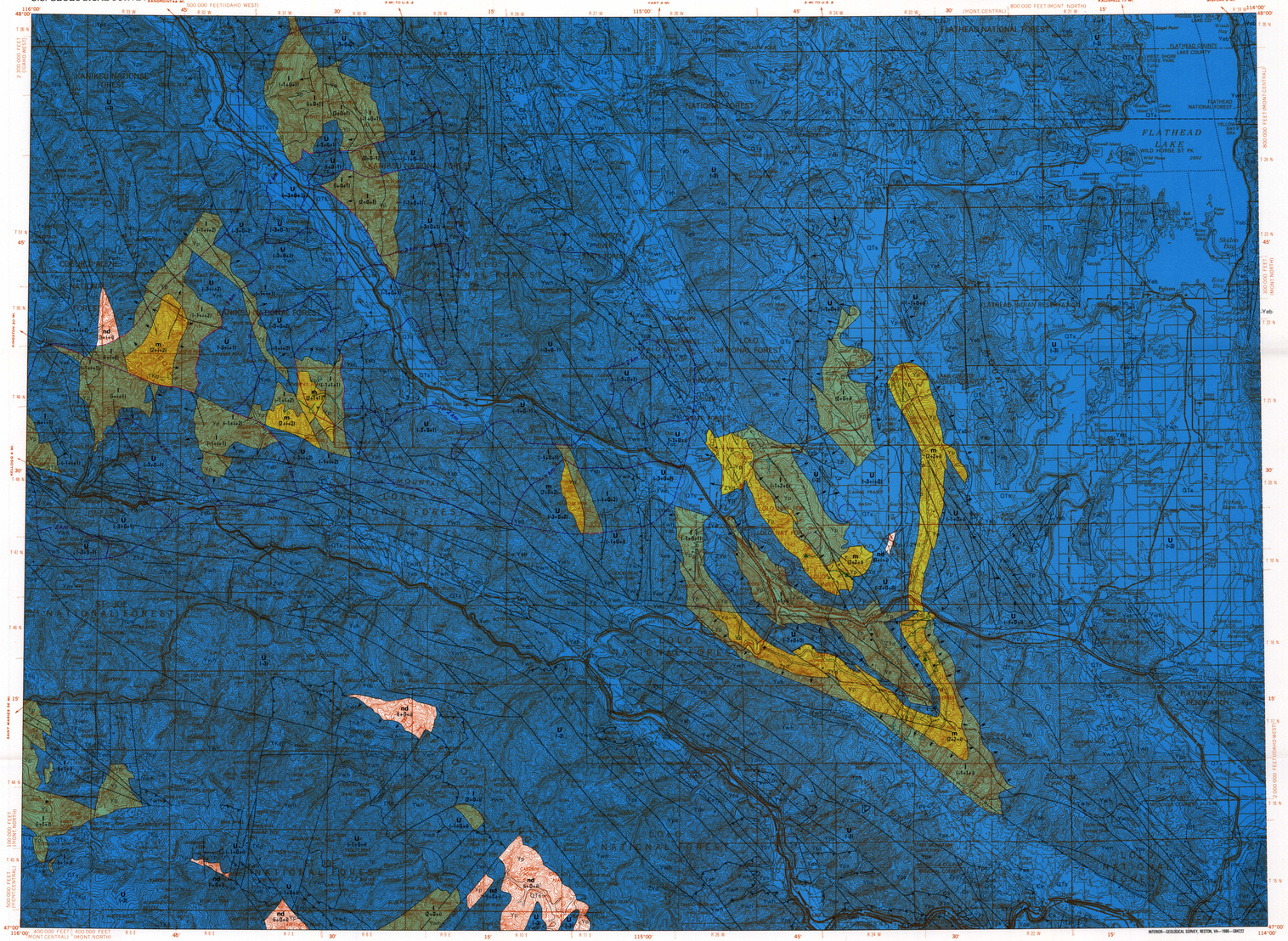
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
MONTANA BUREAU OF MINES AND GEOLOGY

