CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
520-770-3500
http://www.azgs.az.gov
inquiries@azgs.az.gov

The following file is part of the

James Doyle Sell Mining Collection

ACCESS STATEMENT

These digitized collections are accessible for purposes of education and research. We have indicated what we know about copyright and rights of privacy, publicity, or trademark. Due to the nature of archival collections, we are not always able to identify this information. We are eager to hear from any rights owners, so that we may obtain accurate information. Upon request, we will remove material from public view while we address a rights issue.

CONSTRAINTS STATEMENT

The Arizona Geological Survey does not claim to control all rights for all materials in its collection. These rights include, but are not limited to: copyright, privacy rights, and cultural protection rights. The User hereby assumes all responsibility for obtaining any rights to use the material in excess of "fair use."

The Survey makes no intellectual property claims to the products created by individual authors in the manuscript collections, except when the author deeded those rights to the Survey or when those authors were employed by the State of Arizona and created intellectual products as a function of their official duties. The Survey does maintain property rights to the physical and digital representations of the works.

QUALITY STATEMENT

The Arizona Geological Survey is not responsible for the accuracy of the records, information, or opinions that may be contained in the files. The Survey collects, catalogs, and archives data on mineral properties regardless of its views of the veracity or accuracy of those data.

ASARCO

Southwestern Exploration Division

WAK

March 28, 1983

Library Note

Karst Theses
Limestone Replacement Search

Mr. D. M. Smith, Jr. has sent down the attached list of "Karst Theses and Dissertations: U.S. & Canada."

The ASARCO Library has two theses germane to this problem of karst-ore.

Posada, J.H., 1973: Karst-Related Features and Controls on Ore Mineralization in the Leadville Formation, Central Colorado. M.S., Colorado School of Mines, 107 p.

Johansing, R.J., 1982: Physical-Chemical Controls of Dolomite Hosted Sherman Type Mineralization, Lake and Park Counties, Colorado. M.S., Colorado State University, 158 p. (This thesis is not in the attached list.)

James D. Sell

James D. Sell

JDS:mek
Att.

cc: Staff (w/o att.)

ASARCO

Southwestern Exploration Division

March 23, 1983

To: D. M. Smith, Jr.

From: J. D. Sell

Moly-Tin-Tungsten
Limestone Replacement Program
AZ-CO-UT

A copy of your note on Tin Occurrences of SW New Mexico (March 16, 1983) skidded across my desk.

As I had a few compilations readily available on the Limestone Replacement Program which I covered in Arizona, Colorado, and Utah, I thought perhaps some results would be of interest to you.

These are mostly from Skyline 31-element spec analyses. I used 5 ppm or greater Mo, greater than 10 ppm Sn, and greater than 50 ppm W for anomalous. Most, of course, are from limestones and dolomites, some zebras, et al.

Area	No. of Samples	No. of Anomalous Samples		
		Mo	Sn	W
Queen Creek, near Magma Mine, Superior, AZ	7	3	-	-
Colorado Compilation Report of Sept. 20, 1978				
Table 1	4	-	-	-
Table 2A	6	-	-	-
Table 2B	10	3	-	-
Table 3	23	2	-	-
Table 4	27	17	6	-
Table 5	9	7	-	-
Table 6	8	1	-	-
Table 7	6	3	1	-
Table 8	6	2	-	-
Table 9	8	1	-	-
Table 10a	11	2	-	-
Table 10, Smelter Slag	1	1	1	-
Bonanza Area, Colorado by D. Krasowski?	18	1	-	-

Area	No. of Samples	No. of Anomalous Samples		
		Mo	Sn	W
Black Cloud Unit, CO; March 5, 1979; Underground BC-Series	79	38	1	-
Antelope Mtn., Millard Co., UT. Magnum Resources 1981-1982	199	11	7	-
Dugway Project, Tooele Co., UT. 1982				
A. Yellow Jacket-Buckhorn	231	64	14	1*
B. West Fandangle Canyon	104	-	-	-
C. Fandangle Area	124	5	-	-
D. South Dugway	345	2	-	-
Grand Total	1,226	163	30	1

*The sample DG-904 was of a porphyry, dump sample, with pyrite, copper, and ran 10 Mo, 30 Sn, 100 W.

James D. Sell

James D. Sell

JDS/cg

cc: WLKurtz

JDS

ASARCO

Rocky Mountain
Exploration Division

February 18, 1983

WLK File: Carbonate Replacement

FILE MEMORANDUM

Ages of Massive-Sulfide Deposits
Occurring as Replacements in
Carbonate Rocks, Especially in
Southern New Mexico

Based on a long-standing correlation with Laramide igneous activity, Lovering, Tweto, and Lovering (1978) infer as reasonable a Laramide age for some or all of the following Colorado Zn-Pb-Ag deposits: Gilman, Leadville, Kokomo, Breckenridge, Alma, and Aspen. Emplacement of the porphyry copper at Chino, New Mexico occurred 59 m.y. ago (Titley, 1982) and thus the age of the associated Zn-Pb-Ag replacement deposits is also latest Laramide. This apparent restriction of major massive-sulfide replacement of carbonate rocks within our region of interest, with or without the formation of an adjacent porphyry copper deposit, to the time span encompassed by the Laramide orogeny seemed to me to bode ill for many of our current exploration projects in southwestern New Mexico where volcanic rocks hosting "leakage" mineralization range in age from 45 to 33 m.y. (Seager et al., 1982). Granodiorite porphyry of the small Cooke's Peak mining district has been dated at 38.8 ± 1.4 m.y. (Seager et al., 1982) and perhaps confirms the fear that post-Laramide age means low-yield ore deposits of this type. (It should be remembered, however, that at Cooke's Peak over 1,000 ft. of carbonate section remains untested below the historical productive zone.)

New and old information from locations both north and south of New Mexico suggest that the ages of igneous and hydrothermal events in the Cooke's Peak region, including the Macho and Old Hadley mining districts, may actually be close to an optimum for major replacement deposits from Colorado southward to the volcanic axis of Mexico. Unpublished work by C.W. Naeser (T.B.Thomspon, pers. com.) of the U.S.G.S. at Gilman has yielded a 33 ± 0.6 m.y. fission-track age for euhedral apatite crystals growing in vugs contained in ore. Fission-tract ages of the Gilman Sill increase outward from the mineralized zone and are Laramide in the unaltered intrusive. Sanidine from the post-ore Eureka rhyolite pipe and zircon from pre-mineral Pando Porphyry, both collected in the Leadville district, have been dated (K/Ar) at 38.5 ± 0.6 m.y. and 47.0 ± 3.9 m.y., respectively (Cunningham et al., 1977). A mid-Eocene to mid-Oligocene age is thus indicated for the Leadville-type deposits. The ages of all four major deposits which have been dated in northern Mexico (see attached map) also fall within this interval. The biotite-quartz-latite porphyry stock around which replacement orebodies and veins are clustered at Charcas has a K/Ar age of 46.6 ± 1.6 m.y. (Butler, 1972). At Providencia

RECEIVED
FEB 22 1983
EXPLORATION DEPARTMENT

xc: JDS 2/24/83

Buseck (1966) obtained K/Ar dates of 40.0 ± 1.2 m.y. for the granodiorite stock adjacent to the monstrous ore chimneys and 38.0 ± 1.1 m.y. for adularia in late-stage veins. An alaskite dike controlling mineralization in the Second Manto at Naica yielded a whole-rock K/Ar age of 25.9 ± 0.6 m.y. (Clark et al., 1979). Finally, at Santa Eulalia Clark and others (1979) have made K/Ar determinations for a pre-ore diabase dike (whole rock, 37.0 ± 0.8 m.y.) and a rhyolite porphyry sill (26.7 ± 0.6 m.y.) believed to be penecontemporaneous with ore.

Douglas M. Smith, Jr.

DMS:lb
Att.

cc: FTGraybeal)
WLKurtz)
DIFletcher) w/att.
PJBartos)

REFERENCES

Buseck, P.R., 1966, Contact metasomatism and ore deposition: Concepcion del Oro, Mexico: Econ. Geol., v. 61, p. 97-136.

Butler, J.H., 1972, Geology of the Charcas mineral district, San Luis Potosi, Mexico: Unpub. M.S. thesis, Colo. Sch. Mines, 169 p.

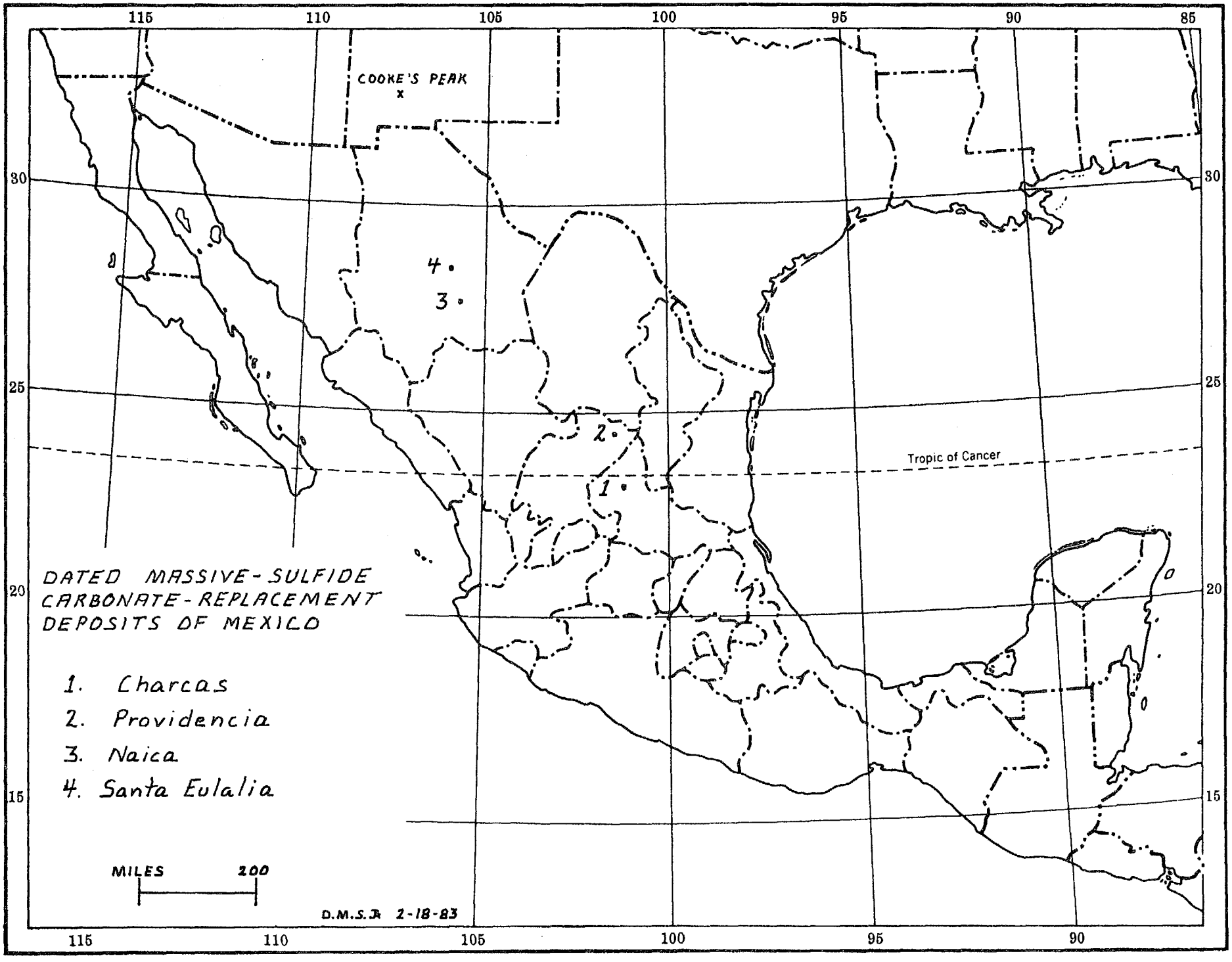
Clark, K.F., Carrasco, C., M.L., Damon, P.E., and Sandoval S., H., 1979, Posicion estratigrafica y distribucion en tiempo y espacio de mineralizacion en la provincia de la Sierra Madre Occidental, en Durango, Mexico: Assoc. de Ing. Min. Met. y Geol. de Mexico, XIII Conv. Nac. en Acapulco, Mem. Tec. XII, p. 197-244.

Cunningham, C.T., Naeser, C.W., and Marvin, R.F., 1977, New ages for intrusive rocks in the Colorado mineral belt: U.S. Geol. Surv. Open File Rept. 77-573, 7 p.

Lovering, T.S., Tweto, O., and Lovering, T.G., 1978, Ore deposits of the Gilman district, Eagle County, Colorado: U.S. Geol. Surv. Prof. Paper 1017, 90 p.

Seager, W.R., Clemons, R.E., Hawley, J.W., and Kelley, R.E., 1982, Geology of the northwest part of Las Cruces 1° x 2° sheet, New Mexico: New Mex. Bur. Mines & Min. Res., Geol. Map 53.

Titley, S.R., 1982, Geologic setting of porphyry copper deposits in Titley, S.R., ed., Advances in geology of the porphyry copper deposits, southwestern North America: Univ. of Ariz. Press, Tucson, p. 37-58.


115
110
105
100
95
90
85
30
25
20
15
COOKE'S PEAK
x
4
3
2
1
Tropic of Cancer
DATED MASSIVE-SULFIDE
CARBONATE-REPLACEMENT
DEPOSITS OF MEXICO
1. Charcas
2. Providencia
3. Naica
4. Santa Eulalia
MILES
200
D.M.S.R 2-18-83

Copy for: PGV Done 9/20/82
library

FTG, WJK - Summary and Conclusions (att.) may be of interest.

JDS → Lmc file Limestone Replacement

THESIS

FLUID INCLUSIONS AND GEOCHEMISTRY OF SELECTED VEINS AND MANTOS IN THE LEADVILLE DISTRICT, COLORADO

Submitted by

Lesslie Walter Osborne, Jr.

Department of Earth Resources

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring, 1982

RECEIVED

SEP 20 1982

EXPLORATION DEPARTMENT

xc: JDS Lms file

SUMMARY AND CONCLUSIONS

The Leadville District is located in central Colorado and has been a major producer of base and precious metals. Ore occurs in veins and mantos. The majority of the veins are located around the Breece Hill intrusive center. They do not crop out at the surface but were discovered by chance during underground development. Most of the veins strike between N12°W and N27°E, and have steep dips. Mineralization occurs primarily in fissures parallel to sub-parallel to regional faults. The fissures average 213 to 244 meters (700 to 800 feet) in length and 1 meter (3 feet) in width; they have been developed vertically through a few hundreds of meters. The veins are predominantly replacement in origin.

Mantos are large replacement bodies hosted in dolomite. They are responsible for the majority of economic production within the Leadville District. They range in size up to 945 meters (3,100 feet) long, 152 meters (500 feet) wide and 37 meters (120 feet) thick, although present production is from bodies approximately one-third as large.

Two major classes of primary ore exist in the Leadville District. The first class is Au-bearing pyritic ore which occurs in veins and has been responsible for the majority of Au produced in the Leadville District. It consists predominantly of quartz and pyrite with minor amounts of chalcopyrite, galena, sphalerite and Au. Gold and chalcopyrite were deposited with quartz and pyrite, whereas sphalerite and galena were deposited later. The average grade of primary Au is several

tenths of an ounce per ton. Secondary enrichment has increased Au-grade. The second class of ore consists mostly of quartz, pyrite, sphalerite and galena with minor quantities of chalcopyrite, tetranedrite-tennantite and Au. This ore occurs in veins and mantos. Quartz was the first mineral to be deposited. Pyrite and sphalerite occur with the later stages of quartz, and sphalerite replaces pyrite. Galena replaces earlier sphalerite and pyrite. The majority of chalcopyrite was deposited after sphalerite. Tetrahedrite deposition was contemporaneous with and after galena. Gold precipitation post-dates sulfide deposition. Mineralization in the base metal ore veins and mantos was very similar except that some of the mantos contain local mineralized skarn that was replaced by later base metal ore. The range in grade of primary base metal ore is: 4.2 to 9.5 percent Zn, 5.1 to 33.1 percent Pb, 0.105 to 0.15 percent Cu, a few ounces of Ag per ton, and a few hundredths of an ounce of Au per ton. Some of the base metal ore veins are spatially associated with mantos and acted as a channel way for mineralizing fluids.

Primary fluid inclusions from the veins and mantos are small (4 to 8 micrometers) and consist of vapor and liquid phases. They homogenize to liquid at the expense of vapor. Fluid inclusions in the quartz, sphalerite and dolomite are generally ovoid whereas those in barite tend to be angular.

The range in NaCl equivalent weight percent for fluid inclusions from Au-bearing ore, as represented by material from the Ibex, Garbutt, Big Four and Venir veins is 1.6 to 2.4. Fluid inclusions from the Sunday, 504 and Winnie-Luema veins (base metal ore veins) have a range in equivalent weight percent NaCl of 0.4 to 5.2. Those from the mantos

range from 2.4 to 4.0 equivalent weight percent NaCl. The first melting temperatures are similar in each ore type suggesting that the composition of salts in solutions is similar. The similarities of the salinities in the fluid inclusions from the different ores indicates that the different classes of ore were deposited by one pulse of hydrothermal fluids.

Average homogenization temperatures of fluid inclusions from quartz coeval with pyrite and early sphalerite in the Au-bearing pyritic ore and the base metal ore are 355 and 315°C, respectively. Temperatures of homogenization for fluid inclusions in sphalerite from the base metal ore are approximately 300°C and lie within the range of those in quartz. The difference in homogenization temperature between the different ore types agrees with relative temperatures indicated by mineral assemblages. An 85°C pressure correction should be added to all homogenization temperatures to obtain the trapping temperature. This pressure correction was obtained from estimates of lithostatic overburden. The trapping temperatures of the Au-bearing pyritic ore and the base metal ore are approximately 440°C and 400°C, respectively.

Trapping temperatures of fluid inclusions from different minerals in the mantos bracket the temperatures of manto mineralization. Early fluids depositing quartz, pyrite and sphalerite were approximately 385 to 400°C. Galena was probably deposited at temperatures similar to those of the quartz, pyrite and sphalerite. The late stage deposition of barite and dolomite was from fluids at approximately 305 to 365°C.

The high temperatures of formation and the presence of chlorine (NaCl) in the ore fluids as indicated by fluid inclusion studies suggests that the metals were transported by chloride complexes. Deposition of the ores occurred with a decrease temperature. The major

reason that there are two different ore types may be due to differences in temperature during mineralization. Experimental studies show that at approximately 440°C, Au will precipitate from Au-chloride saturated complex. Sphalerite at this temperature is two orders of magnitude more soluble than Au. With decreasing temperature below approximately 440°C (and until about 300°C), Au solubility increases and that of sphalerite decreases. It is assumed, therefore, that Au was deposited at 440°C from a Au-chloride saturated solution. Gold solubility had increased in fluids at 400°C (those fluids further from the Breece Hill intrusive center), but sphalerite solubility had decreased to the point of saturation and resultant deposition. The association of galena with sphalerite indicates a similar chemical response. Inference from fluid inclusion trapping temperatures and experimental curves indicates that the concentration of Au in the hydrothermal fluids was 0.04 to 0.08 ppm.

The fluid inclusions have densities greater than the critical density. The Au-bearing pyritic ore was deposited from predominately supercritical fluids, whereas the base metal ore was deposited from subcritical and supercritical fluids.

The Osborne manto has characteristics similar to those of the larger mantos. Semi-quantitative spectrographic analyses of limited, reconnaissance-type samples indicates that elemental concentrations in them are very similar. Moreover, it is a replacement body that is hosted in dolomite with a base metal zone and a pyritic zone. The base metal zone consists mostly of pyrite, sphalerite and galena. The pyritic zone occurs peripheral to the base metal zone and contains mostly pyrite and quartz.

Three geochemical zones occur in the Osborne manto and contain elements that are anomalous relative to the rest of the manto. The Mo zone occupies the southern end of the manto where it is concomitant with the pyritic periphery. It has anomalous amounts of Ba, Be, Ca, Mo, Si, and Sr. The Ba, Ca, and Sr probably are due to relict dolomite. Beryllim and Si values reflect stronger silicification than in the rest of the manto. Molybdenum is probably included in the pyrite, probably when hydrothermal fluid flow was impeded by a siliceous barriet. The Bi zone contains greater amounts of Zn, Pb, Cu, and Cd; however, concentration data are proprietary. Anomalous amounts of Bi and Sn are associated with stronger sphalerite and galena mineralization and are probably contained in these minerals. Anomalous Zr and Y in the Zr zone may be due to undetected relict shaley zones.

The limited sampling of different ore types in the veins and mantos precluded meaningful conclusions of their spectrographic geochemistry.

Information obtained from this study and related work is useful in constructing possible genetic models of mineralization in the Leadville District. Central to the Leadville District is the Breece Hill intrusive complex which intrudes a Paleozoic sedimentary section. Where melt invaded dolomite, skarn mineral assemblages were formed. As the hydrothermal system developed, fluids at approximately 440°C deposited Au-bearing pyritic ore. Some fluids migrated away from the intrusive center along faults and cooled; the temperature of these solutions was about 400°C. Au solubility had increased while sphalerite and galena solubility had decreased; base metal ore was deposited in these relatively cooler environs. Where cooler fluids encountered large masses of dolomite, large replacement mantos were formed. Increased alkalinity of

fluids resulted from this replacement process. This increase in pH of the fluids contributed to the deposition of ore. Fluid inclusion data corroborate mineralogical evidence indicating that the Breece Hill intrusive center is the thermal source for hydrothermal fluids in the Leadville District.

WLK file
Limestone Replacement

August 31, 1982

Mr. James D. Sell, Manager
Southwestern Exploration Division
Tucson Office

Limestone Replacement Exploration

Dear Mr. Sell:

I recently reviewed a few pages from USGS PP 1212-A on the Chitistone Limestone in which the authors infer that zebra textures are a sedimentary-sabkha feature. I will confess I had wondered about this ever since you gave your first limestone alteration field trip 4 or 5 years ago in Colorado. One of the stops on this tour was on the east slope of the Sawatch Range, just east of Fairplay in an area said to be several miles of the nearest show of mineralization. Nevertheless the zebra textures in this area were phenomenally well developed. This and other occurrences of zebra at apparently great distances from mineralization and in a limited stratigraphic interval seemed difficult to explain as hydrothermal features related to a specific mineralization center.

Your notes on the Dugway (August 19) and Homansville (August 18 mapping) contribute further to the question of zebra origin. At Dugway Pass, you note that 3 miles of zebra texture in a single rock type were mapped in an area about 8 miles south of the Dugway Mining District. You suggest this texture was not a direct clue to mineralization but a "further fringe feature". At Homansville you note that linear trends are not present as they are in the main district. Although Mr. Spencer remarks that he saw no alteration in the Ophir or Teutonic carbonates, my review of these two formations on Plate 1 of USGS PP 1024 indicates that too little of these formations are present to permit that kind of conclusion.

To summarize, I wonder if zebra is a product of hydrothermal alteration or a product of diagenesis which is a favorable ore control. Our present limestone replacement program assumes the former. Our approach might differ if the latter applies.

Very truly yours

F. T. Graybeal

F. T. Graybeal

cc: WLKurtz
DMSmith, Jr.

RECEIVED
SEP - 3 1982
EXPLORATION DEPARTMENT

cmc file Carbonate Replacement

ASARCO

RECEIVED

JAN 1 1 1982

EXPLORATION DEPARTMENT

Rocky Mountain
Exploration Division

January 8, 1982

TO: W. L. Kurtz

FROM: D. M. Smith, Jr.

Dolomitization Interrupted by Silicification
Article by Dietrich et. al, 1979

The referenced article (attached) describes outcrop and petrographic evidence for the interruption of dolomitization by silicification during diagenesis immediately following precipitation of the original carbonate. Characteristic of intra-dolomitization silicification are euhedral dolomite rhombs or casts within chert and within silica overgrowths on quartz sand grains which were deposited with the original $CaCO_3$ sediment, zoning of dolomite crystals within chert versus the absence of zoning in dolomite outside silicified zones, anhedral to subhedral form of dolomite grains not encased in silica, and the retention of original clastic shape by quartz sand grains encased by chert as opposed to varying degrees of etching of those exposed to continued dolomitization by alkali or silica-deficient solutions. The recognition of such features could aid in distinguishing diagenetically dolomitized cherty limestone occurring within "dolomitized" hydrothermal mining districts. However, it seems probable that similar intra-event silica-dolomite relationships might have resulted from hydrothermal dolomitization accompanied by the formation of jasperoids. Differences which would allow distinction from shallow burial diagenetic features could be expected to have been introduced by the higher temperature and pressure of a hydrothermal regime. I suggest that a special effort be made to seek out and characterize such phenomena during the course of routine mapping and petrographic work on pertinent deposits.

D. M. Smith, Jr. /lb
D. M. Smith, Jr.

DMS:lb
Att.

cc: FTGraybeal - w/att.
JDSell - w/att.
RJJohansing - w/att.

Dietrich, R.V., Hobbs, C.R.B., and Lowry, W.D., 1979, Dolomitization interrupted by silicification in Silica in sediments: Nodular and bedded chert (E.F.McBride ed.): Soc. Econ. Paleon. and Min. Repring Ser. No. 8, p. 16-33.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 33, NO. 3, PP. 646–663
FIGS, 1–19, SEPTEMBER, 1963

obtained in rather restricted places at any

above the essentially horizontal stylolitic seam above the faulted nodule. White line equals one inch.

W-K file Limestone replacement

F.T.G.

JUL 29 1981

ASARCO

RECEIVED

JUL 1981

EXPLORATION DEPT.

Copies to: WL Kurtz - Tucson
DM Smith - Denver

Eastern Exploration Division

Delbert D. Harper
Manager

RECEIVED
AUG 3 1981
EXPLORATION DEPARTMENT

July 24, 1981

Mr. F. T. Graybeal
New York Office

Following are comments on Beales, F. W., and Hardy, J. L., (1980) Criteria for Recognition of Diverse Dol ....., SEPM Spec. Publ. No. 28, pp. 197-213.

My experience with Mississippi Valley type ores has resulted in considerably different concepts than those described by Beales & Hardy. I do agree that many of the Paleozoic and Precambrian "primary" dolomites may have been developed in hypersaline conditions, but I cannot see the special importance of a direct association of gypsum/anhydrite to ore zones. Rather, the mineralization is usually associated with altered dolomite - that which can be traced laterally to its unaltered equivalent which is usually a high calcium limestone. The ore bearing breccias I have observed do not seem to be attributable to solution of gypsum/anhydrite. Special cases in point mentioned by Beales and Hardy are discussed in the following paragraphs.

In SE Missouri the origin of breccias is inferred by Beales and Hardy to be from removal of gypsum by solution activity. Further the dissolved gypsum was supposedly an original constituent of the "White Rock" facies. In my opinion, there is too poor a spatial relationship of "White Rock" to brecciation to consider the proposals of Beales and Hardy. While breccias do occur in areas of White Rock facies, they also occur in areas where "White Rock" is absent. Breccias occur in parts of the stratigraphic section that is removed from "White Rock", e.g., at West Fork the breccia zone base is some 50 ft. above the White Rock facies with intervening reef and dolarenite sections. Breccias occur stratigraphically below "White Rock" facies in some areas. In no case do I recall a breccia zone immediately overlying "White Rock" which is the spatial relationship needed for the Beales and Hardy concept.

In the Pine Point District, Beales and Hardy make the inference that "Presquilization" developed as a result of solution of gypsum in the original rock. I have observed core and chip samples in the Presqu'ile in an area SW of the Pine Point ore zone and noted that the original rock is a high calcium, bioclastic limestone. The limestone consists of allochems with sparry calcite matrix which converts by some manner of alteration to a coarse grained,

ASARCO Incorporated
Telex No.: WU 55-7354

2640 Broadway, N. E.
Telephone: (615) 525-9536

Knoxville, Tennessee 37917

vuggy dolomite (Presqu'ile facies). Various stages of this conversion can be seen in the samples. This observation is substaniated by statements in Skall (1975) p. 42 as cited in Beales and Hardy's paper. The environment of original rock deposition of the Presqu'ile facies is that of high energy (e.g. reef and arenite) which is not conducive to evaporite deposition. Extensive evaporites occur to the SE of the Presqu'ile facies but this is not the locale of the ore deposits.

In the Tennessee Zinc Districts, the authors have proposed that brines were introducted through a karst system as the method of dolomitization. This concept has some support in that anhydrite and gypsum occur as breccia matrix in some areas. However, the dissolution-affected beds are high calcium limestone units which were originally interbedded with "primary" dolomites.

Most Mississippi Valley type ore deposits are associated with alteration/dissolution of high calcium limestones rather than gypsum units. There is evidence that much of this alteration/ dissolution was developed by karsting. I am therefore not a supporter of Beales and Hardy.

Delbert D. Harper

DDH/gs

ASARCO

RECEIVED
JUN 1 1981
EXPLORATION DEPARTMENT

Rocky Mountain Exploration Division
Douglas M. Smith, Jr.
Manager

May 27, 1981

TO: W. L. Kurtz

FROM: D. M. Smith, Jr.

Recognition of Dolomite Types

The attached paper by Beales and Hardy discusses the criteria for recognizing diverse dolomite types with emphasis on those associated with ore deposits of the Mississippi Valley type. In addition to telling us how to distinguish hypersaline (evaporite) dolomite from the hyposaline or schizohaline (mixing) variety, the authors also explain the probable origin of zebra textures common in many types of limestone replacement deposits.

Tepee (inverted V-shaped zebra) structures are likened to the "buckled margins of saucer-like megapolygons created by the expansion of surface sediments in sabkha zones" which produce hypersaline-type dolomites. Typically low-angle strata-bound zebra textures are common in many dolomites, including those of the Leadville-Weston Pass area of Colorado, and may have been produced by evaporitic wedging along with partial dissolution and reprecipitation of white sparry dolomite in open spaces preserved by "an ephemeral evaporitic precursor."

The possible genetic relationship between zebra textures and evaporites is made all the more plausible in the Sherman mine area of the Leadville district by isotope work done for R.J. Johansing's thesis. With no exceptions, the sulfur in samples collected from Sherman-type mineralization is sedimentary. In addition, I seem to recall that zebra rock becomes more abundant with increasing distance from the Breece Hill stock, until it is nearly pervasive in some localities on the east side of Weston Pass and on Sherman Mountain away from sills. If Johansing's fluid inclusion work reveals high-salinity (i.e., Mississippi Valley type) brines trapped in low-temperature inclusions in the lead-silver-barite ores, we may have a bit of rethinking to do about the genesis of the greater Leadville district.

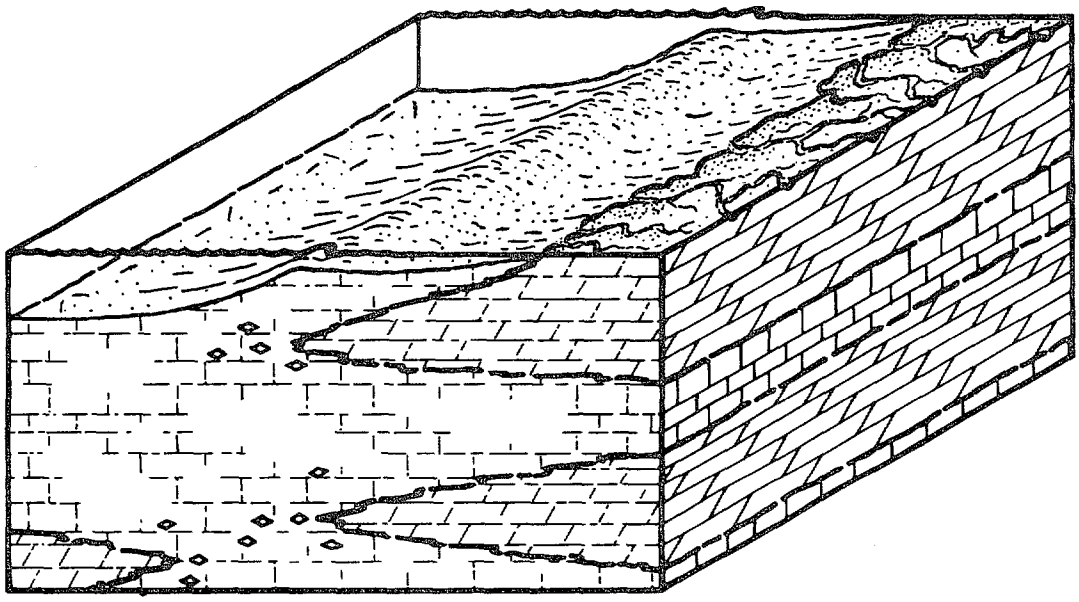
D. M. Smith

Douglas M. Smith, Jr.

cc: FTG, w/att.
JDS, w/att.

CONCEPTS AND MODELS OF DOLOMITIZATION

Based on a Symposium
Sponsored by The Society of
Economic Paleontologists and Mineralogists



Edited by
Donald H. Zenger, Pomona College, Claremont, California;
John B. Dunham, Union Oil Research Center, Brea, California;
and
Raymond L. Ethington, University of Missouri-Columbia

COPYRIGHT © 1980 *by*

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
Special Publication No. 28
Tulsa, Oklahoma, U.S.A. November 1980

SEPM Special Publication No. 28, p. 197–213, November 1980

Copyright © 1980, The Society of Economic Paleontologists and Mineralogists

Cuicga limestone replacement

TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

(INCORPORATED)

VOL. LXXII

CONTAINING PAPERS AND DISCUSSION ON MINING AND SAMPLING PRESENTED AT MEETINGS HELD IN NEW YORK IN 1922, 1923, 1924, 1925, AND OFFERED FOR 1926; SAN FRANCISCO, SEPTEMBER, 1922; BIRMINGHAM, OCTOBER, 1924; AND SALT LAKE CITY, SEPTEMBER, 1925.

NEW YORK, N. Y.
PUBLISHED BY THE INSTITUTE
AT THE OFFICE OF THE SECRETARY
29 WEST 39TH STREET
1925

Trans. of AIME, Vol 72 (1925).

ASARCO

RECEIVED
OCT 1 1979
EXPLORATION DEPARTMENT

Geochemical Office — Exploration Department
L. D. James
Chief Geochemist

September 26, 1979

TO: W. L. Kurtz
Tucson Office

FROM: L. D. James

Limestone Replacement Study - J.D. Sell

I read with interest Mr. Sell's numerous reports on the large quantity of geological and geochemical data relating to limestone replacement mineralization in Colorado he collected last year. He provides persuasive evidence that a combination of specific geological and geochemical data can provide useful leads to areas of high mineral potential in carbonate terrain. Of the geochemical parameters, as in the case of carbonate rocks in a variety of other geological environments (eg. S.E. Missouri, Ireland, etc.), Mn displays particular promise as an exploration guide.

The available geological and geochemical data represent such a wide variety of environments that do not appear to lend themselves to statistical treatment. One particular problem would be assignment of 'weight' to each parameter in each particular type of sample. Empirical evaluation of the data is probably the best that can be achieved at this stage.

As Mr. Sell indicates in his memorandum of July 13, 1979, a major unresolved problem is distinguishing regional from localized mineralization related (?) hydrothermal dolomitization. Cathodoluminescence studies might prove useful in this area. Current ASARCO studies in Mid-Tennessee indicate this approach has considerable potential. Evidence that specific types of dolomite in Colorado might display diagnostic cathodoluminescence patterns was provided by a test I recently made at the University of Tennessee on a sample of unmineralized karst breccia from the Sacramento Mine, west of Fairplay. Apparently Mr. Johansing is considering some cathodoluminescence studies as part of his current MS research program at Colorado State University.

I understand recent studies by others in the Leadville District has supposedly provided evidence that the Belden Shale Unit overlying the Leadville Dolomite is impoverished in a number of elements in the general vicinity of the mineralized district. This type of feature might be worthy of further study in view of its potential value as an exploration guide as well as the light it might throw on deposit genesis.

