GENESIS OF THE ORES OF THE
JARDINE-CREVASSE MOUNTAIN AREA,
PARK COUNTY, MONTANA

by

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INTRODUCTION

The Gold-Arsenic-Tungsten ores and their host and source rocks in the Jardine-Crevasse Mountain area, Southwestern Montana have been investigated by Sulfur isotopic variations, petrographic and mineragraphic studies, and Potassium-Argon and Rubidium-Strontium radioactive age determinations.

The area embraces approximately twenty square miles in the extreme southwest part of the Beartooth-Absaroka uplift along the north boundary of Yellowstone National Park in Park County, Montana. It is within the Gallatin National Forest and on the southern edge of the mapped area of the Livingston folio (Iddings and Weed, 1894). The area is mountainous and elevations range from 5,300 feet to 9,359 feet.

The area can be reached from Gardiner, Montana with ease during the summer months, but heavy snowfall often leaves the area inaccessible during the winter months. The outline of the area and some regional geologic features are shown in Figure 1.

Early investigations indicated that the ores of the area were not typical of other deposits in Montana. Of the several gold occurrences in the Beartooth-Absaroka uplift the Jardine-Crevasse Mountain deposits are the only ones not related to any Tertiary event(s). They also represent the first commercial source of scheelite in the Rocky Mountains (Seager, 1944).

PREVIOUS INVESTIGATIONS

The first geological investigations in the area were reported in the text accompanying the Livingston folio by Iddings and Weed (1894). The relationship of the area to Yellowstone National Park has been studied by Iddings (1896)

and Hague (1899). These reports deal primarily with descriptive geology, petrography, and paleontology of the Park region.

Since 1900 there has been much new information on the Beartooth-Absaroka region but the Jardine-Crevasse Mountain ore deposits have received little mention. Bevan (1923) and Lovering (1930) have made important stratigraphic and general contributions, and Wilson (1934) has reported on the structure of the region. Winchell (1910) published the first detailed account of the ores, and Robie (1925) reported on the mining procedures.

Seager (1944) published the first comprehensive study of both the geology of the district and the origin of the Gold-Arsenic-Tungsten ores. Much of the descriptive material to follow is modified from his work.

There have been no previous Sulfur isotopic studies nor radioactive age determinations on the rocks of the Jardine-Crevasse Mountain area.

GENERAL GEOLOGY
Local Rock Types

General Statement

Most of the Jardine-Crevasse Mountain area is underlain by a complex series of Precambrian schists and quartzite which contain all of the known mineral lodes of the district (see Figure 2). The rest of the area is underlain by extrusive and intrusive igneous rocks and alluvial and glacial deposits. A detailed description of the various samples studied follows later in the APPENDIX.

Precambrian Metamorphic Rocks

Two predominant types of schist occur in the area: (1) Biotite quartzite and quartz-biotite schist and (2) quartz-cummingtonite schist and quartz-hornblende schist.
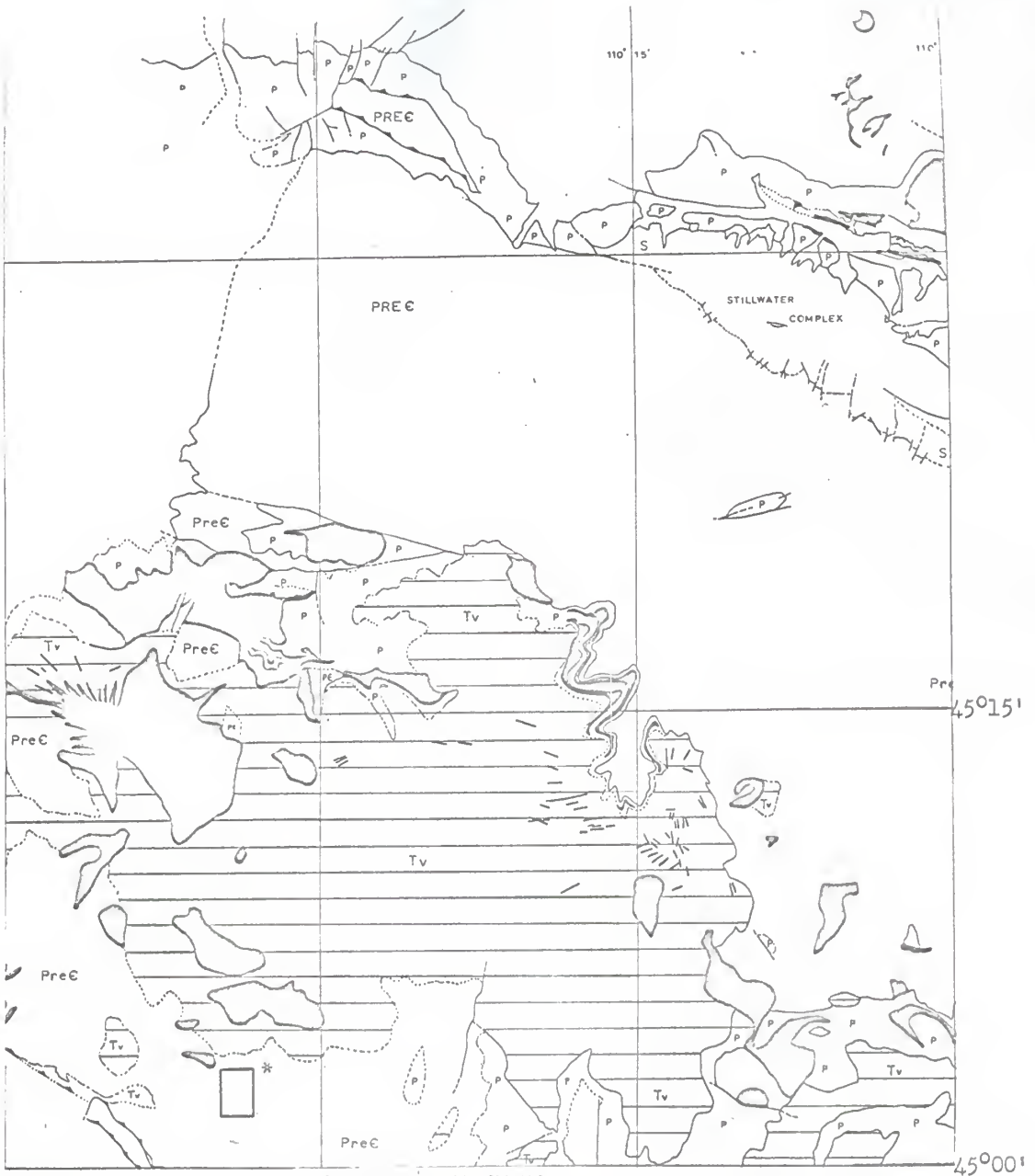
FIGURE 1   BEARTOOTH MOUNTAINS
MONTANA &
WYOMING

*Jardine- Crevasse Mountain
district

FAULTS
FRACTURES   THRUST

PLATEAU
MARGINS   TERTIARY VOLCANIC
                 ROCKS

TERTIARY
INTRUSIONS

P PALEOZOIC
   SEDIMENTARY ROCKS

SCALE

BY
EDGAR SPENCER   0   2   4   10 Miles

The quartz-biotite schist is the most abundant of these and
contains over eighty percent quartz in most cases. Biotite
varies in abundance from ten percent in the quartzite to
twenty five percent in the schist. Orthoclase and plagioclase
(An_{45}) may comprise up to five percent of the rock, and some
of the biotite is replaced by chlorite. Muscovite is locally
important. Because of their structural incompetancy the
schists have been complexly crumpled (see Plate I, nos.
E and F).

The amphibole schists comprise a minor part of the
metamorphic series but are of particular interest as they
have strongly influenced the deposition of Gold and sul-
fides. These schists occur as distinct layers interbedded
with quartz-biotite schist and range in thickness from less
than one inch to fifty feet. Quartz comprises twenty five
to fifty percent of the rock and cummingtonite (and Horn-
blende) up to fifty percent. Hornblende may be locally
more abundant than cummingtonite and often replaces it
(see Plate I, no. D). Biotite and magnetite may be
locally important.

The well preserved bedding and blanket character of
the schists and quartzite as well as their quartz-rich
mineralogy indicate that they are of a sedimentary origin.

Precambrian rocks have been placed into three series
in Montana: (in order of decreasing age) the Pony series,
the Cherry Creek series, and the Belt series (see Tamsley,
Schafer and Hart, 1933). The Jardine-Crevasse Mountain
rocks closely resemble other rocks of the Cherry Creek
series according to Seager (1944).