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I–1509–G



Base from U.S. Geological Survey, 1956, revised 1981

SCALE 1:250 000

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRANGLE LOCATION

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA.—1986—G84222

Geology by J.E. Harrison, A.B. Griggs, and J.D. Wells, 1970–80; assisted by H.R. Covington, 1972, Joseph Boggs, 1973; and J.F. Harrison, 1970–80. Resource appraisal data compiled by J.E. Harrison, 1981

CORRELATION OF MAP UNITS

QTs		QUATERNARY AND TERTIARY
Tv		TERTIARY
TKg, TKd		TERTIARY AND CRETACEOUS
Unconformity		
Cs		CAMBRIAN
Unconformity		
Zyd	Belt Supergroup	LATE AND MIDDLE PROTEROZOIC
Yps	Missoula Group	MIDDLE PROTEROZOIC
? Ywh		
Yeb	Ravalli Group	
Yp		
Unconformity		
Xag		EARLY PROTEROZOIC

DESCRIPTION OF GEOLOGIC MAP UNITS

QTs VALLEY FILL DEPOSITS (QUATERNARY AND TERTIARY)— Alluvium, glacial deposits, and semiconsolidated to consolidated conglomerate interlayered in places with shale, coal, and volcanic ash; shown only in major valleys and basins or along main stream courses

Tv VOLCANIC ROCKS (TERTIARY)—Largely andesitic to dacitic welded tuff

TKg GRANITIC INTRUSIVE ROCKS (TERTIARY AND CRETACEOUS)

TKd DIORITIC INTRUSIVE ROCKS (TERTIARY AND CRETACEOUS)

Cs SEDIMENTARY ROCKS (CAMBRIAN)—Includes Red Lion Formation, Hasmark Dolomite, Silver Hill Formation, Flathead Quartzite, and equivalent rocks

Zyd DIORITIC TO GABBROIC SILLS AND DIKES (LATE AND MIDDLE PROTEROZOIC)

Yps MISSOULA GROUP (MIDDLE PROTEROZOIC)—Includes Pilcher, Libby, Garnet Range, and McNamara Formations, Bonner Quartzite, and Striped Peak, Mount Shields, Shepard, and Snowslip Formations

Ywh WALLACE AND HELENA FORMATIONS (MIDDLE PROTEROZOIC)

Yeb RAVALLI GROUP (MIDDLE PROTEROZOIC)—Includes Empire, St. Regis, Spokane, Revett, and Burke Formations

Yp PRICHARD FORMATION (MIDDLE PROTEROZOIC)

Xag ANORTHOSITE, SCHIST, AND GNEISS (EARLY PROTEROZOIC)

CONTACT

FAULT—Dotted where concealed. Bar and ball on downthrown side; arrows show relative direction of apparent horizontal movement

THRUST FAULT—Dotted where concealed. Sawteeth on upper plate

Note: The generalized and simplified geologic map was prepared as an underlay for various geophysical and geochemical data collected in the Wallace 1° x 2° quadrangle. A fuller treatment of geologic units and structure can be found on map I–1509–A in the Wallace CUSMAP folio.

This map is part of a folio of maps of the Wallace 1° x 2° quadrangle, Montana-Idaho, prepared under the Conterminous United States Mineral Assessment Program (CUSMAP). Background information about this folio is published in U.S. Geological Survey Circular 920.

OCCURRENCE MODEL FOR SULLIVAN-TYPE STRATABOUND LEAD-ZINC-SILVER DEPOSITS

REGIONAL SETTING

A major deposit of stratabound lead-zinc-silver occurs at the Sullivan mine, Kimberly, British Columbia, about 150 km north of the Wallace quadrangle. Our description of the occurrence model is based on that deposit, and our rating scales for favorable ground use the Sullivan ore body as a comparative model. We are grateful for discussions with several staff members of Cominco, Ltd., and Cominco American, Inc., concerning the geologic, geochemical, and geophysical characteristics of the Sullivan deposit.