Although I agree the Skyline semi-quantitative emission spectrographic analytical method provides useful data in the first pass over a district, I remain

unconvinced that it is necessarily adequate as a routine tool once potential pathfinder elements have been tentatively delineated in a particular district. This is especially true when exploration decisions might have to be made on the basis of relatively small numbers of samples of specific geological features. The most Skyline claim for the methods is that the "true" value of each element is within ±1 step of the reported range at the 68% confidence level and within ±2 steps at the 95% confidence level. (Note: The stepped series used for reporting purposes are: 1, 1.5, 2, 3, 5, 7, 10, etc.) Thus, 95% of the time a true value of, say, 2ppm Ag will be reported somewhere in the range of 1-5 ppm. Standard geochemical procedures provide much more consistent results. They also provide lower detection limits in the case of several potentially important elements (eg. Ag, As, Mo, Zn, etc.). S and Au are two additional elements which might be worthy of attention in some circumstances.

I strongly advise against analysis of trace elements by the Barringer MRFAPE procedure until more convincing evidence is obtained of its reliability. Our experience with the method has not been good. Skyline has the instrumental ability to carry out trace element analysis by this means but have chosen to confine attention to major elements until the numerous snags related to trace analysis can be overcome.

L. D. James.

Lloyd D. James

LDJ:cej

cc: TCO/RLB
FTG
DMS
JDS

ASARCO

RECEIVED
AUG 2 1979
EXPLORATION DEPARTMENT

Lloyd copy Sell Rpt to Harper with note endorsing it, copy note to R L Brown

Exploration Department
R. L. Brown
Assistant Director of Exploration

July 31, 1979

Mr. W. L. Kurtz
Tucson Office

Limestone Replacement Search

Dear Mr. Kurtz:

I have before me Jim Sell's report which summarizes observations he made in various limestone replacement districts in Colorado, Utah, and Nevada. As you know, I had a field day with Mr. Sell at Eureka, and I had a further opportunity at that time to have the alteration patterns and zoning around Leadville-type deposits explained to me. I agree with Graybeal that Jim Sell's work is important as it provides a basis and a rationale for systematic exploration for Leadville-type deposits.

Mississippi Valley-type systems are very much larger than the "Leadville systems" and may, when all the fringe alteration is included, occupy entire states. The kind of investigation undertaken by Sell might be applicable to the Mississippi Valley-type deposits. The scope of such an investigation of Mississippi Valley-type systems would be very much (possibly prohibitively so) larger than the present one, and might even be unmanageable.

I note that you have sent a copy of the Sell report to Doug Smith, and I am asking Lloyd James to look it over. I think another copy of the report should go to Del Harper.

Yours very truly,

R L Brown

R. L. Brown

cc: LDJames
DDHarper

8/8/79

FROM: W. L. KURTZ

To: D.D.Harper

Limestone Replacement Search

In accordance with R. L. Brown's letter of July 31, 1979 we are enclosing a copy of Jim Sell's Limestone Replacement Search report dated July 13, 1979.

W.L.Kurtz

cc: RLBrown

ASARCO

Southwestern Exploration Division

July 26, 1979

TO: W. L. Kurtz

FROM: F. T. Graybeal

Limestone Replacement Search

Attached please find a comprehensive resume of J. D. Sell's work done in Summer 1978 in the Colorado Mineral Belt. The objective of this work was to determine if field criteria were present which could assist the explorationist in the search for limestone replacement deposits of the Leadville type. Mr. Sell drew on his past experience at the Magma Mine and spent roughly four months to complete the study. He has concluded that distinct visual and chemical variations exist which are systematically related to the presence of mining districts and ore bodies. The significant variations are summarized on Table 2 and discussed on pages 13-20 along with several useful comments on field procedures.

Although most of the features determined to be significant by Mr. Sell have been described previously in the literature, there are no published accounts which consider the spatial relationship of these features to ore. Mr. Sell's work is therefore an important extension of existing knowledge relating to hydrothermal zoning around deposits of the Leadville type and should be of considerable use to the explorationist.

F. T. Graybeal

F. T. Graybeal

FTG:lb
Att.

cc: TCOsborne - w/att.
DMSmith - w/att.
JDSell - w/o att.

ASARCO

Geochemical Office

RECEIVED
JUN 18 1979
W. U. S. EXPL. DIV.

June 13, 1979

TO: F. T. Graybeal

FROM: L. D. James

Limestone Replacement Study
Check Analysis

As a matter of interest I arranged for a small selection of samples from the Limestone Replacement Study to be analyzed by 'total' geochemical procedures. The results together with those originally obtained by Skyline Lab using emission spectroscopy (ES) are attached.

Assuming the geochemical data to be reasonably accurate the ES procedure appears to often (but not invariably) provide a fair estimate of the general order of element concentrations present. The ES data should usually permit broad categorization of samples but are probably unable to provide consistent definition of more subtle geochemical features.

L. D. James.

Lloyd D. James

LDJ:cej

cc: WLKurtz
DMSmith, Jr.
JDSell

ITEM NO.	SAMPLE NO.
17	G-07
18	G-08
19	WP-01
20	WP-01A
21	WP-02
22	WP-03
23	WP-04
24	WP-05

	WP-1	WP-1A	WP-2	WP-3	WP-4	WP-5
ITEM	19	20	21	22	23	24
ELEMENT						
Fe	34.5 20%	1%	4.1 5%	7.2 5%	2.8 2%	1.8 0.07%
Ca	0.14 0.05%	5%	0.60 0.5%	0.09 0.03%	17.0 20%	1.6 1%
Mg	0.04 0.03%	10%	0.30 0.2%	0.06 0.03%	2.15 2%	0.28 0.2%
Ag	28.5 15	10	<.5 <1	1.0 <1	<.5 <1	<.5 <1
As	<500	<500	<500	2000	<500	<500
B	20	<10	15	<10	<10	10
Ba	<10 <10	<10	450 <10	10 <10	1050 <10	1020 50
Be	<2	<2	2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10
Cd	<50	300	<50	<50	<50	<50
Co	<5	<5	<5	5	<5	<5
Cr	10 <10	<10	15 <10	10 <10	20 10	<2 <10
Cu	310 200	100	6 2	53 100	11 5	8 2
Ga	10	<10	<10	<10	<10	<10
Ge	50	<20	<20	<20	<20	<20
La	<20	20	30	20	50	50
Mn	210 100	300	370 200	600 200	750 500	300 150
Mo	62 50	<2	1.2 <2	14.9 2	2.0 <2	1.0 <2
Nb	20	<20	30	20	20	20
Ni	<5	<5	<5	5	5	<5
Pb	6.9% 10000	>10000	150 150	1000 200	30 20	30 10
Sb	<100	<100	<100	<100	<100	<100
Se	<10	<10	<10	<10	<10	<10
Sn	20	<10	<10	<10	<10	<10
Sr	<100	<100	100	<100	300	200
Ti	<100 20	<20	400 1000	<100 200	700 700	400 300
V	20	10	50	100	30	10
W	<50	<50	<50	<50	<50	<50
Y	<10	<10	10	<10	10	<10
Zn	1.6% 10000	>10000	230 200	1200 <200	140 <200	67 <200
Zr	<20	<20	300	70	20	50

ITEM NO.	SAMPLE NO.
9	CL-05
10	CL-06
11	G-01
12	G-02
13	G-03
14	G-04
15	G-05
16	G-06

ITEM	G-1 11	G-2 12	G-3 13	G-4 14	G-5 15	G-6 16	G-7 17	G-8 18
ELEMENT								
Fe	2.5 1%	1.7 0.5%	52.8 20%	19.0 5%	8.1 5%	5.9 2%	5%	0.2%
Ca	0.12 0.1%	20.0 15%	0.16 0.05%	0.35 0.1%	1.8 0.7%	1.1 0.2%	2%	20%
Mg	0.23 0.1%	12.5 15%	0.06 0.03%	0.13 0.03%	1.65 1%	1.57 0.7%	1%	15%
Ag	<.5 <1	<.5 <1	4.7 1	5.8 10	<.5 <1	<.5 <1	<1	<1
As	<500	500	<500	<500	500	500	500	<500
B	10	<10	20	10	100	20	30	<10
Ba	1050 300	160 <10	170 <10	<10 <10	850 10	700 100	20	<10
Be	<2	<2	<2	3	2	2	3	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	70	<50	<50	<50	<50
Co	<5	<5	<5	5	5	<5	<5	<5
Cr	<2 <10	5 <10	55 10	8 <10	47 <10	41 <10	<10	<10
Cu	2 <2	5 <2	890 300	137 50	15 5	21 10	2	<2
Ga	10	<10	10	<10	15	15	10	<10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	20	<20	<20	30.5% 30	50	30	<20	20
Mn	950 500	4500 2000	1700 500	>10000	600 300	650 200	200	300
Mo	1.2 <2	0.7 <2	3.1 10	1.5 2	3.0 2	1.2 <2	<2	<2
Nb	20	<20	20	20	30	20	20	<20
Ni	<5	<5	<5	20	30	5	5	<5
Pb	30 15	20 20	1.35%/2000	0.88%/1500	20 10	15 10	<10	<10
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	20	<10	<10	<10
Sn	<10	<10	20	<10	<10	<10	<10	<10
Sr	100	100	<100	<100	200	200	100	<100
Ti	<100 500	<100 <20	<100 20	<100 50	3000 3000	2000	1000	20
V	20	20	70	30	100	50	30	20
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	<10	<10	<10	<10	15	10	10	<10
Zn	175 <200	0.75%/5000	1.18%/7000	10.2%/10000	120 <200	420 <200	<200	<200
Zr	30	<20	<20	<20	200	100	150	<20

Project 79-55

W. E. C. LABORATORY ANALYTICAL DATA

Area

Requested By L. D. James

No. Samples

Date June 11, 1979

SAMPLE NUMBER	Fe %	Mn %	Ti %	Mg %	Ca %	Ba PPM	Cr PPM	Cu PPM	Pb* PPM	Zn PPM	Ag* PPM	Mo PPM
G-1	2.5	.095	<.01	0.23	0.12	1050	<2	2	30	175	<.5	1.2
2	1.7	.450	<.01	12.5	20.0	160	5	5	20	0.75%	<.5	0.7
3	52.8	.170	<.01	0.06	0.16	170	55	890	1.35%	1.10%	4.7	3.1
4	19.0	30.5	<.01	0.13	0.35	<10	8	137	0.80%	10.2%	5.8	1.5
5	8.1	.060	0.30	1.65	1.8	850	47	15	20	120	<.5	3.0
6	5.9	.065	0.20	1.57	1.1	700	41	21	15	420	<.5	1.2
SP-1	34.0	.021	<.01	0.04	0.14	<10	10	310	6.9%	1.6%	28.5	62
2	4.1	.037	<.01	0.30	0.60	450	15	6	150	230	<.5	1.2
3	7.2	.060	<.01	0.06	0.09	10	10	53	1000	1200	1.0	14.9
4	2.8	.075	.07	2.15	17.0	1050	20	11	30	140	<.5	2.0
5	1.8	.030	.04	0.28	1.6	1020	<2	8	30	67	<.5	1.0

copy for JDS, FTG WLK

ASARCO

Rocky Mountain
Exploration Division

RECEIVED
JUN 15 1979
EXPLORATION DEPARTMENT

June 5, 1979

TO: D. M. Smith, Jr.

FROM: R. J. Johansing

Limestone Replacement Search
Emission - Spec Values
Colorado - Comment

This is the second part of a review submitted at the request of Mr. Sell and Mr. Kurtz on May 10, 1979. The following material is partly an interpretation of the geochemical data compiled by Mr. Sell. A complete interpretation of Mr. Sell's data is difficult due to its complex nature. My initial reaction to Mr. Sell's work was in fact slightly negative as a result of this complexity. Nevertheless, after spending a little time with the data I have found some of it to be quite interesting and possibly very useful.

Following my comments is an attached sketch of how I might interpret some of the data with respect to a sulfide replacement ore body in a carbonate host. This model is obviously incomplete as it does not include all the characteristics of the ore bodies or the corresponding geochemical signatures of the hosting formation. Construction of a more complete geological and geochemical model would probably aid the interpretation of Mr. Sell's geochemical data. My model has been constructed on the assumption that the formation of the mineral deposit was dependent on the existence of faults and fractures that afforded access to solutions. I believe that this is the only invariable feature of this model.

A factor not included in my model but one I believe to be extremely important is the timing of dolomitization in specific geologic units. I think it is essential to know whether one is dealing with dolomite (penecontemporaneous or diagenic) and limestone of the Redcliff member, massive limestone of the Castle Butte member, or hydrothermally altered carbonate (dolomite) of the Leadville formation in the Colorado Mineral Belt.

I feel that care should be taken when interpreting certain elements, i.e. Ba and Fe, on a district-wide basis. In the Leadville district, there appears to be a zonation of gangue mineralogy. Barite occurs in the peripheral zones whilst siderite and manganosiderite predominate in the more centrally located areas around Breece Hill. Low barium values on Iron Hill may indicate little as compared to high barium values in the Sherman mine. I assume the Ca:Mg ratios are related to dolomitization, mineralization, and sanding; all features generally identifiable in the field.

The presence or absence of favorable geochemical signatures relative to structures should be interpreted with particular care. A sample collected from the breccia of the "West" fault in the Sherman mine, where it cuts the Sawatch quartzite in the haulage level, would undoubtably show favorable E-S values indicative of metal-bearing solution flow. Drilling this structure

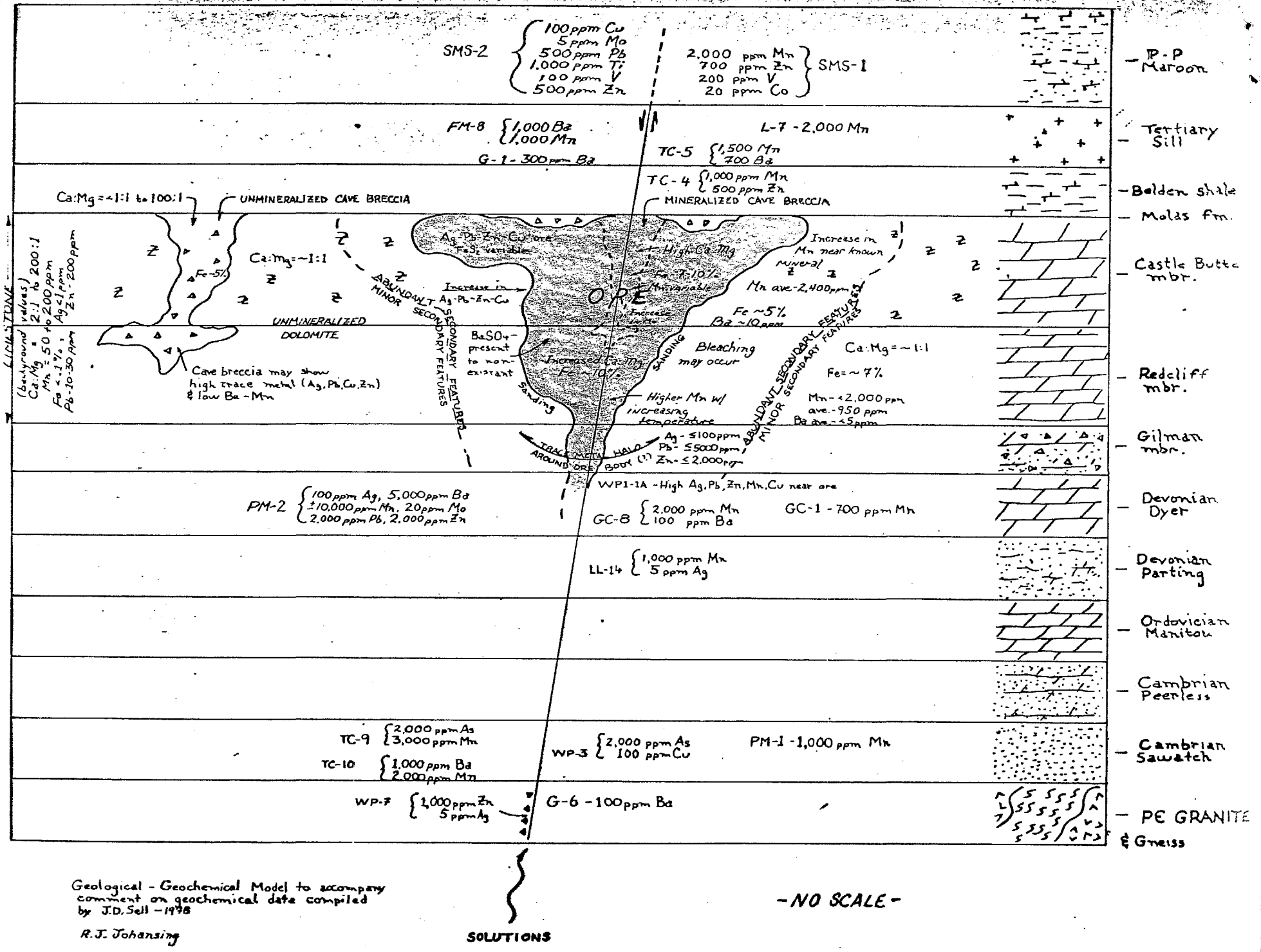
where it intersects the favorable strata of the Leadville formation would result in failure to locate mineralization. This might not have occurred if it was recognized that the ore-bearing solution departed the "West" fault and deposited the metals in the adjacent en echelon faults and fractures to the east.

To conclude, I believe that enhanced manganese values appear to be the most promising indication of a mineralized block in a carbonate host in this region. Trace metal values of Ag, Pb, Cu, and Zn also show some promise of mineralization, particularly when they occur in adjacent porphyry units. Taking into consideration all that has been done, application of this geochemical approach seems to be best suited, as Mr. Sell stated (3-5-79), as, "an additional guide in the establishment of drilling patterns in testing the most favorable stratigraphic and structural traps."

Robert Johansing

Robert J. Johansing

RJJ:cej



Geological - Geochemical Model to accompany comment on geochemical data compiled by J.D. Sell - 1978

R.J. Johansing

6-6-79

ASARCO

Southwestern Exploration Division

May 31, 1979

TO: Geologists

FROM: F. T. Graybeal

Limestone Replacement Textures

Jim Sell has assembled a lovely suite of various alteration textures associated with massive lead-zinc-silver replacements in the Leadville limestone. The individual samples are described in the attached memo by Mr. Sell. The samples are stored in an NC core box presently located on the binocular-microscope table in the microscope room. I suggest you all take the time to review these samples carefully as they are most educational. You never know when you may suddenly find yourselves looking for one of these things or when you might stumble across one while looking for something else.

F. T. Graybeal

F. T. Graybeal

FTG:lb
Att.

cc: WLKurtz - w/att.

ASARCO

Southwestern Exploration Division

May 14, 1979

F.T.G.

TO: F. T. Graybeal

FROM: J. D. Sell

Limestone Replacement Search
Notes for Tucson Hand Specimens
Colorado Samples

For reference purposes, I submit a few representative hand specimens of the Leadville Formation units and their progressive change from limestone to dolomite, to ore-bearing characteristics, to replacement by sulfides. This memo is a revision of the September 21, 1978 report to the Denver Office (DMS,Jr.). Emission-spec reports are contained in individual reports on the areas collected, as well as being compiled in the recently submitted Limestone Replacement Search compendium (May 14, 1979). The numbered LRS- (Limestone Replacement Search -) samples have the following features.

LRS-1. Leadville limestone, Trout Creek Area (TC-1). Very fine crystalline. Note the blocky chocolate conchoidal breakage characteristic of unaltered limestone. Red stain is immediate reaction from Alizarin Red-S.

LRS-2. Leadville dolomite, Hilltop Area (FMH-1). Fine replacement texture has converted the limestone to a dolomitic unit. Note the fine silica ribs and elephant-hide weathering characteristics. The rock contains a trace of manganese (700 ppm), 7 ppm silver, and 1500 ppm lead, indicating metal-bearing solutions have penetrated the area. Alizarin Red-S does not stain this rock.

LRS-3. Leadville dolomite, Leadville district. Extremely well recrystallized; termed "pearly texture" in the literature of Leadville and Gilman areas. Note vug development, with secondary vug filling as well as replacement bands. The stain (a deeper purple red) is from Alizarin Red-S which was allowed to evaporate on the slab. Reaction time is slow. This type of dolomitic recrystallization is pervasive and contains a variable amount of trace elements.

LRS-4. Leadville dolomite, Hilltop area (FMH-2). Coarse recrystallized dolomite, as above, with vug development and secondary dolomite crystal deposition in vugs and interstitial knots. Dusty reddish iron overprint in the secondary dolomite features. As above, may have a variable trace element content, but where found with anomalous values indicates mineral system availability.

LRS-5A. Leadville dolomite, Peerless area (FM-1A). Fine to medium pervasive recrystallization (pearly) with superimposed "zebra" development with coarse white dolomite crystals filling minor vugs and replacing along bands and stripes. In this rock, though only a trace of manganese (700 ppm) was reported, the jump in silver (30 ppm), copper (500 ppm), and lead (5000 ppm) indicates a relationship toward ore. The deep purple stain is again evaporated Alizarin Red-S.

LRS-5B. Leadville dolomite, Peerless area. Well-developed zebra texture of secondary dolomite growths and vug filling. Note control by pre-alteration fractures on size of secondary growths, and the apparent initial limestone depositional feature on control of extent of zebra development.

LRS-6. Leadville dolomite breccia, Mudsill area. Exhibits various recrystallized textures in clast composition, and cemented by secondary dolomite crystal deposition. Often carries anomalous magnesium, manganese, silver, and barium, indicating metal solution pathway.

LRS-7. Leadville dolomite breccia, Mudsill area. As above, with pervasive recrystallization of clasts, with secondary dolomite crystals and quartz crystals. Mineralized with sulfides.

LRS-8. Leadville stratified cave-fill, Hilltop area. Dolomite sand filling karst topography or other solution dissolved pathways. Generally has high metal values suggesting metal pathways following old solution pathways.

LRS-9. Leadville stratified cave-fill, Peerless area. As above, mineralized by sulfides. Note quartz and barite crystal replacement and interstitial filling in the sand.

LRS-10. Leadville karst cave-fill, Hilltop area. Note increased replacement by barite (barite sand). Malachite-azurite generally suggests oxidation from tetrahedrite-ruby silver series of sulfosalts and values in excess of 100 ounces silver per ton are common in this rock.

LRS-11. Leadville dolomite, Peerless area. Replaced by iron-manganese-barite-quartz with variable sulfides of lead-zinc. Now totally oxidized. Base metals may stay behind in oxidized form or may be nearly flushed from system. Silica addition as chert or jasperoid invariably holds amounts of original metal content to indicate favorable zones.

LRS-12. Leadville dolomite, Black Cloud Mine. Zebra texture replaced by sulfides. Note several depositional types and colors of secondary dolomite in vugs and bands. Sulfides apparently replace the grey dolomite bands of the zebra (see LRS-5A and -5B zebra).

LRS-13. Leadville dolomite, Black Cloud Mine. Zebra and birdseye (knot) texture replaced by late dolomite and sulfides. The high percentage of secondary interstitial dolomite (40-50%) may indicate the spent-solution side of fluid flow where the sulfide replaced dolomite (as in LRS-12 above) releases abundant dolomite gangue which moves outward and reprecipitates in the outer zone as in LRS-13.

LRS-14. Leadville limestone, Aspen area. Located within the mineralized trend and is a well-recrystallized limestone with secondary calcite crystal stringers and quartz stringers of cross-cutting nature. The stain is immediate reaction of Alizarin Red-S. The E-S results show 2200 ppm manganese, 2000 ppm lead, 20 ppm moly, with 36% silica. Visually and chemically this is a limestone system equal to that of the dolomite system imposed as of LRS-3 and -4.

LRS-15. Leadville dolomite, Aspen area. This sample is located on the dolomite side of the dolomite-limestone front at Aspen and is in the vicinity of one of the larger producing mines. E-S reports 27,000 ppm manganese, 55,000 ppm lead, 10 ppm moly, plus 40,000 ppm zinc and 106 ppm silver indicating its relationship to ore.

James D. Sell

JDS:lb

Box of hand specimens labeled "LRS"

~~JDS~~ ahha! RJ

WRK - RJJ's comments vis a vis the JDS handspecimen alteration collection. More critique should be forthcoming.

ASARCO

Rocky Mountain
Exploration Division

RECEIVED
MAY 29 1979
EXPLORATION DEPARTMENT

May 18, 1979

TO: D. M. Smith, Jr.

FROM: R. J. Johansing

Limestone Replacement Search
Hand Specimen Collection Notes
Colorado - A Critique

This critique has been done in response to a request by Mr. Sell and Mr. Kurtz on May 10, 1979. My observations and interpretations are based on experience gained at the Sherman mine and thus my comments and comparisons pertain to the Sherman and neighboring mines and prospects, i.e., Liddia, Continental Chief, and Hilltop mines. I believe the only discrepancy between my thoughts and the work done by Mr. Sell lies in the question of hydrothermal dolomite and its timing. Without referring to the work and specifics presented by Tweto, Lovering, De Voto, Engel, etc., about the Leadville formation in the Colorado Mineral Belt, I can say with confidence that the presence of coarsely crystalline, hydrothermal dolomite was by no means indicative of nearby mineralization at the Sherman mine. Out of the 16 hand specimens presented to me, only 8 of these would be indications of nearby mineralization. These 8 samples are the ones containing visible sulfide and oxide mineralization. ? what about ones w. no visible mineraliz. which still contain 20 ppm Ag, 2000 ppm Pb, etc, etc.?

RJJ should be interesting company for JDS Pain Summer

HAND SPECIMEN COLLECTION

1. (TC-1) Unaltered Leadville limestone, Trout Creek Area.

2. (FMH-1) Leadville dolomite, Hilltop Area.
   Interpreted as hydrothermal dolomite by J. D. Sell. This sample is similar to the gray to dark-gray dolomites of the Redcliff member of the Leadville dolomite. If I were to have mapped this unit at the Sherman mine, it would have been interpreted as a penecontemporaneous or early diagenetic dolomite and not a hydrothermal dolomite related to mineralization. These fine to medium grain dolomites usually occur as thin beds (6" to 2' thick) in the Redcliff member as compared to the coarse grain, hydrothermal dolomites of the Castle Butte member.

3. (FMH-2) Leadville dolomite, Hilltop Area.
   Coarse grain, hydrothermal dolomite with FeOx and euhedral crystals of dolomite in vugs. If mapped at the Sherman mine, it would not be interpreted as an indication of nearby mineralization.

Possibly a difference in the scale JDS views things by vs. RJJ scale. JDS - distinct-size; RJJ - orebody-size

4. (FM-1A) Leadville dolomite, Peerless Area.
   Well developed 'zebra' texture and secondary dolomite veining. Mapped similar rock type in the N-24-5 area of the Sherman mine approximately 300 feet from nearest known mineralization. This type of fractured dolomite was most commonly seen at the base of the Castle Butte member.

5. (TC-16) Leadville dolomite with galena and sphalerite, Trout Creek Fault Area.
   Hydrothermally dolomitized, tectonic breccia. A sample of this nature would be somewhat unusual at the Sherman mine due to the lack of hydrothermally generated quartz, epidolomite, and barite gangue.

6. Leadville dolomite, Peerless Area.
   I would describe and interpret the sample the same way as Mr. Sell. It would be interesting to take a sample like this and cut it so as to observe changes, if any, in grain size away from the ore zone.

7. (FMP-1) Leadville formation Gilman Sandstone member, Peerless Area.
   No Comment.

8. Leadville dolomite breccia, Mudsill Area.
   Similar to cave breccias seen at the Sherman mine.

9. Leadville stratified cave-fill, Hilltop Area.
   This sample is characteristic of finely crystalline cave-fill throughout the Sherman mine.

10. Leadville cave-fill breccia, Hilltop Area.
    No Comment.

11. Leadville dolomite - Peerless Area.
    The great abundance of Fe and Mn in this sample would be quite anomalous at the Sherman mine.

12. Leadville dolomite, Hilltop, Peerless, and Mudsill areas.
    Various examples of orebearing features, brecciation, and karst filling. No comment.

Robert Johansing

Robert J. Johansing

RJJ:cej

ASARCO

Geochemical Office

RECEIVED
MAY 18 1979
EXPLORATION DEPARTMENT

May 15, 1979

TO: W. L. Kurtz

FROM: L. D. James

Limestone Replacement Study (J.D. Sell)
Colorado

This is to acknowledge receipt of your memorandum of May 10 relating to the geochemical data from Jim Sell's limestone replacement study in Colorado last year.

Before attempting any detailed study of the data I am having a little check analysis carried out. When this is complete I will look through the data memoranda together with the final report (not yet received) before deciding what, if any, statistical treatment might be applicable.

L.D. James.

Lloyd D. James

LDJ:cej

cc: TCO
FTG
DMS
JDS

ASARCO

Exploration Department
Western USA

May 10, 1979

L. D. James
Denver Office

J. D. Sell's
Limestone Replacement Work
Colorado

This will confirm our phone conversation of yesterday that you will study all of the geochemical data from last summer's limestone replacement studies conducted by Mr. Sell.

You will recall that Mr. Sell gave a brief presentation of his work at the Denver Exploration Meeting last September. At that time he emphasized the megascopic features within and outside of mining districts that an explorationist might use in a limestone replacement search. This suite of samples is available for study in the Denver Office.

Sell's geochem work, complementing his field studies, suggests a number of elements that might be used to augment the megascopic studies.

We would like you to study this data and apply any applicable statistical treatments that might make subtle patterns more obvious. Though the samples in any individual area may be too limited for statistical treatment you will note that samples from different areas (see detailed sample descriptions by Sell) may be grouped.

Please feel free to consult with Mr. Sell -- he is really bullish on the use of both the megascopic criteria and geochemical patterns for limestone replacement ore search.

W. L. Kurtz

W. L. Kurtz

WLK:lb

cc: TCOsborne
FTGraybeal
DMSmith
JDSell

file: Limestone replacement deposits, cathodeluminescence

ASARCO

FTG
JDS

Rocky Mountain
Exploration Division

November 3, 1978

TO: D. M. Smith, Jr.

FROM: D. J. Krasowski

Re: Cathodeluminescence

Phone calls to several U.S.G.S. geologists concerning possible use of Survey cathodeluminescence equipment to study carbonate replacement environments has produced some promising results.

George A. Desborough of the Mineral Resources of U.S.G.S. has offered the use of his cathodeluminescence equipment either as a use-it-yourself, unofficial study (with preliminary instruction included); or as a joint study project with U.S.G.S. personnel.

Dr. Desborough sounded receptive to about anything we may want to propose. He stressed, however, that use of the facilities could not take precedence over their regular work. He is willing to discuss details with us at any time, but indicated that he had a rather complicated travel schedule for the rest of November. He may be contacted at 234-3544 (work) and 233-3887 (home- between 5 and 8 p.m.).

D. J. Krasowski

D. J. Krasowski

DJK/fb

W. L. Kurtz:

An offer too good to refuse, but I fear that our time will be too occupied elsewhere this winter, spring, summer and fall to avail ourselves. I've long wanted to have a crack at 'CL' on limestones and carbonate minerals from around replacement deposits — looking for relict textures, variations in luminescence caused by impurities, recrystallization textures, etc. that might be characteristics of all or most occurrences. Any limestone explorers in Tucson have time?

D. M. Smith

Fair amount of this sort of work been done on Miss Valley-type ores since 1974. Can anyone give application to exploration sufficient to occupy explorationist's time - rather than USGS or University researcher's time? FTG 12/11/78

USGS PP 235 #48

Cell File Limestone Replacement Deposits

Engel + Engel 1956 Distribution of Cu Pb Zn in hydrothermal dolomites assoc with sulfide ore in the Leadville Ls (Abs GSA v.67 p 1692)

Numerous assays of dolomite in close proximity to ore show CuPbZn content to be the same as in unaltered carbonate over an area of approx 5,000 sq. meters.

September 14, 1978

TO: D. M. Smith, Jr.

FROM: J. D. Sell

file

Limestone Replacement Search

Hand Specimen Collection Notes

Colorado

A collection of representative samples ranging from unreplaced Leadville limestone to recrystallized Leadville dolomite ~~thorugh~~ through various stages of alteration and mineralization to oxidized ore has been assembled. Also attached is the respective emission-spec results of the samples and/or similar samples taken from the same areas.

1. Leadville limestone, Trout Creek area (TC-1). Lower middle unit, very fine crystalline, dark, dusky grey coloration, minor cold water solution with deposition of calcite dripstone and blunt calcite crystals, note conchoidal fracturing. No hydrothermal alteration. 3 ppm moly would be interesting if other values were present.

FMH-1

2. Leadville dolomite, Hilltop area (FMH-1). Lower middle unit, fine pervasive replacement texture cut by fine quartz-silica ribs. Elephant hide weathering texture. District wide dolomite alteration by passage of solutions. Trace manganese (700 ppm) with 7 ppm silver & 1500 ppm lead, indicate metal bearing solutions penetrated area.

FMH-2

3. Leadville dolomite, Hilltop area (FMH-2). Lower middle unit, coarse pervasive replacement texture with secondary vug development and secondary dolomite crystal deposition in vugs and interstitial knots. Dusty reddish iron overprint in secondary carbonate features. Increased intensity of hydrothermal-mineralization processes. Trace manganese (700 ppm) and low magnesium (5 %), suggests movement of alteration solutions carrying minor elements.

M-1A 4. Leadville dolomite, Peerless area (FM-1A). Fine to medium coarse replacement texture with superimposed secondary zebra development with secondary dolomite crystals replacing zebra stripes, filling minor vugs, and in veins. Note discordant dolomite crystal development along strike of stripe and across structures. One pyrite pseudomorph as circled. Though only trace manganese (700 ppm), the jump in silver (30 ppm), copper (500 ppm), and lead (5000 ppm), indicates a relationship to mineralization.

TC-16 5. Leadville dolomite, Trout Creek fault area (TC-16). Irregular coarse replacement texture, tectonically broken with secondary dolomite crystal development in crushed zones and vugs. Note discrete black of galena, and sphalerite in coarse groundmass (Not placed in ES sample). This coarse replacement testure may be more common to dry heat sources rather than pervasive movement of hydrothermal solutions. Increased magnesium, but low manganese (700 ppm) and lead (500 ppm).

6. Leadville dolomite, Peerless area. Medium-coarse pervasive replacement texture with sanded zone (more porous unit and high fluid movement) replaced by silica-quartz crystals-late ankerite and other carbonates, and nodules of iron pseudomorphs and clots of tetrahedrite-ruby silver; note azurite-malachite oxidation products. (No ES analysis of this type sample, probably similar to values given in #7 below).

MP-1 7. Leadville dolomite (Gilman sandstone member), Peerless area (FMP-1). Sanded and replaced by silica, quartz crystals, carbonate, and mineralized by galena-sphalerite-tetrahedrite (partially converted to iron oxide pseudomorphs). Very high values of barium, silver, copper, lead, ~~antimony~~ and antimony.

LL-2 8. Leadville dolomite breccia, Mudsill area. Exhibiting various recrystallized textures and cemented by secondary dolomite crystal deposition. (No ES analysis of this type sample, but often carried anomalous magnesium, manganese, barium and silver.

9. Leadville stratified cave-fill, Hilltop area. Fine crystalline dolomite with dusty grey overprint, trace of mineral debris and replacement by sulfide (oxidized). (See report of Leadville Lead sample LL-2 as similar type and ES value.) Noticeable manganese (2000 ppm).

10. Leadville cave-fill breccia, Hilltop area. Sanded and weakly mineralized features (No ES analysis of this type samples; undoubtedly [illegible] manganese and variable amounts of other ~~[illegible]~~ values, esp. barium, silver [illegible]).

11. Leadville dolomite, Peerless area. A strongly replaced unit by secondary dolomite, quartz crystals, and barite followed by iron-manganese and sulfides (now totally oxidized showing pseudomorph forms). (See report on Fourmile sample FM-2, and Leadville sample L-4A for similar types and ES values) Highest iron and high silver, arsenic, barium, copper, manganese, moly, lead, antimony and zinc suggest well mineralized units.

