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David A. Moore
CONSULTING GEOLOGIST

EPIGENETIC COPPER ORES

MOAB AREA

UTAH and COLORADO

December 1970

RECOMMENDATION

Two items stand out from the work reported on herein. First is that in the copper "zone" (see Figure II) there are extensive showings of oxidized copper ores. Secondly, a great deal of careful exploration geology should be done before planning any kind of extraction operation. Lastly, the geologic data at hand suggest that exploration for sulfide ores may be well worthwhile.

Along the lines of item two above, there are available air photographs and already compiled photo-geologic maps (Knox-Bergman-Shearer, 1600 Ogden, Denver, Colorado 80218),as well as extensive geologic literature covering the area. There is nothing equal to using these last two items with a lot of good, old fashioned leg-work by competent exploration geologists. Of course, eventually, extensive core-drill and sampling operation will have to be conducted if exploration geology warrants.

There are two complicating factors inherent in the epigenetic copper deposits of the Moab area. First, the biogenic cell does not give rise to a solid ore body, and as such, mining--yes, even stripping costs might be too high to produce a low priced metal such as copper. Secondly, one might gear up for extraction of oxidized ores (as seen on the surface), when actually sulfide ores may turn out to be (with deeper drilling) the biggest ore bodies.

In short, the area is not ready for large-scale mining and extracting of the epigenetic copper ores without a great deal of preliminary exploration geology and drilling.

SYNOPSIS

A field excursion was made and library investigation undertaken concerning the epigenetic copper ores of the Moab district, Utah and Colorado. It appears that the likely source of metallic ions is the San Juan Mountains extrusive and that distribution was controlled to a large extent by the faults and anticlinal folds paralleling the Uncompahgre Uplift, and lying to the southwest thereof. The anticlines caused concentration of reductants (oil and/or gas) necessary for feed stocks of sulfate reducing bacteria. The H_2S waste from the bacteria serves to precipitate as sulfides the metal ions already concentrated by hydrodynamic means, and serves as the prime agent in production of biogenic cells. Faulting is a further aid in biogenic concentration and also possibly to prevent later destructions of the ore bodies. A zonal arrangement was discovered in which metallic ores are deposited in bands responding to Schürmann's Law and the relative solubility of sulfides in water. A brief discussion of the Four Corners area epigenetic ore bodies is also included.

Recommendation is made that extensive field exploration geology be completed before expensive core drilling, mine and mill planning efforts are begun.

EPIGENETIC COPPER ORES

MOAB AREA

UTAH and COLORADO

In September of this year, the writer toured the Moab area for three days, examining the general geology and sites of epigenetic copper deposits. The field trip was followed by extensive re-reading of the geologic literature available, a study of the potential of Schürmann's Law as applied to mineralization found in the district, and an application was made of hydrodynamic theory as it pertains to the loci of sandstone mineralized zones, both faulted and unfaulted.

GENERAL

The abundance of copper mineralization (usually malachite green, with occasional spots of azurite blue) in the Moab area are all confined to two structural relationships: 1) on the flanks of anticlines; and 2) near, or between, faults and fractures. Further, there appears to be a regular zonation of mineralization northwestward from the San Juan Mountains (of Colorado) which, though complicated, offers aid in searching for certain kinds of mineral deposits. Also, hydrodynamic theory ascertains the reason that certain very thick sandstones have ore bodies, as contrasted to the channel-sand theory generally accepted. Finally, the "geochemical cell", or "biogenic cell" approach to the development of ores is discussed.

STRUCTURE

As mentioned above, the location of epigenetic copper ores in the Moab district is always found on the flanks of anticlines and often between or near faults. As is discussed below, a source of reductant and its retention, as well as a source of metal ions, are necessary to develop sulfate reducing bacterial cells for the start of proto-ores (usually called protores) in epigenetic ore deposits. We find ores in the flanks of anticlines because the up-folded structures have been breached by erosion and mineral showings can be easily seen. Serious attention should be given to studying and drilling unbreached anticlines where potential mineralization might be found at shallow depths.

As to there often being faulting (or fracturing) involved in the loci of mineral deposits, hydrodynamic theory states that faulting is a barrier to the smooth flow of subsurface water, creating a zone of low pressure, little to no water movement, permitting the uninterrupted accretion of the biogenic cell, and possibly preventing later leaching of that cell by oxidizing meteoric waters (see Figure I).

Interesting is the structural situation which concentrates the mineralized deposits along the pronounced structural trend lying to the west of, and parallel to, the Uncompahgre Uplift and northwestward from the San Juan Mountains, and along which zonation of mineral deposits are found within that structural trend (see Figure II). It is almost as if the (later) La Sal and other intrusives played

