes development of a fine, interlocking compact mosaic, with abundant small biotite crystals in random orientation. Cordierite was observed in some rocks, and traces of pyrrhotite occur in minute blebs and stringers. At Sta (S23), near a microwave tower, all gradations from typical schist and quartzite to apparently normal gneisses mixed with hornfels occur within an area of a few hundred square feet. Some of the gneissic rocks contain well segregated mafic and quartzofeldspathic layers, which are usually plicated or crenulated, and these can be traced laterally with decreasing segregation into micaceous quartzites within tens of feet.

Hornfels, manifest by abundant fine-grained biotite with no preferred orientation and the general fine-grained, compact nature of the rocks, is widespread along the northern margin of the Birch Lake Pluton, e.g. (S26, S27, S31). Locally the schists display blastomylonitic textures (S36) or a weak felsic/mafic segregation.

Other indications of thermal upgrading, particularly in quartz-feldspar-mica schist, is the development of lobate patches of myrmekite and various quartz-feldspar-plagioclase intergrowths. Evidence of such alteration was observed north of the Birch Creek Pluton at Station S23, and a rock with granophyric texture was noted in the same vicinity by the U.S. Geological Survey.
Similar myrmekitic textures are variably developed in many of the granofelsic rocks examined, and are taken to indicate regional thermal upgrading.

**Altered Metamorphic Rocks**

a) "White Gneiss"

Although, as discussed in the next section, light-colored bleached or baked schist and gneiss is not uncommon in the Richardson District, this field classification is reserved for a very distinctive rock type found only in the Hinkley Gulch region.

The unit is white to pale buff, very finely banded (0.5-1mm) with alternating layers of clear to opaque white quartz and feldspar. The quartz has a blebby appearance like interlocked and flattened beads. The feldspar is extremely altered to sericite and clay minerals. As with the interlayered quartz, the feldspar layers pinch and swell, and wherever the white gneiss is exposed it is extremely friable due to the weathering of the feldspar.

The white gneiss is exposed in several trenches and pits in the vicinity of Hinkley Gulch, but nowhere are both contacts observed.

The northern, faulted contact is well exposed in a trench some 1300 feet up the gulch, but the southern contact at this station (S165, M15) is covered by rubble. The unit is 80+ feet thick, well jointed, and the foliation (layering) strikes E50°S, dipping 40° to the south. A 2-foot thick epidote-amphibole skarn north of the fault plane is wedged against brown quartz-mica schist with similar strike and dip.

Two hundred feet to the west (S203) the skarn is much thicker, and the "white gneiss", with strike and dip similar to that in the trench,
correspondingly thinner. "White gneiss" is also exposed in a small pit at (S192) about 800' to the west, close to the rhyolite porphyry breccia, but no contacts were found.

About 1000 feet to the northeast of (M15), bleached quartz-mica schist and micaceous quartzite in pits at (S207, 208) are at first glance similar to the "white gneiss" but lack the fine lamination and psephitic or "blebby" aspect of the banding so characteristic of the gneiss.

About 1000 feet southeast of (S165), at Station (S193), "white gneiss" with the distinctive characteristics is exposed as rubble in a small pit. Unfortunately no attitudes were possible, but a few hundred feet east the trend of the schist swings to southeasterly with a southwesterly 40° dip.

The southern contact of a very similar "white gneiss" is exposed in a drainage ditch at (S166, S185, S186), where 40+ feet of the unit is exposed along a two hundred foot strike. The strike is also E 5° S with dip 30-35° south. The foliation appeared to be concordant with the foliation of the superincumbent brown quartz-mica schist, with no apparent structural discontinuity. Approximately 50 feet 'above' the gneiss the schist contains a thin (37 ft.) garnet-bearing horizon.

In the same ditch, at S188, a thin wispy unit of bleached schist, as distinct from the pegmatoidal quartz-feldspar pods and lenses which are occasionally present, occurs in steeply southwest-dipping brown quartz-mica-schist. At least two southeast trending shears with steep westerly dips occur between this locality and the main "white gneiss" outcrop.

The white gneiss at sta (S185) contains numerous thin (2-5mm) milky quartz veinlets which cross-cut the layering, and which do not extend into the adjacent schist. They appear to be confined to the "white gneiss" unit and
increase in frequency and in thickness to the east. At (185) the quartz veins tend to be fracture controlled, but the pattern is almost as complex as in a crackle breccia, while at (S166) the veins are more undulose, less obviously fracture-controlled, thicker (up to 10 cm), and have a light purple tint.

Tailing piles from an active "bench" placer operation, and the settling ponds drained by the ditch effectively, and unfortunately, prevented the tracing of the "white gneiss" unit to the east. The quantity of white clay mineral residue and the abundance of large (1 ft.) cobbles and boulders of subangular to subrounded white quartz similar in character to that in the aforementioned veins strongly suggests that the unit continues for some distance to the east, and that the vein component continues to increase.

A small quantity of tourmaline was noted in some cobbles of quartz on the tailings.

The white quartz and clay in the tailings decreases rapidly eastward from the center of the placer operation, and in a few trenches in the eastern part of the pit which were observed in passing, only quartz-mica schist and mica-ceous quartzite were seen.

