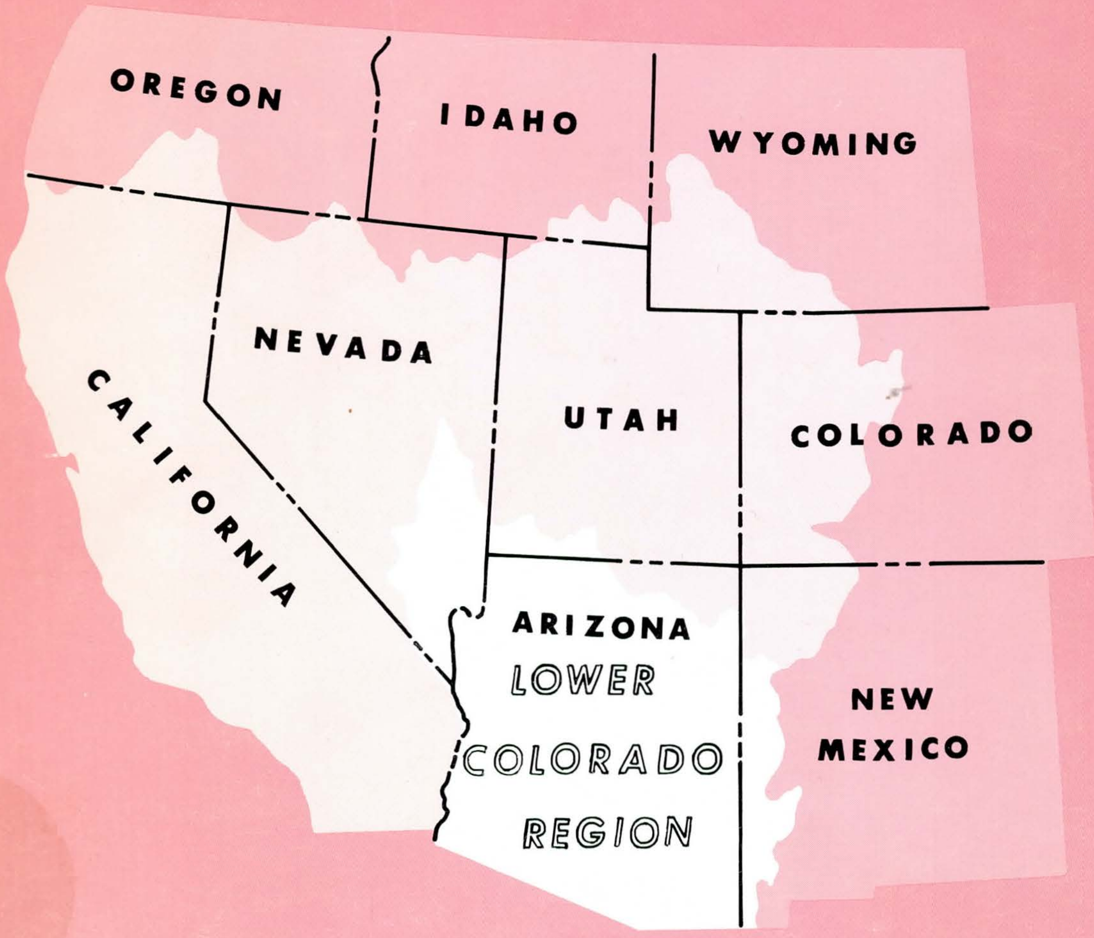
LOWER COLORADO REGION
Comprehensive Framework Study

APPENDIX VII
MINERAL RESOURCES
JUNE 1971



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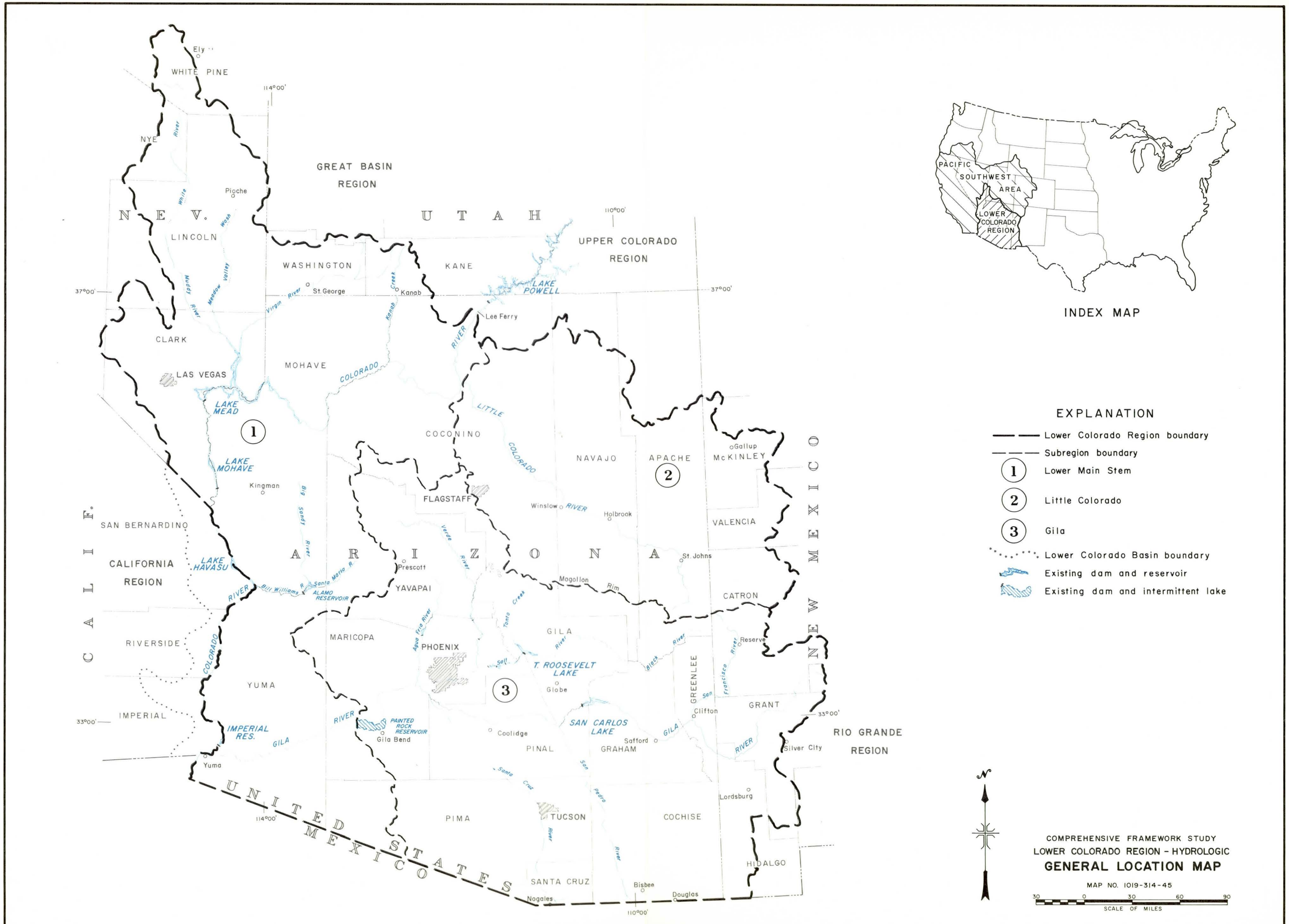
APPENDIXES TO THE MAIN REPORT

LOWER COLORADO REGION



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LOWER COLORADO REGION

COMPREHENSIVE FRAMEWORK STUDY

APPENDIX VII

MINERAL RESOURCES

This report of the State-Federal Interagency Group, Lower Colorado Region, was prepared at field-level and presents a framework program for the development and management of the water and related land resources of the Lower Colorado Region. This report is subject to review by the interested Federal agencies at the departmental level, by the Governors of the affected States, and by the Water Resources Council prior to its transmittal to the Congress for its consideration.

June 1971

This appendix prepared by the

MINERAL RESOURCES WORK GROUP

of the

LOWER COLORADO REGION STATE-FEDERAL INTER-AGENCY GROUP

for the

PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE
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SUMMARY OF FINDINGS

Mineral industry has contributed substantially to the strong growth economy of the Lower Colorado Region during the post-World War II era. In terms of 1958 dollars, value of mineral production was $606 million in 1965, up approximately 200 percent from levels of the late 1940's. Projections for the future, formulated under two sets of criteria with 1965 as the base year, indicate that the value of mineral production should increase 60 to 90 percent by 1980, and could advance as much as 190 to 300 percent by 2020.

Water needs of mineral industry are modest--depletions in 1965 were only about 60,000 acre-feet. Anticipated efficiencies in water use by the industry will be countered by the need to process lower grade ores in the future; therefore, increased water requirements through 2020 will tend to parallel the upward trend in value of mineral output. Water depletions are expected to increase 50 to 65 percent by 1980, and 190 to 275 percent by 2020.

Regionwide land needs for active mineral production are negligible--approximately 76,000 acres were used in 1965. Responsible reclamation efforts by the industry are on the increase and seem certain to minimize environmental impacts related to mining. Future land needs are expected to increase nominally, up about 30 to 50 percent by 1980 and 65 to 190 percent by 2020.

LOWER COLORADO REGION COMPREHENSIVE FRAMEWORK STUDY

APPENDIX VII

MINERAL RESOURCES

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CHAPTER 1 - INTRODUCTION

Purpose and Scope

Appendix VII, Mineral Resources, is one of the 16 appendixes developed for the Lower Colorado Region Comprehensive Framework Study. Background data required for the minerals portion of the study were compiled, reviewed, and organized during calendar years 1967-69.

The primary purpose of estimates of mineral industry output and related land and water needs, as developed herein, is to provide these basic data to interested groups for subsequent use in resource development considerations within broadly defined economic and hydrologic subdivisions of the Colorado River Region (frontispiece, General Location Map).