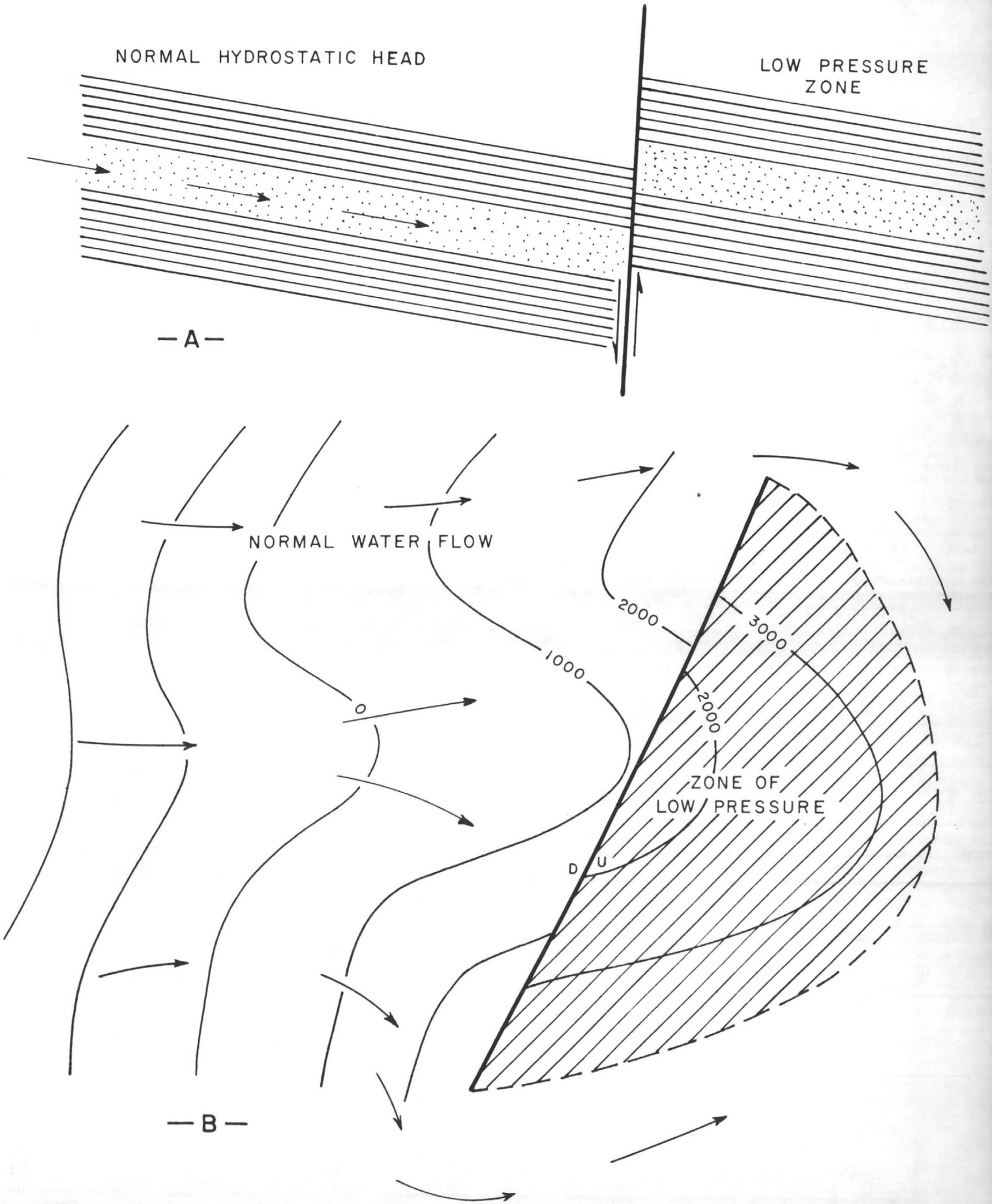

NORMAL HYDROSTATIC HEAD
LOW PRESSURE ZONE
—A—
NORMAL WATER FLOW
0
1000
2000
3000
2000
ZONE OF LOW PRESSURE
D
U
—B—

Figure I

ROCK SPRINGS
WASHAKIE BASIN
OGDEN
SALT LAKE CITY
UINTA UPLIFT
SAND WASH BASIN
TOP OF DAKOTA SANDSTONE
VERNAL
STEAMBOAT SPRINGS
NORTH PARK BASIN
PROVO
UINTA BASIN
Schematic contours
MEEKER
WHITE RIVER UPLIFT
PICEANCE BASIN
PRICE
GRAND JUNCTION
UPHEAVAL DOME
HENRY MTS
MONTICELLO
ABAJO MTS
CIRCLE CLIFFS UPLIFT
MONUMENT UPLIFT
BLANDING BASIN
KAIPAROWITS BASIN
DURANGO
SAN JUAN BASIN
SHIPROCK PLUG
BLACK MESA BASIN
DEFIANCE UPLIFT
EXPLANATION
1 INTRUSIVE PORPHYRIES, VIEN DEPOSITS, (mostly Silver and associated ores)
2 URANIUM - VANADIUM
3 COPPER, MOSTLY
4 MANGANESE

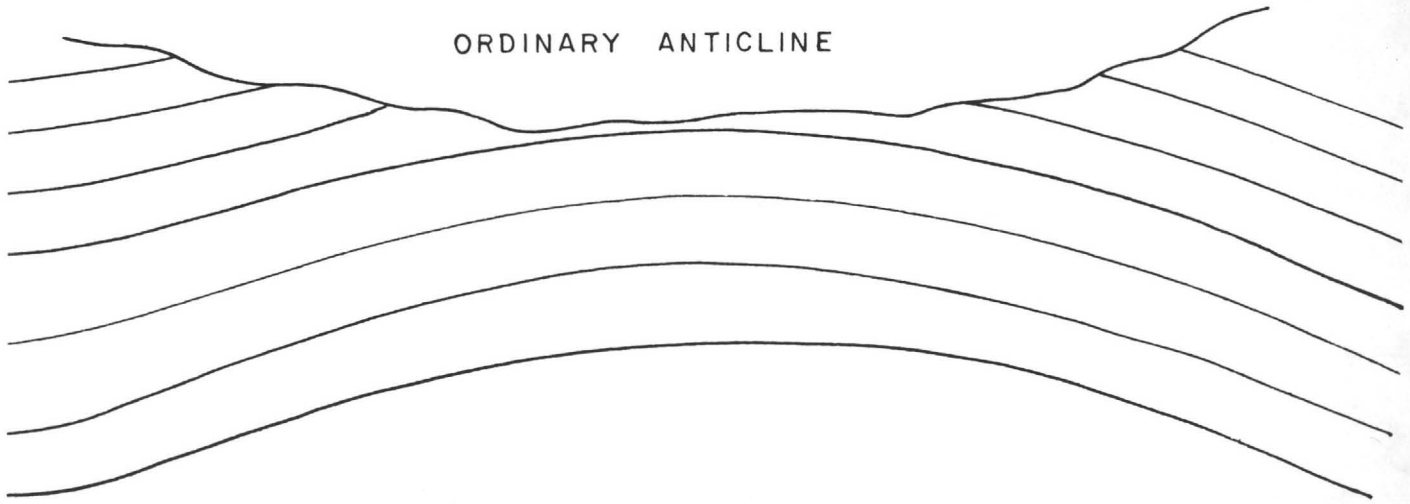
Figure II

little or no part in adding hydrothermal fluids into the system of mineralization. The sketch showing the zonation of mineralization is very much simplified, but it does fit the factors known at the present time (see below, "Schürmann's Law").