12. Leadville dolomite, Hilltop (H), Peerless (P), and Mudsill (M) areas. Various examples of orebearing features, brecciation, and karst filling. Note replacement by secondary dolomite, quartz, barite, and sulfides (and pseudomorph oxidation forms) with azurite-malachite generally indicating oxidation of tetrahedrite-ruby silver series. (Values in excess of 100 ounces silver indicated by azurite-malachite plus sulfide remnants at the Leadville Lead operations.) (See report on Fourmile samples FM-1, ~~and FM-2,~~ and also Leadville Lead samples LL-5A and LL-13B as representative of ES values.) Increased ratio of magnesium vs. calcium, plus high ~~[illegible]~~ mineral values show exploration potential.

James D. Sell

JDS:eff

Attachments: Emission-Spec Values

CC: F. T. Graybeal

TABLE ONE: Representative Emission Spec. Analys

Hand Specimen Number	(1)	(2)	(3)	(4)	(5)
Sample Number	TC-1	FMH-1	FMH-2	FMH-1A	[illegible]
ITEM	1	1	2	21	18
ELEMENT		IENT			
Fe	0.1%	0.5%	0.3%	0.5%	0.5%
Ca	>20%	20%	15%	10%	15%
Mg	0.1%	10%	5%	7%	15%
Ag	<1	7	<1	30	<1
As	<500	<500	<500	<500	<500
B	<10	<10	<10	<10	<10
Ba	<10	<10	<10	10	<10
Be	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50
Co	<5	<5	<5	<5	<5
Cr	<10	<10	<10	<10	<10
Cu	2	300	50	500	10
Ga	<10	<10	<10	<10	<10
Ge	<20	<20	<20	<20	<20
La	20	<20	<20	20	20
Mn	200	700	700	700	700
Mo	3	2	<2	<2	<2
Nb	<20	<20	<20	<20	<20
Ni	<5	<5	<5	<5	<5
Pb	10	1500	150	5000	500
Sb	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10
Sr	100	100	150	<100	100
Ti	150	100	<20	<20	<20
V	<10	<10	<10	10	20
W	<50	<50	<50	<50	<50
Y	<10	<10	<10	<10	<10
Zn	<200	<200	<200	200	500
Zr	<20	<20	<20	<20	<20

*NOTE: 100 ppm Ag = 2.92 troy oz Ag

...isentative Emission Spec. Analysis Values of Hand Specimen Co...

	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	FMH-1	FMH-2	FM-1A	TC-16	Blank	FMP-1		
	1	2	21	18		3		5
NT					No		No	
	0.5%	0.3%	0.5%	0.5%	ES	3%	ES.	2%
	20%	15%	10%	15%	Analysis	0.07%	Analysis	20%
	10%	5%	7%	15%		0.03%		15%
	7	<1	30	<1		700		3
	<500	<500	<500	<500		<500		<500
	<10	<10	<10	<10		<10		<10
	<10	<10	10	<10		>10000		200
	<2	<2	<2	<2		<2		<2
	<10	<10	<10	<10		<10		<10
	<50	<50	<50	<50		<50		<50
	<5	<5	<5	<5		<5		<5
	<10	<10	<10	<10		<10		<10
	300	50	500	10		1500		5
	<10	<10	<10	<10		<10		<10
	<20	<20	<20	<20		<20		<20
	<20	<20	20	20		<20		<20
	700	700	700	700		500		2000
	2	<2	<2	<2		2		2
	<20	<20	<20	<20		<20		<20
	<5	<5	<5	<5		5		<5
	1500	150	5000	500		>10000		150
	<100	<100	<100	<100		2000		<100
	<10	<10	<10	<10		<10		<10
	<10	<10	<10	<10		<10		<10
	100	150	<100	100		200		<100
	100	<20	<20	<20		<20		100
	<10	<10	10	20		<10		10
	<50	<50	<50	<50		<50		<50
	<10	<10	<10	<10		<10		<10
	<200	<200	200	500		300		500
	<20	<20	<20	<20		<20		<20

= ppm Ag = 2.92 troy oz. Ag.

... Collection.

9)	(10)	11		12			
L-2		FM-2	L-4A		FM-1	LL-5A	LL-5B
5		22	2		20	9	20
	No					IENT	
2%	ES	10%	10%		7%	7%	2%
20%	Analysis	0.15%	5%		0.1%	1%	.5%
15%		0.05%	0.03%		0.03%	.2%	.15%
3		500	200		200	7000	1000
500		1000	1000		<500	1500	<500
<10		10	10		<10	<10	10
200		500	7000		>10000	5000	>10000
<2		3	<2		3	<2	<2
<10		<10	<10		<10	<10	<10
<50		300	<50		<50	200	100
<5		<5	<5		<5	<5	<5
<10		<10	20		<10	<10	300
		5000	200		1500	>10000	5000
<10		<10	<10		<10	<10	<10
<20		<20	<20		20	<10	<10
						<20	<20
<20		<20	70		<20	50	<20
000		700	>10000	>1	100	1000	300
2		5	20		5	5	2
<20		20	20		20	20	20
		5			5		
<5		>10000	5		>10000	5	5
150		1000	10000		500	>10000	>10000
100		<10	200		<10	>10000	3000
<10			<10			<10	<10
		<10			<10		
<10		<100	<10		500	<10	<10
100		<20	300		100	200	1000
100		<10	100		30	20	1000
10			70			10	20
		<50			<50		
		<10			<10		
<50			<50			<50	<50
<10		>10000	<10		2000	<10	<10
500		<20	2000		<20	10000	>10000
<20			<20			<20	30

~~JHC~~ ~~PLG~~ ~~JBS~~ → WLK

ASARCO

copy to TCO done 5/31/78
may 31, 1978

Rocky Mountain
Exploration Division

May 11, 1978

RECEIVED
MAY 15 1978
EXPLORATION DEPARTMENT

TO: W.L. Kurtz

FROM: D.M. Smith, Jr.

WLK file
Limestone Replacement

Karst Books

Two books on karst, Morphogenetics of Karst Regions and Karst Hydrogeology, have been acquired by this office. This first volume is authored by Laszlo Jakucs, a rather prolific writer (he cites 42 of his own articles) on the subject which he has studied in the classic areas of Europe and in Cuba. A collection of papers from the 12th International Congress of Karst Hydrogeology comprise the second tome. Selected reading done in both books (tables of contents attached) rate Jakucs' work as by far the more valuable to explorationists.

As is the case with veins, the mineralized portion of limestone replacement deposits, karst controlled or otherwise, represents a mere fraction of the explorable area. When karst topography is suspected as a locus for ore deposition, then knowledge of karst genesis and morphology can contribute greatly to the design of drill patterns as well as earlier phases of exploration. Project geologists can prepare themselves well with Jacuks' book. Some similarities between "empty" karst features and limestone replacement ore bodies are clearly demonstrated by the attached figures. These also suggest that hydrothermal regimes operating in limestone may create forms which adhere quite closely to those resulting from karstic processes.

Bibliographic data is as follows:

Jakucs, L., 1977, Morphogenetics of Karst Regions, Variants of Karst Evolution: Halsted Press, John Wiley & Sons, New York, 284 p., $40.00.

Tolson, J.S., and Doyle, F.L., eds., 1977, Karst Hydrogeology: International Association of Hydrogeologists Memoirs Vol. XII, University of Alabama Press, Huntsville, 578 p., $15.00.

D.M. Smith, Jr.

D.M. Smith, Jr.

DMS:slr
Attachments

CONTENTS

Page

Letter from the IAH Vice President (U.S.A.) v

Foreword vi

Preface vii

I. Worldwide and Eastern Mediterranean Karst Hydrogeology

Etudes sur les Eaux Souterraines en Pays de Roches Karstiques Effectuées par les Nations Unies
Robert Dijon 3

The Karst of Technogenic Saline Deposits
G. V. Bogomolov, V. P. Klementjev, and O. N. Shpakov 9

Evolution of Fossil Karst Aquifers in Israel
L. Picard and E. Wakshal 21

Determinability of Production Capacity for Malya Karstic Springs
Behic Congar 23

More About Paleocene Karst Aquifer in Saudia Arabia
Galip Otkun 25

Development of Submarine Springs in Limestone Formations
Aménagement et Captage Sous-Marins dans Les Formations Calcaires
Louis Potie and B. Tardieu 39

Contrôle Globotectonique des Principaux Aquifères Karstiques Périméditerranéens
Jacques V. Avias 57

Prospects of Forecasting the Karstic Water Regime
V. S. Kovalevsky 73

II. Canadian and Glaciated Areas Karst Hydrogeology

Karst of Canada
Derek C. Ford and James F. Quinlan 83

The Athabasca Carbonate and Evaporite Buried Karst (Alberta, Canada)
György Ozoray 85

Surface and Groundwater Hydrology of a Highly Karsted Subarctic Carbonate Terrain in Northern Canada
George A. Brook 99

Effect of Continental Glaciation on Karst Hydrology, Northeastern, U.S.A.
Arthur N. Palmer 109

III. Caribbean-Gulf of Mexico Karst Hydrogeology

The Circum-Gulf Karst Belt
John E. Fish 113

Geomorphic Evolution of Tropical Karst Terranes
Wayne C. Isphording 115

Ground Water Exploration in the Cul-de-Sac Plain, Republic of Haiti
Philip L. Hall 131

Hydrogeology and "Geoesthetics" Applied to Land Use Planning in the Puerto Rican Karst
Ennio V. Giusti 149

Origin of Karst Depressions in Northern Puerto Rico
Watson H. Monroe 169

Drainage Patterns and Subsurface Flow of An Isolated Karst Basin in the Río Tanamá Drainage, Puerto Rico
Donald G. Jordan 177

Red Snapper Sink and Ground Water Flow, Offshore Northeastern Florida, U.S.A.
F. A. Kohout, G. W. Leve, Fidel T. Smith, and F. T. Manheim 193

Hydrologic Effects of Pumping a Deep Limestone Sink Near Tampa, Florida, U.S.A.
Joseph W. Stewart 195

Neogene Karst in the Florida Straits
David N. Gomberg 213

IV. Exploration and Land Use Problems in Karst

Karsts Anciens et Eaux Actuelles
Henri Paloc 229

Relation of Fracture Zones to the Edwards Limestone Aquifer, Texas
E. G. Wermund and Joseph C. Cepeda 239

Joint Patterns and Solution Channel Evolution in Indiana
Richard L. Powell 255

Remote Sensing of Subsurface Karst by Microgravimetry
Avner A. Arzi 271

High Accuracy Gravity Applied to the Detection of Karstic Cavities
Gildas Omnes 273

The Application of the Tri-Potential Method of Resistivity Prospecting for Ground-Water Exploration and Land Use Planning in Karst Terrains
Keith G. Kirk and Henry Rauch 285

Hydrogeologic Relations of a Karst Area and a Proposed Navigation Canal in Florida
Glen A. Faulkner 301

Induced Sinkholes--A Continuing Problem Along Alabama Highways
J. G. Newton 303

Aspects in the Establishment of Ground-Water Protection Areas in Karst Regions
W. Richter 305

Monitoring for Environment Protection in Huntsville, Alabama, U.S.A.
A. M. Malatino and Nelson A. Lloyd 307

Hydro-Environmental Effects of Sprayed Sewage Effluent, Tallahassee, Florida, U.S.A.
Larry J. Slack 309

Strategic Placement of Waste Disposal Sites in Karst Regions
L.V.A. Sendlein and R. C. Palmquist 323

Water-Resources Management in the Florida Peninsula Buried Karst
Garald G. Parker 337

Land Resource Units for Planning in Carbonate Terranes
E. G. Wermund and C. M. Woodruff, Jr. 339

V. Water Flow and Cavity Development in Karst

On Some Specific Features of Karst Groundwater Circulation
Petar Milanović 357

Diffuse Flow and Conduit in Limestone Terrain in the Mendip Hills, Somerset, England
T. C. Atkinson 359

Hydrology of the Large Karst Springs in the Missouri Ozarks, U.S.A.
Gerald L. Feder 361

The Effects of Hydrogeologic Setting on the Storm Response of Karst Springs in Monroe County, West Virginia, U.S.A.
Albert E. Ogden and Henry W. Rauch 363

Surface Water Hydrology in Carbonate Basins Within the Appalachians
Elizabeth L. White 377

Discharge Characteristics of Karst Drainage Basins in Greenbrier County, West Virginia, U.S.A.
William K. Jones and Henry W. Rauch 391

Determination of Groundwater Flow in Karst Using "Geobomb"
Dušan Arandjelovic 399

A Model for the Development of Broad Scale Networks of Ground-Water Flow in Carbonate Aquifers
Ralph O. Ewers 401

Cave Systems and Ground-Water Hydrologic Organization in Limestones
Derek C. Ford 403

Influences of Geologic Structure on Ground-Water Flow and Cave Developme in Mammoth Cave National Park, Kentucky, U.S.A.
Arthur N. Palmer 405

Cave Development North of the Green River at Mammoth Cave National Park is Strongly Influenced by Recharge from a Filled Pennsylvanian Paleo-Valley
Angelo I. George and John B. Schmidt 415

Porosity and Hydrology of Jointed Middle Ordivician Limestones in the J. Percy Priest Dam Area of Central Tennessee
Richard G. Stearns 431

Lateral Unloading of Isotropic Rock as A Process of Solution Channel Enlargement
Richard L. Powell 433

Karst Hydrology and Water Chemistry in a Mixed Sedimentary Terrain
Douglas Medville and Eberhard Werner 443

VI. Remote Sensing in Karst

Etude du Karst, en Grèce et en Crête, a l'Aide de la Télédéction et du Tritium
P. Ch. Leveque 461

High-Yield Wells and Springs Along Lineaments Interpreted from LANDSAT Imagery in Madison County Alabama, U.S.A.
James D. Moore, Frank Hinkle, and George F. Moravec 477

VII. Geochemistry of Karst

Carbon Dioxide in the Atmosphere of the Unsaturated Zone An Important Control of Groundwater Hardness in Limestones
T. C. Atkinson 489

Relative Solubilities of Limestone and Dolomite
John Thrailkill 491

The Dissolution Kinetics of Calcite in Carbonic Acid
Rane L. Curl 501

Role of Solution Kinetics in the Development of Karst Aquifers
William B. White 503

The Chemical and Isotopic Composition of Carbonate Ground-Waters: Nature of Bedrock Dissolution in Karst Terrains
Russell S. Harmon 519

Heavy Metals and Optical Brighteners as Ground-Water Tracers in the Central Kentucky Karst: Implications Concerning Regional Hydrology
James F. Quinlan, Michael R. McCann, William M. Andrews, and John A. Branstetter 535

Hydrochemical Evaluation of Ground Water in a Limestone Aquifer in Huntsville, Alabama, U.S.A.
Hassan M. Mostafa and Nelson A. Lloyd 537

Hydrogeology and Solution Chemistry of North Venezuelan Karst
Melvyn Gascoyne 553

* * *

Index to Authors 569

Authors' Affiliations and Mailing Addresses 573

Errata 578

CONTENTS

Introduction 7

I. THE PLACE OF KARST MORPHOLOGY IN SCIENCE

The karst concept 15

Meaning of the term karst morphogenetics 19

The place of karst morphogenetics among the geosciences 20

II. GENERAL CRITERIA OF KARSTIFICATION

Presentation of the problem 25

The concept of karst corrosion 26

1. Carbonate dissolution of limestone 26
2. Hydrocarbonate dissolution of limestone 28
3. Non-karstic corrosion of limestone 48

Petrovariance as a factor of karst corrosion 54

1. Specific features of limestone composition 55
2. Influence of limestone crystallinity and lithostructure upon karst corrosion 63
3. Influence of the lithology and limestone structure upon karst corrosion 68
4. Dolomite corrosion 71
5. Dissolution of gypsum and rock salt 78
6. Karst corrosion of polymineral rocks 81

Epeirogenic movements as factors of karstification 86

Climatic control of karstification and the geomorphological consequences of climatic variance 103

1. Karstification in the glacial and periglacial regions of geomorphology 117
2. Karst corrosion in the temperate and Mediterranean zones 127
3. Karst corrosion in the desert zone 129
4. Tropical karstification 130
   a) Rain-forest karst 134
   b) Inselberg karst 134
   c) Karst cone and karst tower 135
   d) Intermontane karst plains 136
   e) Other characteristic tropical karst forms 137

5. Karst morphological consequences of soil microclimates 141
a) Methods of testing soil gas for carbon dioxide content 152
b) Examples of typical carbon dioxide contents in soil atmospheres of karst microspaces differing in biological and climatic features 157

Authigenic and allogenic karst evolution (the role of erosional variance in karst erosion) 166
1. Features of authigenic karst erosion in the presence of an unchanging local baselevel of erosion 168
2. Erosion of authigenic karst when accompanied by displacements of the local baselevel of karst erosion 172
3. Allogenic (B-type) karst erosion 176

Influence of relief configuration upon the karst process (the geomorphological variance of karstification) 195

The anthropovariance of karstification 200
1. Modifications in erosion due to changes in the natural plant cover of a karst region 201
2. Modifications in erosional processes accompanying anthropogenic interference with the natural hydrology of a karst 207
a) Problems connected with human interference with the intake capacity of shallow-holes 208
b) Influence upon the karst process of human interference with karst springs 221
c) Influence upon the karst process of the regulation of surface and underground stream channel sections 225
d) Influence upon erosion of artificial dams 228

Thematic review of the theses put forward in this book 231

REFERENCES 245

INDEX OF NAMES 269

SUBJECT INDEX 271

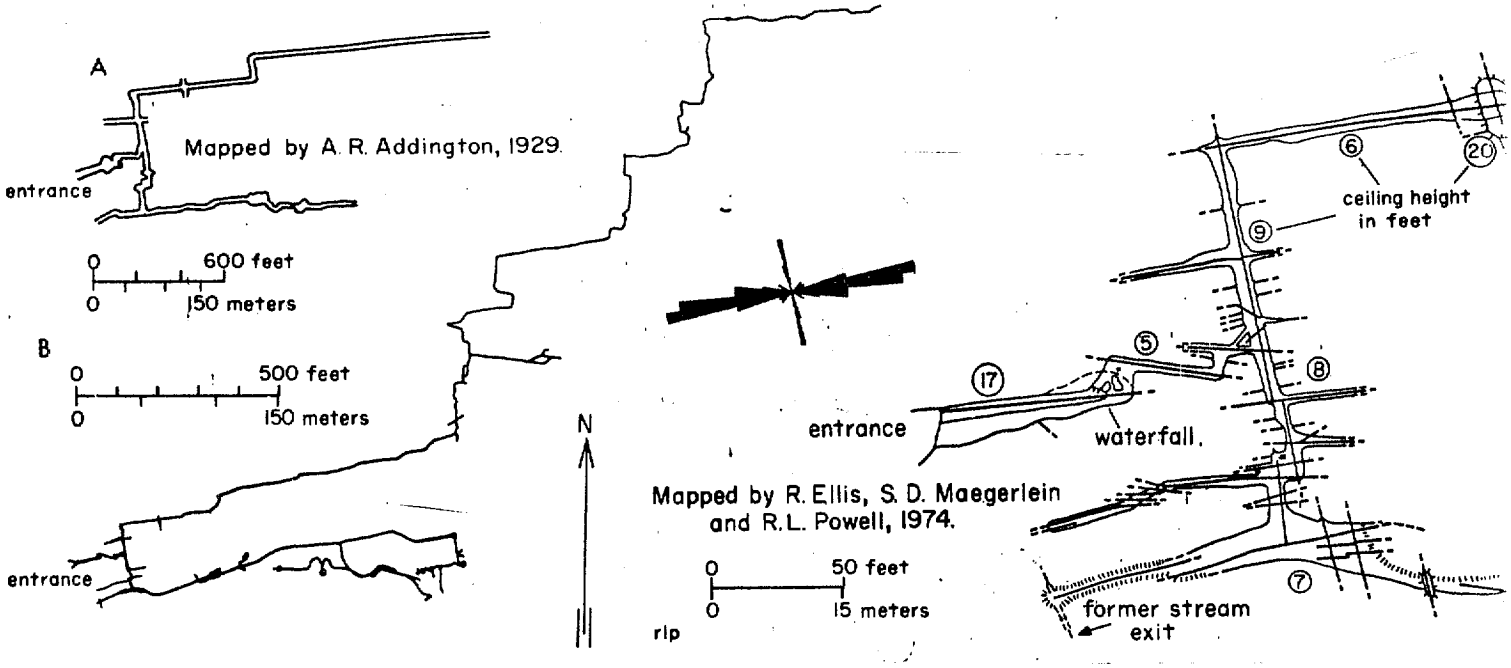


Figure 5. Maps of May Cave showing joint orientation of cavern passages.

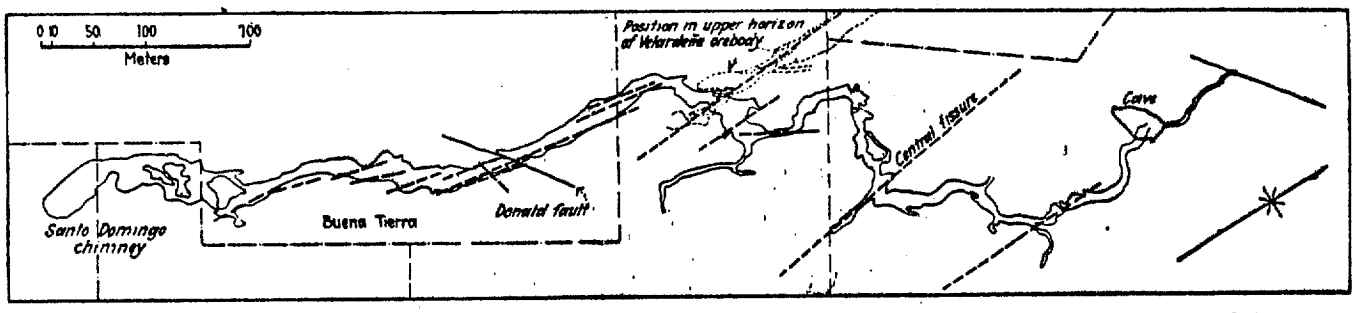


Fig. 5—Santa Eulalia, Chihuahua. Plan of Jean Cave orebody, showing relation to certain pre-mineral fissures.
By permission of American Smelting & Refining Co. and Cia. Minera de Peñoles

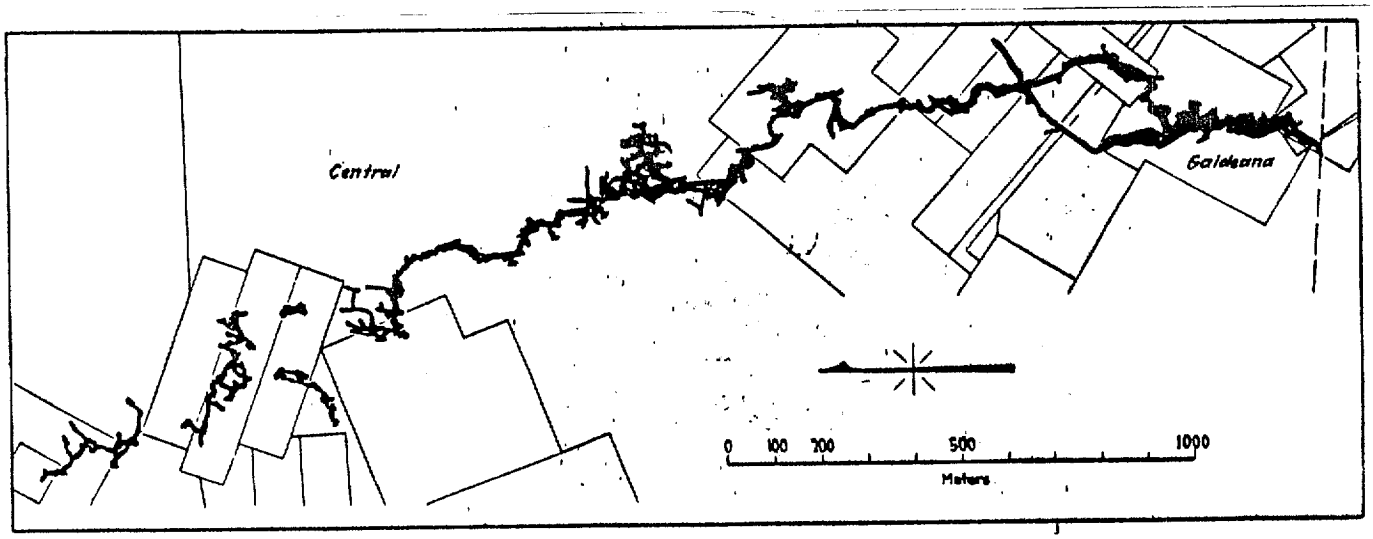


Fig. 4—Santa Eulalia, Chihuahua. Plan and section of Galdeana-Central manto from "N" fault north.
By permission of Cia. Minera de Peñoles

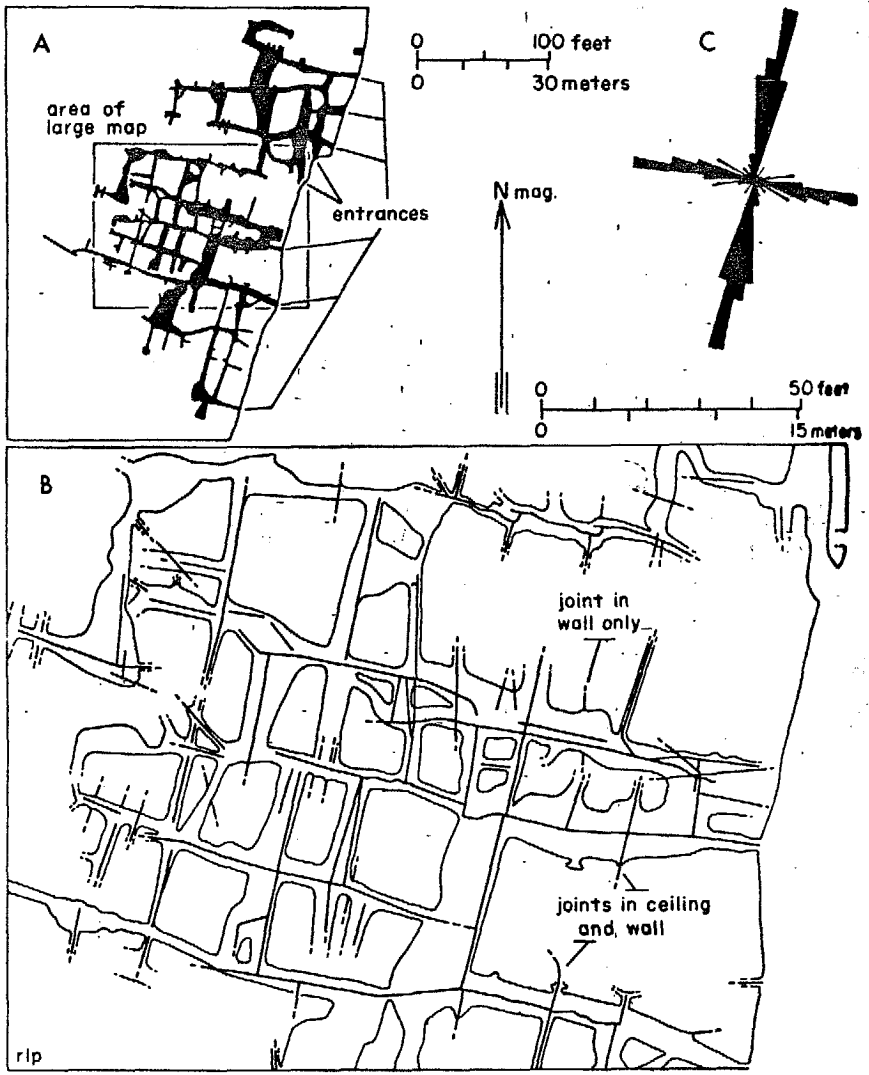


Figure 5. Maps of Herron Cave showing the pattern of master and cross joints in relation to cavern passages. The rose histogram includes 136 joint measurements.

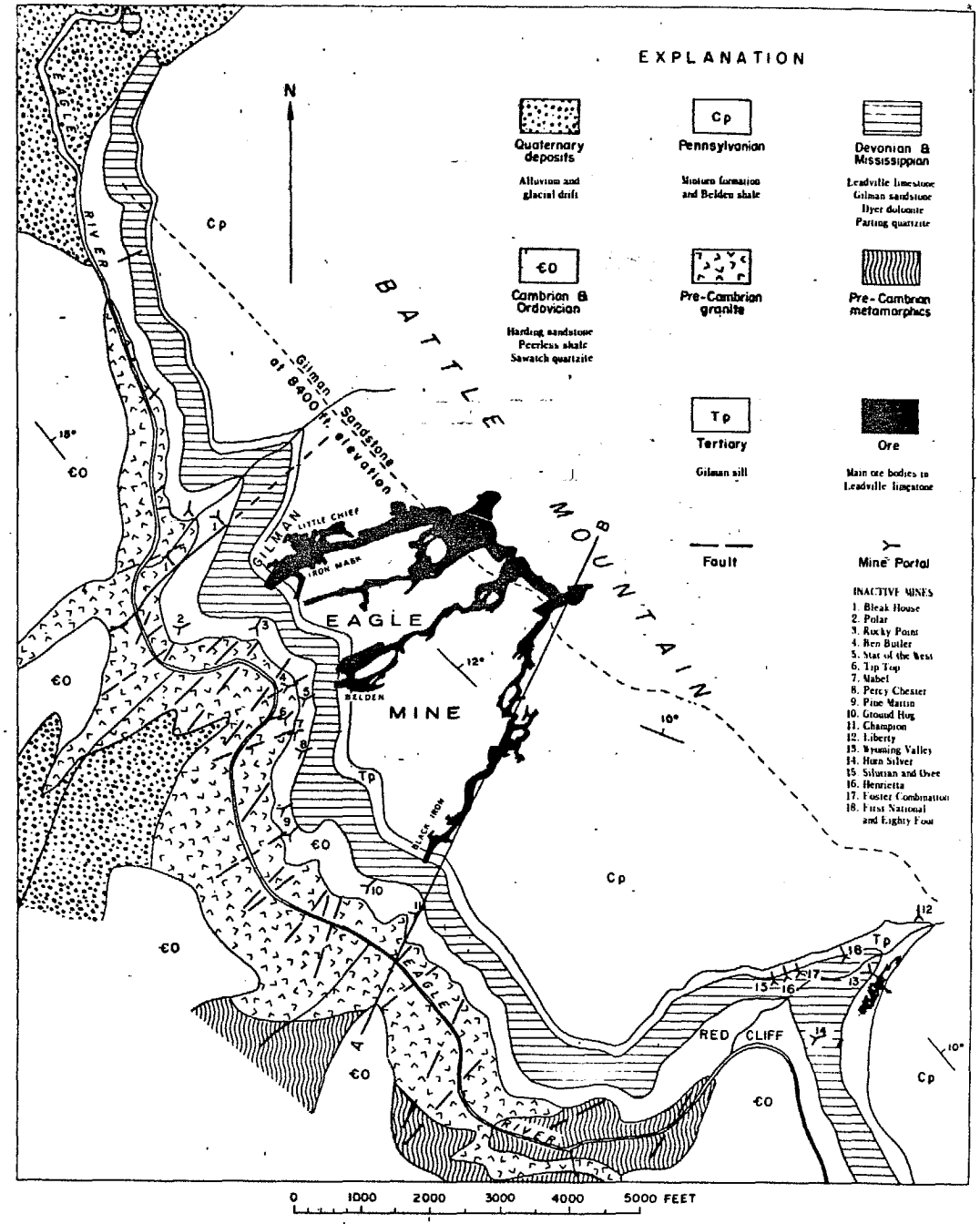


FIG. 1. *Geologic Map of the Gilman District, Eagle County, Colorado, showing location of principal ore bodies. Compiled from maps by The New Jersey Zinc Company and Lovering and Tweto (20).*

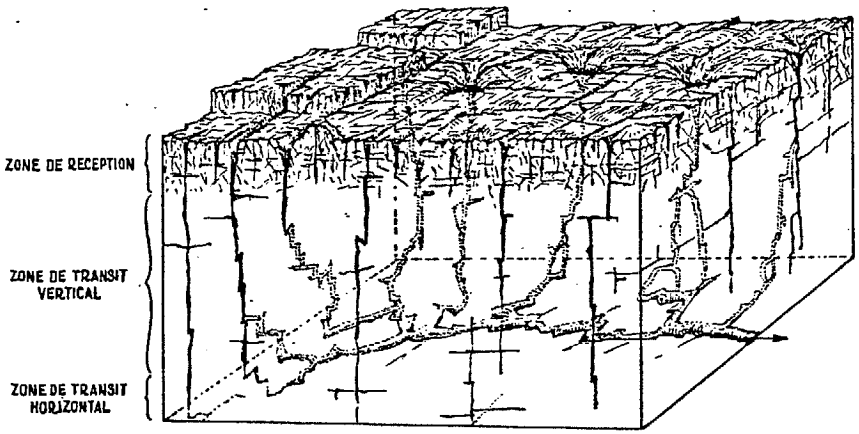
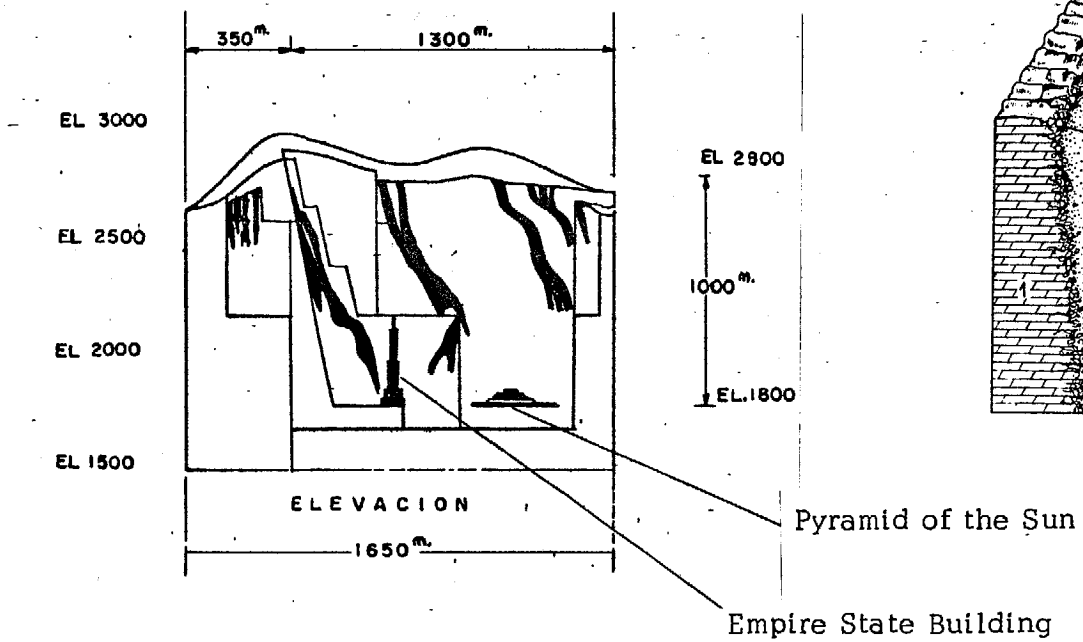


Figure 1

Organisation du réseau de drainage dans un karst



Avalos - Concepcion del Oro District, Zacatecas, Mexico

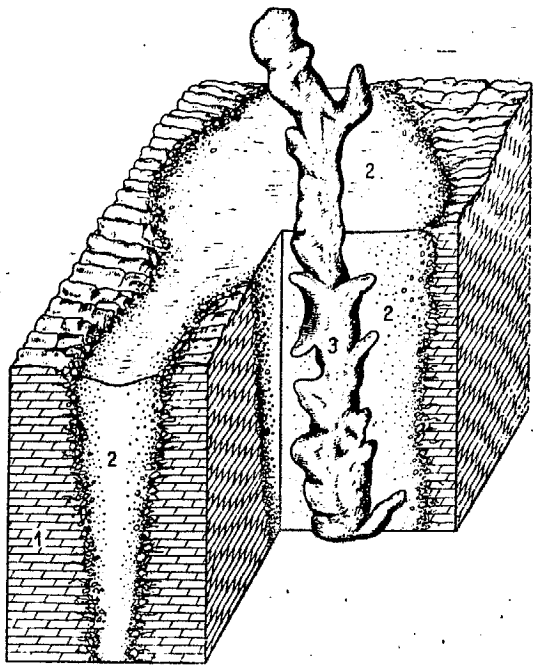


Fig. 18. Hydrothermally induced pulverization in dolomite accompanying a silicified former hot-spring funnel from the Csiki Hills, Budaörs, near Budapest

