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

Cap I

K & K MINING, INC.
P.O. Box 2706
Nogales, Arizona 85628

Tombstone

T-1 1400'W & 1450'S of NE Corn., Sec. 2, T20S, R22E.

6/11/74 0-600 Qal, gravel.
6/14/74 600-774 T.D. Kb Bisbee Grp clastics, dolomite, lmy qtzite,

T-2 1600'S & 100'W of NE Corn. of Sec. 1, T20S, R22E.

6/17/74 0-900 Qal gravel.
6/30/74 900-1385 T.D. Kb qtzite, arkose, mudstone. some pyrite
some Zn 250-6500ppm.

T-3 850'E & 100'N of SW Corn, Sec. 31, T19S, R23E.

7/2/74 0-1050 Qal & gravels.
7/10/74 1050-1443 T.D. Kb qtzite & arkose, mudstone.
some zinc of 2300-3200 ppm.

T-4 1200'W & 300'S of NE Corn. Sec. 7, T20S, R23E,

7/11/74 0-410 Qal + Gravel
7/13/74 410-830 TD. Kb ss arkose qtzite,
minor 1000ppm Zn.

T-5 1300'S & 100'W of NE Corn. Sec. 35, T19S, R22E.

7/14/74 0-1180? Qual & gravel
7/23/74 1180?-1905 T.D. Kb arkose
sericite, some pyrite.
few spikes of Zn 9600 & 2800 ppm.

T-6 1200'W & 3300'N of SE Corn. Sec. 25, T19S, R22E.
7/24/74

0-1850 Qual, gravel.

1850-2014 T.D. green gray porphyry w/ lim clay wice

T-7 1400'S & 450'W of NE Corn. Sec. 26, T19S, R22E.

Assays in Sept 10 0-160 Qual, gravel

160-2000 T.D. Kb clastics, cgl, ss,

T-8 2400'N, of SW Corner ~~...~~ T19, R22E.

9/5/74 0-420 Qual gravel
10/5/74 420-1494 TD Kb arkose cgl,

WLKurtz
Pretty sketchy tour but possible - Hardshell would have to be brief - no UG.

ASARCO

Can discuss next week
Time to go to Tombstone and Tucson in same day?

RECEIVED
MAR 2 1978
EXPLORATION DEPARTMENT

Exploration Department
T. C. Osborne
Director of Exploration

February 27, 1978

Mr. W. L. Kurtz
Tucson Office

Arizona
Tombstone District
Fox Prospect

Dear Mr. Kurtz:

Mr. Devere's memorandum and maps of January 16, with Mr. Graybeal's comments of February 13, serve to give me a good clear picture of the situation in the Fox area. This is the kind of presentation which makes it possible to discuss mineral potential intelligently.

I always expect a letdown to follow that sort of a buildup. Nicely done so the loser thinks he won!

Since the field work shows that the mineralization is pretty clearly confined to veins, and the tonnage seems limited owing to the veins being short, discontinuous, and limited in number, I am inclined to think we should hold this one in abeyance for better times. Meanwhile, I gather Mr. Devere is continuing to look over other parts of the district.

Very truly yours,

T. C. Osborne

cc: FTGraybeal
BJDevere, Jr.

I now clearly see that Mr G's comments should have been several pages of extended discussion of how I would explore a vein in the initial stages. I do not profess any expertise re knowing when to sink a shaft but I think I know how to explore for an intersection in a new district! I never do that sort of thing for a new Por Cu prospect, but I guess TCO has more confidence in my Por Cu expertise than epithermal

ASARCO

RECEIVED 509-489-7870
SEP 4 19..
EXPLORATION DEPT.

AMERICAN SMELTING AND REFINING COMPANY
NORTHWESTERN UNITED STATES
EXPLORATION DIVISION

KEITH WHITING
MANAGER

EAST 920 WOLVERTON COURT
(HAMILTON AT NEVADA)
SPOKANE, WASHINGTON 99207

J. H. C.

August 30, 1973 SEP 4 1973

Mr. W. L. Kurtz
ASARCO - Tucson

Tombstone District
Cochise County, Arizona

Dear Bill:

Mr. Courtright suggests in his memo of May 16, 1973, that the north end of the Schieffelin granodiorite might be an appropriate place to use the geological drill for prospecting the granodiorite-limestone contact.

In 1962 Don McMillan and I did a ground magnetic survey of the north and east end of the Schieffelin granodiorite stock. Because of the contrasts in magnetic susceptibility between the stock and sediments, the location of the contact can be defined rather closely. We never did an I.P. survey along the contact.

I have mixed thoughts on the possibility that a porphyry copper deposit may exist at the north end of the Schieffelin granodiorite stock. When I was preparing the paper discussing the relationship between barren stocks and porphyry copper deposits, I noted a rather puzzling feature: If one considers only the northwest trending barren granitic stocks (Juniper Flat granite--Bisbee, Cananea granite--Sonora Hill, Ruby Star granodiorite--Esperanza), the porphyry copper deposits occur, in each case, at the south end of the barren stock. However, in each case, the north end is covered by alluvium. Whether the north end of these barren stocks also contain a prophyry copper deposit is unknown. The fact that each end is covered by post-mineral alluvium does suggest an interesting exploration target.

Sincerely,

John

John C. Balla

JCB/sa
cc: J. H. Courtright

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

May 16, 1973

TO: W.L. KURTZ

TOMBSTONE DISTRICT
COCHISE COUNTY, ARIZONA

Reference is made to John Balla's letter of March 8th on the Tombstone District wherein its significant features are capably reviewed and summarized relative to the possibilities of porphyry copper mineralization occurring at depth.

During reconnaissance work in 1963, we came across an alteration zone in the Uncle Sam porphyry, five miles southwest of the townsite. Subsequently, Roger Kirkpatrick prepared an alteration map of the area showing a 2000' diameter zone of principally argillic alteration and a few narrow zones trending northeast. The main zone is bordered by alluvial cover to the southeast but barren sediments outcrop 3000' farther in this direction and he concluded that since no evidence of copper was observed, the zone was probably too small to be of exploration interest. However, I don't believe any rock chip samples were taken for geochem analysis.

As Mr. Balla has pointed out, the Schieffelin granodiorite is a Laramide stock with associated base and precious metals in the sediments, and I would agree that a porphyry copper deposit may exist in such an environment; however, the probability of such occurring within practical depth limits is exceedingly slim, I believe. Should the stock extend an appreciable distance under the alluvium to the north, drill prospecting of the stock and its peripheral sediments might be justifiable, providing the cover is not too deep.

J.H. Courtright
J.H. COURTRIGHT

JHC:kre

cc: J.J. Collins
R.K. Kirkpatrick
J.C. Balla w/copy of R.K. Kirkpatrick's report

ASARCO

AMERICAN SMELTING AND REFINING COMPANY
NORTHWESTERN UNITED STATES
EXPLORATION DIVISION

KEITH WHITING
MANAGER

EAST 920 WOLVERTON COURT
(HAMILTON AT NEVADA)
SPOKANE, WASHINGTON 99207

March 8, 1973

Mr. W. L. Kurtz
ASARCO - Tucson

Tombstone District
Cochise County, Arizona

Dear Bill:

Enclosed is my report on the Tombstone District. The report is largely a presentation of facts which, if correctly interpreted by me, suggest that a major copper deposit may exist under the main district. There is a possibility, if not probability, that other interpretations can be made, which would preclude the occurrence of such a deposit.

Even if such a deposit exists, there are formidable problems remaining. These include depth to the deposit, water, proximity of the town, and acquiring the mineral rights.

Considering the state of our knowledge on ore deposits, my report should be considered more as a presentation of an idea, rather than a recommendation for further work.

Should you concur with me that the district has reasonable exploration potential, then the acquisition of the mineral rights will have to be done by dealing with Frank Frankovich here in Spokane.

According to Frank, Tombstone Development company controls all of the significant past producers in the district. The company owns over 100 patented mining claims and fractions, totaling some 1180 acres. In addition, the company owns 18 unpatented claims east of the main district, and Frankovich owns 5 unpatented claims on the west side of the district.

See you in Knoxville!

Sincerely,

John

John C. Balla

JCB/ir
Enc.

P.S. Also enclosed is Hewitt's report on the Charleston district.

Spokane, Washington
March 5, 1973

TO: W. L. Kurtz
FROM: John C. Balla

Tombstone District
Cochise County, Arizona
A Porphyry Copper District?

Introduction:

The following report summarizes some thoughts I have had for a number of years on the Tombstone District. It is based upon field work I did in the district in 1962, supplemented by some current thoughts on porphyry copper deposits. The interpretations of the district should be considered speculative.

The Tombstone District is primarily noted as a silver "bonanza" camp. However, it is really a base metal district. It has produced (to 1936) 7,049,997 ounces of silver, 2,516,040 pounds of copper, 26,965,134 pounds of lead and 1,058,234 pounds of zinc. Tombstone ranks eighth among the lead producing districts of Arizona. Manganese is also an important commodity.

There has been little work done in the district in recent years. Some stratigraphic work has been done by University of Arizona graduate students. The main references are Arizona Bureau of Mines Bulletin 143 on the Geology and Ore Deposits of the Tombstone District by Butler, Wilson & Rasor, (1938) and U.S.G.S. P.P. 281 by Gilluly, on the General Geology of Central Cochise County. I might also mention my report on porphyry copper deposits and barren Laramide stocks, and Ted Eyde's paper on Stratigraphy as an Exploration Guide to Porphyry Copper Deposits.

General Geology:

The stratigraphic column for the district is shown in Figure 1. The figure also indicates what units were mineralized.

The oldest rock in the Tombstone District is the Pinal schist. The Pinal schist has been intruded by an albite granite, also of older Precambrian age.

The younger Precambrian Apache group of sediments are not present. The complete Paleozoic section of sedimentary rocks, totaling about 5500 feet, are present.

Overlying the Paleozoic rocks is the Bisbee group of sediments, which are about 3000 feet thick.

West of the main district, in the Charleston lead mine area, are the pre-ore Bronco volcanics. According to Gilluly (1956), these volcanics are probably from 5000 feet to 6000 feet in thickness. Whether they are pre-thrusting or post-thrusting in age is unknown.

Major thrusting, which is probably gravitational gliding, has occurred in the area. However, the thrusting appears to be all pre-mineral in age.

The Uncle Sam porphyry is a post-thrust, intrusive, quartz latite porphyry. This is an unusual rock in that it appears to be laccolithic in form.

Intruding all of the above rocks is the Schieffelin granodiorite. The granodiorite is a large, barren, Laramide granitic stock. The stock has an isotopic age of 72 m.y.

The Schieffelin granodiorite occurs in two separate areas; immediately north of the Tombstone district, and in the Charleston-Lewis Springs area. These two areas will be treated separately in this report.

