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POTENTIAL GEOTHERMAL RESOURCES IN ARIZONA

*by Claudia Stone**

GEOTHERMAL ASSESSMENT PROGRAM AND ACCOMPLISHMENTS

A five-year program to locate and evaluate the potential geothermal energy resources in Arizona was brought to completion in 1982 and results were summarized in a comprehensive final report. The U.S. Department of Energy (DOE), Division of Geothermal Energy, was the principal funding agency although additional funds were received from the U.S. Department of Interior, Bureau of Reclamation, during two of the years the program was in existence. All funding for the program was awarded to the University of Arizona, Bureau of Geology and Mineral Technology.

Several publications and numerous unpublished technical reports and maps were produced by program personnel. Hahman, Stone, and Witcher (1978) compiled the preliminary geothermal indicators known to that time on a 1:1,000,000-scale map, "Geothermal Energy Resources of Arizona". Four years later this map was updated to include information generated during the intervening years. This 1:500,000-scale map, "Geothermal Resources of Arizona" (Witcher, Stone, and Hahman, 1982), depicts identified and suspected geothermal occurrences in Arizona. Figure 1. Compiled and interpreted

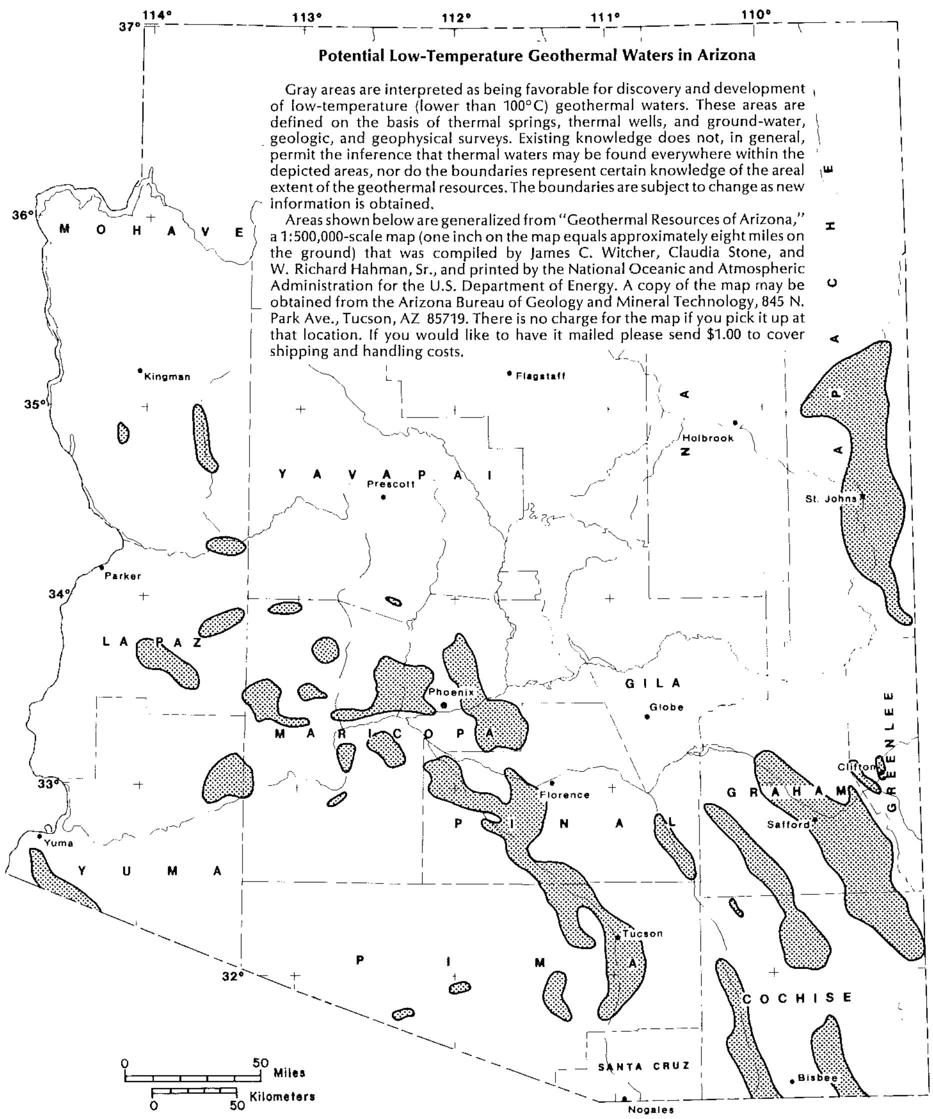

Figure 1. Potential low-temperature geothermal waters in Arizona.

*Claudia Stone worked on the Bureau's geothermal program from start to finish. She began in 1977, shortly after receiving a Master's degree in geology and geophysics from the University of Hawaii, and was promoted to project manager in 1981 with the responsibility for bringing the project to completion. Ms. Stone is now a consulting geologist and principal in Stone and Associates in Sacramento, California.

by the authors, the map was printed by the National Oceanic and Atmospheric Administration for the DOE as part of their State-Coupled Program. A bibliography of geothermal and related research in Arizona was compiled by Calvo (1982) and published by the Arizona Bureau of Geology and Mineral Technology. The final report to the DOE (Stone and Witcher, 1982) summarizes the nature of potential geothermal resources in Arizona, the thermal regime of the state, the principal geothermal anomalies studied, and exploration methods used. All reports, maps, and area assessments have been placed in the Bureau's open-file series and are available for examination or purchase. A complete list of maps and reports in the open-file series was included in the Summer 1983 issue of *Fieldnotes,* the Bureau's newsletter.

Reconnaissance exploration during the geothermal program was used to identify more than 15 areas in Arizona where low- to moderate-temperature geothermal fluids (to about 140°C) are known or believed to occur at depths shallow enough to make them useful as alternate sources of energy. Not all parts of the state were assessed with equal intensity, however. For reasons of accessibility, limited manpower, and proximity to major population centers, exploration generally was concentrated in southeastern Arizona. Thus, the largest number of potential geothermal resource areas were identified there. Other geothermal anomalies may exist in parts of Arizona that were not studied during this program.