Petrographic examination of the white gneiss from S165, 166 and 193 shows that the rock is composed of extremely granulated quartz, stressed untwinned K-spar and oligoclase plagioclase. Porphyroclasts of plagioclase and extremely altered potash feldspar are also present, and twinning of the plagioclase varies from well-defined in the northern outcrop to a plumose or undulose extinction in the southern outcrops.

In some rocks, cryptocrystalline quartz veins cross-cut the mylonitic fabric, with flooding of cryptocrystalline silica from the vein into the
cataclastic banding, selectively replacing the porphyroclasts and feldspars. These first stage veins are themselves cut by veins of coarser-grained quartz.

The spatial distribution of the outcrops, rubble crops and occurrences in tailings suggests the two main trends may be linked in the vicinity of the "bench" placer. Structural attitudes in the "white gneiss", and that at (AI37) in altered schist suggest a southerly flexure of the eastern end of the northern exposure, so that the two exposures may represent the northern and southern limbs of a fold.

b) Bleached and altered schist and quartzite

As already mentioned, although the quartz-mica schist and micaceous quartzite at (S207, S208) on the Hinkley-Dublin Gulch divide are somewhat similar to the "white gneiss", they lack the psephitic, finely-laminated fabric characteristic of the "white gneiss".

In most cases in the Richardson district, the bleached and altered rock is also intensely fractured or brecciated, and iron-stained to a greater or lesser degree.

Petrographic study shows that the main cause of the bleaching is alteration of biotite, chlorite, and possibly other ferromagnesian minerals, to a mixture of muscovite, sericite, iron oxides and possibly clay minerals. In many instances tan- or brown-colored rocks are iron stained only on fracture surfaces, with little penetration of the stain, so that the interior, unfractured portions are lighter colored.

Plagioclase is saussuritized, and epidote occurs as recognizable crystals in some poikilitic portions of porphyroclasts. Late thermal or hydrothermal activity is evident by decussate muscovite and some graphic
intergrowths of quartz and orthoclase, particularly where porphyroblastic overgrowths of orthoclase on highly-sericitized porphyroclasts is present. The dominant fabric is usually synkinematic. Quartz is annealed, (though generally without a preferred lattice orientation), muscovite displays a strong preferred orientation, and iron oxides stringers are parallel to the main fabric elements. Whisps and fragments of oriented biotite are occasionally present in the muscovite. Porphyroclasts of poikilitic orthoclase are generally extremely sericitized, and frequently contain remnants of a fine-grained cataclastic quartz in the strain-shadows.

In the vicinity of Prosperity Gulch fractured, bleached and silicified rock rubble is widespread to the southwest of the rhyolite porphyry dike. Most of the quartz-mica schist and micaceous quartzite between (S177) and (S46), 1500 feet southwest, is iron stained, bleached and altered. In some cases muscovite or sericite is the dominant rock component.

Further south in Prosperity Gulch bleached and altered rocks are present at S194 on the west side, and also at (S202), 2000 feet to the east, where rhyolite porphyry rubble has been reliably reported. It is not known whether similar rocks occur in the covered interval between these two occurrences.

On the divide between Dublin Gulch and the western headwaters of Tenderfoot Creek, numerous pits in the vicinity of stations (B138, S11, S180) contain rubble of fractured and brecciated quartz-mica schist and micaceous quartzite, all of which is more or less altered, silicified, bleached and iron stained. Rubble of rhyolite porphyry at S183, and reliably-reported rhyolite porphyry near S180 indicate this area of alteration is situated to the southwest of, and proximal to, the rhyolite porphyry.
Quartz-mica schist at S179 is a little iron-stained but contains biotite, and is not bleached or particularly altered. Likewise the quartz-mica schist and micaceous quartzite at S204, 205 and 206, though slightly gneissic, shows little evidence of bleaching or alteration except for a slight tan coloration due to iron-staining.

In Hinkley Gulch proper, immediately south of the northern exposure of "white gneiss", a thin unit of finely banded, biotite-bearing quartzofeldspathic gneissic schist is exposed in trenches at S213 on the north side of the road. The unit is not pervasively altered, but is regularly jointed, and bleaching is seen to be joint-controlled, with more pervasive up-dip alteration.

The result of the bleaching and alteration bears a marked resemblance to the "white gneiss" to the north. Unfortunately, the northern and southern contact relationships of this unit were obscured by thick colluvium and tailings.

To the south of the road in Hinkley Gulch a wide zone of pervasively iron-stained, extremely brecciated and altered rock is exposed in several large pits. Many of the fractures are open and are annealed by iron- and manganese-stained quartz. Petrographic study of an example from sta (S212) shows the intense alteration of porphyroclasts of feldspar in a quartz orthoclase-plagioclase cataclastic matrix.

A number of pits on the ridge south of Hinkley Gulch expose rubble of light colored quartz mica schist and micaceous quartzite, but though the intensity of alteration is variable, these rocks do not resemble the "white gneiss" exposed a little further south in the drainage ditch.
In the vicinity of the Democrat Mine slightly bleached and iron-stained schist, gneiss and mica quartzite occur on the northeast side of the rhyolite porphyry dike, and the amphibole-bearing quartzofeldspathic augen gneiss which is generally located along the northeast contact is apparently absent. The intensity of fracturing and alteration of the rocks adjacent to the dike is not great, nor does the alteration extend more than a few hundred feet to the northeast.

At the head of Junction Creek, again on the northeast side of the dike, alteration is quite widespread in the gneiss, as e.g. (S216, S217) and bleaching is more common than iron-staining. The intensity of alteration and bleaching is more intense than at the Democrat Mine, but much less than in the vicinity of Hinkley Gulch.