Tombstone Area:

In the Tombstone area the Schieffelin granodiorite is a barren, elongate stock. It is about two miles wide and three and one-half miles long, as shown on Plate 9. The horizontal long axis of the stock trends about N. 35° W. As I recall, it is not a composite, zoned stock, but is fairly uniform in texture (medium grained) and composition. The above suggests that we may be near the top of the stock, and have not yet eroded down into the composite zoned part.

Butler (1938) indicates the same thing when he states:

> "The Schieffelin granodiorite mass, as indicated by the nature of its contact with Naco limestone and with beds belonging to the Bisbee group, east of The Dome, and by its contact with the Naco limestone west of the Lucky Cuss Mine, increases in size downward and would occupy a larger part of the area of the district were the general elevation of the surface reduced a few hundred feet by erosion; evidently it forms a stocklike body."

Ore Deposits:

At the immediate south end of the Schieffelin granodiorite is the Tombstone District. The main district occupies a structural basin, which is an asymmetrical syncline which plunges southeasterly in its northern half and more easterly in its southern half. The rocks involved in this folding are the Paleozoic and Mesozoic sediments, according to Butler (1938):

> "Within the Tombstone basin the rocks have been folded into secondary anticlines and synclines with a general trend of N. 40 to 65 degrees W. They plunge gently southeastward in the northwestern part and more steeply in the southeastern part of the basin. They are best defined in the eastern part of the basin; in the western part they are more compressed and indefinite.

"Folds of a third order occur as corrugations on the secondary anticlines and synclines of the Tombstone basin. The anticlines of this order are locally termed "rolls", and within them are located many ore bodies." Plate XV from Butler (1938) shows a typical ore occurrence.

Both Butler (1938) and Gilluly (1956) suggest that the folding is due to horizontal compression. This is not necessarily true. It is distinctly possible that the folding is due to doming by an intrusive stock, and subsequent subsidence.

The basin is cut by a series of strong "cross fractures", called the Northeast ore fissures, as shown on Plate IV. According to Butler, (1938):

"Fissures that strike N. 30 to 55 degrees E., cut all the rocks older than the Cenozoic gravels. These fissures prevailingly dip steeply southeastward in the Tombstone basin and northwestward in the western part of the district. The stronger ore fissures within the Tombstone basin are rather uniformly spaced. Within the interval of 2,000 feet between the Intervener and the Arizona Queen fissures are eight large fissures rather uniformly spaced at intervals of about 300 feet. So large a proportion of the deposits is associated with northeasterly striking fissures that the relation may be assumed as general.

"Much of the ore in the Tombstone district has resulted from replacement of a few favorable formations that range from the lower Paleozoic to well above the base of the Mesozoic in the Bisbee group. The most productive sedimentary zones recognized are:

1. Beds of limestone above the Blue limestone in the Bisbee group

2. Blue limestone near the base of the Bisbee group

3. "Novaculite"

4. Upper portion of Naco limestone

5. Beds lower in the Naco: Lucky Cuss and Bunker Hill Mines

6. Lower Paleozoic beds: Emerald Mine.

"In addition to the sedimentary beds the dikes in places, mainly within the Contention, Grand Central, and Head Center areas, were favorable to ore mineralization.

"The central part of the Tombstone district is traversed by several dikes of granodiorite to dioritic composition. Although not noteworthy in their petrographic character, they are of exceptional interest because of their structural relation to ore deposition, their parallelism and persistency, and the manner in which some of them have been faulted. At least five such dikes traverse the central Mesozoic area with a general course of north 12 degrees east and a dip of 75 to 85 degrees west, except the Boss dike, which dips steeply eastward.

"These dikes do not crop out prominently and as a rule are deeply altered (and pyritized). They are believed to have originated as a relatively later phase of the same magma that gave rise to the Schieffelin granodiorite and Uncle Sam porphyry.

"The ores in different parts of the district range greatly in content of the different metals, and whether they were recovered or not depended somewhat on the degree of oxidation. Zinc has been recovered only from sulphide ores, and the distribution of oxidized zinc minerals is little known. Manganese, on the other hand, has been recovered only from oxidized ores.

"The distribution of metals suggests an area of most intense mineralization in the northeast section of the district with a rough zoning outward. The most definite of the metal zones are the central gold zone and the marginal manganese-silver zone. The gold zone is characterized by abundant quartz and fluorite, and the manganese-silver zone by manganese.

"Copper

"Copper is also widely distributed but in small amounts, and its distribution is not well known. It seems to be most abundant in and near strong northeast fissures.

"Copper carbonate stains in the fissures are generally regarded as good indications of ore near by.

"The Emerald Mine probably contained the largest body of copper ore."

The Emerald Mine, interestingly enough, occurred in the Cambrian Abrigo formation. It is also located at the southern end of the district, away from the Schieffelin granodiorite.

"Molybdenum

"Molybdenum occurs in the ores as wulfenite, the lead molybdate. It is present over a considerable part of the district but is most abundant in the gold areas particularly of the Silver Thread roll. Like the gold it is most abundant in and near the northeast fissures. The wulfenite is, however, a secondary mineral not closely associated with gold, and the material high in molybdenum is not generally high in gold. Wulfenite rather commonly occurs around or beneath an ore body, and although conspicuous, it nowhere forms more than a small percentage of the larger bodies of ore."

The suggestion that Tombstone is a porphyry copper district is derived from an attempt to answer three questions:

1. What would the geology be above a porphyry copper deposit that intruded limestones, but never penetrated all of the limestone rocks?

2. Much of the lead-zinc production in Arizona has come from limestone replacement deposits adjacent to porphyry copper deposits. Where is the porphyry copper deposit at Tombstone?

3. Every large, barren, Laramide granitic stock in southern Arizona has an associated porphyry copper deposit. Where is the porphyry copper deposit associated with the Schieffelin granodiorite?

Conclusions:

From a district viewpoint, the following observations can be made:

1. A large, barren, elongate, Laramide granitic stock has intruded a very thick (9000 feet) section of sediments, mainly limestones.

2. At the south end of the stock, in a zone of strong cross fracturing, numerous altered and pyritized dikes, genetically related to the barren stock, have intruded the limestones.

3. The sediments have been complexly folded, which may be due to a buried stock, which rose part way through the sediments, then subsided slightly as it cooled. The altered dikes may then be apophyses off the mineralized intrusive, which would be related to the barren stock.

4. Copper, lead, zinc, silver mineralization occurs as replacement deposits, associated with the dikes and cross fracturing.

5. The mineralization appears to be crudely zoned, with a gold-quartz central zone, and a peripheral manganese-silver zone. Molybdenum, although widely distributed, appears to be most abundant in the central zone. This central zone is located adjacent to the barren stock.

6. Copper is widely distributed, and is associated with the cross fractures. The most abundant copper occurs in the Cambrian rocks.

Exploration Potential:

Porphyry Copper Deposit

There are several possible "porphyry copper type" targets. The first is replacement of the Paleozoic rocks by pervasive mineralization, similar to Mission. Another replacement type would be higher grade replacement deposits, similar to Bisbee type ore. These types would necessitate a mineralized intrusive at some unknown depth beneath the district. The pyritized and altered dikes are apophyses off the stock. This possibility would indicate that part of the lower sedimentary sequence of rocks may not exist, or be very complexly folded and faulted.

From the available data, there is an excellent chance that the Lower Paleozoic rocks (Abrigo, Martin, Escabrosa) contain significant mineralization, assuming that they exist. At Bisbee, according to Bryant and Metz, 1966:

> "Copper ore has been found in all the Paleozoic limestone; however, the most productive formations have been the upper half of the Abrigo Limestone, all of the Martin Limestone, and the lower half of the Escabrosa Limestone, a total thickness of about 1,000 feet (Fig. 2). The favorable formations are brittle and tend to shatter when subjected to diastrophic stresses, whereas the other formations above and below tend to yield, resulting in a fold or failure along a single break."

As noted above, the main copper deposit (Emerald Mine) occurs at the south end of the district, in the Abrigo formation. The possibility that the Abrigo formation in the main part of the district is more intensely mineralized appears to be quite good.

Another replacement type would be similar to the Christmas, Arizona, deposit. I think the chances for this are less than the Bisbee type, due to the overall geology, and the altered nature of the dikes.

Silver Possibilities

About all of the silver produced from the district came from secondarily enriched deposits. These have been essentially mined out.

In conversation with Frank Frankovich (see below, under ownership), he feels that there is considerable potential for large tonnages of high grade silver ore. The area he has in mind is north of the main district, under the town of Tombstone. (See Plate IV). He notes that the previous mining stopped at the town, but there is no geologic reason for the ore not continuing to the north. (Perhaps true, but what a place to look for ore - right under the town.)

Water

As is well known, water was encountered at the 520' level of the Sulphuret shaft. Pumping in the mines showed that the water in the various mines is connected by fractures, such that pumping in one shaft would lower the water table in the entire district.

Mr. E. F. Hollyday, in a recent M.S. thesis at the University of Arizona, suggests that the amount of water in the district has been greatly exaggerated. Attached is his abstract and Summary and Conclusion.

Ownership

Almost all of the claims covering the main district were consolidated by Phelps Dodge Corp. into a company called Tombstone Development Co. This company was subsequently acquired by Newmont Mining Company. About 10-12 years ago Frank Frankovich, acting on behalf of a group of private investors from Nebraska, acquired from Newmont, Tombstone Development Company for something like $120,000. This group of investors still holds the company.

There is an agreement between Tombstone Development Company and American Silver Mining Company (a Coeur d'Alene mining company), that when American Silver stock reaches $2.00/share (it is currently selling at around $2.25) Tombstone Development will be merged into American Silver, with American Silver being the surviving company. Mr. Frankovich is a director of Tombstone Development Company and vicepresident and general manager (and a director) of American Silver.

Negotiations between ASARCO and American Silver for American Silver's claims in the Coeur d'Alene district are currently in progress.

Charleston District:

I have never visited the Charleston area. I see little geologic relation between the Tombstone district and the Charleston district at the present time. It would appear that the Charleston district will have to be evaluated on its own merits.

Dutch Van Blaricom has reviewed the geophysical work done by Hewitt Enterprises. Dutch feels that maps No. 9 and 10 have no value. He is also suspicious of the anomaly that is in the east-center portion of Section 30. He suspects that a north-south fence line may exist along the section line. Should someone be in the general area, they might check the section line.