POTENTIAL GEOTHERMAL RESOURCES IN SOUTHERN ARIZONA

Southern Arizona is in the Basin and Range province (Figure 2), where deep sediment-filled basins are separated by generally high, broad mountain ranges. Because temperatures normally increase with depth in the earth, temperatures in the deeper basins are high and deeply circulating ground water becomes quite warm. A basin 1500 m deep could produce water with temperatures as high as 70°C. A 4000 m basin could contain 140°C water.

Many basins in southern Arizona have different geologic conditions, a situation that leads to a variety of cold, warm, and hot water occurrences. In some basins, water movement may be hindered by impermeable clay layers or structural barriers to circulation, and the water in these basins will remain cool. Some basins are not deep enough to have high temperatures so the ground water remains cool even if there is unrestricted circulation. In other basins, ground water lies at great enough depths to be naturally heated without a hydrothermal convection system. Sufficiently deep wells will encounter these fluids. If it is under artesian pressure, the water will rise in the well bore and may flow at the surface. Numerous such thermal artesian wells are present in the San Simon Valley, for example. In still other basins, geologic conditions enable a natural hydrothermal convection system to become established. The circulating hot water rises toward the surface, usually along a fault plane; if it leaks out, thermal springs develop.

Witcher (1981b) identified 20 hot springs and 25 warm springs in Arizona. The hottest springs are in Greenlee County, southeastern Arizona. Gillard Hot Springs discharges 84°C water and Clifton Hot Springs, 70°C water.

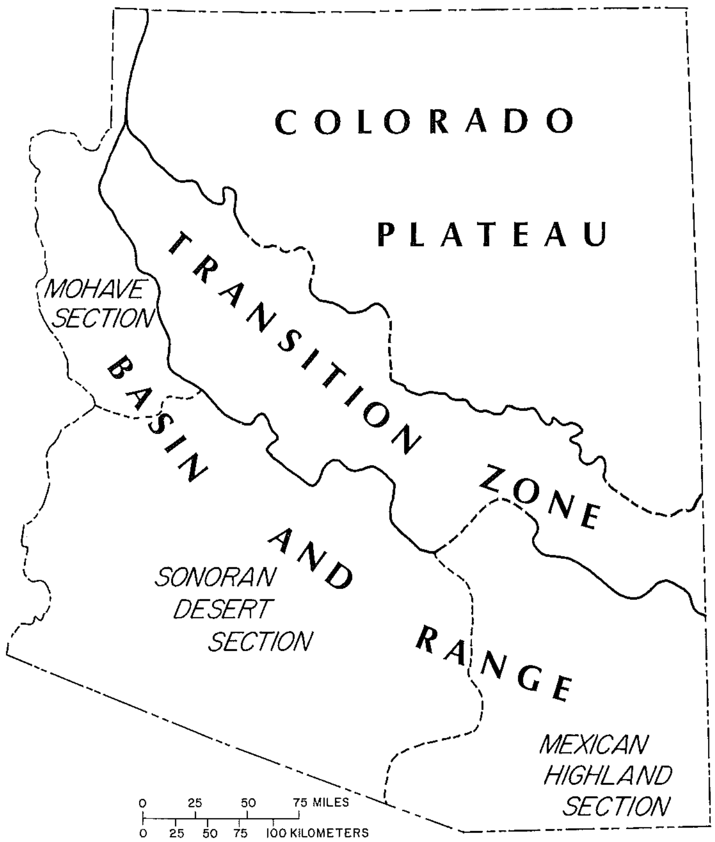

Figure 2. Physiographic provinces and subprovinces of Arizona.

Reconnaissance studies in this region (Witcher, 1981a; Witcher and Stone, 1980, 1981), however, suggest that temperatures at depth may be as high as 160°C at Clifton and 140°C at Gillard. Ross and Farrar (1980) showed that hot springs in Verde Valley, which have discharge temperatures as warm as 39°C, may have reservoir temperatures greater than 100°C. In a detailed study of Clifton Hot Springs, Witcher and Stone (1980) concluded that two processes prevent the hot reservoir fluids from reaching the surface with their initial temperature. As the fluids rise toward the surface (1) the thermal water mixes with cold, shallow ground water, and (2) the hot water loses heat to the enclosing country rock. One or both of these processes probably operate at Gillard Hot Springs, as well as at other hot springs in Arizona and elsewhere. Thus, the temperature of a thermal spring may or may not represent the maximum water temperature at depth.

Other areas in southeastern Arizona that have geothermal anomalies, some of which are associated with warm artesian wells rather than hot springs, are listed in Table 1. The thermal water in most of these reservoirs is contained in coarse-grained sands and gravels confined beneath impermeable beds of clay and silt.

Low- to moderate-temperature geothermal waters are present in numerous other parts of southern Arizona (Witcher, Stone, and Hahman, 1982). Witcher (1982) concluded that geothermal fluids beneath Tucson occur in a deep aquifer (greater than 500 m depth) that is apparently confined and hydrologically separate from the shallow aquifers (less than 200 m depth) that provide drinking water for the Tucson metropolitan area. The shallow

TABLE 1. SELECTED GEOTHERMAL AREAS IN SOUTHEASTERN ARIZONA

Area Name	Maximum Measured Temperature (Degrees C)	Estimated Reservoir Temperature (Degrees C)
Willcox	54	60 - 65
Buena Vista	49	60 - 70
Cactus Flat-Artesia	46	65 - 70
San Simon	43	35 - 45
Bowie	37	90 - 100

aquifers produce 30° to 33°C water; the geothermal fluids have temperatures between 52°and 57°C and their chemistry is distinctive.

Temperature measurements in domestic water wells belonging to th city of Scottsdale show a zone of lateral flow of 40° to 50°C water at 335 m depth beneath the city. Stone (1981) estimated that fluids with temperatures to about 60°C exist to depths of about 900 m, and that significantly hotter waters may exist at depths of 1,800 m and greater. Pumped wells in Mesa produce 37° to 54°C water from depths of 90 to 300 m.