The Lower Colorado Region is subdivided into three economic subregions--Lower Main Stem, Little Colorado, and Gila--and includes 21 counties in four States as follows:

LOWER MAIN STEM

Arizona	Nevada	Utah
Coconino	Clark	Washington
Mohave	Lincoln	
Yuma		

LITTLE COLORADO

Arizona	New Mexico
Apache	McKinley
Navajo	

GILA

Arizona	New Mexico
Cochise	Catron
Gila	Grant
Graham	Hidalgo
Greenlee	
Maricopa	
Pima	
Pinal	
Santa Cruz	
Yavapai	

Data have been organized primarily to conform with regional (economic) boundaries. When the necessary supporting information was available, data were adjusted to hydrologic boundaries so as to meet the needs of other groups participating in the framework study.

Detailed descriptions of the Lower Colorado Region, its other natural resources, climate, history, and current state of development, may be found in the Main Report of the Comprehensive Framework Study and in other appropriate supporting appendices.

Data for the two levels of potential economic development herein are designated respectively as the OBE-ERS and Modified OBE-ERS levels. The first is based upon national projections of basic data as prepared by the OBE-ERS (Office of Business Economics, Department of Commerce, and Economic Research Service, Department of Agriculture), and the second is based upon estimates by regional Federal and State personnel who possess an intimate knowledge of in-region mineral resources and their development prospects. The comprehensive study of the Lower Colorado Region is future oriented; therefore, the concluding tabular projections of mineral output and related water and land needs are the crux of this report. As indicated, projections are incorporated for both the OBE-ERS and Modified OBE-ERS levels of potential development. Which estimate best stands the test of time may begin to be apparent when subbasin and project studies ultimately are made, examining smaller areas in greater detail.

Source material was obtained primarily from reports and files of the U.S. Geological Survey and Bureau of Mines, but was supported by a considerable volume of State publications and from data sources in the private sector.

Projections of mineral industry output through 2020 obviously extend well beyond the productive life of most existing mines and their known reserves. This inferred short-supply situation is not a matter of grave concern; rather, it is a situation that requires objective analysis to search out realistic solutions to mineral resource problems.

Stone, sand, and gravel resources, as well as the Nation's extensive coal deposits, for example, are generally considered adequate for anticipated needs. In contrast, the domestic 9-year crude oil reserve and about a 5-year uranium reserve are obviously matters for concern unless the projected discovery rate or import potential indicate otherwise.

Supply problems do exist--not only in discovery and development, but also in the establishment of economically viable operations. Among the many problems to be resolved are legal access to mineral-bearing lands, acquisition of rights to related resources--water in particular, and ecological implications in mineral resource exploitation. Nevertheless, the 50-year outlook for mineral resource development in the Lower Colorado Region can be generally categorized as bright with promise.

Relationship to Other Appendixes

Estimates of mineral resources, demand, and production, together with related land and water needs, have been developed herein for subsequent integration with other appendixes in the study. Terminology, inasmuch as feasible, conforms with standards used by agencies involved in land and water resources development.

Mineral industry estimates herein, when integrated with studies related to the other sectors of the economy, should provide the framework needed for more detailed analysis, objective planning, and optimum development of resources--in line with established conservation principles--in the several regions of the Pacific Southwest.

CHAPTER 2 - MINERAL INDUSTRY IN THE LOWER COLORADO REGION

Historical Highlights

Archaeological evidence reveals that the art of mining is as ancient and continuous as the story of indigenous man in the Lower Colorado Region. The archaeologic record discloses a widespread and generally progressive utilization of mineral resources by both agrarian and nomadic Indians: stone for agricultural and household utensils as well as weapons; clays, sand, and gravel for ceramic and structural needs; limonite, hematite (two mineral oxides of iron), and numerous other minerals for pigments and other decorative purposes; semiprecious gemstones and precious metals for ornamental, religious, and trading uses. Archaeology, in fact, is a reflection of mining history because most artifacts, relics, and monuments from prehistoric cultures are mineral remains. Moreover, the progressive degree of sophisticated mineral resource use affords one of the best insights to the development of prehistoric cultures. For example, the recorded improvements in prehistoric pottery making in the southwest are clear evidence of a maturing culture, using improved clay mixtures, over time, to produce more enduring and functional vessels to which decorative minerals and mineral pigments have been applied in increasingly complex and artistic designs.

Explorers and missionaries began entering the Lower Colorado Region in the early part of the 16th century. By the 1850's pioneers began to arrive in increasing numbers, but no one time period was marked by a massive influx of outsiders as was the case in the Upper Colorado Region when gold was first discovered there. The first discovery of gold, in placer deposits along the Gila River in Arizona territory, occurred in 1858, one year after the discovery of considerably richer and more extensive deposits in Colorado territory. Silver and copper were the most important metals in early mining ventures. Copper ore was first mined in Ajo in 1854, and shipped overseas to Wales for processing. Silver-copper ore apparently was first mined and domestically processed near Tubac in 1856. Nearly all of the early mining activity occurred in central and southeast Arizona and southwest New Mexico.

A century later much mining activity is still centered in these same areas--copper mining in particular--but increasingly important quantities of minerals, such as copper, uranium, and, most recently, petroleum, are now produced in the northern part of the region. Copper's predominant position in the region's mineral industry is unique; copper output from the region has overshadowed all the combined remainder of Nation's copper output since Arizona and New Mexico became States in 1912. And for many years prior to statehood Arizona territory and the southwestern part of New Mexico territory led all the mineral provinces of the Nation in copper production. Moreover, because of the huge volume of copper ore produced, the associated traces of silver and gold became statistically impressive. (Traces of silver and gold commonly are intimately associated with copper mineralization and usually are carried along with the copper in the mining, milling and smelting steps of copper processing, being separated from the copper in the refining step. Byproduct molybdenum, when economically recoverable, requires special attention in the milling step, or otherwise it is discarded in mill tailings.)

Along with copper the leading commodities of the 1960's have been uranium, sand and gravel, lead-zinc, and cement. This commodity-mix has persisted since the late 50's; prior to the late 50's uranium was not produced in volume in the Lower Colorado Region, and lime was usually found among the top five minerals. There is an excellent chance that petroleum soon will be in the top five and probably will maintain a leading position through the end of the century.

Uranium output has been confined almost exclusively to the Colorado Plateau in the Lower Colorado Region--specifically in Coconino, Apache, and Navajo Counties, Ariz., and McKinley County, N. Mex. Most of the earlier discoveries were found in walls of incised canyons in the plateau, or incidental to exploratory drilling for oil and gas, and occasionally, water. Subsequently, more comprehensive drilling programs were initiated, but with the slack demands of the mid-60's, exploration was curtailed sharply throughout the plateau. Considering the vast area that comprises the Colorado Plateau and the relatively limited amount of sophisticated exploration for uranium in the area, it seems reasonable to conclude that the uranium potential of the plateau remains promising.

Because of the present and potential importance of uranium output in the Lower Colorado Region, the following brief review of uranium industry history in the Upper Colorado Region is considered pertinent.

Initial production of uranium was recorded in Montrose County, Colo., in 1898, some 27 years after its occurrence was first noted in a central Colorado gold-mining district. The uranium ore eventually ended up in Paris and (apparently) was used by the Curies and Bemont who first isolated traces of radium from uranium late in 1898. The history of uranium production from 1898 to the late 1960's is worthy of note because it is a classic example of the boom-bust cycle that unfortunately has been all too common in some branches of the minerals industry.

Soon after the isolation of radium from uranium ore, and because of the supposed therapeutic value of radium in the treatment of cancer, the first uranium boom was launched. The volume of ore mined was relatively minor, and ironically, much of the uranium in the "uranium ore" was lost and low-grade material was discarded. The ore was identified in the field by the canary yellow color of the uranium mineral carnotite, and, although the minute trace of radium in the mineral was the ultimate target, the name "uranium ore" commonly appears in the earliest of production statistics. Uranium also found some limited use as a dye and as a coloring agent in glass.

During the mid 1920's the price of radium had collapsed, but the uranium industry survived to the early 1930's owing to a discovered process for recovering the commonly associated metal vanadium from the ore.

In 1939 scientists at Columbia University in New York City first split the uranium atom, and in 1940 identified the isotope uranium-235 as the prime fissionable form of uranium. In 1942 the first nuclear chain reaction was accomplished by physicists at the University of Chicago. Thus, with the mushrooming advent of the Manhattan Project, uranium ore was disguised by being rechristened "vanadium ore," and then was urgently mined for its uranium content for use in atomic bombs. More precisely, the vanadium ore was mined for uranium-235 (U^{235}), a uranium isotope representing only 0.7 percent of total natural uranium content. (Natural uranium is composed of three isotopes: 99.3 percent U^{238}, the common isotope; 0.7 percent U^{235}, the fissionable material; and a trace of U^{234}, the rarest isotope.)

Following World War II, another uranium boom-bust occurred. Next was the Cold War and the uranium boom of the 50's. A uranium glut developed and a "stretch out" purchase program by the Atomic Energy Commission cushioned the bust of the early 1960's.

Now, in the early 1970's, and with the on-coming development of nuclear powerplants, the uranium industry with four booms under its belt is about to set sail on what appears certain to be its greatest boom. The domestic market has used something like 0 percent (when only radium was sought) to as much as 0.7 percent of the uranium produced during the past two-thirds of a century, and a substantial supply of uranium--the common U^{238} isotope--overhangs the market. Unfortunately, U^{238} is not an atomic fuel. However, U^{238} can be converted into plutonium which then, like U^{235}, can be used as a source of atomic energy. Only 0.7 percent of the uranium produced today is useful for atomic fuel, but if all the U^{238} could be converted into plutonium, there would be something like a 140-fold increase in atomic fuel supply from current output of uranium. The breeder reactor, presently under development, is intended to perform the U^{238}-to-plutonium conversion while producing energy from U^{235}. Thus, with the perfection of the breeder reactor, possibly as much as half the U^{238} supply might be converted economically into plutonium--sometime in the future. At that time--say in 1980's--uranium-mining bust number five may become a reality.

