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DIAGENESIS AND METAMORPHISM IN THE REVETT QUARTZITE

(MIDDLE PROTEROZOIC BELT), IDAHO AND MONTANA

by

Stephen D. Herndon

B.A., California State University at Humboldt, 1975

Presented in partial fulfillment of the
requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1983

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Diagenesis and Metamorphism in the Revett Quartzite (Middle
Proterozoic Belt), Idaho and Montana

Director: Don Winston

   A representative collection of quartzite from the Precambrian
Revett Formation of Idaho and Montana was examined petrographically
for evidence of its diagenetic and metamorphic history.
   The quartzite contains an early authigenic mineral assemblage
of quartz-hematite-sericite which indicates Revett sands were
initially in an oxidizing and approximately neutral diagenetic
environment. Subsequently-formed albite-microcline-phengite
and later carbonate-chlorite indicate diagenetic waters became
progressively more reducing and alkaline as burial proceeded.
Authigenic pyrite is very rare in these quartzites and would
have been chemically unstable during early and mid-stage diagenesis
and during regional metamorphism when oxygen fugacity was relative-
ly high. It occurs only with other sulfides in local deposits
within interbeds of quartzite with pyritic siltite-argillite and/
or adjacent to sulfide-bearing fault zones.

ACKNOWLEDGMENTS

Special thanks are due Don Winston and the other members of my thesis committee for their interest and continued efforts on my behalf. Also, gratitude is extended to my family, Barbara and Jason Herndon, who have contributed immensely to all phases of this project.

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INTRODUCTION

The Revett Formation forms a southwestward thickening quartzitic wedge within the Ravalli Group of the Late Proterozoic Belt-Purcell Supergroup which outcrops in Montana, Idaho, Washington, and British Columbia (Harrison, 1972). Three widespread stratigraphic subdivisions of the Revett Formation are recognized (White and Winston, 1982): 1) a lower unit with characteristic beds of thick vitreous quartzite, 2) a middle unit comprised wholly of argillite and siltite, and 3) an upper unit which includes intervals of sericitic and vitreous quartzite. The upper Revett generally contains a complete suite of quartzite-lithologies including those with copper-silver-bearing sulfides at Asarco's Spar Lake deposit and the lead-zinc-silver deposits of the Coeur d'Alene district.

A variety of Revett quartzites have been described, including pyritic and non-pyritic types, which can be evaluated in terms of their depositional, diagenetic, and metamorphic mineralogies. Most geologists agree that "Revett-type" stratiform copper-sulfide deposits originated in sandstone by syngenetic or diagenetic processes (ie., Clark, 1971; Harrison, 1972; Morton et al, 1973; Lindsey and Lange, 1981). An understanding of the regional distribution of Revett diagenetic facies might prove useful in locating Revett-type deposits and in evaluating sedimentologic models of the Belt.

1

This thesis addresses basic questions about diagenesis in Revett sands: 1) what diagenetic facies are present; 2) how are these facies distributed; and 3) do diagenetic facies correlate with sedimentary facies. Also, it provides an opportunity to observe whether or not regional metamorphic overprints affect the distribution of sulfide-precursors as suggested by White (1978) for Coeur d'Alene deposits.

A regional-scale investigation is dictated by the need to distinguish metamorphic overprint from diagenetic facies. Accordingly, a regional-scale reconnaissance approach was adopted.

A variety of quartzite occurs at each Revett section and different quartzite-types occur at various sections. After reviewing sections compiled by Don Winston and coworkers, representative sections were identified at Maple Cliff, Thompson River, and Trout Creek. Representative collections of quartzite were gathered at these sections and from Graves Creek, Squaw Peak, and near the Snowstorm Mine. In addition, some samples were gathered along I-90 near the Montana-Idaho border and from ore dumps at the Spar Lake, Bunker Hill, Lucky Friday, and Snowstorm Mines. A collection of about one-hundred samples including grey, green, purple, tan, red, and white Revett quartzite was assembled.

Thin-sections and polished sections were made of most samples; also, representative sets of cathode luminescence slides and sodium cobaltinitrate-stained sections were prepared. X-ray diffraction was

used to evaluate green mica in three samples. All specimens were studied with particular attention to grain-size, mineralogy, and textural indications of mineral paragenesis. The resulting data is synthesized in terms of its relation to Revett diagenesis and metamorphism.

ALBERTA

IDAHO   MONTANA

-N-

+ —Spar Lake

*—Trout Creek

Maple
Cliff-*   *— Graves Creek
                           *— Thompson River

Snowstorm Mine ————— *
                    +
Bunker Hill Mine   + +—I-90

Lucky
Friday Mine ——   *—Squaw Peak

|—40 mi.——|

one inch = forty miles (64.6km)

+   sites of limited sampling

*   sites of significant sampling
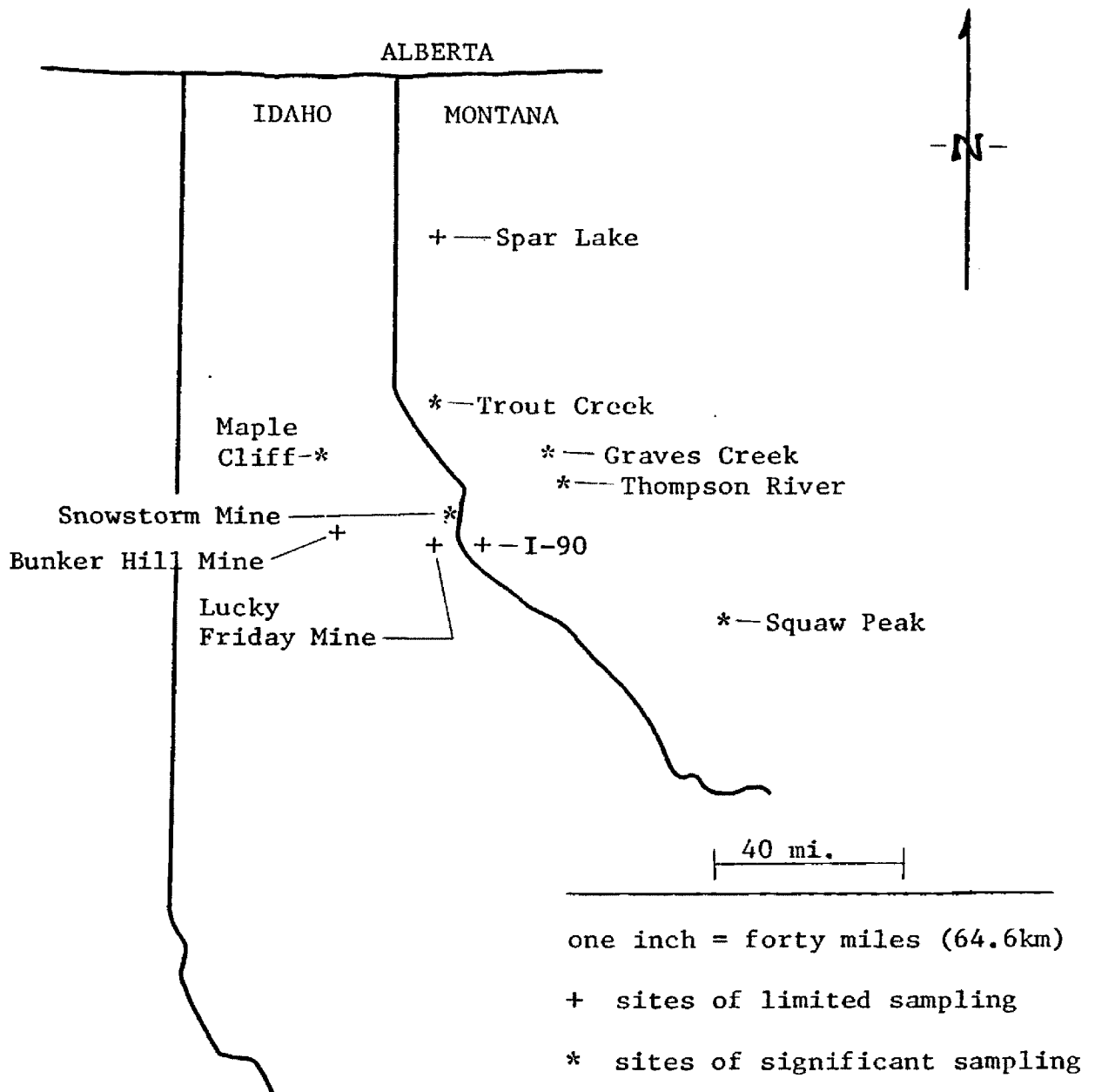
Figure 1:   study area

PETROLOGY

Introduction

According to Harrison and Grimes (1970), the bulk composition
of Belt rocks is granitic to granodioritic and the material was
derived from crystalline rocks of the regional Archean basement.
However, uniform albite compositions described in this thesis may
indicate the Revett Formation was derived from sedimentary or
alkaline granitic source rocks.

White and Winston (1982) defined three major Revett lithologies
found in the Bunker Hill Mine of Idaho as follow: ..." 1) crossbedded
and horizontally laminated, medium- to thick-bedded, hard, vitreous,
light grey or white quartzite ...; 2) horizontally laminated, medium-
to thick-bedded, light to medium grey-green, subvitreous, sericitic
quartzite ...; and 3) horizontally to ripple cross-laminated, fine-
grained, thin-bedded strata, which contain abundant resedimented,
soft-sediment mud inclusions or "mudskins", here named siltite-
argillite." These rock-types are common throughout the Revett Form-
ation although other types are significant.

Revett quartzites are characteristically feldspathic and well
indurated. Individual grains and textures are generally obscured
in hand specimen by diagenetic and metamorphic overprint. Maxwell
and Hower (1967), Norwick (1972), and others documented diagenetic,

burial-, and dynamothermal metamorphic features of Belt rocks
including: 1) a transition of metamorphic grade from unmetamorphosed
upper-Belt rocks through greenschist facies in the Ravalli Group to
amphibolite facies in the underlying Prichard Formation; 2) the con-
version of 1M illite to 2M illite with increasing grade; 3) the
occurrence of untwinned, anhedral, metamorphic oligoclase in the
Prichard Formation; and 4) the occurrence of authigenic microcline
in the Prichard Formation.

The following sub-sections describe in turn the individual min-
erals and petrography of Revett quartzite. All compositional percent-
age estimates are volumetric.

Quartz

Quartz grains were used as representative clasts for estimates
of grain size because they tend to distort rather than fracture when
subjected to shear stress. Estimates of quartz-grain-size are com-
plicated by metamorphic overprint ranging from slight grain-distortions
and deformation lamellae to distorted polygonized mortar textures
(Figures 2, 3, and 4). Many grain diameters were estimated by
averaging long and short axes of modal-sized grains. In rocks with
polygonized mortar textures, grain-size was estimated from the large-
diameter mode and checked by estimating hydrodynamic-equilibrium-size
from undeformed detrital heavy minerals.
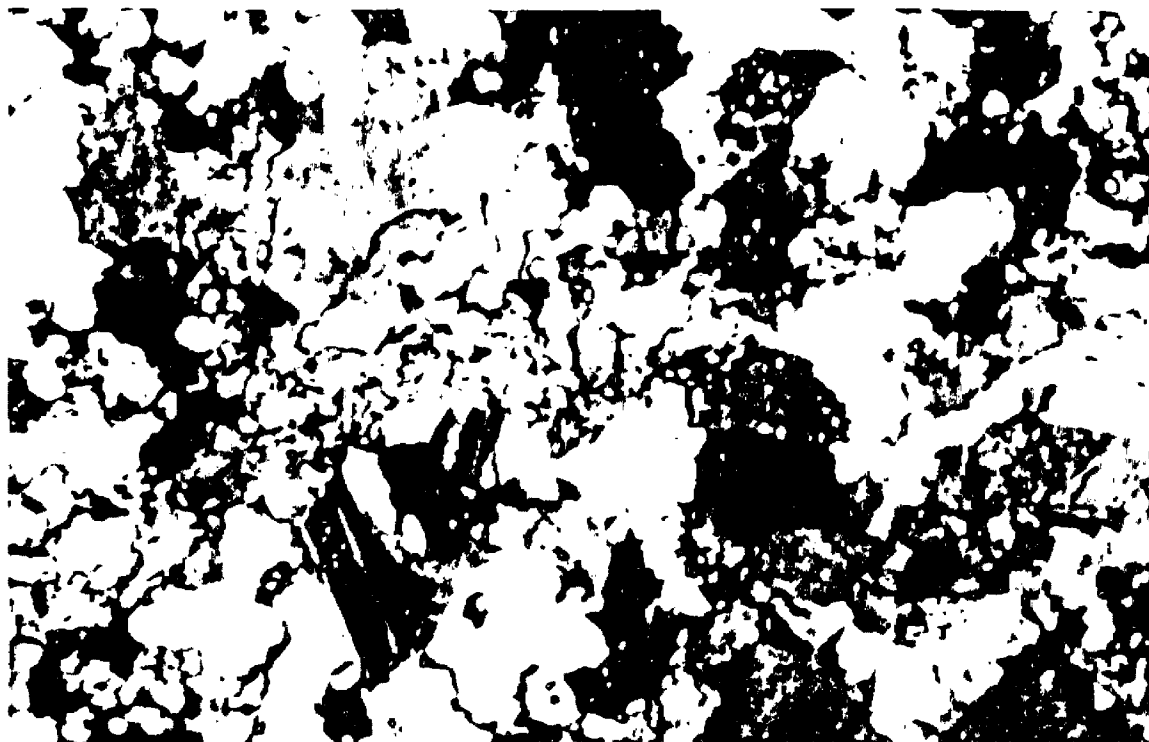
Figure 2:   polygonized mortar texture, 50X; sample GC-10
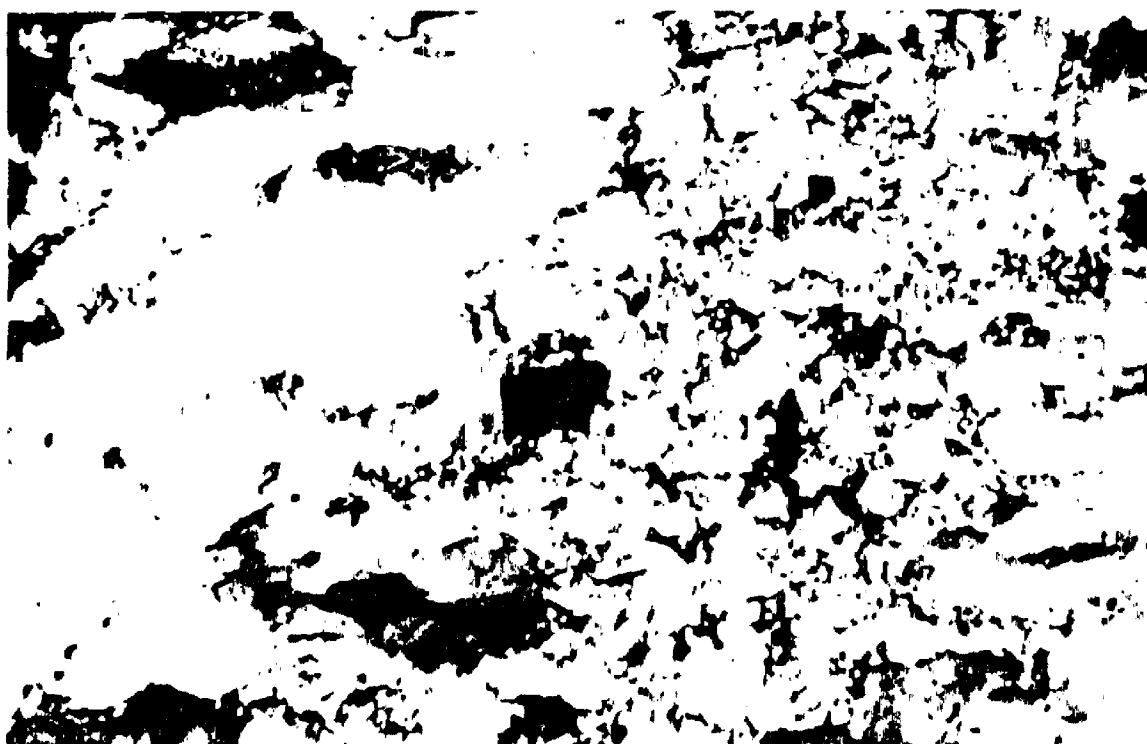
Figure 3:   deformed polygonized grains, 50X (S_1 is at a high angle
to S_0); sample SPA-1.