Precambrian Igneous Rocks

The Precambrian igneous rocks are all intrusive and
consist of the following types: gabbro and diabase,
biotite-muscovite granite, pegmatite, and aplite.

GEOLOGIC MAP OF THE

JARDINE-CREVASSE MOUNTAIN MINING DISTRICT

PARK COUNTY, MONTANA

EXPLANATION

▉	Alluvium	QUATERNARY
▉	Extrusive rocks undifferentiated	TERTIARY
▉	Granite and granite pegmatite	
▉	Gabbro and diabase	PRECAMBRIAN
☐	Schist and quartzite	

1012   Sample location

Scale
0   1500   3000 FEET

Modified after Seager, 1944

The gabbro and diabase are the oldest igneous rocks and they show pronounced structural and textural variation. In some samples pronounced shearing is seen whereas others show little or no deformation. The grain size is variable as well, as these rocks range from porphyritic sills to fine grained and coarse grained dikes and sills (see Plate II, nos. B and D).

The gabbro and diabase are believed to be pre-minerlization because they are cross-cut by pegmatite and aplite believed to have controlled ore deposition. In addition, the diabase is strongly hydrothermally altered near ore zones (see Plate II, nos. A, B, C, D).

Plagioclase usually comprises fifty percent of the rocks and ranges in composition from An_{45} to An_{55}. It is highly altered, particularly in the diabase. The remainder of the rock is composed of uralitic hornblende and actinolite and altered pyroxene. Magnetite is locally important.

The main mass of granite occurs on the south slope of Crevasse Mountain; and the nearby granite sills, aplite dikes, and pegmatites are apophyses of the main mass. Field evidence shows that the ore deposition is largely controlled by the emplacement of the granitic material (Seager, 1944).

The granite is medium grained and is composed essentially of quartz, microperthite, biotite, and muscovite. The micas occur in nearly equal amounts and comprise ten to twelve percent of the rock. Accessory minerals include apatite, magnetite, ilmenite, rutile, and zircon. The rock is not distinctly banded but a slightly gneissic appearance is evident. The texture is slightly granulated and shows some signs of recrystallization, and the quartz shows pronounced strain effects. The aplite and pegmatite are mineralogically similar to the granite.

Tertiary Volcanic Rocks

Much of the Jardine-Crevasse Mountain area is covered
by extrusive volcanic rocks related to the Yellowstone Park
extrusive rocks (Seager, 1944), and they will not be discussed
here as they are not genetically related to the ore deposits.

Quaternary Deposits

Thick sand and gravel deposits occur along the major creeks
in the area and have produced some placer Gold. These deposits
are largely alluvial, but some glacial debris occurs. As the
Quaternary deposits have no bearing on the genesis of the ores
the reader is referred to Seager (1944) for more details.

STRUCTURAL GEOLOGY

The units of schist have a prevailing easterly dip and
northerly strike. Near Jardine the average dip is near 80°
whereas a range in dip from 7° to 30° is common in the vicinity
of Crevasse Mountain. The Bear Gulch fault cuts and offsets
the lodes. It is a normal fault and dips 40° westward. The
major structure west of the Bear Gulch fault is an asymmetri-
cal syncline (east flank steepest). It trends north-south
and is cut by the fault, and it has been modified by cross
folds which plunge to the southwest. The salient structural
features are shown in Figure 3, and the reader is referred
to Wilson (1934) and Seager (1944) for further discussion.

GEOLOGIC HISTORY

The oldest rocks were formed by regional metamorphism
of a sedimentary series in Middle or Early Precambrian time.
A later pre-Beltian event was accompanied by intrusion of
gabbro, diabase, and granite; and by deposition of ores in
the schist which emanated from the granite. At least part
of the cross folding in the Jardine area is the result of
deformational forces that occurred during mineralization.

DESCRIPTION OF PLATE I

Plate No.	Sample No.	Description
A	1019	Polished section of arsenopyrite-quartz ore. Light HNO_3 etch spot shows arsenopyrite (light grey) veined by quartz (dark lines) and later pyrite (dark grey). X 10.
B	1019	Polished section showing arseno-pyrite veined by quartz. X 5.
C	1008	Polished section showing arseno-pyrite in amphibole schist. X 5.
D	1007	Thin section showing disseminated sulfide ore in quartz-cummingtonite schist. Arsenopyrite (black) re-places cummingtonite (white). The ends of the fibrous cummingtonite crystals are partly replaced by hornblende (dark grey). Some secondary quartz (small white spots). X 35.
E	1010	Thin section showing disseminated sulfide ore in quartz-biotite schist. Arsenopyrite (black), quartz (white), crenulated bio-tite (grey). X 25.
F	1010	Thin section showing tightly folded quartz veins cutting the schistosity. X 3.

PLATE I
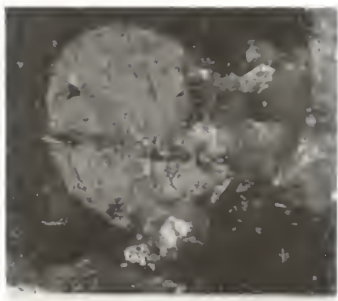
A.
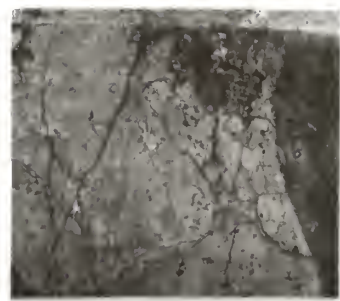
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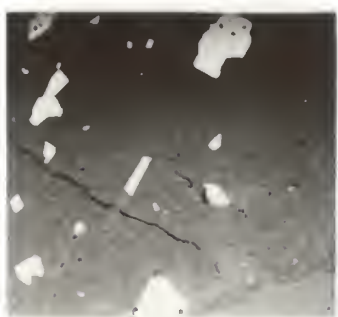
C.
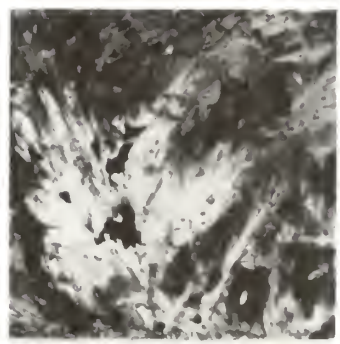
D.
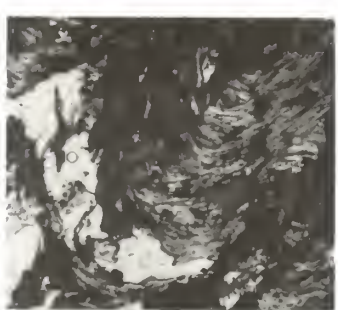
E.
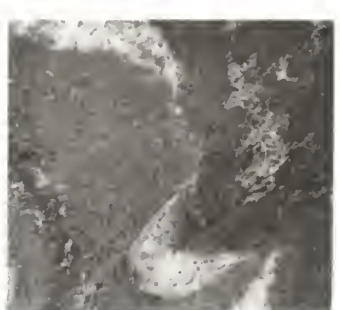
F.

DESCRIPTION OF PLATE II

Plate No.	Sample No.	Description
A	1002	Thin section showing typical diabasic texture of the altered fine grained diabase. X 3.
B	1002	Thin section of altered diabase showing amphibole replacing plagioclase (An-48) and secondary magnetite. Very little evidence of deformation or shearing. X 25.
C	1009	Thin section of intensely altered diabase showing secondary quartz and most complete replacement of the feldspar and pyroxenes. X 25.
D	1009	As C (above), X 25.

PLATE II
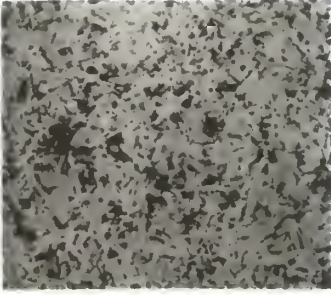
A.

B.

C.

D.

A period of Precambrian erosion was followed by sedimentation through Paleozoic and Mesozoic time, which in turn was followed by uplift of the Beartooth-Absaroka plateau during the Laramide Orogeny. None of these post-Precambrian events had an appreciable effect on the ores. These events were followed by deep erosion which removed the sedimentary cover and cut into the Precambrian complex. Most of the area was covered by volcanic rocks during Tertiary time, and erosion and some supergene alteration are the last geologic events affecting the ore deposits.