Trends in sand and gravel output are unsurpassed indicators of local construction activity because low value and high bulk necessitate their production as close to markets as possible. Moreover, when sand and gravel data are subjected to a close analysis and modified where necessary (to remove, for example, the one-time-only influence of a major dam project), they can be an excellent indicator of local and regional growth. Furthermore, as cyclic indicators, sand and gravel tend to reflect the change in money rates, peaking out rather early in a business cycle as interest rates rise, and tending to turn up somewhat before the business nadir is approached. Sand and gravel data for the 1947-66 period, as modified, record these typical cyclic characteristics to a remarkable extent when the relatively small output for so large an area is considered. Also, the sand and gravel data clearly reflect the region's pronounced population growth since World War II--although again, in relatively small absolute figures for so large an area.

Lead and zinc have been produced in the Lower Colorado Region since early territorial days. These geologically associated metals have been found in many mining districts in the region; however, most output has been recovered from a wide "mineral belt" of land extending from southern Nevada to southwestern New Mexico. Lead-zinc output in the 1947-66 interval has been extremely variable, reflecting the volatile market prices of the metals. Between 1947 and 1955 annual value of output ranged from less than $10 million to more than $50 million; since the mid-50's value of output has varied between $10- and $20-million. Because of severe competitive factors outside the region--primarily the recent discovery of rich deposits in Missouri, and continuous pressure from low-cost imports--it is difficult to visualize any substantial increase in the region's lead-zinc output.

Cement production in the Lower Colorado Region is confined to Arizona; production commenced in Pima County in 1949 and in Yavapai County in 1959. Cement is considerably more valuable per unit volume and more easily handled than sand and gravel; therefore, its marketing area is commonly quite large. As might be expected, the cement is intended mostly to serve the Lower Colorado Region, and output has paralleled the region's impressive growth. Cement statistics as provided by the Arizona operations to the Bureau of Mines are held confidential in line with company requests.

Mineral Production, Value, and Related Background Data

Mineral production in the United States, Upper Colorado Region, and Lower Colorado Region in base-year 1965 is recorded in table 1. This table stems from a machine printout of mineral industry statistics for the years 1947-66, inclusive. Just as the printout of 1965 data was condensed into this table, subsequently the table will be distilled to a workable quantity of pertinent individual mineral commodity information.

The problem of maintaining company confidentiality when required is apparent in the table; note, too, that the problem extends all the way to the national level. In subsequent tables at the regional and the subregional level, the confidentiality problem has been resolved in most cases by simply averaging several recent years of mineral output data for the base-year figures, and/or by consolidating data for commodities that mostly are produced from a common source. For example, petroleum will be the catch-all term herein for crude oil, natural gas, liquid petroleum gases, helium, etc. Likewise, uranium data subsequently will include vanadium data because the two commodities are commonly produced from the same ores in the northern part of the Colorado Plateau. (If the uranium value predominates, the ore is called uranium ore; if vanadium value is greater, it is vanadium ore; if uranium and vanadium values are about equal, it becomes a difficult choice. Herein, uranium is the commodity of vital concern; therefore, vanadium is always relegated to byproduct status for convenience--no matter whether the ore has been customarily classified as uranium ore, vanadium ore, uranium-vanadium ore, or vanadium-uranium ore.

The term "byproduct" and its close kin "coproduct" will be used frequently herein; thus, implicit definitions are timely. Byproducts refer to minerals economically recovered from ores, fluids, or gases incidental to the recovery of a primary mineral. Coproducts refer to the two or more minerals that must be recovered from ores, fluids, or gases in order to establish and maintain the economic soundness of a mineral industry operation. Mineral byproducts are considerably more commonplace than coproducts in the Colorado Region. However, it should be realized that commodity prices can fluctuate to such an extent that the rigid definitions of byproduct and coproduct commonly fail in time. Moreover, the trend in many sectors of the mining industry is toward treatment of lower grade ores; thus, byproducts on occasion may be elevated to the status of a coproduct. For example, molybdenum is a byproduct recovered at a number of copper mining operations in Arizona--but in a recently committed mine development the molybdenum will be a coproduct because copper mineralization by itself is too low in grade to be mined economically. In essence, the value of the molybdenum mineralization, although substantially less than that of the copper, was a necessary component for the project to be economic.

TABLE 1. - Mineral production in the United States, Upper Colorado Economic Region, and Lower Colorado Economic Region in 1965[1/]

Mineral	United States		Upper Colorado Region		Lower Colorado Region		Value contribution to total U.S. production (percent)		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Upper Colorado Region	Lower Colorado Region	Colorado Region
Mineral fuels:									
Coal, bituminous....thousand short tons..	512,088	$2,276,022	10,905	$54,245	352	$1,816	2.4	0.1	2.5
Helium ....thousand cubic feet..	4,365,068	66,687	80,583	2,821	2/	2/	4.2	2/	2/
Natural gas....million cubic feet..	16,039,753	2,494,542	687,905	85,398	3,106	376	3.4	n	3.4
Natural gas liquids:									
Natural gasoline....thousand gallons..	7,288,070	494,354	127,843	7,735	-	-	1.6	-	1.6
LP gases .... do....	11,257,267	417,249	456,377	16,679	-	-	4.0	-	4.0
Petroleum .... thousand 42-gallon barrels..	2,848,462	8,158,150	67,118	181,330	2/	2/	2.2	2/	2/
Uranium ore.... short tons..	4,362,614	83,915	942,282	19,517	1,835,898	34,318	23.3	40.9	64.2
Other fuels[3/]....	XX	137,714	XX	5,780	XX	3,307	XX	XX	XX
Total mineral fuels	XX	14,129,000	XX	374,000	XX	40,000	2.6	0.3	2.9
Metals:									
Copper .... short tons..	1,351,734	957,028	3,822	2,707	802,026	567,834	0.3	59.3	59.6
Gold .... troy ounces..	1,705,190	59,682	35,188	1,232	155,060	5,427	2.1	9.1	11.2
Iron ore .... thousand long tons..	84,472	804,498	114	787	8	51	0.1	n	0.1
Lead .... short tons..	301,147	93,959	20,470	6,387	10,016	3,125	6.8	3.3	10.1
Manganiferous ore (5 to 35 percent Mn).... do....	332,763	2/	-	-	50,090	2/	-	2/	2/
Mercury .... 76-pound flasks..	19,582	11,176	-	-	158	90	-	0.8	0.8
Molybdenum .... thousand pounds..	77,310	120,801	50,715	78,609	10,312	17,296	65.1	14.3	79.4
Silver .... thousand troy ounces...	39,808	51,469	1,755	2,269	6,550	8,469	4.4	16.5	20.9
Vanadium .... short tons..	5,226	18,284	4,788	15,753	109	381	86.2	2.1	88.2
Zinc.... do....	611,153	178,284	51,210	14,953	59,825	17,469	8.4	9.8	18.2
Other metals[4/]....	XX	2/	XX	2,150	XX	2/	XX	XX	XX
Total metals....	XX	2,388,000	XX	125,000	XX	621,000	5.2	26.0	31.2
Nonmetals:									
Asbestos ....short tons..	118,275	10,162	-	-	3,469	441	-	4.3	4.3
Clays .... thousand short tons..	55,089	203,772	293	650	150	278	0.5	0.3	0.8
Gypsum .... do....	10,035	37,423	-	-	585	2,147	-	5.7	5.7
Lime .... do....	16,794	232,939	2/	2/	448	8,205	2/	3.5	2/
Pumice .... do....	3,483	6,640	52	78	1,161	1,516	1.2	22.8	24.0
Sand and gravel .... do....	908,049	957,416	6,895	7,126	19,685	22,578	0.7	2.4	3.1
Stone .... do....	780,072	1,203,618	2,473	3,807	3,410	5,925	0.3	0.5	0.8
Other nonmetals[5/]....	XX	2,265,000	XX	2/	XX	11,413	XX	XX	XX
Total nonmetals	XX	4,916,000	XX	43,000	XX	53,000	0.9	1.1	2.0
Grand total mineral production[6/]....	XX	21,433,000	XX	542,000	XX	714,000	2.5	3.3	5.9

n Negligible. XX Not applicable.

1/ Source: Bureau of Mines Minerals Yearbook, Volume I, 1965, and files of the Denver and San Francisco Offices of Mineral Resources. Values are unadjusted 1965 dollars.

2/ Figure withheld to avoid disclosing individual company confidential data; value included with value of other fuels, other metals, and other nonmetals.

3/ Other fuels (in order of value) are gilsonite and natural carbon dioxide in the Upper Colorado Region and helium and petroleum (values combined but withheld) in the Lower Colorado Region.

4/ Other metals are tungsten, pyrite, and tin in the Upper Colorado Region and pyrites, tin, and tungsten in the Lower Colorado Region.

5/ Other nonmetals are sodium carbonate, potash, phosphate rock, salt, and lime (value withheld) in the Upper Colorado Region and cement, perlite, feldspar, mica, diatomite, and salt in the Lower Colorado Region.

6/ Total mineral production for 1965, as listed in the table and footnotes 3, 4, and 5, was comprised of 29 mineral commodities in the Upper Colorado Region and 30 mineral commodities in the Lower Colorado Region. Other mineral commodities produced in the Region since World War II are as follows: Upper Colorado Region--manganese, manganiferous ores, columbite-tantalite, beryllium, rare earths, clays (varieties other than those produced in 1965), feldspar, barite, fluorspar, lithium, gypsum, and mica. Lower Colorado Region--coal, manganese, columbite-tantalite, beryllium, rare earths, clays (varieties other than those produced in 1965), brucite, barite, fluorspar, and vermiculite.

Table 1 also serves as a reference to all the mineral commodities produced in the Colorado Regions during the 1947-66 interval. The tabular listing and footnotes 3, 4, and 5 cover the minerals produced in 1965--footnote 6 completes the post-World War II picture. This "minerals register" may seem impressive at first glance, but upon further inspection, it is apparent that some items are unimportant to a comprehensive framework study. For example, it is clear that in 1965 the value of copper production in the Lower Colorado Region was overwhelmingly predominant in the minerals industry, whereas the value of iron ore output was quite insignificant.