All modal-size estimates are between 0.06mm and 0.25mm diameter (very-fine- through fine-grained on the Wentworth scale). The mean average quartz-content of Revett quartzite is about 80%. However, quartz-content is bimodal and correlates with grain-size (Figure 4). The dominant mode contains about 80% quartz and occurs in sediments with a mean grain-diameter of 0.07mm (very-fined-grained sand). The smaller mode contains about 90% quartz and occurs in sediments averaging about 0.13mm diameter (fine-grained sand).

Figure 4: quartz-content modes

GROUP	$\overline{M}$ DIA.	S. DEV.
A	0.13mm	0.04
B	0.07mm	0.01
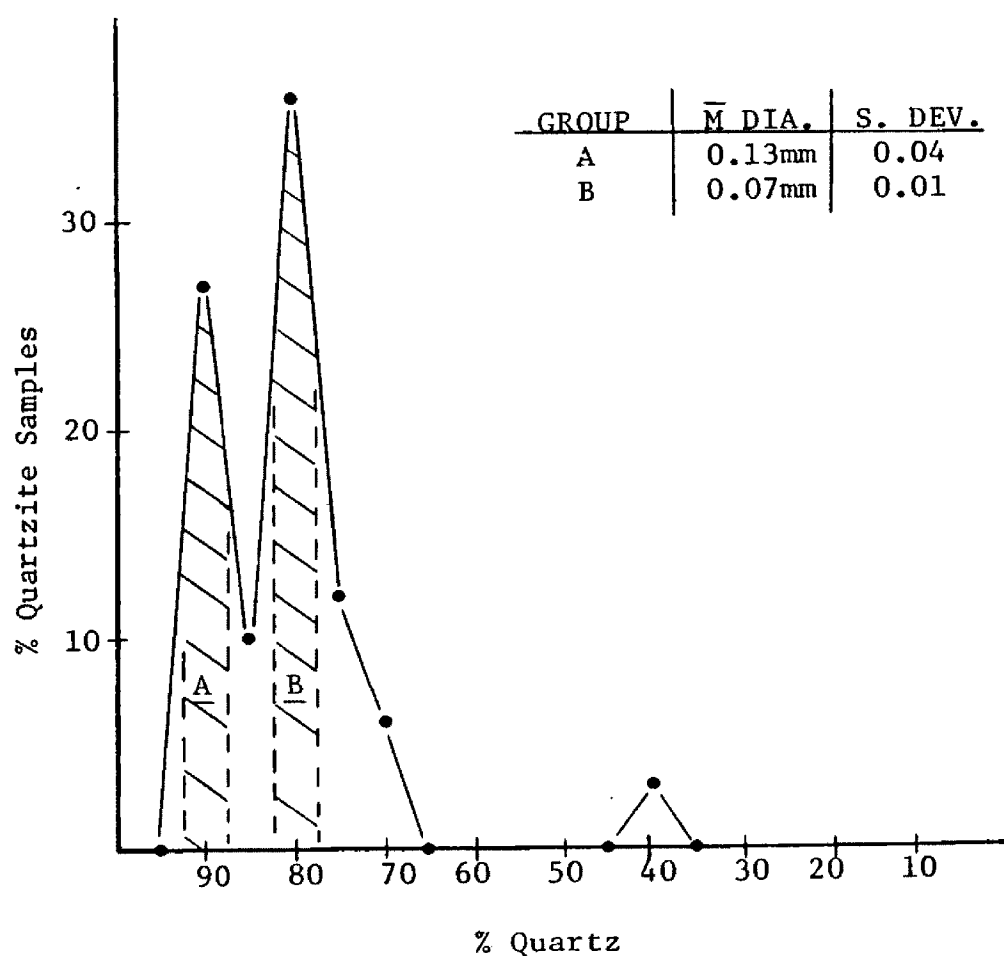
% Quartz

Quartz grain-overgrowths are widespread in Revett quartzite and most common in fine-grained rocks of high detrital quartz content. Overgrowths are separated from cores of detrital quartz by arcs and rings of irresolvable "dust" and very small hematite or sericite crystals (Figures 5, 6, and 9) as described by Wolf and Chilingarian (1976), Blatt (1979), and Borak and Friedman (1981).

Figure 5:   deformation lamellae and quartz overgrowth, 125X; sample SS-M5.
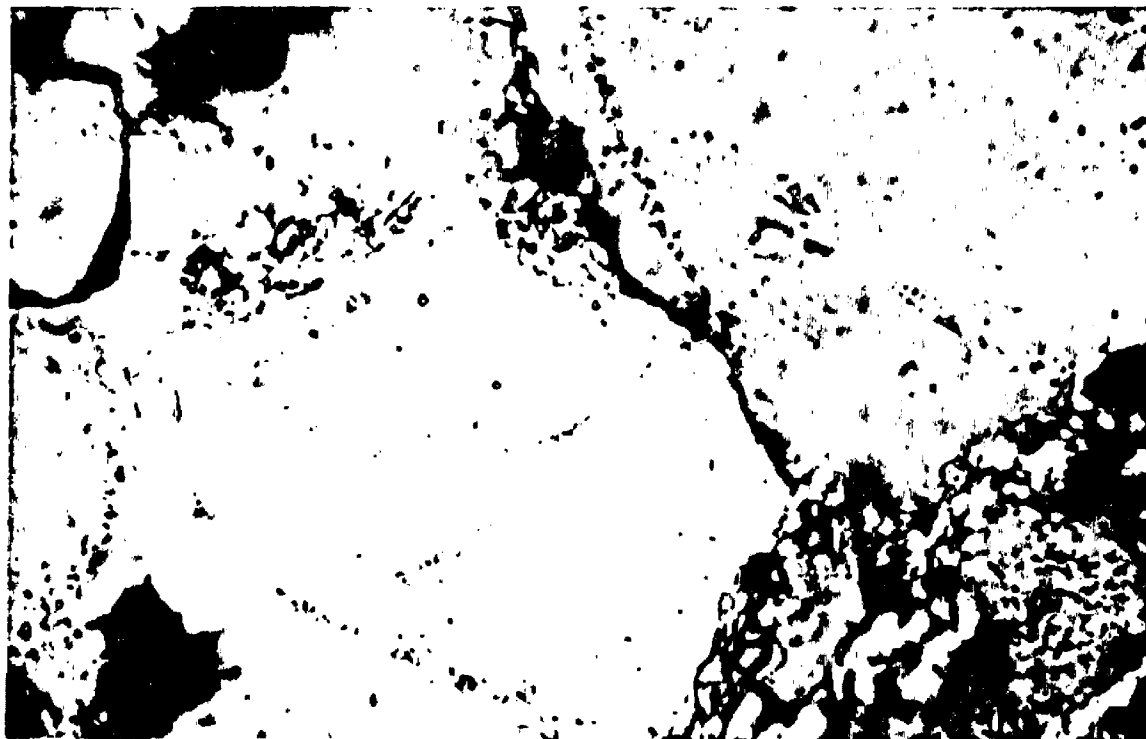
Figure 6:   quartz overgrowths, 50X; sample SS-M2.

Cathode luminescence does not discriminate between overgrowth and detrital grains in these rocks. Overgrowths reflect a porosity of more than 20% at the time of pore-filling quartz-cementation.

Feldspar

The feldspar content of Revett quartzite ranges from nearly 10% in fine-grained rocks of 0.13mm grain-diameter to about 20% in very-fine-grained rocks of 0.07mm grain-diameter (Figure 7). Overall,

Figure 7: feldspar content verses sediment size
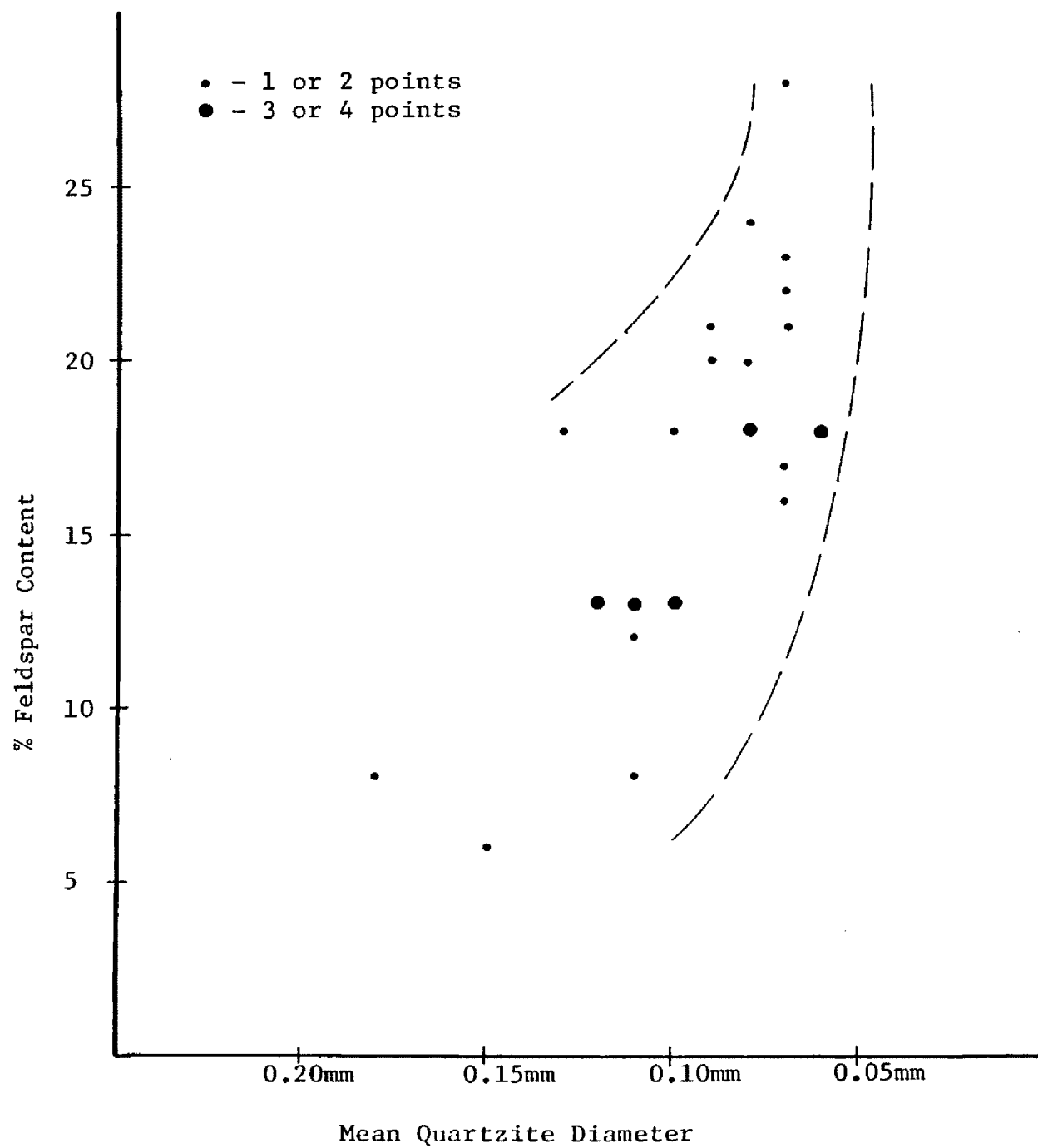
feldspar averages 17% with a standard deviation of 6.

Five subgroups of feldspar were distinguished in thin-sections and from sodium cobaltinitrate stained samples: 1) twinned albite, 2) untwinned albite, 3) orthoclase, 4) microcline, and 5) feldspar-grains replaced by whole-grain argillic-sericitic alteration. Each is discussed in turn.

Twinned albite

Twinned albite grains average 8%, one standard deviation = 4. Except where deformed, corroded, or hydrothermally altered, the size and form of twinned albite grains are similar to those of adjacent detrital quartz grains.

The composition of twinned albite grains was estimated by the Y-angle-010, perpendicular to x, polysynthetic-twin-extinction method. A group of 44 determinations from 14 representative samples yields a mean anorthite content of 6%, one standard deviation = approximately 1. A tight clustering of anorthite contents is atypical of detrital grains in feldspathic sediments (i.e., Simonen and Kouvo, 1955) and suggests the albite content of plagioclase was equilibrated. However, because plagioclase composition does not vary with calcite content and diagnostic textures such as albite-rich grain rims are lacking, diagenetic equilibration is not reflected in Revett quartzite. More calcic clasts might have been removed during transport and earliest diagenesis because anorthite is

less stable than albite under surface conditions. However, a more probable alternative is that the Revett source-terrain contained uniform albite. Such albite might have been equilibrated during the diagenesis of a sedimentary source-rock.

Untwinned albite

Untwinned albite comprises less than 4% of several quartzite samples from Graves Creek. Microscopically, clear euhedral grains are of similar size or are larger than adjacent detrital grains. A more widespread habit, although rare, is as clear untwinned rims on twinned albite grains. Because of the difficulty in identifying these untwinned grains, their content was estimated by subtracting estimates of total K-feldspar (stained with sodium cobaltinitrate) and twinned albite contents from estimated total feldspar content (relief method).

Untwinned albite is interpreted to be authigenic because of its euhedral or rimming form, unaltered condition, and coarse size. Such diagenetic albite is widely recognized in sandstones (i.e., Fuchtbaur, 1966 and 1974; Correns, 1968; Blatt et al, 1980; Milliken and Loucks, 1981).

Orthoclase

The orthoclase content of Revett quartzite averages 5%, one standard deviation = 5. Most unaltered and undeformed orthoclase grains are similar in size and form to adjacent detrital grains. Fresh orthoclase forms rare overgrowths on

detrital orthoclase grains.

The relatively large standard deviation of orthoclase contents and the scarcity of authigenic orthoclase suggest that it was generally removed during diagnesis.
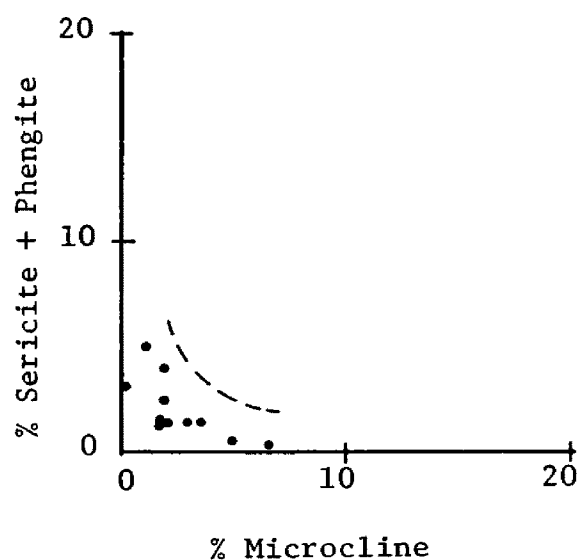
Microcline

Figure 8: microcline content verses sericite content

Microcline is widespread and averages about 1.5%, one standard deviation = 2, in Revett quartzites. It occurs as clear grains of size and form similar to adjacent grains or distinctly different and amoeboidal, having replaced adjacent grains.

Microcline is known to form under conditions ranging from diagenesis through amphibolite facies metamorphism (Correns, 1968; Hyndman, 1972).