In south-central Arizona, geothermal fluids rise through fractured bedrock at the intersection of two fault zones at Papago Farms on the Papago Indian Reservation. Fluids pumped from about 240 m depth have temperatures as high as 51°C, but deeper reservoir temperatures may be as high as 140°C (Stone, 1980a). Other geothermal areas in south-central and southwestern Arizona, together with their estimated reservoir temperatures, are listed in Table 2.

TABLE 2. SELECTED GEOTHERMAL AREAS IN SOUTH-CENTRAL AND SOUTHWESTERN ARIZONA

Area Name	Maximum Measured Temperature (Degrees C)	Estimated Reservoir Temperature (Degrees C)
Castle Hot Springs	46	85 - 100
Coolidge	72	105 - 110
Tonopah	51	65 - 70
Avra Valley	53	50 -55
San Manuel	42	less than 60
Northern Hassayampa	53	70 - 75
Southern Palomas	49	90 - 95
Yuma	38	greater than 100

POTENTIAL GEOTHERMAL RESOURCES IN NORTHERN ARIZONA

That portion of northwestern Arizona within the Basin and Range province (Figure 2) appears on the map, "Geothermal Resources of Arizona" (Witcher, Stone, and Hahman, 1982), to have little resource potential. However, this conclusion probably is not correct. Most likely the area appears barren because it has received only limited attention.

Thermal springs in northwestern Arizona have discharge temperatures as high as 58°C and geothermometer temperatures, which suggest reservoir temperatures at depth, as high as 120°C. Goff (1979) concluded that the area between Kingman and Williams has several small, isolated geothermal reservoirs with fluids that may be as hot as 115°C. West and Laughlin (1979) showed that the Aquarius Mountain area has many of the anomalous conditions associated with thermal enhancement of the crust. They concluded that although the area does not have an insulating blanket of sedimentary rocks, "the prospect appears worthy of additional investigation. . . ." Shearer and Reiter (1981) proposed that high heat-flow values on the west side of the Big Sandy Valley are due to shallow hydrothermal convection systems. Industry showed some interest in the area during the late 1970s, but results of their investigations are unknown.

The north-central and northeastern portions of Arizona are in the Colorado Plateau province (Figure 2), an elevated area of comparatively flat-lying, relatively undeformed sedimentary rocks that are slightly tilted to the northeast. Preliminary information suggests that three areas in this region may have geothermal energy potential: the San Francisco volcanic field near Flagstaff, the White Mountain volcanic field near Springerville, and an area southwest of Sanders.

Thermal water has not yet been identified in the Flagstaff region, but Stone and Witcher (1982) proposed that "a significant geothermal resource may exist at depth (beneath the younger part of the field) judging from the number, size, and youth of silicic volcanic centers". Extensive investigations have been conducted in this region by the U.S. Geological Survey, but their results have not yet been published. Stone (1980b) showed that in the White Mountain volcanic field a corridor from St. Johns to Alpine has low- to moderate-temperature geothermal potential. The area has anomalously high heat-flow values and geothermometer temperatures (to 110°C). The Springerville-Alpine geothermal anomaly is the only area in Arizona known to be currently receiving attention from a private development company. Phillips Petroleum Company has conducted limited geothermal exploration in both the San Francisco and White Mountain areas, but results of their investigations are unknown. About 15 km southwest of Sanders, nine thermal wells and two anomalously high heat-flow values cluster in an area less than 100 km^2. The source of this anomalous heat is not well understood because the area has not been studied.

CURRENT GEOTHERMAL PROJECTS IN THE WESTERN UNITED STATES

Geothermal energy can be used in two principal ways. The first is generation of electric power by steam or high-temperature fluids, generally above 180°C. Electricity has been produced from steam at the Geysers in northern California since 1960, with present output exceeding 1,000 megawatts. The second and more common way is direct utilization in which the far more abundant low- to moderate-temperature fluids, such as exist in Arizona, are used directly to supply low-grade heat without the intermediate stage of power production. Many direct-use applications and their required temperatures were listed by Anderson and Lund (1980). District heating systems are in operation in Boise, Idaho; Jemez Springs, New Mexico; and Klamath Falls, Oregon. The Campus Heating Project at New Mexico State University, Las Cruces, achieved a gross cost avoidance of $250,757 between February 1982 and March 1983 by using geothermal energy to heat several buildings on campus.

POSSIBLE USES OF GEOTHERMAL ENERGY IN ARIZONA

Numerous opportunities exist in Arizona to use the abundant low- to moderate-temperature geothermal fluids that have been identified. The possibility of implementing geothermal space conditioning has been studied for Williams Air Force Base, Chandler (cooling), Swift Trails Federal Prison Camp, Safford (heating), and a hotel complex in Tucson (heating). Space conditioning, especially heating, which requires lower fluid temperatures than cooling, could probably be established in a number of Arizona towns. White and Goldstone (1982) showed that recovery of copper in a dump-leaching operation increases from about 55 percent using 25°C water to 70 percent using 40°C water. Studies of cyaniding show that the rate of dissolution of gold in 25 percent KCN at 20°C increases about 120 percent when the temperature is increased to 50°C. Other applications include preheating boiler water for conventional power plants, controlled-environment agriculture (greenhouses and nurseries), process heat for slaughterhouses, fish farming, grain and vegetable dehydration, and soil warming for mushroom growing and earthworm farms. The actual list of potential geothermal applications is as long as one's imagination. Wherever low-grade heat is needed in Arizona, the possibility of using this alternate energy should be examined. Development awaits the entrepreneur.

CONCLUSIONS

Geothermal fluids having low to moderate temperatures are abundant in Arizona. This alternate source of energy is not free, and without vigilance, development could be impeded by legislative and institutional constraints. However, the benefits to be derived from development of geothermal resources in Arizona today are major. Such benefits include an improved quality of life because of the low environmental impact made by low-temperature geothermal projects, energy independence, and relief from escalating fossil-fuel prices, which are certain to rise in the future. Other potential benefits require only a little imagination.

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ANNOUNCEMENT: Bulletin 194, "Metallic Mineral Districts and Production in Arizona," has been released by the Arizona Bureau of Geology and Mineral Technology. The bulletin consists of a map (1:1,000,000 scale) that shows metallic mineral districts, brief text, and a table that indicates metal types and amounts produced from each district. Mineral districts were defined by geological criteria and classified by age of mineralization, if known, style of mineralization, and metallic minerals produced or present.