A detailed history of tectonics will not be attempted here. Suffice to say that deepseated faults parallel to the Uncompaghre Uplift initiated salt flowage of the Paradox (Pennsylvanian age) formation, which gave rise to the "salt anticline" structures (see Figure III) present northwest and southeast of the Moab district(1). Prior to those anticlines being breached by salt movement and/or erosion they provided loci for the accumulation of hydrocarbons, which in turn, under certain conditions, provided feed-stock for sulfate reducing bacteria whose waste product of H_2S provided the sulfur needed to produce metallic sulfides. Hence, the concentration of epigenetic ores of this area being found on the flanks of (breached) anticlines. Faulting associated (largely) with the collapse features associated with salt-intrusive structures play an important role (as noted above) in the local accumulation and retention of epigenetic ores.

STRATIGRAPHY

A long history of mining for radium, vanadium and uranium has benefited the geology of the area by development of specific, general and correlatable geologic data throughout the eastern Colorado Plateau. There is extensive literature on the thickness and type of deposits known. The metals uranium,


ORDINARY ANTICLINE

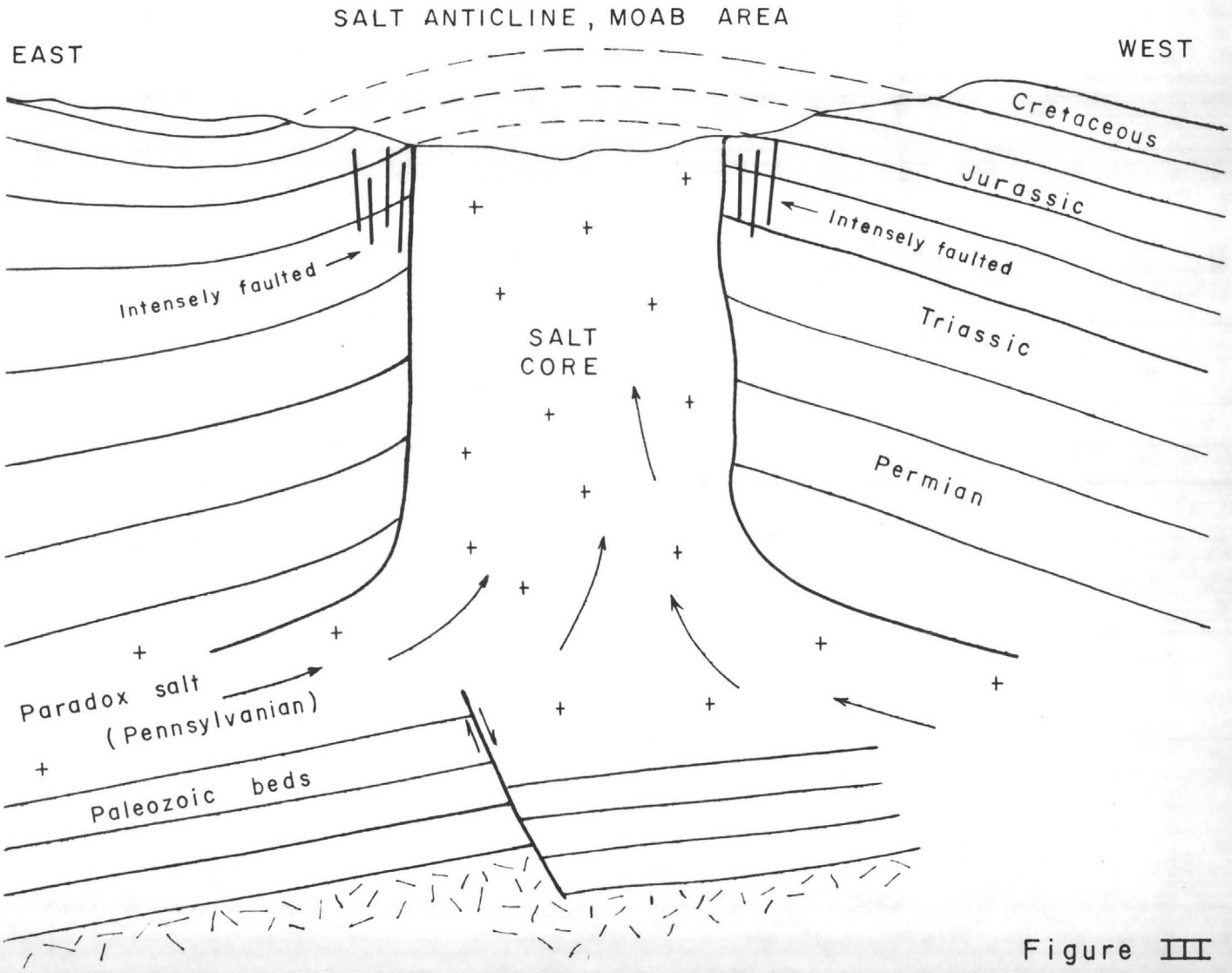

SALT ANTICLINE, MOAB AREA
EAST
WEST
Cretaceous
Jurassic
Triassic
Permian
Intensely faulted
Intensely faulted
SALT
CORE
Paradox salt
(Pennsylvanian)
Paleozoic beds

Figure III

vanadium, copper and manganese have been found, in that order of importance, as epigenetic sandstone ores. Mineable concentrations of minerals have been found in the following important formations, listed in their order of importance:

1) Morrison formation, Jurassic age: Salt Wash and Brushy Basin members.
2) Shinarump formation, Triassic age.
3) Dakota formation, Cretaceous age: Burro Canyon member.
4) Cutler formation, Permian age.