The percentage of microcline in Revett quartzite varies inversely with that of sericite plus phengite (Figure 8). No textural evidence of the replacement of one mineral by the other was observed. However their inverse relationship suggests that either they were opposite end-members of a reaction such as, $3KAlSi_3O_8 + H_2O \rightleftharpoons KAl_2(AlSi_3O_{10})(OH_2) + 6SiO_2 + K_2O$, or their occurrence was determined by the availability of potassium. Authigenic microcline might occur where potassium ions were available and not totally removed by the growth of illite, sericite, or phengite as argued by Knadle (1981) for the Precambrain Deep Spring Formation.

Altered feldspar

Sericite-altered feldspar grains range in abundance from 0 to 25% in Revett quartzites. Most samples contain small amounts of slightly altered grains having sparse intra-granular sericite flakes. In many Maple Cliff samples feldspar grains have been totally replaced by sericite.

Because most feldspar grains are unaltered, minor sparsely altered grains present in most samples were probably deposited as such. At Maple Cliff the undeformed habit of sericite-replaced-grains and the random orientation of their contained sericite flakes indicate alteration occurred after dynamothermal

metamorphism, possibly the result of hydrothermal fluids
that accompanied Tertiary faulting.

Summary

Revett feldspar is mostly detrital twinned albite of
uniform composition. Lesser components are untwinned authi-
genic albite, detrital orthoclase, and both detrital and
authigenic microcline.

The distribution of quartz and feldspar contents relative
to grain-size indicates two modes occur: 1) a fine-grained
mode, with a mean grain-diameter of about 0.13mm, composed of
approximately 90% quartz and 10% feldspar; and 2) a very-fine-
grained mode of about 0.07mm, composed of about 80% quartz and
20% feldspar.

Mica

Muscovite, sericite, phengite, biotite, and chlorite can be
identified microscopically in Revett quartzite. Their occurrence and
characteristics follow.

Muscovite

Muscovite is distinguished from sericite by its larger
grain-size. Muscovite flakes are commonly size-sorted indicating
a detrital origin. They normally comprise 1 to 2% of Revett
quartzite and sub-parallel bedding plane schistosity (S_0).
Ragged or fibrous flakes are absent but, although sparse, bent

and broken flakes occur widely. Thus, metamorphically recry-
stallized detrital muscovite was later deformed by widespread
minor dynamic metamorphism.

Sericite

Sericite flakes commonly occur as individuals encapsu-
lated in quartz-grain overgrowths and in narrow intergranular
spaces. They also occur as internal alterations of some twinned
albite grains (previously discussed). Sericite is optically dis-
tinguishable from phengite of the same size by its clear color;
phengite is greenish. Because green phengite grades composition-
ally into sericite, the distinction of very-light green phengite
from sericite in thin-section is somewhat arbitrary. In
unaltered quartzites these minerals normally total between 1
and 4% of composition and phengite is more abundant than seri-
cite.

The small size of sericite relative to adjacent detrital
grains indicates it is authigenic. It might have precipitated
directly or developed by the dehydration of authigenic or
sieved detrital clays as described by Walker (1974). Its
restriction to isolated regions of primary pore-space indi-
cates it formed before and possibly during the precipitation
of hematite and quartz overgrowths. Later, it was widely
removed or altered to phengite.

Phengite

Many clear mica flakes, especially in green and purple quartzite, are distinctly yellowish-green under the microscope and greater in optical relief than uncolored varieties. X-ray diffraction patterns from several green and purple quartzites (GC-3, MC-620, and SP-A1) are very similar and indicate the presence of muscovitic mica with 001 peaks approximately three times the magnitude of 002 peaks. This configuration occurs with iron-bearing muscovitic mica and is permissive evidence of phengite (Thompson, verbal communication). Alternatively, chlorite which might also provide green pigmentation is absent in diffraction patterns. In thin-section the birefringence of green micas is like that of muscovite and sericite, and distinctly greater than the birefringence of chlorite. Thus phengite is indicated in Revett quartzites. Similar x-ray indication of phengite is noted in other Revett rocks (Maxwell and Hower, 1976; and Winston, verbal communication).

Phengite occurs as polycrystalline interstitial masses (Figures 9 and 10). Some phengite-masses occupy diagenetically-formed interstitial space indicating that phengite is authigenic (Schmidt and McDonald, 1979). Phengite is normally attributed to high pressure/low temperature regional metamorphism where stable assemblages of phengite plus green biotite may indicate conditions transitional between lower and higher

greenschist facies or a bulk composition rich in K_2O, MgO,

and FeO (Ernst, 1963). With increasing metamorphic grade the

compositional range of dioctahedral mica decreases converting

phengitic mica to muscovite. In the Revett Formation the most

strongly colored (iron-rich) phengite occurs in green and

purple rocks. Such green and purple quartzites outcrop near

or adjacent to quartzites of other coloration indicating that

phengite occurrence was determined by local rock composition.

Within quartzites phengite is restricted to interstitial areas

and lacks schistosity or disseminated habit indicating

that it formed prior to dynamothermal metamorphism.
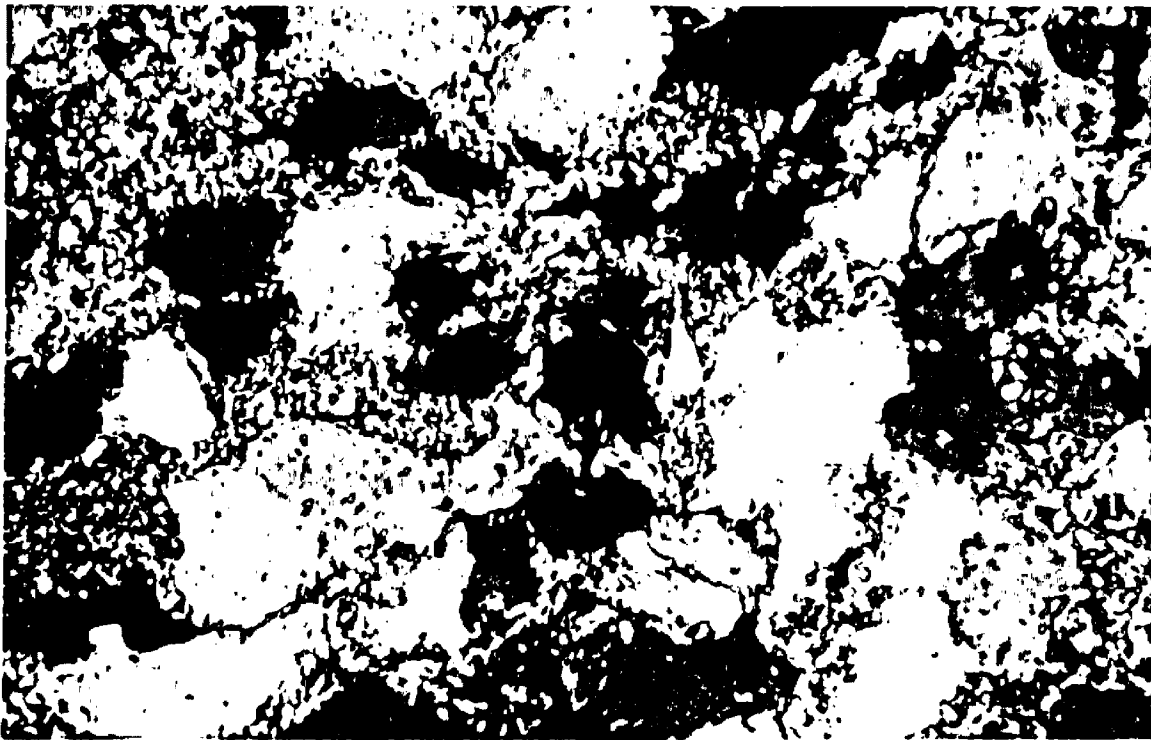
Figure 9: phengite in interstitial masses, 50X; sample MC-620
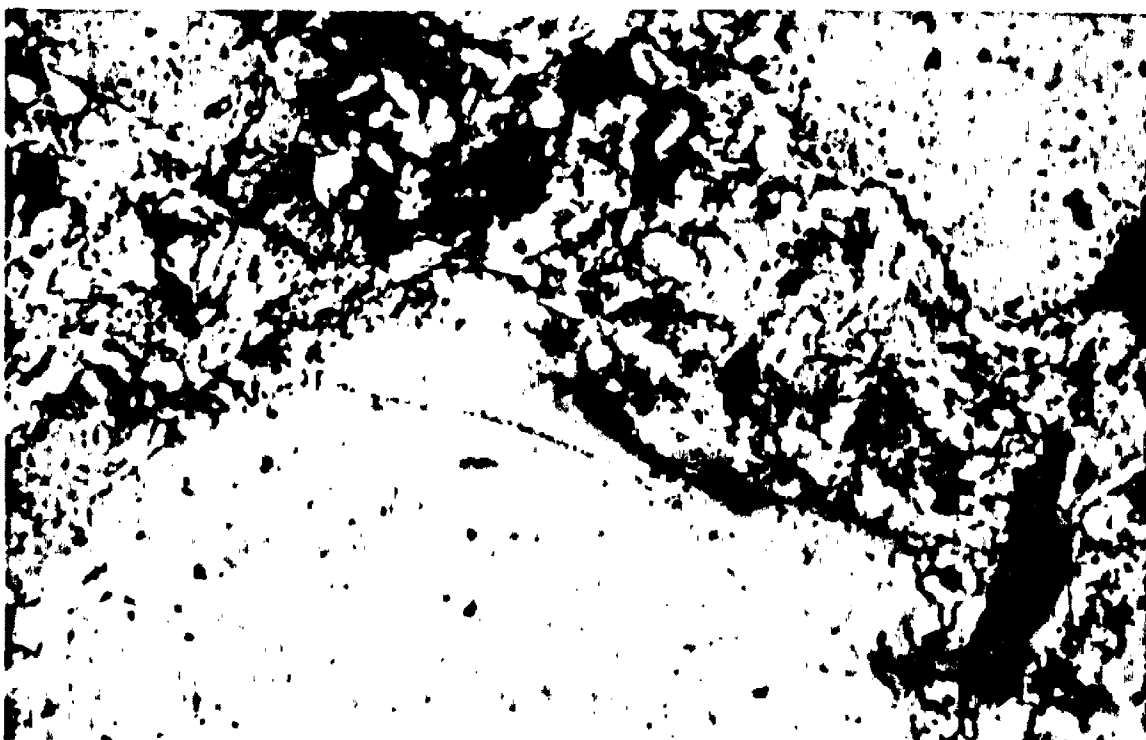
Figure 10: phengite embaying quartz overgrowth, 125X; sample MC-555

Biotite

Most Revett quartzite contains no biotite; however, some units contain amounts less than 5%. It normally occurs as randomly oriented, green or green-brown (ferric iron rich), euhedral, poikiloblastic flakes. Some brown (titanium rich) biotite forms the axial-plane cleavage (S_1) in quartzite at Squaw Peak. (Biotite chemistry is from Deer et al, 1969).

Chlorite

Chlorite normally occurs in very-fine-grained Revett quart-

zites in small amounts as a retrograde metamorphic mineral, rimming magnetite porphyroblasts. However, in one sample it embays a quartz grain and is truncated by S_1 schistosity indicating growth before dynamothermal metamorphism.

Iron and Titanium Minerals

Hematite

Hematite is common in Revett quartzite where it ranges up to 2% and is relatively abundant in some very-fine-grained units. It occurs as tiny platelets and prisms that rim detrital quartz grains or are disseminated in quartz overgrowths and interstitial areas (Figures 11 and 12).

In a hematitic quartzite sample from Squaw Peak, diffusion bands occur along-side of detrital laminae that contain magnetite, rutile, sphene, and zircon grains. Magnetite grains in these laminae are corroded by pits filled with hematite. Hematitic diffusion bands include the detrital laminae and extend outward from the laminae on one side (Figure 13). Megascopically, one edge of the diffusion bands, by the laminae, is sharp and the other edge, a millimeter or two away, is wispy or serrate. These greyish bands were not produced by surface oxidation like the more common orange and red-brown diffusion bands. In some "white" quartzite, containing no

magnetite, hematite is disseminated in quartz overgrowths but not elsewhere. These observations suggest the following: 1) detrital magnetite was removed from many white and light grey sandstones; 2) oxidized iron from magnetite formed hematite; 3) hematite precipitation began early in diagenesis while quartz overgrowths were filling open pores; and 4) hematite was later extracted from some quartzite except where protected by encapsulation in silica overgrowths.

Rare hematite platelets coating detrital quartz-grains and protected by quartz overgrowths may record authigenic geothite grain-coatings as discussed by Van Houten (1968) and Walker (1974) that were later altered to hematite by dehydration.