ORE DEPOSITS
General Character of Deposits

The veins of the district occur as selective replacements of either the quartz-biotite schist and biotite quartzite or the quartz-cummingtonite schist. In general, the veins are parallel to the foliation of the schist which in turn is essentially parallel to the original bedding planes.

There are two distinct belts of mineralization in the district; one trends slightly east of north through Mineral Hill at Jardine, and the other trends west of north through Crevasse Mountain.

The veins in quartz-biotite schist and biotite quartzite are composed of quartz with minor variable amounts of sulfides, Gold, and scheelite. Arsenopyrite is the most abundant sulfide and Gold values generally follow its concentration. Scheelite is most abundant in the quartz-rich veins but appears to be independent of sulfide concentration.

The veins in quartz-cummingtonite schist are of two types: (1) rather well defined arsenopyrite-rich veins with occasional small pods of quartz and (2) irregularly distributed sulfide and quartz stringers. In both types arseno-

Figure 3

HAVLAND 7004

NEW YEAR 7007

KENNEBEC 9681

SHAFT

SIDE STEP 6374

GEORGE 6377

EMMA 6376

MILL

MEDONA TUNNEL

E. F. MEDONA 9681

SHAFT

POP INCLINE

JONES CABIN

CREVASSE MOUNTAIN

SHAFT   SHAFT

USLM

SNOWSHOE MINE

MILL

CUCKOO 4537

JUPITER 4905

FOWLER 4338

15 14
22 23

WATSON

SNOWSHOE 4533

VENUS 4904

MILL

FIRST CHANCE 8670

SHAFT

COLUMBUS 9906

McCAULEY 5614

LITTLE BONANZA 9869

PRATT 4902

DELAY

SHAFT

KENTUCK 4899

KENTUCKY

GEORGE WASHINGTON 5613

GRANITE 4557

SUMMIT 4558

CONSOLIDATED MIZPAH 4559

TOWER GROVE 4901

OLD CROW 4900

EXPLANATION

METAMORPHIC ROCKS

st and quartzite (quartz-biotite and quartz-amphibole schist, biotite quartzite) | PRE-CAMBRIAN

EXTRUSIVE ROCKS

s-quartz latite porphyry

oclase basalt | TERTIARY

INTRUSIVE ROCKS

ite and granite pegmatite (bathplith and dikes, gneissic)
tized gabbro (irregular masses, dikes, and sills; locally gneissic) | PRE-CAMBRIAN

GUEST TUNNEL

and dip

nittent streams

and prospects

CONRAD INCLINE

Springs

J TUNNEL

CREVASSE FRACTION 9023

M TUNNEL

HIGHLAND CHIEF 4560

BLACKSMITH SHOP TUNNEL

SCALE

0 200 400 600 800 1000 Feet

1944

Geology by George F Seager

HIGHLAND PLACER 9024

YELLOWSTONE   NATIONAL   PARK

GEOLOGIC MAP OF CREVASSE MOUNTAIN, JARDINE CREVASSE MOUNTAIN DISTRICT, PARK COUNTY, MONTANA

pyrite is the dominant sulfide, but pyrite and pyrrhotite
are locally abundant.

Mineralogy

A mineralogical classification of the ores (modified
from Seager, 1944) follows:
I. Siliceous ore: Gold bearing quartz with local scheelite,
    arsenopyrite, pyrite, and local galena.
II. Sulfide ore:
    A. Quartz-arsenopyrite ore (see Plate I, nos. A and B)
        ranges from nearly massive arsenopyrite to types as-
        sociated with quartz and local pyrite and galena.
    B. Disseminated arsenopyrite-pyrrhotite-pyrite ore:
        1. Arsenopyrite in biotitized and chloritized quartz-
           biotite schist (see Plate I, nos. E and F).
        2. Irregular grains and well formed crystals of
           arsenopyrite with variable amounts of pyrrhotite
           and pyrite occurring in a dark matrix composed
           chiefly of hornblende (after cummingtonite),
           chlorite, and some biotite. This ore also has
           a variable but low quartz content with traces of
           scheelite (see Plate I, nos. C and D).
        3. Finely disseminated quartz, arsenopyrite, pyrite,
           and pyrrhotite in a fine grained matrix of cum-
           mingtonite, hornblende, chlorite, carbonate
           minerals, and some quartz with traces of scheelite.
III. Oxidized Ore: This ore is essentially a weathered pro-
     duct of disseminated sulfide ore and consists of a de-
     composed, Iron stained, crumbly, soft schist which
     may contain residual arsenopyrite, scheelite, and
     quartz nodules. Limonite boxworks after arsenopyrite
     are common.

Paragenesis

The sequence of mineralization can be divided into four stages according to Seager (1944). These are (in order): (1) silicate stage, (2) sulfide-scheelite stage, (3) Gold stage, and (4) carbonate stage. Stages (1) and (2) are early hydrothermal, and (3) and (4) are late hydrothermal. Although the time of precipitation of the various minerals may vary somewhat, all of the primary minerals are thought to have been deposited during a single major period of mineralization. The sequence of mineral deposition is shown in Figure 4 and is based on careful petrographic and mineragraphic studies (Seager, 1944).

The deposition of quartz proceeded throughout the entire period of mineralization. Some Gold deposition occurred in the sulfide stage but most occurred in the Gold stage and was accompanied by chloritization and quartz deposition. Except for some late pyrite deposition of sulfides was terminated before Gold deposition.

Hydrothermal Alteration

Hydrothermal alteration occurred in two distinct manners: (1) recrystallization with little or no apparent chemical change resulted in the formation of fibrous sheaths of cummingtonite in the quartz-cummingtonite schist and possibly by biotite in quartz-biotite schist, (2) minerals formed by alteration of pre-existing minerals were principally hornblende, biotite, chlorite, and garnet. Some of these appear to also have been introduced in large amounts into some zones. Other minerals introduced were quartz, muscovite, arsenopyrite, scheelite, pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, Gold, barite, siderite, and calcite; and to a limited extent, tourmaline, zoisite, and oligoclase.

The hydrothermally introduced products resemble the original minerals (except for garnet and sulfides), but their abundance in vein zones and their large size are conspicuous features. The amount of alteration appears to be controlled by the fissility of the schist.

Supergene Alteration

All of the ores of the area have been subjected to some supergene alteration, although this is commonly restricted to the development of limonite stains on fissure surfaces. Zones of fissle schist are usually deeply oxidized with most of the sulfide minerals removed. The hard and impermeable ores show very little oxidation even near the surface. Nowhere has there been any significant enrichment of the ores except locally by residual concentration.

GENESIS OF THE ORE DEPOSITS

The Crevasse Mountain granite served as the source for the ores according to Seager (1944) who cites the following evidence in support of this theory:

1. The mineralogy of the veins and wall rocks indicate that hydrothermal conditions were more intense near the granite contact as evidenced by the greater development of garnet and other hydrothermal minerals.
2. Quartz veins containing arsenopyrite, Gold, and scheelite occur closely associated with pegmatite and aplite on Crevasse Mountain and can be traced along their strike into feldspar-rich granite pegmatite.
3. Hydrothermal alteration is similar along both the quartz veins and pegmatite sills on Crevasse Mountain.
4. Oligoclase is common as a subordinate constituent of

quartz veins and enclosing schists in all parts of the district, and also occurs in the pegmatites. The occurrence of andalusite in aplite, in muscovite granite pegmatite, and in veins with feldspar indicates a similarity in the solutions responsible for deposition.

AGE OF THE ORE DEPOSITS

Known magmatic hydrothermal ore deposits in the Northern Rocky Mountains are related to intrusions of one of three ages: Precambrian, Mesozoic, or Early to Late Tertiary. The Jardine-Crevasse Mountain deposits have been tentatively dated as Precambrian by Seager (1944) based on field evidence.

The structural history of the deposits is incompatible with post-Beltian events recognized in Montana. It is also significant, although inconclusive, that no veins or signs of metallization occur in the Paleozoic formations west of the Gardiner fault. Other factors being equal, the Paleozoic limestones should have been at least as susceptible to mineralization as the schist if the ore deposition occurred during Mesozoic or later time.

Assuming the granite to be genetically related to the ore deposits the following evidence bearing on the age of the granite also applies to the age of vein formation:

1. The granite has a gneissic structure not possessed by post-Cambrian granites in Montana.
2. Microscopically the granite is granulated and shows evidence of recrystallization under stress.
3. The pegmatite is more distinctly gneissic than the granite and shows muscovite orientation.
4. Sillimanite, and to a lesser degree andalusite, in the aplite sills shows a preferred orientation.