At (B120), about 500 feet northwest of (B217), alteration, iron-staining and bleaching are confined to the southwest side of the narrow rhyolite porphyry dike, and amphibole-bearing quartz feldspathic augen gneiss is present on the northeast side of the dike. The extent of the alteration and bleaching is not known.

In the vicinity of rhyolite porphyry rubble east of Harding Lake, sta (S70, S73, B71) the schist in rubble-crop is light-colored and muscovite-rich. Similarly iron-stained, bleached mica-schist and micaceous quartzite occurs as rubble in the trail at sta (S64) east of Midway Lodge and is also associated with abundant rubble of rhyolite porphyry and amygdular (?) andesite porphyry.

Rather frequent rubble-crops occur along a trail leading from Canyon Creek to Junction Creek. As has been mentioned, an isolated rubble crop of impure marble with thin veinlets of quartz and feldspar occurs high on the ridge at (S136). Porphyroclastic schist at (S137) is fresh and unaltered, but
progressively more bleached and altered schist, variably iron-stained, occurs in rubble further down the hillside (S138, S139, S140). Garnet and a little sillimanite is present in extremely bleached and altered quartz-feldspar porphyroclastic and porphyroblastic schist or gneiss at stations (S141, S142). The texture of these rocks clearly shows that they have been affected by a late thermal event after the earlier synkenematic fabric developed from an even earlier dynamic event.

The above sequence is very similar to that in the Buckeye-Banner area as the rhyolite dike is approached from the south and crossed into the gneiss terrane, but no quartz flooding was noticed in the bleached and altered schist or gneiss at (S141).

Bleached and altered gneiss occur at (S154) on the southern shore of Harding Lake, and muscovite-rich, light-colored gneissic schist and mica-quartzite outcrops in road cuts between (S155) and (S157) about 2 miles to the northeast.

**Surficial Deposits**

The ridges and hillslopes in the Richardson District are covered in many places by loess and reworked silt to a depth of many feet. Colluvial material is mixed with the reworked silt and loess on some of the steeper slopes.

Stream alluvium is present in the major valleys beneath the silt at variable depths.

At Sta S220 at the confluence of Democrat and Banner Creeks the bedrock surface slopes gently northward towards the nose of the ridge. River alluvium up to cobble size indicates by the imbrication that the flow was formerly towards the present higher elevation, suggesting that the slope of the bedrock
surface may be due to recent slumping or uplift. It is possible that the
imbricate gravels were deposited by Democrat Creek, rather than by Banner
Creek, but the necessity for some structural adjustment of the bedrock surface
remains.

In the vicinity of the 'bench' placer on the divide between Hinkley Gulch
and Tenderfoot Creek most of the gravel- to boulder-size material is angular
to subangular, and only the abundant quartz cobbles and boulders are sub-
rounded. Because of the active mining it was not possible to examine the
bedrock interface with the colluvial or eluvial material, which appears to be
about 20 feet thick in places, particularly where the quartz boulders are most
abundant. It is not known how much overburden, if any, was removed to expose
the quartz-rich material, nor what the relationship is between the quartz-rich
rubble and the more normal schist and quartzite rubble.

From the characteristics of the material on the tailings it seems
unlikely that it was transported very far by water.

Geochemistry

Three hundred seventy-eight stream sediment and one hundred eleven pan
concentrate samples were collected in the district. Sample locations are
shown on Plates I and II and the anomalous sample locations and anomalous
elements are shown on Plates V and VI. The geochemistry of the district is
discussed in a separate report by Metz et al. (1984).

Geochronology

Limited potassium-argon radiometric data exists for the Birch Lake Pluton
and the adjacent quartz-porphyry dike and the enclosing hornblende gneiss
(Bundtzen and Reger, 1977; Wilson and Shew, 1982) and is summarized in Table 1. The hornblende gneiss sample is from the contact aureole of the quartz feldspar porphyry dike and thus the age is probably an age of contact rather than regional metamorphism. A dioritic to gabbroic phase of the Birch Lake Pluton has a biotite minimum age of 91.2 m.y. while the more felsic granodioritic phase has a minimum age of 89.3 m.y. The quartz feldspar porphyry dike which is adjacent to the pluton has a minimum age of 86.9 m.y. Although the uncertainties of these ages are large, the progressively younger dates of the three phases may represent fractional crystallization of a parent magma. Kaolinization and mineralization of the youngest phase may represent partition of volatiles and hydrous fluids into the later stage of crystallization.
TABLE 1. Potassium-argon age dates of igneous and metamorphic rocks of the Richardson mining district (From Bundtzen and Reger, 1977; Wilson and Shew, 1982).