The Sullivan ore is in a deep-water facies of the Middle Proterozoic Aldridge (equals Prichard) Formation of the Purcell (equals Belt) Supergroup. Thick gabbroic to dioritic sills intrude the Aldridge. All host rocks are metamorphosed to upper greenschist or lower amphibolite facies. This stratigraphic unit is found at places throughout the 130,000 km^2 of Belt terrane in the northwestern United States and adjacent parts of Canada. A major west-trending crustal flaw appears to trend through the Sullivan area. North-trending faults bound the deposit.

DEPOSIT CHARACTERISTICS

The Sullivan ore body is at the base of the middle part of the Aldridge Formation just above a megabreccia and a conglomerate. Host rocks are gray turbidites interlayered with evenly laminated black and gray argillites that form marker beds ranging in thickness from less than three feet to several tens of feet. These marker beds can be traced across hundreds of square kilometers and are identified in outcrop by the distinctive pattern of their varvelike laminations. Some marker beds and black argillites between turbidites are highly pyrrhotitic.

Mafic sills and a few dikes intrude the turbidite sequence but are not clearly shown to cut or be cut by the ore. They are, however, characteristic of the Prichard Formation throughout its known exposures. One sill south of the ore deposit but in the same stratigraphic position yields a zircon age of 1,430 million years (m.y.), which is believed to represent the minimum but approximate age of the Sullivan deposit.

The ore body is more or less tabular, is massive on the west end, and gradually becomes a series of highly continuous strata to the east. Some strata are composed of alternating lead and zinc layers that contain small folds having axial-plane cleavage. The ore body has a zone of black tourmaline below and a zone of albite above. Cassiterite-bearing veins cut the ore body.

Lead isotopes from the ore body are interpreted to represent two-stage crustal lead, the original lead being derived by homogenization of pre-Belt lead from the crystalline rocks that were source terranes for Belt rocks, followed by a "hot brine" leaching of that lead from lower Aldridge to form sea-floor ores in the middle Aldridge. Isotopic data suggest that the sulfur was derived from bacterial reduction of sea-water sulfate. Ore fluids are believed to have come up along fractures and spilled onto a deep basin floor, where distal turbidites and pyritic black argillite laminites were being deposited in varvelike couplets. Either abundant sills or a deeper intrusive mass provided heat to drive the fluid circulation, and faults penecontemporaneous with sedimentation provided fluid channels.

ORE CHARACTERISTICS

Principal minerals in the Sullivan ore are galena, sphalerite, pyrite, and pyrrhotite. Minor constituents include chalcopyrite, arsenopyrite, magnetite, cassiterite, boulangerite, jamesonite, and tetrahedrite. Part of the ore is massive, but part is laminated in continuous layers 1 km in length. Laminated ore contains small fold and boudin structures and alternates with waste bands of metasedimentary rocks.

The ore body is zoned in a domelike system. From the core and basal zone outward are zones of pyrrhotite, then arsenopyrite and cassiterite, then galena, sphalerite, and silver, then sphalerite and galena, and, finally, an outer zone of antimony-bearing sulfides.

GEOCHEMICAL CHARACTERISTICS

The Sullivan ore body has a trace-element signature of anomalous lead, zinc, silver, antimony, copper, tin, arsenic, and boron. Some work by the Cominco, Ltd., staff (Freeze, 1966) suggests that manganese may also be anomalous in or near the deposit.

GEOPHYSICAL CHARACTERISTICS

The Sullivan ore body is a large massive sulfide that can be detected by detailed gravity surveys, but is small enough to be missed by reconnaissance surveys. The ore body has a high (unspecified) electrical conductivity and can be detected by several types of electrical and electromagnetic methods.

RESOURCE DATA

The Sullivan ore body has an average grade of 6 percent lead, 5 percent zinc, and 2.5 ounces of silver per short ton. Production from the mine to 1976 was about 130 million short tons of ore that contained 7.5 million tons of lead, 6 million tons of zinc, and 250 million ounces of silver. Significant byproducts have included arsenic, sulfur, antimony, and tin.