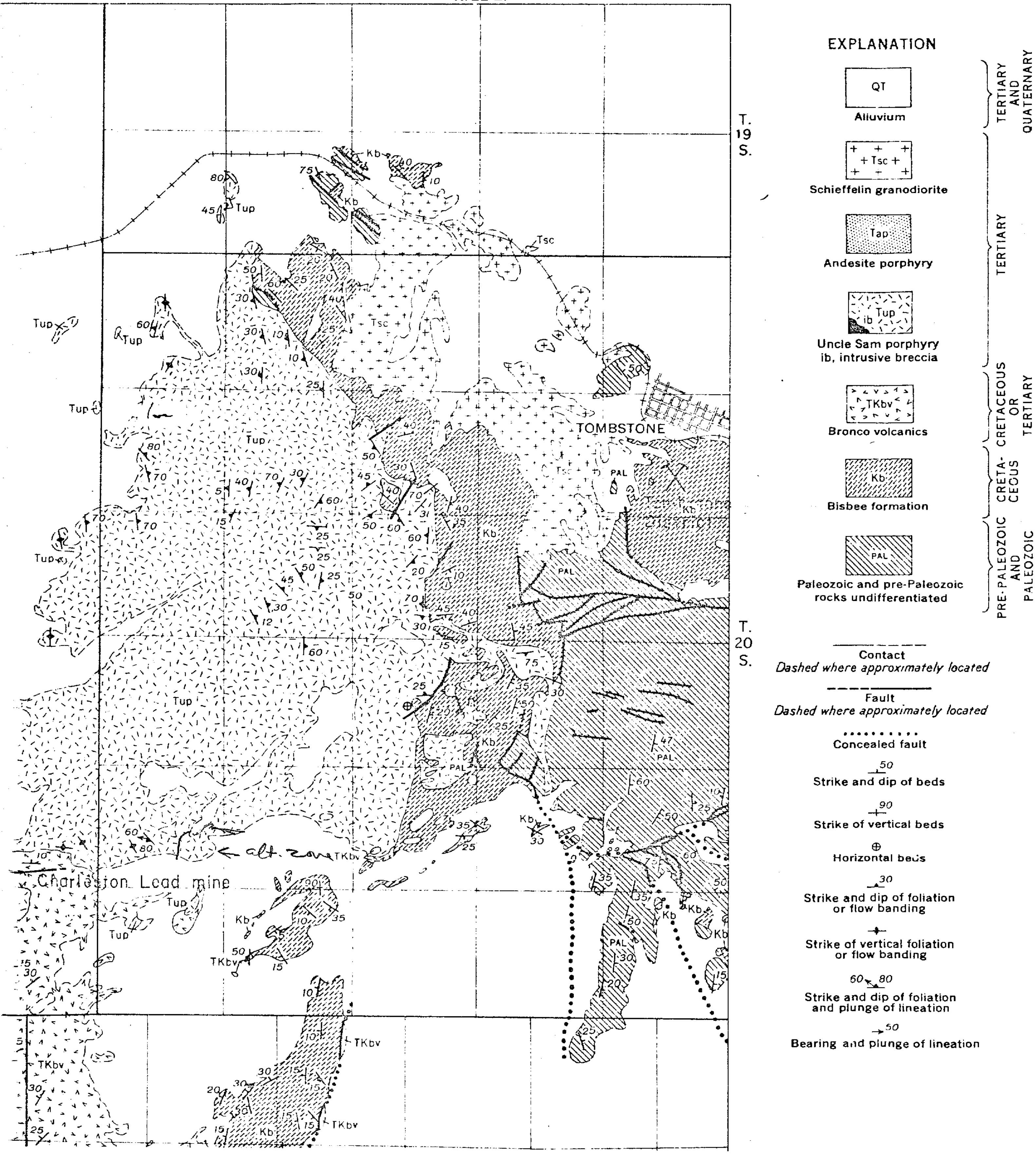
John

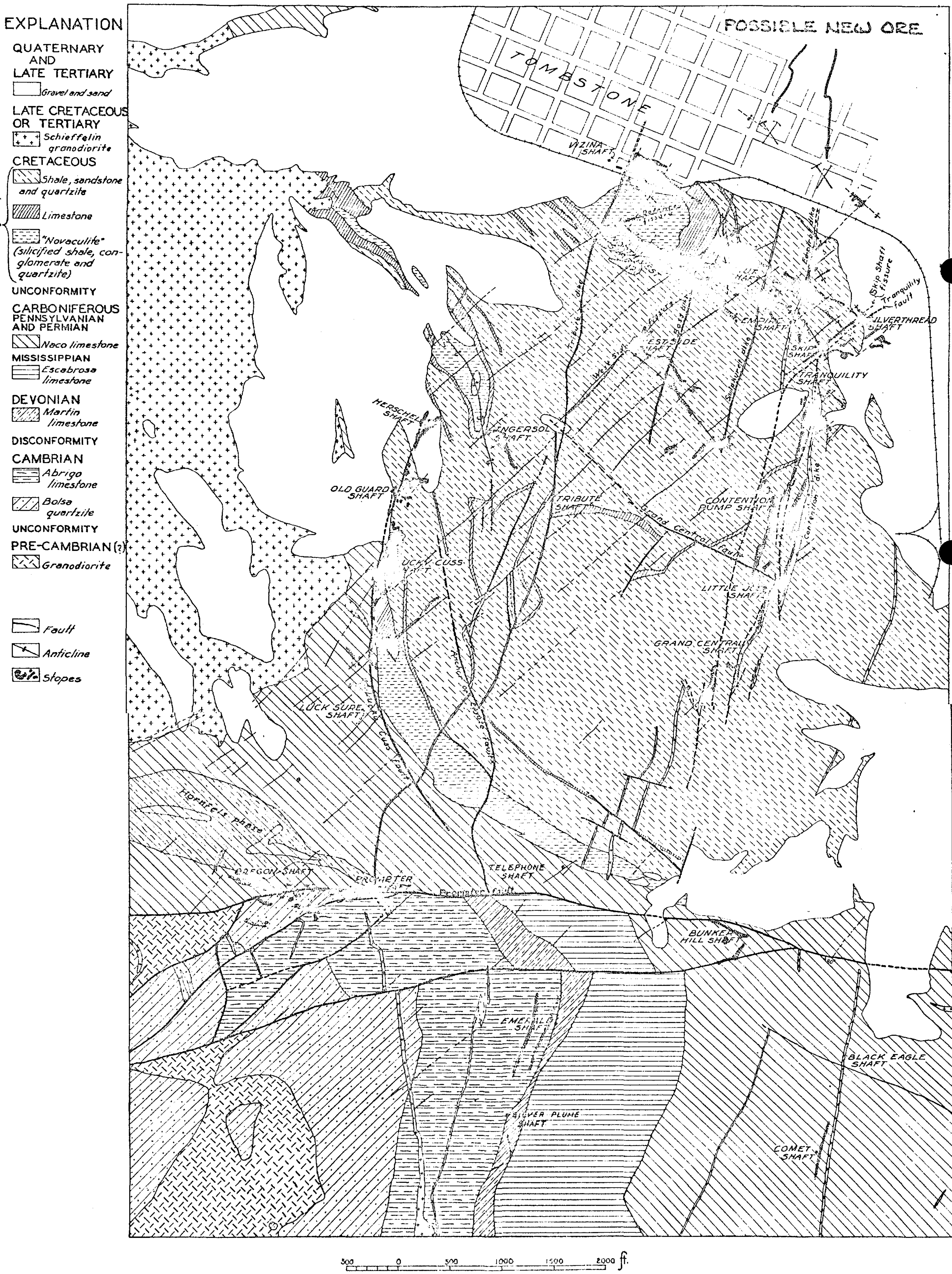
John C. Balla

Figure 1

GENERAL GEOLOGIC COLUMN
Tombstone District
Cochise County, Arizona

		Ore Occurrences
Quaternary	Alluvial deposits Basalt intrusive	
Tertiary	Gila Conglomerates: conglomerate, sandstone, silt, clay; several hundred feet. Rhyolite dikes, plugs, sills. Sandstone, conglomerate, mudstone; 80 feet. Schieffelin granodiorite: quartz-poor granodiorite to quartz monzonite. Andesite porphyry dikes. Uncle Sam porphyry: quartz latite porphyry to quartz monzonite porphyry.	No known associated mineralization. Ore is associated with the genetically related granodiorite-diorite dikes. A little mineralization in a few faults.
Lower Tertiary-Upper Cretaceous	Bronco volcanics: quartz latite flows and tuffs, andesite flows and flow breccias, 6,000 feet.	
Cretaceous	Bisbee formation: conglomerate, sandstone, mudstone, a little limestone at the base, 3,000 ft.	The basal "Novaculite" (55-70 ft. and overlying Blue Limestone (20-40 ft.) were the main ore horizons in this formation. Som: ore also occurred higher in the formation.
Permian	Epitaph dolomite: dolomite, sandstone, limestone, 780 feet. Colina limestone: limestone, 635 feet.	Main ore horizon in the Naco Group. May have contained ore.
Pennsylvanian	Earp formation: limestone, shale, limestone conglomerate, and thin dolomite beds, 595 feet. Horquilla limestone: limestone, 1,000-1,200 ft.	May have contained ore. Contained some ore.
Mississippian	Escabrosa limestone: crinoidal limestone, 886 ft.	Not known to contain ore.
Devonian	Martin limestone: limestone, shale, sandstone, a little chert; 230 feet.	Not known to contain ore.
Cambrian	Abrigo limestone: limestone, shale, a little quartzite; 844 feet. Bolsa quartzite: quartzite, grit, conglomerate; 440 feet.	Contained some oxide silver and copper ore from the lower portion of the formation. Contained some oxide silver and copper ore.
Pre-Cambrian	Albite granite. Pinal schists: muscovite, chlorite, quartz schist, minor amphibolite.	No known associated mineralization


R. 22 E.
T. 19 S.
T. 20 S.
TOMBSTONE
Charleston Lead mine
alt. zone
Tup
Tsc
Kb
TKbv
PAL
EXPLANATION
QT
Alluvium
TERTIARY AND QUATERNARY
Tsc
Schieffelin granodiorite
Tap
Andesite porphyry
TERTIARY
Tup
ib
Uncle Sam porphyry
ib, intrusive breccia
TKbv
Bronco volcanics
CRETACEOUS OR TERTIARY
Kb
Bisbee formation
CRETACEOUS
PAL
Paleozoic and pre-Paleozoic rocks undifferentiated
PRE-PALEOZOIC AND PALEOZOIC
Contact
Dashed where approximately located
Fault
Dashed where approximately located
Concealed fault
Strike and dip of beds
Strike of vertical beds
Horizontal beds
Strike and dip of foliation or flow banding
Strike of vertical foliation or flow banding
Strike and dip of foliation and plunge of lineation
Bearing and plunge of lineation