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Rock Type</th>
<th>Phase Dated</th>
<th>Age (m.y.)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>76BT302A</td>
<td>Hornblende gneiss</td>
<td>Hornblende</td>
<td>113.0±3.4</td>
<td>Bundtzen and Reger, 1977</td>
</tr>
<tr>
<td>76BT302A</td>
<td>Hornblende gneiss</td>
<td>Hornblende</td>
<td>102.9±3.1</td>
<td>Bundtzen and Reger, 1977</td>
</tr>
<tr>
<td>76BTRICHAGE</td>
<td>K-feldsparqtzporphyry</td>
<td>K-feldspar</td>
<td>86.9±2.6</td>
<td>Bundtzen and Reger, 1977</td>
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<tr>
<td>75AFr2182</td>
<td>Diorite</td>
<td>Biotite</td>
<td>91.2</td>
<td>Wilson and Shew, 1982</td>
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<tr>
<td>75AFr2184</td>
<td>Granodiorite</td>
<td>Biotite</td>
<td>89.3</td>
<td>Wilson and Shew, 1982</td>
</tr>
<tr>
<td>75AFr2184</td>
<td>Granodiorite</td>
<td>Hornblende</td>
<td>87.3</td>
<td>Wilson and Shew, 1982</td>
</tr>
</tbody>
</table>
Structural Geology

Structural information collected in the field consisted of attitudes of joint planes, of fabric elements such as foliation or layering, and of fold axes. Analysis of this information consisted of the transfer of the data to lower hemisphere stereographic projections, using the perpendiculars, (poles), to joint planes and fabric elements to produce Pi diagrams. These diagrams were then contoured to provide convenient groupings of data.

1. Fabric Elements

The fundamental fabric elements of foliation in the schist and layering in the gneiss were quite obvious in the field, though it was necessary at times to use modifications such as "schistose gneiss" or "gneissic schist" to adequately describe the textures observed. As was more fully described in the section on geology, the layering of the gneiss becomes gradually less distinct with increasing metamorphic grade, and granoblastic or igneous textures result. The observations of fabric elements are therefore limited within the gneiss terrane. No preferred fabric orientation was seen in either the plutons or in the igneous dikes.

For the purposes of structural analysis the foliation of the schists and the layering of the gneiss are considered to be the original S-plane, simply reinforcing original bedding and probably caused by burial metamorphism. This is also suggested by the concordance of compositional layering with the main fabric elements.

Refolded folds were observed at several geologic stations, mainly in the schist terrain, where early isoclinal folds about northwesterly or westerly axes are refolded in a more open style about northerly or northeasterly
trending axes. In some instances dislocation is demonstrable on the axial plane of the early isoclinal fold, with one limb dragged over the other. At many other stations in the schist terrain, though the refolding of early fold axes could not be seen, two fold axes with disparate trends were measured, or crenulation cleavage was noted with an orientation indicative of fold trends other than the observed trends.

Outcrops in the gneiss terrain are far fewer, and much smaller, than the roadcut outcrops in the schist terrane, and direct observations of folds correspondingly less. Three fold trends were observed in a large block on a felsenmeer on VABM Buck, where an early isoclinal fold is refolded in an open style about a subparallel axis. A third fold axis, almost perpendicular to the others in the same plane produces open, inclined folds similar to drag folds. The relative age of the two open style folds is not apparent. The three phases of folding seen in the detached block can be discerned in a plot of regional observations, and suggest the orientation and style of folding in the gneiss terrane is similar to that in the Fairbanks district (Swainbank & Forbes, 1975).

Figures 4a and 4b are lower hemisphere stereographic projections of 67 poles to the foliation in the schist terrane, and of 62 poles to the foliation or layering in the gneiss terrane. In both there is a point maximum within the Pi-girdle close to the center of the diagram, showing that in general the fabric elements dip rather gently.

In the schist terrane (Figure 4a) three Pi-girdles are evident, indicating well-defined folding about an axis plunging 12° to N88°E, moderately well-defined folding about an axis plunging 40° to S32°W, and rather weak folding about an axis plunging 18° to S14°E.
The Pi-diagram for the gneiss terrane (Figure 4b), also suggests three distinct folding episodes, where that about an axis plunging 24° to an azimuth of N16° is well-defined, and where the other two, about axes plunging 34° to N 42°E and 16° to N89°E are only weakly defined.

Thus the refolding of tight, overturned folding and of isoclinal, recumbent folding which was observed in outcrop appears to be a common feature in the Richardson district. It may be significant that the axial trend of the early, tight folding in the gneiss terrane appears to be rotated about 28° clockwise relative to that of the comparable style of folds in the schist terrane.

Axial-plane slip is demonstrable in some of the isoclinal style folds, but in all cases observed the planes were gouge-filled. Dilational features which might serve as conduits for mineralization or intrusive pathways would be anticipated in tensional areas of crests and troughs of more open folds, such as the later folds in both the schist and gneiss.

2. **Joints and Faults**

51 joint attitudes were measured in the Birch Lake Pluton, 152 in the gneiss and 145 in the schist terrane. Except in the schist, where roadcuts provide good continuous outcrop, any widely spaced joints were probably under-represented because of the limited size of the outcrops. Very closely-spaced joints were also possibly under-estimated due to time constraints, so the measured attitudes represent joints with spacings between six inches and six feet.
Figure 4a. Lower hemisphere projection of 67 poles to foliation in the schistose terrane. Contours in percent.
Figure 4b. Lower hemisphere projection of 62 poles to foliation in the gneissic terrane. Contours in percent.
<table>
<thead>
<tr>
<th>SCHIST</th>
<th>GNEISS</th>
<th>PLUTON</th>
</tr>
</thead>
<tbody>
<tr>
<td>N60°, Vertical, (5)Q</td>
<td>N138°/40°NE (6)</td>
<td>N100°/64°SW (6)Q</td>
</tr>
<tr>
<td>N142°, 80°SW (5)R</td>
<td>N60°/60°NW (4)</td>
<td>N52°/60°NW (4)Q</td>
</tr>
<tr>
<td>N96°, Vertical (4)Q</td>
<td>N52°/Vertical (4)</td>
<td>N14°/Vertical (3)R?</td>
</tr>
<tr>
<td>N166°, Vertical (4)</td>
<td>N64°/Vertical (4)</td>
<td>N20°/Vertical (3)R?</td>
</tr>
<tr>
<td>N12°, Vertical (4)</td>
<td>N150°/Vertical (4)R</td>
<td>N110°/Vertical (2)</td>
</tr>
<tr>
<td>N22°, 50°NW (4)</td>
<td>N178°/Vertical (4)</td>
<td>N146°/Vertical (2)R</td>
</tr>
<tr>
<td>N130°, 44°NE (3)</td>
<td>N114°/Vertical (3)</td>
<td>N06°/10°W (2)</td>
</tr>
</tbody>
</table>