RATING SCALE

Sullivan-type ore bodies, though possible in the Wallace quadrangle, have not yet been found. We assume that if such bodies do exist, they have geologic, geochemical, and geophysical characteristics similar to those of the Sullivan ore body. For the rating scale, geologic factors are based on the geologic setting of the Sullivan mine. Specific geochemical and geophysical data for the Sullivan area are not in the public domain. For geochemical characteristics, we use only lead, zinc, and silver as signature elements. Our rock and stream-sediment samples contain anomalous lead and zinc in many samples, but we have used them as indicators of Sullivan-type stratabound mineralization only where we are reasonably certain that no lead- or zinc-bearing veins could be contributing to the anomaly. Anomalous boron occurs in some samples where tourmaline is visible. Because tourmalinization is used as a geologic characteristic, we have not included boron as a geochemical indicator; to do so would give double weight to a single rock feature. For geophysical characteristics, the regional gravity surveys do not have sufficient detail to detect small massive sulfide deposits of the Sullivan type, and gravity has not been considered in our rating scale. Because of the known electrical conductivity of the Sullivan ore, however, one of us (Long) conducted regional audio-magnetotelluric surveys and traverses as an experiment to see whether conductive zones in the Prichard Formation could be detected by such reconnaissance methods. We use results of that experiment in our evaluation for mineral resource potential in the Prichard Formation, even though we recognize that the resistivities we cite and the calculations on depth to a conductive zone are approximate at best. Details of the audio-magnetotelluric data collection and interpretation are given in a separate part of the Wallace CUSMAP folio (see Circular 920).

Geologic characteristics

+4 Prichard Formation consisting of varvelike black argillite laminites, pyritic or pyrrhotitic, interbedded with gray turbidites (deep-basin facies); tourmalinized rock plus albite veinlets or albitized rock

+3 Same as above but without tourmaline and albite

+2 Prichard Formation consisting of black laminated argillite and siltite, graded in part, pyritic or pyrrhotitic; also minor argillite-pebble conglomerate and tourmalinized or albitized rock (moderately deep basin facies)

+1 Prichard Formation consisting of laminated argillite and siltite, graded in part, some cut-and-fill structures, minor pyrite, interbedded with turbidite; large soft-sediment slump structures (slope facies); tourmalinized rock common

0 Same as +1 but without tourmaline

−1 Prichard Formation consisting of black, uneven to evenly bedded laminated argillite and siltite, interbeds of siltite; some small-scale sedimentary structures including mud cracks; may be pyritic in places (outer-shelf to shallow-water facies)

−2 Prichard Formation consisting of gray interbedded and interlaminated argillite, siltite, and quartzite; crossbeds, ripple marks, cut-and-fill structures (shallow-water facies)

−3 Map units other than the Prichard Formation

Geochemical anomalies

+3 Anomalous lead, zinc, and silver in stream sediments or rock samples

+2 Anomalous lead and zinc in stream sediments or rock samples

+1 Anomalous lead or zinc in stream sediments or rock samples

0 No anomalous lead or zinc in stream sediments or rock samples

Geophysical characteristics

+4 Electrically conductive zone in Prichard Formation having resistivity of less than 30 ohm-meters and less than 1 km below surface

+3 Same as above but greater than 1 km below surface

+2 Electrically conductive zone in Prichard Formation having resistivity between 30 ohm-meters and 300 ohm-meters and less than 1 km below surface

+1 Same as +2 but greater than 1 km below surface

0 Poorly defined conductive zone within 1 km of surface below Prichard Formation

−1 Same as above but deeper than 1 km below surface

−2 No conductive zone identifiable in Prichard Formation

Known resources

No known resources have been identified yet within the Wallace quadrangle.

SCALE VALUES

The confidence-favorability diagram based on the scale values for Sullivan-type stratabound lead-zinc-silver deposits is given in figure 1.