Bulletin 194 may be purchased for $6.50 plus $2.00 for handling and shipping, if it is to be mailed. The map may be purchased separately for $2.00 plus $1.50 for shipping and handling, if it is to be mailed. Address orders to the Arizona Bureau of Geology and Mineral Technology, 845 N. Park Avenue, Tucson, AZ 85719.

MINERAL-RESOURCE POTENTIAL OF WILDERNESS AREAS IS ASSESSED

A report that summarizes assessments of the mineral-resource potential of about 45 million acres of wilderness and potential wilderness tracts on U.S. Forest Service and Department of the Interior lands has been published by the U.S. Geological Survey (USGS). The two-volume report, which represents 20 years of study by scientists of the USGS and the U.S. Bureau of Mines (USBM), contains summaries of the mineral- and energy-resource potential of about 800 wilderness and proposed wilderness tracts, almost all within national forests.

The report shows that of the 332 tracts studied, 220 contain areas considered to be favorable for the occurrence of one or more kinds of mineral or energy resources. The summaries are organized by states and contain sketch maps of each wilderness study area showing which parts have mineral potential. The Arizona chapter, in volume one, is comprised of assessments of 25 tracts. A number of tracts have not yet been studied by the USGS or the USBM.

Each area assessed has been the subject of field studies, including geologic, geochemical, and geophysical surveys and investigations of mines, mineral prospects, and mineralized areas. When available, data obtained from private-sector exploration were incorporated in the assessments. Each of the summaries in the report is based on more-detailed reports released during the past 20 years, or to be released soon.

Mineral-resource potential, as discussed in the summaries, is defined as a measure of the likelihood of the occurrence of valuable metallic, nonmetallic, or energy minerals in a specific area. This potential is determined by analyses of the known resources and the characteristics of the geology of each area and comparison to areas with known mineral deposits.

Dr. Dallas Peck, director of the USGS, said the resource assessments by the two Interior agencies are aimed at providing impartial information on the resource potential of each study area that can be used by Congress and government officials in deciding how the area is to be used.

The Wilderness Act of 1964 and subsequent legislation required the agencies to assess the mineral potential of all lands within the National Wilderness Preservation System and all lands being considered for inclusion in the system. Since the program began in 1964, the amount of land to be studied has tripled from the original 14.8 million acres to 45 million acres.

The report, titled "Wilderness Mineral Potential — Assessment of Mineral-Resource Potential in the U.S. Forest Service Lands Studied 1964-1984", was published as USGS Professional Paper 1300. The report and the individual summaries were compiled and edited by Sherman P. Marsh and Susan J. Kropschot of the USGS and Robert G. Dickinson of the USBM, all in Denver, CO.

The report can be purchased from the Branch of Distribution, U.S. Geological Survey, 604 South Pickett St., Alexandria, VA, at a cost of $32 for each two-volume copy. Orders must include the full name and the identification number (PP 1300) of the report along with checks or money orders payable to the U.S. Department of the Interior-USGS.

Copies of the report are also available for inspection only at USGS libraries and at various other public and university libraries across the nation.

BUREAU GEOLOGISTS LEAD FIELD TRIP TO EXAMINE MAJOR FAULTS AND ASSOCIATED MINERALIZATION IN WEST-CENTRAL ARIZONA

A major responsibility of the Bureau is to conduct research and provide information about the geology and mineral resources of the State. Bureau geologists often use geologic field trips to communicate results of new research to geologists from industry, governmental agencies, and academic institutions. In November, Bureau geologists Robert Scarborough, Stephen Reynolds, and Jon Spencer led the Arizona Geological Society Fall Field Trip into the Plomosa and Granite Wash Mountains of west-central Arizona (Figure 1). The trip was attended by approximately 140 persons, most of whom were mineral exploration geologists interested in the relationships between mineralization and gently dipping faults. Others in attendance included geologists from the U.S. Geological Survey, the Bureau of Land Management, and other Arizona universities and colleges. The focus of the trip was to examine major thrust and detachment faults, some of which were unrecognized prior to geologic mapping by Bureau geologists. Parts of the Field Trip Guide are available as the following Bureau Open-File Reports:

Scarborough, R., and Meader, N., 1983, Reconnaissance geology of the northern Plomosa Mountains: Open-File Report 83-24 (36 p.).

Reynolds, S.J., Spencer, J.E., and Richard, S.M., 1983, A field guide to the northwestern Granite Wash Mountains, west-central Arizona: Open-File Report 83-23 (11 p.).

Please refer to pages 11 and 12 of this issue for more information on how to obtain Bureau Open-File Reports.

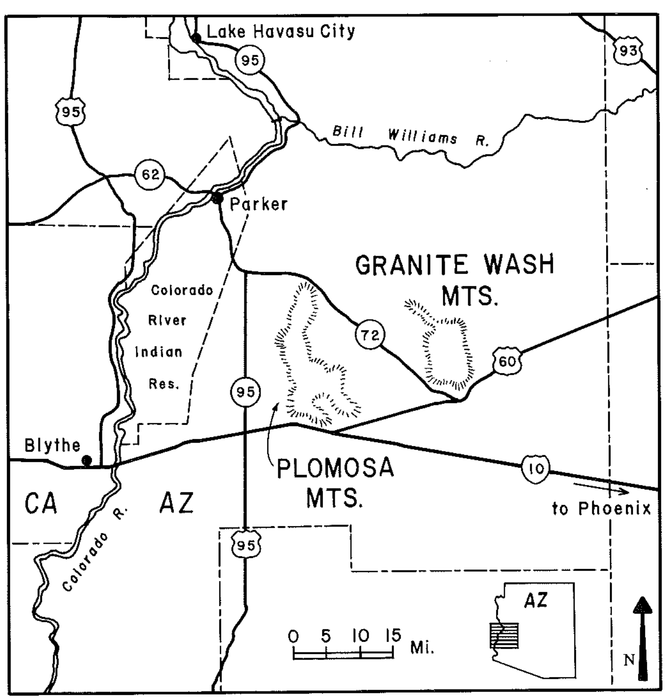

Figure 1. Location map of Granite Wash and Plomosa Mountains, Arizona.