1 — fresh dolomite; 2 — pulverized dolomite; 3 — silicified spring funnel raised above the surface by selective erosion

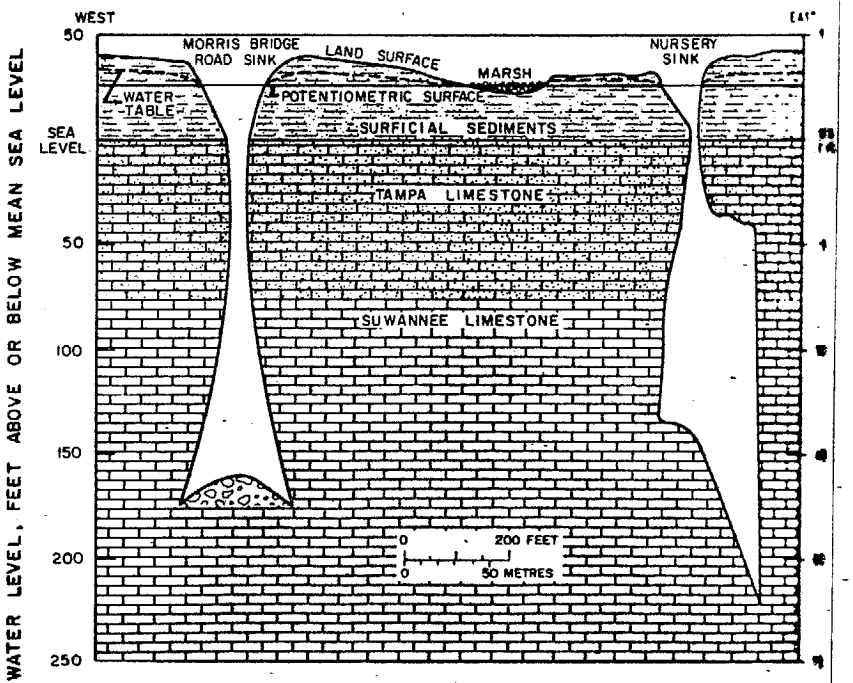
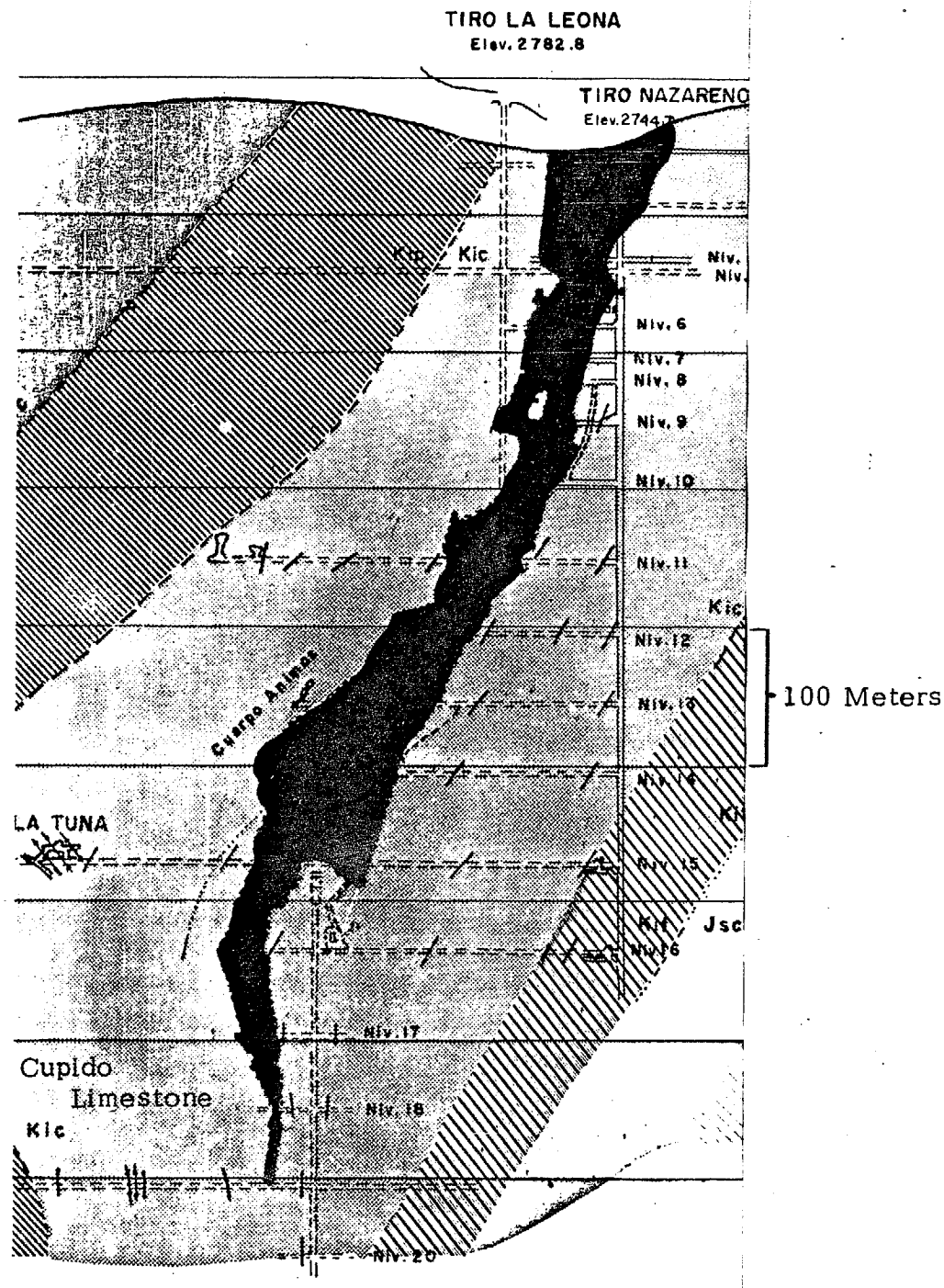


FIGURE 3. GENERALIZED SECTION THROUGH MORRIS BRIDGE ROAD SINK AND NURSERY SINK, BASED IN PART ON REPORTS OF SCUBA DIVERS



Animas Chimney, Avalos - Concepcion del Oro District, Zacatecas, Mexico

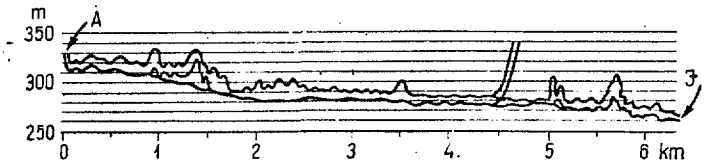


Fig. 85. Longitudinal section of the Main Branch of the Baradla Cavern between Aggtelek (A) and Jósvafő (J)

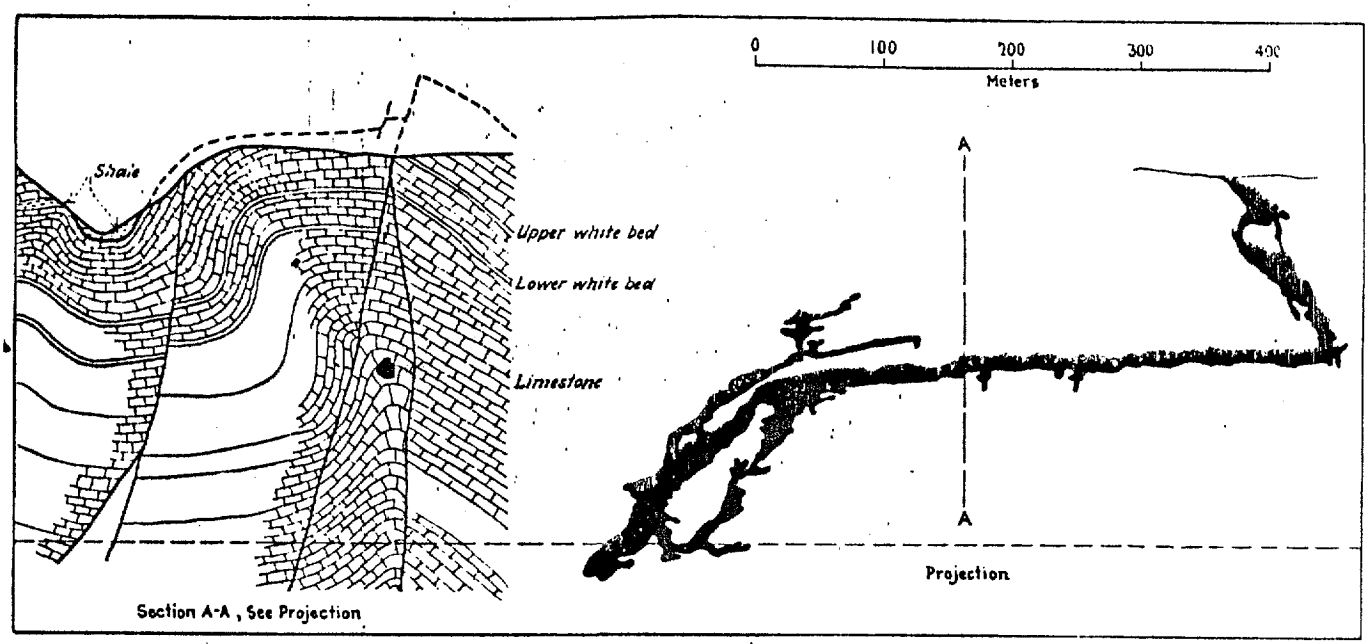


Fig. 9—Ojuela mine, Mapimi, Durango. San Jorge-San Juan orebodies. By permission Cia. Minera de Peñoles

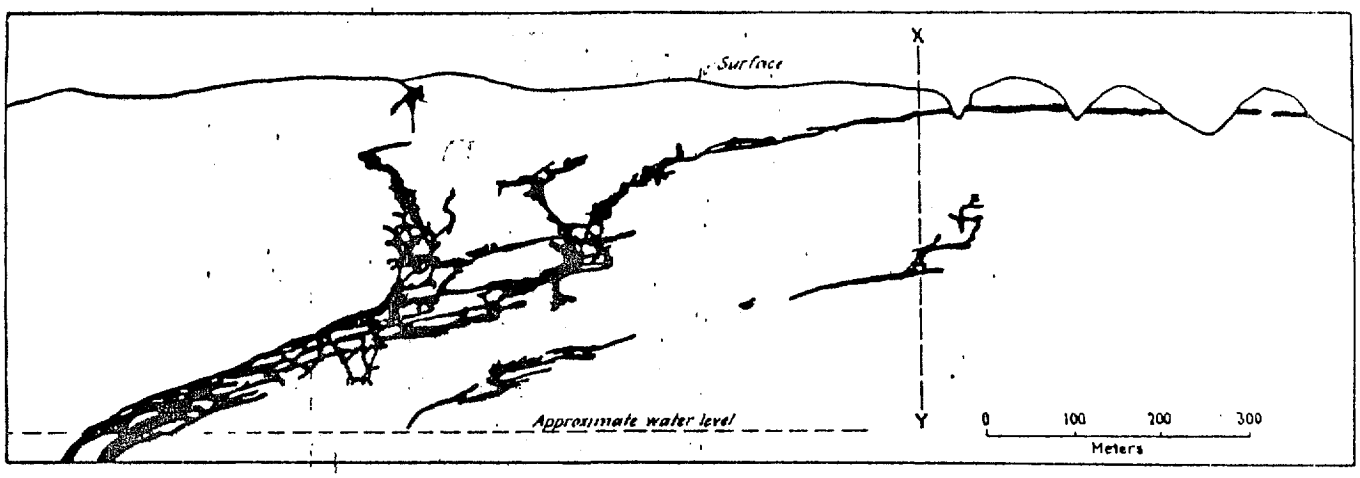


Fig. 10—Ojuela mine, Mapimi, Durango. Cumbres orebody. Projection N. 32° W., looking northeast

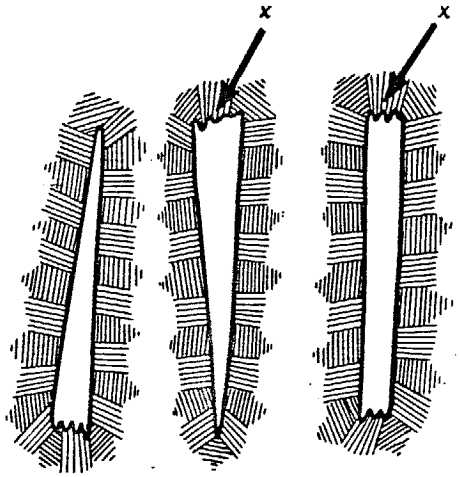


Fig. 26. Most frequent profile types of passages in structurally controlled caverns (there is usually a mylonitic breccia at the point marked *x*)

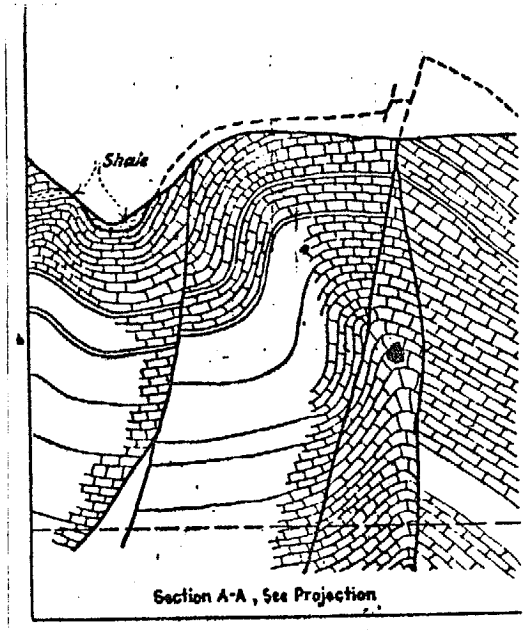


Fig. 9—Ojuela mine, Mapimi, Durango

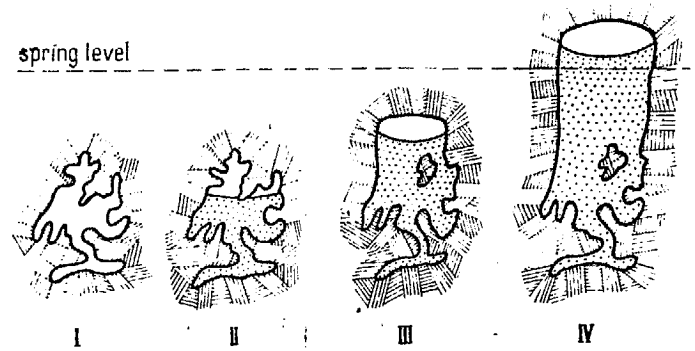


Fig. 78. Upward enlargement by scour of cavern passages in a B-type lenticular zone

I — cross-section of a passage sculptured by corrosion in an A-type lenticular zone; II — deposition of sediment by the B-type stream at the bottom of the cavern; III — upward enlargement of the cavern profile by scour towards the spring level as the sediment is deposited; IV — a state of equilibrium sets in as determined by the stream gradient and the position of the spring level

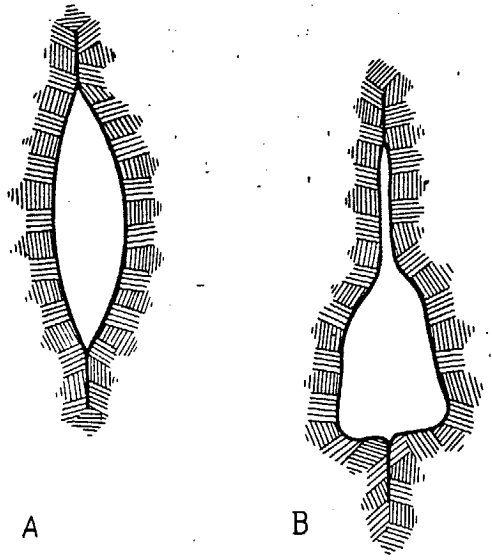


Fig. 30. Types of cross-sections of cave passages structurally preformed but sculptured by water

A — section indicating sculpture largely by corrosion, with full inundation in the phase of active evacuation; B — section indicating sculpture largely by erosion, with at any rate the presence of an open water surface

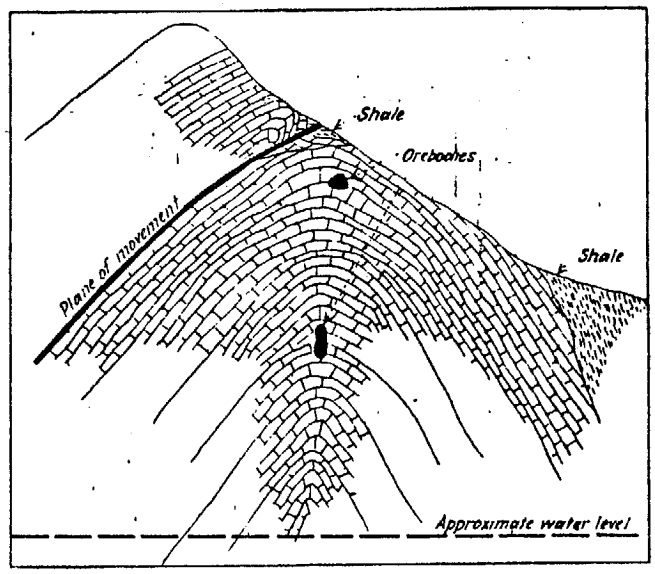


Fig. 11—Cumbres orebody, Ojuela, Durango. Section through line X-Y. See projection

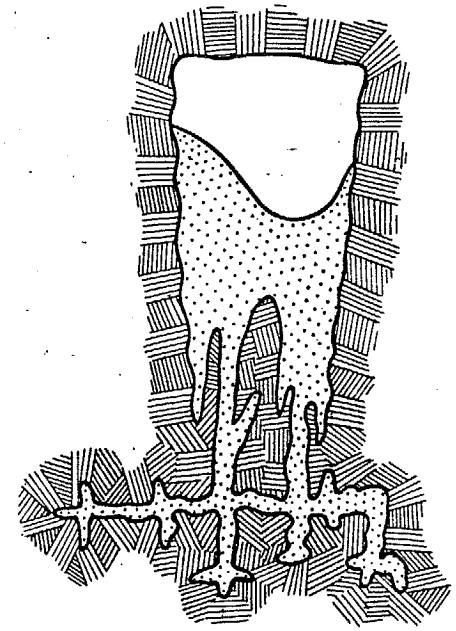


Fig. 80. Cross-section of a cavern passage originally of the A-type, sculptured by B-type processes. The section of the profile due to corrosion is totally silted up by sediment, but that due to scour is partly visible

CROSS-SECTIONS OF CAVERNS AND ORE BODIES

WLK - I pass this on to you re any future plans TCO may have for an exploration meeting. FTG 3/20/78

ASARCO

Southwestern Exploration Division

March 14, 1978

use file Limestone Replacements

F.T.G.

TO: F. T. Graybeal

FROM: J. D. Sell

Prospecting for Ores in Carbonates
In-House Seminar Proposal

I attach the following article by Callahan to renew the interest in prospecting for ores in carbonates. The article is entitled: "Some Thoughts Regarding Premises and Procedures for Prospecting for Base Metal Ores in Carbonate Rocks in the North American Cordillerans," by W. H. Callahan: Economic Geology, V. 72, No. 1, p. 71-81, 1977.

Callahan clearly and strongly endorses the main locations of ore deposits in carbonate rocks. However, he leaves it up to the reader to devise the means and ways of determining how to find additional members of the Appalachian—Mid-Continent—Rocky Mountain—Cordilleran suite of deposits.

I believe there are a number of ways to help zero in on the general environment and habitat of these deposits and I am encouraged that additional clues might be available to the outcrop geologists for a tighter control prior to prospecting by drill hole.

I propose an in-house seminar on the guides to mineralized districts and ore deposits, in specific, through the collection and interchange of ideas, thoughts, concepts, and specific details by interested people from the various offices. Mr. Vance Greene, Knoxville, has extensive knowledge in this area and initiated a study in central Colorado several years ago and undoubtedly could add considerable thought to the specific problem.

Some topics of discussion should include:

1) What are the visual characteristics of favorable limestones-dolomites?
2) What are the chemical characteristics?
3) Do certain ores have a preference? If so, how?
4) How far away are the characteristics observed?
5) Change in type or pattern of characteristic as district or deposit is approached?
6) Do structures enhance the environment? If so, how?
7) Do intrusives enhance the environment? If so, how?
8) Other thoughts, biostratigraphic recognition, etc.?

Perhaps outside speakers could be brought in to chat for a session, such as Dr. Tommy Thompson, who did some Leadville studies for Asarco.

Denver would be a good meeting place from the standpoint of underground studies and relationships at Leadville. Arizona has a number of areas and mines of interest but access underground might be limited.

The interested participants should have some of the data available for discussion and perhaps reproduction, but it would be productive if the sessions could be taped and ultimately condensed into a workbook of knowledgeable facts and thoughts for distribution.

James D. Sell

James D. Sell

JDS:lb
Att.

Economic Geology
Vol. 72, 1977, pp. 71–81

WLK file Limestone Replacement

ASARCO

Southwestern Exploration Division

July 13, 1979

TO: F. T. Graybeal

FROM: J. D. Sell

Limestone Replacement Search

Attached is a compilation of features and parameters of replacement districts with comments on the search for additional ore bodies and evaluation of lesser districts which may have far greater potential than presently expressed.

The work is essentially a compilation of the visual and chemical features developed during the past summer's work in Colorado, and I feel that much of the material can be used and applied throughout the western carbonate areas in the search for viable target areas and districts.

James D. Sell

JDS:lb
Att.

LIMESTONE REPLACEMENT SEARCH

James D. Sell

July 13, 1979

LIMESTONE REPLACEMENT SEARCH

Summary
Size and habitat of known replacement ore bodies and districts
Production data from four major districts
Comments on mapping, sampling, interpretation, and drilling
Visual and chemical parameters
Areas investigated during 1978
References

Table One. Production-Value Data
Table Two. Tabulation of trend values in Leadville and related carbonate formations in Central Colorado

Appendix A. Summary of Skyline emission spec and Barringer MRFAPE data
Appendix B. List of previous reports containing analytical data

Plates
1. Surface plan of Iron-Rock Hill group of ore bodies, Leadville District, Colorado
2. Surface plan of mantos and chimneys in Leadville Dolomite and underlying fissure veins in quartzite and granite, Eagle Mine, Gilman District, Colorado
3. Surface plan of some ore bodies in the Aspen District, Colorado
4. Plan of mantos and chimney ore runs, Main Tintic District, Tintic, Utah
5. Surface plan of ore bodies, Chief Consolidated Mine, Tintic District, Utah
6. Vertical section ABC of the deep ore zone of the Chief Mine, Tintic District, Utah
7. Long section XYZ of the Chief ore zone, Chief Mine, Tintic District, Utah
8. Generalized section of the Gemini ore zone, Tintic District, Utah
9. Generalized section of the Iron Blossom ore zone, Tintic District, Utah
10. Plan and section of Liddia Mine and Continental Chief Mine, Leadville District, Colorado
11. Plan of workings of the Hilltop Mine, Mount Sheridan District, Colorado

LIMESTONE REPLACEMENT SEARCH

Summary

The perplexity of configuration and extent of limestone replacement ore bodies, with their usual sharp contact between ore and host unit, have long been a grey hair in the explorationist's head who searches for them. Probably more physical and chemical factors are associated with these deposits than most other types of mineral deposits, and this includes the usual stratigraphic, structural, and mineral zoning problems. Accenting the exploration problem is the rapid change in the third dimensional path of very productive ore bodies having small subcylindrical cross-section while extending in hundreds and thousands of feet along the axial direction.

Two factors appear to be able to guide the explorationist: 1) fluid movement in a carbonate terrain will leave a path and this resultant alteration-recrystallization-replacement intensity can be mapped, 2) mineral-bearing fluids add and subtract components to the units involved and the distribution intensity and trends can be outlined.

This report addresses the field and laboratory findings on the two factors.

Size and Habitat of Known Replacement Ore Bodies and Districts

The size and habitat of replacement ore bodies varies as with most ore deposits. However, the aggregate deposits found within a district are often large and the profit realized from individual ore bodies is also often large -- factors which attest to their exploration potential.

Four districts, showing the plan extent of ore bodies, are used as examples: 1) Leadville, 2) Gilman, 3) Aspen (all in Colorado), and 4) Tintic, Utah.

Leadville's known productive district extends 3-1/4 miles east-west by 2-1/2 miles north-south. In this report, the Iron-Rock Hill group of ore bodies is taken as typical of the manto type with intra-connecting channels and chimneys. Plate 1 is a tracing of Norman's (1971) compilation taken mainly from an earlier report by Loughlin (1926). Note that in plan the ore bodies range from five to ten feet and up to 400 feet in width and in length from several hundred to over 1400 feet. Height of the stoped areas is reported to be 10-20 feet and up to 100 or more feet, especially near or along cross fractures and feeder systems. As noted in the plan, overall aggregate of ore runs is substantial, but outlines of the mined shoots are very irregular with non-mined masses in the interior and isolated mined pods outside the main run or channel.

At Gilman (Plate 2), four major ore runs were mined from an area having a trapezoidal outline with the bases of 4500 and 2000 feet and a height (length) of 3000 feet. The individual ore runs have a general width of 50-80 and up to 200 plus feet and lengths of 2600-4000 feet; all of which were upwardly terminated by erosion. The runs were typically elliptical and range from several feet to 150 feet in height. The several chimneys found at the lower termination, and also along the length of the run, extend through several stratigraphic units and obtain heights in excess of 250 feet as a downward terminating cone. The widest portion of the largest chimney was in excess of 400 feet in diameter.

The Aspen ore bodies (Plate 3) are in a long string (some 3-1/2 miles long) of individual bodies ranging from 20-50 and up to 200 feet in width. The length ranged from 300-400 feet and up to 2200-2400 feet. The Aspen ore bodies also tend to form elliptical-shaped cross-sections of 20-30 feet and up to 100 feet in height. Steep folding at Aspen (see cross-section C on Plate 3) gives the impression of a number of ore bodies stacked one upon the other, but essentially they follow along a favorable horizon.

The Tintic district, Utah, has the best available maps showing the ore bodies and their configuration. The Main Tintic district of limestone replacement ore bodies extends 1.8 miles in length by 1.5 miles in width. Plate 4 is a tracing of the Main Tintic district with its three main ore runs and several cross-overs. Widths within the ore runs are commonly 30-50 feet and up to 150-200 feet connected by narrow 10-20 foot wide bodies, with the individual stoped masses being 400-1600 feet long. Heights of ore runs were 20-50 and up to 100 feet high. Numerous connecting chimneys of similar dimensions tie the ore bodies together. The string of ore bodies in the individual runs total 5000 to 10,000 feet in length.

A portion of the ore bodies at Tintic have been enlarged to give better detail as to the horizontal and vertical configurations on the mined areas. Plate 5 is a plan of the Chief Consolidated Mine, at the scale of 1" = 300', which is at the north end of the Chief Ore Zone of Plate 4. The general trend of the ore run is north-south subparallel to the strike of the bedding with subsidiary control along northeast-trending structures. Two sections accompany the plan: 1) a vertical section northeasterly through the deep ore zone (section A-B-C) is shown on Plate 6, while 2) Plate 7 is the accompanying north-south section X-Y-Z. Note that along the Chief Consolidated zone, all the ore bodies are within the Bluebell dolomite.

Two additional sections, at 1" = 300', show the Gemini ore zone to the west and the Iron Blossom ore zone to the east within the Main Tintic district. The Gemini ore zone (Plate 8) is not only in the Bluebell dolomite, but extends by long chimneys along fault zones down into underlying units which are several thousand feet stratigraphically below the Bluebell. These chimneys are 1600-1800 feet in vertical length. On the other hand, the Iron Blossom ore zone (Plate 9) is nearly a horizontal trend which on the south cuts across dipping units below the Bluebell, then through the Bluebell in the central part of the run, then finally cuts horizontally through dipping units, which were dropped across the Sioux Ajax fault, that are stratigraphically far above the Bluebell dolomite.

This propensity of ore runs to change direction and/or stratigraphic units is a general rule in the larger districts and should be looked for during any exploration program.

Cook (1957b) has described these Tintic zones quite graphically and I reproduce his pages 63-71 below. Of special note is his Figure 6 showing the distribution of the production versus the geologic units from which the production was mined. The Devonian-Silurian Bluebell dolomite and the lower Cambrian Ophir Formation produced about 45% of the total dollar value from the Main Tintic district.

D. R. Cook, 1957b, p. 63-71

Limestone Replacement Ore Bodies

Most of the ore produced from the Main Tintic district has come from limestone replacement ore bodies. An examination of Plates 3 and 4 shows that these deposits are situated at the north end of the district, occur in definite linear zones and are on the northern projection of many of the prominent fissure vein systems.

The term "ore zone" is used here although they are called ore runs in the Main Tintic district. They resemble in form and mineralogy the "mantos and chimneys" of the Mexican silver - lead province and especially the Santa Eulalia orebodies in the State of Chihuahua, Mexico. In certain respects they also resemble the limestone replacement ore bodies of Gilman, Colorado.

The four principal ore zones named from west to east are the Gemini, Chief, Godiva, and Iron Blossom. The Plutus, located between the Chief and Godiva, although of smaller magnitude, is of the same general type. The ore zones strike north, are parallel or subparallel to the bedding, and have a gentle plunge to the north similar to that of the synclinal axis. Commonly the ore zones have one long dimension and two short ones; they often contain individual ore bodies or ore shoots, sometimes side by side and sometimes one vertically above another. These shoots may be interconnected, as in the Godiva and Iron Blossom zones, or they may be isolated, as in parts of the Chief and Gemini zones. Although the general strike and plunge of the ore zones can be predicted with some degree of certainty, much development and exploratory work is necessary to find the ore shoots within the zones. This explains the repeated attempts of the mining companies and lessees to explore for individual ore shoots that might have been missed when the zone was being mined.

In many cases the ore zones show considerable modification by northeast faulting and, to a lesser extent, by northwest faulting. At intersections with faults they often enlarge in plan and section and form vertical chimneys or very rich horizontal concentrations of ore. It is safe to state that the major profits of the mines have been derived from such areas. Such ore bodies as the Granite pipe and 18-316 ore body of the Chief Consolidated mine, the Billings pipe of the Gemini mine, the California and Virginia pipes of the Centennial Eureka mine and the Mammoth pipe of the Mammoth mine have accounted for the bulk of the profits from these properties.

The persistence of the ore zones across faults and through different stratigraphic units is a very striking feature. Because of the distribution of the ore zones in the syncline and also because of the extensive faulting, ore is found through a range of 6,000 feet in a great number of formations from Cambrian to Mississippian in age (see Figure 6).

AGE		UNIT	THICKNESS	Approximate Gross PRODUCTION
			Feet	(Dollars)
Middle or Upper Eocene	Intrusive	Silver City Monzonite		
		Swansea Quartz Monzonite		12,000,000.
Middle Eocene	Extrusive	Laguna Latite Series		
		Packard Rhyolite Series		
Mississippian		Humbug	650	
		Deseret	875	46,500,000.
		Madison upper member	500	
		Madison lower member.	250	
Miss-Dev.		Piñon Peak	160	43,000,000.
Devonian		Victoria	350	
Dev.-Sil.		Bluebell	500	110,000,000.
Ordovician		Fish Haven	280	10,000,000.
		Opohonga	875	9,000,000.
U. Cambrian		Ajax	640	60,500,000.
		Opex	500	7,500,000.
		Cole Canyon	600	7,000,000.
		Blue Bird	180	
M. Cambrian		Herkimer	375	10,000,000.
		Dagmar	95	
		Teutonic	390	
M-L. Cambrian		Ophir	440	84,500,000.
L. Cambrian		Tintic	3,000	25,000,000.
TOTAL GROSS PRODUCTION~425,000,000.				

8,155 Feet

FIGURE 6. Distribution of the total production of the Main and East Tintic mining districts from various rock units.

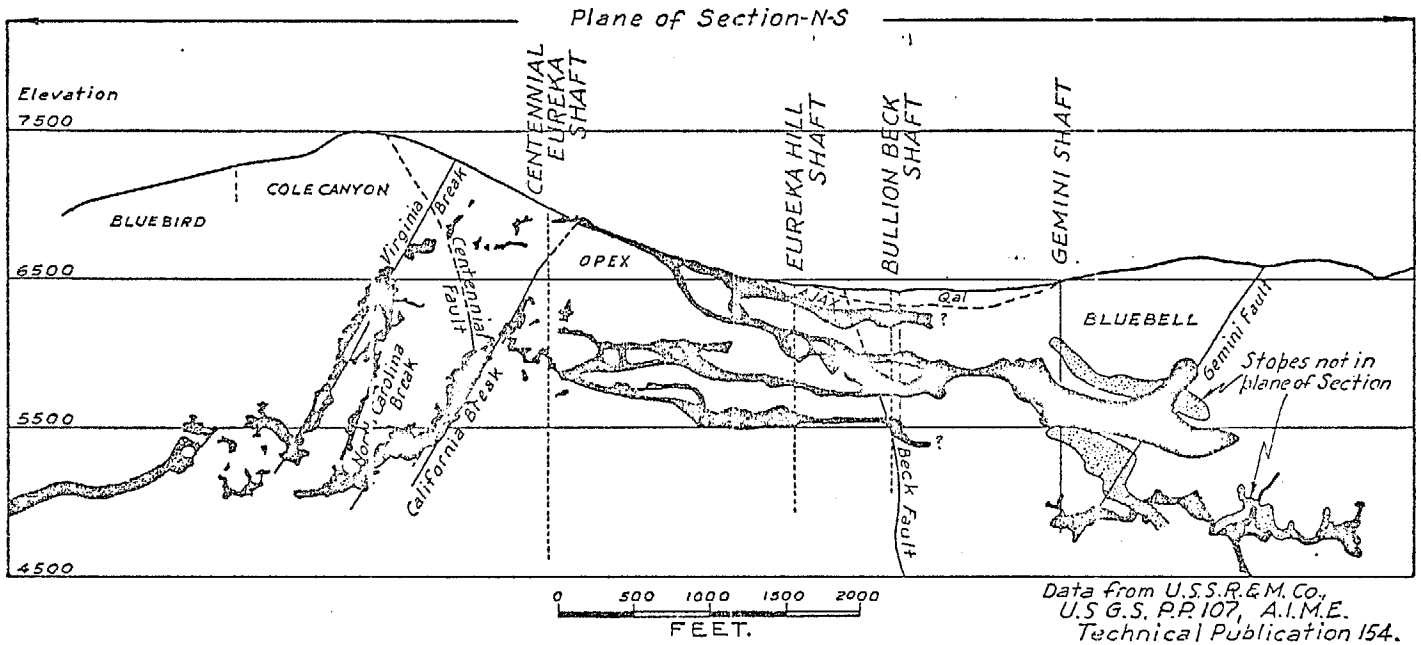
The ore zones are surprisingly continuous in their strike, persisting for distances of 8,000 to 9,500 feet. Only the Chief ore zone has been intensively mined below the water table, although recently this operation was discontinued. The failure to explore the Chief ore zone down dip and to follow the Gemini ore zone beneath the water table was entirely the result of adverse economic factors rather than exhaustion of ore. We now have reason to believe that the Gemini and Chief ore zones continue to the north, and we believe that the Godiva and Iron Blossom ore zones also continue in a northerly direction.

The habits of each ore zone differ and for this reason a brief description will be given of each.

Gemini Ore Zone: This ore zone (see longitudinal section, Figure 7) extends from the Grand Central mine to the Gemini mine, a total distance of 8,000 feet. Production is estimated to exceed $97,000,000, half of which has come from the Centennial Eureka mine. An examination of Plate 3 shows the pronounced zoning from copper to lead in following the ore from south to north.