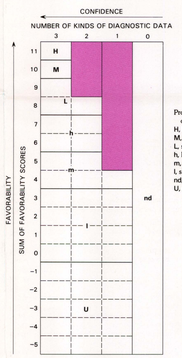


Figure 1.—Confidence-favorability diagram for Sullivan-type stratabound lead-zinc-silver deposits.

DISCUSSION

Our appraisal for Sullivan-type lead-zinc-silver deposits depends heavily on an occurrence model based on the unique world-class Sullivan ore body. Perhaps as a consequence, the most favorable ground we identify in the Wallace quadrangle is classified as moderately suggestive ("m"). If Sullivan-type ore bodies occur in small, less than world-class, deposits, then the criteria we are using based on a unique world-class body may be too specific or too restrictive to identify highly favorable ground for any but the largest deposits. In other words, areas we identify as moderately suggestive ("m") for a world-class ore body may actually be moderately diagnostic ("M") for a smaller ore body. Borehole exploration could provide an answer as to whether our "m" should be "M" or even "H."

Another complication in accurate appraisal arises in areas, such as the Coeur d'Alene district, where the geochemical signature from the many mesothermal veins carries abundant lead, zinc, and silver. This signature may mask any contribution from a Sullivan-type stratabound ore deposit. In appropriate areas we have used "/" (incomplete data) for the geochemical score in our rating formula, because we cannot be certain that our geochemical signature has a contribution from Sullivan-like occurrences. If such a contribution does exist, the score for favorability could be increased by as much as three points.

EXPLANATION FOR RESOURCE APPRAISAL

ROCK SAMPLE CONTAINING AN ANOMALOUS AMOUNT OF LEAD OR ZINC

STREAM-SEDIMENT SAMPLE AND TRACE OF DRAINAGE SAMPLED—Sample contains anomalous lead and zinc

STREAM-SEDIMENT SAMPLE AND TRACE OF DRAINAGE SAMPLED—Sample contains anomalous lead or zinc

AREA OF RECONNAISSANCE AUDIO-MAGNETOTELLURIC (AMT) SURVEY

1 km HIGHLY GENERALIZED AMT CONTOUR ON CONDUCTIVE ZONE IN THE PRICHARD FORMATION—Contour shows depth in kilometers from surface to conductive zone; hachures point in direction of increasing depth

ADDITIONAL AMT SOUNDING SITE AND APPROXIMATE AREA OF SURFACE THAT INFLUENCES THE READING

AREA OF INCOMPLETE GEOCHEMICAL DATA

LITHOLOGIC CONTACT SHOWING DIRECTION OF DIP OF MORE FAVORABLE UNIT INTO SUBSURFACE BELOW LESS FAVORABLE UNIT AND OUTLINE OF GROUND FAVORABLE OR UNFAVORABLE FOR STRATABOUND LEAD-ZINC-SILVER DEPOSITS—Short arrow, dip greater than 30°; long arrow, dip less than 30°; no arrow, nearly horizontal units or units bounded by faults having major displacement

m (2++2) RESOURCE APPRAISAL BASED ON RATING SCALE GIVEN IN TEXT— Values in parentheses are maximum for outlined area and are listed in order of geology, geochemistry, and geophysics (AMT data)

nd (++0++) AVAILABLE DATA ARE NOT DIAGNOSTIC FOR EITHER FAVORABLE OR UNFAVORABLE GROUND—Used when all parts of formula are either 0 or i

U (−3++0) UNFAVORABLE AREA—A single number in parentheses indicates unfavorable ground based on geologic characteristics alone

i INCOMPLETE DATA OR, FOR THE WEST-CENTRAL AREA, INABILITY TO DISTINGUISH WHETHER LEAD OR ZINC ANOMALIES IN STREAM SEDIMENTS ARE DUE TO ABUNDANT LEAD-ZINC VEINS IN THE AREA OR ARE DUE TO ANOMALOUS LEAD OR ZINC IN POSSIBLE STRATABOUND OCCURRENCES IN THE PRICHARD FORMATION