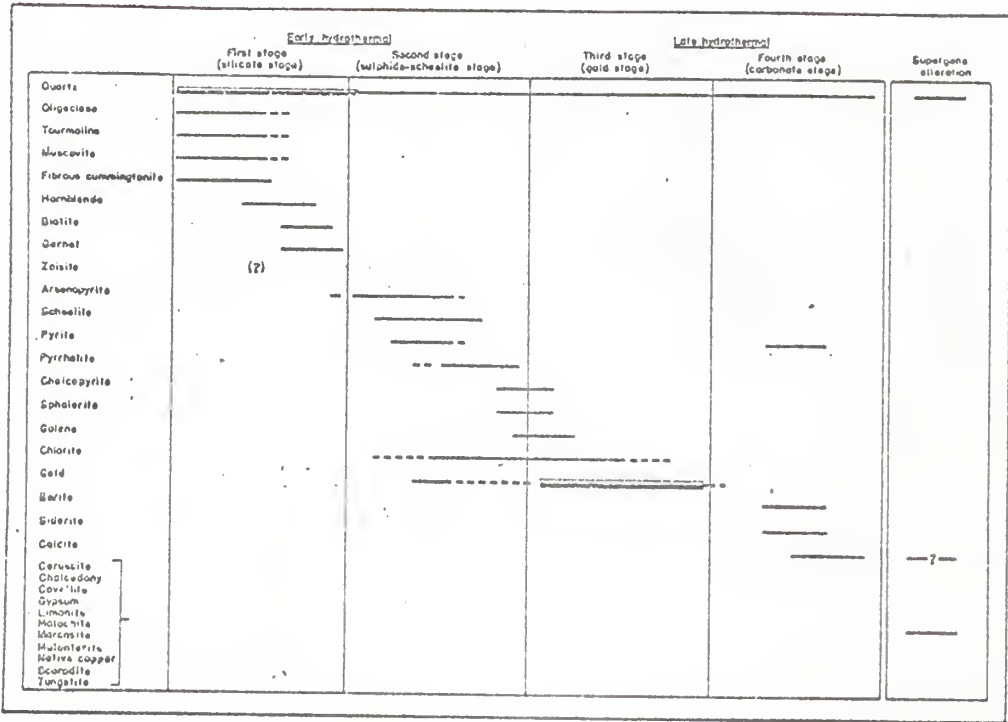|	Early hydrothermal		Late hydrothermal		
	First stage (silicate stage)	Second stage (sulphide-scheelite stage)	Third stage (gold stage)	Fourth stage (carbonate stage)	Supergene alteration
Quartz					
Oligoclase					
Tourmaline					
Muscovite					
Fibrous cummingtonite					
Hornblende					
Biotite					
Garnet					
Zoisite	(?)				
Arsenopyrite					
Scheelite					
Pyrite					
Pyrrhotite					
Chalcopyrite					
Sphalerite					
Galena					
Chlorite					
Gold					
Barite					
Siderite					
Calcite					
Cerussite Chalcedony Covellite Gypsum Limonite Malachite Marcasite Melanterite Native copper Scorodite Tungstite					

Figure 4.—Sequence of mineral deposition in the veins
of the Jardine-Crevasse Mountain district.

from Seager (1944)

5. Post-Beltian regional metamorphism of a degree to
   produce the above effects is unknown in this region.

TECHNIQUES AND PROCEDURES

Sampling

All of the major country rock and ore types of the area
were sampled and the locations are shown on Figure 2. Samples
for which age determinations were intended were so selected
that weathering and supergene effects were avoided, and all
samples were checked microscopically in the laboratory to
verify their purity. Eleven ore and host rock samples
were taken from the Jardine area and one from Crevasse Moun-
tain for Sulfur isotopic analysis.

Investigation and sampling of the ores was handicapped
because of the inaccessibility of most of the underground
developments due to caving of the main adits during the
Yellowstone earthquake of 1959. As a result some of the ore
samples were taken from bunkers and ore cars.

Samples for Sulfur Isotopic Analysis

General Statement:

Separation of minerals for Sulfur isotopic analysis
involved three main steps: (1) crushing, (2) sieving, and
(3) mineral separation and concentration. Minerals were
separated and concentrated by a combination of magnetic,
heavy liquid, flotation, precipitation, and gravity methods
(described below).

All equipment and glassware used in preparing samples
were carefully cleaned by washing with a soap solution,
rinsing with hot tap water, rinsing again with vycor dis-
tilled 2N HCl, rinsing again with deionized water, and

drying by evaporation using either heat or pure acetone.
After this general cleaning the equipment was pre-contami-
nated with a small aliquot of the sample to be prepared.
Extreme care was taken to prevent any contamination from
laboratory reagents and compounds containing Sulfur.

Crushing

Sulfide-rich ores were crushed in a steel mortar and
0.3 grams of the clean sulfide were handpicked under a
40 power binocular microscope. Samples containing small
amounts of disseminated sulfides were reduced to a maximum
size of about one-half inch in a pre-contaminated Sturtevant
jaw crusher and then reduced to less than 40 mesh in a Braun
disc grinder.

Sieving

Size fractions of 40-100, 100-200, and less than 200
mesh were separated in clean, pre-contaminated U. S. Standard
Copper sieves. The 100-200 mesh fraction is desirable for
subsequent separations, and the other fractions were not
used if 0.3 grams could be separated from this fraction.
This and other separation techniques did not permit the re-
covery of all of the sulfides in the rock samples, but
there should not be significant isotopic differences between
primary sulfides in the same rock (see discussion under
SULFUR ISOTOPY). In all sulfide samples arsenopyrite was
the principal sulfide extracted although some concentrates
contained up to twenty percent pyrite and small amounts of
galena.

Mineral Separation and Concentration

 I. Magnetic separation: A Frantz isodynamic separator
   set for inclined feed was employed. Procedural
   details varied slightly from sample to sample but
   included the following steps:

A. Steel chips from the crushing equipment and the ferromagnetic minerals (magnetite, pyrrhotite, and some ilmenite and leucoxene) were removed with a hand magnet.

B. The 100-200 mesh fraction was washed with deionized water, dried, and the separator was cleaned and pre-contaminated.

C. The separator was set at 0.5 amperes with a side slope of 15° and forward slope of 30°. The samples were fed into the input funnel at a moderate rate and separating efficiency was redorded. The flow was gradually increased to the maximum rate permitting effective separation. This run could be made at a relatively high rate of flow and effectively remove the more highly paramagnetic minerals such as ilmenite, biotite, chlorite, and some pyroxenes and amphiboles.

D. The current was increased to 0.8 amperes and the side and forward slopes decreased to 10° and 20° respectively and the nonmagnetic fraction at 0.5 amperes was separated.

E. The current was increased to 1.2 amperes and the side slope decreased to 5°. The forward slope remained at 20° and the fraction nonmagnetic at 0.8 amperes was removed. The nonmagnetic fraction collected during this run consisted of quartz and arsenopyrite with minor pyrite and galena.

II. Gravity concentration: Samples 1011 and 1017 were highly oxidized and contained very little sulfide. A heavy mineral concentrate was prepared from these samples by panning the minus 40 mesh fraction. The heavy concentrate was rinsed with deionized water and

evaporated with acetone to prevent oxidation of the steel chips (which could cause Iron staining of the sulfides). The sulfides were then extracted magnetically.

III. Flotation: Most of the sulfides in sample 1002 were less than 70 microns in diameter. For this sample a low grade concentrate was obtained by flotation. The concentrate was washed in light, clean kerosene to remove the oil and xanthate frothing agent; then rinsed in acetone to remove the kerosene. Most of the silicate minerals were washed out of the concentrate with water. Steel and ferromagnetic chips were removed with a hand magnet and the sulfide concentrate obtained by centrifuging in heavy liquids. The xanthate frothing agent used in the flotation process contains Sulfur but has been shown by Smitheringale and Jensen (1963) not to be a source of contamination.

IV. Heavy liquids: Heavy liquids were used for the final sulfide concentration. Bromoform and methylene iodide were employed to remove the silicates.

V. Native Sulfur and sulfate separations: Native Sulfur was extracted from sample 1004 by crushing to minus one-half inch and washing with Sulfur-free benzene. The soulution was filtered and the filtrate evaporated to collect the Sulfur. The procedure for separating the sulfate from sample 1014 was identical except that deionized water was used as a solvent.