At the south end of the zone the ore occurs chiefly in the Ajax formation and is localized by the intersection of favorable beds and northerly and notheasterly trending fissures. Near the Grand Central mine the ore zone is horizontal, but in the vicinity of the Centennial fault the principal ore bodies occur as steeply inclined chimneys. These chimneys account for the bulk of the production from the Centennial Eureka mine and are localized where the ore zone intersects a series of south dipping, east-striking crossbreaks. North from the Centennial Eureka mine and through the Eureka Hill mine, the ore zone is composed of a series of separate lenticular ore shoots lying along steep bedding planes in the Ajax formation. At the Beck fault, the ore zone forms another irregular vertical chimney of ore which passes from the Ajax formation south of the fault to the Bluebell formation north of the fault. The difference in lithology does not appear to affect the character of the ore in any respect. The Gemini mine is located on the most northerly part of the known limits of the ore zone and the ore shoots are similar to those in the Eureka Hill and Bullion Beck mines, being characterized by great irregularity and discontinuity. However, the ore zone itself is well-defined in these mines, is parallel to the bedding and plunges gently to the north. The last known ore in the Gemini mine is 2,400 feet lower in elevation than the outcrop of the ore zone a short distance south of the Eureka Hill shaft. The available information suggests that only economic factors (e. g. costs of mining below the water table) prevented the development of the ore farther to the north.

Except for a minor amount of leasing in the Bullion Beck mine, very little exploration or mining activity is being carried out along this ore zone (1957).



GENERALIZED SECTION OF THE GEMINI ORE ZONE

FIGURE 7

Chief Ore Zone: This ore zone (see longitudinal section, Plate 8) extends from the Mammoth mine to the Chief Consolidated mine, a total distance of 9,500 feet. Production is estimated to exceed $140,000,000 over half of which has come from the Chief Consolidated mine. It is interesting to note that at prices prevailing in 1957 this production would be valued at approximately $250,000,000. From south to north the ore shows a zoning of copper - gold - lead - silver, to lead - silver and finally to lead - silver - zinc.

The Chief ore zone begins at the impressive Mammoth ore pipe, a nearly vertical chimney 2,400 feet in vertical extent containing shoots of copper, gold, lead, and silver ores. Mining of this pipe was stopped at the water table, but it is reported that mineralization continues below this level. Unfortunately, the geology and ore controls of this great ore chimney have not been worked out in detail, but it is probable that the intersection of mineralized north-northeasterly - trending fissures and the eastward striking Sioux - Ajax fault zone is to a large extent responsible for the localization of this orebody and the associated brecciation.

From the area of the Mammoth pipe and the Mammoth fault, the ore zone plunges steeply northward along favorable beds to the Grand Central mine where the run flattens out and is localized in the steeply eastward dipping beds of the Bluebell formation. Proceedings north again along the zone, the ore shoots become increasingly complex through the Eagle and Bluebell mines and into the Chief Consolidated mine. The most striking feature of this part of the ore zone is the modification and enlargement of the ore in plan and section at its intersection with numerous cross-faults, especially those with a northeasterly trend. Within the boundary of the Chief Consolidated mine the ore zone continues persistently northward until it reaches the Beck fault where it expands and follows this fault to the northeast for 2,000 feet. Then it turns and again follows a northerly course. To date the zone has been followed about 600 feet north of the Beck fault where mining has been discontinued because of high pumping costs and the lack of development work.

In longitudinal section, the northern half of the Chief ore zone has an overall northward plunge of about 21°, roughly parallel to the plunge of the Tintic syncline. At the intersections with cross - faults (for example the 1050 fault, the Centennial fault, the Intermediate fault) steeply inclined ore chimneys are developed. The ore zone had been mined to the 2800 level at its most northerly extension and was partially developed on the 2900 level when operations were suspended in 1955 because of economic factors.

Within the Chief Consolidated mine there has been a pronounced decrease in silver and an increase in the zinc content of the ore in depth. Most of the ore above the water table is oxidized to some extent, and this may explain the high silver content in the upper part of the mine.

The last development work on its northerly extension indicates that the ore probably continues its downward plunge in the Bluebell formation.

The management of the Chief mine recently suspended all operations and at present there is very little mining activity on this ore zone.

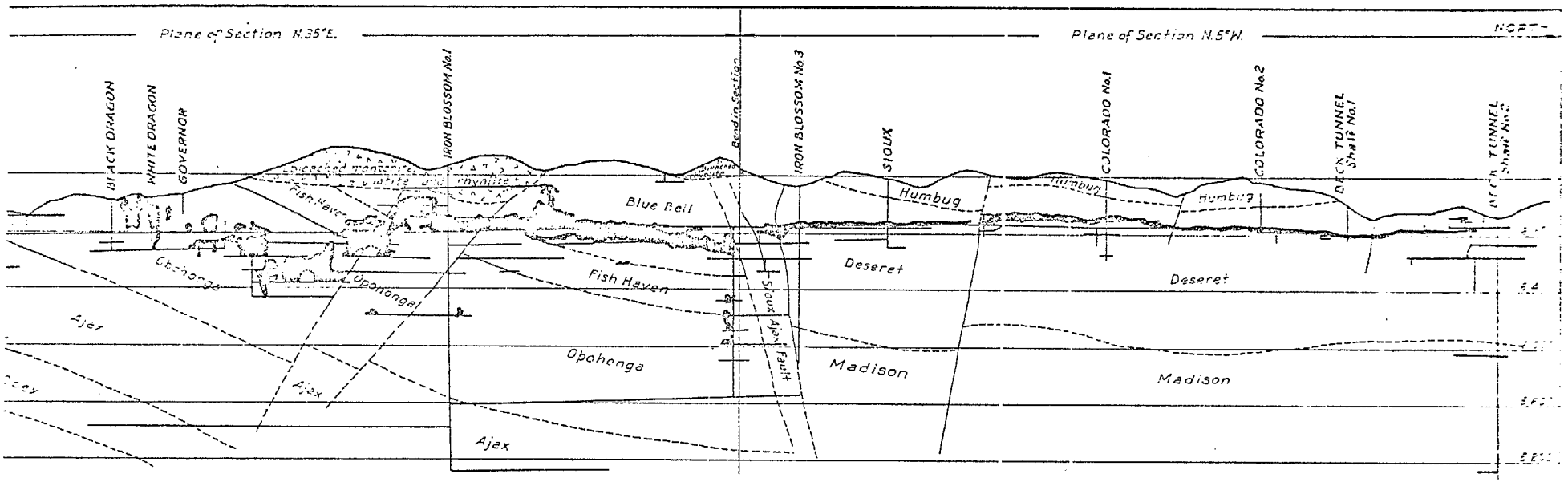
Godiva Ore Zone: This ore zone extends from the Sioux - Ajax fault to the Godiva mine, a total distance of slightly over 8,000 feet. Production figures are very scanty, but the value of ores produced is estimated to exceed $20,000,000.

This ore zone has its beginning in the extension of a well-defined system of northeasterly-trending mineralized fissures, described previously. From the Sioux - Ajax fault the ore zone extends almost due north, is generally horizontal and follows a coarse-grained limestone bed in the Deseret formation. The Deseret limestone along this ore zone is on the west limb of the Tintic syncline near the synclinal axis and dips between 30 and 60 degrees to the east. Unlike the Gemini and Chief ore zones, the Godiva ranges through only a small vertical interval, generally between 7,000 and 7,300 feet in elevation. Although the ore never crops out, it comes within 60 feet of surface in one place (low-grade jasperoid does crop out in the Little Spy and Humbug mines). North of the Godiva mine it plunges to the north, and Kildale (1936) reports that the ore becomes more siliceous and increases in zinc.

Little mining or exploration work is being done on any part of the Godiva ore zone; however, a small amount of leasing is going on in the Spy, Salvador and Mountain View mines.

Iron Blossom Ore Zone: This ore zone (see longitudinal section, Plate 6) extends from the Iron Blossom No. 3 mine to the Beck Tunnel No. 2 shaft, a total distance of approximately 5,200 feet; however, if the fissure vein system of the Iron Blossom No. 1, Governor, Martha Washington and Triumph are included, a total length of 15,000 feet is obtained (see Plate 3). Production is estimated to exceed $36,000,000. Because of the ease of mining and the high silver values, profits were unusually high; probably in the order of 33 percent of the gross.

This ore zone is similar to the Godiva, in that it is on the northern extension of a well-defined system of mineralized fissures. These fissures upon reaching the Sioux - Ajax fault die out and are aligned with north-trending replacement ore bodies. North of the Sioux-Ajax fault the ore zone can be traced for 5,200 feet and at its northern end turns northwesterly and joins the Godiva. The Iron Blossom ore in the Deseret formation is approximately along the axis of the Tintic syncline. The zone is unique in that it consists of a horizontal pipe of ore 5,000 feet in length with a width of 20 to 170 feet and a height of 20 to 60 feet. Near the Sioux - Ajax fault the controls for this zone appear to be the intersection of steep fissuring with a flat, coarse - grained limestone bed along the axis of the syncline. In the northern



GENERALIZED SECTION OF THE IRON BLOSSOM ORE ZONE

Looking Westerly

0 1000 2000 3000

FEET

PLATE 5

Modified from Map of the Tintic Standard Mining Co.

part of the Beck Tunnel property the horizontal ore swings northwesterly out of the synclinal axis. The zone then joins the Godiva zone south of the May Day mine and individual ore shoots become more irregular and less continuous.

A moderate amount of leasing is being done (1957) in the Iron Blossom No. 1, Iron Blossom No. 3, and Colorado No. 1 mines. In the main, however, the work appears to be scavenging operations.

Mineralogical Characteristics of the Ores

The principal metals of the fissure ores are copper, silver and gold, with minor amounts of lead and zinc. Important primary minerals of the fissure ores are enargite, silver sulfides and galena. Minor amounts of sphalerite, chalcopyrite, arsenopyrite and tetrahedrite also are present. The gangue minerals most commonly are pyrite, quartz, calcite and barite.

The principal metals of the limestone replacement ores are silver and lead with lesser amounts of gold, copper and zinc. In some mines, such as the Centennial Eureka and the Mammoth, copper and gold account for the major part of the production. The more important primary minerals of the limestone replacement ores are galena, sphalerite, argentite, enargite and tetrahedrite.

The sulfide ore tends to be vuggy and crustiform while the oxide ore, from which the bulk of the production of the district has been obtained is crumbly, cellular and iron stained with an overall density lower than that of the host rock. The zone of oxidation is deep, ranging down to 2000 feet below the surface at the north end of the Main Tintic district. The larger ore bodies are seldom completely oxidized and some sulfides are often found high above the water table, especially where they have been protected from oxidation by fault gouge or shales. The more common oxidized ore minerals include malachite, azurite, chrysocolla, covellite, anglesite, cerussite, smithsonite, calamine, hydrozincite, cerargyrite, native silver and plumbojarosite as well as a host of rarer minerals. Noncommercial minerals associated with the oxidized ores include kaolin, alunite, gypsum, limonite and the manganese oxides.

This complexity of habitat of replacement ore bodies in carbonate units is typical of most of the districts.

Around the Leadville Lead Mine, located east and outside the main Leadville area, are three mines which exhibit characteristics similar to that shown previously. All three are in well-altered and recrystallized Leadville dolomite with excellent secondary features and show only limited mining activity with probably no exploration work of recent vintage having been conducted. At a scale of 1" = 100', this includes the Liddia Mine and the Continental Chief Mine in both plan and cross-section (Plate 10). These two are northwest and north of the Leadville Lead workings. South of Leadville Lead is the Hill Top Mine shown on Plate 11. Further south is the Peerless area of interest.

Production Data from the Four Major Districts

As noted in Cook's text in the previous section, individual ore bodies can be very profitable. Production data is difficult to assemble for the districts as to the tons of ore produced, but production and dollar value figures for the major metals have generally been reported and collected by government agencies. Using the figures available and some estimation of tonnage, the following tabulation is made for the Leadville, Gilman, Aspen, and Tintic districts.

Table One. Production-Value Data

1. Leadville District, 1859-1963 (Tweto, 1968). Estimated 4 million tons of ore produced.

Metal	Amount of Metal	$ Value	% of Value
Au	2,985,776 oz.	$ 66,942,109	13.2 %
Ag	240,055,514 oz.	196,259,750	38.6
Cu	53,109 tons	15,521,319	3.1
Pb	1,088,204 tons	110,542,249	21.8
Zn	785,380 tons	118,222,469	23.3
		$507,487,896	100.0 %

2. Gilman District, 1880-1972 (Lovering, et al, 1978). Estimated 7-1/2 million tons of zinc-lead ore, and 3-1/2 million tons of copper-silver ore produced.

Metal	Amount of Metal	$ Value	% of Value
Au	393,491 oz.	$ 11,379,892	3.5 %
Ag	66,070,544 oz.	50,457,484	15.3
Cu	104,801 tons	28,643,454	8.7
Pb	148,444 tons	28,517,001	8.7
Zn	857,862 tons	210,239,328	63.8
		$329,237,159	100.0 %

3. Aspen District, 1880-1952 (Bryant, 1972, and Henderson, 1926). Estimated 5 million tons of ore produced.

Metal	Amount of Metal (Bryant 1880-1952)	$ Value (Henderson 1880-1923)	% of Value
Au	neg.	neg.	neg.
Ag	103,110,000 oz.	$ 73,340,613	72.6 %
Cu	565 tons	197,443	0.2
Pb	294,000 tons	25,781,812	25.5
Zn	11,000 tons	1,659,909	1.7
		$100,979,777	100.0 %

4. Tintic District
   A) Lindgren (1919), production 1869-1916, with estimated 5 million tons of ore from Main Tintic district.

Metal	Amount of Metal	$ Value	% of Value
Au	1,532,926 oz.	$ 31,688,389	18.7 %
Ag	119,712,919 oz.	78,762,811	46.5
Cu	76,188 tons	25,063,297	14.8
Pb	353,485 tons	32,341,622	19.1
Zn	7,810 tons	1,470,129	0.9
		$169,326,248	100.0 %

   B) Cook (1957b) reported production 1880-1957 of approximately 12.1 million tons of ore from the Main Tintic district.

Metal	$ Value*	% of Value
Au	$ 50,400,000	16.0 %
Ag	137,025,000	43.5
Cu	31,500,000	10.0
Pb	89,775,000	28.5
Zn	6,300,000	2.0
	$315,000,000	100.0 %

*Cook gave total dollar figure and the percentage of value and I calculated the individual metal dollar value.

   C) Shepard (1968) (Amount of Metal) and Bush (1957) (Value and percent) reported about 3.8 million tons of ore produced from the East Tintic district (1916-1957).

Metal	Amount of Metal	$ Value	% of Value
Au	537,439 oz.	$ 32,770,000	29.0 %
Ag	62,808,012 oz.	46,330,000	41.0
Cu	13,827 tons	3,390,000	3.0
Pb	371,485 tons	30,510,000	27.0
Zn	14,220 tons	not valued	not valued
		$113,000,000	100.0 %

*Bush reported only the total dollar value and the percentage of value of Au, Ag, Cu, and Pb. I calculated the individual dollar value. If the value for zinc would have been included, then the percentage of value for the other metal would be lowered slightly.

Comments on Mapping, Sampling, Assaying, Interpretation, and Drilling

In mapping, the primary requirement in the carbonate terrain is identical to that of porphyry copper exploration -- the recognition of the changes from the normal. Thus, mapping in initial stages is only a matter of looking and observing at the degree of dolomitization and recrystallization. As the degree becomes apparent and thicker packets of sedimentary units become involved, and as fracture and fault control become evident, then mapping can proceed on a systematic basis to outline and delineate the patterns present. The several stages as categorized in Appendix A are subdivisions applicable, but it must be remembered that the alteration process is an ongoing event and gradational effects are the rule. Remember also that initial carbonate depositional characteristics have a profound effect in the initial reaction or changes, thus a medium crystalline, fossiliferous limestone will exhibit effects long before a fine-grained dolomite unit will indicate the amount of alteration activity which has taken place in the district. Separation of initial sedimentary packets is necessary (generally chemically distinct units, i.e., limestone, dolomite, shale, sandstone, etc., which in general have been initially separated out by the rock unit mappers of previous surveys) in order to determine the degree and extent of involvement.

Contacts between units are especially favorable for alteration effects and subsequently ore, whether this be a lower dolomite-upper limestone as at Aspen (both Mississippian), or shale beds, unconformities, or various igneous dikes and sills. Most districts exhibit a "most favorable bed," but note that all districts show a range of deposits throughout most of the stratigraphic section.

As at Magma and Christmas, Arizona, the basal portion of the Devonian limestone shows the most lateral extent of alteration-mineralization, but the bulk of the ore is within the Mississippian unit. At Leadville, Colorado, the uppermost unit of the Mississippian is the best host and contains the largest production tonnage, but excellent ore bodies extend to or are found in lower units.

Because of the apparent control often shown by the original carbonate unit and its reaction to the alteration-recrystallization-mineralizing fluids, it is important during sampling that the type of unit, the amount of alteration, nearby structures, and igneous masses, etc. should be noted.

In order to establish trends it is necessary to know the background or normal value of the rock chemistry. In the replacement limestone search it is critical to have sufficient samples within each stratigraphic unit or sub-unit so as to have confidence in the range of values found and their apparent favorable directional increase. Sample size should be sufficient to be representative of the area in question. As stratigraphic position is also critical, then density of sample number along strike and dip of an individual entity packet (which may range from several feet to perhaps a hundred feet) or the thickness of recognized alteration sub-unit can be at a wider spacing than sampling up and down the stratigraphic section where individual entity packets vary rapidly and usually along very sharp boundaries. Concentration of sampling along the most favorable bed(s) and along structures will soon evolve as experience is gained in correlating visual alteration changes with probable chemical content.

Changes in the pattern of metal content point to areas of increased interest. With individual replacement beds being the host for mineralization it is necessary to pay attention to the various sub-units within the area to gain the important clues leading to a mineral body. Thus grid sampling is of less importance than several lines up and down section to establish the visual-chemical parameter variations.

Each district undoubtedly has its favorable suite of elements and, as the overall change in a number of elements and their pattern is the initial step in locating a favorable district, it is suggested that the 31 element emission-spec be used as the first pass. This ES gives iron, calcium, magnesium, silver, barium, manganese, molybdenum, copper, lead, zinc, arsenic, antimony, and 19 others at a cost of about $12.00 per sample (plus preparation) versus nearly 2-1/2 times that for the individual geochem analyses of the element listed. Skyline Labs with their 6-step incremental value reporting has the most usable format of reporting as well as precision nearly equal and consistent to that of AA or conventional geochem analysis.

As noted in the Tables reported in Appendix A, a wide range of values is noted within the specific group separations. The range points up the fact that sufficient sample values must be accumulated for evaluation purpose, and, further, that any one element variation is probably not as indicative as a suite of sample element values.

At the present state-of-the-art, specific knowledge as to the nearness of ore from a specific sample has not been pinpointed, but certainly it appears that identification of most favorable target areas within the sampled area can be suggested (see the Black Cloud report on underground sample results for insight into the problem). The detailed work being done this summer in the Leadville District should add new information on the problem.

Some mineral zoning appears in the districts. In most districts which contain manganese, it tends to be widespread but increases in the outer silver-manganese zone. Copper, barite, gold, and possibly moly, tend to increase in the quartzitic units and in the fissure veins cutting the sedimentary units. These mineral elements may also reflect the center portion of the mineralized system. Antimony and arsenic are very common, being tied up in the original base metal and silver-bearing sulfosalts. Silver occurs throughout the system but tends to be rich in the lead portions. The monitoring of calcium, magnesium, and iron, along with manganese and silver, are clues to the alteration and mineralization effects, which have taken place, long before the obvious visual characteristics are developed.

In districts where structural and cover conditions obscure the total relationship (and this is where the remaining blind ore bodies and subdistricts and, hopefully, a whole brand new district will be found) the integration of a multitude of facets and facts on scraps of data points is ever important.

As noted in Cook's (1957b) Tintic paper, the Godiva Ore Zone (reproduced on page 8 of this report) was slightly over 8,000 feet long and produced some $20 million and never outcropped. It did come within 60 feet of the surface and other workings got close to it and encountered its low-grade jasperoid

shell prior to its actual interception by another group. Knowledge of the habitat of the Tintic ore bodies coupled with analytical data from the jasperoid shell might have prompted discovery of this channel earlier in the history of the camp.

The very erratic and discontinuous outlines of the ore bodies, as shown on the four district maps of this report, makes for difficult drilling evaluation. Any trends, especially mineralized structural trends, should be closely outlined. As noted in all districts, ore runs and chimneys may not be manifested by a large fault obvious to all concerned, yet the dominant fracture pattern appears to guide the general trend of ore runs within the district. The large manto ore runs at Tintic trend subparallel to the strike of the formations, whereas at Gilman they trend with the dip of the formation. In both cases, strong shearing and fissures are found in the lower competent rock units subparallel to the overlying ore runs.

How then does one go about it within an area which is obviously a packet of well-altered, recrystallized, and geochemical anomalous units and fissures? The experience at Leadville Lead and at Santa Eulalia, Mexico, may indeed be the best approach. Both groups follow fractures as they are aware that most ore concentrations are along side one of these fractures and its intersection with favorable replacement units. At Leadville Lead, it was apparent that they spent some time on the visual fractures that came in on a cross-trend to the main direction of ore run. At Santa Eulalia, after finding a fracture which may or may not contain visible mineralization and knowing where they are in relation to their "most favorable" sequence, they step out only a short distance (generally less than ten feet) away from the fissure and fan a series of holes parallel to the fissure trend and into the elevation of their favorable replacement horizon. Since several horizons are favorable, they drill into the closest zone in relation to the drill station. Of course if mineral is noted in the fissure they also drill horizontal holes, also in the plane of the fissure, in hopes of hitting one of the large productive chimneys which intraconnect the different horizons of ore runs.

Surface drilling would be similar by drilling for an intercept where a fissure and the replacement horizon are in proximity. The testing of multiple favorable horizon adjacent to or near a fissure would also best be accomplished by a hole parallel to the plane of the fissure. They have found that this gives them the best control on where they are at within the sequence at all times and, of course, tests for small isolated bodies which are often found throughout the section. In moderately deep drilling, an angle hole may, by numerous causes, not intercept the favorable horizon in proximity to a projected fissure-horizon intercept, and would not test other zones along the fissure.

Multiple fracture intersections are very productive in most districts, but all multiple intercepts do not necessarily cause an additional ore run along the cross-trend nor does it necessarily cause an increase in ore values. However, the probably increased structural breakage in the vicinity of premineral intersections will enhance the ore potential. Thus, drilling a series of holes in the vicinity of intersections would be prime target areas, especially if the intersection is premineral in age.

In reviewing the cross-sections of the Tintic District, it is well shown that if possible the drill hole should be continued even after finding a mineral horizon because of stacked lenses, etc. Likewise, a "barren" hole near to a mineralized hole should be carefully checked in order to establish nearness criteria on internal blocks and embayments.

Understanding the master direction of ore trend is desirable early in the program as it is an evident control on the width of the ore run. Note that along the edges of most runs, a number of tongues of ore go out irregularly into the wall. These are often controlled by small visible fractures and faults which persist outward but do not continue to carry ore. Leadville Lead spends some time drifting on these visible fractures hoping to find more ore, but in general this fails because it is too far from the master fracture or trend (which may show up only as the dominant overall trend to the mined ore). However, careful mapping may reveal a strike slip fault of small magnitude as being the prime directional control.

Visual and chemical parameters

It has long been indicated that wall-rock changes have occurred around the replacement deposits in carbonate host rocks of the western states. That the bulk of the Colorado deposits and districts are in dolomitic units was also established. Part of the past, and still continuing, problem is the separation of wide-spaced basin dolomitization versus that dolomitization imprint imposed as a result of mineral fluids which led to the development of ore bodies and district mineralization.

Perhaps the best of the recent publications on dolomitization related to ore is in the Lovering-Tweto-Lovering USGS Prof. Paper 1017 concerning the work and observations in the Gilman, Colorado district. They clearly say that they cannot differentiate the two types, but I believe that their own observations coupled with the chemical data and visual characteristics establish patterns which indicate the existence of mineral districts and their contained mineral deposits. Additional research is necessary before pinpointing ore bodies, but certainly their existence can be strongly indicated.

The basic premise that replacement deposits are formed by the removal of some constituents and the addition of others, with attendant visual and chemical changes, provides the handle to open the door.

Table Two summarizes the visual and chemical changes which are noted from a traverse outside the district to inside the district to near ore and in ore.

The field test using 10% hydrochloric acid to differentiate limestones from dolomite works quite well, but it has been found that in some cases of hydrothermal dolomitized units, which have undergone other changes and end up with a very low magnesium content, will not fizz with acid. As an alternative, a solution similar to that used by petrologists for staining carbonate sections has been found to be useful in separating calcium-bearing units from calcium-magnesium (dolomite) units. The reagent-solution (0.2 grams of Alizarine Red-S in 100 cc. of 1.5% HCl solution) will immediately stain the calcium carbonate a bright purplish-red while not affecting dolomite. (Note: If the dolomite is crushed or the solution is allowed to stand on the rock surface for a considerable length of time, then a deeper purple coloration

Table Two -- Tabulation of Trend Values in Leadville and Related Carbonate Formations in Central Colorado

→ → Increasing → Trend → Values

Outside District	Inside District	Near Ore Zone	Orre Zone
Limestone (see Note 1): variable bedding; variable grain size; variable coloration.	Marble or dolomitic limestone: less distinct bedding; fine to medium, 2-5 mm, crystallinity; white to light grey coloration; marble generally coarse grained.	Marble, or dolomite, or "quartzite": massive appearing; generally 2-3 mm of uniform crystallinity but may be quite coarse (especially marble); color is white to light to medium mouse grey to dusky grey, may have reddish tint especially as silica content increases; siliceous and gritty when replaced by silica to form chert masses and pseudo-quartzite.	Reeplaced by base metal sulfides and iron-manganese with variable precious metal content; wiith and without chert as jasperoid material in interior or as outer shell. Oxidation paroducts formed which may be mobilized and removed from outcrop except in siliceous or jiasperoid material.
Dolomite (see Note 2): variable bedding; variable grain size, but generally microcrystalline; variable but tends to be a dark grey coloration.	Dolomite: less distinct bedding; 2-5 mm mosaic crystallinity; mouse grey coloration.	Dolomite: massive appearing; generally 2-3 mm uniform crystallinity; mouse to dusky grey, some dark grey, may have reddish tint; siliceous and gritty when replaced by silica to form pseudo-quartzites and "crystalline" chert.	Ass above.
Vugs: rare, except as a result of tectonic process.	Vugs of miarobitic openings along crystal boundaries and along irregular fractures, with minor filling by secondary calcite, dolomite, or quartz crystals.	Vugs are partially to completely filled with secondary white calcite or dolomite crystals and having halo of secondary material; lines of secondary crystal development often connect vug alignment.	Vvugs often remain within the ore as partial or filled vugs with secondary halo material sourrounding vug. Identical to those found near ore.
Megacrysts: none, other than original detrital material.	Megacrysts of variable calcite or dolomite crystals as isolated individual crystals, to small splotches, and irregular alignment; fine, delicate isolated quartz crystals along fractures.	Megacrysts of complete overgrowths by calcite and dolomite in crystal vugs and as lines, bands, and veins of interlocked crystals, and in pods, masses, knots; quartz crystals in secondary vugs and along fracture openings; scattered grit of silica-quartz coalescing to complete conversion to a pseudo-quartzite; replacement of original microcrystalline chert into a crackle-mosaic "shattered" silica-chert-sandstone-quartzite.	MMegacrysts often as near ore, as interstitial to base metal sulfides similar to those found nnear ore.
Common descriptive names: microcrystalline, lithographic, nondescript, block chocolate conchoidal.	Common descriptive names: saccharoidal, pin-points of light, weak replacement texture, crinkly, irregular.	Common descriptive names: recrystallized texture, marble, pearly, birdseye, rod, and zebra textures, sanding and sand runs.	CCommon descriptive names: zebra ore, coon-rings, banded, massive.
Thickness of original units are variable with mixed initial lithology.	Most susceptable units recrystallized with increased thickness of uniform "look-alike" units.	Entire column of favorable packet of units is altered and recrystallized to uniform textures with loss of individual bedding plane continuations.	SStructural and stratigraphic control on partial to complete replacement as above.

Emission-Spec. Values	Outside District
Iron, %	less 1%
Calcium, % (in Lms) (see Note 3)	greater 20%
Calcium, % (in Dolomite) (see Note 3)	5-10%
Magnesium, % (in Lms) (see Note 3)	less 5%
Magnesium, % (in Dolomite) (see Note 3)	less 5%
Silver, ppm	less 1 ppm
Arsenic, ppm (see Note 4)	less 500 ppm
Barium, ppm	less 10 ppm
Copper, ppm (see Note 6)	less 5 ppm
Manganese, ppm	200 ppm
Molybdenum, ppm	less 3 ppm
Lead, ppm (see Note 6)	less 50 ppm
Antimony, ppm (see Note 4)	less 100 ppm
Zinc, ppm (see Note 6)	less 200 ppm

Note 1. Original limestone carbonates may stay in the calcium carbonate mode and transform into marble with the attendant features of metacryst development also staying in the calcium carbonate mode or, with magnesium addition, will follow the calcium-magnesium carbonate path. If it stays in the calcium carbonate mode, then in general the zones of alteration-recrystallization intensities are measureable in tens of feet instead of hundreds of feet as in the calcium-magnesium carbonate zones and the geochemical intensity values are generally lower and stay closer to the ore zone.

Inside District
less 5%
15%
15-20%
greater 5%
10-15%
1-2 ppm
less 500 ppm
less 20 ppm
5-110 ppm
500-1000 ppm
2-3 ppm
50-100 ppm
less 100 ppm
200-300 ppm

Note 2. Original dolomites show less effect of alteration-recrystallization effects from magnesium additions in relation to altered-recrystallized limestone until both trend line paths reach the point of the original dolomites being out of equilibrium with the advancing solutions and then both carbonates advance along similar alteration-recrystallization paths to full conversion and addition.

Near Ore Zone	
Dolomite	Mineral Jasperoid
less 5%	10-15%
15-20%	less 5%
10-15%	less 5%
greater 5%	less 1%
10-15%	less 1%
greater 5 ppm	greater 50 ppm
less 500 ppm	1000 ppm
10-20 ppm (see Note 5)	greater 500 ppm
5-plus 10	greater 100 ppm
greater 1000 ppm	greater 1000 ppm
2-5 ppm (see Note 5)	greater 10 ppm
100-plus 1000 ppm	greater 1000 ppm
less 100 ppm	greater 100 ppm
200-500 ppm	greater 1000 ppm

Note 3. Calcium to magnesium ratios generally reflect the effect of alteration-recrystallization more graphically by the change from 4 to 1, 2 to 1, 1 to 1, calcium % to magnesium %, as one traverses from outside the district to inside and to near ore zones.

Note 4. Arsenic and antimony values are generally low, but where found reflect the complex Cu-Pb-Zn sulfosalts with attendant silver values.

Ore Zone
10-20%
less 5%
less 5%
less 1%
less 1%
greater 50 ppm
greater 500 ppm
10-20 ppm (see Note 5)
greater 1000 ppm
greater 5000 ppm
greater 10 ppm
greater 1000 ppm
less 100 ppm
greater 1000 ppm

NNote 5. Barium and molybdenum values of greater than plus 500 and plus 5 ppm, respectively, generally suggest ore egress channelways, main solution pathways, and centers of mineralization.

NNote 6. Copper, lead, and zinc are very mobile in the oxidized zone and show very erratic values, but tend to remain in entrapped silica and in mineralized jasperoids, and in the wall rock around sulfide bodies below oxidation effects.

will slowly develop.) When the reagent-solution is dispensed from a squeeze bottle it is an easy method for determining the extent and configuration of mixed calcite-dolomite veining and vug filling sequences. As with acid, the rapidity of staining effect denotes increased amounts of calcium carbonate. Dolomite will normally not react if the solution is placed on the surface and the excess shaken off or allowed to spread out.

Your handy petrographic lab or chemical supply house can supply the Alizarine Red-S reagent, while the local assay office will be glad to prepare the solution. The storage bottle should be kept covered and cool for best stability, although Western Petrographics has had no problem with lab shelf stability of the prepared reagent-solution. (Note: The petrographic solution is much more dilute than the field rock staining solution and must be made up separately.)

Visual Changes. Primary limestone and dolomite are found in a variety of colors and textures and this variability is in itself significant. As dolomitization or alteration takes place it selectively changes the most susceptible units first into a relatively fine-grained interlocking mosaic of dolomite of a soft medium-grey coloration. If this dolomitization is the result of widespread regional or basinal derived source, many hundreds of feet of section may be changed to varieties of dolomite textures, but will retain a variation in size and colors along with bedding plane separations, shale interbeds, fossil identification, etc., and in general show a variability.

As hydrothermal mineral fluids are superimposed on this, or indeed is a continuum of the process, then the textures become more uniform as well as a more uniform mouse-grey coloration with variable abundance of dolomite facets that reflect the light into a myriad of pinpoints. Also accompanying this dolomitization or recrystallization is a reduction in volume which appears first as a scattering of miarolitic-type cavities. With increased intensity of alteration, and a probable increase in magnesium content which releases the calcium radical, small cracks and seams of white calcite/dolomite will be scattered throughout the units, often connecting the open cavities which now may contain an infilling of white calcite/dolomite. By visual identification the fossil content is rapidly dropping and former bedding planes are not nearly as noticeable. (Thus, the noting that in mineral districts the stratigraphers tend to start lumping units into broader subdivisions whereas outside the districts they have a field day in numbering numerous beds and units.) At this stage, the abundant variability of color and texture has given way to a more uniform color and texture (soft mouse-grey to grey-black).

Increased recrystallization, alteration, and addition bring about a pervasive appearance to the unit and in isolated outcrop the assignment of the outcrop as to its relative position within the unit becomes less sure. The cavities often increase in size and become lined and filled with secondary dolomite crystals, while secondary dolomite crystals form layers, streaks, veins, and discontinuous masses and nodules. Quartz crystals may line portions of the cavities, form within the rock mass, and ultimately form jasperoid types.

The coloration may become a dusky grey with the increase in manganese content and ultimately manganiferous dolomite is identifiable which grades into manganese replacements. Other visible minerals such as iron as pyrite and amorphous masses, barite, and base metals become noticeable.

As with any alteration effects, the increased pervasiveness of the recrystallization cutting across all previous rock types such as primary limstones and dolomites, and shaly sediments; the involvement of thicker packets of units; the increased chemical content whether it be addition or remobilization of the original rock unit calcium and magnesium into increased visual calcite crystallization and discrete dolomite crystals, seams, and nodules, or the increase in metallic mineral trace and visual content -- all indicate that hydrothermal fluids capable of replacing carbonate host with metallic mineralization has taken place within the system or area affected.

In central Colorado, the recrystallization effects have been termed "pearly," "birdseye," and "zebra" textures based on their characteristic and these indeed indicate the strength and involvement of a changing chemical system. The interpretation of these in relation to ore is based not on their characteristics as an entity, but the total involvement of these characteristics and the rock column in which they are distributed. Thus, a good zebra texture found adjacent to a fault zone cutting only weak and poorly recrystallized limestone-dolomite would not be as indicative to the nearness of ore (or a district) as would be that same feature found within an ever increasing thickness packet of well and pervasively recrystallized units. However, the zebra-textured fault zone may point to an area of increased interest not observable from the present position either because of cover conditions or position within the stratigraphic sequence. Anomalous values of silver, barium, manganese, moly, etc. would indicate a feeder zone and further checking laterally and stratigraphically at the junction with the feeder system and the most favorable replacement unit would be in order.

Chemical Changes. The visual changes are accompanied by chemical changes and those associated with the ore deposits are most indicative. One element by itself is not as interpretive as a suite of elements. With the previous encouragement of the use of Skyline Labs, and the emission-spectrographic analysis, it was suggestive that iron, calcium, magnesium, silver, arsenic, barium, manganese, molybdenum, antimony, along with copper, lead, and zinc, are the most useful. Although sometimes reported in anomalous amounts are the elements cadmium, cobalt, chromium, nickel, titanium, vanadium, and zirconium (with an occasional other element), it was not found that these elements could be interpreted with assurance, but probably would be of interest in some cases. Silica and gold are not reported by E-S but undoubtedly would be useful.