The Future of the United States Copper Industry:

Part Two. The Consumption Side

*by Richard Newcomb**

Is the U.S. losing its comparative advantage in copper metal production to other countries? In this second of two articles economic trends in and the future of the U.S. copper industry are examined. Part one (*Fieldnotes*, Fall 1983) was an analysis of the formidable problems of the domestic industry on the supply side related to depletion, environmental and safety regulations, higher wages, and other factors. It demonstrated that, in general, Western copper mines, by adopting new smelting technology, can expand at well below the incremental costs required for new mines abroad, even in the richest mining districts. Therefore, when the rates of growth in world copper consumption resume as predicted, the $1.40-$1.50 per-pound price necessary for new capacity abroad will make it profitable to continue or expand domestic metal production. Some smelters may have to be relocated and, as a result, mining may cease in some places. But on average the Western copper reserves will remain an important and competitive source of new metal output if there is growth in demand. Will, however, markets grow at rates or in ways that foster the growth and profitability of U.S. copper fabricators? In this concluding part of the analysis, attempts will be made to answer these demand-site questions.

COPPER DEMAND, SUBSTITUTION, AND TECHNOLOGICAL CHANGE

Copper is widely used because of its high conductivity and resistance to corrosion, properties which give it strong comparative advantages in electrical uses, plumbing, and ordnance. About 80 percent of all copper demands are related to high conductivity, a factor which impels the use of copper in electrical wire or heat transfer systems. The other 20 percent of usage is related to its durability and convenience (malleability, etc.) in construction tubing, sheet metal, or durable mill products. Exhibit 11 is the industry's breakdown of recent annual U.S. consumption of mill, foundry, and powder products including alloy materials plus direct use of new and old scrap. Forecasts of copper's share in the future in these selective markets are generally based on the assumption that there will be continued use at these established "intensities." In contrast to publicity the industry has given to the increasing copper-production costs, it has not widely publicized its apprehension over inabilities to maintain shares of traditional markets in competition with other sources or materials, especially the lightweight metals and super-alloy steels.

For a long time the industry has believed that low, stable copper prices relative to aluminum and steel alloys must be maintained in order for copper to be competitive with other metals. This implies that demand for copper is

EXHIBIT 11

U.S. CONSUMPTION OF COPPER MILL, FOUNDRY, AND POWDER PRODUCT[1] BY END USE (IN THOUSAND SHORT TONS)

End Use	1970	1973	1976	1979
Electrical	770	902	724	893
Construction[2]	817	1090	854	1076
Machinery	612	699	526	617
Transportation	294	443	418	437
General	440	496	399	502
TOTAL	2933	3630	2921	3525

Source: Copper Development Association, Inc., Sousa (1981).

[1] Refined copper plus alloy materials plus direct new and old scrap.
[2] Includes building wire.

"highly elastic", i.e., rather sensitive to small changes in the price of copper. Variable or rising copper prices may induce users to switch to alternative materials or designs. The major integrated brass and wire mill producers also dread the cyclical swings in copper demand which result in corresponding price changes. Whenever there is stagnation in the heavy utility and construction industries as exists currently, in durable investment goods such as machinery, and in the auto and transportation industries until recently, the copper producers are largely dependent on residual ordnance, inventory, and export demands. Inventory demands revive normally as the user industries recover from recession. The U.S. is open to imports, but exports of mill products from the United States are prohibited by tariffs and non-tariff barriers in most countries. Japan and Europe are especially unwilling to accept the level of U.S. copper products that the U.S. mill advantages dictated in the past. For these reasons, it is not clear than an industry strategy of focusing on price stability or on the cost of copper per pound relative to rival metals can preserve markets for domestic copper producers. This is particularly true when one considers the openness of U.S. markets to sizeable imports of copper-intensive final goods, such as automobiles from Europe or electronic consumer goods from Japan. All these factors result in reduced copper use and in a reduced share in world production for the U.S.

The emphasis on price stability in order to insure against customer switching has led U.S. producers to maintain prices that were commonly well below the world spot-market prices. This is reflected by the large gap between U.S. producers' price and price quoted on the London Metal Exchange (LME) for extended periods. This behavior is curious because during such periods, of course, the major U.S. producers have to forego profits and ration copper. Buyers, on the other hand, unable to secure copper, are given an incentive to switch to aluminum-intensive alternatives quite independent of the increase in

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the price of imported copper. Indeed, the switch away from copper to the light metals has been occurring while the price of copper has been falling relative to that of rival materials, because of the lower cost performance of new replacement technologies. Thus, a key factor for analysis of demands by the industry should be the impact of technological change, and the changes in engineering associated with *system* optimality and total user cost.

For example, in power transmission systems the switch away from underground cables intensive in the use of copper and lead, to overhead cables intensive in aluminum, took place despite aluminum's poorer conductivity and rising price. The switch occurred because the final cost per unit of power transmitted by the overhead systems fell below that of ground installations. More currently, the switch to composite materials and aluminum radiators in automobiles reflects the technological change to high-temperature combustion, which aids emission control and also eliminates weight. The overall result is a higher performance automobile with lower variable and fixed costs for the user. The elimination of conventional copper radiators is but a part of the system redesign.

In the U.S. currently, 60 percent of the demand for copper is tied to electrical uses. However, copper is being replaced by steel-core aluminum cable in power transmission, by aluminum in magnet wire, transformers, and switch-gears, and by silicon chips and fiber optics in electronic circuits. Copper is being replaced by thinner gauge wire in communication systems, and by improvements in myriad alternate designs, such as multiplexing via pulse-code modulation to upgrade capacities in junction circuits and trunk lines. Fiber-optic cable systems for communication, using glass fibers as conductors, can carry far greater volumes of traffic than equal-sized copper cables. Microwave towers, satellites, and waveguide systems also replace long-distance communication systems using copper. In construction, copper can be displaced by polyvinylchloride tubing, and in transportation by thinner walled and narrower tubing of aluminum, steel, or plastic. These materials in a variety of new systems are resulting in increasing substitution for copper in hydronic thermal applications. Military uses of copper as a percent of strategic materials demands also continue to decline.