Table 1 implies that a wide variety of metalliferous ores was mined in 1965, but many of these commodities were byproducts. In the Lower Colorado Region more than 10 million pounds of molybdenum was produced but no molybdenum ore was mined because, as previously indicated, it was recovered as a byproduct from copper ore from several mines. In contrast, all molybdenum in the Upper Colorado Region was recovered from molybdenum ore at one mineral operation--and from this molybdenum ore, the byproducts tungsten, pyrite, and tin were recovered. Regionwide, virtually no gold and silver ores were mined; most of the gold and silver was recovered as byproducts from copper operations in the Lower Colorado Region and as byproducts (or coproducts) from lead-zinc operations in the Upper Colorado Region. And finally, the copper output in the Upper Colorado Region also was a byproduct of lead-zinc output. Thus, it is evident that only a handful of the 40 or so mineral commodities listed in table 1 dominate the production and value figures in both the Upper and Lower Colorado Regions.

As pointed out earlier, the 1965 data in table 1 reflect but one point in time in the 1947-66 interval. This interval was selected because of its relative economic stability and moderate growth, and the absence of major wars and depressions, but it included localized military conflicts and short, minor, economic recessions--in summary, conditions that are expected to persist over the near-term, say through 1980, and may well prevail throughout the extended period of consideration. Thus, the 1947-66 interval is an era of basic concern.

If a table of 1947 mineral production was developed, it would be somewhat similar to table 1 as far as the list of mineral commodities is concerned, but quantities and values would be noticeably less. In unadjusted dollars the value of mineral production for the United States increased from $12.4 billion to $21.4 billion between 1947 and 1965, an increase of 73 percent. In Colorado River Basin States during the same period, Arizona output soared from $187 million to $580 million, up 210 percent, and Colorado output rose markedly from $105 million to $331 million, up 215 percent. For this 1947-65 interval the important point is neither the approximate similarity in the mineral commodity mix through the period nor the marked increase in value of output: the significant point is--and this cannot be overstressed--that many of the commodities produced in 1965 and listed in table 1 were produced from reserves not known to exist in 1947. That is, if the known mineral reserves of 1947 were now reviewed in detail, almost all such reserves would be found to have been exhausted before 1965. Moreover, it is equally true now, in 1970, that currently known reserves of almost all the mineral commodities listed in table 1 will be exhausted by the year 2000, if not before.

The Geological Survey and Bureau of Mines use the following terminology in classifying ore reserves:

> Measured Ore: Is ore from which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are so closely spaced and the geologic character is so well defined that the size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits which are stated, and no such limit is judged to differ from the computed tonnage or grade by more than 20 percent.

> Indicated Ore: Is ore for which tonnage and grade are computed partly from specific measurements, samples or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to outline the ore completely or to establish its grade throughout.

> Inferred Ore: Is ore for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition for which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred ore should include a statement of the special limits within which the inferred ore may lie.

In the Lower Colorado Region, reserves of essentially all minerals fall short of the foreseen needs through 2020; therefore, it is necessary to look beyond reserves and to rely upon the probable existence of a substantial number of presently unknown ore deposits in the largely undefined mineral resource base as the source of long-range supply to meet expected demands.

An example may help to clarify the difference between reserves and resources. The Upper Colorado Region has about 139 billion tons of coal resources, and about one-half the resource customarily is considered to be recoverable. Coal resources are classified by type, bed thickness, overburden or depth, chemical characteristics, etc. However, of this vast resource, possibly only 100 to 200 million tons can be labeled as coal reserves--specific coal resources that have been explored, blocked out, and earmarked for certain defined markets affording a fairly satisfactory economic return. Anticipated market demands for mineral commodities stimulate the search for and investigation of mineral resources in a continuing effort to develop new sources of supply--and when identified and economically committed to the market, the specific mineral resource is reclassified as a mineral reserve.

Thus, it is true that almost all presently known mineral reserves will be exhausted; but, it is equally true that, given suitable incentives, exploration efforts will uncover hidden mineral deposits that will be subsequently classified as mineral reserves. It is almost a certainty, for example, that no mineral listed in table 1 will be exhausted by 2020. From a broad viewpoint, mankind generally has neither more nor less mineral than at any time in the past. Except for the conversion of some mineral fuels into different forms of energy, the supply of mineral resources seems unimpaired in volume.

It must be recognized, however, that there is a critical problem in developing adequate supplies of domestic mineral that are economically available. That availability is chiefly a function of developing demand and technology, quality of mineral deposits, and access to land and related water resources.

Some other mineral supply problems appear inevitable. For example, man's supply of light, heat, and other forms of energy historically has been derived from organic materials--in historic sequence, animal matter and fuelwood, coal, oil, and gas. Currently, oil and gas supply about 75 percent of total domestic energy demands. However, it is always timely in long-range planning to consider alternate sources of future energy supplies. In this specific example three avenues of approach to the developing mineral fuels problem seem evident. First, a step could be made back in the organic fuel series to coal and its huge resource base. Second, the status quo could be maintained by technology to convert coal, oil-shale, and tar sands into the current market favorites, oil and gas. Third, technology could be developed on a broad front toward utilization of energy from such new sources as fuel cells, fission, fusion, and solar sources.

It is most likely that all three avenues will be traveled in some degree to satisfy the Nation's fuels-mix requirement. The resource base will yield a variety of mineral fuels, the marketplace will accept the wide array of energy supplies, and vested interests in both emerging and ebbing fuels industries will press for representation in the Nation's future fuels mix.

The Mineral Resource Base

Background data in the foregoing section partially have been intended to ease the departure from emphasis on customary considerations for the short term, such as reserve data and recent output trends, and thus permit a more flexible approach to the long-range outlook. Reserve data have proved useful in developing projections of mineral output and related land and water needs for 1980; however, for projections to 2000 and 2020, it has been necessary to make some broad assumptions.

The basic assumption is that all important mineral resources customarily produced in the Lower Colorado Region will be available through 2020. This basic assumption does not assume away the underlying problem of an adequate mineral supply at realistic costs because, in the Lower Colorado Region, only a few important mineral commodities are matters of concern. Important minerals, by definition, are the handful of commodities that constitute the bulk of production value, generate the most income and employment, and require the vast majority of related land and water resources.

A second assumption is that the regional structure of the non-fuel mineral industries will not be markedly changed through 2020. For example, Lower Colorado Region copper output in the past several decades has represented about 60 percent of the national output, and this share of national copper production seems secure--probably through 2020. Even uranium, with its relatively short period of substantial production and its limited amount of measured reserves, illustrates some structural stability. The Colorado Region, predominantly in the Four Corners area, has produced about 65 percent of domestic uranium output since the late 1950's; or more specifically, approximately 40 percent of national uranium output has been from the Lower Colorado Region and about 25 percent from the Upper Colorado Region. (These data tend to fail during periods of depressed uranium activity--the mid-60's being a recent example.)

In summary, the mineral resource base is assumed to be sufficient to meet all reasonable demands through 2020. Given suitable incentives and the institutional flexibility that will permit all resources to rise to their most rewarding economic use, realistic demands for mineral resources--as well as demands for other raw materials--can be satisfied.

Markets

Markets for the mineral commodities currently mined in the Lower Colorado Region--those listed in table 1--can be treated briefly.

In general, mineral fuels produced in the Lower Colorado Region find markets outside the region, metals are marketed nationwide, and nonmetals are used within the region.

The Lower Colorado Region is an important exporter of uranium, the only mineral fuel currently produced in substantial volume. Oil and gas only recently have been discovered and produced, and output of coal, although intermittently produced for decades, has been negligible in importance, too. Uranium is marketed nationwide, but some foreign sales contracts also have been recorded.

Future market potential, both domestic and foreign, is excellent. Oil and gas output is expected to increase in the near-term with distribution to southwest and West Coast markets most probable. Coal output is to increase markedly to feed a thermal powerplant in southern Nevada; over the longer-term, however, coal's future in the region does not appear promising.

Almost all metals output leaves the Lower Colorado Region, mostly in the form of mill concentrates, or smelter product, for further upgrading or refining and subsequent industrial use elsewhere in the Nation. During the 1960's molybdenum has been the only metal consistently produced in sufficient quantity to satisfy some foreign demand. Periodically the Nation has been a net exporter of copper, and obviously the region's vast annual copper output was largely responsible for this occasionally favorable balance-of-trade item. Statistically the Nation has hovered about self sufficiency in copper output for many years, usually falling short of a balance by some small margin. Considering the on-going new mine developments and expansion programs at established operations in the region (and elsewhere in the Nation), a marked surplus production potential seems virtually certain at least until the mid-1970's or so. Therefore, with due consideration to political and social instability in several important foreign copper-producing countries, the region's output seems destined to become much more widely distributed through the 1970's, thus periodically enhancing the Nation's balance-of-trade account.

Essentially all nonmetals production in the Lower Colorado Region is for internal use, mostly to meet regional construction industry needs. Typically bulky, low in unit value, and nearly ubiquitous in contiguous regions, the more important nonmetallics--sand, gravel, cement, stone, gypsum, and clays--ordinarily are transported only short distances to markets. Therefore, future output primarily will be in response to regional construction industry demands, and such construction demands are a function of regional population growth and local developments.

CHAPTER 3 - GEOLOGY

The kinds of mineral deposits that occur in any region are controlled by the character and structure of the rocks, and these factors also largely determine the topography which, in turn, affects climate and accessibility--all items that have an important bearing on the exploitation of the mineral resources. The following broad summation of the geology should be helpful in understanding where the significant mineral resources are concentrated and in indicating the physical features that may be factors to consider in developing mineral resources of the Lower Colorado Region.

The Lower Colorado Region encompasses parts of two physiographic provinces, the Colorado Plateaus province in the northeastern part and the Basin and Range province in the southwestern part (fig. 1). The juncture of these two provinces constitutes a broad northwestward-trending belt that has structural as well as physiographic characteristics that are similar to both provinces. For descriptive purposes this area will be referred to as the mountain belt. The physiographic and geologic features of both provinces and the mountain belt are described below.