<center>Samples for Potassium-Argon and
Rubidium-Strontium Age Determinations</center>

General Statement:

Samples for K-Ar and Rb-Sr age determinations were

crushed, cleaned, and separated by methods very similar to those described earlier. Muscovite, biotite, and microcline from the Crevasse Mountain granite (samples 1022 and 1024) were separated by use of the magnetic separator followed by heavy liquids. Because of the wider range in magnetic susceptibility of the minerals to be extracted the separating procedures were considerably different from those for sulfide extraction.

Biotite Separation

The magnetite and steel chips were removed from the 100-200 mesh fraction with a hand magnet. The sample was then run on the Frantz with the following settings: Current: 0.55 amperes, forward slope: 25°, side slope: 15°. This procedure removed the highly paramagnetic minerals. The biotite-bearing magnetic fraction was rerun with the same slope settings but at 0.4 amperes. As the fraction was being run the separation was inspected and the current carefully readjusted to permit the bulk of the sample to collect in the nonmagnetic fraction. This nonmagnetic fraction was then rerun with continual readjusting of the current until a concentrate containing greater than ninety nine biotite was obtained.

Muscovite and K-feldspar Separation

The nonmagnetic fraction from the first biotite run contained muscovite, feldspar, quartz and biotite. The biotite occurred combined with other grains. This fraction was run at 0.8 amperes with the forward and side slopes unchanged yielding a clean mixture of biotite-free minerals in the nonmagnetic fraction. This fraction was then run at 1.4 amperes, side slope 5°, forward slope 25° to give an impure magnetic concentrate of muscovite and a nonmagnetic concentrate of quartz and feldspar.

Bromoform was used to obtain a pure muscovite concentrate,

and acetone diluted with bromoform to a density of 2.62 to
2.60 was used to clean the feldspar concentrate.

K-Ar Samples

Ten grams of sample of each of the three minerals were
prepared for commercial K-Ar analysis without further treat-
ment.

Rb-Sr Samples

Three to five grams of each mineral are needed for Sr
isotopic ratio determinations and one to three grams for Rb
and Sr weight determinations. Each whole rock analysis
required a total of about twenty grams. To obtain a rep-
resentative whole rock aliquot each size fraction was cored
and quartered and representative fractions from each were
combined. This step preceeded any mineral separation.

The samples were first reduced to minus 400 mesh in a
Pica mill. One to three grams of the resultant powder was
set aside for the Rb/Sr weight determination ratio, and a
Sr concentrate was prepared from the remaining sample. This
last step involved three different procedures: I. Sample
dissolution, II. Ion exchange chromatography, III. Final
Sr concentration. The work area and all apparatus were
thoroughly cleaned and kept clean throughout the entire
preparation. Because of the abundance of $CaCO_3$ and $CaSO_4 \cdot 2H_2O$ (both are potential sources of Sr contamination) in
the general non-laboratory work area extreme care was taken
to prevent airborn contamination.

I. Sample dissolution:

    A. The sample is transferred to a clean teflon dish
and a few ml of deionized water are added to
moisten the sample.

    B. Sr^{85} tracer is added until the gamma-activity is
about 0.5 millirems/hour.

    C. 20 ml HF and 3 ml $HClO_4$ per gram-sample are then
added to the dish.

D. The dish is then transferred to a hot plate and evaporated without boiling until dense, white fumes of $HClO_4$ appear (HF evaporates before $HClO_4$).

E. Steps C. and D. are repeated once and the sample is evaporated to near dryness.

F. The dish is cooled and 3/4 filled with deionized water and evaporated to about 20 ml, and then repeated to about 10 ml.

G. The sample is cooled and transferred to a clean polypropylene beaker and covered with parafilm. The transfer is monitored by a gamma counter.

II. Ion exchange procedures:

A. The cool solution is filtered into another clean beaker and washed with vycor distilled 2N HCl until 90 % of the gamma activity is in the filtrate.

B. The filtrate is carefully poured on the top of the resin without disturbing the flat surface and the walls of the column are carefully washed.

C. When the sample has soaked into the resin top 20 ml aliquots of vycor distilled 2N HCl are added until the gamma activity is at least one inch below the resin top.

D. More acid is then added by continuous feed until the sample is less than one half inch above the quartz wool plug.

E. Eluant is added and 50 ml aliquots are collected until all the sample has passed through the column.

III. Sample concentration:

A. All beakers containg sample are slowly evaporated and combined into a teflon dish and then evaporated to dryness.

B. The residue is dissolved in a few drops of vycor
distilled HNO_3 and transferred to a 4 ml beaker.

C. The sample is evaporated to dryness and slowly
fused to burn off the resin until the sample turns
white. It is then cooled and ready for mass
spectrometric analysis.

SULFUR ISOTOPY

Natural Variation of Sulfur Isotopes

Introduction

Natural Sulfur contains four isotopes: $S^{32}, S^{33}, S^{34}, S^{35}$.
Of these S^{32} and S^{34} constitute over 99 % of total Sulfur
and the S^{32}/S^{34} ratio in nature varies from 23;3 for sulfate
in the cap rocks of salt domes to 20.8 for sulfides in shales
according to Ault (1959). Figure 5 shows this natural vari-
ation.

The theoretical explanation for this natural variation
is that when a light element can exist in the gaseous state
(i.e. H_2S, S_2 , SO_2, SO_3 , ...) as well as in the solid or
liquid state an isotopic exchange may occur such that the
gaseous phase is enriched in the lighter isotope. This
results from the fact that the thermodynamic equilibrium
constants for equilibrium reactions are different for
different isotopes (see the discussion in Ramberg, 1963,
pp. 319-341 for a thorough discussion).

The importance of this natural variation is that
Sulfur isotopes can be used as tracers for certain geo-
chemical processes. In particular, limits on the genesis
of ores and post-depositional events can be investigated.

Standards and Reporting of Data

The Sulfur from the troilite phase of the Canon Diablo
meteorite is used as the standard for most analytical work

for the following reasons: (1) all analyzed uncontaminated meteorites fall very near the Canon Diablo S^{32}/S^{34} value of 22.21, (2) this value is thought to be very close to the average for terrestrial Sulfur, and (3) there is abundant material available for interlaboratory comparisons.

For convenience of handling data and to emphasize degrees of fractionation all Sulfur isotopic data is now reported in permil deviations from the Canon Diablo standard ($\delta S^{34} = 0.00$) according to the equation:

$$\delta S^{34} \ (\ o/oo \ ) = \left[\frac{(S^{34}/S^{32})_{\text{sample}}}{(S^{34}/S^{32})_{\text{standards}}} \ - \ 1 \right] \ 1000$$

It follows that (+) δS^{34} values indicate enrichment and (-) δS^{34} values depletion relative to the standard.

Magmatic Hydrothermal Sulfides

Sulfides deposited from magmatic hydrothermal solutions generally exhibit a very narrow δS^{34} range for any one deposit, but the total spread for all known deposits is large due to the differences in the source for the Sulfur. In other words, local contamination from other magmas or country rock, etc. will change the isotopic composition of the Sulfur in the hydrothermal solution. It must be emphasized, however, that the $\pm \delta S^{34}$ range for magmatic hydrothermal sulfides will always be less than 2 o/oo. Similarly, if a wide range of δS^{34} values are noted from a single deposit then this can be taken to indicate: (1) source inhomogeneity, (2) local contamination, (3) post-ore events, and so forth. All of these possibilities can be examined (Ault and Kulp, 1960). In general, deposits originating from a shallow source in the earth's crust exhibit a fairly wide range of fractionation whereas deep seated deposits show a very narrow range of fractionation (see Gavelin, Parwel, and Ryhage, 1960).