The complexity of these substitutions due to technological changes brings into question the historic concerns of U.S. producers that stabilizing the price of copper at low levels relative to rival materials is sufficient to insure the constant use of copper in traditional applications. The simplest way to sort out the various influences on intensity of use is to combine engineering with economic analysis. In the short run, technology and plant investment are fixed, so that only within relatively narrow limits can a change in the price of a metal inspire much substitution. However, substitution becomes somewhat easier in the long run. Technological changes can shift demands up or down, as can cyclical changes in the user industry and changes in Gross National Product (GNP). Studies show that many manufacturers can successfully alter material usage if given enough time to react to shortages or higher prices of materials which become scarce. In any event, it is clear that to estimate the total consumption of primary copper one has to aggregate all sorts of influences and varied sectoral coefficients of use. Electric, construction, and transportation demands are cyclical. Furthermore, scrap recycling rates and imports vary over time. Thus, the rate of a given industry's copper consumption depends on a host of factors including business cycles, government policies, and an economy's stage of development. Materials substitution may take place at more rapid rates in the U.S. because most research is done here and replacement trends are often more advanced here than abroad. Without attempting to sort out the fundamental causes of substitution over time, one can speculate, as did Malenbaum (1977), that the declines in intensity of copper use in the U.S. are due to the advanced stage of industrialization. In contrast, developing countries have rising copper-usage rates. From this perspective, the administration of prices, by U.S. firms, below world market levels in an attempt to maintain copper-market shares appears futile.

An implication is that demands for copper may be overestimated if forecasters assume that conditions that prevailed in the past will remain constant. Despite this, most projections incorporate this assumption and predict growth on that basis (Exhibit 12). They also characteristically ignore cyclical influences. Detailed information on the distribution by sector of copper demands in Europe and Japan is not readily available. However, a recent study by Leontief and others (1982) confirms that forecasters in these countries, like those in the underdeveloped countries, assume constant use rates and are concerned primarily about deficits in supply. The higher coefficients observed abroad are partly due to the inavailability of cheap plastics and aluminum, the unfamiliarity or reluctance of manufacturers to risk a decline in quality, which may attend the adoption of new methods and materials, and lags in the diffusion of innovations abroad. Higher coefficients may also be attributed to the early stage of a country's industrialization, or to the growth in exports of copper-intensive goods, such as automobiles or electronic equipment. Whatever the causes, there is no reason to believe that high coefficients of use will persist in those countries as they follow the U.S. course. I have, therefore, in Exhibit 13, modified the estimates of world demand outside the U.S. that were made by Leontief and others. By fixing growth in

EXHIBIT 12

WORLD REFINED COPPER DEMAND FORECASTS, YEAR 2000 (IN MILLION SHORT TONS)

Study	United States	Rest of World	World
Bureau of Mines[1]	3.5	16.0	19.5
Malenbaum[2]	3.5	15.0	18.5
SRI[3]	4.2	16.9	21.1
Fischman[4]	3.4	14.6	18.0
Australian MEP[5]	2.9	15.7	18.6
Leontief[6]	3.7	20.0	23.7
Newcomb[7]	2.5	12.3	14.8

Sources:
1. Schroeder and Jolly (1980)
2. Malenbaum (1977)
3. cited by Sousa (1981)
4. Fischman (1980)
5. Australian Mineral Economics Pty, Ltd. (1979)
6. Leontief and others (1982)
7. Exhibit 13, this article

the developed countries at historical rates observed in the U.S., I have reduced the forecast world consumption of copper from 25 million to 14.8 million tons in 2000.

This prediction is much lower than those on which others have based forecasts of future capacity expansion, especially in Latin America. If considerable new world capacity results, copper from underdeveloped countries could be "dumped" in U.S. markets, further disturbing domestic producers.

EXHIBIT 13

WORLD REFINED COPPER SUPPLY AND DEMAND FORECAST, YEAR 2000 (IN MILLION SHORT TONS)

Supply	No. Am.	Lat. Am.	Demand Pacific	Africa	Soviet	Europe	TOTAL SUPPLY
No. Am.	2.7					.6	3.3
Latin Am.	.1	.8	1.1		.1	1.9	4.0
Pacific			1.2				1.2
Africa			1.0	.2	.2	2.0	3.4
Soviet Bloc					2.7		2.7
Europe						.2	.2
TOTAL DEMAND	2.8	.8	3.3	.2	3.0	4.7	14.8

Note: Author has assumed that world demand for refined copper will grow at rates approximate to forecast U.S. total demand growth. Supply shares are as estimated for producing countries on the basis of production costs.

Another implication of this analysis is that short-run costs (because they reflect supply and demand shifts, or "lags", and thereby affect the profitability expectations of investment decisions) should determine prices rather than historical average costs. The appropriate market for marginal costs pricing are the spot markets, such as the LME.

Between 1960 and 1980, as was illustrated in part one, U.S. producers, ignoring marginal costs in the rest of the world, set prices along a second tier or path closer to the historical average costs then existing in the industry. This created a two-tiered pricing system in which U.S. producers lost substantial profit and which discouraged expansion and renovation in the domestic mines and mills.

PRICE FORMATION IN THE COPPER INDUSTRY

U.S. producers did not follow the short-run fluctuations of the world free-market price, but instead chose to maintain the trend of long-range average cost, partly because they believed that short-run conditions would adjust quickly. However, as described above, they may have been motivated primarily by the fear that important copper markets would be lost if the industry myopically tried to profit from the wide fluctuation and rise in world prices. The government encouraged low, stable prices by manipulating its stockpile and threatening the industry during the Kennedy and Johnson administrations. Noting that, somehow, major firms were able to administer a lower price and ration copper, Henry Houtakker, Chairman of President Nixon's Council of Economic Advisors, viewed this attempt at apparent average-cost pricing as collusion by the integrated companies to limit competition in the brass and wire markets. Antitrust action was threatened and was followed by some rise in U.S. producers prices. Throughout, both the Japanese and U.S. Governments attempted, by stockpile manipulation, to keep copper prices below levels dictated by the international metal exchanges.