GEOLOGIC MAP OF TOMBSTONE DISTRICT, ARIZONA

MODIFIED FROM F. L. RANSOME

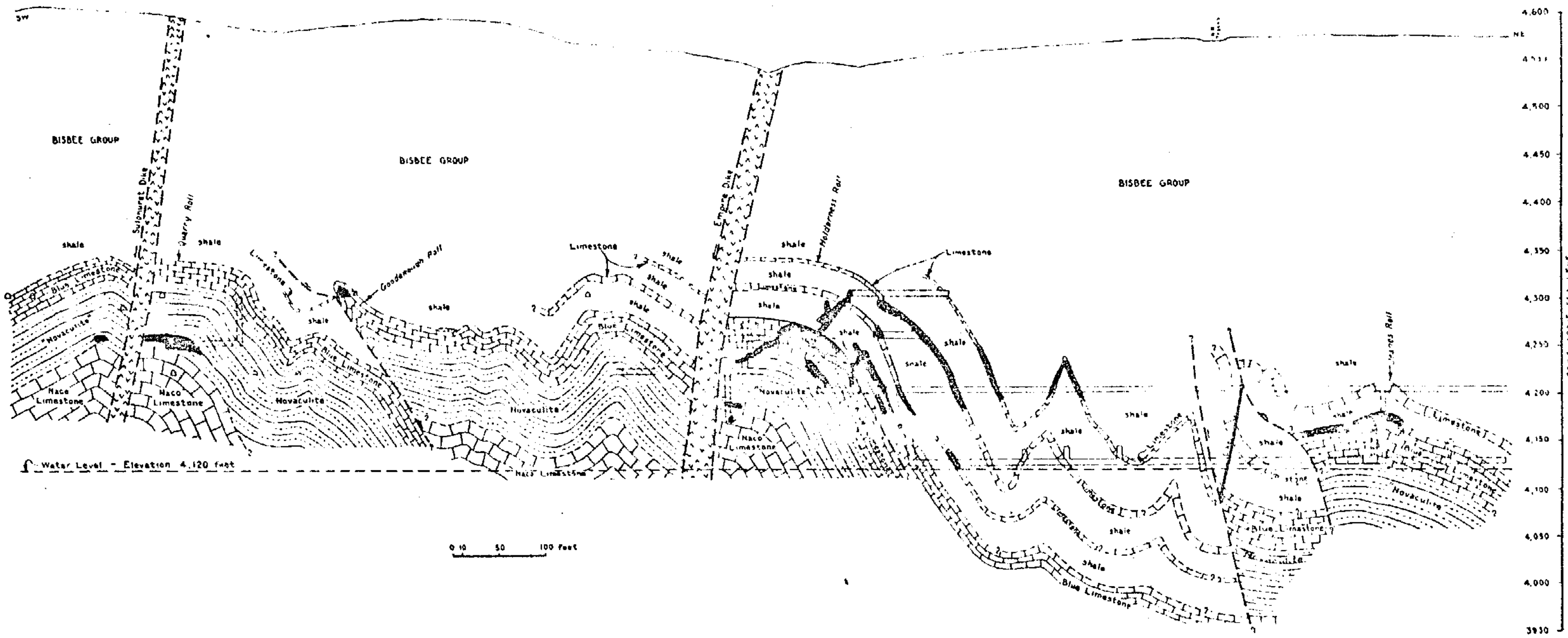


Plate XV.—Section along "409" fissure, looking northwest.

A GEOHYDROLOGIC ANALYSIS OF MINE DEWATERING AND WATER DEVELOPMENT, TOMBSTONE, COCHISE COUNTY, ARIZONA

by

Este F. Hollyday

ABSTRACT

Tombstone, 73 miles southeast of Tucson, has been a site of extensive dewatering for mining operations. During an 8-year period between 1902 and 1911, a total of 36,000 acre-feet of water was withdrawn from ground-water storage in the mine rocks with a maximum decline in water level of 440 feet. For the 8-year period of pumping, this volume of water could have supported a city of 30,000 population.

The sedimentary rocks within the mining district have a composite thickness of 6,600 feet and include the normal stratigraphic sequence of southeastern Arizona from the Precambrian Pinal Schist to the top of the Cretaceous Bisbee Formation. Siliceous and quartzose-carbonate rocks within the mining district have been altered to quartzite, marble, and jasperoid and have the best porosity and permeability as a result of innumerable fractures and fissures. Among the siliceous

rocks, the Bolsa Quartzite and Bisbee Formation are the best water-bearing units within the district. The carbonate rocks, predominant in the section, have been fractured and subjected to solutioning. They have their best porosity and permeability within the zone of maximum circulation near the water table.

The mining district is bordered on the west by the impermeable Schieffelin Granodiorite and related intrusives that partly isolate the district from areas of natural ground-water discharge along the San Pedro River. The district is bordered on the south and east by predominantly crystalline carbonate rocks. The igneous core of the Mule and Dragoon Mountains lies farther to the east. An alluvial valley with large ground-water storage lies immediately north and northeast of the mining district.

A review of the history of previous water development indicates that the magnitude of the yield of the aquifer complex has been exaggerated out of proportion as a result of circumstances connected with dewatering operations.

For comparative purposes the coefficient of transmissibility of the aquifer complex is estimated as 10,000 to 15,000 gallons per day per foot and the coefficient of storage is estimated as .01. Prediction of the aquifer performance using these two coefficients is greatly modified by anisotropy and boundary conditions within the aquifer complex, and the yield is rapidly reduced with time. As a result, empirical log-log approximations of the time-drawdown curves are proposed for predicting the long-term performance of the aquifer complex.

The geohydrologic evidence indicates that the Tombstone mining district may provide a suitable location for long-term, moderate production of municipal water. With extensive development, the aquifer complex could support a population several times the present size of Tombstone, but this would result in an appreciable drawdown of the water table. On the other hand, the location is moderately good as a site for the consumption of ground-water storage and dewatering that would necessarily accompany mining below the static water level.

CHAPTER VI
SUMMARY AND CONCLUSIONS

Geohydrologic Setting

(1) The principal ground-water sources of the Tombstone region are in the valley alluvium and the fractured siliceous rocks, particularly the Bolsa Quartzite and Bisbee Formation.

(2) The greater porosity and permeability in the carbonate rocks occurs between the water table and 200 to 300 feet below the water table.

(3) The intrusive rocks and Precambrian metamorphic rocks act as barriers to ground-water movement. The Schieffelin Granodiorite and related intrusives along the western margin of the mining district partly isolate the district from areas of natural discharge along the San Pedro River. Igneous and metamorphic rocks in a crystalline high within the Mule and Dragoon Mountains and areas in between apparently isolate the district from the Sulphur Spring Valley.

(4) During pumping periods, water is withdrawn from ground-water storage to the north, south, and east of Tombstone from fractures, fissures, and solution openings communicating with pore space in the valley alluvium.

History of Water Development

Review of the history of water development indicates that the potential yield of the principal aquifers has been extrapolated out of all proportion. This exaggeration basically is due to two facts connected with dewatering operations:

(1) There is a very large but finite amount of water in storage in the Tombstone region. This finite amount of water may be developed in a very short period of time with large drawdown and large apparent yield as in dewatering operations, or it may be produced over a much longer period of time at moderate drawdown with smaller yield as in water-supply development adjusted to the capacity of the aquifer. Large drawdowns may produce a spectacular amount of water for a short period of time, but as the saturated thickness is rapidly reduced, the initial yields decline very rapidly and the life of the water supply is greatly reduced. The Tombstone mining district won its reputation for large water production during a period of extreme drawdown. The withdrawal rates which typified the initial dewatering cannot be maintained over a longer period of time.

(2) Large amounts of water in addition to what might be expected from normal municipal well production in the same aquifer were obtained from storage for a short period of time by crosscut development in the Pump Shaft.

Quantitative Determination of Aquifer Performance

(1) For comparative purposes, the Tombstone aquifer complex has a local coefficient of transmissibility of the order of 10,000 to 15,000 gpd per foot and a coefficient of storage of .01.

(2) The aquifer performance based upon these ideal coefficients is strongly modified by boundary conditions and the anisotropy of the fissure and solution-opening system as indicated by pumping tests conducted at different pumping rates.

(3) Future development may be programmed with empirical equations designed to include the significant variables in the geohydrologic setting.

Appraisal of Geohydrologic Setting For Water Development

The geohydrologic evidence indicates that the Tombstone mining district may provide a suitable location for long-term, moderate production of municipal water. With extensive development, the aquifer complex could support a population several times the present size of Tombstone, but this would result in an appreciable drawdown of the water table. On the other hand, the location is moderately good as a site for the withdrawal of ground-water storage and dewatering that would necessarily accompany mining below the static water level.

Recommendations for Further Study

Geohydrology of Tombstone Region

A more accurate determination of the hydrologic performance of the Tombstone aquifer complex was hampered by a lack of knowledge of the effective aquifer thickness and the zonation of the hydrologic properties. The effective thickness and zonation of hydrologic properties were inferred from pump-test results but could not be accurately determined in order to adjust the values of transmissibility for changes in aquifer thickness as a result of excessive drawdown. Very useful information could be obtained from a deep exploratory well in which each zone penetrated could be tested individually for its hydrologic performance. This information could be used to adjust the coefficient of transmissibility for changes in aquifer thickness and to subdivide the aquifer complex into principal water-bearing zones.

In order to estimate the total amount of water in storage in the region, a thorough investigation should be made of the nature, thickness, and configuration of the alluvium in the surrounding valleys. At this time there are too few wells and well logs available to make a reasonable estimate of the volume of storage.

Geohydrology of fractured Crystalline Rocks and Mine Dewatering

Investigations connected with this report have revealed at least four areas of research in which significant contributions could be made to the knowledge of geohydrology.

Apparently very little is known about the interrelationship between rock deformation and metamorphism and the development of secondary porosity in rocks of various compositions. Published research on rock deformation would at least in theory indicate that quite different fracture systems may be developed in siliceous rocks as opposed to carbonate rocks, although interbedded and subjected to the same conditions of pressure and temperature. The implications for differences in ground-water circulation are obvious.

Little is known about fissure and solution networks, their vertical and lateral variations, and the manner in which fluids occur and move within them. Research on the quantitative interrelationship of fissures and solution openings and fluid motion would add to our knowledge of ground-water hydraulics, ore emplacement, and secondary recovery from dolomite petroleum reservoirs.

A wet mine shaft is a unique rock-wall well in which the well remains dewatered at all times during active mine development. Research is needed to quantitatively determine the head losses due to turbulence in the neighborhood of the well and due to convergent flow at the bottom of the well. Quantitative evaluation of the losses would permit analysis of pumped shaft data for determining aquifer coefficients.

The programming of dewatering operations would be greatly helped by a nonequilibrium, quantitative analysis and theoretical analysis of incremental discharge additions due to progressive well development as a result of drifting and crosscutting.

In general, the hydrology of fractured crystalline rocks, although limited in economic importance to small domestic water supplies, mine dewatering, petroleum-reservoir production, and engineering construction, is a wide open field for hydrologic research. The field is difficult, but the benefits to planned environmental control from constructive research may be very rewarding.