Figure 11: hematite at detrital grain-rim, phengite in
           secondary interstices, 125X; sample SS-M5
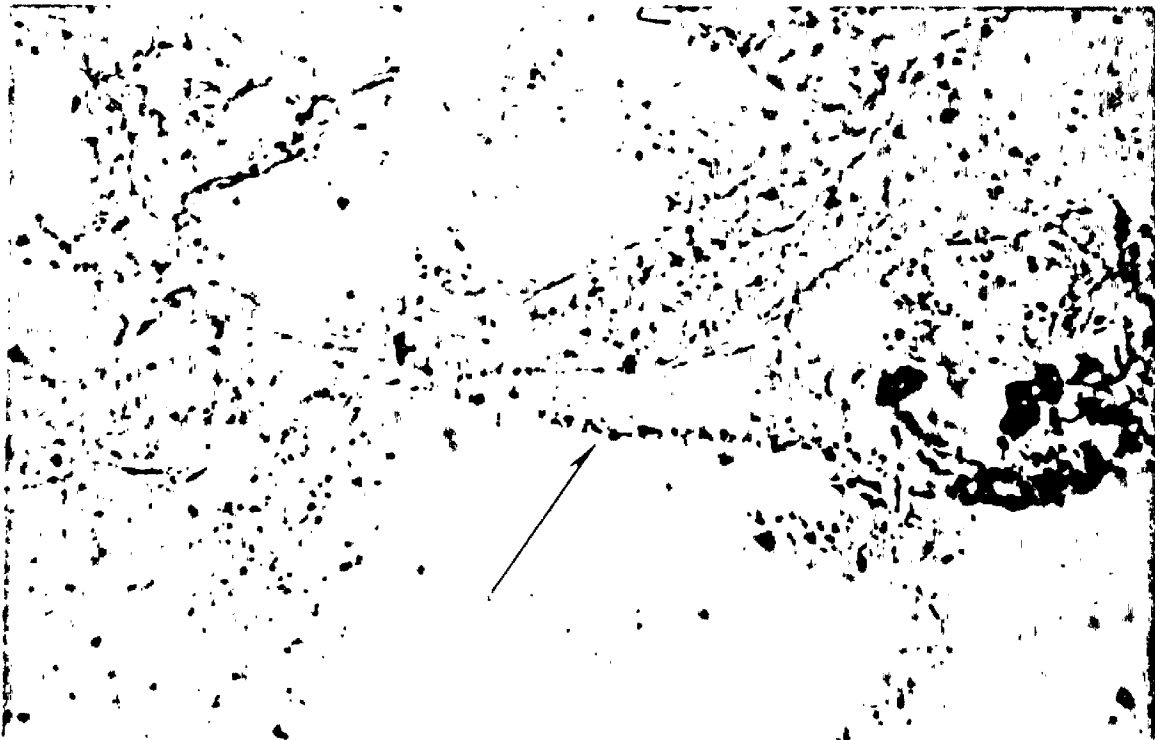
Figure 12: hematite in authigenic quartz, 125X: sample
          TR-1450
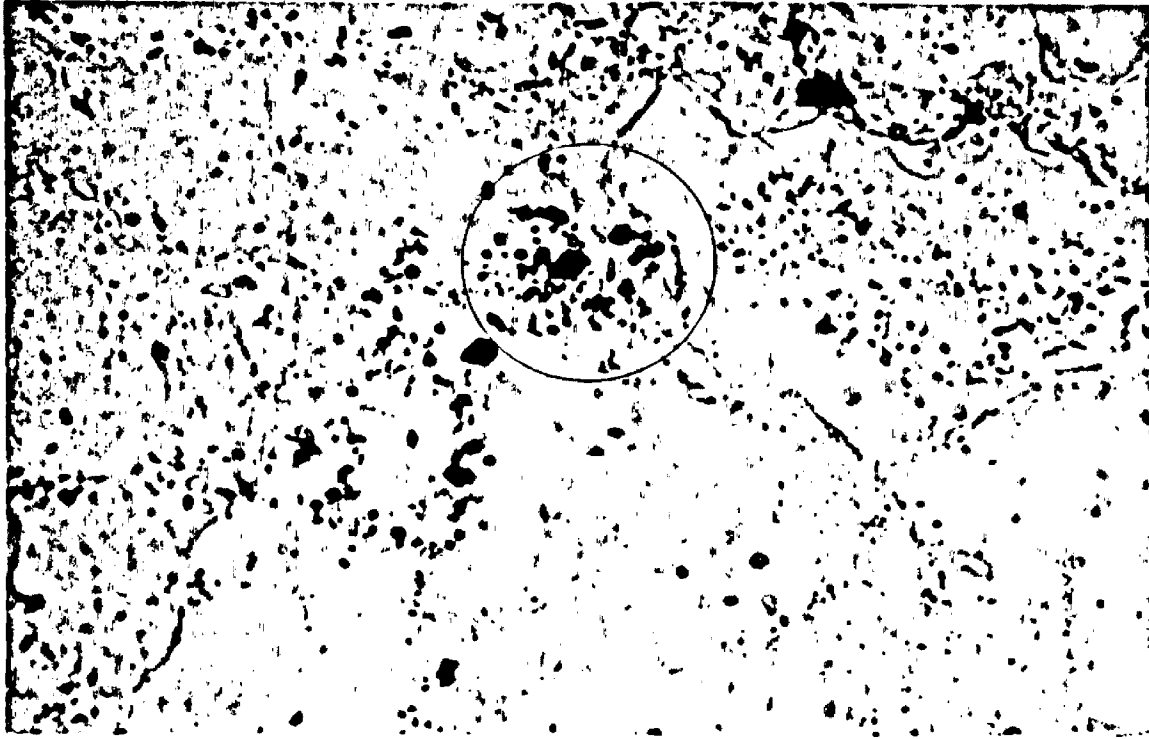
Figure 13: hematitic diffusion band, 125X; sample SP-1
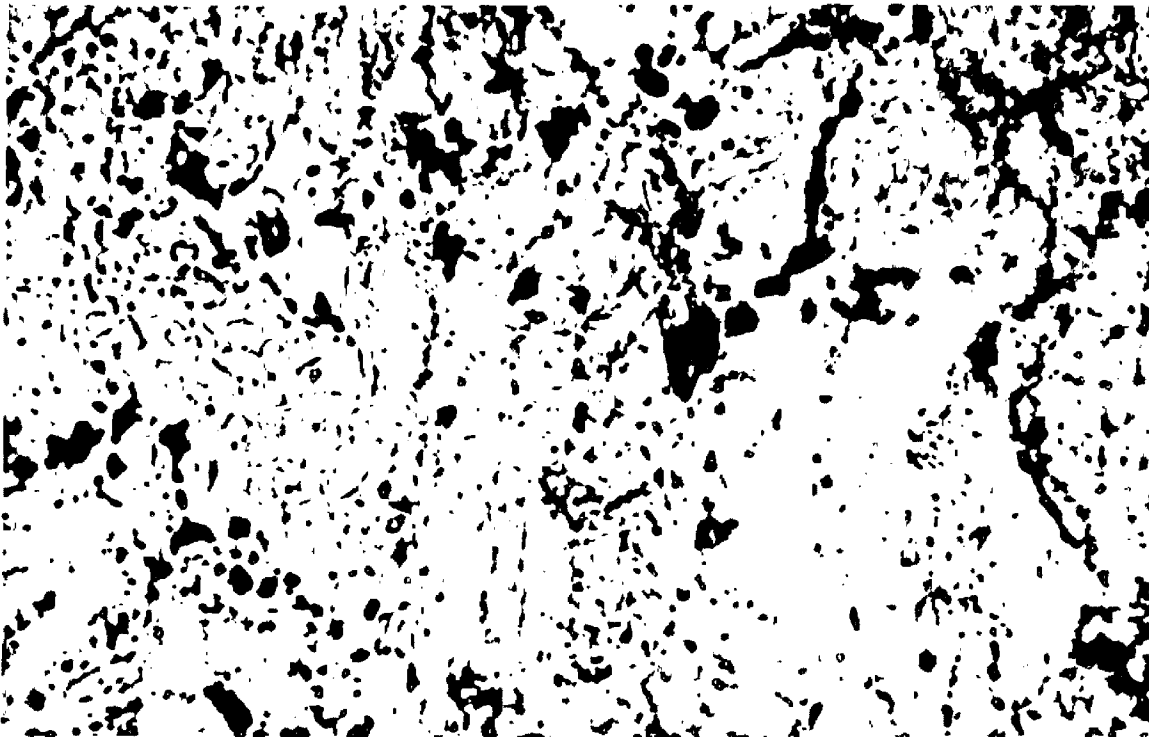
Ilmenite/rutile

Ilmenite is rare in Revett quartzite. However, rec-
tangular clots of rutile-after-ilmenite occur widely in
heavy mineral laminae. Further indicating this replacement of
ilmenite by rutile are rutile/magnetite intergrowths in detrital
grains that are identical to rare ilmenite/magnetite intergrowths
in detrital grains, the size-equivalence of rutile clots with
detrital heavy minerals, and the fact that ilmenite is a common
constituent of crystalline and sedimentary rocks. Rutile is
common in Revett quartzites and averages 1.4%, one standard
deviation = 0.04.

Minute amounts of rutile occur as very-high-relief,
yellowish, disseminated prisms in some quartzite. These are
not detrital placer grains and probably indicate a transient
TiO_2 phase, anatase, that preceded metamorphic recrystallization
to rutile.

Magnetite

Magnetite is common in Revett quartzite. It ranges up to
7% of rock composition and averages 1.6%, one standard
deviation = 2. Some detrital magnetite occurs in heavy mineral
laminae. Most, however, occurs as euhedral porphyroblasts
which range in diameter to about 0.8mm and are generally too
large to be size-sorted detrital grains (Figure 14). Magnetite
porphyroblasts commonly occur in clusters and include some
quartz grains.

Figure 14:   magnetite porphyroblasts, 12.5X;   sample ID-4
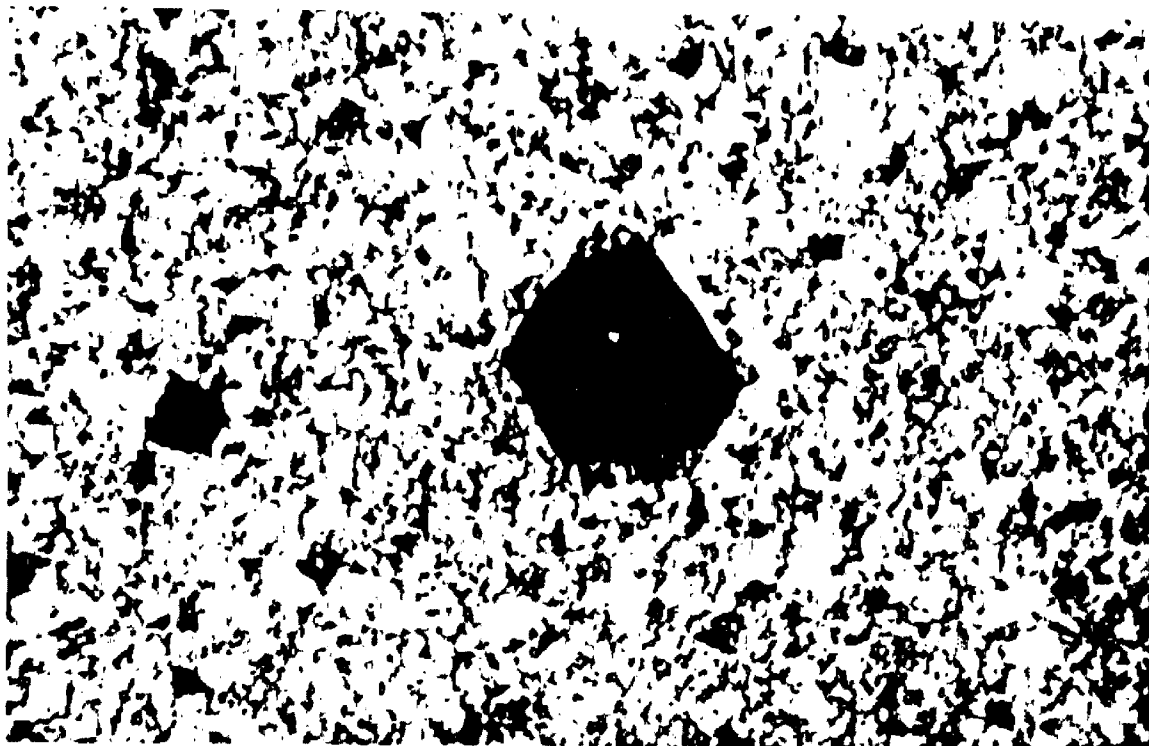
Figure 15:   magnetite and rutile contents verses grain-size
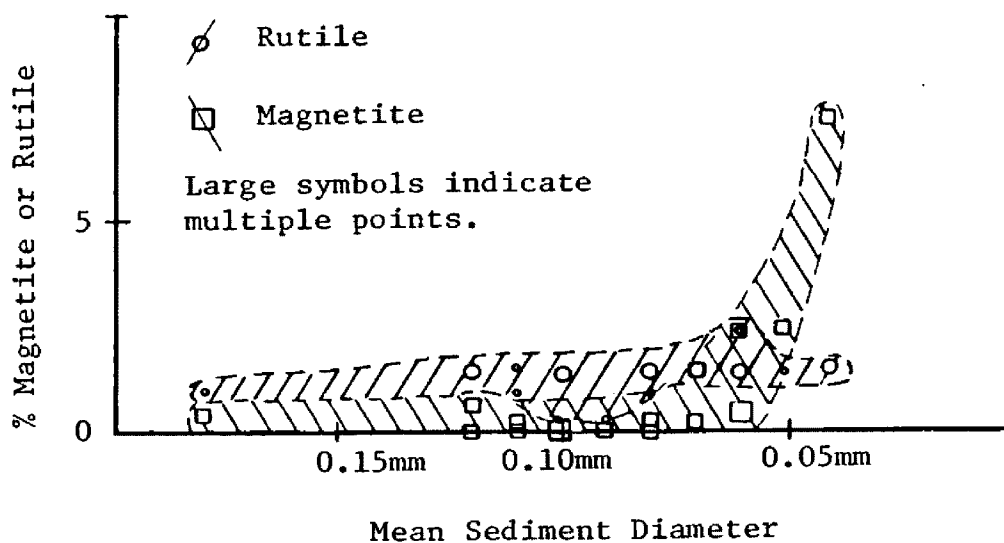
Figure 15 indicates that the ratio of magnetite to

rutile varies with grain size. Because rutile has probably

formed from detrital ilmenite, the ilmenite averaged about

1.4% and was uniformly distributed in deposits ranging in size

from sand to silt. Because, magnetite and ilmenite have similar

chemical and physical stabilities and paleo-current data indicate

Revett quartzites are transported from a common source-area

(Hrabar, 1973; Bowden, 1977), their distribution should be

similar. However, magnetite is anomalously deficient in fine-

grained sands and abundant in sediments finer than 0.07mm.

This indicates grain-size-dependent alteration and precipi-

tation occurred after burial. Van Houten (1968) and Walker

(1974) described diagenetic alteration of magnetite to ferric

iron hydrates and hematite (discussed further on p. 33). The

growth of magnetite at the expense of hematite during metamorphism

is discussed on p. 41. Magnetite may be anomalously low in

Revett quartzite as a whole. Blatt (1967) estimated the abun-

dance of magnetite in unweathered first-cycle sediments,

derived from plutonic rocks and deposited in large basins,

as twice that of ilmenite. The average ratio of magnetite

to ilmenite in Revett quartzite is about 1:1.

Summary

Magnetite was probably extracted from relatively permeable,

fine-grained sands by percolating ground water during an

early phase of diagenesis and converted to hematite or

goethite. In a subsequent phase of diagenesis, hematite

was extracted from many fine-grained quartzites, except where

protected by quartz overgrowths. Hematite remained in the less

permeable, very-fine-grained quartzites. Later, during regional

metamorphism, some hematite in very-fine-grained quartzites was

converted to porphyroblastic magnetite. Ilmenite along with

traces of anatase was widely oxidized to rutile during regional

metamorphism.

Carbonate

Carbonate grains are widespread minor components of Revett

quartzite and range up to about 2% in some beds. Most carbonate

occurs as euhedral rhombs a phi-size, or more, larger than ad-

jacent detrital grains, tentatively identified as ankerite on the

basis of their lack of twins, straight rhomb-faces, index of refrac-

tion and clear-rhombic habit (Deer et al, 1966). (X-ray diffraction an-

alysis is necessary to technically differentiate ankerite from siderite).

Clear, poikiloblastic calcite is uncommon. It occurs only in

samples with ankerite. The rims of both ankerite and calcite are

locally goethite-stained.

In Figure 17 the percentage of carbonate-bearing samples is

plotted relative to grain size. A carbonate-maximum is shown in the

very-fine-grained size-range. This may be because early, relatively

large fluid-flow caused increased dissolution in fine-grained sediments as proposed above (p. 25).

Figure 16: carbonate occurrence verses grain-size.
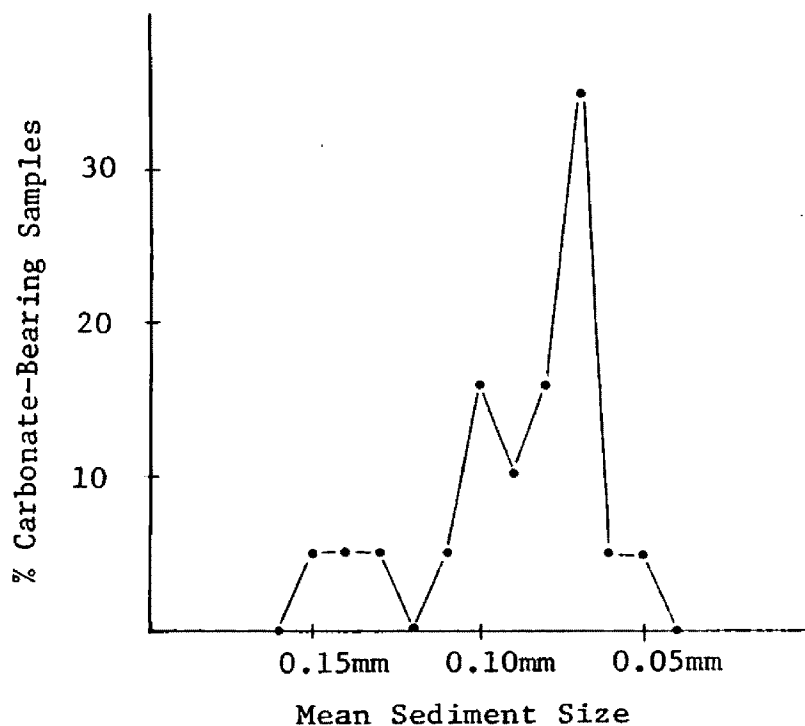
Ankerite rhombs are generally disseminated in clusters. Individual rhombs are superimposed on intersitial areas with their long axes sub-parallel to bedding foliation (S_0). This orientation indicates crystal growth prior-to or during burial metamorphism. Most ankerite has replaced phengite (Figure 17) although it also has replaced quartz and feldspar grains. Randomly oriented, irregular,

poikiloblastic calcite patches occur near and within ankerite grains (Figure 18). These apparently post-date dynamic metamorphism and may be derived from the ankerite.