Q = Within ±50° quartz vein orientation  
R = Within ±50° of known rhyolite porphyry dike orientation
With these known constraints, structural analysis of the poles to joint planes was attempted for the intrusive bodies and for the foliated schist and gneiss terrane.

Table 2 summarizes the joint orientations and frequency of occurrence.

a) Joints in the Birch Lake Pluton

Obviously joints could develop in the pluton only after solidification, and discounting flat-lying joints interpreted as unroofing joints, at least two, and possibly three, pairs of joints can be recognized.

If, as seems likely, the gently dipping joints are unroofing joints, it is not possible to pair off the remaining 5 directions as conjugate pairs, unless the grouping with trends N14°E to N20°E actually represent a single group with an average azimuth of about N17°.

The strongest jointing in the pluton is well displayed in a borrow-pit about 1 1/2 mile west of Birch Lake, where the steeply dipping joints with N52° and N100° azimuths both contain irregular quartz veins, and both are iron-stained and are not offset by other joints. It seems likely that these joints represent a relatively young conjugate pair, indicative of a principal stress with an eastnortheast/westsouthwest trend.

The next most frequent joints in the Birch Lake Pluton are those trending about N17°E, either vertical or dipping steeply to the west. As already mentioned, these may represent two separate sets of joints, conjugate with the remaining strong vertical joints trending S34°E, and a less well-developed vertical set with a N110° azimuth.

It is of interest that rhyolite dikes in the crystalline terrane have trends of about N15°-20°E and also S36°E, and further that the Richardson
Lineament (Buntzen & Reger, 1977) also appears to be close to vertical, trending about S36°E.

b) Joints in the metamorphic terrane

Figures 5b and 5c show the lower hemisphere projections of the poles to joint planes in the schist and gneiss terranes respectively, and the predominant orientations and attitudes are summarized in Table 1.

In the gneiss terrane the two most common joint directions are oriented N60°E and S42°E and both have only moderate dips to the northwest and northeast respectively. Similar low-angle joints are present, though not dominant, in the schist terrane, where they are oriented N22°E and S50°E, and these likewise dip to the northwest and northeast respectively. These joint sets correspond more closely in trend if the Pi-diagram for the gneiss terrane is rotated approximately 28 degrees anticlockwise.

S38°E joints with an 80°SW dip are fairly common in the schist terrane, but are only poorly represented in the gneiss terrane by joints with a trend approximately S10°E and with variable dips with 70°SW, again suggesting that the trends would more closely correspond if the gneiss terrane had been rotated some 28 clockwise relative to the schist terrane.

Most of the other joints in both terranes are near vertical, and grouping into conjugate pairs appears to be impractical, but in both terranes a strong, near-vertical joint set has an orientation within 5 degrees of that of the Richardson Lineament, (Buntzen and Reger, 1977), and the associated rhyolite dike. With an azimuth of N150° the joints in the gneiss are again several degrees advanced clockwise from the joint azimuth of N142° in the schist terrane.
Figure 5a. Lower hemisphere projection of 51 poles to joints in the Birch Lake pluton. Contours in percent.
Figure 5b. Lower hemisphere projection of 145 poles to joints in the schist terrane. Contours in percent.
Figure 5c. Lower hemisphere projection of 152 poles to joints in the gneissic terrane. Contours in percent.
In summary, synthesis of structural fabric data is supportive of isolated observations which indicate that early isoclinal recumbent folds about east-southeasterly axes were refolded in a more open and upright style about northeasterly axes, and these refolded folds were again warped about southeasterly axes. The outcrop pattern of lithologic units caused by these events would be expected to have a sinuous northwest-southeast trend, modified by the present topography.

Analysis of the fractures, mainly joints, in the Birch Lake Pluton suggests that quartz veining accompanied late-stage, steeply-dipping joints indicative of a stress field with an east northeasterly azimuth, and that there may have been some post-consolidation rotation of the pluton clockwise relative to the enclosing metamorphic terrane.

A well-developed joint set is present in both the pluton and the metamorphic terrane conformable with the overall trend of the Richardson Lineament and associated rhyolite dike. The trends of several minor dikes west of the pluton are similar to northerly-trending joint set in both the pluton and the metamorphic terrane. Unfortunately the attitudes of the abundant mineralized quartz veins present in the rhyolite dike at the Democrat Mine could not be discerned, and their relationship, if any, to regional fractures, is unknown.