JHC cpy

RECEIVED

MAR 12 1973

S. W. U. S. EXPL. DIV.

AMERICAN SMELTING AND REFINING COMPANY
NORTHWESTERN UNITED STATES
EXPLORATION DIVISION

KEITH WHITING
MANAGER

EAST 920 WOLVERTON COURT
(HAMILTON AT NEVADA)
SPOKANE, WASHINGTON 99207

March 8, 1973

J. H. C.

APR 17 1973

Mr. W. L. Kurtz
ASARCO - Tucson

file

Tombstone District
Cochise County, Arizona

Dear Bill:

Enclosed is my report on the Tombstone District. The report is largely a presentation of facts which, if correctly interpreted by me, suggest that a major copper deposit may exist under the main district. There is a possibility, if not probability, that other interpretations can be made, which would preclude the occurrence of such a deposit.

Even if such a deposit exists, there are formidable problems remaining. These include depth to the deposit, water, proximity of the town, and acquiring the mineral rights.

Considering the state of our knowledge on ore deposits, my report should be considered more as a presentation of an idea, rather than a recommendation for further work.

Should you concur with me that the district has reasonable exploration potential, then the acquisition of the mineral rights will have to be done by dealing with Frank Frankovich here in Spokane.

According to Frank, Tombstone Development company controls all of the significant past producers in the district. The company owns over 100 patented mining claims and fractions, totaling some 1180 acres. In addition, the company owns 18 unpatented claims east of the main district, and Frankovich owns 5 unpatented claims on the west side of the district.

See you in Knoxville!

Sincerely,

John C. Balla

JCB/ir
Enc.

P.S. Also enclosed is Hewitt's report on the Charleston district.

Spokane, Washington
March 5, 1973

TO: W. L. Kurtz
FROM: John C. Balla

Tombstone District
Cochise County, Arizona
A Porphyry Copper District?

Introduction:

The following report summarizes some thoughts I have had for a number of years on the Tombstone District. It is based upon field work I did in the district in 1962, supplemented by some current thoughts on porphyry copper deposits. The interpretations of the district should be considered speculative.

The Tombstone District is primarily noted as a silver "bonanza" camp. However, it is really a base metal district. It has produced (to 1936) 7,049,997 ounces of silver, 2,516,040 pounds of copper, 26,965,134 pounds of lead and 1,058,234 pounds of zinc. Tombstone ranks eighth among the lead producing districts of Arizona. Manganese is also an important commodity.

There has been little work done in the district in recent years. Some stratigraphic work has been done by University of Arizona graduate students. The main references are Arizona Bureau of Mines Bulletin 143 on the Geology and Ore Deposits of the Tombstone District by Butler, Wilson & Rasor, (1938) and U.S.G.S. P.P. 281 by Gilluly, on the General Geology of Central Cochise County. I might also mention my report on porphyry copper deposits and barren Laramide stocks, and Ted Eyde's paper on Stratigraphy as an Exploration Guide to Porphyry Copper Deposits.

General Geology:

The stratigraphic column for the district is shown in Figure 1. The figure also indicates what units were mineralized.

The oldest rock in the Tombstone District is the Pinal schist. The Pinal schist has been intruded by an albite granite, also of older Precambrian age.

The younger Precambrian Apache group of sediments are not present. The complete Paleozoic section of sedimentary rocks, totaling about 5500 feet, are present.

Overlying the Paleozoic rocks is the Bisbee group of sediments, which are about 3000 feet thick.

West of the main district, in the Charleston lead mine area, are the pre-ore Bronco volcanics. According to Gilluly (1956), these volcanics are probably from 5000 feet to 6000 feet in thickness. Whether they are pre-thrusting or post-thrusting in age is unknown.

Major thrusting, which is probably gravitational gliding, has occurred in the area. However, the thrusting appears to be all pre-mineral in age.

The Uncle Sam porphyry is a post-thrust, intrusive, quartz latite porphyry. This is an unusual rock in that it appears to be laccolithic in form.

Intruding all of the above rocks is the Schieffelin granodiorite. The granodiorite is a large, barren, Laramide granitic stock. The stock has an isotopic age of 72 m.y.

The Schieffelin granodiorite occurs in two separate areas; immediately north of the Tombstone district, and in the Charleston-Lewis Springs area. These two areas will be treated separately in this report.

Tombstone Area:

In the Tombstone area the Schieffelin granodiorite is a barren, elongate stock. It is about two miles wide and three and one-half miles long, as shown on Plate 9. The horizontal long axis of the stock trends about N. 35° W. As I recall, it is not a composite, zoned stock, but is fairly uniform in texture (medium grained) and composition. The above suggests that we may be near the top of the stock, and have not yet eroded down into the composite zoned part.

Butler (1938) indicates the same thing when he states:

> "The Schieffelin granodiorite mass, as indicated by the nature of its contact with Naco limestone and with beds belonging to the Bisbee group, east of The Dome, and by its contact with the Naco limestone west of the Lucky Cuss Mine, increases in size downward and would occupy a larger part of the area of the district were the general elevation of the surface reduced a few hundred feet by erosion; evidently it forms a stocklike body."

Ore Deposits:

At the immediate south end of the Schieffelin granodiorite is the Tombstone District. The main district occupies a structural basin, which is an asymmetrical syncline which plunges southeasterly in its northern half and more easterly in its southern half. The rocks involved in this folding are the Paleozoic and Mesozoic sediments, according to Butler (1938):

> "Within the Tombstone basin the rocks have been folded into secondary anticlines and synclines with a general trend of N. 40 to 65 degrees W. They plunge gently southeastward in the northwestern part and more steeply in the southeastern part of the basin. They are best defined in the eastern part of the basin; in the western part they are more compressed and indefinite.

> "Folds of a third order occur as corrugations on the secondary anticlines and synclines of the Tombstone basin. The anticlines of this order are locally termed "rolls", and within them are located many ore bodies." Plate XV from Butler (1938) shows a typical ore occurrence.

Both Butler (1938) and Gilluly (1956) suggest that the folding is due to horizontal compression. This is not necessarily true. It is distinctly possible that the folding is due to doming by an intrusive stock, and subsequent subsidence.

The basin is cut by a series of strong "cross fractures", called the Northeast ore fissures, as shown on Plate IV. According to Butler, (1938):

> "Fissures that strike N. 30 to 55 degrees E., cut all the rocks older than the Cenozoic gravels. These fissures prevailingly dip steeply southeastward in the Tombstone basin and northwestward in the western part of the district. The stronger ore fissures within the Tombstone basin are rather uniformly spaced. Within the interval of 2,000 feet between the Intervener and the Arizona Queen fissures are eight large fissures rather uniformly spaced at intervals of about 300 feet. So large a proportion of the deposits is associated with northeasterly striking fissures that the relation may be assumed as general.
>
> "Much of the ore in the Tombstone district has resulted from replacement of a few favorable formations that range from the lower Paleozoic to well above the base of the Mesozoic in the Bisbee group. The most productive sedimentary zones recognized are:
>
> 1. Beds of limestone above the Blue limestone in the Bisbee group
> 2. Blue limestone near the base of the Bisbee group
> 3. "Novaculite"

4. Upper portion of Naco limestone

5. Beds lower in the Naco: Lucky Cuss and Bunker Hill Mines

6. Lower Paleozoic beds: Emerald Mine.

"In addition to the sedimentary beds the dikes in places, mainly within the Contention, Grand Central, and Head Center areas, were favorable to ore mineralization.

"The central part of the Tombstone district is traversed by several dikes of granodiorite to dioritic composition. Although not noteworthy in their petrographic character, they are of exceptional interest because of their structural relation to ore deposition, their parallelism and persistency, and the manner in which some of them have been faulted. At least five such dikes traverse the central Mesozoic area with a general course of north 12 degrees east and a dip of 75 to 85 degrees west, except the Boss dike, which dips steeply eastward.

"These dikes do not crop out prominently and as a rule are deeply altered (and pyritized). They are believed to have originated as a relatively later phase of the same magma that gave rise to the Schieffelin granodiorite and Uncle Sam porphyry.

"The ores in different parts of the district range greatly in content of the different metals, and whether they were recovered or not depended somewhat on the degree of oxidation. Zinc has been recovered only from sulphide ores, and the distribution of oxidized zinc minerals is little known. Manganese, on the other hand, has been recovered only from oxidized ores.

"The distribution of metals suggests an area of most intense mineralization in the northeast section of the district with a rough zoning outward. The most definite of the metal zones are the central gold zone and the marginal manganese-silver zone. The gold zone is characterized by abundant quartz and fluorite, and the manganese-silver zone by manganese.

"Copper

"Copper is also widely distributed but in small amounts, and its distribution is not well known. It seems to be most abundant in and near strong northeast fissures.

"Copper carbonate stains in the fissures are generally regarded as good indications of ore near by.

"The Emerald Mine probably contained the largest body of copper ore."

The Emerald Mine, interestingly enough, occurred in the Cambrian Abrigo formation. It is also located at the southern end of the district, away from the Schieffelin granodiorite.

"Molybdenum

"Molybdenum occurs in the ores as wulfenite, the lead molybdate. It is present over a considerable part of the district but is most abundant in the gold areas particularly of the Silver Thread roll. Like the gold it is most abundant in and near the northeast fissures. The wulfenite is, however, a secondary mineral not closely associated with gold, and the material high in molybdenum is not generally high in gold. Wulfenite rather commonly occurs around or beneath an ore body, and although conspicuous, it nowhere forms more than a small percentage of the larger bodies of ore."

The suggestion that Tombstone is a porphyry copper district is derived from an attempt to answer three questions:

1. What would the geology be above a porphyry copper deposit that intruded limestones, but never penetrated all of the limestone rocks?

2. Much of the lead-zinc production in Arizona has come from limestone replacement deposits adjacent to porphyry copper deposits. Where is the porphyry copper deposit at Tombstone?

3. Every large, barren, Laramide granitic stock in southern Arizona has an associated porphyry copper deposit. Where is the porphyry copper deposit associated with the Schieffelin granodiorite?

Conclusions:

From a district viewpoint, the following observations can be made:

1. A large, barren, elongate, Laramide granitic stock has intruded a very thick (9000 feet) section of sediments, mainly limestones.

2. At the south end of the stock, in a zone of strong cross fracturing, numerous altered and pyritized dikes, genetically related to the barren stock, have intruded the limestones.

3. The sediments have been complexly folded, which may be due to a buried stock, which rose part way through the sediments, then subsided slightly as it cooled. The altered dikes may then be apophyses off the mineralized intrusive, which would be related to the barren stock.

4. Copper, lead, zinc, silver mineralization occurs as replacement deposits, associated with the dikes and cross fracturing.

5. The mineralization appears to be crudely zoned, with a gold-quartz central zone, and a peripheral manganese-silver zone. Molybdenum, although widely distributed, appears to be most abundant in the central zone. This central zone is located adjacent to the barren stock.

6. Copper is widely distributed, and is associated with the cross fractures. The most abundant copper occurs in the Cambrian rocks.

Exploration Potential:

Porphyry Copper Deposit

There are several possible "porphyry copper type" targets. The first is replacement of the Paleozoic rocks by pervasive mineralization, similar to Mission. Another replacement type would be higher grade replacement deposits, similar to Bisbee type ore. These types would necessitate a mineralized intrusive at some unknown depth beneath the district. The pyritized and altered dikes are apophyses off the stock. This possibility would indicate that part of the lower sedimentary sequence of rocks may not exist, or be very complexly folded and faulted.