Figure 17: carbonate rhombs, 50X; sample GC-10
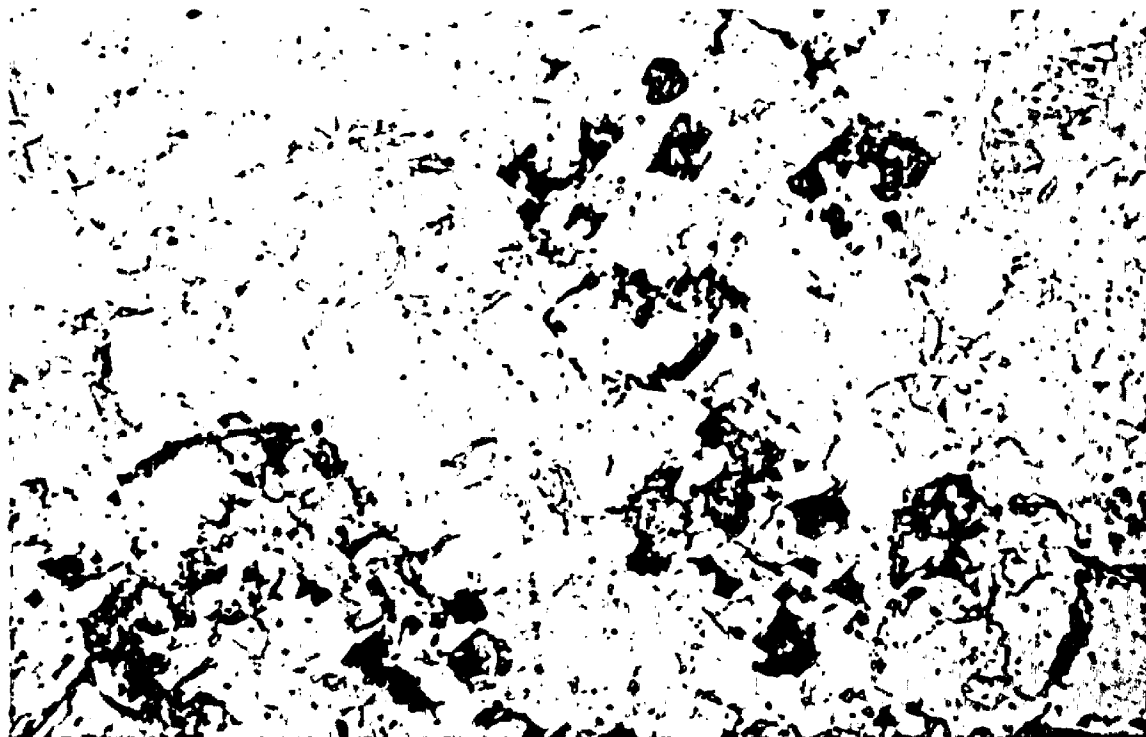
Figure 18:   carbonate rhombs with calcite, 50X; sample SLa
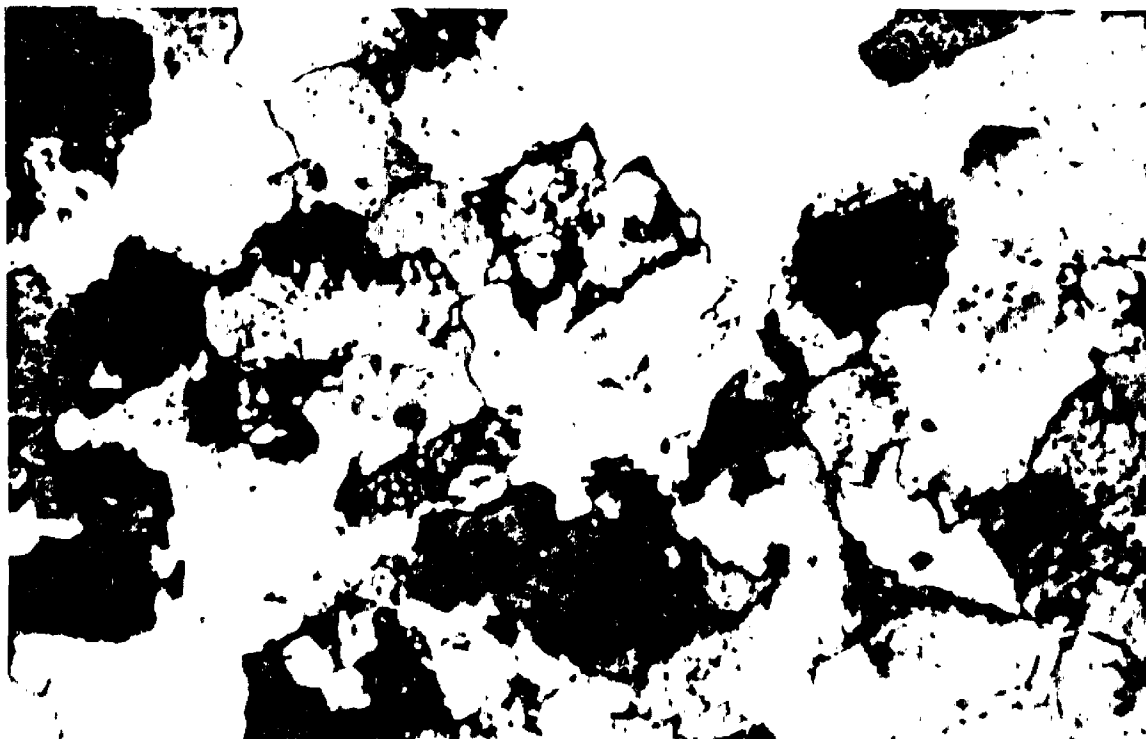
Berner (1980) argues that diagenetic iron-carbonate indicates low sulfate-ion concentrations in connate waters, such as found in modern brackish and fresh waters. This concurs with the alluvial fan interpretation of the Revett Formation.

Sulfides

Bornite, chalcocite, chalcopyrite, covellite, galena, pyrite, and sphalerite occur together locally in Revett quartzites. They

are stratigraphically restricted to relatively coarse horizons in quartzite and interbedded siltite. Lead-zinc-silver deposits of the Coeur d'Alene district occur in faults and fractures. Copper-silver, Revett-and Greenbed-type, deposits are widely regarded as syngenetic or diagenetic in origin (i.e., Clark, 1971; Harrison, 1972; Morton et al, 1973; Trammell, 1975; Lindsey and Lange, 1981).

Revett-type, copper-silver deposits are generally enveloped by pyrite and progressively copper-rich toward their centers (Clark, 1971). Polymineralic sulfide-blebs are common in these deposits and contain cores of pyrite, chalcopyrite, or bornite with one or more progressively copper-rich sulfide-mineral rims. Although such bleb-zoning might be the result of regional metamorphism (Lindsey and Lange, 1981), chalcopyrite-after-pyrite pseudomorphs occur indicating that pyrite was replaced by copper-sulfide-minerals. Lindsey and Lange found that copper sulfide replaced euhedral magnetite grains as well. All euhedral magnetite observed in this study is metamorphic. It might be that detrital magnetite with sulfide rims recrystallized during metamorphism, or that sulfide replaced magnetite during or after metamorphism. Pyrite and magnetite have similar or identical cross-sections so that some other copper-sulfide-deposits considered to be pyrite-alteration might actually be magnetite-alteration.

Only a small number of sulfide-bearing-samples from well known deposits were examined in this study. No new deposits or textural features were identified. Pyrite appears to be sparse in

in Revett quartzites, and thus, no regional-scale diagenetic pyrite-facies (or halo) is evident. The fact that pyrite occurs only with or near other sulfide-minerals suggests all sulfides were subject to the same local controls. Therefore, all sulfur and metallic ions probably migrated simultaneously into Revett quartzites.

Pyrite occurs widely in siltite-argillite interbeds of the Revett Formation. These units, may be chemically similar to those of Harrison's (1972) greenbed copper strata and they may have provided sulfide and metal ions in solution to intercalated quartzite beds at some stage of dewatering. The resultant sulfide-minerals could be preserved locally where adjacent low-Eh-minerals were sufficient to buffer sand-waters. Alternatively, such solutions might have migrated through fault systems to appropriately buffered regions. The restriction of sulfide-minerals to relatively coarse horizons in quartzites and siltites lends support to the idea of a migration of sulfide-mineral-components along permeable conduits.

Zircon, Tourmaline and Sphene

Trace amounts of zircon, tourmaline, and sphene are widespread in Revett quartzite beds. Their hydrologic equivalence with adjacent grains and consistant occurrence in heavy mineral laminae indicate a detrital origin. Their concentrations and textures do not appear to have been altered since burial. Because of their stability and and minute concentration, no attempt was made to catalogue their features.

DIAGENESIS

Introduction

The chemistry and mineralogy of sediments change with pro-
gressive burial. In the Belt, diagenesis was followed by burial- and
dynamothermal metamorphism. Because opinion varies as to the definition
and range of diagenesis (ie., Von Englehardt, 1967; Hayes, 1979; Hoff-
man and Hower, 1979: and Blatt, 1979), it is defined here after
Winkler (1979) as those chemical processes occurring after sedimen-
tation but before the formation of pressure/temperature grade-specific
metamorphic minerals. Diagenetic and metamorphic minerals occur
widely in Revett quartzites. However, their stability fields are not
sufficiently known to differentiate a specific burial metamor-
phic assemblage and textural evidence is indeterminant as well.

The following interpretations of mineral paragenesis are based
on observed textures in conjunction with the stability realms of
authigenic minerals relative to one another in actual sediments and
theoretical stability diagrams. Although Revett sands differ
from those in Dapples (1967), Figure 19, and Wolf and Chilingarian
(1976), Figure 20, relationships between the stability fields of
their contained authigenic minerals are comparable because they agree
with interpretations based on measured mineral-stability fields and
with textural indications of paragenesis.

Early Diagenesis

The oldest diagenetic phase apparent in Revett quartzites is indicated texturally by authigenic quartz, hematite, and sericite. Traces of hematite and sericite along with unidentiable "dust" outline the surfacial rims of some detrital quartz grains later overgrown by quartz cement. Some quartz overgrowths include disseminated hematite. Most commonly, hematite is concentrated in the space between quartz overgrowths. Thus, some hematite and sericite, or their hydrated precursors, predate quartz cementation. However, hematite continued to accumulate during and after quartz cementation. The development of quartz overgrowths before the formation of other, authigenic minerals is indicated texturally by the fact that other diagenetic minerals are limited to spaces between quartz overgrowths.

Figure 19 indicates that the stability realm of hematite is generally more oxidizing than that of iron-carbonate. Figure 20 indicates that the stability realm of muscovite (sericite) is generally oxidizing and of intermediate pH. Figure 21 indicates that silica is least soluble at pH values below 8. This theoretical field of quartz-stability agrees with data from actual rocks in Figures 22 and 23 which indicate that quartz formed at about pH 7.5 and also that authigenic feldspar and carbonate were stable in realms of successively higher pH. Thus the initial assemblage of quartz-hematite-sericite indicates relatively oxidizing and approximately neutral pH conditions

Figure 19: relative stability fields of iron minerals; from Krauskopf, 1979.
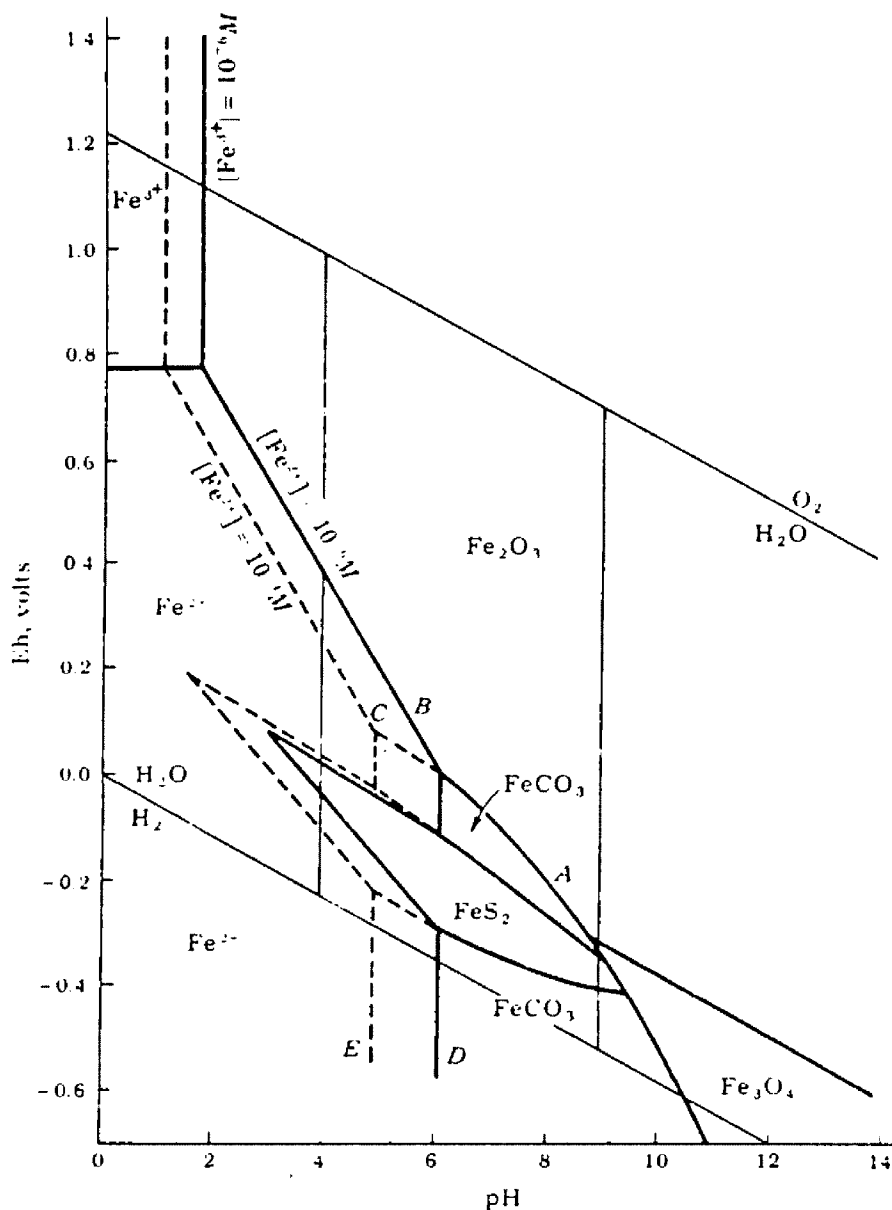
Figure 9-5 Eh-pH diagram showing stability fields of common iron minerals. Total a... ...y of dissolved carbonate, 1M, of dissolved sulfur, 10⁻⁶M. Solid field boundaries on left side of diagram are for total dissolved iron = 10⁻⁶M, dashed lines for 10⁻⁴M. (After Garrels and Christ 1965, page 224.)

Figure 20: relative stability realms of clay and mica; from Dapples, 1967.
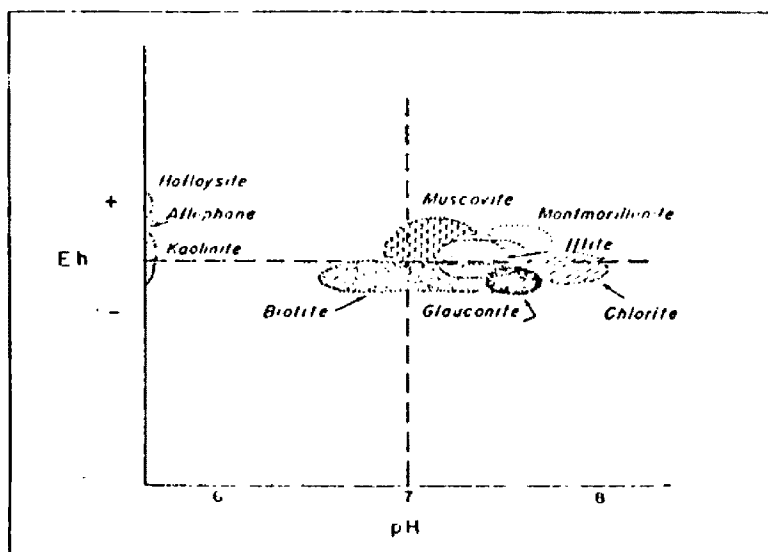
Fig. 7. Generalized stability realms of clay minerals and micas based upon paragenetic sequence of associated minerals and miscellaneous environmental indicators. The intent is to show the Eh and pH conditions under which a clay mineral or mica assemblage tends to form preferentially in sandstones.