A recap of the first group of elements has been compiled in Appendix A where the sample has been categorized into the various groups: 1) Leadville limestone, 2) Leadville dolomite with weak recrystallized texture and only minor secondary features, 3) Leadville dolomite with pervasive recrystallization and abundant secondary features but low visible iron-manganese, 4) Leadville dolomite with pervasive recrystallization and replaced in bulk by iron and manganese, various sulfides, and various silica-jasper types, 5) Karst and cave-fill types ranging from normal weathering, to cold-water solution, to hydrothermal cave-fill, and mineralized karst replacement, 6) Ore, and 7) thru 11), the various rock-type units ranging from Precambrian to Tertiary porphyries which contain replacement ore bodies or are in close proximity to host-unit distribution.

The full E-S results of the samples are appended to the original reports on the sample site and can be consulted in those reports.

It should be noted that some samples probably are anomalous in the category in which they were originally placed and these should be further reviewed. However, the Appendix will indicate the relative change in the rock unit as alteration (recrystallization) and mineralization increase.

In general, the Leadville limestone has high calcium values and generally lacks any metal values (additional comments will be made later about ore districts such as Aspen, Colorado which are partially in a limestone host). The Leadville dolomite attains a magnesium content with a ratio of around 2 calcium/1 magnesium and low and variable silver, barium, manganese, molybdenum, lead, and zinc values. Increased pervasive replacement texture brings in additional silver, manganese, with variable lead-zinc, but may also accompany a de-dolomitization, i.e., loss of magnesium, in the unit.

The iron-manganese jasperoids show a jump in silver, barium, and manganese as well as retaining the values of copper, lead, and zinc. The multiplicity and variability of the elements reflect the mineralized versus barren jasperoids. The karst material shows increased values toward ore types and in addition to high silver, barium, copper, manganese, moly, lead, and zinc, often have anomalous arsenic and antimony.

Mineral zoning of the system undoubtedly influences the trace element distribution. Barium and moly appear to favor mineral channel zones and centers of mineralization. High silver, arsenic, and antimony, with or without copper, suggest the silver-copper sulfosalt zone which in general is interior but may be exterior to the overall zone. Manganese and silver tend to increase on the outer zone. Copper, lead, and zinc are very mobile in the oxidized zone (unless retained by silica-jasperoids), but in general in mined districts show a central or deeper copper zone followed outward and upward by zinc then lead, followed by manganese. As noted, precious metal values, principally silver, will occur throughout.

Cook (1957b) has described the Tintic district metal and mineral zoning and the general arrangements follow my own and others' observations. His text is reproduced below.

D. R. Cook, 1957b, p. 71-72

Metal and Mineral Zoning

A broad zonal arrangement of metals is suggested in the Main Tintic district with dominantly copper-gold giving way northward to silver-lead ores and finally to lead-zinc ores. The exact interpretation of this zoning is made difficult by the differences in mineralogy between fissure ore and bedding ore, and by the differences in mineralogy between ores of the vertical chimneys and the horizontal shoots in the same locality.

The following facts seem to be well established:

1. Copper - barite - gold is a characteristic assemblage of the fissure vein type of mineralization even where bedding replacement ores are in juxtaposition.

2. Lead - silver - zinc is a characteristic assemblage of the bedding replacement ores. Zinc increases in both the Chief and Godiva ore zones where they plunge steeply north at their northerly extensions.
3. The chimneys or pipes associated with the ore zones are higher in lead, zinc and silver than the average ore from the zone and contain considerably more gold and copper. In many of the chimneys, however, gold - copper and lead - silver ore shoots have been found side by side, and in the Mammoth pipe rich copper ore bodies were found to overlie those rich in lead and silver.
4. An examination of Plate 3 shows a definite increase in copper at the south end of both the Gemini and Chief ore zones. However, this apparent horizontal zoning might be due to the chimneys at the southern end of these zones.

The values in other rock types need to be examined for any suggestive trend. Other replaceable limestone-dolomite units react similarly to the Leadville sequence in recrystallization, visual, and chemical additions and changes.

It should be noted that a primary dolomite unit (such as the Dyer) will not show the same early dolomitization effects as that acting on a limestone unit until the secondary superimposed phase of crystal growth and mineral addition is reached.

At Aspen, it was noted that in the Leadville limestone surrounding ore bodies, the limestone reacted using a calcium carbonate system instead of a magnesium carbonate system. That is, crystal growth, vug filling, and veining formation showed forms of calcite instead of dolomite. In general, the alteration front was measurable in tens of feet rather than hundreds of feet. Metal distribution was similar in both systems, but somewhat reduced in the limestone front.

The Barringer Research MRFAPE system (Multi-element Radio Frequency Argon Plasma Emission) was also used on some of the samples with a variety of E-S samples cross-checked. In addition to most of the wanted elements reported by E-S, the MRFAPE also reported silica, alumina, and K_2O, along with a few others. It was originally thought that the more precise value reporting level would be beneficial; however, for reconnaissance and comparative values this is probably not a valid consideration.

The full range of values is reported in the previous individual reports and is recapped in the Appendix A attached. The MRFAPE values are similar to those reported by E-S.

In sampling it was noted that in general the three directions around a sub-cylindrical mineral mass will show the same intensity of trace metal addition, but at various distances from the mineral mass. The farthest expression of the mass is found along the extension of the long axis in the same bedding units; the next intermediate expression is at right angles to the long axis,

i.e., parallel to the cross-sectional area, and in the same bedding units; while the closest reflection of anomalous values is found in other beds perpendicular to the long axis and the right angled cross-section axis, i.e., stratigraphically above and below the bedding units which host the subcylinder.

Areas Investigated During the Limestone Search Program

A number of areas in Arizona and Colorado were investigated where the various favorable sedimentary units were present. The visual and chemical criteria were built up during the investigation and reported in individual area memos. Appendix B is a listing of these reports and should be consulted for the full analytical and compiled data results.

James D. Sell

JDS:lb
Atts.

REFERENCES

Behre, C.H., Jr., 1953, Geology and Ore Deposits of the West Slope of the Mosquito Range: U.S.G.S. Prof. Paper 235, 176 p.

Bryant, B., 1972, Map showing mines, prospects, and areas of significant silver, lead, and zinc production in the Aspen quadrangle, Pitkin County, Colorado: U.S.G.S. Map I-785-D, 1 sheet.

Bush, J.B., 1957, Introduction to the geology and ore deposits of the East Tintic mining district in Cook, D.R. (ed.), Geology of the East Tintic mountains and ore deposits of the Tintic mining district: Utah Geological Society Guidebook 12, p. 97-102.

Cook, D.R., editor, 1957a, Geology of the East Tintic mountains and ore deposits of the Tintic mining district: Utah Geological Society Guidebook 12, 183 p.

Cook, D.R., 1957b, Ore deposits of the Main Tintic mining district in Cook, D.R. (editor), Geology of the East Tintic mountains and ore deposits of the Tintic mining district: Utah Geological Society Guidebook 12, p. 57-79.

Evans, M.T., 1957, Ore deposits of the Chief Mine in Cook, D.R. (editor), Geology of the East Tintic Mountains and ore deposits of the Tintic mining district: Utah Geological Society Guidebook 12, p. 80-93.

Henderson, C.W., 1926, Mining in Colorado -- A history of discovery, development, and production: U.S.G.S. Prof. Paper 138, 263 p.

Lindgren, W., and Loughlin, G.F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S.G.S. Prof. Paper 107, 282 p.

Loughlin, G.F., 1926, Guides to ore in the Leadville district, Colorado: U.S.G.S. Bulletin 779, 37 p.

Lovering, T.S., Tweto, O., and Lovering, T.G., 1978, Ore deposits of the Gilman district, Eagle County, Colorado: U.S.G.S. Prof. Paper 1017, 90 p.

Norman, G.W.H., 1971, Surface plan of ore bodies, Leadville district, Colorado: Newmont Mining Corporation of Canada, Ltd., 1 sheet.

Radabaugh, R.E., Merchant, J.S., and Brown, J.M., 1968, Geology and ore deposits of the Gilman district, Eagle County, Colorado in Ridge, J.D. (editor), Ore deposits in the United States, 1933-1967, vol. 1: AIME, New York, p. 641-664.

Shepard, W.M., et al, 1968, Geology and ore deposits of the East Tintic mining district, Utah in Ridge, J.D. (editor), Ore deposits in the United States, 1933-1967, vol. 1: AIME, New York, p. 941-965.

Spurr, J.E., 1898, Geology of the Aspen mining district, Colorado: U.S.G.S. Monograph, vol. 31, 260 p. with Atlas.

Tweto, O., 1968, Leadville district, Colorado in Ridge, J.D. (editor), Ore deposits in the United States, 1933-1967, vol. 1: AIME, New York, p. 681-705.

Appendix A. Compilation of Selected Elements of Emission-Spec Values from Colorado limestone replacement search

To clarify the visual and chemical parameters found to be useful in the various units encountered in the Limestone Replacement Search, the following compilation is presented. Full 31 element ES results are found in the original reports on the individual study areas listed in Appendix B. The study indicated that iron, calcium, magnesium, silver, arsenic, barium, copper, manganese, molybdenum, lead, antimony, and zinc were the most useful in delineating patterns and trends.

Table One. Leadville limestone description: generally original depositional features with rare secondary features such as silica, calcite, vugs, or iron oxides-jasper development.

Table One A. Emission-Spec Values of Leadville Limestone. Note lack of metal values and high calcium values.

Table Two. Leadville dolomite: exhibiting recrystallized replacement textures in various degrees, but with only minor secondary features (such as zebra and birdseye development, secondary dolomite, and quartz crystal growth) and weak iron and manganese additions.

Table Two A. Emission-Spec Values of Leadville dolomite with only minor secondary features. Note abnormal magnesium versus calcium values, variable but often abnormal silver, barium, manganese, molybdenum, lead, and zinc values. Note also that limestone samples generally show lower values even though they have some otherwise favorable secondary characteristics.

Table Three. Leadville dolomite: pervasive recrystallized replacement texture with abundant secondary features such as zebra and birdseye development, secondary dolomite crystals replacing zebra stripes, knots, and filling vugs, also quartz crystal growths which are often iron stained, vug development, sanding development, silica development, and brecciation, with variable, but generally low to non-observable, iron-manganese addition and replacement.

Table Three A. Emission-Spec Values of Leadville dolomite with pervasive replacement texture and abundant secondary features. Note the often de-dolomitization values in magnesium as well as the increase in magnesium values versus calcium. Also the silver and especially manganese increase with variable lead-zinc.

Table Four. Leadville dolomite: originally pervasive recrystallized replacement type replaced to a high degree by iron-manganese, various sulfides, and various silica-jasper types; now totally oxidized and forming various iron-manganese pseudomorphs.

Table Four A. Emission-Spec Values of iron-manganese oxide jasperoids. Note the general jump in silver values as well as barium plus the increased manganese and retention of copper, lead, and zinc values. The multiplicity of elements and variability reflect the mineralized versus barren jasperoids.

Table Five. Karst and cave-fill type material ranging from normal weathering (terra rosa), to cold water solution, to hydrothermal cave-fill and mineralized karst replacement.

Table Five A. Emission-Spec Values of Karst and Cave-fill Material. Note blah values in terra rosa and cold water (drip-stone) deposits versus the very high silver, arsenic, barium, copper, manganese, moly, lead, antimony, and zinc values which reflect the original mineral species found in the mineralized (non oxidized) karst and cave-fill material.

Table Six. Sulfide ore values from Manitou Dolomite and Leadville Dolomite, Black Cloud Unit, Leadville, Colorado.

Table Six A. Emission-Spec Values of Sulfide Ore. Note increase in all values other than calcium and magnesium. Arsenic and antimony also low in Black Cloud samples.

Table Seven. Cambrian Sawatch Quartzite descriptions.

Table Seven A. Emission-Spec Values in Sawatch Quartzite. Any increase in values should be carefully evaluated in terms of the total system as trends to solution and metal transport.

Table Eight. Ordovician Manitou Dolomite descriptions.

Table Eight A. Emission-Spec Values of Manitou Dolomite samples from sulfide zone of Black Cloud Unit. The Manitou is also a favorable host unit and reacts similar to the Leadville Dolomite, but in general has more subtle features.

Table Nine. Devonian Dyer Dolomite descriptions.

Table Nine A. Emission-Spec Values of Dyer Dolomite samples. The Dyer is also a favorable host unit and reacts similar to the Leadville dolomite. Textured and chemical parameters of interest are equal to those of the Leadville; i.e., increased magnesium values, silver, manganese, moly, lead, and zinc are favorable characteristics as well as the visual zebra, dolomite crystals, quartz crystals, vugs, sanding, etc.

Table Ten. Pennsylvanian Belden Shale description. Generally, the Belden is dirty black, shiny, thin-bedded, platy shale, but when in areas of hydrothermal-mineralization activity the shale often becomes dirty brown-black, manganese-soot appearance, with gypsum flakes and white efflorescent material along partings and disentegration mud debris, and with variable yellow iron oxides as films, small knots and nodules, and often fine pyrite in cross-cutting seams.

Table Ten A. Emission-Spec Values of Belden Shale. The Belden is often the capping shale to the ore zones and hence any hint of leaking up into and through the shale should be carefully evaluated in overall context. Erratic values of boron, chromium, strontium, vanadium, and possibly zirconium may reflect original basin depositional values.

Table Eleven. Tertiary Porphyry, generally the Pando or Gilman sill type. In areas of mineralization the porphyry generally exhibits increased fracturing, alteration features, and increased iron and manganese limonites.

Table Eleven A. Emission-Spec Values of porphyry units. Titanium is undoubtedly part of the rock-forming elements, but increases in barium, manganese, and moly should be treated as possible leakage features and evaluated in total context.

Table Twelve. Other rock unit descriptions: includes Precambrian granite, Cambrian Peerless Shale, Devonian Parting Quartzite, Pennsylvanian-Permian Maroon formation, and recent smelter slag.

Table Twelve A. Emission-Spec Values of various units and material. These units and values should be evaluated as passage and leakage trends in relatively unreactive units.

Abbreviations of the sampled areas are listed below:

ASP - Aspen
BC - Black Cloud (Underground)
C - Cooper Mountain
CL - Carbonate Hill
DC - Deep Creek
FM - Four Mile
G - Gilman
GC - Glenwood Canyon
GOC - Gold Cup
L - Black Cloud Mine Area
LL - Leadville Lead
M - Missouri Hill
OCC - Opposite Cattle Creek
OI - Ouray-Ironton
PM - Pennsylvania-Mosquito Creek
SMS - South Mount Sopris
TC - Trout Creek
WP - Weston Pass

All samples were run by Skyline Lab, Denver using ES method, except for the following which were run by Barringer Research, Denver-Toronto, using MRFAPE: Series ASP-1 thru -6; FM-20 thru -25; GOC-1 thru -12; and OI-1.

Table One - Leadville limestone descriptions.

DC-4 Fine vugs with brecciation.

TC-1 Conchoidal fracturing, trace calcite, FeOx.
TC-2 Silica bands and chert, trace zebra texture.
TC-3 Conchoidal fracturing, weak silica and yellow-orange jasper.

ASP-5 Slight recrystallization, minor yellow FeOx on fractures.

Table One A - ES Values of Leadville Limestone

Sample No.	DC-4	TC-1	TC-2	TC-3	ASP-5 (1ms)
Element					
Fe	<0.05%	0.1%	0.1%	1%	0.1%
Ca	>20%	>20%	>20%	10%	37.6%
Mg	5%	0.1%	2%	5%	1.0%
Ag	<1	<1	<1	<1	ND
As	<500	<500	<500	<500	ND
Ba	20	<10	<10	<10	23
Cu	<2	2	<2	5	4
Mn	50	200	200	200	222
Mo	3	3	3	2	ND
Pb	<10	10	10	30	55
Sb	<100	<100	<100	<100	
Zn	<200	<200	<200	<200	49
				SiO_2	0.61

Table Two - Leadville dolomite, recrystallized, but with minor secondary features (Z, zebra; B, birdseye; D, dolomite crystals; Q, quartz crystals).

Section Minus - relatively less and weaker characteristics.

CL-6 Trace Z and minor Fe-Mn.
FM-9 Fine crystalline black cut by medium white.
G-5 Upper shaly unit with calcite veins.
GC-3 (limestone) Lower fetid unit, calcite, FeOx limonite.
LL-12 Trace Z, B, and D.
WP-6 Minor D, Q, iron pseudomorphs.
BC-9 Minor sanding, siliceous-chert, fault zone gouge.
FM-23 Gilman ss member, leached, minor yellow FeOx.
OI-1 (limestone) marble with weak Mn stain and fracture filling.

Section Plus - relatively more and varied characteristics.

FM-4 Manganiferous.
FM-7A Crosscutting Z and D.
FM-11 Z, D, Q.
G-2 Upper unit, D vugs and veins.
GC-4 (limestone) Ocher, dog spar, FeOx nodules.
L-4 D, rare Q, weak FeOx.
LL-6 Minor silica, trace D, trace FeOx.
LL-9 Minor Z, D, Q, weak FeOx-jarosite.
LL-10 Minor pyrite, yellow-orange limonite, silica, trace D.
LL-15 Trace Z, D, Q, and minor FeOx.
ASP-1 (limestone) silicified, dark brown, sanded, manganese dust.
ASP-3 (limestone) weak FeOx in siderite-ankerite-barite, w/vugs.
ASP-6 (dolomite) manganese repl., siliceous, qtz xls, barite xls.

Table Two A - ES Values of Leadville Dolomite, recrystallized, with minor secondary features

	Section Minus									Section Plus												
Sample No.	CL-6	FM-9	G-5	GC-3	LL-12	WP-6	BC-9	FM-23	OI-1	FM-4	FM-7A	FM-11	G-2	GC-4	L-4	LL-6	LL-9	LL-10	LL-15	ASP-1	ASP-3	ASP-6
Element																						
Fe	0.5%	2%	5%	2%	2%	0.01%	2%	2.4%	0.5%	3%	0.5%	0.2%	0.5%	7%	0.2%	3%	2%	1.5%	0.2%	2.5%	5.6%	8.6%
Ca	10%	15%	0.7%	15%	10%	15%	0.03%	13.9%	35.0%	15%	15%	15%	15%	0.7%	15%	20%	10%	15%	10%	21.0%	13.1%	11.4%
Mg	15%	15%	1%	0.3%	10%	15%	0.2%	2.6%	1.4%	15%	10%	15%	15%	0.1%	15%	15%	15%	10%	7%	4.3%	3.6%	3.1%
Ag	1	1	<1	<1	2	<1	<1	ND	ND	5	5	<1	<1	<1	<1	100	10	3	1	29	11	106
As	<500	<500	500	<500	<500	<500	<500	420	ND	<500	<500	<500	500	500	<500	<500	<500	<500	<500	210	3470	ND
Ba	<10	200	10	20	<10	<10	<10	76	22	<10	<10	<10	<10	2000	<10	10	<10	<10	10	48	273	286
Cu	2	10	5	3	5	<2	2	11.7	35.9	20	100	2	<2	15	<2	200	50	20	2	75	74.6	197
Mn	500	1500	300	1000	300	200	3000	770	2550	1500	1000	500	2000	700	1500	700	1000	1000	1500	9680	3540	27420
Mo	<2	3	2	3	2	<2	2	ND	20	<2	2	2	<2	5	2	3	5	<5	<2	10	40	10
Pb	100	2000	10	20	30	10	50	60	310	1000	1500	50	20	50	10	3000	200	150	100	60000	2500	55000
Sb	<100	<100	<100	<100	<100	<100	<100	--	--	<100	<100	<100	<100	<100	<100	200	<100	<100	<100	--	--	--
Zn	300	<200	<200	<200	<200	700	200	194	2860	<200	300	<200	5000	200	<200	<200	200	300	<200	1510	3630	39700
SiO_2								48.4	2.38											8.5	37.4	12.2

5139 m

Table Three - Leadville dolomite, recrystallized with abundant secondary features and variable iron-manganese oxides.
(Z, zebra; B, birdseye; D, dolomite crystals; Q, quartz crystals; V, vugs; S, sanding)

CL-3 Z, B, D, V, minor Fe-MnOx.
DC-2 D, Q, V, S, ocher.
FM-1A Z, D, Mn dusting.
G-8 Z, D, V.
GC-2 (Gilman ss) S, dog spar, limonite.
GC-5 (limestone) FeOx ocher, silica, jasper, dog spar.
GC-6 (limestone) FeOx ocher, S, brecciation, dog spar.
GC-7 (limestone) FeOx ocher, silica, dog spar.

L-1 D.
L-2 S.
L-5 S, mangano-siderite.
L-7A Weak Z, D, and mangano-siderite.
L-7B S, iron-manganese replacement.
LL-1 Z, D.
LL-3 B.
LL-4 B, D, S, brecciation, weak FeOx knots.
LL-7 Z, B, FeOx films.
LL-8 Z, D, minor Q, silica, barite.

LL-9A Z, D, manganese limonite.
LL-13 Z, D, weak FeOx.
LL-15A Z, D, Q, S, barite, breccia, trace galena.
LL-16A Z, D, crosscutting FeOx.
TC-16 Z, D, Q, V, abundant yellow FeOx.
BC-1 B, D, few V.
BC-2 Z, D.
BC-4 Z, D.
BC-5 Z, B, D, pearly.
BC-6 Z, B, D, pearly.

BC-7 D, siliceous.
BC-8 D.
BC-10 Z, D.
BC-11 Z, D.
BC-11B Z, D.
BC-12 B(sparse), D.
BC-15 D.
BC-17 D, siliceous.
BC-18 B, D.

BC-19 D.
BC-20 Z, B, D.
BC-21 B, D.
BC-23 D.
BC-24 B.
BC-25 Z, B.
BC-26 Z, B.
BC-27 B, siliceous.
BC-28 Z, B, D.
BC-29 D, V.

BC-30 S, FeOx.
BC-31 B, V (minor).
BC-32 B, D.
BC-33 B, D.
BC-34 D (minor).
BC-35 B, D, siliceous.
BC-36 D (stockwork).
BC-37 B, D.
BC-41 D.

BC-42 D (around chert).
BC-43 D, siliceous.
BC-44 Z (minor), D.
BC-45 B (minor), D.
BC-46 B, D.
BC-47 B, D, chert.
ASP-2 (limestone) high Mn, trace py, calcite As, Q xls.
GOC-10 qtz bx w/calcite; strong Mn repl.
GOC-11 orange-blk limonite & FeOx, gal-zinc carb, Q druse.
FM-20 high grade galena, sph; w/trace azurite-malachite, D, Q, silic, minor Mn.
FM-24 D, silica druse, weak Fe-MnOx in fault zone.

Table Three A - ES Values of Leadville Dolomite, recrystallized, with abundant secondary features.

Sample No.	CL-3	DC-2	FM-1A	G-8	GC-2	GC-5	GC-6	GC-7	L-1	L-2	L-5	L-7A	L-7B	LL-1	LL-3	LL-4	LL-7	LL-8	LL-9A	LL-13	LL-15A	LL-16A	TC-16	BC-1	BC-2	BC-4	BC-5	BC-6	BC-7	BC-8	BC-10	BC-11	BC-11B	BC-12	BC-15	BC-17	BC-18
Element																																					
Fe	0.5%	1%	0.5%	0.2%	2%	1.5%	1%	0.5%	3%	5%	1%	0.5%	1%	2%	5%	5%	1%	5%	7%	2%	0.2%	0.5%	0.5%	0.5%	1%	0.5%	1%	0.5%	5%	10%	0.7%	1%	1%	0.7%	7%	1%	0.7%
Ca	20%	15%	10%	20%	7%	1%	20%	15%	20%	1%	20%	15%	7%	20%	>20%	15%	15%	10%	15%	15%	7%	15%	15%	10%	15%	10%	15%	15%	10%	15%	10%	15%	15%	20%	15%	10%	15%
Mg	15%	0.2%	7%	15%	0.3%	1%	0.3%	0.5%	15%	7%	15%	10%	1%	15%	15%	10%	15%	15%	15%	15%	3%	10%	15%	5%	10%	7%	5%	10%	0.2%	0.15%	7%	10%	10%	15%	7%	5%	7%
Ag	2	<1	30	<1	<1	<1	<1	<1	<1	<1	10	10	10	7	1	<1	1	10	5	2	15	100	7	<1	<1	1	2	<1	10	15	<1	<1	<1	<1	1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
Ba	10	<10	10	<10	20	20	500	100	<10	10	10	50	<10	<10	<10	<10	<10	100	<10	20	>10000	20	<10	<10	10	<10	<10	2000	<10	<10	<10	<10	<10	10	<10	<10	<10
Cu	<2	3	500	<2	2	3	2	2	15	5	3	3	5	5	<2	10	50	20	5	10	50	3	10	5	10	15	<2	5	2	3	2	10	1000	100	3	2	3
Mn	2000	700	700	300	200	500	700	700	7000	2000	>10000	10000	>10000	500	1000	700	700	1500	3000	1000	1000	500	700	>10000	1000	10000	1000	2000	10000	2000	2000	5000	7000	10000	>10000	1500	2000
Mo	<2	5	<2	<2	2	3	2	3	3	2	2	2	3	2	3	3	2	5	3	3	2	<2	<2	5	2	2	2	2	10	7	2	5	3	3	2	2	2
Pb	500	10	5000	<10	30	20	30	<10	30	200	200	100	500	20	10	150	500	200	100	100	5000	50	500	200	70	500	20	150	30	150	100	500	10000	3000	200	30	20
Sb	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	200	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Zn	500	<200	200	<200	<200	<200	<200	<200	<200	<200	300	500	1000	<200	<200	300	<200	<200	200	<200	2000	<200	500	<200	<200	500	<200	<200	>10000	>10000	<200	<200	<200	<200	500	200	200

Sample No.	EBC-19	BC-20	BC-21	BC-23	BC-24	BC-25	BC-26	BC-27	BC-28	BC-29	BC-30	BC-31	BC-32	BC-33	BC-34	BC-35	BC-36	BC-37	BC-41	BC-42	BC-43	BC-44	BC-45	BC-46	BC-47	ASP-2	GOC-10	GOC-11	FM-20	FM-24
Element																														
Fe	2%	2%	0.2%	1%	0.5%	0.5%	0.3%	1%	0.5%	10%	5%	2%	0.5%	1%	0.3%	1%	2%	7%	1.5%	0.5%	0.5%	0.5%	0.2%	0.2%	1%	2.9%	1.3%	8.8%	3.0%	1.9%
Ca	15%	10%	10%	10%	15%	15%	10%	7%	10%	1%	7%	15%	10%	2%	10%	10%	15%	7%	10%	15%	15%	10%	15%	15%	10%	18.7%	27.5%	9.4%	6.0%	1.2%
Mg	7%	5%	7%	5%	7%	7%	7%	5%	5%	0.15%	0.5%	10%	10%	5%	10%	10%	10%	5%	10%	15%	15%	10%	10%	10%	10%	0.2%	0.5%	0.6%	2.9%	0.4%
Ag	<1	1	<1	<1	<1	<1	<1	1	<1	70	5	2	<1	2	<1	<1	<1	10	1	1	<1	<1	<1	<1	2	ND	ND	537	726	ND
As	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	700	<500	<500	<500	<500	<500	<500	<500	200	ND	ND	ND	ND
Ba	<10	10	10	10	<10	50	<10	<10	20	<10	<10	2000	<10	70	70	<10	<10	7000	<10	<10	<10	200	<10	<10	<10	99	699	928	429	48
Cu	11000	10	3	150	500	2	2	2	5	<2	3	5	20	7	700	2	3	150	50	5	3	3	2	2	5	45.2	16.2	1040	5660	44.2
Mn	11000	3000	1000	2000	1000	10	1500	5000	100	2000	2000	3000	7000	5000	5000	10000	>10000	3000	1500	5000	3000	2000	1000	7000	2280	8130	1330	4100	2300
Mo	5	5	2	2	2	2	<2	2	3	5	10	2	2	2	3	2	5	15	10	5	5	2	2	2	3	20	ND	810	40	20
Pb	>100000	500	30	5000	7000	70	20	50	100	20	20	100	500	300	10000	10	100	2000	3000	50	100	200	100	10	100	2000	190	67500	60000	35
Sb	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	150	<100	<100	<100	<150	<100	<100	<100	--	--	--	--	--
Zn	200	300	<200	<200	<200	<200	<200	500	<200	>10000	5000	300	200	<200	500	<200	<250	10000	1000	<200	<200	<250	<200	<200	200	351	552	14200	18300	35
SiO_2																										35.9	24.4	33.3	44.7	91.0

Table Four - Leadville dolomite, with high degree of replacement by iron-manganese, and various sulfides; now totally oxidized, often with various silica-jasper types.

L-3 Sulfide Ore from Black Cloud No. 6 Orebody.
CL-2 Black jasper and silica with zinc carbonate.
CL-4 Fe-Mn-Silica jasper.
CL-5 Orange-brown to red-black Fe-Mn jasper.
DC-1 (limestone) FeOx-silica jasper.
FM-1 Q, S, bx, barite, FePbZn pseudomorphs.
FM-3 (Gilman ss) FeOx sinter, PbOx?
FM-6 (Gilman ss) Siliceous bx, sparse galena, tetrahedrite.
FM-7 D, siliceous, with galena, tetrahedrite.

G-3 Red-black hematite, minor jasper.
G-4 Manganese-specularite.
L-4A Fe-MnOx, weak jasper.
L-5A Fe-Mn replacement.
L-6 Orange jasper with black FeOx.
LL-13A Q, barite, FeOx, pyrite pseudomorphs.
LL-13B Q, barite, silica bx, azurite, malachite, sphalerite.
LL-17 D, Q, silica, FeZn pseudomorphs.

M-1 Fe jasper.
M-2 Fe jasper with Z, D, Q.
P-1 Orange-brown jasper with magnetite-hematite.
TC-7 V, silicified, FeOx, and silica-jasper.
TC-8 Complete replacement by FeOx and py-sphal pseudomorphs.
TC-13 (Gilman ss) Silica, red-yellow FeOx, weak jasper.
TC-14 (Gilman ss) Weak replacement by yellow-pink FeOx and silica-jasper.
TC-17 Silicified yellow-red ocher and silica-jasper with Q.
WP-2 FeOx-jasper-quartz grains in sanded unit.
WP-6A FeOx sinter.

WP-8 Fe sinter and pyrite pseudomorphs, weak jasper.
ASP-4 (limestone) yellow-brown jasperoid w/qtz druse.
ASP-4A (limestone) mod. strong red-blk FeOx, siliceous, porous.
GOC-1 high iron-garnet jasperoid.
GOC-2 pulverulent dark yellow-brown FeOx and blk FeOx, cuts GOC-1
GOC-3 silicified, Q xls, tr malachite, barite, sooty FeOx-MnOx.
GOC-4 Fe-Mn-qtz-dolomite-siliceous, w/zn carb & tr azurite.
GOC-5 dense blk Fe-Mn jasperoid, minor garnet, Q xls.
FM-21 blk FeOx sinter w/leached yellow-orange FeOx, Z, Mn.

FM-22 deense yellow-orange jasperoid.
FM-22A reed-blk FeOx, Q xls, jasperoid, cuuts FM-22.
FM-25 sttrong FeOx repl; massive to slinter texture.

Table Four A - ES Values of Leadville Dolomite with high degree of replacement by Iron-Manganese Jasperolds.

Sample No.	L-3	CL-2	CL-4	CL-5	DC-1	FM-1	FM-3	FM-6	FM-7	G-3	G-4	L-4A	L-5A	L-6	LL-13A	LL-13B	LL-17
Element																	
Fe	10%	10%	1%	10%	15%	7%	15%	0.7%	1%	20%	5%	10%	7%	10%	10%	2%	15%
Ca	2%	0.7%	0.5%	0.1%	10%	0.1%	0.1%	1%	2%	0.05%	0.1%	5%	0.5%	0.2%	2%	5%	0.2%
Mg	0.5%	0.1%	0.2%	0.1%	0.3%	0.03%	0.05%	0.5%	1%	0.03%	0.03%	0.03%	0.03%	0.03%	1%	15%	0.05%
Ag	50	100	15	10	<1	200	150	500	1000	1	10	200	150	150	2	1000	50
As	500	<500	<500	<500	<500	<500	500	<500	1500	<500	<500	1000	2000	5000	<500	<500	1000
Ba	5000	5000	50	500	20	>10000	100	50	50	<10	<10	7000	7000	5000	10	>10000	>10000
Cu	700	5	150	20	2	1500	500	1000	3000	300	50	200	30	100	30	5000	500
Mn	5000	>10000	>10000	>10000	700	100	10	200	300	500	>10000	>10000	>10000	>10000	1000	300	200
Mo	20	10	<2	5	7	5	3	<2	2	10	2	20	10	10	7	2	100
Pb	10000	5000	200	500	20	>10000	10000	7000	>10000	3000	1500	10000	7000	5000	200	>10000	10000
Sb	<100	<100	<100	<100	<100	500	500	500	5000	<100	<100	200	100	100	<100	3000	150
Zn	>10000	>10000	>10000	7000	<200	2000	1000	10000	>10000	7000	>10000	2000	10000	3000	500	>10000	2000

Sample No.	M-1	M-2	P-1	TC-7	TC-8	TC-13	TC-14	TC-17	WP-2	WP-6A	WP-8	ASP-4	ASP-4A	GOC-1	GOC-2	GOC-3	GOC-4	GOC-5	FM-21	FM-22	FM-22A	FM-25
Element																						
Fe	15%	15%	20%	2%	20%	0.5%	0.5%	0.7%	5%	20%	20%	7.4%	26.9%	35.5%	31.5%	1.6%	1.2%	38.2%	12.8%	4.5%	103.4%	47.2%
Ca	5%	0.05%	0.02%	0.2%	0.2%	0.5%	5%	1%	0.5%	1.5%	0.1%	0.2%	0.1%	0.1%	0.1%	13.9%	8.0%	0.1%	0.1%	1.2%	03.1%	4.7%
Mg	0.1%	0.1%	0.03%	0.05%	0.05%	0.3%	1.5%	0.1%	0.2%	0.2%	0.05%	0.2%	0.1%	0.7%	1.9%	0.8%	2.1%	0.05%	0.1%	0.5%	0.004%	0.3%
Ag	1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	ND	213	357	178	152	678	131	14	ND	ND	11
As	<500	<500	<500	<500	<500	<500	<500	<500	<500	5000	5000	430	3420	1730	1300	ND	ND	660	2600	ND	17730	3470
Ba	10	<10	20	<10	10	<10	<10	100	<10	<10	10	405	208	43	113	1070	81	ND	4970	17	3330	2070
Cu	150	700	200	2	100	<2	2	<2	2	5	10	51.4	526	1070	1020	804	11200	1560	1650	5.6	733.4	157
Mn	3000	500	100	100	500	200	100	1000	200	50	50	5030	4890	1190	3090	56770	30670	3140	79770	2910	33860	350
Mo	10	20	15	2	15	<2	<2	2	<2	10	10	60	20	20	30	50	80	80	260	ND	170	ND
Pb	10	10	<10	<10	<10	10	15	20	150	50	70	1200	41000	6250	10500	16500	32000	62500	60000	65	9950	11500
Sb	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	--	--	--	--	--	--	--	--	--	--	--
Zn	<200	200	1000	<200	500	<200	<200	<200	200	<200	200	595	17300	3430	20400	48200	159000	5400	2390	62	7724	14400
SiO_2												85.2	34.4	28.0	40.8	42.3	29.3	18.7	49.9	73.1	880.4	6.98

5139o

Table Five - Karst and Cave-fill Type Material ranging from cold water solution, to sanded cave-fill, to mineralized cave-fill-karst deposits.

DC-3 Terra rosa karst.
TC-2A Karst of cold water solution bx, calcite, dripstone, wk terra rosa.
FM-2 Karst with FeMnOx replacement, galena, tetrahedrite.
LL-2 Cave-fill, tan, sanded dolomite.
LL-5 Karst with D, Q, FeOx.
LL-5A Karst with azurite-malachite.
LL-16 Karst, fine D, Q, silic dolomite with weak FeMn.
PM-3 Karst, late D, Q, S, bx, Mn-massive sulfide, trace malachite.
TC-15 Karst and other material, V, silic bx, py, dog spar, FeOx.