Colorado Plateaus Province

The Colorado Plateaus province in the northeastern part of the region encompasses Subregion 2 and the northeastern part of Subregion 1. Its western and southern boundary is marked by a line that extends southwestward from Iron County, Utah, to near Kingman, Mohave County, Ariz., then it swings southeastward and extends along the Mogollan Rim into central Catron County, N. Mex. The part of the Colorado Plateaus province within the Lower Colorado Region is a flat-topped feature that is incised by the canyons of the Colorado River system. The general altitude of the surface is more than 5,000 feet, much of it exceeds 6,000 feet, and parts are more than 9,000 feet. The structural counterpart of the physiographic feature is the Colorado Plateau, which can be visualized as a saucerlike stack of strata, mainly of Paleozoic and Mesozoic ages, that covers Precambrian base rocks to depths generally of several thousand feet. The slightly upturned "rims" of the stack are exposed in cliffs a few hundred to 1,500 feet high that mark the southwestern margin of the Colorado Plateau as a physiographic element. Locally strata of the plateau are mildly warped into broad domes, synclinal basins, or monoclinal flexures and displaced by high-angle faults. Complexly deformed rocks are confined to the older formations of the Precambrian basement, which is exposed only in very restricted areas within the province--as in the depths of the Grand Canyon. The deepest and broadest of the basins, and therefore the ones that contain the thickest remnants of Mesozoic rocks, and concomitantly the most widespread coal resources, are the Black Mesa Basin of northcentral Navajo County, and the San Juan Basin

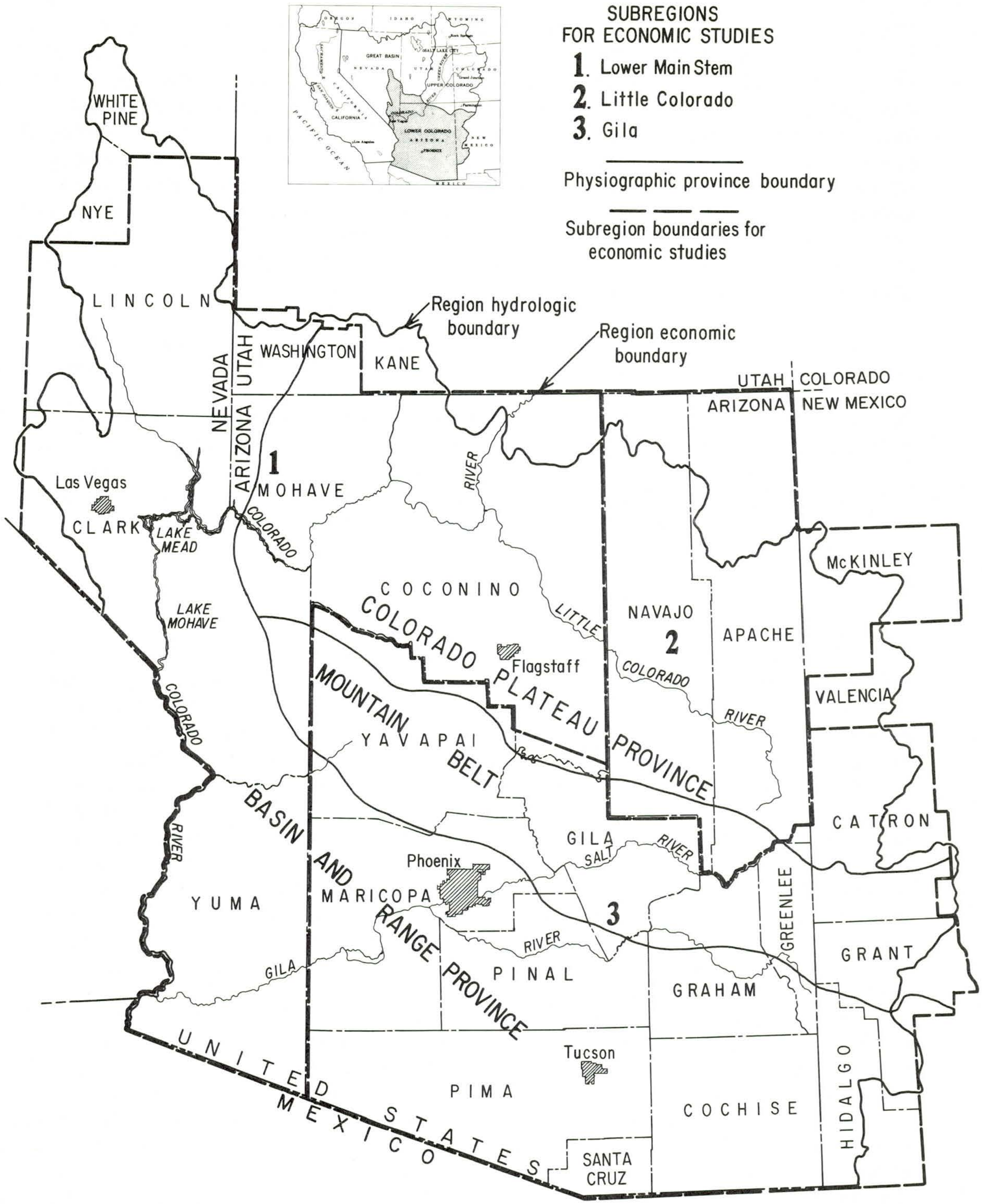


FIGURE 1. – Index map of Lower Colorado Region showing subregions and physiographic province boundaries.

principally off the northeast corner of McKinley County, N. Mex. Nonmarine sedimentary strata of Cenozoic age discordantly cover older strata through a small part of central Navajo County, Ariz., and through considerable parts of Apache County and adjacent parts of New Mexico. Over much broader areas, as in the vicinity of Flagstaff and in southern Apache County, Ariz., and adjacent Catron County, N. Mex., lavas of Cenozoic age surmount the high plateau surface and locally make up volcanic cones and peaks, some more than 12,000 feet in altitude. At the least these volcanic materials cover any underlying resources, such as stratiform uranium and coal deposits, and generally bury them to depths beyond economic exploitation.

Basin and Range Province

That part of the Basin and Range province encompassed by the Lower Colorado Region is characterized by elongate, generally north- or northwest-trending mountain ranges that are isolated by broad, aggraded desert plains. Structurally these ranges contrast with the highlands of the Colorado Plateau in that the rocks are complexly faulted, strata of the fault blocks are variously tilted or folded, and in a great many localities invaded by plutonic rocks. East of a line between Tucson and Phoenix rugged ranges that rise 5,000 feet or more above intervening broad valleys make up about half of the area. The greatest part of the base metal produced in the Lower Colorado Region has been from mines in this mountainous terrain. Commonly the alluvium of the valley fill, which is detritus that was wasted from the ranges during and since their uplift in Cenozoic time, is hundreds to several thousands of feet thick. Southwest of the Tucson-Phoenix line the ranges are lower and narrower, but still commonly precipitous, and the intermontane plains make up much larger parts of the area. These lower mountains are fringed in many places by broad rock-cut surfaces (pediments) that are covered by a veneer of alluvium. In recent years the search for metal deposits concealed beneath such veneered parts of the desert plains of Pima and Pinal Counties has been spectacularly successful and accounts for a considerable part of the copper resources presently known. North of the Bill Williams River large mountain masses constitute a large part of the area, but the ranges are not as high as in southeastern Arizona, and their rocks are not as pervasively intruded by plutons of the type that were the "metal-bringers" farther southeast.

Mountain Belt

The mountain belt is roughly a 50-mile-wide area that extends southeastward from near Kingman, Mohave County, Ariz., into Catron and Grant Counties, N. Mex. The terrane is very rugged, and alluvial-filled basins are minor elements. In the western part, the belt is delineated by the Mogollon Rim and other south-facing escarpments. In the eastern part, these features extend under volcanic mountains where the margins of the belt are obscure and are drawn rather arbitrarily.

Geologic structures in the belt generally are transitional between those in the Basin and Range and in the Colorado Plateau. This transition, however, is abrupt within the mountain belt along a line drawn from Roosevelt Lake east-southeast across Gila County: The complexly faulted and intricately intruded terrane to the south terminates at this line and, to the north, younger Precambrian and Paleozoic strata generally are flatlying and, where deformed, are faulted and folded similar to the rocks still farther north in the Colorado Plateau. Furthermore, plutons comparable to those with which the metal deposits are spatially associated do not occur north of the structural transition. Elsewhere, the nature of the transition is not as clear. Farther east it must extend a few miles north of Morenci and Silver City, but it is obscured by thick covers of Tertiary volcanic rocks. Northwest of Gila County the Paleozoic strata have been almost completely eroded from the older Precambrian basement rocks, which were complexly deformed and locally mineralized before the Paleozoic strata were laid down. Moreover, through about half of this northwestern part of the mountain belt, the stripped Precambrian rocks are covered also by Cenozoic lavas. Northwest from Roosevelt Lake, the structural transition can be projected northwestward about through Prescott.

Regardless of exact delineation, it is well established that the search for and exploitation of mineral resources north and south of the structural transition present different physical problems as well as different mineral commodities for the most part in the two geologically dissimilar areas.

Geologic Relations of the Mineral Resources

In the Colorado Plateau part of the region, the principal resources are those for which sedimentation processes played a considerable genetic role, namely, coal, oil and associated commodities, and salines. Of the metals, only uranium and vanadium, in more or less stratiform sandstone-type deposits, are to be expected in significant amounts. Exceptions are the metals emplaced in Precambrian rocks but generally buried to depths prohibitive for exploitation. Any resources of the plateau-type that once existed farther south were largely destroyed by pervasive deformation, igenous intrusion, and erosion that occurred in Mesozoic and Cenozoic times.

These same processes, however, were all important in the emplacement, secondary enrichment, and exposure of the highly productive and significant base-metal deposits in the Basin and Range part of the Lower Colorado Region. The porphyry copper and zonally associated lead-zinc deposits are spatially related to the numerous quartz-bearing granitoid intrusions that were emplaced in southeast Arizona and the adjacent part of New Mexico. Most of the ore-related intrusions are of Late Cretaceous or early Tertiary age. Notable exceptions are in the Bisbee district, in which deposits are associated with one of the few Early(?) Jurassic centers of igneous activity known in the region, and massive sulfide replacement deposits in Precambrian rocks, mainly in Yavapai and Mohave Counties. At least some of the larger of these replacement deposits, such as the now almost exhausted deposits at Jerome, were formed in Precambrian time.