Remote Sensing and Geophysics

A single Landsat image (E 21304-20140-7) was examined to compare major mapped faults with linear features and trends in the Richardson area. Figure 3 shows the faults and linears interpreted from that image. The linears were digitized and a length weighted histogram with 1 degree class intervals was computed. Peaks occur at N15E, N45E, N65E, N85E, N80W, N40W, and N15W.
Figure 3. Landsat linear features in the central Yukon-Tanana Uplands.
The major mapped faults in the Richardson area are the Shaw Creek and Salcha and these trend N45E and N65E respectively. The Richardson Lineament and the quartz porphyry dike trend approximately N40W. The linear trends with peaks at N15E, N85E, N80W, and N15W are probably a function of the joint sets in the metamorphic rocks with corresponding orientations.

Plates V and VI show the aeromagnetic contours from one mile flight lines (APGGS, 1973). The aeromagnetic anomalies generally do not have well defined trends with the following exceptions. A poorly defined low is congruent with the Richardson Lineament and quartz porphyry dike. This low may be due to intensive late kaolinization of the quartz porphyry dike and adjacent areas.

A magnetic high trends east-west between Tenderfoot Creek and Shaw Creek flats. The lack of outcrop and stream drainage in the area precluded both geologic mapping and geochemical sampling thus there is no evidence to estimate the source of the anomaly.

A large irregular magnetic low is associated with the Birch Lake pluton. This low may be due to kaolinization of the pluton or due to differential magnetic susceptibility between the pluton and the hornfels and schist.

Economic Geology

Gold was discovered on Tenderfoot Creek in 1905 by E. H. Luce and Gilling. A small gold rush followed with gold discoveries and production in 1906 on Banner, Buckeye, Redmond, Junction, Gold Run, Empire, Last Chance, and First Chance Creeks. In 1908 gold was discovered on the divide between Banner and Tenderfoot Creeks. Gold production peaked in 1908. The district went into decline, in part due to competition from the newly discovered rich Iditarod gravels.
B. E. Shuff discovered gold in a tributary of Banner called Democrat Pup in 1909. Pay gravel was found the following year on the left limit of Tenderfoot Creek. By 1911, though, production from the district was primarily from Shuff's Democrat Pup property (Prindle, 1913).

Lode gold was found by Shuff in bedrock on the Democrat Pup in 1913. A 93' tunnel was driven, "on a porphyry dike with considerable quartz in stringers and pockets". A mill was constructed in 1921 but no lode gold was produced, (Brooks, 1922).

Fred Campbell produced small amounts of gold during the 1930's and 1940's from the divide between Banner and Tenderfoot Creeks. Gil Martin had a small operation on this ground in the early 1950's (Saunders, 1965). There was a revival of interest in the district in the late 1970's and operations were active on the old Campbell property and on the old Shuff placer property in the summer of 1982.

Although no lode mineralization was located during geologic mapping, stream sediment and pan concentrate sampling indicated at least six new areas of potential lode mineralization (Metz, et al., 1984). Anomalous areas are defined by more than one sample with one or more anomalous elements. Roman numerals on Plates V and VI depict these anomalous areas.

Area I is located in Sec. 20, T 6 S, R 76, F.M. (Plate V). The major elemental associations include Hg-W+Au-Ag and Cu-Ni-Zn-FetAu-Ag. Bedrock in the area is felsic and mafic gneiss, felsic granofels, schistose gneiss, marble, and a small quartz monzonite pluton.

Area II is located in Sec. 31, T 6 S, R 8 E, F.M. (Plate V). The elemental associates and bedrock is the same as in Area I.
Area III is located in Sec. 21, T 6 S, R 5 E, F.M. (Plate VI). The major elemental associations are Hg-Sb and Fe-Mn. Bedrock exposure is poor, however rubble crops indicate the predominance of mafic gneiss with minor schistose gneiss, quartzite, rhyolite porphyry and andesite porphyry.

Area IV is located in Sec. II, T 63, R 5 E, F.M. (Plate VI). The major elemental associations are Hg-Sb-W-As, and Fe-Mn+Cr. Bedrock exposure is poor, however rubble crops indicate the predominance of mafic gneiss, schistose gneiss, quartz-mica-feldspar schist and quartzite.

Area V is located in Sec. 27, T SS, R 6 E, F.M. (Plate VI). The major elemental association is Cr and the predominant bedrock type is amphibole gneiss.

Area VI is located in Sec. 22, T 7 S, R 6 E, F.M. (Plate VI). The major elemental associations are Sn-W-As+Sb-Au-Ag and Cu-Ni-Zn+Fe-Mn-Cr. Bedrock in the area is quartz-mica-feldspar schist, marble, hornfels, skarn, and granite of the Birch Lake Pluton.

In summary, stream sediment and pan concentrate sampling in the Richardson mining district indicates six additional areas of potential lode mineralization. Although bedrock exposures are poor to non-existent, inferences can be made to possible genetic types of lode mineralization based on the elemental associations and limited petrologic data.

The copper-nickel-zinc-gold-silver elemental associations in areas of mafic gneiss indicate possible metamorphosed syngenetic basemetal sulfide mineralization. Saunders (1965) suggested that the low fineness values of the placer gold from the district (Smith 1941) is a function of a basemetal sulfide source. The low fineness values for Banner and Buckeye Creeks (Metz and Hawkins, 1981) and the stream sediment base metal anomalies in this area are further supporting evidence for that hypothesis.