Lesser amounts of ores, some commercial, have also been found in:

1) Glen Canyon Group, Triassic age: Wingate sandstone.
2) San Rafael Group, Jurassic age: Entrada sandstone.
3) Mossback formation, Triassic age.

Numerous other mineralized zones are found in various other formations.

SCHÜRMANN'S LAW

The chemical sequence for the zonal sequence of sulfides is found in Schürmann's Law (1888). According to this law(2), the metals can be arranged in a series, namely, mercury, silver, copper, bismuth, cadmium, lead, zinc, nickel, cobalt, iron and manganese, in which a solution of a salt of any of these metals will be decomposed by the sulfide of any succeeding metal and the first metal will be precipitated as a sulfide. It is interesting to note in tables of sulfide mineral solubility that uranium and vanadium (sulfides of which

are insoluble) will occur at a position ahead of mercury (see above), and most of the other sulfides follow (approximately) as Schürmann's Law states.

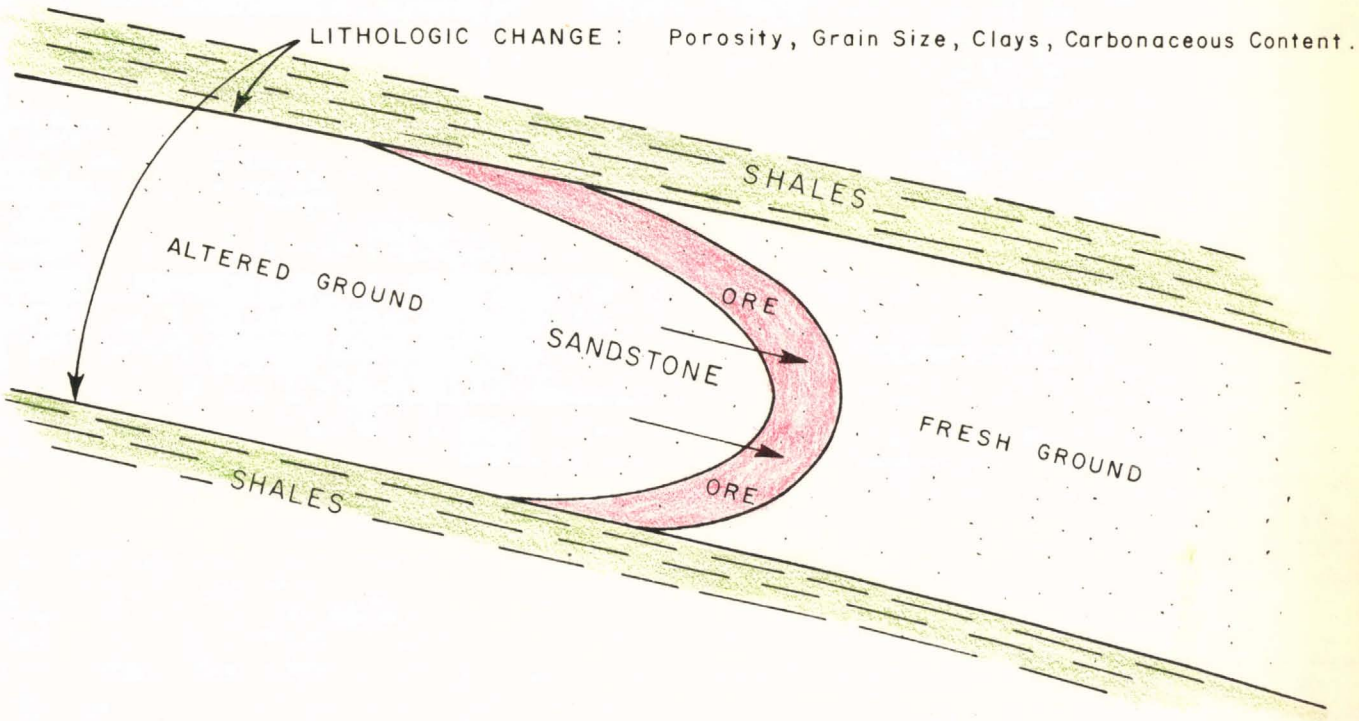
While there are various minor departures from the above zonation, the regional picture northwest of the San Juan intrusives fits the law quite well.

BIOGENIC CELL DEVELOPMENT

Intensive study of the origin and development of epigenetic uranium ores has resulted in much new theory which appears generally applicable to other epigenetic deposits. Briefly, the presence of sulfate-reducing bacteria (in a reducing environment), with a source of hydrocarbons on which the bacteria can feed (gas, oil, carbonaceous materials), tend to create enough excess H_2S (exhaust of the bacteria) to alter soluble mineral salts into (more or less) insoluble sulfides. There is a host of literature on uranium exploring the above ideas (3) (4), and much more needs to be done on other metal deposits.

The areas of precipitated, more or less insoluble sulfides, are called protores, which move with reference to: 1) enclosing host rocks; 2) position of water table (area of reducing zone); 3) source and amount of sulfates available as bacterial feed; and 4) availability of minerals in solution to be converted to sulfides. The shape the ore body assumes is crescentic (called "C" shaped), convex side (generally) pointing down dip (see Figure IV). The classic "C" shape is only occasionally seen in mines, but a rough crescentic shape is clear

BIOGENIC ORE BODY



Changes (alteration) characterize host rock leached by biogenic (ore) cells :

(a) Pore-filling pyrite ("matrix" pyrite) is either destroyed or strongly oxidized by the passage of the cell.

(b) Iron released by destruction of pyrite is combined with oxygen to form hematite and /or limonite thus often imparting a bright, oxidized color (in the subsurface) to altered sands (sometimes at surface as "pink" sands.)