Through parts of the Basin and Range province, especially in western Pinal and much of Maricopa and Yuma Counties, Late Cretaceous-early Tertiary plutons seemingly are sparse and few significant base-metal deposits are known. Whether this reflects a real lack of intrusions and associated metal deposits or reflects their general concealment beneath the cover of volcanic rocks common in many of the mountain ranges or beneath the broad fills of the intervening plains remains to be determined. Certainly, the recent discovery of large porphyry and tactite-type copper deposits in the pediments of eastern Pima and southwestern Pinal Counties offers encouragement for additional discoveries to be made in this area.

Geothermal resources in the form of extremely hot water or even dry steam may be present at depth in some of the larger intermontane basins of the western part of the Lower Colorado Region. These basins are thought to be tensional rifts in the earth's crust, into which have been deposited several thousands of feet of alluvial debris. The larger rifts, such as Amargosa Valley, may be essentially bottomless so far as bedrock is concerned, and there may be a high heat flow into the saturated alluvial fill of such basins. It would be advisable to include systematic temperature measurement at all wells and test holes as a part of the future ground-water investigations of these basins.

CHAPTER 4 - MINERAL RESOURCES

The mineral resources considered here are only those that occur in large enough volume or value so that their exploitation can have significant impact on (1) water use, (2) land use, or (3) the economy within a local geographic subunit (usually county).

"Known resources" are those for which there is considerable tangible evidence of their location and disposition; some are reserves for which quantity and grade are well established; others are submarginal because of low grade or other factors and consequently are less well outlined but are potentially exploitable in the next 50 years. The "predicted additional resources" are those comparable in character that, from geologic premises, will likely be discovered in the next few decades. Their exact location is not known, but target areas in which they may be found are broadly established. At least 50 percent of the minable reserves of copper now known in the Lower Colorado Region were in the "predicted resource" category in the early 1950's. The consumption of some resources, such as certain construction materials, hinges on local need more than on occurrence in specific grade and quantities; and for some, such as halite, or potash, no real hint of need for exploitation presently exists--nonetheless they are listed and discussed because they have potential use. Actually there are few specific data on such resources, so they are summarized in the narrative discussion.

The resources are discussed under three general groups: (1) mineral fuels, (2) metallic minerals, and (3) nonmetallic minerals. Individual resource data are shown in accompanying maps by county.

Mineral Fuels

Coal

Coal resources of the Lower Colorado Region total about 17.5 billion tons. All significant resources are enclosed in strata of Late Cretaceous age, and all resources are subbituminous to bituminous in rank. More than 98 percent of the resources are in Subregion 2 (fig. 2), mostly in McKinley County, N. Mex., and the Black Mesa field of northern Apache and Navajo Counties, Ariz. The relatively small resources assigned to Coconino County (Subregion 1) are in the western fringe of the Black Mesa field.

The estimates presented in table 2 are for original coal resources in the ground as determined by mapping and exploration. This original tonnage has been reduced by past mining and losses in mining, but the reduction is trivial in comparison with the amount remaining. Recoverable resources are about half of the totals presented in table 2. Most of the tonnage is near outcrops, and the great bulk is less than 1,000 feet below the surface.

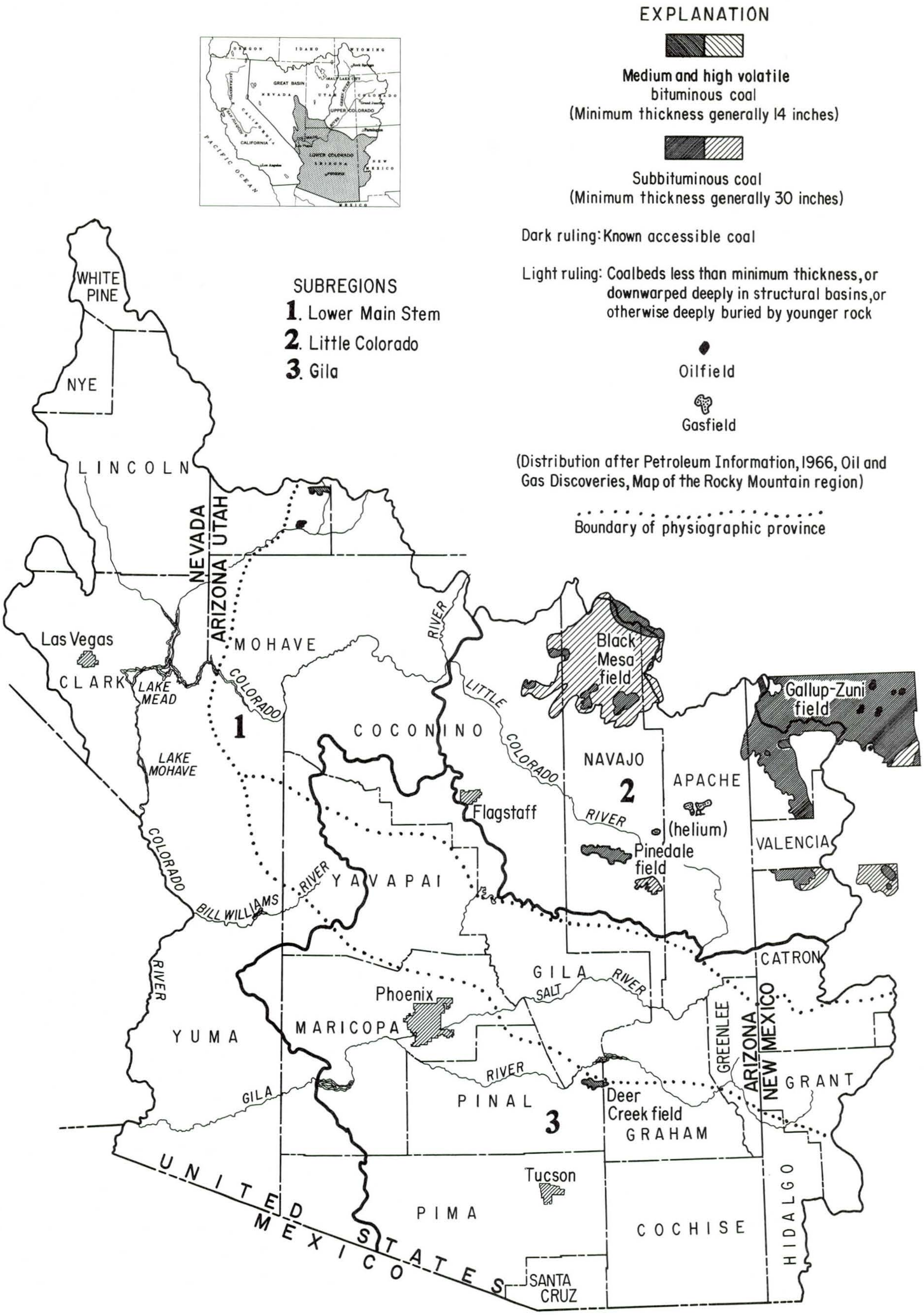


FIGURE 2. – Coal deposits and oil and gas fields, Lower Colorado Region.

TABLE 2. - Coal resources, Lower Colorado Region

Subregion State County	Type of coal	Quantity (million short tons)			
		Measured	Indicated	Inferred	Unclassified
Lower Main Stem					
Arizona					
Coconino	Subbituminous	-	-	-	25
Utah					
Washington	Bituminous and negligible anthracite	-	-	-	-
Lower Main Stem total		-	-	-	25
Little Colorado					
Arizona					
Apache and Navajo	Subbituminous to bituminous	-	-	-	4,000
New Mexico					
McKinley	Subbituminous	234	240	12,721	-
Little Colorado total		234	240	12,721	4,000
Gila					
Arizona					
Pinal	Bituminous	-	-	-	10
New Mexico					
Catron	Subbituminous	-	-	267	-
Gila total		-	-	267	10
Lower Colorado Region totals		234	240	12,988	4,035

The estimates include bituminous coal in beds as thin as 14 inches and subbituminous coal in beds as thin as 30 inches, because some coal in these thinner beds is recoverable by strip and auger methods. However, most of the coal is in thicker beds.

Crude Oil, Natural Gas, and Associated Helium

Only three counties in the Lower Colorado Region have had oil and gas production--Washington County, Utah, in Subregion 1 and Apache County, Ariz., and McKinley County, N. Mex., in Subregion 2. In addition three counties in Arizona--Coconino and Mohave in Subregion 1, and Navajo in Subregion 2--have some potential. These resources are entirely in Mesozoic or Paleozoic host rocks; none of the areas contain Tertiary rocks favorable to the accumulation of oil and gas. The 12 counties of Subregion 3 and Clark and Lincoln Counties of Subregion 1 are mostly within the structurally deformed and therefore less favorable Basin and Range province or have been widely stripped of favorable host strata. There has been very little drilling in these counties; for lack of information no attempt has been made to estimate resources from them.

Total crude oil resource in the Lower Colorado Region is about 275 million barrels, of which about 52 million barrels is estimated as reserves and the rest is predicted resources. Of the total crude oil resource, 75 percent is concentrated in Subregion 2 and 25 percent in Subregion 1.

Total resources of natural gas in the region are about 1,640 billion cubic feet, of which 125 billion cubic feet is estimated as reserves and about 1,515 billion cubic feet is predicted resources. Similar to the crude oil resources, about 75 percent of the gas resources are in Subregion 2 and 25 percent in Subregion 1.

Total helium resources, which are associated with the natural gas, were estimated in 1967 as about 2.5 billion cubic feet; all are allocated to Apache County. Helium has been discovered in Navajo County, but the field was shut-in in 1969. Gas resources only recently have been found in east-central Navajo County and in the new Dineh-bi-Keyah oilfield of northern Apache County. If helium can be recovered from these gases, the resources--all in Subregion 2--may be increased appreciably.