From the available data, there is an excellent chance that the Lower Paleozoic rocks (Abrigo, Martin, Escabrosa) contain significant mineralization, assuming that they exist. At Bisbee, according to Bryant and Metz, 1966:

> "Copper ore has been found in all the Paleozoic limestone; however, the most productive formations have been the upper half of the Abrigo Limestone, all of the Martin Limestone, and the lower half of the Escabrosa Limestone, a total thickness of about 1,000 feet (Fig. 2). The favorable formations are brittle and tend to shatter when subjected to diastrophic stresses, whereas the other formations above and below tend to yield, resulting in a fold or failure along a single break."

As noted above, the main copper deposit (Emerald Mine) occurs at the south end of the district, in the Abrigo formation. The possibility that the Abrigo formation in the main part of the district is more intensely mineralized appears to be quite good.

Another replacement type would be similar to the Christmas, Arizona, deposit. I think the chances for this are less than the Bisbee type, due to the overall geology, and the altered nature of the dikes.

Silver Possibilities

About all of the silver produced from the district came from secondarily enriched deposits. These have been essentially mined out.

In conversation with Frank Frankovich (see below, under ownership), he feels that there is considerable potential for large tonnages of high grade silver ore. The area he has in mind is north of the main district, under the town of Tombstone. (See Plate IV). He notes that the previous mining stopped at the town, but there is no geologic reason for the ore not continuing to the north. (Perhaps true, but what a place to look for ore - right under the town.)

Water

As is well known, water was encountered at the 520' level of the Sulphuret shaft. Pumping in the mines showed that the water in the various mines is connected by fractures, such that pumping in one shaft would lower the water table in the entire district.

Mr. E. F. Hollyday, in a recent M.S. thesis at the University of Arizona, suggests that the amount of water in the district has been greatly exaggerated. Attached is his abstract and Summary and Conclusion.

Ownership

Almost all of the claims covering the main district were consolidated by Phelps Dodge Corp. into a company called Tombstone Development Co. This company was subsequently acquired by Newmont Mining Company. About 10-12 years ago Frank Frankovich, acting on behalf of a group of private investors from Nebraska, acquired from Newmont, Tombstone Development Company for something like $120,000. This group of investors still holds the company.

There is an agreement between Tombstone Development Company and American Silver Mining Company (a Coeur d'Alene mining company), that when American Silver stock reaches $2.00/share (it is currently selling at around $2.25) Tombstone Development will be merged into American Silver, with American Silver being the surviving company. Mr. Frankovich is a director of Tombstone Development Company and vicepresident and general manager (and a director) of American Silver.

Negotiations between ASARCO and American Silver for American Silver's claims in the Coeur d'Alene district are currently in progress.

Charleston District:

I have never visited the Charleston area. I see little geologic relation between the Tombstone district and the Charleston district at the present time. It would appear that the Charleston district will have to be evaluated on its own merits.

Dutch Van Blaricom has reviewed the geophysical work done by Hewitt Enterprises. Dutch feels that maps No. 9 and 10 have no value. He is also suspicious of the anomaly that is in the east-center portion of Section 30. He suspects that a north-south fence line may exist along the section line. Should someone be in the general area, they might check the section line.