(c) The amount of disseminated carbonaceous material is greatly diminished; often imparting a white, bleached appearance to the host rocks.

Figure IV

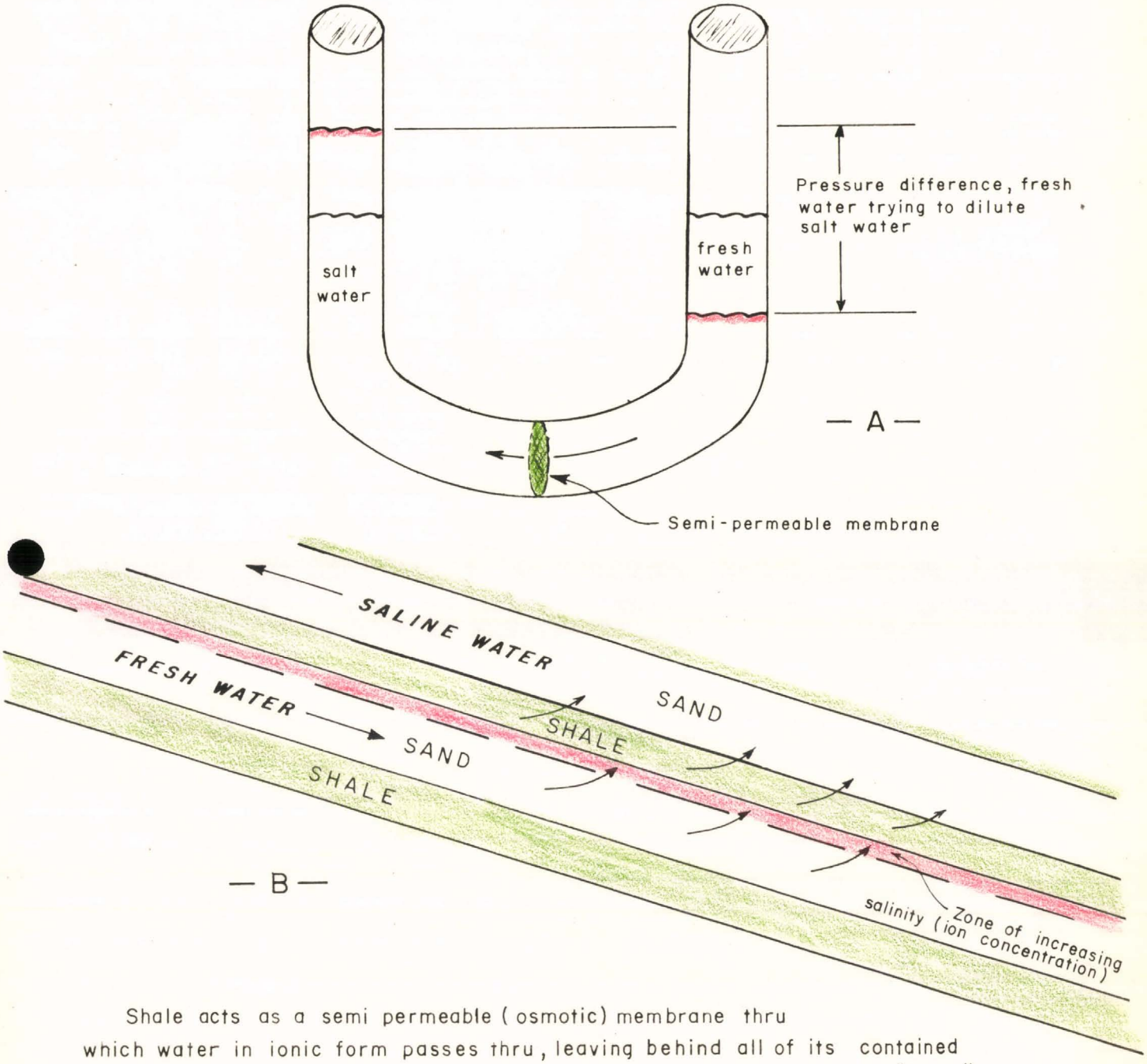
in many deposits, and not only in uranium. In the writer's opinion, the development of "roll front" biogenic ore bodies applies to most, if not all, epigenetic mineral deposits.

The irregular shape of the "biogenic" ore bodies creates serious problems relating to finding out how much ore-grade mineralized material is present (calling for very close spacing in drilling and coring) and also in mining those ore bodies without moving too much waste.

HYDRODYNAMICS

The role of fluid movement in the sub-surface (hydrodynamics) has not yet found expression in literature pertaining to mineral deposits. Hydrodynamics, in the opinion of the writer, play a critical role in concentrating sufficient ions for the development of epigenetic ores, and in thus localizing those ore bodies, prior to their movement by biogenic chemistry (Figures V-A and V-B illuminate the method of ion concentration).

Osmotic membranes can be as thin as the covering on a single cell, or as thick as several thousand feet of shale, with the requirement being that the flow is ionic. In living cells, ionic flow includes nutrients and/or waste. In thick shales the ionic flow includes only water (except very near the shale boundaries). As the ionic flow of water from the (relatively) fresh aquifer to the saline aquifer continues, the dissolved material in the fresh water is left



Shale acts as a semi permeable (osmotic) membrane thru which water in ionic form passes thru, leaving behind all of its contained dissolved salts; until there is a balance between the salinity of the "fresh" water sand and the saline water sand.

Figure V

behind. Eventually, a thermodynamic equilibrium is reached wherein the previously fresh water contains so much dissolved material that its salinity is similar to that saline aquifer toward which the water flow is directed. If the low salinity water contains enough metallic ions, it will be possible for epigenetic ores to be localized at the boundaries of the semi-permeable membrane. Hydrodynamic flow around faults causing further loci of epigenetic ores is explained above (see Figure I).