Sulfur Isotopic Data from the
Jardine-Crevasse Mountain area

Explanation of data

The Sulfur isotopic data from this study is presented
in Table 1. The mineral separation and purification was
done at Kansas State University and the isotopic analyses
at Yale University. Except for samples 1004a (native
Sulfur) and 1014b (melanterite) the data were obtained
from sulfide separates. The complete description of the
samples is to be found in the APPENDIX. The data is shown
for comparison to other Sulfur isotopic data in Figure 5.
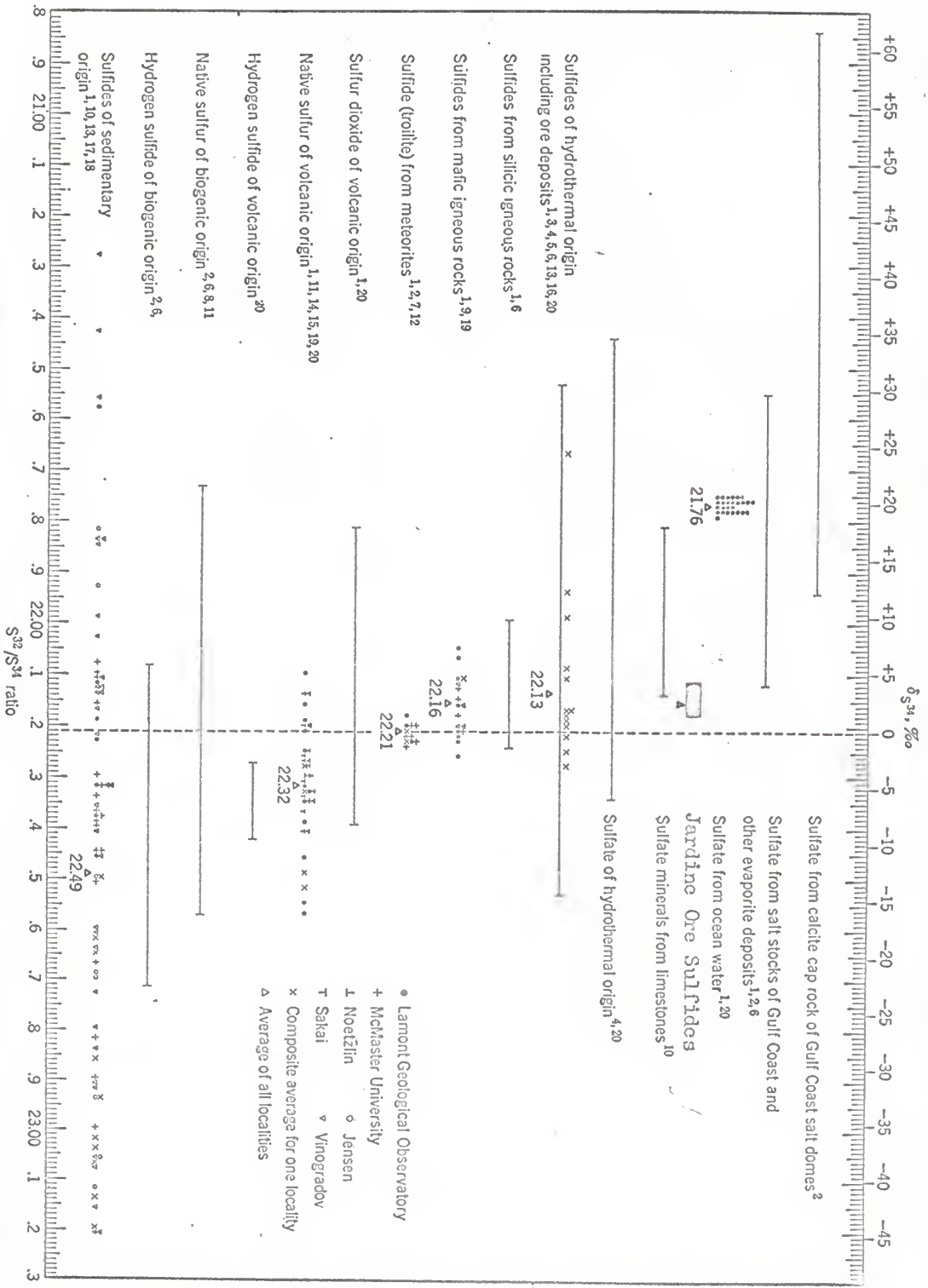
Discussion of Results

There are not enough data to determine a meaningful
mean or range relative to depositional and/or post-depo-
sitional events connected with the ores but a hydrothermal
magmatic origin for the ores is clearly indicated (M. L.
Jensen, written communication). For example, the Yellow-
knife area, Northwest Territories, Canada contains Pre-
cambrian Gold-bearing arsenopyrite associated with granite
intruding schists; and Wanless, Boyle, and Lowdon (1960)
found that the average δS^{34} value for 140 samples was
2.2 o/oo with a range of 0.5 o/oo to 4.0 o/oo. The near
agreement of this last value with the 2.5 o/oo average
value for the Jardine-Crevasse Mountain area is probably
fortuitous but certainly the narrow range of 3.7 o/oo
again is strongly suggestive of a magmatic hydrothermal
origin. In addition, post-depositional events have not
affected the ores to any great extent as no evidence for
large scale remobilization of Sulfur is noted.

Seager (1944) also concluded that the ores are of
a deep seated, magmatic hydrothermal origin from field
and petrographic studies, but he also postulated that

TABLE 1
Sulfur Isotopic Data From
The Jardine-Crevasse Mountain Area

Sample	δs^{34}	Description
1002	+ 4.7	Sulfide (arsenopyrite: 50%, pyrite: 40% other sulfides: 10%) from diabase.
1004a	+ 4.7	Native Sulfur from oxidized quartz-biotite schist.
1004b	+ 1.6	Arsenopyrite (100%) from oxidized quartz-biotite schist.
1006	+ 4.4	Arsenopyrite (100%) ore from chloritized quartz-biotite schist.
1007	+ 3.2	Arsenopyrite (100%) ore from quartz-amphibole schist.
1008	+ 1.8	Arsenopyrite (100%) ore vein in quartz-amphibole schist.
1010	+ 2.7	Disseminated sulfide ore (arsenopyrite: 85%, pyrite 10%, galena 5%) from quartz-biotite schist.
1011	+ 2.9	Arsenopyrite (100%) from oxidized quartz-biotite schist.
1014a	+ 2.1	Arsenopyrite (100%) ore (oxidized) from quartz-amphibole schist.
1014b	+ 3.7	Melanterite (100%) from coatings on 1014a.
1016	+ 3.3	Disseminated sulfides (arsenopyrite: 70%, pyrite 25%, galena 5%) from biotite quartzite.
1017	+ 2.6	Arsenopyrite (100%) ore from quartz-biotite schist.
1019	+ 1.0	Sulfide (arsenopyrite: 90%, pyrite: 8%, chalcopyrite: 2%) from quartz-biotite schist.
1026	+ 2.7	Arsenopyrite (100%) ore vein in quartz-biotite schist.

After Ault, 1959   Figure 5.

Sulfides of hydrothermal origin including ore deposits[1,3,4,5,6,13,16,20]

Sulfides from silicic igneous rocks[1,6]

Sulfides from mafic igneous rocks[1,9,19]

Sulfide (troilite) from meteorites[1,2,7,12]

Sulfur dioxide of volcanic origin[1,20]

Native sulfur of volcanic origin[1,11,14,15,19,20]

Hydrogen sulfide of volcanic origin[20]

Native sulfur of biogenic origin[2,6,8,11]

Hydrogen sulfide of biogenic origin[2,6]

Sulfides of sedimentary origin[1,10,13,17,18]

Sulfate from calcite cap rock of Gulf Coast salt domes[2]

Sulfate from salt stocks of Gulf Coast and other evaporite deposits[1,2,6]

Sulfate from ocean water[1,20]

Jardine Ore Sulfides

Sulfate minerals from limestones[10]

Sulfate of hydrothermal origin[4,20]

21.76   22.13   22.16   22.21   22.32   22.49

δS^{34}, ‰

S^{32}/S^{34} ratio

• Lamont Geological Observatory
+ McMaster University
⊥ Noetzlin   ○ Jensen
⊤ Sakai   ▽ Vinogradov
× Composite average for one locality
△ Average of all localities

that the gabbro and diabase were early differentiates of the same parent magma which gave rise to the Crevasse Mountain granite. Late stage products of magmatic crystallization tend to be enriched in S^{34} and isotopic fractionation continues into the hydrothermal stage resulting in slightly greater enrichment of S^{34} in minerals formed by emanations from the magma (Smitheringale and Jensen, 1963). Therefore, assuming a common primary source for the ores, granite, and mafic rocks the ores should show the greatest δS^{34} values and the primary sulfides in the diabase and gabbro the lowest. This is not the case in the Jardine-Crevasse Mountain area as the diabase is much higher than the ores and the granite and a lack of any genetic relationship between the mafic rocks and the granite (plus ores) is indicated.