In retrospect, because foreign firms with low average unit costs in Africa garnered large profits abroad, the failure to raise prices resulted in large losses to U.S. producers. The size of economic rents foregone can be estimated. If one assumes that 13 million tons of U.S. copper were underpriced, U.S. firms lost half or more of the difference between LME and producers' prices from 1965 to 1975. Thus $3.5 to $7.0 billion in revenues was lost by major U.S. producers, and an even larger sum was earned by firms abroad due to the phenomenon of two-tiered pricing. Although some profits were recovered in higher brass-mill prices obtained by integrated U.S. firms, the U.S. losses hurt the industry's ability to refurbish its outmoded plant, while the higher world prices assisted in sustaining very high cash flows on new copper projects abroad. Mill-product prices and scrap prices were higher in Japan and the Organization for Economic Cooperation and Development (OECD) countries than in the United States. However, U.S. firms were unable to export mill products to Japan or the OECD countries because of trade barriers. This experience, even under the simplified analysis employed here, draws attention to the very different mineral policies of the U.S. and other countries.

DIFFERING U.S. AND FOREIGN MINERAL POLICIES

National monopsonies (trading companies with exclusive buying rights) and national producer monopolies or cartels are accepted abroad. The U.S. government, in contrast, has until recently ignored the presence of international combinations and frowned on domestic combinations. European and Japanese buyers' cartels have traditionally been assisted by their governments in negotiating favorable arrangements with the newly nationalized copper industries in producing countries. Expansions have thereby been encouraged, with higher LME prices and higher rates of return accruing to the foreign producers. Meanwhile, the U.S. government's acquisition of abundant copper inventories helped to keep domestic prices down and to create a large discrepancy between free world LME and the U.S. producers' price. This led ultimately to the confiscation of U.S. mines abroad. In Latin America, countries such as Chile and Peru, which are host to U.S. firms, felt deprived of taxes on profits that would have been obtainable had their copper been priced on the LME market. In Africa, the hosts to already nationalized European firms were more cooperative because they could expand their markets at the higher prices afforded by LME-based contracts. At one time, the Johnson administration negotiated with U.S. firms to permit the release of Chilean copper for world market sales, replacing the ore with equal tonnages of stockpiled domestic copper. Such measures helped prevent U.S. prices from rising, but did little to ease the poor relations between U.S. subsidiaries and their hosts. In contrast, European companies negotiated diplomatically and assisted host countries with the expansion of their mines.

During all these years U.S. brass-mill products and electrical equipment were not welcome in the Common Market or Japan, which sought to protect their domestic fabricators. Prevented from extending metal trade by high tariffs and non-tariff barriers, U.S. firms participated abroad only in ore development ventures. As confiscation of mines abroad occurred, major U.S. firms were increasingly restricted to their domestic markets. At the same time, antitrust actions prevented the large copper firms from increasing their domestic market shares. Thus little incentive for growth existed; the major U.S. copper firms stagnated. Instead of exporting during periods of excess capacity at home, domestic firms abandoned the home market to increased imports and secondary metal whenever excess demands occurred. Thus, even though U.S. copper prices were considerably below world prices, declining growth, world trade, and profits resulted from domestic policies. Recently attitudes toward discriminatory foreign country trade practices have begun to change in the United States. However, this occurs at a time when short-run downward shifts in demand, combined with U.S. monetary policies, have complicated the long-run prospects for U.S. copper producers.

THE FUTURE OF U.S. FIRMS

Part one of this paper demonstrated that domestic U.S. copper mining firms do not have disadvantages in resources or technology that would prevent them from competing vigorously for domestic smelted-product demands. Experience with barriers to trade over the past thirty years also confirms that U.S. copper fabricators maintain comparative advantages in both wire and brass-mill products over the rest of the world, including most European and Japanese producers. Nonetheless, differences in the relationships between government policy and the behavior of firms here and abroad have brought about condiditons of zero growth for domestic firms while both mining and copper fabrication have boomed abroad. Because of the high ratios of fixed to variable costs, without the prospect for domestic growth in smelter products, U.S. firms are reluctant to replace their old smelter technology with energy- and labor-efficient alternative technologies. Currently strict emissions policy and increased costs for both labor and fuel make the variable costs of the obsolete smelters too high for them to be competitive. This is occurring at a time when high-interest-rate policy makes the fixed cost of replacement to comply excessive. Yet U.S. firms retain sufficient long-term advantages over expansion costs abroad to encourage the replacement of their outmoded reverberatory technology and, in some locations, even to resume the smelting of foreign concentrates. Will these firms do so?

The answer depends on what is done to remove the interference of governments, including our own, on capital markets, final goods markets, and access to free trade. World demands will undoubtedly not come close to the projections of the OECD nations or the U.S. Department of Interior recorded in part one, which foresee 18 to 25 million tons of copper consumption by 2000. More likely, world demands will reach levels of only 15 million tons by that date. U.S. metal demands should rise under the same assumptions also, but the U.S. firms are not likely to share in this growth because present currency and trade restrictions discourage industry reinvestment plans.

As long as U.S. fabricators face restrictions on the export of wire and mill products to the rest of the world, while imports of autos and other items cut their home coefficients of use significantly, they face zero-growth prospects at best. These prospects are further dimmed by high-interest U.S. monetary policy, which greatly slows the corporate investment and residential construction associated with the major copper-consuming sectors. In contrast, producers abroad have two notable advantages. First, neither their metal exports nor their copper-intensive final goods face restrictions on entering U.S. markets. Of equal or greater importance, the high-interest policy of the U.S. overvalues the dollar relative to costs in the exporting country. Prominênt industrial economists variously estimate the disadvantage to U.S. producers to be 30-35 percent on average traded goods. Copper metal imports, however, come primarily from Latin American countries with currency disparities much greater than average due to the hyper-inflation policies pursued there. Thus, the sol (Peru) and the peso (Mexico and Chile) are undervalued by an additional 30-50 percent vis-a-vis the dollar. This means that copper exports paid in dollars, even at low current prices of $.67 per pound, yield 65-85 percent more purchasing power to the exporter in those countries. The industry has made much of the tendency of nationalized or subsidized foreign mines to overproduce during recession and over-expand on subsidized loans during boom periods. However, in the light of currency disparities and the terms-of-trade distortions obtaining under current monetary policies of these trading countries, the dollar equivalent of exports in Chile, Peru, and Mexico in terms of pre-devaluation pesos or sols ranges from $1.10 to $1.25 per pound. As long as overvalued currencies are available from exports to the U.S., mines in those countries will have realization prices close to the new facility expansion costs estimated in part one. Certainly most existing capacity will be quite profitable and incremental capacity worth considering.