Figure 21: silica solubility verses pH; from Blatt et al, 1980
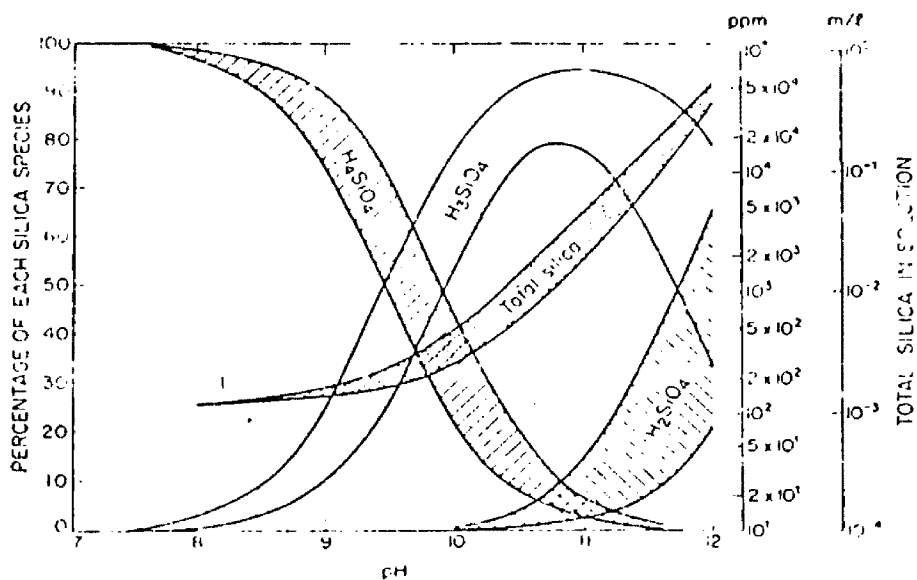
Fig. 9-5 Total silica and relative amounts of silica species in solution in water at 25°C as a function of pH.

Figure 22:   relative stability fields of quartz, calcite, and pyrite; from Wolf and Chilingarian, 1976
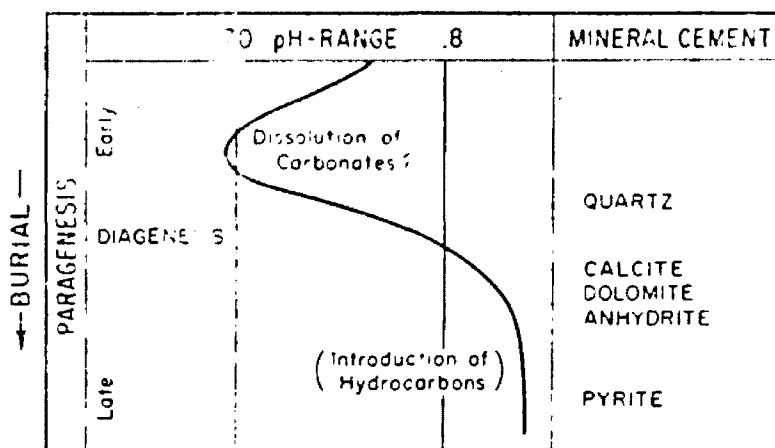
Fig. 6. D... showing pH relation during all st... of pararenesis in Halfway Formation as ...red in cores. Order of dissolution an... .cipitation of minerals ... o presented. (After S...rma, 1969 fig. 9; courtesy Min ralia ... deposita.)

Figure 23:   relative stability fields of quartz, feldspar, and calcite; from Wolf and Chilingarian, 1976
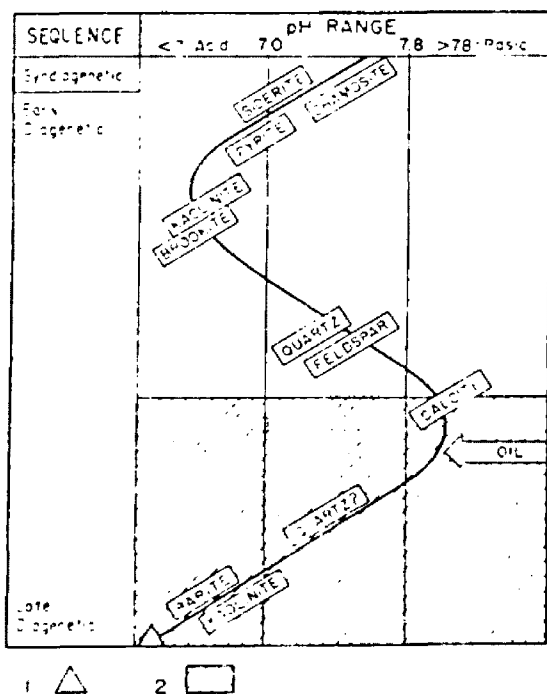
Fig. 3-185. Schematic paragenesis o... the cement and the neomorphic miner... depending on the maximum pH value in the Dogger-β Sandstone of the Plon-Ost Oil Field + = pH of the formation waters - 5.9—6.6; 2   ...nge of th... intrastrata solutions" which evi dence is available. (After Zimmerle 3...3, fig. 8, p. 1...; courtesy Erdöl Kohl...)

during deposition and subsequent quartz cementation. The absence

of detrital magnetite in some hematitic quartzite and the presence

of corroded magnetite grains in an unweathered quartzite bed indicate

that magnetite was probably oxidized to hematite or goethite during

early diagenesis as described by Walker (1974). Quartz overgrowths

reflect high fluid-transfer rates (Blatt, 1979), thus high permeability

during hematite formation.

The work of Milliken et al (1981) and Walker et al (1974)

suggests that the silica of quartz overgrowths might have been

released at depth by the transformation of detrital smectite to illite

or the destruction of orthoclase or unknown silicate minerals and

encapsulated sericite might be derived from detrital or early authigen-

ic clay minerals. Early authigenic clay might have formed from alumina

released by orthoclase destruction at depth.

Mid- and Late-stage Diagenesis

Authigenic minerals formed after the early diagnetic

assemblage and prior to greenschist-metamorphic biotite have

stability ranges that overlap diagenetic and metamorphic conditions.

These are regarded as mid- and late-stage diagenetic minerals because

burial-metamorphic minerals or textures are not recognized.

Phengitic mica plus lesser amounts of microcline, untwinned

albite, ankerite, and rare pre-metamorphic chlorite occur together

filling pore-space not earlier filled by quartz overgrowths. In addition, they project from interstitial areas into adjoining grains of quartz and feldspar. Phengitic micas commonly embay quartz overgrowths and are in-turn replaced by ankerite, but other textural details or paragenesis are lacking. However, Eh and pH requirements for the growth of phengite, feldspar, carbonate, and chlorite are significantly more reducing and/or alkaline than those of the prior diagenetic assemblage (recall Figure 19, 20, and 23). This indicates a trend in the evolution of diagenetic fluids toward lower Eh and higher pH. The stability realms of carbonate and chlorite suggest they formed later, after the development of mid-stage feldspar and phengite (Figures 19, 20, and 22).

The components that formed mid- and late-stage authigenic minerals might be derived from sources compiled by Milliken et al (1981) as follows:

COMPONENT	SOURCE	AUTHIGENIC MINERAL
Na	halite dissoulution, smectite/illite transformation	albite
CO_3	carbonate in shale	ankerite
Fe	hematite	ankerite, chlorite, phengite
Si	smectite/illite transformation	chlorite, feldspar
K	orth. dissolution, albitization	illite-phengite, microcline

Diagenetic Facies

Most diagenetic facies coincide with specific sedimentary facies (i.e., Fuchtbaur, 1966; Blatt, 1979; and Berner, 1981). The two grain-size modes of Revett quartzites correlate well with sedimentary facies as interpreted by Winston (1978). Accordingly, fine-grained quartzites with characteristic cross-bedded members correlate with braided stream facies and very-fine-grained quartzites with distinct horizontal laminations correlate with sheetflood facies in a distal alluvial fan environment.

Because both fine- and very-fine-grained quartzites contain diagnetic hematite and silica, their early diagenesis was probably similar. Later diagenesis formed two widespread, grain-size-dependent, diagenetic facies. Fine-grained quartzite was depleted of iron during mid-stage diagenesis. Very-fine-grained, more ferrugenous, quartzite contains most mid- and late-stage diagenetic and/or metamorphic iron-bearing minerals.

The relationship of grain-size to the authigenic mineralogy of Revett quartzite is reflected by color. "White" quartzite is generally fine-grained and normally contains only traces of hematite. Very-fine-grained Revett quartzite contains diagenetic and/or metamorphic ankerite, biotite, chlorite, hematite, magnetite, and phengite. "Green" quartzite contains phengite $\pm$ chlorite and green biotite. "Purple" quartzite contains disseminated hematite and phengite $\pm$ chlorite and green biotite. "Brown" quartzite contains brown biotite. "Grey" quartzite contains magnetite $\pm$ ilmenite.

METAMORPHISM

Burial metamorphism in Revett rocks has been demonstrated by Maxwell and Hower (1967) and Norwick (1972) who point out that irregularly shaped laths of muscovite, sericite, and phengite were probably recrystallized and oriented sub-parallel to bedding (S_0) during this phase.

Quartz and sericite, which were widely deformed during dynamic metamorphism, were subsequently annealed. Brown, metamorphic biotite in S_1 cleavage at Squaw Peak is the highest indicator of metamorphic grade determined in this study. The randomly oriented and/or disseminated-euhedral habit of biotite, magnetite, and some rutile, relative to S_1 indicates they crystallized after a dynamic phase of regional metamorphism. Some strained quartz-grains and slightly deformed sericite-flakes indicate minor dynamic activity occurred after regional annealing. Retrograde chlorite, replacing magnetite, occurs in some quartzite.

Two lines of evidence indicate that oxygen fugacity, was maintained at a relatively high level in Revett quartzites during dynamo-thermal metamorphism. Mineral stability diagrams constructed by Condie (1967) and Lindsley (1976) indicate that oxygen fugacity in similar systems increased. For example, Figure 24 illustrates that greater oxygen fugacity is required for magnetite formation under the

conditions of greenschist metamorphism than for hematite formation

under the conditions of early diagenesis. Secondly, Rumble (1976)

argues that an increase in oxygen fugacity with metamorphic grade

may be the general case because many reactions cited as evidence of

reduction can be rewritten as dehydration reactions. He states

further (1976, p. R-16) that ..."so long as the quantity of

hematite is not exhausted by reduction, the chemical potential of

oxygen (u_{O_2}) is defined at a relatively high value by virtue of the

relation $u_{O_2} = 6u_{Fe_2O_3} - 4u_{Fe_3O_4}$. As reduction proceeds ....the

porportion of magnetite increases at the expense of hematite".

Hematite and metamorphic magnetite coexist in many Revett quartzites

and rutile (TiO_2) has replaced most ilmenite indicating that oxygen

fugacity was generally high in Revett quartzites during metamorphism.

Figure 24: stability relations of some oxides, sulfides, and
native iron; from Condie, 1967. Dashed lines at
$25^{\circ}C$ and solid lines at $400^{\circ}C$.
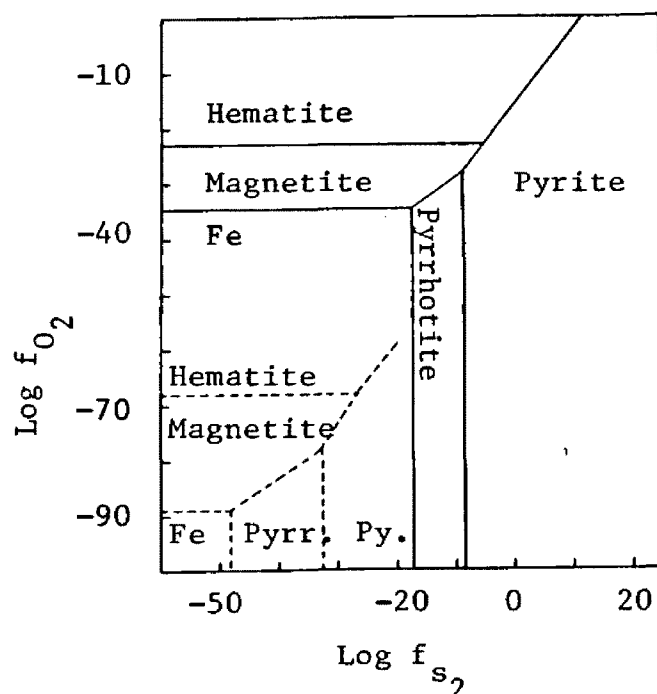
If the Revett were metamorphically zoned, the following indices might reflect progressive metamorphic grade: biotite color (Hyndman, 1972); carbonate/plagioclase ratio (Hyndman, 1972); K-feldspar/plagioclase ratio (Eslinger and Sellars, 1981); hematite/magnetite ratio (Rumble, 1976); and phengite/muscovite ratio (Ernst, 1965). However, a regional-scale zoned pattern was not found. Thus it seems unlikely that regional metamorphic gradient affected the distribution of sulfide-precursors as proposed by White (1978).

SUMMARY AND CONCLUSIONS

Revett quartzites contain the following detrital minerals: quartz, albite, orthoclase, microcline, magnetite, ilmenite, muscovite, and minor non-metallic heavy minerals including zircon, tourmaline, and sphene. The detrital composition of Revett quartzite was influenced by grain-size. Fine-grained quartzite (approximately 0.13mm diameter) is composed of about 90% quartz and 10% feldspar. Very-fine-grained quartzite (0.07mm diameter) is composed of about 80% quartz and 20% feldspar.

The textures and stability fields of authigenic minerals in Revett quartzite indicate that at least 3 diagenetic stages occurred: 1) a relatively early oxidizing and approximately chemically neutral stage characterized by the assemblage quartz-hematite-sericite; 2) an intermediate stage, reducing and alkaline relative to stage 1, characterized by the assemblage feldspar-phengite; and 3) a late stage, more reducing and alkaline than stage 2, characterized by the assemblage carbonate-chlorite.

Large tracts of diagenetic sulfides were not found in Revett quartzites and the early diagenetic chemistry of these rocks suggests sulfides were not widespread. Because pyrite does occur locally in siltites and argillites within quartzite sequences, it could have migrated from these to adjacent sands during diagenesis and might have been locally preserved where the mineralogy of siltites and argillites was of sufficiently low Eh to buffer sand-waters.

Magnetite, biotite, and rutile occur widely as regional metamorphic minerals. Metamorphic magnetite and diagenetic hematite occur together indicating that oxygen fugacity was relatively high during regional metamorphism. Metamorphic grade has not affected sulfide distribution.

In the terms of Winston's Ravalli Group model (1978), braided channel deposits became fine-grained, iron-poor, quartzites and sheetflood deposits became very-fine-grained, ferrugenous quartzites.

The generalized mineral paragenesis of Revett quartzite is illustrated in Figure 25.

Figure 25: generalized mineral paragenesis of Revett quartzite

Detrital	Diagenesis			Metamorphism		
Minerals	1	2	3	burial	dynamotherm.	retro.

quartz ————

        quartz ————————————————————————

albite ——————————————————————————————

        albite ———————————————————————————

orthoclase ——————→ — — —(partly destroyed)— — — — — —→

microcline ——————————————————————————————

        microcline ——————————————————————————

muscovite ——————————————————————————————

ilmenite ————————————————————————→(mostly destroyed) —→

                            rutile ——————————→

magnetite ——→ — — — — (mostly destroyed) — — — — — — — —→

        hematite — — — — —(partly destroyed) — — — —→

               phengite — — — —(partly destroyed) — —→

                    ankerite ——————————————→

                    chlorite ——→ — — — — — —→

                         biotite ———————→

                         magnetite ——→ — ——→

                             chlorite

sieved   (dehydrated)

clay (?) ————————————————————→sericite ———————————————————→

    alternatives:

                (dehydrated)

        clay (?) ————————————→sericite————————————

        sericite ——————————————————————————→

zircon   ⎫

tourmaline ⎬————————————————————————————————→

sphene   ⎭

Note: Dashed lines indicate alteration.