Although the concentration of ions outlined above is important, of equal significance is the then development of biogenic cells which serve to further concentrate the protores, and move those ore bodies about in response to the availability of a reductant source and the position of the water table (oxidation-reduction potential). All of the above becomes very complicated, but does serve, along with detailed knowledge of the geologic history, to sift the data for areas which are promising sites for commercial ore deposition and retention.

SUMMARY OF FORMATION OF ORES

To try to summarize all of the data combined from the discussions above runs the risk of being too simplistic. However, here is a step-by-step presentation of the available data.

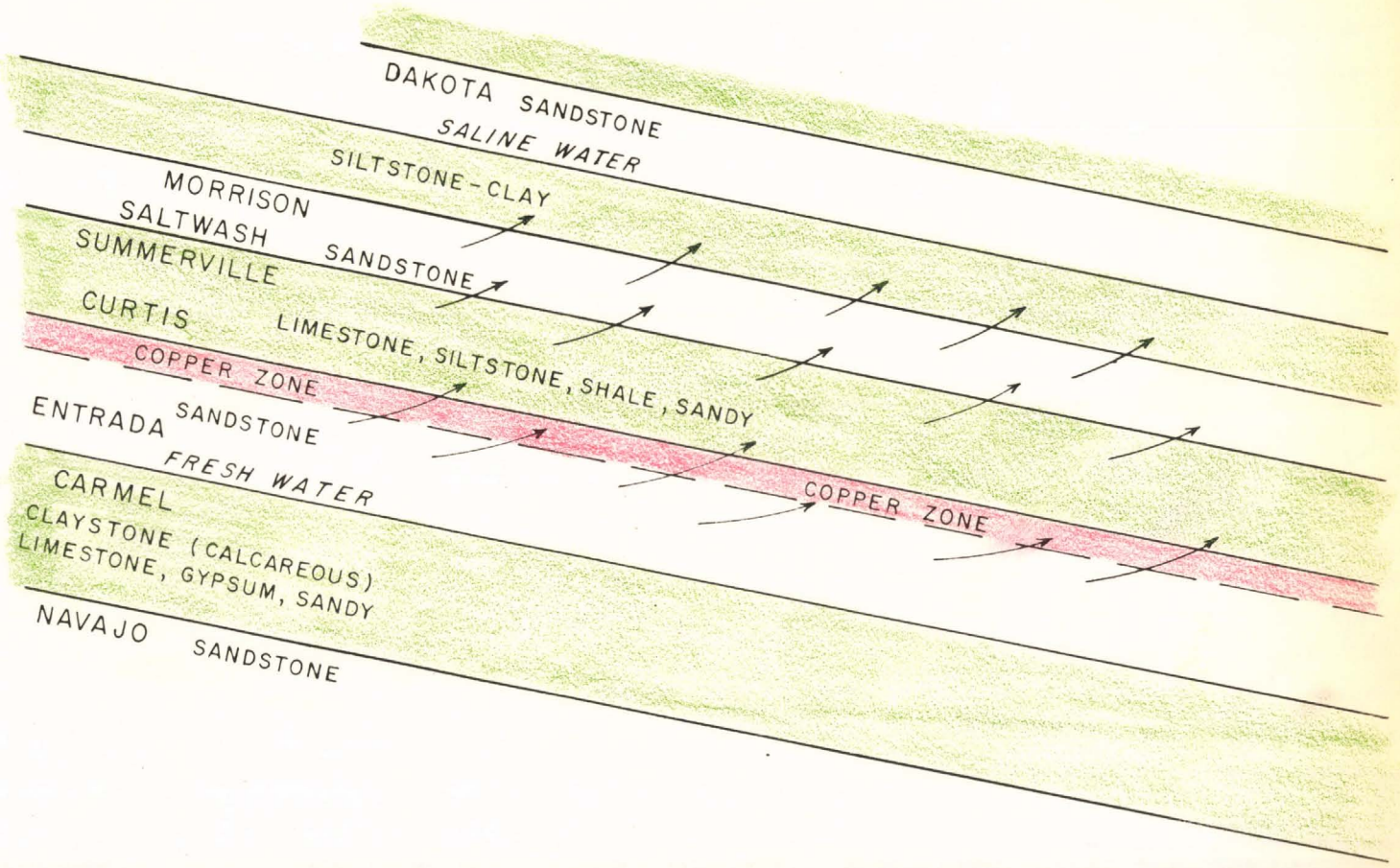
1) The source of the hydrothermal fluids from which the ores came appears to have been the San Juan Mountains intrusives. Those fluids on being introduced into aquifers became dilute, and are translated into epigenetic deposits by the concentrating mechanisms of hydrodynamics and biogenic cell development.

2) Regional tilt of the area to the north until very late in Tertiary time caused a northerly, down dip flow of waters through the aquifers.

3) The anticlinal trends of the area parallel to the Uncompahgre Uplift provided avenues for the collection and retention of reductants (oil or gas) which are feed-stock for sulfate reducing bacteria.