The tin-tungsten-arsenic-gold-silver elemental associations in the contact areas of the Birch Lake Pluton are suggestive of the Cornubian tin-granite association. The sericitized, greisenized, and kaolinized quartz porphyry dikes slightly younger than the granitic intrusives are very similar to the elvan dike systems of Cornwall, England. The presence of cassiterite, scheelite, and tourmaline in the placer deposits below the quartz porphyry dike (Wedow et al., 1954; Saunders, 1965) in T 7 S, R 7 E, F.M. (Plate VI) further supports this genetic model.

The chromium anomalies in Area V are associated with amphibolite gneiss. The association suggests a mafic volcanic or ultramafic origin of the gneiss. The economic potential of any chromite mineralization is low, however if the original bedrock source is an ultramafic rock there may be some potential for platinum group metal mineralization.

**Summary and Conclusions**

Placer gold has been mined in the Banner Creek - Tenderfoot Creek part of the Richardson District since 1905, and a hard rock mine operated on Democrat Creek in 1913. The lode gold was apparently associated with sulphide-bearing
quartz veins crosscutting altered phases of a rhyolite porphyry dike which has been dated at 86.9±2.6 my.

The rhyolite porphyry dike trends northwesterly across the placer gold field, and may be localized along the Richardson Lineament, which is one of several northwest-trending structures in the area. Regional joint sets parallel the trend of the lineament, and are also evident in a large granitic pluton at Birch Lake, which has been dated at 89.3±2.7 my. Fan concentrate samples from creeks draining the pluton suggest that it has a typically Cornubian tin/tungsten signature, accompanied by base metal geochemical anomalies on the northernmost side, at the head of Canyon Creek.

In part the Richardson Lineament is the demarcation between schistose rocks to the southwest, and gneissic rocks to the northeast.

Calcareous rocks are present in the schist terrane, and are locally converted to garnet-epidote-clinopyroxene skarns close to the Birch Lake Pluton, but pelitic schists and mica quartzites are the most common units. Close to the pluton hornfels is developed in the schist, and the rocks locally develop gneissic layering. Garnet is surprisingly rare in the schist, and the metamorphic grade ranges from epidote-amphibolite to almandite-amphibolite. Near the Tanana River some pelitic rocks appear to be of upper greenschist facies. Textures of the schist indicate that the present synkinematic fabric was derived from an earlier fabric indicative of a period of intense cataclasis, and in several places early isoclinal recumbent folds about almost east-west axes are refolded in a more open style about northeast-trending axes. It is possible that the cataclastic fabric relates to shearing which would be expected in the early fold episode.
In the gneiss terrane to the northeast of the Richardson Lineament refolded folds were observed, and structural analysis indicates that the fold styles and orientations are similar to those in the schist terrane, though the more open style appears to be less common than the isoclinal style. Relict cataclastic fabrics are ubiquitous in the gneiss terrane, but the subsequent sykninematic fabric is frequently modified, especially in quartzofeldspathic variants, by a thermal overprint. Where the thermal overprint is most intense, the gneissic rocks lose all traces of layering, and have a granoblastic aspect. Such rocks are referred to as granofels, and locally include biotite-rich mafic variants. Sillimanite is an ubiquitous component of the gneissic rocks, and garnet is also present, particularly in several distinctive lithologic units which occur on the northeast side of, and trend parallel to, the rhyolite porphyry dike in the Banner Creek area. The presence of sillimanite in the gneiss terrane and the lack of it in the schist terrane suggest that the Richardson Lineament may be a fault with considerable downthrow to the southwest.

A small granitic pluton similar in composition to the Birch Lake Pluton is exposed northwest of VABM Buck in the northern part of the gneiss terrane. Subcrops of a distinctive impure marble in the vicinity suggest the regional trend of the gneissic rocks in the area is easterly, and both aeromagnetic data and the presence of abundant granofelsic rubble for several miles to the east and southeast of the small pluton suggest that it may have a considerable subsurface extent. Stream sediment and pan concentrate samples derived from this terrane suggest the presence of tungsten, gold, antimony, mercury, and arsenic, and the distribution of the anomalies indicate that there must be several discrete sources.
The Banner Creek area provides more outcrop in natural and man-made exposures than most of the district, but is also anomalous in that considerable placer gold is present. This factor alone suggests that the lithologic and structural interpretations which are made possible by the superior exposure should be applied with care in other parts of the area.

Granofelsic rocks are common northeast of the Richardson Lineament and the associated rhyolite porphyry dike in the Banner Creek area, but appear to be more common in the lower slopes of the valleys. This observation in conjunction with the aeromagnetic signature and few veinlets of pegmatite which locally crosscut the gneissic layering suggest the presence of one or more small plutons at depth.

Immediately northeast of the rhyolite dike between Banner and Buckeye Creeks a distinctive association of lithologic units permits some predictions, and may constitute a mapping horizon. Proceeding northeast from the dike a thin unit of amphibole augen-gneiss is succeeded by more normal, biotite-bearing, quartzofeldspathic gneiss and a distinctive unit of greenish, epidote-bearing, impure marble. Northeast of the marble, a resistant unit of very light colored quartzofeldspathic gneiss contains small euhedral garnets of an unusual pink color with definite purple hue. Using the association, it was possible to predict the presence of the impure marble in Buckeye Creek, and after considerable effort find rubble of the marble where predicted.