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APPENDIX I

SAMPLE-DATA-DIRECTORY

Sheet 1:   Sample Numbers (complete listing)
           Rock Color (many "white" rocks contain traces of red)
           Grain Size
           Sorting

Sheet 2:   Sample Numbers (representative samples only)
           % Quartz
           % Detrital Albite
           % Anorthite in Detrital Albites
           % K-spar (from stained sections)
           % Microcline

Sheet 3:   Sample Numbers (representative samples only)
           % Rhombic Carbonate
           % Calcite
           % White Mica
           % Detrital Mica
           % Sulfides

Sheet 4:   Sample Numbers (representative samples only)
           % Opaque Minerals (plain-light estimate)
           % Hematite
           % Ilmenite (ore microscope estimate)
           % Leucoxene
           % Magnetite

Sheet 5:   Sample Numbers (representative samples only)
           Authigenic Quartz
           Biotite
           Phengite
           Notes

SAMPLE-DATA-SHEET 1

Sample	Location	Color	Grain Size	Sort.
GC-1a	Graves Ck. road			
GC-1b	(grab samples)			
GC-2				
GC-3				
GC-4				
GC-5				
GC-6		white	.11mm	m-w
GC-7				
GC-8				
GC-9		grey	.09mm	w
GC-10		grey	.07mm	w
GC-11		green	.07mm	m-w
GC-15		grey	.09mm	w
GC-17		green	.10mm	w
ID-1	I-90 (grab sample)	purple	.07mm	
ID-2	Square Lake	purple	.04mm	
ID-3	Square Lake			
ID-4	I-90	purple	.05mm	
LF	Lucky Friday Mine	white	.15mm	w
MC-1	Maple Cliff (grab	white		
MC-2a	samples)	grey		
MC-2b		purple		
MC-2c				
MC-3		purple		
MC-4		grey		
MC-5				
MC-6				
MC-6a				
MC-7				
Mc-730'	(Numbers indicate	brown		
MC-620'	footage of established	green	.06mm	w-vw
MC-555'	section.)	green		
MC-530'		green	.09mm	
MC-515'		green	.07mm	m-w
MC-418'		white	.11mm	w
MC-385'		white	.11mm	m-w
MC-15	(float)	grey	.12mm	w

SAMPLE-DATA-SHEET 1 (CONTINUED)

Sample	Location	Color	Grain Size	Sort.
MP-1	Minton Pass (grab	white	.07mm	m-w
MP-2	samples)	grey	.08mm	w
Quill a	Bunker Hill Mine (grab)		.14mm	w
Quill b		white	.08mm	m-w
SLa	Spar Lake (grab samples)	white	.10mm	m-w
SLb		white	.07mm	w
SLc			.06mm	w
SLd				
SP1	Squaw Peak (grab Samples)			
SP2				
SP3				
SPA				
SPA1		green	.18mm	m
SPA2				
SPA3				
SPA4				
SPA6			.10mm	w
SPA8				
SPA10				
SPA11				
SS-1	Snowstorm Mine area	white-red		
SS-2	(grab samples)	white	.12mm	w
SS-3		red		
SS-5				
SS-6				
SS-7		white	.15mm	w
SS-drn 2		white	.14mm	w
SS-u1		white		
SS-u2		white	.12mm	w
SS-u3		white		
SS-u4				
SS-u5			.06mm	w
SS-M1	Snowstorm Mine (grabs)			
SS-M2			.11mm	w

SAMPLE-DATA-SHEET 1 (CONTINUED)

Sample	Location	Color	Grain Size	Sort.
SS-M3		grey	.12mm	w
SS-M4				
SS-M5			.18mm	m-w
SS-M6		white	.11mm	w
SS-M7				
TC-1740'	Trout Creek Section	brown		
TC-1800'		white	.13mm	
TC-1820'		grey		
TC-1840'		white		
TC-1860'		white	.08mm	m-w
TC-1920'				
TC-1940'		white	.08mm	m-w
TC-1950'		grey		
TC-1960'		brown	.07mm	w
TC-1975'		green		
TC-2100'		grey		
TC-2142'		grey	.07mm	w
TC-2220'		green	.05mm	w
TC-2270'			.07mm	w
TC-2370'		green	.06mm	w
TR- 995'	Thompson River Section	grey	.06mm	m-w
TR-1120'				
TR-1140'		grey	.07mm	w
TR-1190'				
TR-1195'		grey		
TR-1250'		grey	.07mm	w
TR-1390'		white	.08mm	m-w
TR-1410'		grey		
TR-1430'				
TR-1450'		grey	.09mm	m-w
TR-1460'		grey		
TR-1500'		white	.08mm	m-w
TR-1515'		grey	.07mm	m-w

SAMPLE–DATA–SHEET 2

Sample	% Quartz	Detrital Albite %	(An)	% K-spar	% Microcline
GC-6	75	5	(4)	1	trace
GC-9		7.5		1	trace
GC-10	80	9.5	(6)	0	0
GC-11	85	5			0
GC-15	75		(3)	0	
GC-17	75	5			3
ID-1	75	12.5			0
ID-2					0
ID-4	70				
LF	90	trace		trace	
MC-620'	80	0		4	0
MC-530'	85	0		2.5	0
MC-515'	80	0			0
MC-418'		0			0
MC-385'	90	trace		0	0
MC- 15				6	
MP-1	85	7.5	(9)	12.5	2
MP-2		12.5	(6)	7.5	
Quill a	70	2 ?			2
Quill b	40	7.5		4	3
SLa	80	7.5	(7)	12.5	3
SLb	85		(4)	7.5	2
SLc		7.5			2
SPA1	90	3			0
SPA6	90	2			0

SAMPLE–DATA–SHEET 2 (CONTINUED)

Sample	% Quartz	Detrital Albite %	(An)	% K-spar	% Microcline
SS-2	90				?
SS-7	92.5	trace		2	0
SS-drn 2				5	5
SS-u2	85			4	
SS-u5					trace
SS-M2	92.5	3		5	1.5
SS-M3	90	1.5		7.5	trace
SS-M5	90	2			4?
SS-M6				7.5	
TC-1740'	80		(8)		
TC-1800'			(5)		,4.5?
TC-1940'		7.5		12.5	2
TC-1960'	80		(4)		
TC-2142	80	9.5		12.5	2
TC-2270'	80		(5)		
TC-2370'	80	1.5		0	0
TR- 995'	90	10?	(5)		
TR-1140'				7.5	
TR-1250'		7.5		12.5	3
TR-1390'	80	7.5	(7)		3.5
TR-1450'		9.5		12.5	1.4
TR-1500'	80	7.5	(6)	7.5	7.5?
TR-1515'		5		12.5	2

SAMPLE–DATA–SHEET 3

Sample	Rhombic Carbonate	Calcite	White Mica	Detrital Muscovite	Sulfides
GC- 6	present	present			0
GC-10	present			1.5%	0
GC-11	present	0	4%	2.5%	0
GC-15	3.5%			1.0%	0
GC-17	1.5%	0	17.5%	trace	0
ID-1	1.5%			3.0%	0
ID-2			17.5%		0
ID-3				1.5%	0
ID-4		1.5%	11.5%		0
LF		1.5%	4.0% ?		7.5%
MC-620'	0	0	17.5%	1.0%	0
MC-505'	present		5.0%+		0
MC-385'			12.5%	1.5%	0
MP-1		0	1.5%	1.0%	0
MP-2	1.5%			1.0%	present
Quill a		trace	7.5%		12.5%
Quill b			25.0%		4.0%
SLa	present	present	1.5%		0
SLb	0	2.0%	1.5%	1.0%	trace
SLC		2.5%	4.0%	1.5%	2.0%
SPA1	0	0	4.0%	1.5%	0
SPA6			present		0

SAMPLE-DATA-SHEET 3 (CONTINUED)

Sample	Rhombic Carbonate	Calcite	White Mica	Detrital Muscovite	Sulfides
SS-7					0
SS-u5			4.5%	1.5%	0
SS-M2			present		3
SS-M3	present				present
SS-M5		0	1.5%	1.0%	12.5%
SS-M6					present
TC-1740'				3.5%	0
TC-1800'	1.5%		1.0%		0
TC-1860'					0
TC-1940'	present		present		0
TC-1960'	3.5% ?			1.5%	0
TC-2100'	1.0%				0
TC-2142'	1.0%	0	2.5%	2.5%	0
TC-2220'	present				0
TC-2270'	1.0%				0
TC-2370'			17.5%		0
TR- 995'				1.5%	0
Tr-1390'	0	0	1.5%	1.0%	0
TR-1410'				2.5%	0
TR-1450'				1.0%	0
Tr-1500'	0	0	1.0%	1.0%	0
TR-1515'	present	0	1.0%	1.0%	0

SAMPLE-DATA-SHEET 4

Sample	Opaque Min. %	% Hematite	% Ilmenite	% Leucox.	% Magnetite
GC-6	1.5%	trace	0	1.5%	0
GC-11	3.0%		0	1.5%	1.5%
GC-15	1.5%	present			
GC-16		1.5%			
GC-17		trace		1.5%	0
ID-1		1.5%			
ID-2	3.5%	1.0% +		1.5%	
ID-3		1.5%		1.5%	7.5%
ID-4		1.0%		1.5%	2.5%
LF	3.0%				
MC-730'		0			
MC-620'	1.5%	trace		2.5%	trace
MC-530'		trace		trace	0
MC-505'	2.5%				
MC-385'	1.0%	trace		1.0%	trace
MP-1	1.5%			1.5%	
MP-2	4.0%				
Quill a				0	0
SLa	1.5%	trace			0
SLb	1.5%	trace			trace
SLc		trace		2.5%	
SPA1			trace	1.0%	trace

SAMPLE-DATA-SHHEET 4 (CONTINUED)

Sample	Opaque Min. %	% Hematite	% Ilmenite	% Leucox.	% Magnetite
SS-2				1.5%	0
SS-7	2.5%				
SS-drn 2	2.5%				
SS-u2	1.5%			1.5%	trace
SS-M1		trace			
SS-M2	3.5%	trace		1.5%	
SS-M3	1.5%				
SS-M5				trace	
SS-M6	8.5%				
TC-1740'	3.0%				
TC-1800'	1.0%				
TC-1860'	1.5%				
TC-1940'	1.5%			1.5%	0
TC-2142'	3.0%				
TC-2270'	1.5%			1.5%	trace
TC-2370'	3.0%			1.5%	2.5%
TR- 995'	2.0%			1.5%	trace
TR-1140'	1.5%				
TR-1250'	1.0%				
TR-1390'	1.5%				
TR-1410'		trace			
TR-1450'	1.5%	trace			
TR-1500'	1.5%			1.5%	trace
TR-1515'	2.5%			trace	0

SAMPLE-DATA-SHEET 5

Sample	Authigenic Quartz	Biotite	Phengite	Notes
GC-6	trace			
GC-8		x		
GC-11	trace	x		
GC-15	0	x		
GC-17	present			
ID-1	present		x	
ID-2			x	St. Regis Fm.
ID-3			x	St. Regis Fm.
ID-4	common		x	
LF	common			
MC-730'		trace	x	
MC-620'	present		x	2ndary porosity
MC-555'	present	x	x	2ndary porosity
MC-530'			x	
MC-515'		x	x	
MC-418'	present			
MC-385'	present		x	
MP-2	trace			
Quill a		x		
Quill b	trace			
SLa	trace			feld. o-growth
SLb	trace			feld. o-growth
SLc	trace		x	2ndary porosity

SAMPLE-DATA-SHEET 5 (CONTINUED)

Sample	Authigenic Quartz	Biotite	Phengite	Notes
SPA1	present		x	
SPA6		x	.	
SS-2	abun.			
SS-5	abun.			pre-MM chlorite
SS-7	abun.			
SS-u5	common	x		cell.-web text.
SS-M1	abun.			
SS-M2	abun.			
SS-M3	abun.			
TC-1740'		x		
TC-1940'	present	x		feld. o-growth
TC-1960'		x		
TC-1975'		x		
TC-2142'	present			
TC-2220'	present			
TR-1390'				microcl. o-growth
TR-1410'	present			
TR-1450'	present			
TR-1500'				microcl. o-growth
TR-1515'	trace			

