PART 2. CASE HISTORIES OF DISCOVERIES [1]

by

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The period following World War II has seen a wave of porphyry copper discoveries in the Southwest with the bulk of these deposits having been found in southern Arizona. The attached tabulation of several selected features of each discovery has been prepared in an attempt to point up changes in techniques over this 33-year period, together with changes in the typical settings of deposits found.

A discussion of discoveries is always a subjective matter from the standpoint of who was responsible and which technique was responsible for the discovery. There are invariably rival claimants, however, the discovery typically results from a team effort of several different geologists, supported at different levels of management, sometimes aided by geophysists and geochemists, and often basing their work on regional geologic mapping, or stratigraphic or tectonic relationships worked out by geologists in government agencies. Peter Joralemon has pointed out in a recent paper that the contribution of prospectors or engineers or metallurgists is also the significant factor in many discoveries.

During the 33-year period covered by the tabulation (Table 1) fundamental changes have occurred in the parameters for porphyry copper exploration in the Southwest which are reflected to some extent in the tabulation. The most obvious change is the fact that, for practical purposes, all of the deposits have now been found in which the orebody, or the leached capping after ore, crops out. The deposits remaining to be found are those either completely covered by postmineral formations, or overlain by non-ore, premineral rocks, either in fault contact with ore or related to ore through vertical or lateral zoning relationships. Future discoveries will require greater use of indirect techniques—geologic projection, and geochemical and geophysical work, and perhaps most important, more exploration drilling per discovery, both in number of holes and average depth of holes. In a paper at the 1976 Annual AIME Meeting Schultz and Spat pointed out that the drilling cost per discovery has risen rapidly for the past several years.

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Another factor which may loom larger than any other in the future is the question of the basic economics of porphyry copper mining in the Southwest. The price of copper in constant dollars diminished progressively during the period of 4000 B.C. to 1933, and then began to progressively increase. At the same time the minimum grade of ore which it was possible to mine progressively decreased from ancient times until the date of the most recent recession and the Middle East oil boycott and world energy crisis. Since that time the minimum minable ore grade has increased in both bulk underground, and open-pit copper mines. This trend could, of course, be reversed by a substantial increase in the price of copper, but this magnitude of increase is far from certain during the next few years. Most previous porphyry copper discoveries in the Southwest have been deposits which could be exploited as open pits. Most future discoveries will be potential underground mines, or in situ leaching situations. The ore habit in the Southwest favors deposits whose overall grade is less than 0.8% Cu. The San Manuel mine whose grade is about 0.72% Cu and 0.015% Mo could be taken as an example of the best type of deep, undiscovered deposit, which we are likely to find in the future. However, using current mining costs and present copper price a newly discovered, undeveloped San Manuel would not be a viable orebody. A copper grade of 0.9%-1.0% Cu, or a copper price of over $1.00 per pound would be required to make this hypothetical example a viable deposit. The increase in copper price is much more likely than finding the 1% plus copper deposit. If the price increase does not occur there will be few, if any, future discoveries of viable orebodies in the Southwest. Another effect of this factor is that there may be no longer be a tendency for known deposits to evolve into orebodies.

Exploration techniques which have been most successful in the Southwest have, as indicated by the tabulation, been geologic mapping and geologic interpretation, and leached capping interpretation. Geochemical and geophysical surveys have been of assistance in some discovery—the Pima orebody. Neither geochemical nor IP geophysical techniques are as effective in the Southwest as in western Canada and most other porphyry districts, because basin-range faulting has resulted in deep, postmineral valley fill; transported rath-

Table 1. United States tabulation of Southwest porphyry copper discoveries [1]