PROBABILITY FOR OCCURRENCE OF STRATABOUND LEAD-ZINC-SILVER DEPOSITS

m Moderately suggestive

l Slightly suggestive

nd No diagnostic data

U Unfavorable

GENERAL REFERENCES

Campbell, F. A., Ethier, V. G., Krouse, H. R., and Both, R. A., 1978, Isotopic composition of sulfur in the Sullivan orebody, British Columbia: Economic Geology, v. 73, no. 2, p. 246–268.

Earhart, R. L., Van Loenen, R. E., and Whipple, J. W., 1980, Unpublished U.S. Geological Survey data on mineral resources of the Flathead Indian Reservation, Montana.

Ethier, V. G., and Campbell, F. A., 1977, Tourmaline concentrations in Proterozoic sediments of the southern Cordillera of Canada and their economic significance: Canadian Journal of Earth Sciences, v. 14, no. 10, p. 2348–2363.

Ethier, V. G., Campbell, F. A., Both, R. A., and Krouse, H. R., 1976, Geologic setting of the Sullivan orebody and estimates of temperatures and pressure of metamorphism: Economic Geology, v. 71, no. 8, p. 1570–1588.

Freeze, A. C., 1966, On the origin of the Sullivan ore body, Kimberley, B. C., *in* Tectonic history and mineral deposits of the western Cordillera: Canadian Institute of Mining and Metallurgy Special Volume 8, p. 263–294.

Harrison, J. E., Griggs, A. B., and Wells, J. D., 1981, Generalized geologic map of the Wallace 1° x 2° quadrangle, Montana and Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF–1354–A.

Irvine, W. T., Gondi, J., and Sullivan Mine Geologic Staff, 1972, Major lead-zinc deposits of western Canada: International Geological Congress, 24th, Ottawa, Canada, 1972, Guidebook, Field Excursions A24–C24, 36 p.

Leach, D. L., Hopkins, D. M., Domenico, J. A., and Dawson, H. E., 1983, Distributions of total lead in samples of nonmagnetic heavy-mineral concentrate and of total and partially extractable lead in samples of stream sediment from the Wallace 1° x 2° quadrangle, Montana and Idaho: U.S. Geological Survey Open-File Report 83–304.

Leach, D. L., Hopkins, D. M., Domenico, J. A., and Goldfarb, R. J., 1983, Distributions of total zinc in samples of nonmagnetic heavy-mineral concentrate and of total and partially extractable zinc in samples of stream sediment from the Wallace 1° x 2° quadrangle, Montana and Idaho: U.S. Geological Survey Open-File Report 83–308.

Long, C. L., 1983, Map showing results of audio-magnetotelluric studies in the northwestern part of the Wallace 1° x 2° quadrangle, Montana and Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF–1354–B.

Long, C. L., Tippens, Charles, and Lewis, Vernon, 1981, Audio-magnetotelluric data log and station-location map for part of the Wallace 1° x 2° quadrangle, Montana and Idaho: U.S. Geological Survey Open-File Report 81–1153.

Thompson, R. I., and Panteleyev, Andrejs, 1976, Stratabound mineral deposits of the Canadian Cordillera, *in* Wolf, K. H., ed., Handbook of stratabound and stratiform ore deposits: Amsterdam, Elsevier Scientific Publishing Company, p. 37–108.

RESOURCE APPRAISAL MAP FOR SULLIVAN-TYPE STRATABOUND LEAD-ZINC-SILVER DEPOSITS IN THE WALLACE 1° x 2° QUADRANGLE, MONTANA AND IDAHO

By
Jack E. Harrison, Earle R. Cressman, Carl L. Long,
David L. Leach, and James A. Domenico
1986

MONTANA BUREAU OF MINES AND GEOLOGY
MONTANA ATLAS SERIES
MA 4–G

For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225