Two of the samples (1004a, 1014b) are in a higher state of oxidation than the ore sulfides with which they are associated. Oxidation-reduction reactions are capable of producing isotopic fractionation by such equations as:

$$H_2S^{34} + S^{32}O_4^= = H_2S^{32} + S^{34}O_4^=$$

$$H_2S^{34} + S^{32} = H_2S^{32} + S^{34}$$

The heavier, less energetic isotope (S^{34}) is concentrated in the higher state of oxidation and the lighter isotope in the reduced state (Tupper, 1960). It has been shown that during supergene oxidation of sulfides there is very little fractionation and that the oxidized ore is only slightly enriched in S^{34}. Only when a primary sulfide co-exists with a primary sulfate will there be a significant difference in the isotopic ratio of the two (M. L. Jensen, written communication). Thus the native Sulfur (1004a) and melanterite (1014b) data indicate their local derivation as they show higher δS^{34} values than their parent sulfides.

AGE DETERMINATIONS

Potassium-Argon Age Dating

Introduction

The naturally radioactive isotope K^{40} decays by electron capture to $*Ar^{40}$ and by beta-minus emission to $*Ca^{40}$ (the asterisks indicate that the isotopes are radiogenic). Three constants must be known for K-Ar age determinations: (1) the atomic abundance of K^{40} ($= K^{40}/\Sigma K$), (2) the decay constant for the formation of $*Ar^{40}$ (λ_e), and (3) the decay constant for the formation of $*Ca^{40}$ (λ_{β^-}). The values used for these constants in this report are: (1) 1.22×10^{-4} g/g (2) 0.585×10^{-10}/yr, (3) 4.72×10^{-10}/yr. The age of any sample is given by the standard equation:

$$Age = \frac{1}{\lambda_e + \lambda_\beta} \ln\left[\left(\frac{\lambda_e + \lambda_{\beta^-}}{\lambda_e}\right)\left(\frac{*Ar^{40}}{K^{40}}\right) + 1\right]$$

Commercial K-Ar age determinations (by Geochron Laboratories, Cambridge, Massachusetts) were made on muscovite (M1024), biotite (B1024), and K-feldspar (F1024) from a whole rock sample (R1024) of the Crevasse Mountain granite, and the data are presented in Table 2. The $*Ar^{40}$ was measured by replicate isotope dilution determinations using a Reynolds-type mass spectrometer (see Hart, 1960, for a discussion of the instrumentation), and the K^{40} was calculated from replicate total K analyses made on a Beckman-DU spectrophotometer with flame attachment. The minerals analyzed (K-feldspar, biotite, muscovite) are sufficiently K-rich so that flame photometric methods are adequate for age work (see Cooper, 1964).

TABLE 2

K-Ar Age Determinations

Argon Analyses				Potassium Analyses		
$^*Ar^{40}$, ppm	$^*Ar^{40}/$ Ar	avg. $^*Ar^{40}$, ppm	%K	Avg. %K	K^{40}, ppm
(Sample F1024, $^*Ar^{40}/K^{40}$ = 0.0960, apparent age 1180 ± 35 m.y.)						
0.405	0.983	0.400	3.38	3.42	4.17
0.396	0.980		3.46		
(Sample B1024, $^*Ar^{40}/K^{40}$ = 0.155, age 1655 ± 40 m.y.)						
1.277	0.995	1.273	6.78	6.74	8.21
1.269	0.994		6.69		
(Sample M1o24, $^*Ar^{40}/K^{40}$ = 0.179, age 1820 ± 50 m.y.)						
1.841	0.994	1.86	8.52	8.52	10.40
1.880	0.985		8.51		

Discussion of Results

It has been shown by Damon and Kluft (1956) that primary Ar^{40} is only incorporated into ring structures (i.e. beryl) during magmatic crystallization and not into mica or feldspar structures. Therefore $^*Ar^{40}$ accumulates due to the decay of K^{40} with increasing age providing no post-crystallization event disturbs the crystal structures. If a post-crystallization event does occur the $^*Ar^{40}$ is driven out of the structure and removed from the system (providing the event is comparable to regional metamorphism). Hart (1960) has discussed this problem in detail.

The data show a range in ages from 1180 ± 35 m.y. to 1820 ± 50 m.y. and suggest that some post-emplacement event has occurred. The K-feldspar shows the lowest age, and this has been noted in other igneous rocks where the micas consistently show older ages than K-feldspar. Wasserburg, Hayden, and Jensen (1956) estimate this $^*Ar^{40}$ loss from K-feldspars to be approximately 30%. The reasons for this age lowering may be due to: (1) monoclinic-triclinic inver-

sion, (Wasserburg, Hayden, and Jensen, 1956), (2) hydro-
thermal alteration (Genter and Kley, 1957), (3) exsolution
of the Na component within the structure (Genter and Kley,
1957). All of these and many other processes tend to
weaken the structure such that $^*Ar^{40}$ may diffuse out of
its metastable site.

The difference between the muscovite age (1820 ± 50
m.y.) and the biotite age (1650 ± 40 m.y.) is more diffi-
cult to explain. The greater retentivity of muscovite
relative to biotite for $^*Ar^{40}$ has been observed in lab-
oratory diffusion studies by Gerling and Morozova (1957),
but most cogenetic micas in granites yield the same age
(Ramberg, 1963).

Certainly the data indicate some post-emplacement
history did occur but was not severe enough (at least
after 1800 m.y.) to cause a complete loss of $^*Ar^{40}$ from
all primary phases. Further the ages confirm the Precam-
brian origin of the granite as well as its suspected
pre-Beltian origin postulated by Seager (1944).

<div align="center">Rubidium-Strontium
Age Dating</div>

Introduction
Natural Strontium contains four stable isotopes: Sr^{84},
Sr^{86}, Sr^{87}, and Sr^{88}. Natural Rubidium contains one stable
isotope, Rb^{85}, and one radioactive isotope, Rb^{87}, which de-
cays by beta-minus emission to $^*Sr^{87}$. Therefore in a
closed system the relative abundance of Sr^{87} increases with
time. It is convenient to measure both Sr^{87} and Rb^{87}
relative to Sr^{86} in the laboratory (see discussion in
Brookins, 1963). A plot of several samples of the same
age but of different Rb/Sr ratios will define a slope

equal to t (where t=age and λ =decay constant for Rb^{87}= 1.39 x $10^{-11}yr^{-1}$). This results from the standard age formula for the Rb-Sr method:

$$t = \frac{(Sr^{87}/Sr^{86})_{present} - (Sr^{87}/Sr^{86})_{initial}}{\lambda \ (Rb^{87}/Sr^{86})_{present}}$$

The present isotopic ratios Sr^{87}/Sr^{86} and Rb-87/Sr-86 are directly measurable, but the initial Sr(87/86) ratio is not. Thus in order to calculate an age at least two samples (whole rock subsystems) of the rock unit (megasystem) must be analyzed so that the initial Sr(87/86) ratio can be determined graphically (see Brookins, 1963, and Shields, 1964).

During any post-emplacement history involving a thermal event $^{*}Sr^{87}$ may diffuse from its original site. Unlike $^{*}Ar^{40}$ however $^{*}Sr^{87}$ is generally not removed from the megasystem but is instead redistributed among the recrystallizing phases within the subsystems. Thus a Rb-rich Ca(and Sr)-poor mineral such as biotite will lose $^{*}Sr^{87}$ and a Ca-rich Rb-poor mineral such as plagioclase will gain $^{*}Sr^{87}$. It must be again emphasized that the $^{*}Sr^{87}$ is not removed from the subsystems. Thus two more whole rock samples may yield the true age of emplacement of the rock in question, and the minerals the age of the last metamorphism (see discussion in Brookins, 1963).

Work in Progress

Several samples have been prepared chemically for Rb-Sr age determinations which will be carried out in the Geochronology Laboratory at the Massachusetts Institute of Technology during the summer and fall, 1965. The samples ready for analysis are tabulated in Table 3.

TABLE 3

Samples for Rb-Sr Age Dates

Sample	Description	Type of Analysis Intended
R1022a	Crevasse Mountain granite	whole rock
R1022b.1	do.	whole rock
R1022b.2	do.	whole rock
F1024	do., K-feldspar	mineral
M1024	do., muscovite	mineral
B1024	do., biotite	mineral
R1016	biotite quartzite	whole rock
R1007	quartz-amphibole schist	whole rock

Preliminary Report

A preliminary analysis of R1022b shows a present Sr(87/86) ratio of 0.9535 and a Rb/Sr ratio of 2.36 (by quick scan X-ray spectrography). Assuming and initial Sr(87/86) ratio of 0.71 (a reasonable value for Precambrian granites, D. G. Brookins, personal communication) an age of 2500 m.y. is calculated. This age can not be safely applied pending the outcome of subsequent analyses. Moorbath (1962) has demonstrated that granitic intrusions associated with magmatic hydrothermal ore deposits all have very characteristic Sr isotopic abundances, and it is hoped that this phase of the investigation will be fruitful.