The crude oil and natural gas resources have been reviewed as possible sources of sulfur. Because most crude oils contain less than 0.5 percent sulfur, and less than 10 percent of the 500 natural gas samples analysed from the Colorado Region contained more than a trace of hydrogen sulfide (about 2 percent of the samples contained as much as 1 percent), resources of associated sulfur are not considered significant.

Metallic Minerals

Copper and Associated Resources

During recent years the Lower Colorado Region has supplied 55-60 percent of the U. S. copper production; furthermore, the rate of discovery has been high, so in the next several decades an even greater proportion of domestic copper is expected to come from this region. Copper and associated molybdenum, gold and silver, and some zinc occur in three principal types of deposits in the region: (1) disseminated or porphyry, (2) replacement or contact metamorphic, and (3) sandstone. The disseminated deposits are of greatest importance, the replacement or contact metamorphic deposits are important locally, and the sandstone-type deposits are only of minor importance. Copper resources of minor importance also occur in complex deposits, and are discussed under associated base and precious metals.

About 95 percent of the known copper resources in the region--approximately 50 million tons of copper--is in the disseminated (porphyry-type) deposits and is contained in 7.8 billion tons of ore. This represents more than 99 percent of the ore that contains the total known copper resource. This ore tonnage, however, includes only a small part of the submarginal rock that is being moved to leach piles and is providing an important and increasingly significant yearly part of the copper production. Significant porphyry-type deposits occur in every Arizona county of Subregion 3 except Maricopa County, and in Grant County, N. Mex.; they also occur in Mohave County, Ariz., of Subregion 1 (fig. 3). At least 60 percent of the copper resources in the western half of Subregion 3 is in occurrences that have been discovered since 1954. Furthermore, this western area is considered most favorable in which to find new deposits, especially in a belt that extends from Santa Cruz County northwest toward Phoenix (fig. 3).

Molybdenum is a substantial byproduct resource in the copper ores, and it totals about 690,000 tons of metal in the known ores that are suitable for its recovery. The content in these ores generally ranges from 0.005 to 0.05 percent molybdenum. Some of the ore bodies, as in Pima County, tend to average near the higher-grade end of this range so that molybdenum in such deposits can be considered a coproduct and, thus, permit a lower-grade copper cutoff.

The significant silver and gold resources in the region also are mainly in the disseminated copper ores. In such ores, the known resources are estimated to total 400 million ounces of silver and 10 million ounces of gold. This estimate is based on recoveries of gold and silver from districts in which disseminated ores are being mined. Inclusion of 124 million ounces of silver and 3.6 million ounces of gold as byproducts of disseminated copper ores is only a part of this

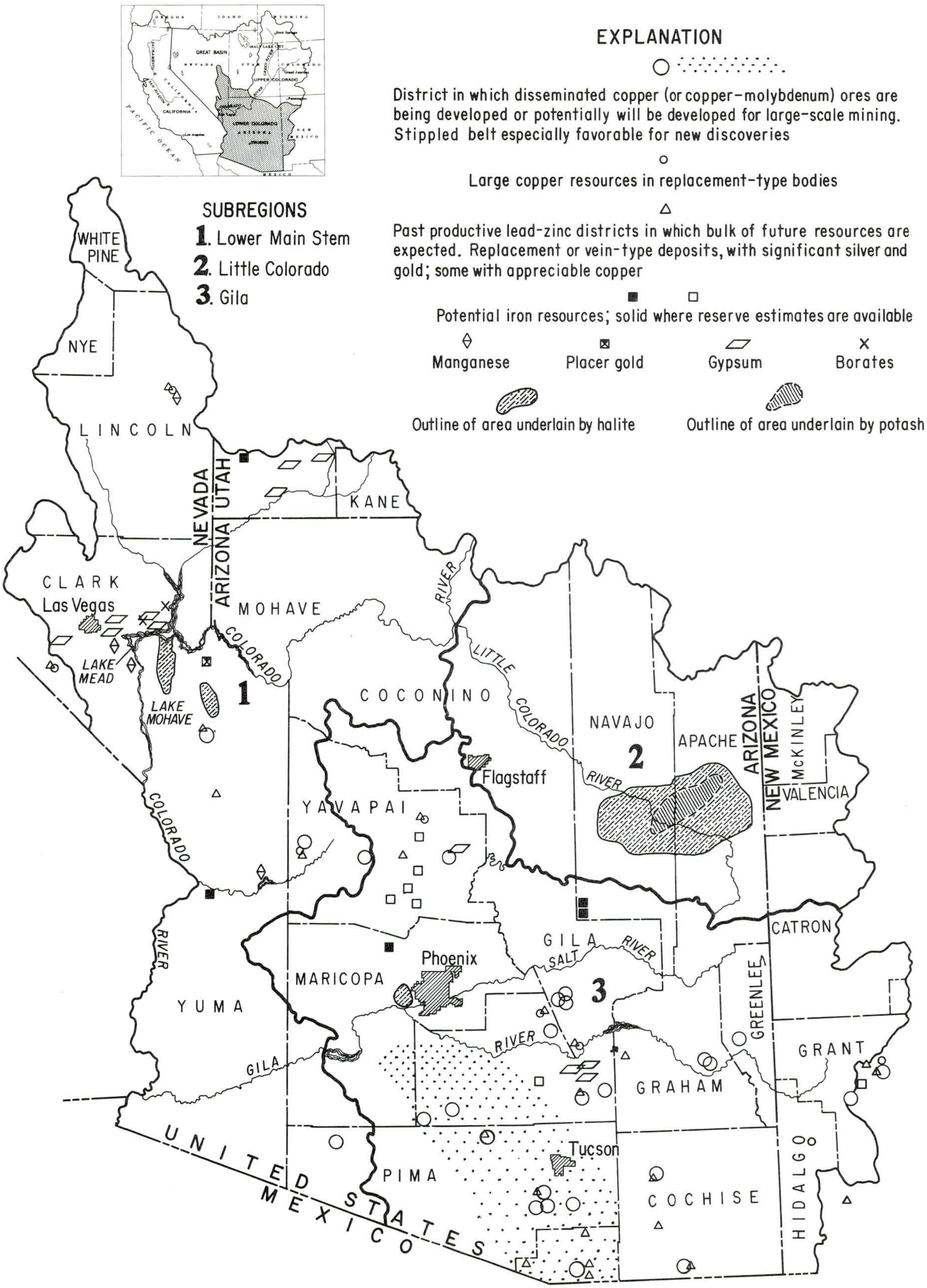


FIGURE 3. – Copper, associated base and precious metals, ferrous metals, placer gold, and nonmetallic resources, Lower Colorado Region.

estimate because data are not available on the gold and silver contents of many of the disseminated copper bodies.

Some occurrences are dominantly composed of sulfide copper minerals, either primary or secondary; others are largely in partly oxidized ores, and some are mixed oxide-sulfide ores. Recent developments in leaching technology permit very low grade oxide ores--down to 0.2 percent copper--to be included in the known reserves. The trend toward exploitation of the latter type of ores may give impetus to the building of more sulfuric acid plants in the region.

All of the disseminated deposits are spatially related to stocks, plugs, sills, or dikes of granitoid rock. Some are mainly within the shattered cupola of a stock; the greater parts of other deposits are in the crackled host rock peripheral to the intrusions. Included in the latter are ores disseminated in silicated limestone or other silicate-bearing sedimentary rock; except for their grade and relation to adjacent ores these would ordinarily be termed contact metamorphic or tactite ores. Some of these tactite ores locally include appreciable amounts of zinc, and zinc-bearing ores may become an increasing part of the recovered resources as the low-grade transitional interval between the porphyry ores of the stocks and the higher grade zinc ore bodies peripheral to the stocks are mined.

A few breccia pipe occurrences offer some promise. As a type, these deposits tend to be individually small, but are high in molybdenum content. None of the breccia pipe deposits are now being mined, but present data suggest that some groups of pipes are potentially the nuclei for a large-scale operation.

The disseminated ore bodies are commonly irregular in plan and section and display a wide range of tonnages and grades. They range from bodies that are accessible for open-pit mining--some to depths of several hundred feet--to those amenable to block caving, in which the top of the ore body is several hundred feet below the surface and the bottom more than 1,000 feet lower. The individual bodies that make up the bulk of the resources range from 50 million to more than 500 million tons and individually contain 400,000 to more than 3.5 million tons of copper. The deposit near Safford contains a known resource of 2 billion tons of material that averages 0.41 percent copper, occurs in shoots of sulfide, oxide, or mixed sulfide--oxide ores that are disposed in such geometric and depth relations that development under present conditions is uncertain. This resource, however, may become available within the near future through improved technology, so is included with the known resources.

Replacement or contact metamorphic ores, somewhat higher grade than the disseminated tactite ores, make up the next most important category of copper resources. Some deposits, such as the larger sources in the Central district, Grant County, N. Mex., range between 1 and 2 percent copper; others average more than 5 percent copper. The precious metal content in these deposits generally is high compared with the porphyry deposits. The significant replacement bodies are all in the east half of Subregion 3; they contain 1,480,000 tons of copper (in about 70 million tons of ore), 15 million ounces of silver, and 420,000 ounces of gold. Most additional predicted resources of this type are likely to be found in Grant County, N. Mex.

About 18,000 tons of copper is estimated to occur in sandstone-type deposits in Coconino County. This copper and the copper that is a minor constituent of many of the complex metal ores of Subregions 1 and 3 is considered of minor importance. Ore tonnages of the copper-bearing complex deposits are tabulated with lead-zinc resources.

The predicted resources probably occur in about the same ratios, as to types of ore, as indicated for the known ores. Predicted resources of about 5 billion tons of disseminated ores contain nearly 30 million tons of copper and nearly 1 million tons of molybdenum. These resources are anticipated for Subregion 3.

Though the predicted additional resources are distributed throughout Subregion 3, a somewhat greater part of these, compared with the known resources, are anticipated in the western block of counties. The disseminated resources of Subregion 1 plus the predicted ores in the replacement and complex categories of Subregions 1 and 2 add about 1 million tons of copper to the predicted resources of the region.