Porphyry Copper Deposit	Date(s) Discovered	Published or Estimated Tonnage And Grade Prior To Production[2]	Distance from Known Porphyry Copper When Discovered	Percent Outcrop of Ore Body or of Ore Leached Capping	Percent Post Ore Cover Over Ore Body	Geochemical Anomaly Useful In Outlining Ore Body	Geophysical Anomaly Useful in Outlining Ore Body
(1) San Manuel, Arizona	1917/1943	457,000,000 T 0.75 Cu	40 miles	± 5	± 95	Yes	Not used
(2) Safford-KCC, Arizona	1947/1955	500,000,000 T(+) 0.5(+) Cu	20 miles	30(?)	70(?)	Yes	Probably (IP)
(3) Tyrone, New Mexico	1920's/1950	±400,000,000 T 0.7 Cu	60 miles	±100	± 0	Yes	Probably not
(4) Pima, Arizona	1951	3,000,000 T(?) 0.5 Cu(?)	+60 miles	0	100	No	Yes (Magnetic)
(5) King Peak-Metcalf, Ariz.	1865/1952	±400,000,000 T(?) ±0.75 Cu(?)	1 mile	±100	± 0	Yes	Not used
(6) Imperial-Silver Bell, Ariz.	1909/1954	30,000,000 T(?) 0.75 Cu(?)	½ mile	± 10(?)	± 5	No	No
(7) Mission, Arizona	1954	200,000,000 T(+) ±0.75 Cu	1 mile	0	100	No	Uncertain
(8) San Xavier North, Ariz.	1955/1957	100,000,000 T(+) 0.5(+) Cu	2 miles	1(?)	99	No	Probably not
(9) Esperanza, Arizona	1955	150,000,000 T 0.68 Cu equiv.	8 miles	100	0	Yes	Uncertain (IP)
(10) Christmas, Arizona	1870/± 1955	100,000,000 T(+) 0.4(+) Cu	15 miles	± 40	± 60	Yes	Uncertain (IP)
(11) Twin Buttes, Arizona	1957/1963	530,000,000 T(?) ±0.70 Cu	5 miles	0	100	No	Mag. trend hlpfl.
(12) Dos Pobres (P.D.), Safford, Arizona	1957	400,000,000 T(+) (?) 0.72 Cu(?)	±3 miles	± 25	± 75	Yes	Yes (IP)
(13) Ithica Peak, Arizona	1959	175,000,000 0.53 Cu	90 miles	±100	± 0	Yes	Possibly (IP)
(14) Sierrita, Arizona	1960/1963	±450,000,000 0.45 Cu equiv.	1½ miles	± 90	± 10	Yes	Probably (IP)
(15) East Helvetia (Rosemont), Arizona	1961	200,000,000 T(+) 0.7 Cu (?)	15 miles	± 10(?)	± 30(?)	Yes	Possibly (IP)
(16) Sacaton, Arizona	1961	±50,000,000 T 0.8(+) Cu	15 miles	0	100	No	No
(17) Battle Mtn., Nevada	1869/1961	50,000,000 T(+) 0.5(+) Cu	145 miles	±100	± 0	Probably	Uncertain
(18) Kalamazoo, Arizona	1965	500,000,000 T(+) 0.73 Cu	½ mile	0	± 50	Yes	Not used
(19) Vekol, Arizona	1965	75,000,000 T(?) 0.5(+) Cu(?)	±30 miles	0	90	No	Uncertain (IP)
(20) Copper Creek, Arizona	1966	50,000,000 T(+) (?) 0.7(+) Cu(?)	15 miles	0	0	No	Probably not (IP)
(21) Caridad, Mexico	1967	600,000,000 T 0.8 Cu	70 miles	100	0	Uncertain	Uncertain(IP)
(22) Copper Basin, Arizona	1920/1968	100,000,000 T(+) ±0.6 Cu eq.	35 miles	± 70	± 30	Yes	Probably (IP)
(23) Lakeshore, Arizona	1955/1968	472,000,000 T 0.76 Cu(?)	10 miles	± 10	± 90	Probably	Uncertain (IP)
(24) Poston Butte-Florence, Az.	1961/1970	400,000,000 T(?) 0.45 Cu(?)	±25 miles	0	100	No	Probably not (IP)
(25) Red Mountain, Ariz.	1970	ND	30 miles	0	0	Yes	No
(26) Hillsborough, N.M.	1930/1975	70,000,000 T(?) 0.7 Cu(?)	±40 miles	60	40	Yes	Uncertain (IP)

1. Includes Caridad (No. 21) in Mexico. 2. (?) Indicates uncertain data with only order-of-magnitude accuracy.

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Table 1. United States tabulation of Southwest porphyry copper discoveries—continued

Apparent Discovery Method	Porphyry Copper Deposit	
Geologic mapping and structural interpretation indicated that a small outcrop could expand downward into a large orebody	San Manuel, Arizona	(1)
Geologic mapping and interpretation of peripheral hydrothermal effects encouraged testing through postore volcanics	Safford-KCC, Arizona	(2)
Sampling and leached capping study. An old, higher grade underground mine evolved into a bulk low grade open pit	Tyrone, New Mexico	(3)
Geophysical survey on geologic projection located high magnetite skarn under postmineral gravel	Pima, Arizona	(4)
Leached capping interpretation and sampling indicated chalcocite orebody	King Peak-Metcalf, Arizona	(5)
Geologic interpretation and research of old mine records indicated possible hidden orebody	Imperial-Silver Bell, Arizona	(6)
Geologic interpretation and research of nearby mine openings and outcrop indicated possible extension of zone of alteration-mineralization at Pima	Mission, Arizona	(7)
Aerial reconnaissance located small outcrop of leached capping, and orebody found with offset drilling	San Xavier North, Arizona	(8)
Geologic mapping and leached capping study	Esperanza, Arizona	(9)
Sampling and geologic interpretation of old mineral prospect	Christmas, Arizona	(10)
Geologic interpretation based partly on magnetics, followed by wide-spaced offset drilling	Twin Buttes, Arizona	(11)
Geologic and leached capping interpretation of unusual outcrop and geochemical survey	Dos Pobres (P.D.), Safford, Arizona	(12)
Geologic and leached capping interpretation of old mineral prospect	Ithica Peak, Arizona	(13)
Geologic mapping and test drilling—old prospect evolved into orebody in part due to shifting economics	Sierrita, Arizona	(14)
Geologic and leached capping interpretation of old mineral prospect	East Helvetia (Rosemont), Arizona	(15)
Geologic reconnaissance program located small outcrop interpreted to be pyritic capping peripheral to orebody	Sacaton, Arizona	(16)
Old deposit which evolved into an orebody with geologic mapping, drilling and improvement in economics	Battle Mtn., Nevada	(17)
Geologic mapping and interpretation of structure and concentric zoning	Kalamazoo, Arizona	(18)
Geologic mapping and IP survey	Vekol, Arizona	(19)
Geologic interpretation of surface geology and re-interpretation of previous drilling	Copper Creek, Arizona	(20)
Leached capping and geologic interpretation	Caridad, Mexico	(21)
Geologic mapping and test drilling. Old prospect evolved into orebody	Copper Basin, Arizona	(22)
Geologic mapping and drilling done near fault segment orebody. Also IP survey	Lakeshore, Arizona	(23)
Geologic interpretation of peripheral outcrops followed by wide-space offset drilling	Poston Butte-Florence, Arizona	(24)
Geologic interpretation of vertical zoning followed by deep drilling	Red Mountain, Arizona	(25)
Geologic interpretation of previous drill data	Hillsborough, New Mexico	(26)