To the extent that only the U.S. dollar's *over*valuation is involved, the problems of U.S. copper fabricators are not dissimilar to those faced by other basic industries. Like steel, copper may find imports coming from foreign mills at economic scale competing freely with domestic production at uneconomic scales from obsolete facilities. Yet domestic fabricators will not be permitted to export new mill products abroad should they opt to replace and relocate their old facilities. In the case of fabricators, some new mills would favor new locations accessible to both Pacific basin or Europen markets as well as domestic users. This would cause realignments of some smelter capacity, which may, in turn, be open to foreign ores or concentrates.

Monetary policies responsible for high interest rates and the associated exchange-rate disparities are admittedly short-term in nature. Clearly, if they persist over a long period, they will encourage establishment of compensating U.S. tariffs or subsidies in an increasing number of traded goods. What can be predicted about the effects of such distortions given the present environment of world metals trade in which there are so many asymmetries?

The average impact of dollar overvaluation can be estimated by noting the 35 percent distortion estimated above for U.S. exchange rates, which apply to all traded goods. As long as the burden of inflation control falls on monetary policy alone, high interest rates will depress U.S. copper demands. At the same time, they will raise the value of exports to foreign copper producers by 23¢ per pound.

The specific impact of greater than average undervaluation in the case of Chile, Peru, and Mexico can also be estimated. Each has devalued its currency by 50 percent or more and offers producers greater than average disparity with the dollar. In these major sources of export copper, the realization price of copper sold in the U.S. includes a premium ranging from 43 to 58 cents per pound.

In the early days of Western mine development, copper firms responsed to dramatic changes in the peso/dollar exchange rate by pegging miners' wages to copper prices. It is curious to see this expedient resorted to now by tough or "creative" bargaining. In addition, companies have asked for tax relief. Finally, tariffs on imported copper equivalent to the exchange distortions estimated above might be requested. Past tariffs on lead and zinc, quotas on oil, and differential realization prices for intra- and inter-regional gas sales are reminders that the U.S. government has frequently yielded to pressures for regulation of mineral markets. The result would be a rise in the price of smelter products inside the U.S. to levels between $.90 and $1.48 per pound.

In the Eastern mill regions, tariffs and non-tariff barriers to copper products from Japan or Europe, similar to existing barriers or subsidies in those countries, can also be adopted. The minimum distortion of such measures is indicated by the current level of tariffs abroad, which average 5-10 percent in Japan and the Common Market countries on brass- and wire-mill products from the U.S. The maximum distortion required is indicated by the higher initial tariffs, 25-40 percent, maintained on U.S. imports by those countries in the immediate postwar period. The presumption is that as these levels have been reduced they have been replaced by non-tariff barriers. The distortion is many times the transportation costs of U.S. brass-mill products for higher valued exports. Finally, policies subsidizing U.S. exports can be considered.

The problem with all these restrictive policies in the long run is that they bring mercantilist protection to inefficient firms. Of course they also bring an end to apparent U.S. disadvantages in copper production, and would, therefore, encourage investment in U.S. mines and mills. They may also bring retaliation in other U.S. markets.

The best alternative, therefore, is not U.S. discrimination, but efforts to end discrimination against U.S. products in the rest of the world. Under more liberal trade conditions, nationalized firms abroad would lose their special protected positions. However, to date, little has been done to remove the non-tariff discrimination against copper products from the U.S. in the developed or underdeveloped countries.

As a result, U.S. mines, although possessed of real comparative advantages approximating 30-50¢ per pound over new mines abroad, appear to have equal or greater *disadvantages* vis-a-vis their major producing rivals: Peru, Mexico, and Chile.

CONCLUSIONS

It is my opinion that neither industry nor government has paid adequate attention to the changing character of international copper markets. Now that the significance of world market conditions to U.S. producers is more generally recognized, U.S. firms are tempted to urge policies of market interference similar to those practiced in the Common Market countries, Japan, or underdeveloped regions. A new regionalism has surfaced in the U.S. among mining firms, which are now recommending protective tariffs, delays in smelter regulations, and the like. Some authorities are protesting the granting of the bank loans under special conditions for use in the expansion of foreign copper mines. The industry recently challenged the International Monetary Fund (IMF) loans to developing countries. Industry pressures have also been placed on Western mine labor to reduce wages and on legislatures to reduce taxes. In the Eastern fabricating sector, advocates of "industrial policy" have broadly suggested subsidies for mill reinvestment.

Such policies address mining as if it were independent of fabricating, but most brass and wire mills in the East are fully integrated back into Western mines and smelters. More data are required for a full analysis of what the impact of specific regional protection would be on the industry as a hole. Nonetheless, crude measures of the levels of distortion created by protection can be provided.

If Latin and African countries expand as now proposed, any future slowdown of world copper demands will probably create serious excess supply. While protected Japanese and European markets will be unaffected or receive cheaper copper, the U.S. will be seriously affected. These prospects should encourage U.S. companies to modernize and to press aggressively for an end to foreign restrictions on their wire- and brass-mill products. In addition they should work progressively to redesign copper back into many of the systems from which the metal has been eliminated. This would not prevent the influx of cheap metal imports into Eastern mills, but the growth of mill capacity in both East and West would open up additional markets for Western mines as well as foreign concentrates.

Failing the effort to remove foreign tariffs and other barriers, the Western states may proceed independently to seek relief for mines by tax reductions or extensions of variances which permit pollution. Most economists regard these last measures as "second best". Variances are regarded as the least efficient because the obsolete Western furnace capacity carries with it very high labor and energy inefficiencies (costs). This means that high penalties are associated with any delay in the adoption of cleaner and more efficient new technologies.

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