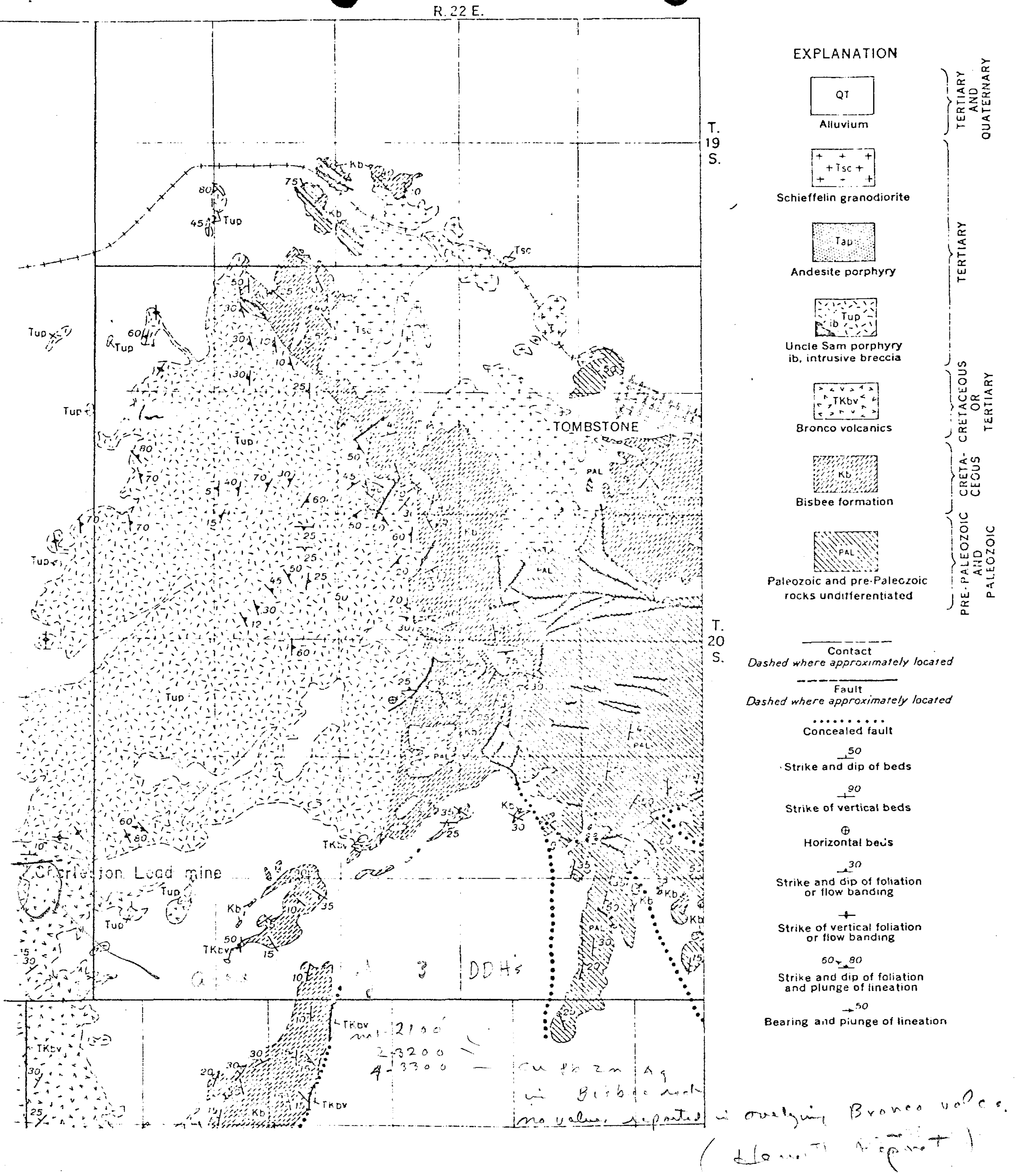
John

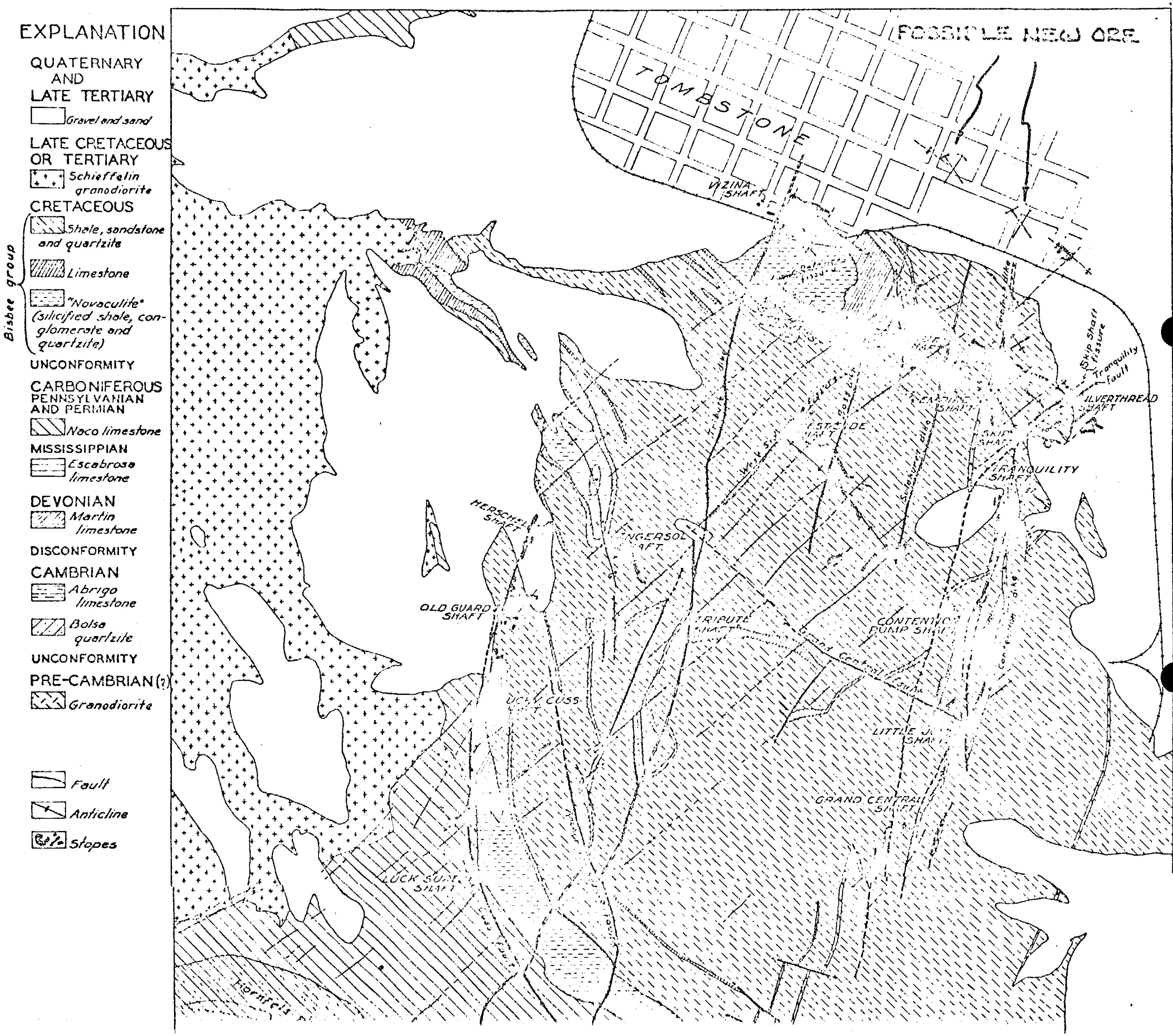
John C. Balla

Figure 1

GENERAL GEOLOGIC COLUMN
Tombstone District
Cochise County, Arizona

		Ore Occurrences
Quaternary	Alluvial deposits Basalt intrusive	
Tertiary	Gila Conglomerates: conglomerate, sandstone, silt, clay; several hundred feet. Rhyolite dikes, plugs, sills. Sandstone, conglomerate, mudstone; 80 feet. Schieffelin granodiorite: quartz-poor granodiorite to quartz monzonite. Andesite porphyry dikes. Uncle Sam porphyry: quartz latite porphyry to quartz monzonite porphyry.	No known associated mineralization. Ore is associated with the genetically related granodiorite-diorite dikes. A little mineralization in a few faults.
Lower Tertiary-Upper Cretaceous	Bronco volcanics: quartz latite flows and tuffs, andesite flows and flow breccias, 6,000 feet.	
Cretaceous	Bisbee formation: conglomerate, sandstone, mudstone, a little limestone at the base, 3,000 ft.	The basal "Novaculite" (55-70 ft. and overlying Blue Limestone (20-40 ft.) were the main ore horizons in this formation. Some ore also occurred higher in the formation.
Permian	Epitaph dolomite: dolomite, sandstone, limestone, 780 feet. Colina limestone: limestone, 635 feet.	Main ore horizon in the Naco Group. May have contained ore.
Pennsylvanian	Earp formation: limestone, shale, limestone conglomerate, and thin dolomite beds, 595 feet. Horquilla limestone: limestone, 1,000-1,200 ft.	May have contained ore. Contained some ore.
Mississippian	Escabrosa limestone: crinoidal limestone, 886 ft.	Not known to contain ore.
Devonian	Martin limestone: limestone, shale, sandstone, a little chert; 230 feet.	Not known to contain ore.
Cambrian	Abrigo limestone: limestone, shale, a little quartzite; 844 feet. Bolsa quartzite: quartzite, grit, conglomerate; 440 feet.	Contained some oxide silver and copper ore from the lower portion of the formation. Contained some oxide silver and copper ore.
Pre-Cambrian	Albite granite. Pinal schists: muscovite, chlorite, quartz schist, minor amphibolite.	No known associated mineralization


R. 22 E.
T. 19 S.
T. 20 S.
TOMBSTONE
Charleston Lead mine
DDH's
1 - 2100'
2 - 3200
4 - 3300
Cu Pb Zn Ag
in Bisbee rock
no values reported in overlying Bronco volcs.
(Hewitt report)
EXPLANATION
QT
Alluvium
TERTIARY AND QUATERNARY
Tsc
Schieffelin granodiorite
Tap
Andesite porphyry
TERTIARY
Tup
ib
Uncle Sam porphyry
ib, intrusive breccia
TKbv
Bronco volcanics
CRETACEOUS OR TERTIARY
Kb
Bisbee formation
CRETACEOUS
PAL
Paleozoic and pre-Paleozoic rocks undifferentiated
PRE-PALEOZOIC AND PALEOZOIC
Contact
Dashed where approximately located
Fault
Dashed where approximately located
Concealed fault
Strike and dip of beds
Strike of vertical beds
Horizontal beds
Strike and dip of foliation or flow banding
Strike of vertical foliation or flow banding
Strike and dip of foliation and plunge of lineation
Bearing and plunge of lineation


EXPLANATION
QUATERNARY AND LATE TERTIARY
Gravel and sand
LATE CRETACEOUS OR TERTIARY
Schieffelin granodiorite
CRETACEOUS
Bisbee group
Shale, sandstone and quartzite
Limestone
"Novaculite" (silicified shale, conglomerate and quartzite)
UNCONFORMITY
CARBONIFEROUS
PENNSYLVANIAN AND PERMIAN
Naco limestone
MISSISSIPPIAN
Escabrosa limestone
DEVONIAN
Martin limestone
DISCONFORMITY
CAMBRIAN
Abrigo limestone
Bolsa quartzite
UNCONFORMITY
PRE-CAMBRIAN (?)
Granodiorite
Fault
Anticline
Stopes
POSSIBLE NEW ORE
TOMBSTONE
VIZINA SHAFT
HERSCHEL SHAFT
OLD GUARD SHAFT
TRANQUILITY SHAFT
Tranquility fault
Skip Shaft fissure
GRAND CENTRAL SHAFT
Grand Central fault

GEOLOGIC MAP OF TOMBSTONE DISTRICT, ARIZONA

MODIFIED FROM F. L. RANSOME

Plate IV

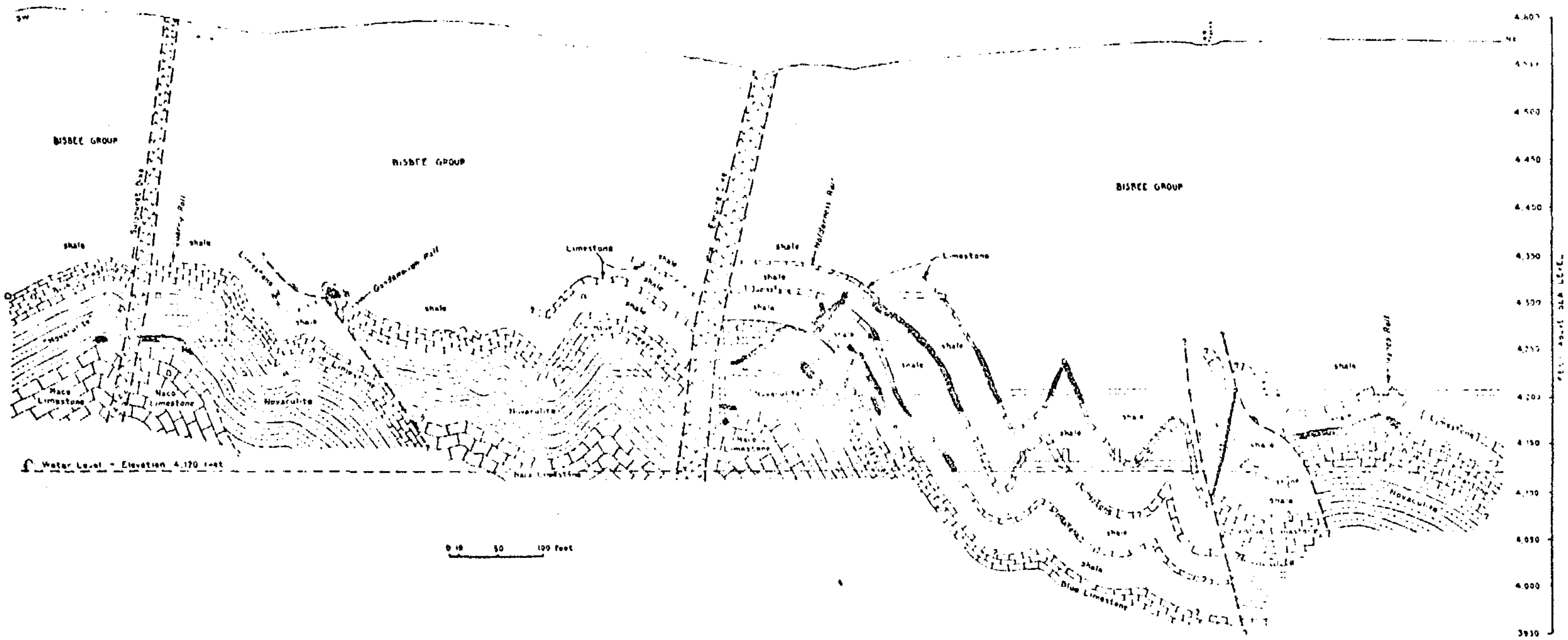


Plate XV – Section along "400" fissure, looking northwest

GEOHYDROLOGIC ANALYSES OF MINE DEWATERING AND WATER DEVELOPMENT, TOMBSTONE, COCHISE COUNTY, ARIZONA

by

Este F. Hollyday

ABSTRACT

Tombstone, 73 miles southeast of Tucson, has been a site of extensive dewatering for mining operations. During an 8-year period between 1901 and 1911, a total of 36,000 acre-feet of water was withdrawn from ground-water storage in the mine rocks with a maximum decline in water level of 440 feet. For the 8-year period of pumping, this volume of water could have supported a city of 30,000 population.

The sedimentary rocks within the mining district have a composite thickness of 6,000 feet and include the normal stratigraphic sequence of southeastern Arizona from the Precambrian Pinal Schist to the top of the Cretaceous Bisbee Formation. Siliceous and quartzose-[illegible] rocks within the mining district have been altered to quartzite, [illegible], and jasperoid and have the best porosity and permeability as a result of innumerable fractures and fissures. Among the siliceous

[illegible], the Bolsa Quartzite and Bisbee Formation are the best water-bearing units within the district. The carbonate rocks, predominant in the section, have been fractured and subjected to solutioning. They have their best porosity and permeability within the zone of maximum circulation near the water table.

The mining district is bordered on the west by the impermeable Schieffelin Granodiorite and related intrusives that partly isolate the district from areas of natural ground-water discharge along the San Pedro River. The district is bordered on the south and east by predominantly crystalline carbonate rocks. The igneous core of the Mule and Dragoon Mountains lies farther to the east. An alluvial valley with large ground-water storage lies immediately north and northeast of the mining district.

A review of the history of previous water development indicates that the magnitude of the yield of the aquifer complex has been exaggerated out of proportion as a result of circumstances connected with de-watering operations.

For comparative purposes the coefficient of transmissibility of the aquifer complex is estimated as 10,000 to 15,000 gallons per day per foot and the coefficient of storage is estimated as .01. Prediction of the aquifer performance using these two coefficients is greatly modified by anisotropy and boundary conditions within the aquifer complex, and the yield is rapidly reduced with time. As a result, empirical log-log approximations of the time-drawdown curves are proposed for predicting the long-term performance of the aquifer complex.

The geohydrologic evidence indicates that the Tombstone mining district may provide a suitable location for long-term, moderate production of municipal water. With extensive development, the aquifer complex could support a population several times the present size of Tombstone, but this would result in an appreciable drawdown of the water table. On the other hand, the location is moderately good as a site for the consumption of ground-water storage and dewatering that would necessarily accompany mining below the static water level.

CHAPTER VI
SUMMARY AND CONCLUSIONS

Geohydrologic Setting

(1) The principal ground-water sources of the Tombstone region are in the valley alluvium and the fractured siliceous rocks, particularly the Bolsa Quartzite and Bisbee Formation.

(2) The greater porosity and permeability in the carbonate rocks occurs between the water table and 200 to 300 feet below the water table.