er than residual soils; and typically thick leached and oxidized zones which do not give an IP response. Both the IP and geochemical methods are best suited to a British Columbia environment of near-surface sulfides and shallow cover. As Southwest exploration progresses into deeper and deeper postmineral cover these methods will also tend to become less effective unless new and more reliable techniques can be developed.

The tabulation of discoveries indicates that seven of the last eleven deposits were essentially completely covered (one, Lakeshore, had 10 percent outcrop), and that since 1960, seven of the ten discoveries in Arizona have been completely covered. The percentage of covered discoveries is certain to increase in the future.

Reviewing some of the other factors on the tabulation we see that there were ten deposits discovered in the period 1943-1955, nine deposits discovered from 1955-1965, and seven deposits discovered after 1965. This suggests a progressive decrease in the success rate. It should be noted that many of the deposits have multiple discovery dates which reflect an earlier intersection of the mineralized body, and a later decision that it may represent a minable deposit—often by a different company. There seems to be no consistent variation in size of the deposits through the 33-year period, nor is there a noticeable change in the distance from a known porphyry. As mentioned, the amount of postmineral cover over discoveries has progressively increased through the period. Geochemical surveys appear to have been somewhat more useful than geophysical surveys, although geochemistry has never been the principal factor in a discovery as was the case for the Pima magnetometer survey. Geophysical surveys also have had some useful depth-of-cover and groundwater applications.

It's interesting to note that one orebody was found in an old company file cabinet, and one deposit was found by a re-interpretation of old drill data. Zoning interpretations and offset drilling are mentioned more frequently toward the bottom of the table as no more ore outcrops remain to be tested. Also almost every deposit was specifically discovered by a drill hole—whether drilled for the right reason or the wrong reason. There would have been very few discoveries without the drill rig, and the programs which never progressed from the "think stage" to the "drilling stage" were invariably doomed to failure.

It would perhaps be useful to select three deposits representative of the three decades covered by the tabulation and describe each to illustrate changes in settings and in successful exploration techniques over this period.

The first example is King Peak—Metcalf, immediately east of the Morenci—Clay orebody. This exploration target was identified in a careful and accurately interpreted leached capping study completed in 1952, and the first exploration hole intersected ore. The pre-discovery drilling cost of the project was very low. Tyrone would be a similar example, but no targets of this type now remain untested in the United States, although there may still be a few in Latin America and Iran and Pakistan.

The second example is the Sacaton deposit found near Casa Grande, Arizona in 1961. This discovery was one of several Asarco finds which resulted from a comprehensive district-wide program of geologic mapping in southern Arizona of features related to porphyry copper mineralization. This regional work tended to bridge the gap between theoretical and applied geology, particularly in the areas of stratigraphic and structural interpretation. Several holes at Sacaton were initially drilled as offsets around a small outcrop identified as being pyritic, but probably porphyry-copper-related, leached capping, before ore was intersected. Many additional drill holes were required before a viable orebody was confirmed, and the overall ratio of development drill footage to tons of ore developed was also high.

The third example is the Red Mountain deposit near Patagonia, Arizona, discovered in 1970, and described in a recent Economic Geology paper by Russ Corn. This is the deepest porphyry which has so far been found. It is in an area of premineral outcrop where shallow, sub-commercial mineral deposits have been known for many years. Discovery of the deep deposit resulted from persistent and thoughtful exploration to progressively deeper depths over a period of 12 years. The key to the discovery was vertical hydrothermal zoning theory. The pre-discovery driling expense was very large, and post-discovery drilling and development expense will be very large.

The conclusion from this review must be that deposits are becoming harder and more expensive to find. Most of our exploration tools become less effective with increase in thickness of postmineral cover. Recent shifts in copper economics have been a further obstacle; however, copper exploration, like the copper market, has always been a cyclic field, and many additional deposits remain under the Tertiary gravel and volcanics which will probably be discovered in the next 30-year period.