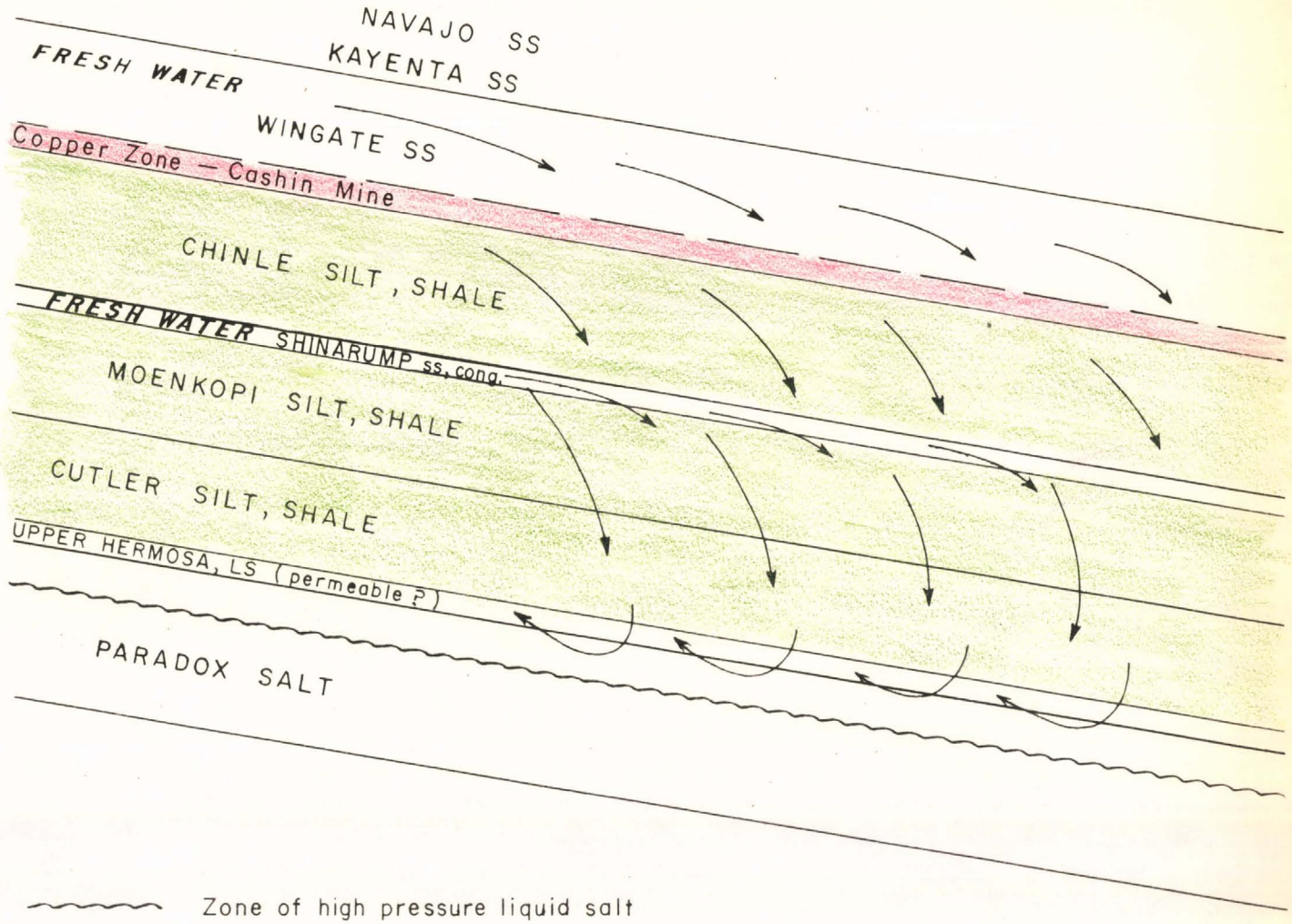
4) Cross-formational, ionic water flow upward from the Entrada and subjacent sands into the more saline basal Cretaceous (Dakota formation) provided local concentration of metallic and other ions in the Entrada, Brushy Basin, etc., sands (see Figure VI). Downward flow from the Wingate and superjacent sands, and also from and through the Shinarump conglomerate, toward the Paradox salt (see Figure VII), provided other zones of concentration of metallic ions. (It can be further shown that many " channel deposits" are derived from the same hydrodynamic means of concentration as here explained, but do not apply at this time to the search for copper).

5) The combination of anticlinal and fault-controlled water flowage, anticlinal concentration of reductants and the hydrodynamic concentration of



Possible initiating mechanism for the uppermost Entrada sandstone (about 60'-80' thick) receving a host of ions left as fresh water passes (upward) thru the Summerville-Curtis semi-permeable, (osmotic) membrane to dilute the salt water of the Dakota sandstone.

Figure VI



Zone of high pressure liquid salt

Position at base of Wingate ss of Cashin mine copper

Membrane shales

Copper shows at the Cashin Mine, Montrose County, Colorado occur only in the lower part of the Wingate Sandstone, with no copper shows in the superjacent Kayenta and Navajo sands. The Shinarump conglomerate is sometimes present and often absent (it is reported to contain commercial copper near Mineral Point, due West of Moab, Utah.)

Figure VII

metal (and other) ions created loci for the development of biogenic cells, culminating in many instances in ore-grade concentrations of certain metals.

6) A zonation of metallic sulfide ore deposition developed which follows Schürmann's Law of metallic sulfide precipitation and the relative solubility of the various metal sulfides.

7) Faulting associated with anticlinal growth and collapse was also instrumental in further localization and retention of sulfide ores.

8) Very late (Middle Pliocene?) Tertiary epeirogeny and resulting severe folding and faulting has altered the position of some ores, caused some to become oxidized, and probably destroyed a great many ore bodies. Further, the erosion resulting from the uplift has exposed many ore bodies thus leading to their being found and exploited.

FOUR CORNERS EPIGENETIC ORE DEPOSITS

There is a complication introduced into the above statements (see SUMMARY) about the formation of epigenetic ore bodies, from about the Four Corners area into the south. From that point southward, there was in latest Jurassic-early Cretaceous time a great uplift, relicts of which are the Zuni (Gallup) uplift, the Naciemento uplift, the Chuska Mountains uplift, etc. The erosion of a vast amount of sediment with the soluble minerals flowing outward from the uplift created many opportunities for concentrations of

epigenetic minerals, all contemporaneous, or nearly so, and in a variety of aquifers and localities (see Figure VIII).

In northern Arizona and New Mexico, and in southeastern Utah and southwestern Colorado, the contemporaneously deposited epigenetic ores impinge on the areas in which ores from other sources (principally the San Juan Mountains sources) are deposited. In any attempt to locate epigenetic ores in this area, one should be aware of the complications involved, and also be cognizant of the vast source for those ores, and the possibility of their being very large.