APPENDIX II

SAMPLE LOCATION DIRECTORY

LOCATION MAP

GRAVES CREEK COLLECTION

T23N
R29W

1" = 2000'
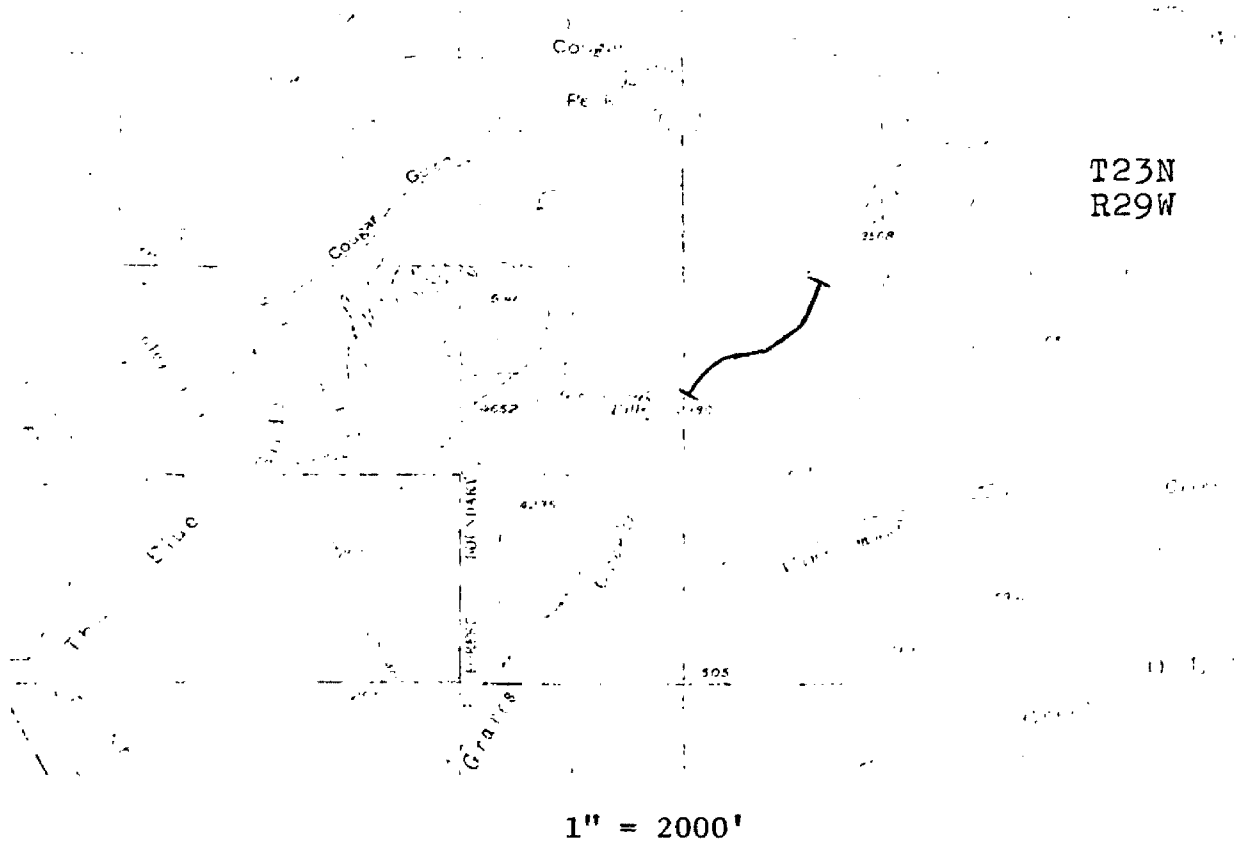
From: THOMPSON FALLS QUADRANGLE
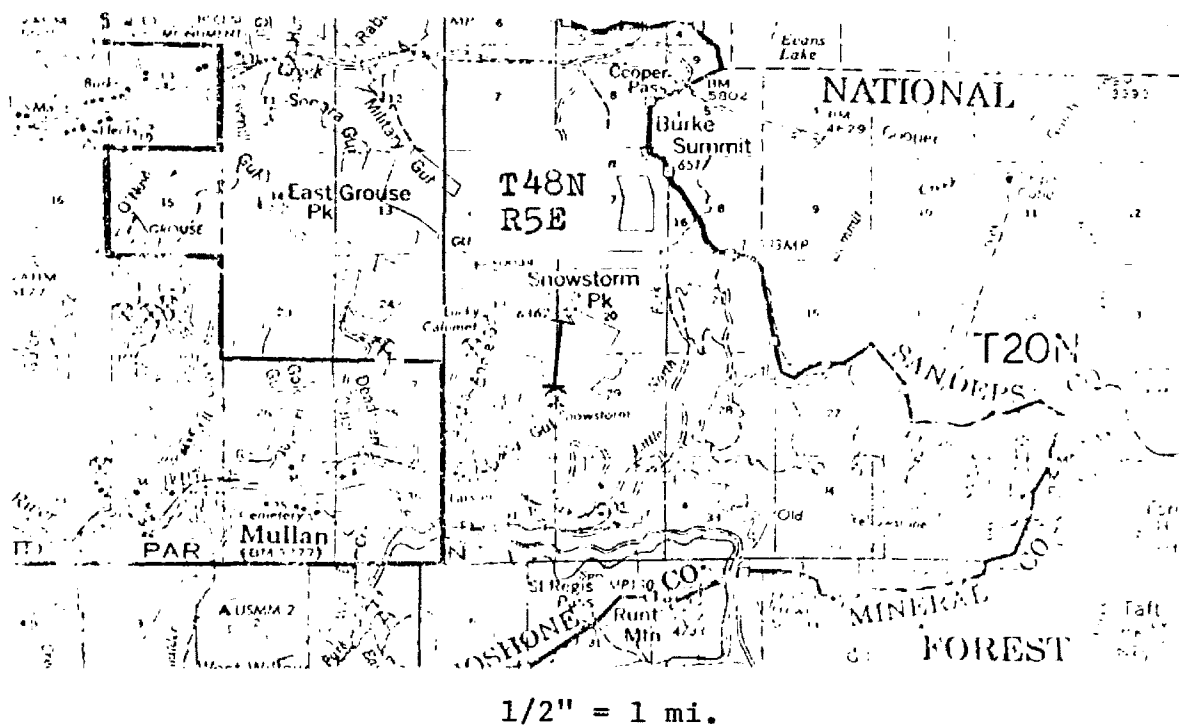   Montana — Sanders Co.
       15' series
       1957

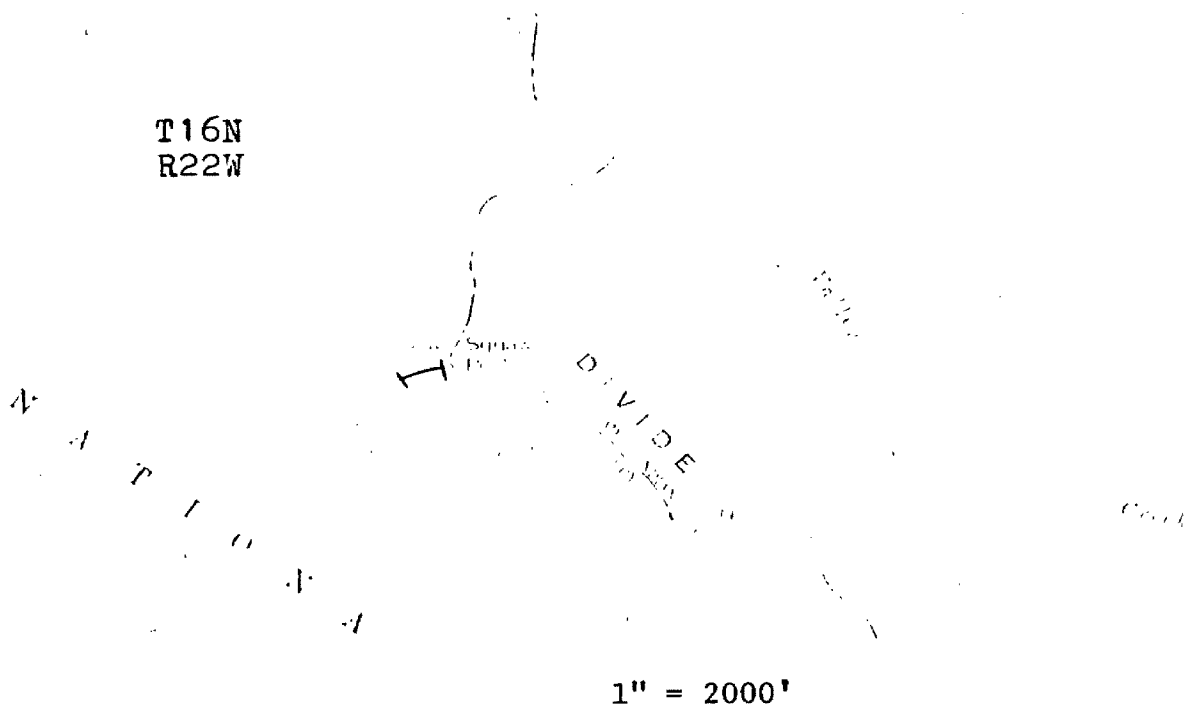LOCATION MAP

MAPLE CLIFF COLLECTION
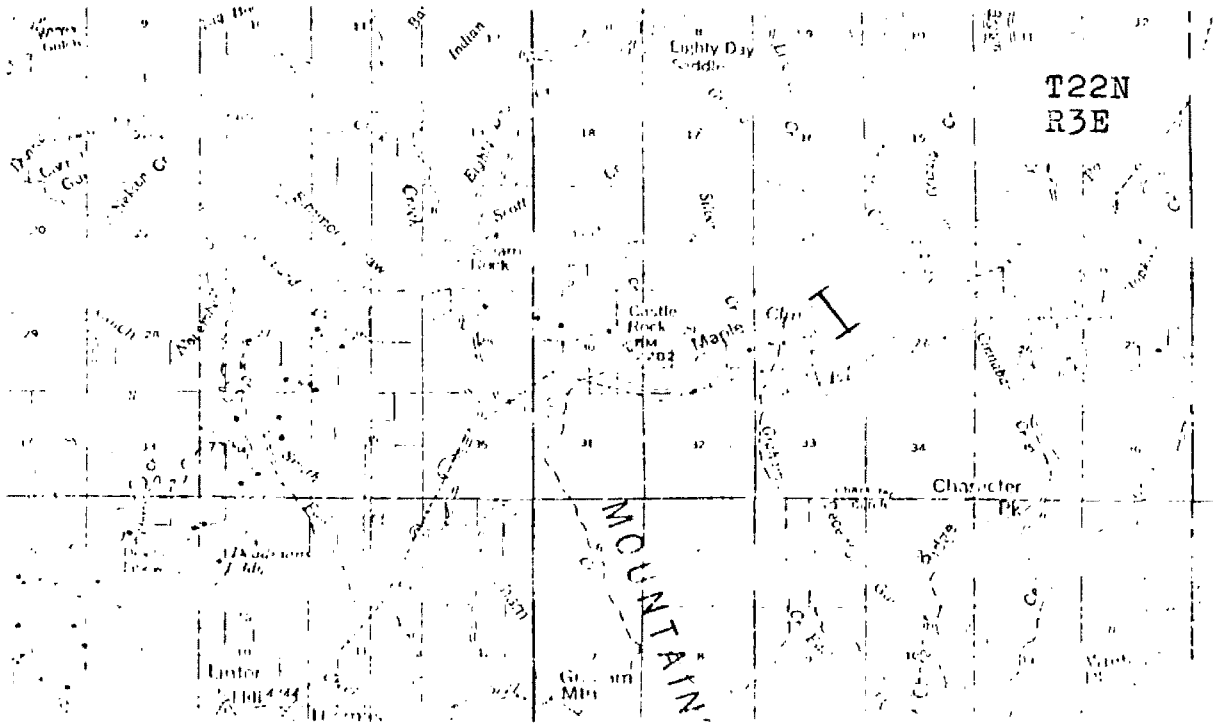
T22N
R3E

1/2" = 1 mi.

From: Forest Visitors' Map
Coeur d'Alene National Forest
Idaho and Montana (Idaho Portion)
1972

LOCATION MAP

SNOWSTORM MOUNTAIN COLLECTION

1/2" = 1 mi.

From: Forest Visitors' Map
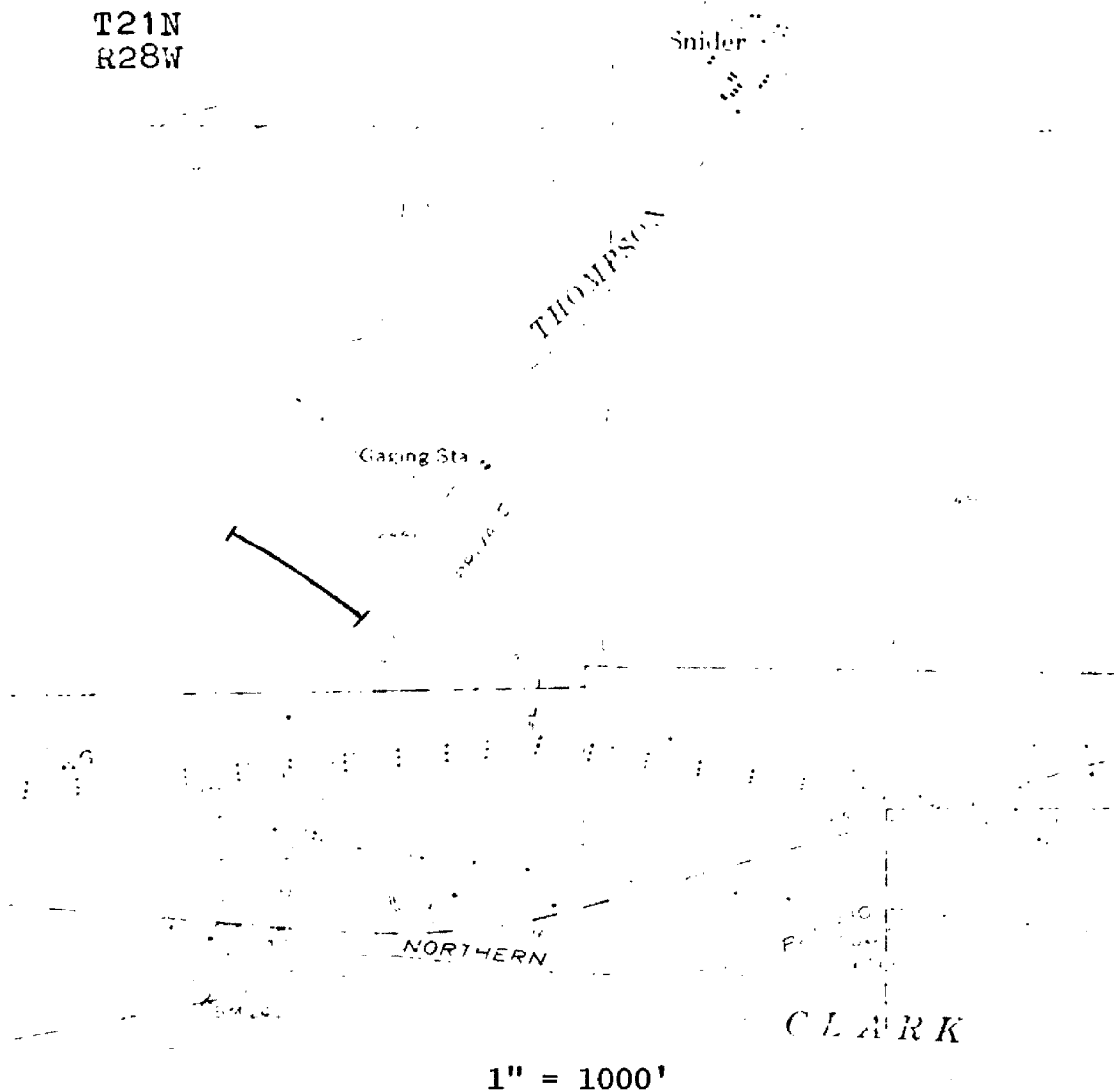   Coeur d'Alene National Forest
       Idaho and Montana (Idaho Portion)
       1972

LOCATION MAP

SQUAW PEAK COLLECTION

T16N
R22W

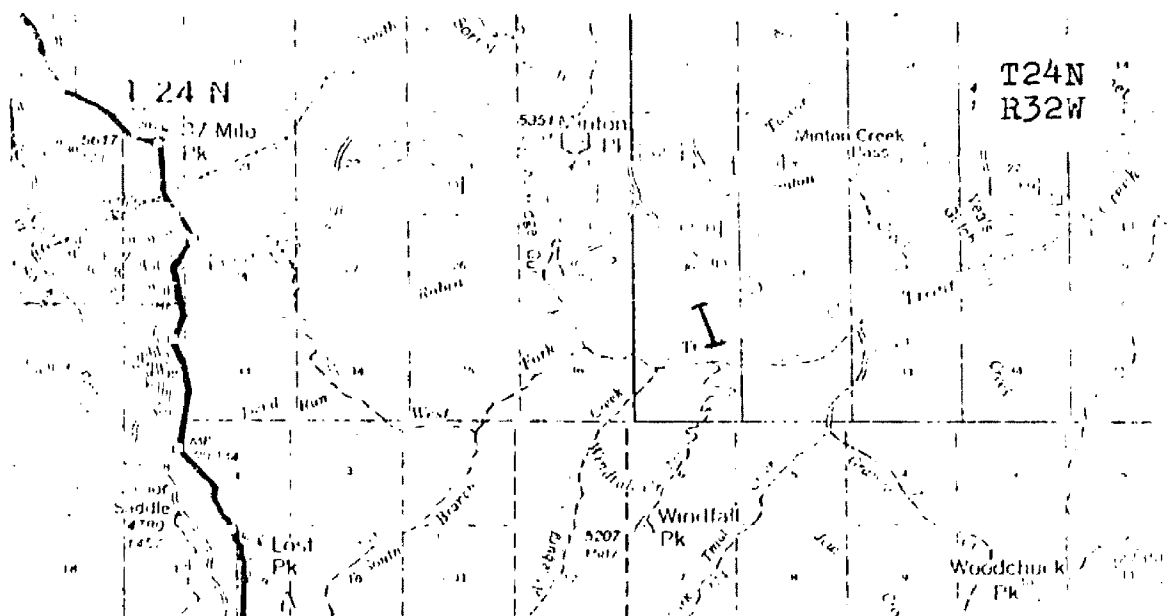1" = 2000'

From: ALBERTON QUADRANGLE
        Montana
        15' series

LOCATION MAP

THOMPSON RIVER COLLECTION

T21N
R28W

Snider

THOMPSON

Gaging Sta

NORTHERN

CLARK

1" = 1000'

From: EDDY MOUNTAIN MONTANA
       7.5' Quadrangle
       1964

LOCATION MAP

TROUT CREEK COLLECTION,

MINTON PASS PROSPECT SAMPLES

1/2" = 1 mi.

From: Forest Visitors' Map
        Kootenai National Forest and East Half Kaniksu National Forest
        Idaho and Montana (Montana Portion)
        1978