Table Five A - ES Values of Karst & Cave-Fill Type material.

Sample No.	DC-3	TC-2A	FM-2	LL-2	LL-5	LL-5A	LL-16	PM-3	TC-15
Element									
Fe	1%	5%	10%	2%	10%	7%	2%	7%	1.5%
Ca	20%	20%	0.15%	20%	7%	1%	10%	0.7%	10%
Mg	0.2%	5%	0.05%	15%	2%	2%	7%	0.02%	2%
Ag	<1	<1	500	3	100	7000	10	200	<1
As	<500	1000	1000	<500	<500	1500	<500	<500	700
Ba	<10	50	500	200	50	5000	500	5000	50
Cu	2	100	5000	5	2000	>10000	15	1500	3
Mn	700	2000	700	2000	700	1000	10000	10000	100
Mo	2	5	5	2	10	5	5	20	7
Pb	<10	500	>10000	150	5000	>10000	100	10000	<10
Sb	<100	<100	1000	<100	200	>10000	<100	<100	<100
Zn	<200	200	>10000	500	>10000	10000	300	10000	<200

Table Six - Sulfide Ore Values

A. Manitou Dolomite

BC-53 mixed py-sph-gal in dolomitic-quartzitic w/clay seams.
BC-59A banded py-qtz-sph with residual dolomite clots.
BC-60 banded py-qtz-sph-gal-abundant carbonate.
BC-61 banded py-sph-gal with carbonate-qtz seams.
BC-62 vein, carbonate walls w/massive qtz-sph-gal center.
BC-63 banded py-qtz-sph-gal-carbonate seams and vugs.
BC-69 banded py-qtz-sph-abundant dolomite bands.
BC-70 banded py-sph-gal-carbonate.
BC-71 vein, py-sph-gal with carbonate stringers.
BC-72 banded, py-sph-gal-carbonate.

B. Leadville Dolomite

L-3 from conveyor belt, Black Cloud No. 6; py-qtz-sph-gal.
BC-3 massive py, sph, gal, and carbonate.
BC-16 massive py, sph, gal, with 20% carbonate-silica.

Table Six A - ES Values of Sulfide Ore.

	A. Manitou Dolomite										B. Leadville Dolomite		
Sample No.	BC-53	BC-59A	BC-60	BC-61	BC-62	BC-63	BC-69	BC-70	BC-71	BC-72	L-3	BC-3	BC-16
Element													
Fe	15%	15%	20%	20%	10%	15%	20%	20%	15%	10%	10%	10%	15%
Ca	2%	1%	1%	1%	7%	5%	7%	1%	3%	5%	2%	0.2%	1%
Mg	0.5%	0.5%	0.2%	0.2%	0.5%	0.5%	1%	0.5%	1%	2%	0.5%	0.1%	0.2%
Ag	150	100	150	50	50	20	50	30	100	10	50	70	20
As	500	500	1000	700	500	<500	500	1000	<500	<500	500	500	500
Ba	<10	10	20	10	200	10	<10	<10	<10	<10	5000	<10	<10
Cu	2000	3000	5000	1500	2000	1500	1500	1000	2000	300	700	15	5
Mn	5000	5000	7000	3000	5000	5000	>10000	5000	10000	>10000	5000	>10000	1500
Mo	7	7	15	7	10	7	50	7	30	5	20	15	15
Pb	10000	10000	7000	7000	>10000	7000	>10000	7000	>10000	5000	10000	50	200
Sb	<100	<100	<100	<100	<100	<100	<100	<100	200	<100	<100	100	<100
Zn	>10000	>10000	>10000	>10000	>10000	>10000	>10000	>10000	>10000	>10000	>10000	>10000	>10000

Table Seven - Cambrian Sawatch Quartzite description.

PM-1	Sandy with weak FeOx.
TC-9	Sandy, yellow-red ocher.
TC-10	Sandy, chrome green with yellow FeOx.
TC-11	Sandy, yellow FeOx and red-brown jasper.
TC-12	Sandy, bx, quartz, abundant yellow-red FeOx.
WP-3	Fault breccia with FeOx.
WP-9	Chrome green grains (may be lower Peerless).
WP-10	Sanded, FeOx seams.

Table Seven A - ES Values of Sawatch Quartzite

Sample No.	PM-1	TC-9	TC-10	TC-11	TC-12	WP-3	WP-9	WP-10
Element								
Fe	2%	10%	3%	7%	7%	5%	10%	5%
Ca	0.5%	0.05%	0.05%	0.15%	1%	0.03%	0.1%	0.02%
Mg	0.5%	0.05%	0.1%	0.05%	1%	0.03%	0.1%	0.03%
Ag	<1	<1	2	<1	<1	<1	<1	<1
As	<500	2000	<500	<500	<500	2000	<500	500
Ba	150	200	1000	<10	<10	<10	<10	<10
Cu	5	20	3	10	10	100	100	50
Mn	1000	3000	2000	50	100	200	100	50
Mo	<2	5	2	<2	2	2	2	2
Pb	<10	<10	15	15	30	<100	<100	<100
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Zn	<200	200	<200	<200	<200	<200	<200	<200

Table Eight - Ordovician Manitou Dolomite descriptions.

BC-50 Quartzitic, minor Fe-Mn.
BC-51 Quartzitic and siliceous with py-sph-gal, tr. malachite.
BC-54 Trace recrystallization.
BC-55 Fine recrystallized texture, clay seams.
BC-56 Bleached, silicic bands, minor pyrite, tr. oxidation.
BC-57 Bleached, pyrite along bedding, clay-FeOx seams.
BC-58 Bleached, pyrite, FeOx on bedding.
BC-59 Bleached, coarse recrystallization, silicic, pyrite.
BC-64 Bleached, silicic, pyrite, clay-carbonate seams.
BC-65 Bleached, weakly silicic, pyrite.
BC-66 Fine crystalline, few carbonate seams.
BC-67 Bleached, silicic, black pyrite-sulfide seams.
BC-68 Bleached, clay-silica seams.

Table Eight A - ES Values of Manitou Dolomite.

	Manitou Dolomite (in sulfide zone)												
Sample No.	BC-50	BC-51	BC-54	BC-55	BC-56	BC-57	BC-58	BC-59	BC-64	BC-65	BC-66	BC-67	BC-68
Element													
Fe	7%	10%	5%	2%	7%	5%	2%	5%	5%	2%	5%	5%	3%
Ca	1%	0.1%	15%	15%	5%	15%	10%	10%	10%	3%	10%	10%	10%
Mg	0.2%	0.5%	10%	10%	1%	10%	10%	7%	10%	1%	7%	10%	10%
Ag	5	10	5	<1	<1	<1	1	2	10	10	1	10	3
As	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
Ba	200	10	<10	<10	300	<10	20	100	<10	<10	20	<10	<10
Cu	15	150	50	3	50	20	10	100	100	50	10	20	15
Mn	3000	5000	3000	3000	5000	7000	7000	>10000	>10000	>10000	5000	3000	5000
Mo	2	15	5	3	3	2	2	5	5	2	5	5	5
Pb	700	5000	1000	50	30	50	50	500	300	200	100	300	1000
Sb	<100	100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Zn	1500	>10000	2000	<200	500	200	<200	1000	1000	500	500	1000	1000

Table Nine - Devonian Dyer Dolomite descriptions.

GC-1	Weak FeOx and sanding.
GC-8	Yellow ocher, minor silica, and red FeOx.
PM-2	Sandy, minor black-brown manganese.
TC-13A	Partly recrystallized, sandy, vuggy, minor FeOx.
WP-1	Q, iron, red-brown jasper.
WP-1A	Recrystallized with galena.
BC-48	Laminated, fine grey-brown, fine recrystallization.
GOC-6	Weak manganese stain.
GOC-9	Patchy Z, dolomite clots, weak crystal stripes (Note: this may be lower Leadville dolomite).

Table Nine A - ES Values of Dyer Dolomite.

Sample No.	GC-1	GC-8	PM-2	TC-13A	WP-1	WP-1A	BC-48	GOC-6	GOC-9
Element									
Fe	5%	7%	3%	0.1%	20%	1%	1.5%	1.0%	0.3%
Ca	7%	0.7%	7%	15%	0.05%	5%	10%	23.2%	21.9%
Mg	0.1%	0.05%	1%	10%	0.03%	10%	10%	7.1%	10.6%
Ag	<1	<1	100	<1	15	10	<1	196	ND
As	<500	<500	<500	<500	<500	<500	<500	ND	ND
Ba	<10	100	5000	<10	<10	<10	200	1110	60
Cu	3	20	200	2	200	100	2	265	2.7
Mn	700	2000	>10000	300	100	300	3000	16110	1190
Mo	2	5	20	2	50	<2	5	ND	ND
Pb	10	20	2000	30	10000	>10000	10	2980	20
Sb	<100	<100	100	<100	<100	<100	<100	--	--
Zn	<200	200	2000	<200	10000	>10000	<200	1610	202
							SiO_2	3.86	0.59

Table Ten - Pennsylvanian Belden Shale descriptions.

FM-10	Yellow ocherous spots.
LL-11	Bright yellow FeOx.
TC-4	Nodules of weak FeOx.
TC-6	Limestone lens with blackjack (zinc).
WP-4	Gypsiferous, fine pyrite.
WP-11	FeOx knots and pyrite pseudomorphs.
GOC-12	Red-black, partially oxidized FeOx nodules and lenses.

Table Ten A - ES Values of Belden Shale.

Sample No.	FM-10	LL-11	TC-4	TC-6	WP-4	WP-11	GOC-12
Element							
Fe	2%	0.5%	15%	2%	2%	10%	45.3%
Ca	0.07%	0.1%	0.2%	20%	20%	0.1%	0.05%
Mg	0.2%	0.2%	0.05%	0.2%	2%	0.15%	0.1%
Ag	<1	<1	<1	<1	<1	<1	ND
As	<500	<500	<500	<500	<500	<500	100
Ba	200	200	<10	700	<10	10	465
Cu	3	2	20	3	5	30	87.8
Mn	<10	10	1000	500	500	70	1010
Mo	3	3	5	7	<2	3	30
Pb	50	20	20	10	20	<10	115
Sb	<100	100	<100	<100	<100	<100	--
Zn	<200	<200	500	<200	<200	<200	955
						SiO_2	12.8

Table Eleven - Tertiary Porphyry (Gilman sill type), except where noted otherwise.

C-1 Lincoln porphyry, weak clay.
CL-1 Argillic with Fe-MnOx.
FM-8 Orange-yellow FeOx.
G-1 Argillic with fine manganese and limonites.
L-7 Argillic with FeOx.
M-3 Weak clay.
TC-5 Hornblende diorite, fresh.
WP-5 Sulfidized ferromags with trace pyrite.
BC-13 Johnson Gulch; fragmental, argillic, pyrite.
BC-14 Johnson Gulch; fragmental, argillic, pyrite.
BC-22 Johnson Gulch; argillic, weak FeOx on fractures.
BC-38 Johnson Gulch; argillic (dirty sample).
BC-39 Johnson Gulch; weak argillic, silicic (dirty sample).
BC-40 Johnson Gulch; weak argillic, silicic (dirty sample).
BC-58A White porphyry, weak argillic (in Manitou).

Table Eleven A - ES Values of Porphyry Types.

Sample No.	C-1	CL-1	FM-8	G-1	L-7	M-3	TC-5	WP-5	BC-13	BC-14	BC-22	BC-38	BC-39	BC-40	BC-58A
Element															
Fe	2%	0.5%	5%	1%	10%	3%	10%	0.07%	1%	2%	1.5%	0.5%	2%	0.5%	5%
Ca	0.07%	0.02%	0.5%	0.1%	0.07%	0.07%	3%	1%	1%	1.5%	0.7%	0.2%	0.7%	5%	2%
Mg	0.05%	0.1%	0.15%	0.1%	0.05%	0.2%	1%	0.2%	0.5%	0.5%	0.2%	0.3%	0.5%	1%	1%
Ag	<1	<1	<1	<1	2	<1	<1	<1	<1	1	<1	<1	<1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
Ba	<10	100	1000	300	50	200	700	50	<10	<10	<10	50	500	200	1000
Cu	2	2	10	<2	2	5	30	2	3	10	<2	2	<2	3	2
Mn	100	200	1000	500	2000	150	1500	150	>10000	1500	700	1000	3000	7000	3000
Mo	<2	<2	2	<2	5	<2	<2	<2	2	5	7	5	2	3	<2
Pb	10	30	100	15	50	20	<10	10	500	20	15	100	70	100	30
Sb	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Zn	<200	<200	<200	<200	<200	<200	<200	<200	500	500	500	500	200	300	<200

Table Twelve - Other Rock Unit descriptions.

G-6 Precambrian biotite granite gneiss with Fe-MnOx films.
WP-7 Precambrian granite with quartz-sericite and pyrite pseudomorphs.
G-7 Peerless Shale, sandy dolomite with orange-brown limonite.
LL-14 Parting Quartzite with FeOx intragranular and along sheeting.
BC-73 Parting Quartzite, dense vitreous, w/patchy sulfides.
BC-74 Parting Quartzite, dense vitreous, w/patchy sulfides.
BC-75 Parting Quartzite, dense vitreous, dolomitic lenses, patchy sulfides.
GOC-7 Parting Quartzite, quartz shear zone cutting quartzite.

OCC-1 Maroon Sandstone, burnt yellow.
OCC-2 Maroon Sandstone, white.
OCC-3 Maroon Sandstone, black residuals.
OCC-4 Maroon Sandstone, limestone lens with replacement texture and dog spar.
SMS-1 Maroon Sandstone with quartz crystals, pyrite, magnetite, and ocher.
SMS-2 Maroon Sandstone, total ocher, sanded.
SMS-3 Maroon Sandstone, sanded breccia, minor yellow ocher.

BC-11A Ontario, 1250 Level, Black Cloud.
BC-52 Ontario, 1500 Level, Black Cloud.
BC-49 Hellena, 1250 Level, Black Cloud.
FM-5 Smelter (1890) slag.

Table Twelve A - ES Values of Miscellaneous Units & Slag.

	pЄ Granite		Peerless Shale	Parting Quartzite					Maroon Sandstone							Fault Gouge			Smelter Slag
Sample No.	G-6	WP-7	G-7	LL-14	BC-73	BC-74	BC-75	GOC-7	OCC-1	OCC-2	OCC-3	OCC-4	SMS-1	SMS-2	SMS-3	Ontario BC-11A	Hellena BC-49	Ontario BC-52	FM-5
Element																			
Fe	2%	1%	5%	0.5%	1%	2%	1%	7.3%	1%	0.7%	0.5%	0.7%	10%	10%	0.7%	1.5%	1.5%	0.7%	>20%
Ca	0.2%	0.05%	2%	0.7%	2%	1.5%	1%	0.1%	15%	2%	20%	15%	10%	0.1%	0.05%	0.1%	5%	15%	1%
Mg	0.7%	0.1%	1%	0.2%	0.2%	0.2%	0.2%	0.1%	0.7%	0.2%	0.3%	0.15%	0.05%	1%	1%	0.2%	1%	10%	0.2%
Ag	<1	5	<1	5	<1	<1	<1	442	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	10
As	500	<500	500	<500	<500	<500	<500	ND	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
Ba	100	20	20	20	300	50	500	122	100	50	200	70	<10	<10	50	<10	100	<10	>10000
Cu	10	150	2	20	2	2	<2	749	<2	<2	5	3	7	100	3	2	3	3	700
Mn	200	50	200	1000	2000	5000	200	6980	700	100	500	700	2000	30	150	7000	2000	5000	500
Mo	<2	<2	<2	<2	7	<2	20	40	3	2	3	5	3	5	2	2	2	3	10
Pb	10	200	<10	150	200	100	20	8500	20	<10	10	10	100	500	10	50	50	100	>10000
Sb	<100	<100	<100	<100	<100	<100	<100	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	300
Zn	<200	1000	<200	200	<200	<200	<200	3960	<200	<200	<200	<200	700	500	<200	200	300	500	5000

SiO_2 77.4

5139 w

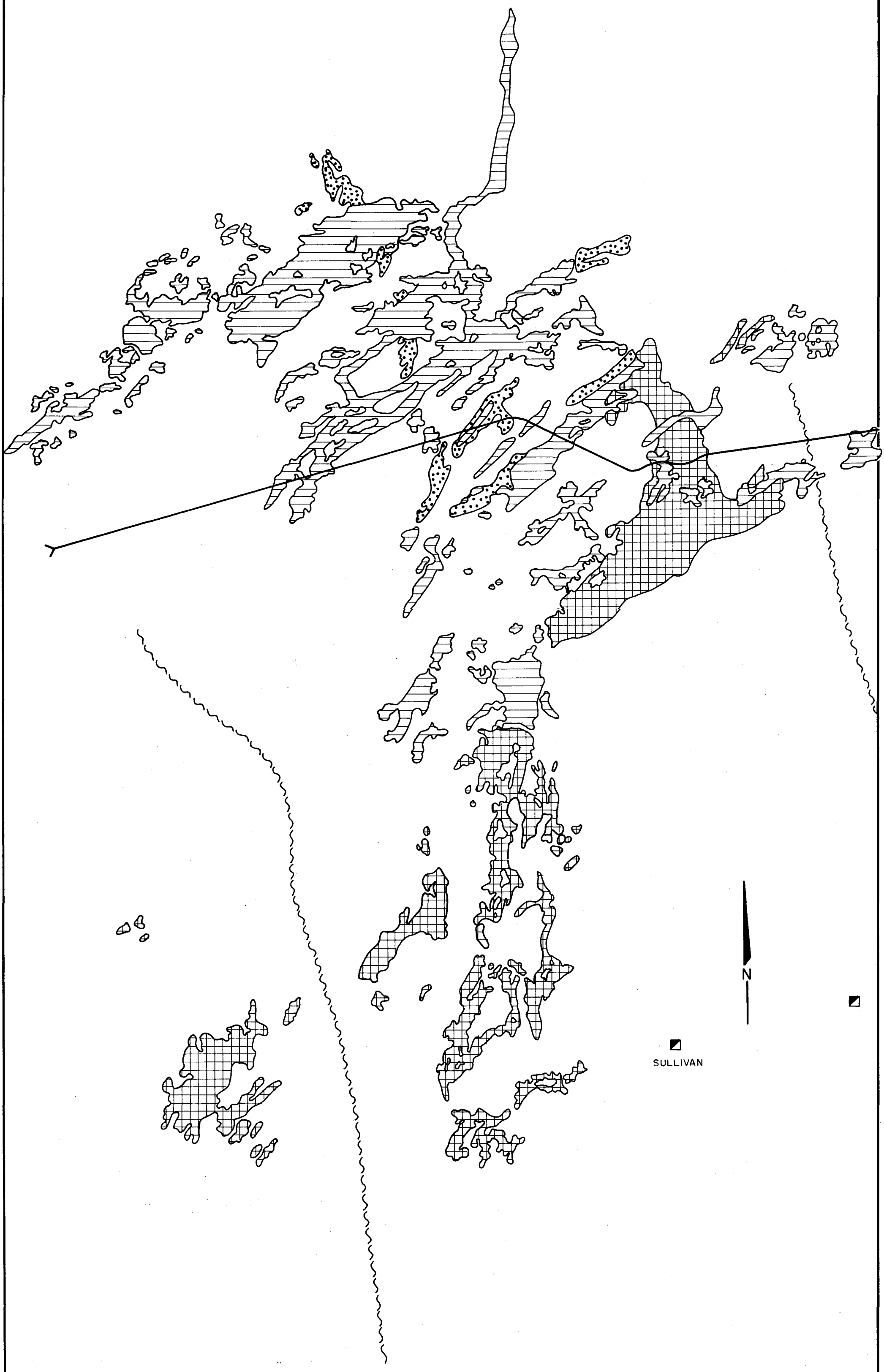
Appendix B. List of Completed Reports on the Limestone Replacement Search Program with Analytical Data

GENERAL

1. Replacement Limestone Assays -- Queen Creek Area, Magma Copper Co., Arizona. July 10, 1978.
2. Limestone Replacement Search -- Compilation of Emission-Spec. Values. Sept. 20, 1978.
3. Limestone Replacement Search -- Hand Specimen Collection Notes. Sept. 21, 1978.
4. Glenwood Springs Progress Report, by F. Gomez. Sept. 26, 1978.
5. Limestone Replacement Search -- Comparison of Values from Pulps submitted to Skyline Labs and Barringer Labs, Colorado. Dec. 14, 1978.

LIMESTONE REPLACEMENT SEARCH (SERIES), COLORADO

1. Weston Pass Area (WP-series). Aug. 7, 1978.
2. Gilman Area (G-series). Aug. 7, 1978.
3. Missouri Hill (M-) and Cooper Mtn. (C-series) Areas. Aug. 8, 1978.
4. Carbonate Hill Area (CL-series). Aug. 9, 1978.
5. Black Cloud Ore -- #6 Ore Body. Aug. 11, 1978.
6. Opposite Cattle Creek Area (OCC-series). Aug. 15, 1978.
7. South Mount Sopris Area (SMS-series). Aug. 15, 1978.
8. Glenwood Canyon Area (GC-series). Aug. 16, 1978.
9. Deep Creek Area (DC-series). Aug. 16, 1978.
10. Trout Creek Area (TC-series). Sept. 22, 1978.
11. Fourmile Area (FM-series). Sept. 25, 1978.
12. Pennsylvania-Mosquito Creek Area (PM-series). Sept. 26, 1978.
13. Black Cloud Mine Area (L-series). Sept. 26, 1978.
14. Leadville Lead Area (LL-series). Sept. 27, 1978.
15. Ouray-Ironton Area (OI-series). Dec. 14, 1978.
16. Aspen Area (ASP-series). Dec. 18, 1978.
17. Gold Cup Area (GOC-series). Dec. 19, 1978.
18. Addendum -- Fourmile Area (FM-series). Dec. 20, 1978.
19. Possible Ore Trend Values, Black Cloud Unit (BC-series). March 5, 1979.



Ore Bodies in Leadville Dolomite

Ore Bodies in Leadville or Dyer Dolomite

Ore Bodies in Manitou and Peerless Formations

Fault at Surface

Yak Tunnel

Shaft

PLATE-I

SURFACE PLAN
OF
IRON-ROCK HILL GROUP
ORE BODIES

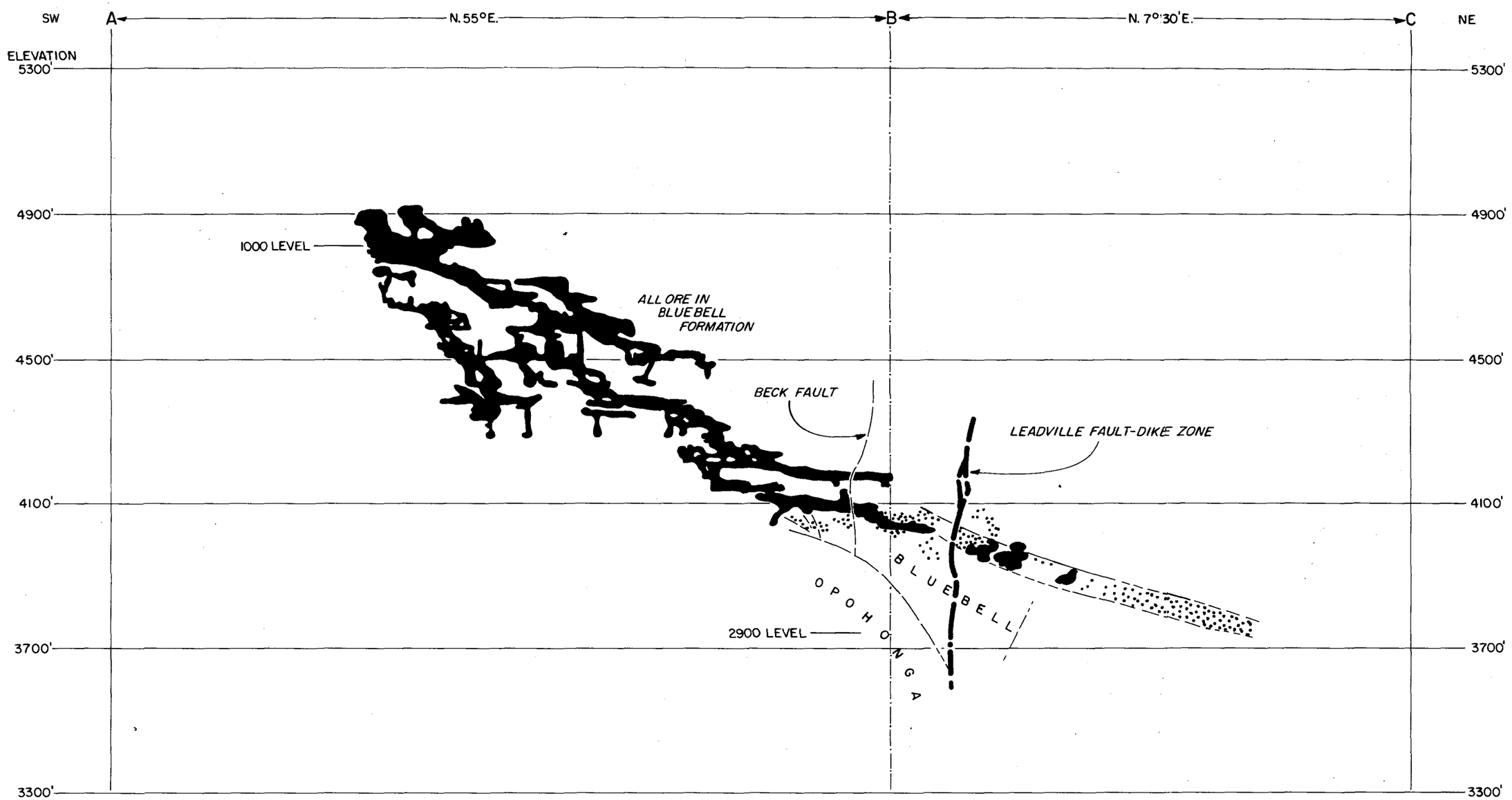
LEADVILLE DISTRICT, COLORADO

(MODIFIED FROM G.W.H. NORMAN, 1971)

0 500' 1000'

1" = 500'

mn 5139a dam



0 100' 200' 400' 600'
scale 1" = 300'

PLATE 6

VERTICAL SECTION ABC OF THE DEEP ORE ZONE OF THE CHIEF MINE

TINTIC DISTRICT, UTAH

(MODIFIED FROM EVANS, 1957)

mn 5139f dam

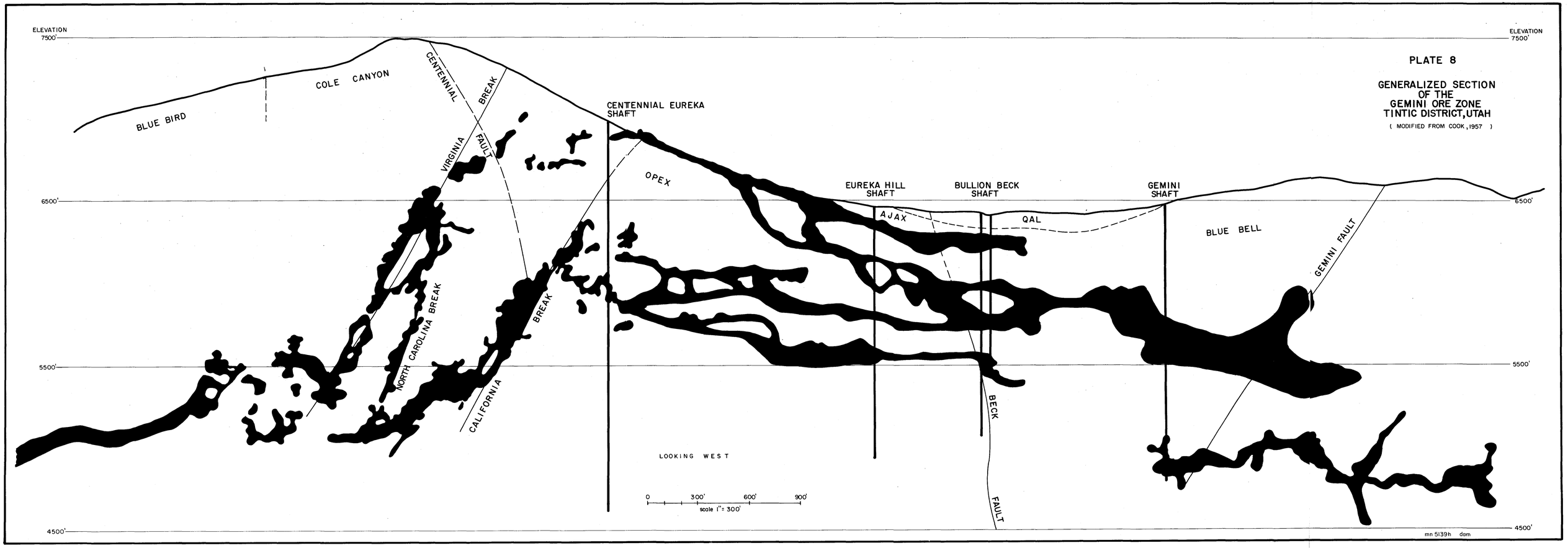
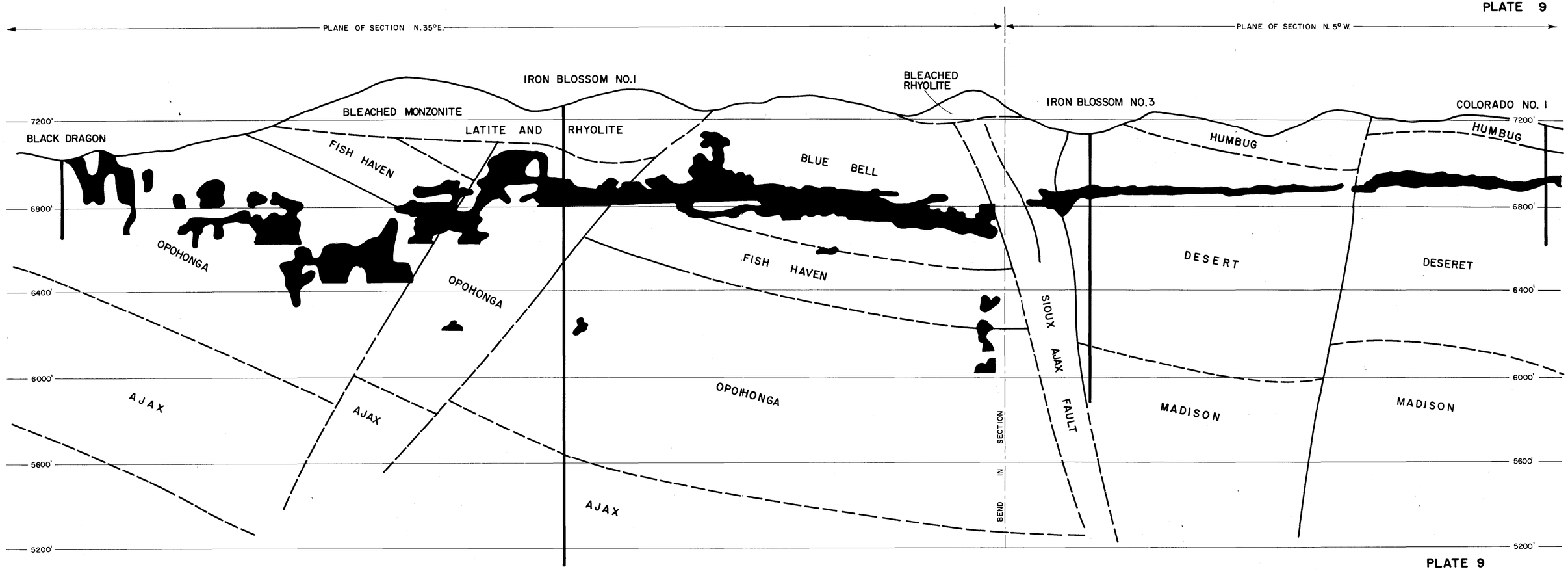


PLATE 8
GENERALIZED SECTION OF THE GEMINI ORE ZONE TINTIC DISTRICT, UTAH
(MODIFIED FROM COOK, 1957)
ELEVATION
7500'
6500'
5500'
4500'
BLUE BIRD
COLE CANYON
CENTENNIAL BREAK
VIRGINIA FAULT
NORTH CAROLINA BREAK
CALIFORNIA BREAK
CENTENNIAL EUREKA SHAFT
OPEX
EUREKA HILL SHAFT
BULLION BECK SHAFT
GEMINI SHAFT
AJAX
QAL
BLUE BELL
GEMINI FAULT
BECK FAULT
LOOKING WEST
0 300' 600' 900'
scale 1" = 300'
mn 5139h dam



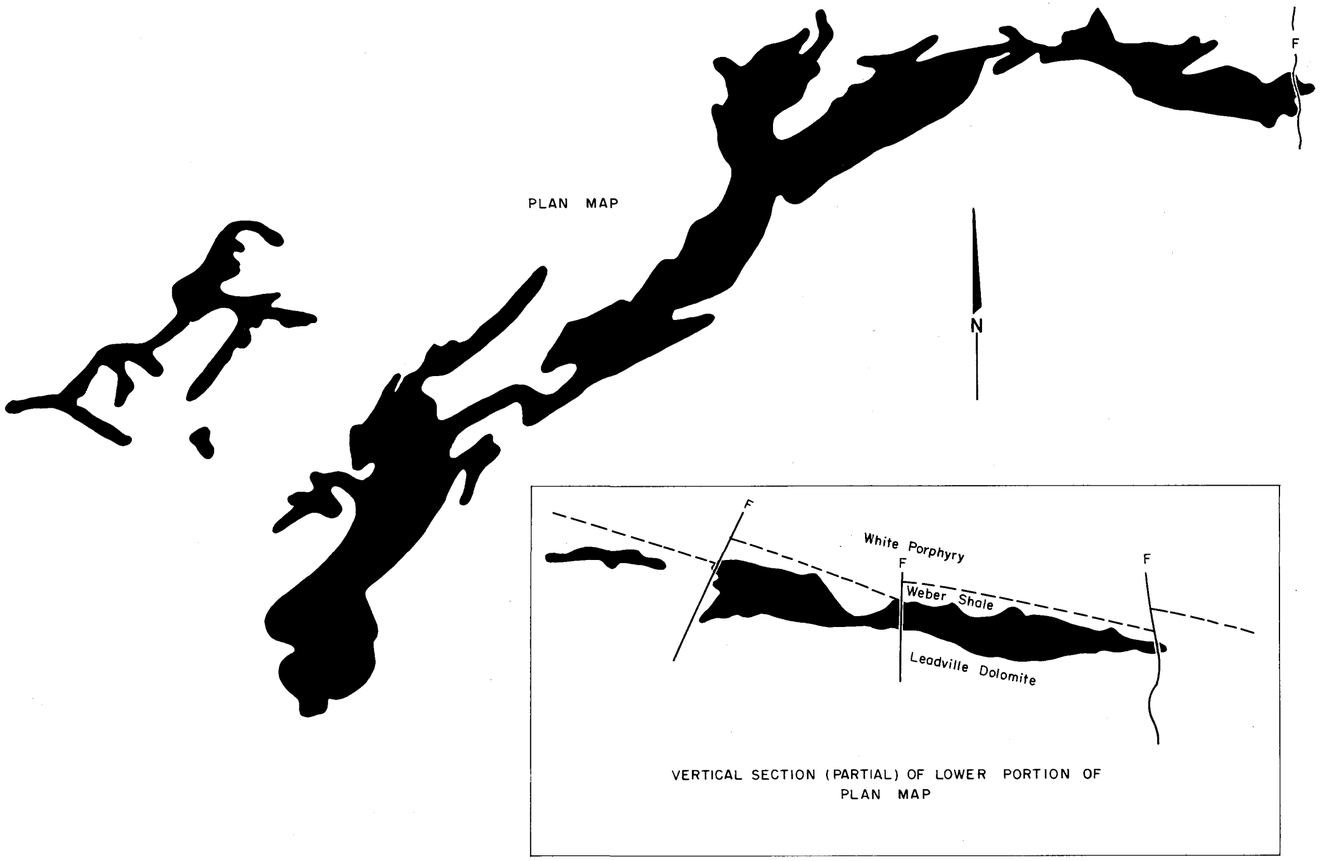
0 300' 600' 900'
scale 1" = 300'