SUMMARY AND CONCLUSIONS

The Jardine-Crevasse Mountain area is quite similar to other Gold-bearing Precambrian deposits. Seager (1944) has noted the similarity between this area and the Homestake area, South Dakota and McConnell (1964) has reported on the recently discovered Contwoyto Lake area, Northwest Territories, Canada. This latter deposit consists of Gold-bearing arsenopyrite and pyrrhotite bands in quartz-amphibole schists intruded by a Precambrian granite. In the Jardine-Crevasse Mountain area undisturbed Beltian and

Paleozoic rocks occur nearby which lends support to Seager's (1944) views, but quantitative data has been lacking until this investigation.

The K-Ar age determinations definitely show that the Crevasse Mountain granite is Precambrian and pre-Beltian as well. The low 1180 ± 35 m.y. K-feldspar date is probably due to low grade events occurring after about 1800 m.y. The preliminary 2500 m.y. Rb-Sr whole rock "date" of 2500 m.y. indicates an even older history and, if this is the case; (1) the basement schists may be very old (greater than Cherry Creek?), and (2) a strong thermal event may have occurred at about 1800 m.y. This would explain the gneissic texture and shear effects noted in the granite, as the severity of the textural changes could not have occurred under conditions mild enough to affect only the K-feldspar. This investigation is still under investigation.

The Sulfur isotopic data indicate that:(1) the ores are of a deep seated magmatic hydrothermal origin, (2) there has been no significant post-ore history, (3) the ores are Precambrian and probably associated with the emplacement of the Crevasse Mountain granite, (4) the native Sulfur and melanterite occurring in some of the ore samples have been locally derived due to their higher δS^{34} values than their associated sulfides, and (5) the diabase and gabbro are probably not genetically related to the granite.

More investigation is needed, viz: (1) more Rb-Sr data as to the original source of the granite, (2) more Sulfur isotopic data on the disseminated sulfides in granite, (3) geochemical studies on the supergene processes, and (4) the exact relationship of the mafic rocks to the granite and to the ores.

ACKNOWLEDGMENTS

APPENDIX
Sample Descriptions

Number	Description
1002	Hydrothermally altered diabase. Sample taken from the center of a 20 foot wide dike 15 feet south of and parallel to a prospect tunnel which follows a zone of alteration in soft, fissle chlorite schist. The rock consists chiefly of plagioclase (An_{50}) and uralitic hornblende after pyroxene in nearly equal amounts. Other minerals include biotite, quartz, epidote, chlorite, magnetite, and ilmenite. The plagioclase grains are penetrated by and partly replaced by fibrous amphibole (see Plate II, no. A).
1003	Diabase from the center of a 40 foot wide dike 200 feet southeast of the Iron Duke Shaft (near 1002).
1004	Oxidized massive ore taken 30 inches from the north contact of the diabase (1002) eight feet below the surface directly above a caved adit which follows the diabase contact. Most of the sulfide has been removed and crack and fissure surfaces are coated with native Sulfur. The presence of original sulfide is indicated in thin section by the presence of numerous crystal ghosts.
1006	Sulfide ore taken from bunker below the North Cut. The sample consists of abundant, well formed crystals of arsenopyrite (up to 1 cm diameter) in chloritized quartz biotite schist that contains pods and lenses of quartz.
1007	Quartz-amphibole (cummingtonite-hornblende) schist from the Iron Duke shaft 30 feet below the surface $2\frac{1}{2}$ feet below sample 1008. This is a dark, dense rock consisting of hornblende, cummingtonite, quartz, arsenopyrite, and some biotite. The arsenopyrite occurs as small (less than .1 mm)

grains replacing cummingtonite (see Plate I, D).

1008   Sulfide ore from the Iron Duke shaft 28 feet below the surface consisting of large (1 cm), well formed crystals of arsenopyrite in a dark matrix of amphibole and quartz (see Plate I, no. C).

1009   Diabase from the South Cut of the Jardine Mine. In contrast to sample 1002, this sample has been intensely sheared as well as hydrothermally altered (see Plate II, nos. C. and D).

1010   Sulfide ore in quartz-biotite schist from the South Cut of the Jardine Mine, sample taken about 20 feet below the surface. Arsenopyrite occurs as small grains throughout the rock which consists of biotite and quartz that is cut by seams of relatively clean quartz. The quartz veins show close irregular folding with crenulations in the biotite (Plate I, nos. E and F).

1011   Oxidized sulfide bearing quartz-biotite schist from the South Cut of the Jardine Mine 15 feet northwest of sample 1009.

1014   Oxidized sulfide ore from the South Cut of the Jardine Mine consisting of highly altered, coarse grained arsenopyrite in a matrix of amphibole and quartz with some pyrite. The rock is stained with melanterite, limonite, and scorodite which fill cavities in reticulate solution channels.

1016   Biotite quartzite from a prospect tunnel 100 feet from the portal to the Jardine Mine; taken about 70 feet below the surface. The rock consists of 70% quartz, 29% biotite, 0.5% arsenopyrite and pyrite.

1017 Laminated quartz-biotite schist from an oxidized zone in the North Cut of the Jardine Mine. The rock contains nearly equal amounts of biotite (some chloritized) and quartz in separate thin (1 mm) lamallae. Limonite is abundant on fissure surfaces and along the lamallae. Most of the sulfide has been removed by supergene oxidation and solution.

1019 Sulfide-quartz ore from an irregular two to six inch wide arsenopyrite rich quartz vein enclosed in chloritized quartz-biotite schist from the First Chance mine on Crevasse Mountain.

1022 Biotite-muscovite granite from the southwest slope of Crevasse Mountain about 1500 feet from the granite-schist contact. The rock is light grey in color and medium grained. It consists of microperthite, microcline, some orthoclase, quartz, and nearly equal amounts of muscovite and biotite (5% each). Thin section shows granulation and the quartz shows pronounced strain effects.

1024 Biotite-muscovite granite from the southwest slope of Crevasse Mountain about 1000 feet south of sample 1022 and 1000 feet from the granite-schist contact.

1026 Sulfide ore from 4 feet below the surface in the Iron Duke shaft of the Jardine Mine, similar to sample 1008.

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GENESIS OF THE ORES OF THE
JARDINE-CREVASSE MOUNTAIN AREA,
PARK COUNTY, MONTANA

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

The Jardine-Crevasse Mountain district, Park County, Montana has been investigated by means of Sulfur isotopy and Potassium-Argon age determinations as well as by petrographic and mineragraphic methods.

Most of the area is underlain by complex units of Precambrian schists and quartzite intruded by dikes and sills of diabase, irregular masses of gabbro, and a large mass of granite. The granitic intrusion was accompanied by ore deposition and hydrothermal alteration, and is thought to be the last Precambrian event (according to Seager, 1944). Post-Precambrian events include sedimentation through Paleozoic and Mesozoic time followed by uplift of the Beartooth-Absaroka plateau during the Laramide Orogeny. These events were followed by erosion and Tertiary vulcanism. Deposition of alluvial and glacial sediments were the last geologic events affecting the area.

K-Ar age determinations have been made on the granite yielding dates of 1820 ± 50 m.y. for muscovite, 1650 ± 40 m.y. for biotite, and 1180 ± 35 m.y. for K-feldspar. The muscovite date represents a minimum age of emplacement for the granite, and the K-feldspar date indicates the end of the last metamorphic event in the area.

Sulfur isotopic ratios were determined for twelve samples from sulfide veins, disseminated sulfide ores, siliceous ore veins, and disseminated sulfides in host rocks. In addition, single samples from supergene native Sulfur and melanterite ($FeSO_4 \cdot 7H_2O$) were also analyzed. The isotopic composition of all samples fall in a range of $+ 1.0$ to $+ 4.7$ δS^{34}. The average composition of $+ 3.0$ δS^{34} is near the average of $+ 3.6$ δS^{34} for all previously investigated sulfides of magmatic hydrothermal origin.

In support of other evidence the Sulfur isotopic ratios

and age determinations indicate that: (1) the ores are
of magmatic hydrothermal origin and are probably related to
the granite, (2) the granite and related ores are of Pre-
cambrian age, (3) there has been no significant post-depositional
Sulfur isotopic fractionation or remobilization of the ore
sulfides, and (4) post-ore alteration, though locally impor-
tant, was not extensive and thus the supergene minerals have
been locally derived.