Generally the schist and gneiss close to the rhyolite dike in the Banner Creek area shows evidence of bleaching and baking, probably indicating some hydrothermal activity. At the Democrat Mine the rhyolite porphyry itself is propylitically altered, and is frequently hematite-stained. Quartz veins
carrying arsenic and antimony sulphides cut the rhyolite, and often have a broad muscovite-rich selvage. Clearly there was considerable hydrothermal activity after emplacement of the dike.

Hydrothermal activity is most intense in schistose rocks in Hinkley Gulch, a tributary to Buckeye Creek. Rocks exposed in the Gulch are extremely baked and intensely fractured, and on both the north and south sides of the Gulch a distinctive "white gneiss" is present. On the north side of the Gulch it is in fault contact with more normal biotite schist to the north, and is associated with a lensoid mass of garnet-amphibole and epidote-amphibole skarn. The southern contact is not exposed, but strongly jointed biotite-quartz-feldspar schist nearby are bleached and silicified close to the joints, and selective alteration pervades the fabric on the up-dip side of the joint.

Only the southern contact of the "white gneiss" can be seen on the south side of the Gulch, where it is rather sharp, though apparently conformable with the foliation of superincumbent unaltered pelitic schist. This 'gneiss' unit is also extremely altered to kaolinite, and contains inumerable quartz veinlets with at least three episodes of formation. The quartz veinlets appear to be restricted to the "white gneiss" unit, and become volumetrically more important, though less random in orientation, easterly to the ridgecrest. Large boulders of quartz with an unusual purple tint occur in clay piles derived from the placer operation to the east, and some of the quartz has associated tourmaline.

Numerous structural features, including the orientation of drag fold axes, indicate that the "white gneiss" on the north side of Hinkley Gulch and that on the south side occupy the limbs of an antiformal fold plunging about 20° to an azimuth of about N110°. It is possible that the fracturing in the
Gulch is related to a major shear zone approximately parallel to the axis of the fold.

This discussion is not academic, since placer gold is being produced from an operation on the ridgecrest, approximately coincident with the crest or nose of the proposed fold. Regrettably mining activity did not permit the examination of this critical area, but cursory examination indicated no alluvial material in the tailing piles, suggesting that this placer is a residual placer, at least spatially associated with hydrothermally altered rocks.

The Hinkley Gulch-Dublin Gulch area is unusual in that a vent agglomerate or intrusive breccia of rhyolite porphyry occurs near the mouth of Hinkley Gulch, and a dike of scoriaceous rhyolite porphyry trends northeasterly towards Dublin Gulch. Except in this area the main rhyolite porphyry dike trends northerly, but from the head of Tenderfoot Creek to Prosperity Gulch the presence of the dike cannot be determined due to lack of exposure. Except at the foot of Hinkley Gulch no rhyolite porphyry rubble was found in the vicinity of the placer workings. The possibility of a mineralized intrusive breccia in the foldcrest should be investigated.

The relative ages of the short, northeast-trending rhyolite porphyry dike at Hinkley Gulch and the main northwest trending dike could not be determined, but the unproven continuity of the main dike, the disparate trend of the Hinkley Gulch dike, the extreme hydrothermal alteration of schistose rocks in this particular area, and the occurrence of residual placer gold are enigmatic.
The presence of abundant clasts of unaltered schist and quartzite in the vent breccia of Hinkley Gulch, and particularly the lack of any skarn, "white gneiss" or bleached and baked schist clasts, strongly suggests that the hydrothermal alteration and silicification in the area postdated the vent breccia and the dike. The more brittle and chemically susceptible quartzofeldspathic schists would tend to be selectively replaced rather than the more pelitic variants which were subject to plastic deformation, and which would tend to form impervious layers.

At the northwesternmost exposure of the main rhyolite dike, at the head of Junction Creek, the trend appears to swing to the west, diverging from the projected trace of the Richardson Lineament. Some of the distinctive rock types which are associated with the dike at Banner Creek occur as rubble on the southside of Junction Creek where a trail leads over to Birch Lake. Amphibolite gneiss, impure marble and a quartzite containing purplish-pink euhedral garnets were associated in rubble with extremely sheared and bleached schist or gneissic schist. Though no rhyolite prophyry was observed, this locality is approximately midway between the rhyolite dike at the head of Junction Creek and a series of northerly trending rhyolite, andesite and basalt dikes near the Silver Fox Lodge in the Richardson Highway six miles west of Birch Lake.

Further work should include careful examination of this possible continuity.

Although placer gold production to date has been spatially associated with the Richardson Lineament and the associated rhyolite dike, the presence of interestingly anomalous amounts of gold in pan concentrate samples from Banner Creek and in O'Brien Creek several thousand feet northeast of the dike
suggest additional lode source areas. In Banner Creek, stream sediment samples contained silver, as noted by Saunders (1965), but the only rock which might provide a source was a very fine-grained, sulphide-bearing amphibolite of unknown, but apparently limited, areal extent. The trend of this unit, if persistent, would be expected on the basis of structural interpretation to be easterly to southeasterly, and it may also account for the gold found in O'Brien Creek.

Acknowledgements

This work was completed under a grant from the Alaska State Legislature entitled "Mineral Resource Evaluation of Interior Alaska Mining Districts." We wish to thank Robert Loveless, Donald May, Gilbert Monroe, and Edward Smith for permission to examine their mining properties.
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