(3) The intrusive rocks and Precambrian metamorphic rocks act as barriers to ground-water movement. The Schieffelin Granodiorite and related intrusives along the western margin of the mining district partly isolate the district from areas of natural discharge along the San Pedro River. Igneous and metamorphic rocks in a crystalline high within the Mule and Dragoon Mountains and areas in between apparently isolate the district from the Sulphur Spring Valley.

(4) During pumping periods, water is withdrawn from ground-water storage to the north, south, and east of Tombstone from fractures, fissures, and solution openings communicating with pore space in the valley alluvium.

History of Water Development

Review of the history of water development indicates that the potential yield of the principal aquifers has been extrapolated out of all proportion. This exaggeration basically is due to two facts connected with dewatering operations:

(1) There is a very large but finite amount of water in storage in the Tombstone region. This finite amount of water may be developed in a very short period of time with large drawdown and large apparent yield as in dewatering operations, or it may be produced over a much longer period of time at moderate drawdown with smaller yield as in water-supply development adjusted to the capacity of the aquifer. Large drawdowns may produce a spectacular amount of water for a short period of time, but as the saturated thickness is rapidly reduced, the initial yields decline very rapidly and the life of the water supply is greatly reduced. The Tombstone mining district won its reputation for large water production during a period of extreme drawdown. The withdrawal rates which typified the initial dewatering cannot be maintained over a longer period of time.

(2) Large amounts of water in addition to what might be expected from normal municipal well production in the same aquifer were obtained from storage for a short period of time by crosscut development in the Pump Shaft.

Quantitative Determination of Aquifer Performance

(1) For comparative purposes, the Tombstone aquifer complex has a local coefficient of transmissibility of the order of 10,000 to 15,000 gpd per foot and a coefficient of storage of .01.

(2) The aquifer performance based upon these ideal coefficients is strongly modified by boundary conditions and the anisotropy of the fissure and solution-opening system as indicated by pumping tests conducted at different pumping rates.

(3) Future development may be programmed with empirical equations designed to include the significant variables in the geohydrologic setting.

Appraisal of Geohydrologic Setting For Water Development

The geohydrologic evidence indicates that the Tombstone mining district may provide a suitable location for long-term, moderate production of municipal water. With extensive development, the aquifer complex could support a population several times the present size of Tombstone, but this would result in an appreciable drawdown of the water table. On the other hand, the location is moderately good as a site for the withdrawal of ground-water storage and dewatering that would necessarily accompany mining below the static water level.

Recommendations for Further Study

Geohydrology of Tombstone Region

A more accurate determination of the hydrologic performance of the Tombstone aquifer complex was hampered by a lack of knowledge of the effective aquifer thickness and the zonation of the hydrologic properties. The effective thickness and zonation of hydrologic properties were inferred from pump-test results but could not be accurately determined in order to adjust the values of transmissibility for changes in aquifer thickness as a result of excessive drawdown. Very useful information could be obtained from a deep exploratory well in which each zone penetrated could be tested individually for its hydrologic performance. This information could be used to adjust the coefficient of transmissibility for changes in aquifer thickness and to subdivide the aquifer complex into principal water-bearing zones.

In order to estimate the total amount of water in storage in the region, a thorough investigation should be made of the nature, thickness, and configuration of the alluvium in the surrounding valleys. At this time there are too few wells and well logs available to make a reasonable estimate of the volume of storage.

Geohydrology of fractured Crystalline Rocks and Mine Dewatering

Investigations connected with this report have revealed at least four areas of research in which significant contributions could be made to the knowledge of geohydrology.

Apparently very little is known about the interrelationship between rock deformation and metamorphism and the development of secondary porosity in rocks of various compositions. Published research on rock deformation would at least in theory indicate that quite different fracture systems may be developed in siliceous rocks as opposed to carbonate rocks, although interbedded and subjected to the same conditions of pressure and temperature. The implications for differences in ground-water circulation are obvious.

Little is known about fissure and solution networks, their vertical and lateral variations, and the manner in which fluids occur and move within them. Research on the quantitative interrelationship of fissures and solution openings and fluid motion would add to our knowledge of ground-water hydraulics, ore emplacement, and secondary recovery from dolomite petroleum reservoirs.

A wet mine shaft is a unique rock-wall well in which the well remains dewatered at all times during active mine development. Research is needed to quantitatively determine the head losses due to turbulence in the neighborhood of the well and due to convergent flow at the bottom of the well. Quantitative evaluation of the losses would permit analysis of pumped shaft data for determining aquifer coefficients.

The programming of dewatering operations would be greatly helped by a nonequilibrium, quantitative analysis and theoretical analysis of incremental discharge additions due to progressive well development as a result of drifting and crosscutting.

In general, the hydrology of fractured crystalline rocks, although limited in economic importance to small domestic water supplies, mine dewatering, petroleum-reservoir production, and engineering construction, is a wide open field for hydrologic research. The field is difficult, but the benefits to planned environmental control from constructive research may be very rewarding.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

J.H.C.
FEB 14 1964

February 13, 1964

MEMORANDUM FOR MR. J. H. COURTRIGHT

TOMBSTONE DISTRICT
Cochise Co., Arizona

During December, 1963, and January, 1964, I spent a total of about one week checking outcrops in the western part of the Tombstone district for alteration and to determine the extent of alteration that you had previously noted.

Mapping was done on available 1:24000 scale topographic maps in conjunction with an enlargement to the same scale of the geologic map of the area, Plate 5, Professional Paper 281, by James Gilluly. The accompanying map is based on Plate 5, with the geology in some portions generalized, and may be superimposed on the plate as the scales are the same.

The eastern part of the district, where most of the mining has been, was not covered in any detail and consequently the alteration pattern is not shown here. The rocks in this part of the district are generally well exposed and are unaltered except locally along veins. Most of the outcrops west of the San Pedro River (on the west side of the map) are now within the Fort Huachuca Military Reservation and consequently are inaccessible.

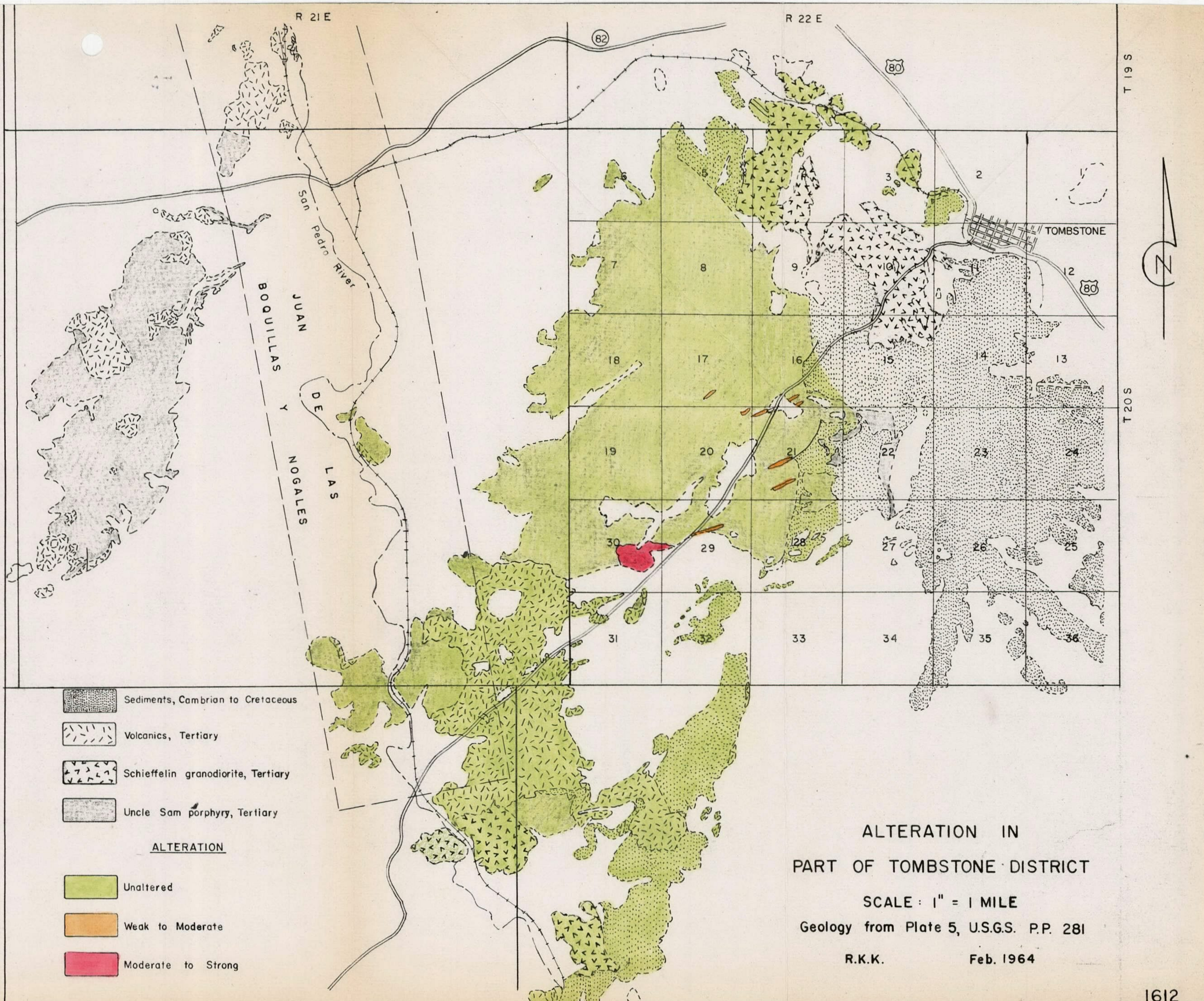
Alteration The alteration that was found in the Tombstone district all occurs in the Uncle Sam porphyry, an intrusive quartz latite porphyry that outcrops in approximately 14 square miles in the western part of the district. Gilluly thought that the main part of the porphyry was intruded as a sill.

The extent and degree of alteration that was found is shown on the accompanying map. The main alteration in Section 30, T. 20 S., R. 22 E., is well exposed for about one half mile along a wash just north of the Tombstone-Sierra Vista road. In this small area the porphyry is closely fractured and pervasively altered to moderate degree. The alteration is principally argillic, although locally there is some sericitic alteration. Limonite after pyrite is present but no "live" limonite after chalcocite or limonite after chalcopyrite was recognized.

The south edge of the alteration zone is covered by alluvium and exploration of the zone in this direction would certainly be justified were it not for the fact that fresh rocks appear again in the next outcrops with a relatively short distance, as shown on the map. In view of the lack of any evidence of copper in the exposed part of the zone, the area of possible alteration under cover is too small to be considered for exploration.

R. K. Kirkpatrick
R. K. Kirkpatrick

RKK:bam
Attached: Map of alteration
Scale 1" = 1 mi.



ALTERATION IN
PART OF TOMBSTONE DISTRICT
SCALE : 1" = 1 MILE
Geology from Plate 5, U.S.G.S. P.P. 281
R.K.K. Feb. 1964