PLATE 9

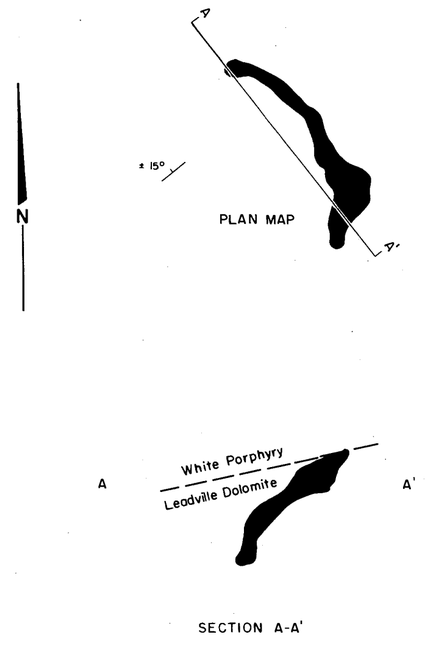
GENERALIZED SECTION OF THE IRON BLOSSOM ORE ZONE TINTIC DISTRICT, UTAH

(MODIFIED FROM COOK , 1957)

mn 5139i dam



CONTINENTAL CHIEF MINE



LIDDIA MINE

PLATE 10

PLAN AND SECTION OF
LIDDIA MINE
AND
CONTINENTAL CHIEF MINE
LEADVILLE DISTRICT, COLORADO

0 50' 100' 200'

scale 1" = 100'
(MODIFIED FROM BEHRE, 1953)

mn5139j dam

PLATE II

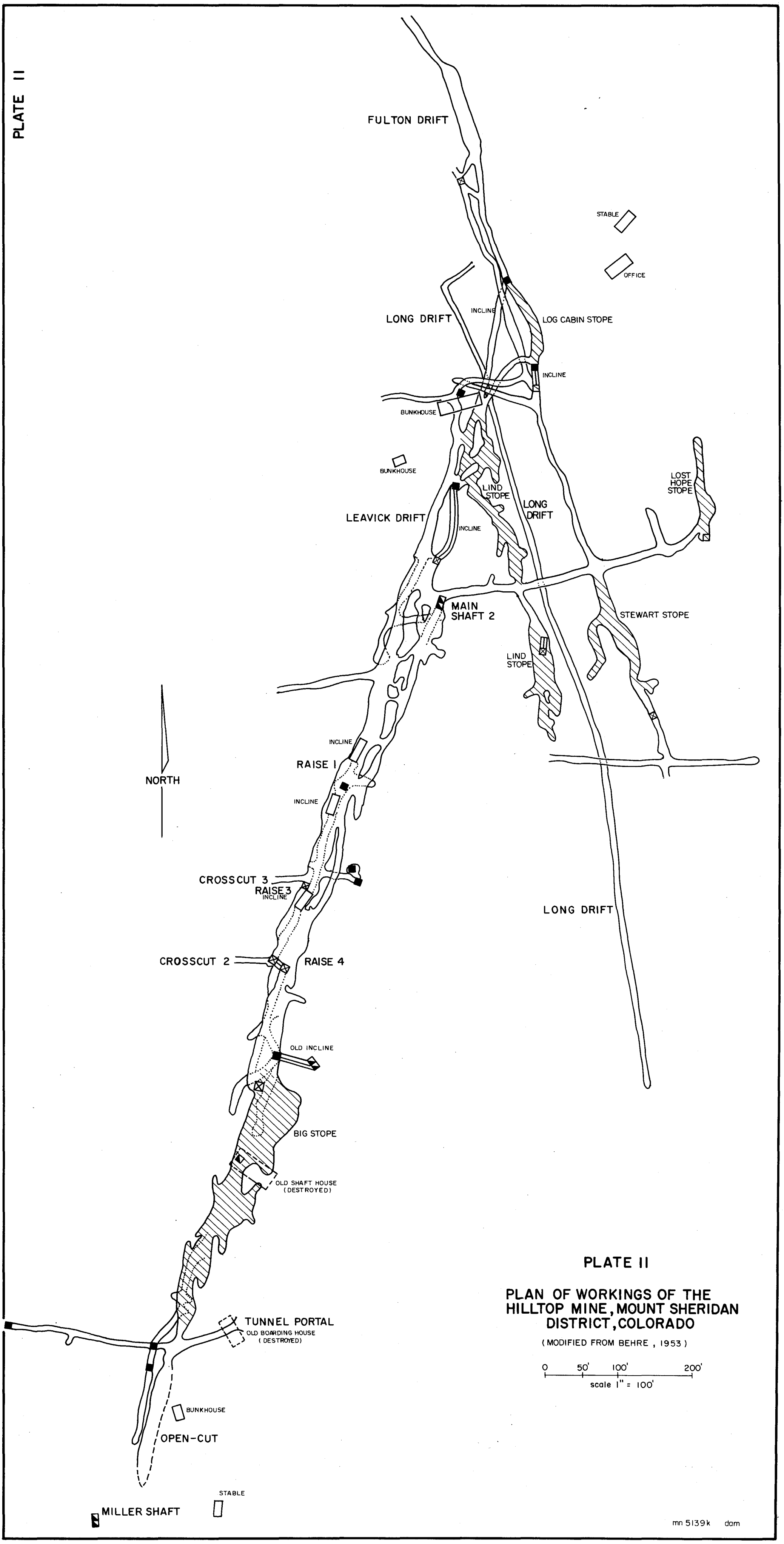


PLATE II

PLAN OF WORKINGS OF THE HILLTOP MINE, MOUNT SHERIDAN DISTRICT, COLORADO

(MODIFIED FROM BEHRE, 1953)

0 50' 100' 200'

scale 1" = 100'

mn 5139k dam

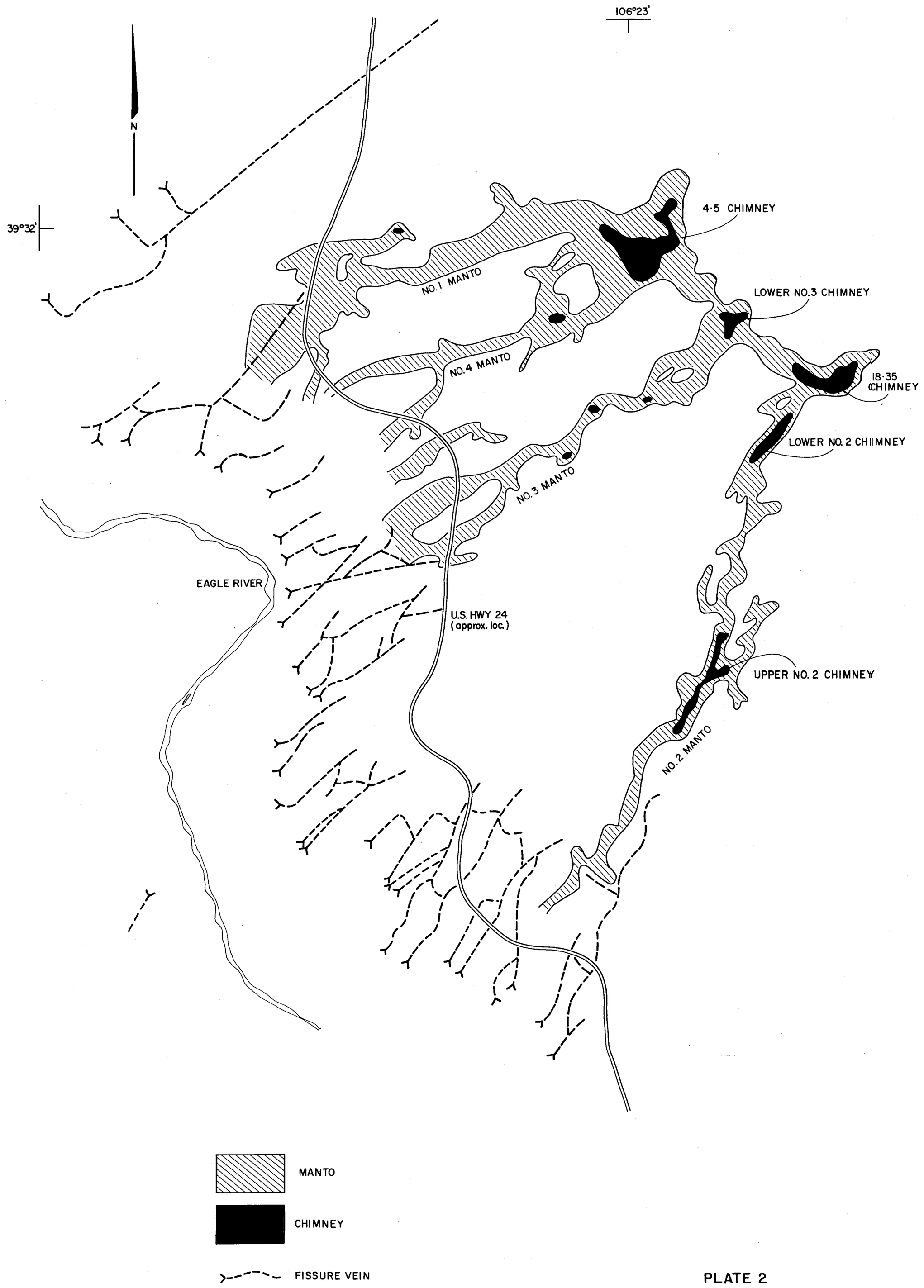


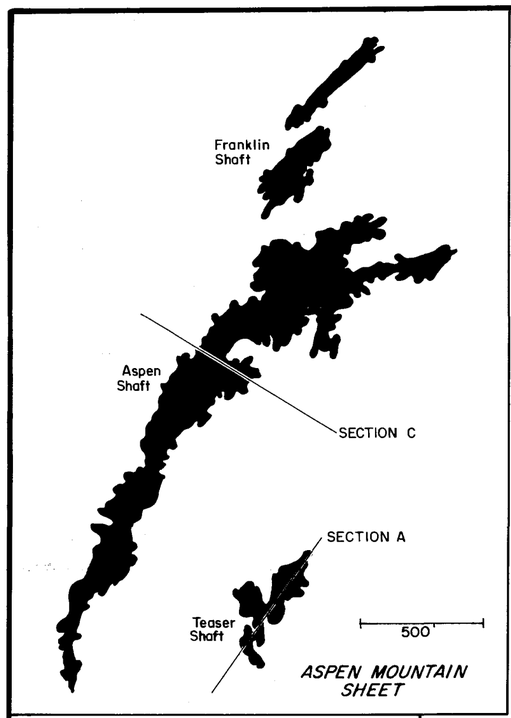
PLATE 2

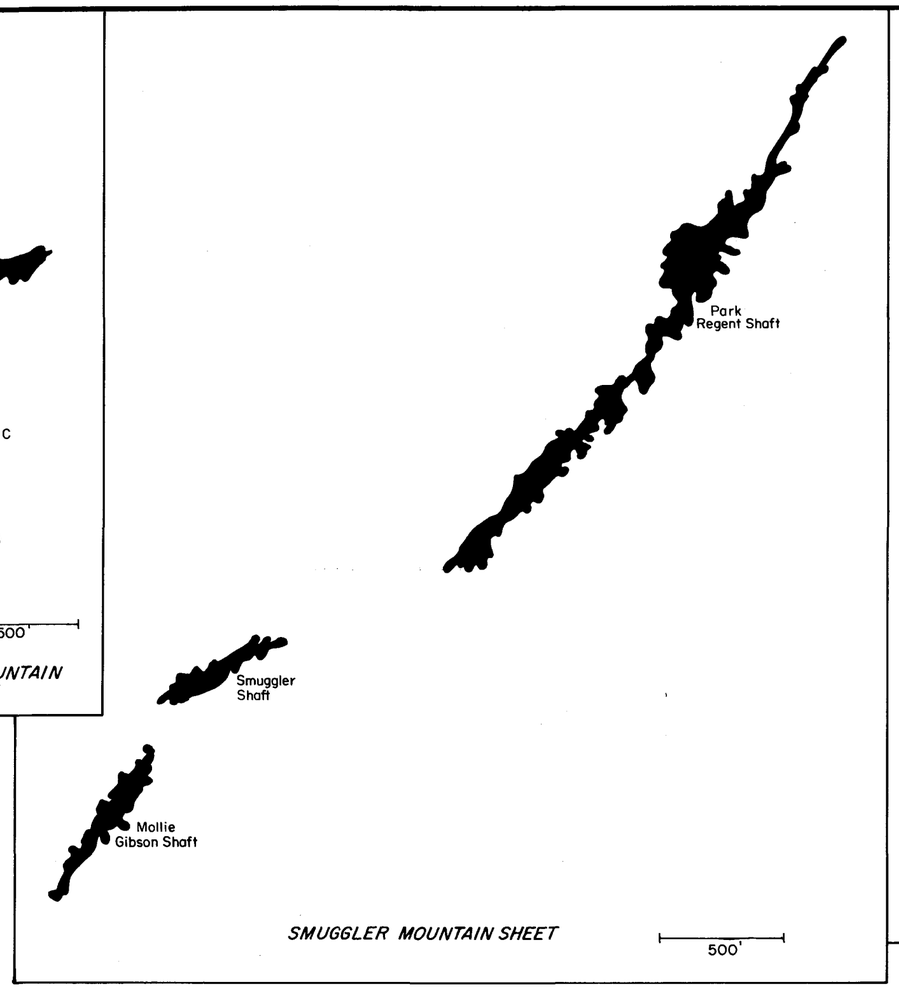
SURFACE PLAN OF MANTOS AND CHIMNEY'S IN LEADVILLE DOLOMITE AND UNDERLYING FISSURE VEINS IN QUARTZITE AND GRANITE

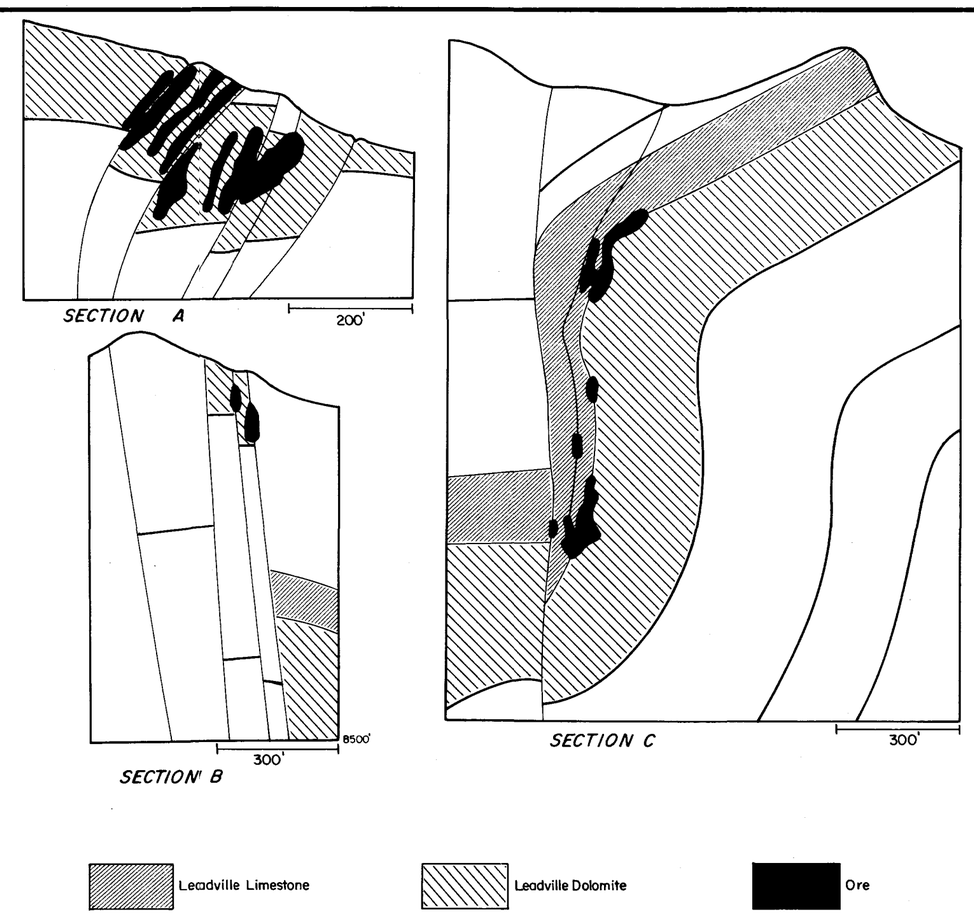
EAGLE MINE, GILMAN DISTRICT, COLORADO

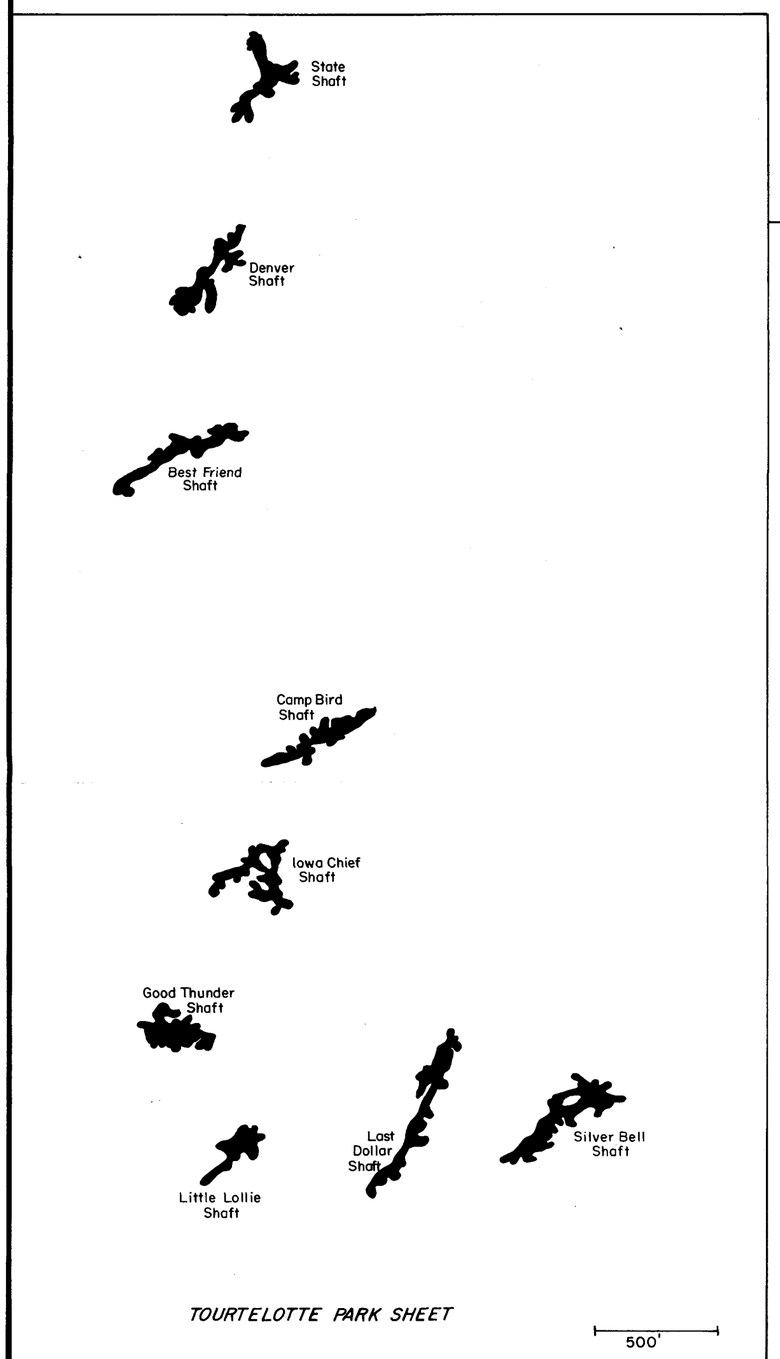
(Modified from Radabaugh, et al, 1968)

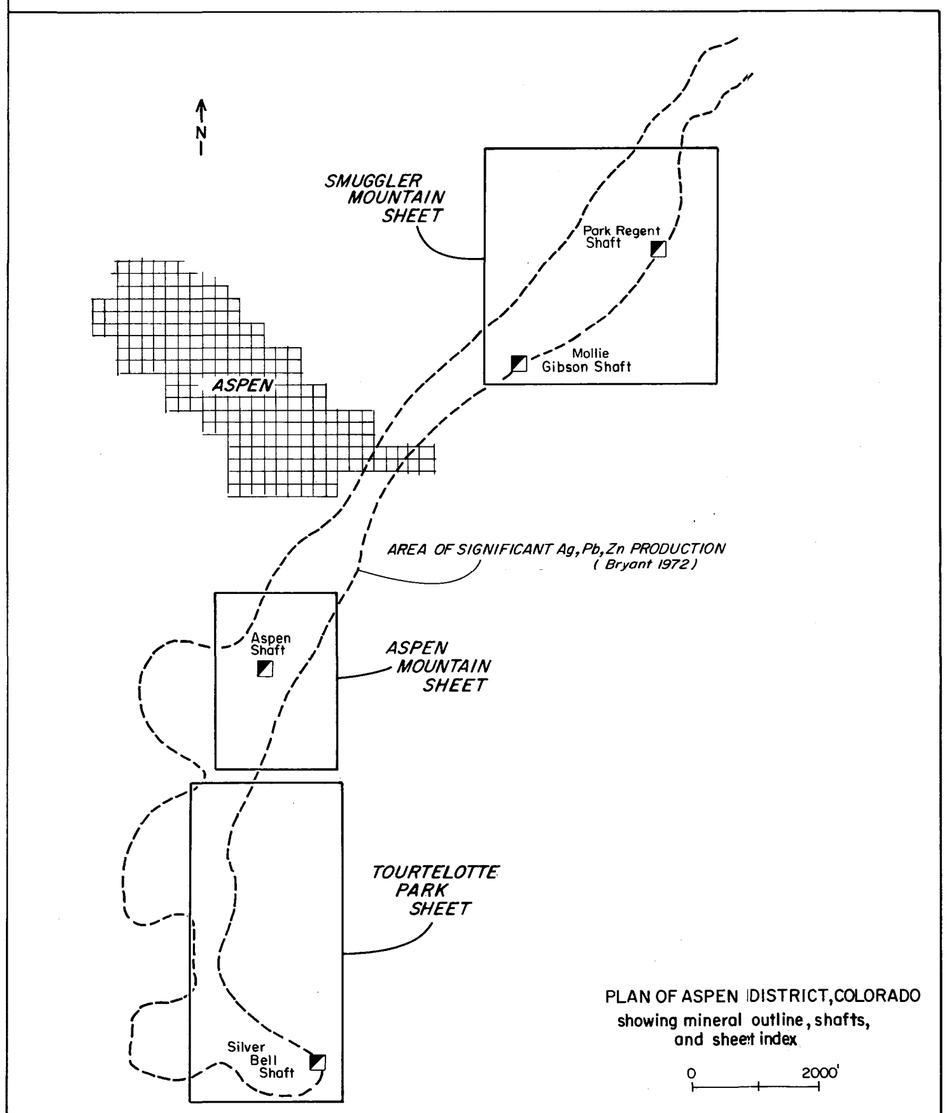
mn 5139b dam











PLAN OF ASPEN DISTRICT, COLORADO
showing mineral outline, shafts, and sheet index

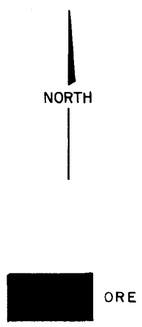


PLATE 3

SURFACE PLAN OF SOME ORE BODIES IN ASPEN DISTRICT, COLORADO

(Modified from Spurr, 1898)

scale (various)

mn 5139c dam

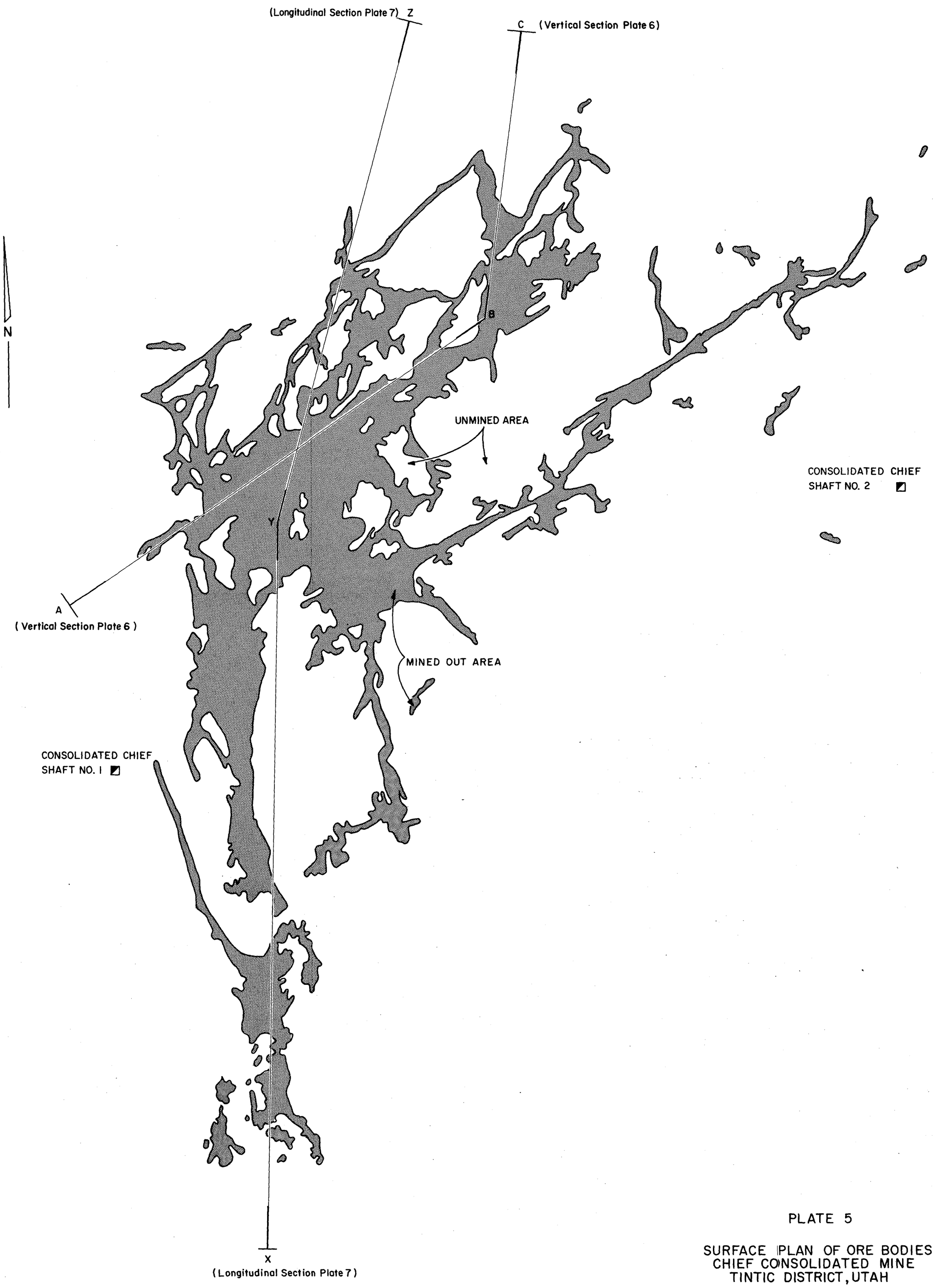


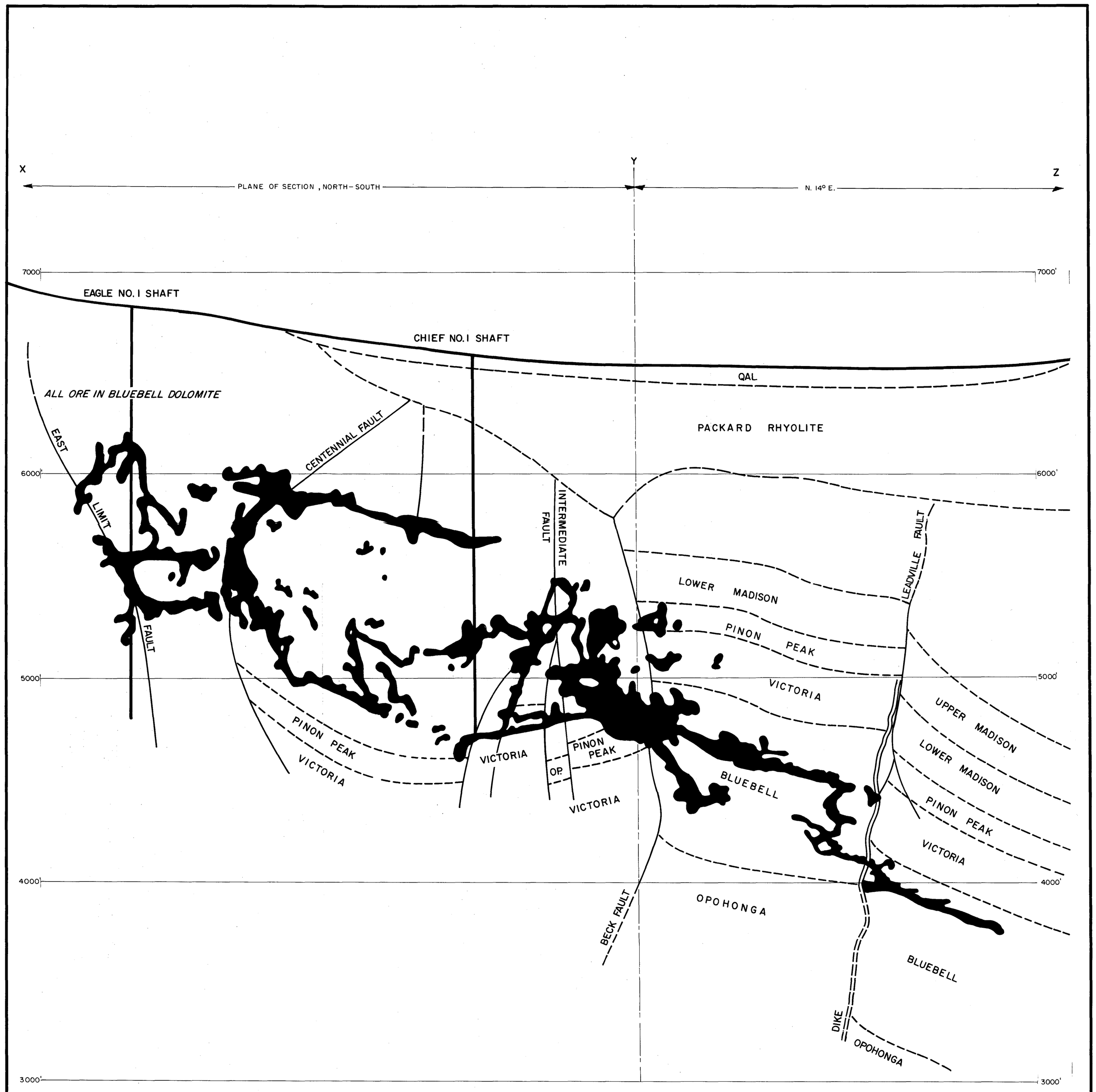
PLATE 5

SURFACE PLAN OF ORE BODIES
CHIEF CONSOLIDATED MINE
TINTIC DISTRICT, UTAH

(MODIFIED FROM EVANS, 1957)

0 150' 300' 600'
scale 1" = 300'

mn 5139e dam



PLATE·7

LONGITUDINAL SECTION XYZ OF THE
CHIEF ORE ZONE, CHIEF MINE
TINTIC DISTRICT, UTAH

(MODIFIED FROM EVAN, 1957)

0 300' 600'

scale 1" = 300'

mn 5139 g dam

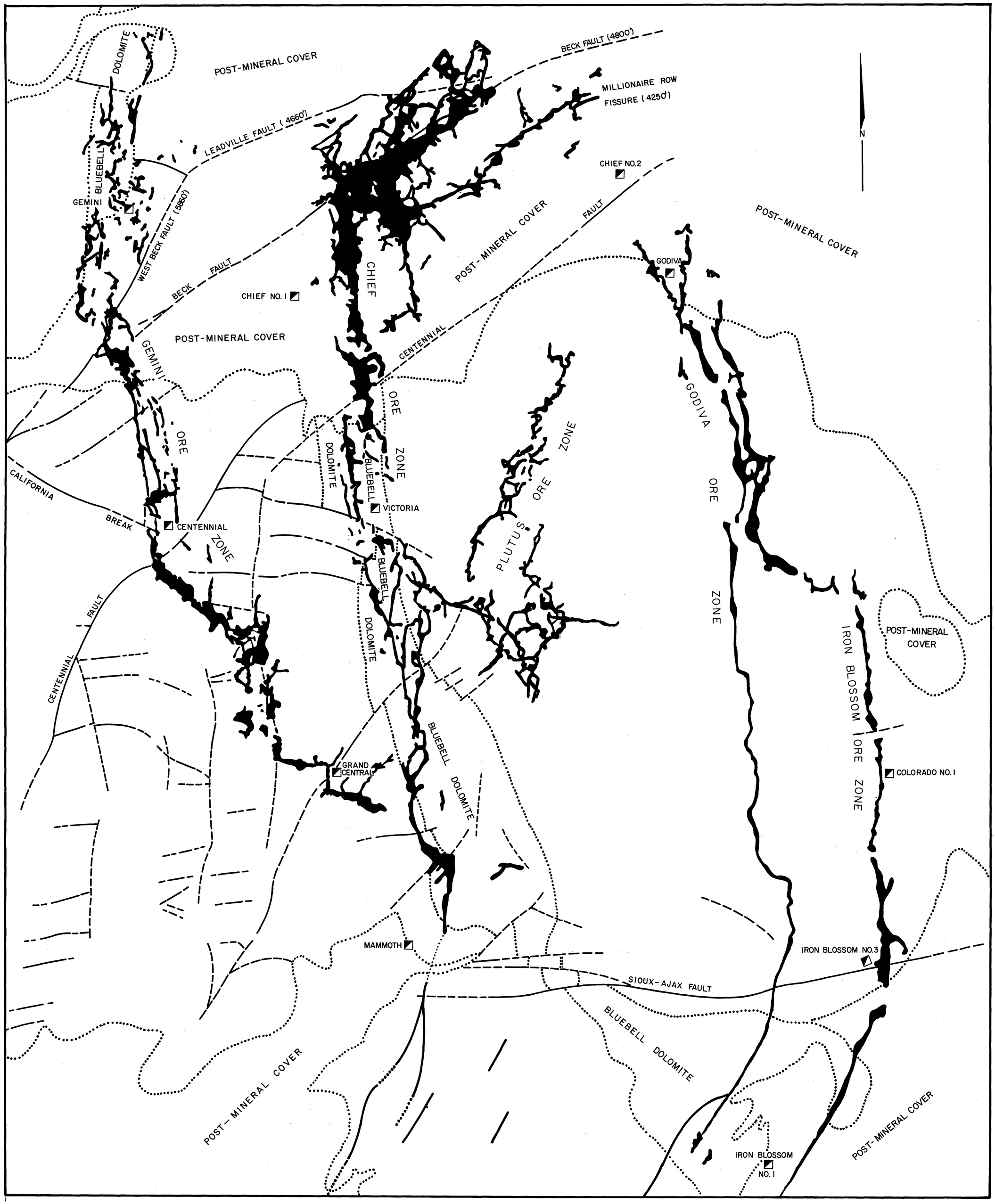


PLATE 4

PLAN OF MANTOS AND CHIMNEY ORE RUNS MAIN TINTIC DISTRICT TINTIC, UTAH

(MODIFIED FROM COOK, 1957 b)

0 500 1000
scale 1" = 500'

mn 5139d dam