The above is an aside from looking at copper ores in the Moab area, but came out of digging into the general geology of the region, and particularly the geologic history.

REFERENCES

(1) Four Corners Geological Society Guidebook, "Geology of the Paradox Fold and Fault Belt". Third Annual Field Conference, 1960. Articles by Budd, Maret and Coe, Robeck.

(2) Garlick, W. G., 1961. "Geology of Northern Rhodesian Copper Belt", editor F. Mendelsohn. See pages 154-155.

(3) Rackley, R. I., et al, 1968. "Concepts and Methods of Uranium Exploration", Wyoming Geological Association Guidebook, Black Hills Area.

(4) Contributions to Geology, University of Wyoming, "Stratigraphic Control of Sandstone Uranium Deposits in Wyoming", Vol. 8, No. 2, Part 1, 1969. See articles by Bailey, Melin, Renfro, and Webb.

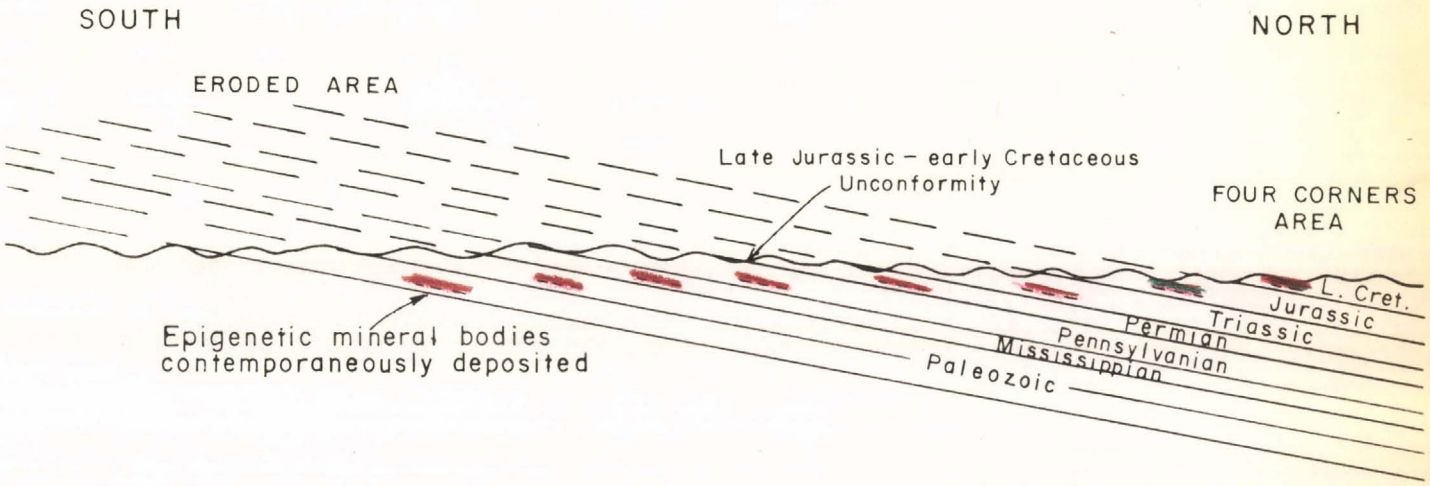

SOUTH
NORTH
ERODED AREA
Late Jurassic – early Cretaceous
Unconformity
FOUR CORNERS
AREA
L. Cret.
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Paleozoic
Epigenetic mineral bodies
contemporaneously deposited

Figure VIII

David A. Moore
CONSULTING GEOLOGIST
1285 South Jay, Denver, Colorado 80226

December 11, 1970

SXM
DEC 14 1970
RECEIVED

Mr. Howard Lanier, Manager
Essex International, Inc.
1704 West Grant Road
Tucson, Arizona 85705

Re: Sedimentary Copper Prospect

Dear Howard:

The other day when we were meeting in Tucson you asked that I write a note regarding new ideas for exploration of a potentially large syngenetic copper prospect on which I have been working.

Since there has been oil prospecting in the area, it seems feasible to drill 45 to 50 holes, instead of the ten holes outlined in my letter of May 23rd, last, and pretend it is petroleum-oriented stratigraphy we are studying. The area is quiet from any exploration standpoint, and I think it will be possible to obtain drilling permits for the drill holes, rather than leases, drill the holes about three miles apart, catch samples at two foot intervals, then run atomic absorption on the samples (about 75¢/sample). The holes will be about 60 feet deep. There are three unconformities involved, and about 16 holes will test each one. Obtaining the permits (about $25 to each landowner) and paying the broker, drilling and logging the holes, having a permit man on the job to keep the ranchers happy (mostly fee lands in here), having a geologist describe and correlate the sample (and log) data, running the samples through a lab for copper determination can be done in five or six weeks, at a total cost of about $60,000.

If some potentially mineable showings of copper are found, we could put several brokers to work to obtain options (probably 10¢/acre, or $25/option) for six months, on the area (or areas) which look promising, and then do such detailed drilling and coring as seems indicated from the previous work. Obtaining options in this second phase, drilling, coring and logging of perhaps 25 to 50 core holes will probably run around $100,000 per area taken up by option.

The targets we are shooting at are major. The expected type of target would be a copper-bearing shale eight to twelve inches thick, averaging 3% (+) copper, strippable to four miles wide, and being fifteen miles long, or longer. Such a copper deposit would recover about 50,000 tons of copper per section (640 acres) of land, worth about $50 million on today's market (copper 50¢/lb.). An investment of $40 - $50 million would extract three sections of land per year, for a gross income of $150 million, payout in a year or so, and have a life expectancy of twenty years or more. Further, it is anticipated that because the project involves inexpensive stripping (as compared to a pit) and because the ore is a simple sulfide (chalcocite), which is inexpensive to concentrate and extract, the cost per pound of copper should be as low as any produced anywhere.

Respectfully submitted,

D. A. Moore

DAM:hgb