Associated Base and Precious Metals

Most of the lead and zinc resources of the Lower Colorado Region occur in complex ores, mainly as massive replacement bodies that occur in Precambrian schists in Yavapai County, Ariz., and elsewhere in carbonate rocks of Paleozoic or Mesozoic age; lesser amounts occur in tactite replacement bodies or in vein deposits. Copper makes up a small part of many of these occurrences, but this copper resource is insignificant compared with the copper in the disseminated deposits. In recent decades an appreciable part of the gold and silver production of the region, about 15 percent, has come from these complex ores. Precious metals will continue to be won in proportion to the extent these complex ores are exploited. Metal ratios in the complex ores vary greatly, in part according to geologic environment. The tactite ores, for instance, are mainly copper-zinc ores. The replacement ores differ from the disseminated copper ores in being higher grade (combined metal contents commonly 10-15 percent), but they occur in individual bodies that are much smaller.

Known reserves of the complex base-metal ores are small. In the Lower Colorado Region the mining of these ores in 1969 was at a low ebb, and resource information was scant. Consequently, the resources are largely in the predicted category and are estimated largely on the basis of the known and unexploited geologically favorable terranes. In Arizona more than 85 percent of the lead and 90 percent of the zinc produced has come from 14 of the districts shown in figure 3. Yavapai County deposits have been the principal Arizona sources of lead-zinc during the past 10 years, but recently mining there has been curtailed drastically; during the prior 20 years, Cochise, Santa Cruz, and eastern Pima Counties were especially productive. These counties plus Grant County, N. Mex., which has long been the principal source in that State, contain the principal known resources in the region and are geologically the most favorable areas for potential resources in Subregion 3. The ores in Hidalgo County differ from the other complex ores in containing little lead or zinc. In Subregion 1, mainly before 1940, lead-zinc ores were mined in substantial amounts from only a few districts in Mohave County, Ariz., and in Clark and Lincoln Counties, Nev. (fig. 3). These districts and perhaps a few areas in Yuma County are still the most likely places in Subregion 1 to contain undiscovered lead-zinc resources. Subregion 2 lacks such ores.

Gold

Numerous lode and placer deposits of gold have been mined in the Basin and Range part of the Lower Colorado Region, especially in Lincoln, Clark, Mohave, and Yuma Counties of Subregion 1 and Yavapai County of Subregion 3, but such deposits have not furnished noteworthy amounts of gold since 1942. Only the Lost Basin gold placer district of Mohave County possibly is significant. In recent years gold production from the region has been about 150,000 ounces annually; at least 80 percent of this output came from disseminated copper ores and most of the remainder came from complex lead-zinc ores. With the rapidly increasing capacity for production from disseminated copper sources, this level of gold production certainly will be maintained and probably will be increased appreciably, even though lead-zinc production may continue to decline.

Iron

Many iron occurrences are known through much of the southern part of the Lower Colorado Region, but the relatively few that are possibly minable are mostly concentrated in or near the mountain belt south of the Colorado Plateau, principally in Subregion 3 (fig. 3). The only continued production, of about 8 million tons, has been from hematite-magnetite replacement ores in Paleozoic limestones that border igneous intrusions of Tertiary age in the Hanover-Fierro and Silver City areas of Grant County, N. Mex. The 60 million tons of ores remnant in these deposits are the best known and most readily recoverable iron resources in the region.

Perhaps the largest volume of potential resources occurs in the Hieroglyphic Mountains (Pikes Peak district) 35 miles northwest of Phoenix (Maricopa County, Subregion 3), where low-grade, taconite-type, ferruginous layers are thinly interlayered with steep-dipping, more or less barren metasediments or metatuffs of the older Precambrian Yavapai Series. Concentrations of these layers, with iron mainly in the form of hematite, occur in lenticular bodies that crop out in widths of 50 to 300 feet and are 400 to 2,000 feet long. The aggregate known resources in these bodies is about 100 million long tons. At least 20 somewhat similar occurrences occur to the north, mainly in Yavapai County, through an area 35 miles wide in an east-west dimension and 70 miles long. Most of these deposits apparently are much less extensive than the Hieroglyphic Mountain occurrence; cursory evaluations hint that a few might have the potential to supplement that deposit if it proves amenable to exploitation.

Earthy to hard, siliceous, hematite ores, formed as residual karst deposits along an unconformity between the Mescal Limestone and the overlying younger Precambrian Troy Quartzite, are disposed as a discontinuous but widespread, thin, tabular, flat-lying blanket, which is dissected in the rugged mountain belt at the southwestern corner of Navajo County. The two best explored, and possibly largest occurrences, are estimated to contain 15 million long tons having an iron content of 43-67 percent, and 10-15 million tons having an iron content of 23-62 percent. This resource is actually in the drainage basin of Subregion 3. Such resources should not be appraised separately from similar deposits, particularly those that occur within a radius of 25 miles to the west in Gila County (Subregion 3), but they are not as well exposed. Adjacent to diabase intrusions, many of the hematite occurrences, particularly farther south in central and southern Gila County and northeastern Pinal County, have been reconstituted partly or completely to magnetite-bearing tactite deposits.

Because outcrops of hematite commonly abound where the localizing Mescal Limestone-Troy Quartzite unconformity is exposed in canyon walls, and because certain conspicuous outcrops--especially of magnetite--have a high content of iron, these late Precambrian deposits have been cited as the most likely sources for a potential iron industry in Arizona. Even though undiscovered deposits as large or much more extensive than those known are within geologic premise, the habit and geometry of the deposits makes large-scale exploitation unlikely. In the rugged canyon terrane of the northern part of this iron belt, the flat-lying thin deposits underlie a thick cover so that only small parts could be exploited by surface mining. Farther south the deposits are sparse, and apparently are mere pockety remnants that are preserved locally along the old erosion surface. In the Basin and Range part of the belt, such remnants were further fragmented by faulting and erosion so that the larger bodies total only about 1-2 million tons.

Magnetite-bearing alluvium, recognized at many localities through an area of about 800 square miles in eastern Pinal County, has been the subject of considerable investigation since the mid-1950's and is the source for a 25,000-ton-per-year sponge iron plant built about 1961. Titaniferous magnetite occurs in thin layers in, or is disseminated through, readily disaggregated sandy alluvium throughout intervals that have been test sampled to depths ranging from 50 to 250 feet below the surface. The magnetite reportedly occurs in amounts ranging from 1 to 15 percent, but probably averages less than 5 percent. One estimate indicates a resource in a square mile area of 1 million tons of magnetite concentrate (55-63 percent iron) for every 15 feet of depth and suggests that more than 100 million tons probably has been outlined in the 60-square-mile area most thoroughly investigated.

Manganese

Manganese deposits are numerous through considerable parts of Subregions 1 and 3, but significant resources occur at only a few localities in Subregion 1. The largest known resources of manganese in Nevada are bedding replacement deposits, containing small amounts of zinc, lead, silver, and gold, that form halos or extensions around base-metal deposits of the Pioche district, Lincoln County. Known resources of manganese total 4 million long tons, which consist mainly of manganoan siderite. This material is amenable to selective flotation, which also permits recovery of the other metals. An additional resource of more than 4 million long tons contains much oxidized material, which makes metallurgical separation more difficult. Several low-grade bedded deposits of manganese oxides occur in lacustrine strata of Pliocene age to the south and west of Lake Mead, Clark County. Layers of oxide range from a few inches to 50 feet thick, and from 2 to 25 percent in manganese content; some are traceable along strike for several miles. The Three Kids mine, which is in one of these deposits, has yielded 2 1/4 million long tons of crude ore. This ore averaged 18 percent manganese and yielded more than 600,000 long tons of concentrates, which averaged 45 percent manganese. Of these bedded deposits, only the Boulder City deposit, south of Lake Mead, contains a significant manganese reserve.

A much larger resource, about 175 million short tons of material, that averages 3-4 percent manganese, occurs in the Artillery Mountains area of southern Mohave County. This material consists of bedded manganese oxides that are concentrated in an interval 65 feet thick. The zone is overlain by tens to hundreds of feet of overburden in most places. Manganese in a lower zone, which has not been well explored and is buried much deeper, is not considered in this estimate.

The largest resource of manganese in New Mexico is the Boston Hill deposit of Grant County (Subregion 3), which consists of 10 million tons of material that contains 8-15 percent manganese. In this deposit iron and manganese minerals are too intimately mixed for economic separation at the mine, so the resource is included as manganiferous iron ore.

Uranium and Vanadium

About 176,000 tons of U_3O_8 (153,000 tons U) is estimated to be in sandstone-type uranium deposits in the Lower Colorado Region. Another 2,400 tons of U_3O_8 (2,100 tons U) is estimated in vein-form deposits. Of the amount in sandstone-type deposits, 117,000 tons U_3O_8 is in bodies that range in grade from 0.10 to 0.87 percent U_3O_8, and the remainder, 59,000 tons U_3O_8, is in bodies of submarginal material that ranges in grade from 0.02 to about 0.09 percent U_3O_8.

Most of the uranium in veins is in ore bodies ranging in grade from 0.10 percent to about 0.4 percent U_3O_8, and a few hundred tons is in bodies that contain less than 0.10 percent U_3O_8.

About one-third of the total uranium is considered a known resource, and the other two-thirds is in concealed deposits and constitutes the predicted additional resources.

About 90 percent of the resources is in the Morrison Formation of Jurassic age, about 7 percent in the Chinle Formation of Triassic age, and the balance in many other rock units.

All the subregions contain resources, but they are largely concentrated in Subregion 2 (about 95 percent). A little more than 3 percent is in Subregion 1, and about 1 percent is in Subregion 3 (fig. 4).

Uranium deposits in both the Chinle and Morrison Formations in northern Apache and Navajo Counties, Ariz., are vanadiferous. About 17,000 tons of vanadium pentoxide is contained in these deposits. Of this amount, about 70 percent is in rock that ranges in grade from 0.4 percent to 1.4 percent V_2O_5, and the remainder is in rock that ranges in grade from about 0.1 to 0.25 percent V_2O_5.

The uranium and the uranium-vanadium deposits that contain the resources in the Chinle, Morrison, Dakota, and Toreva Formations are in tabular elongate bodies that are roughly concordant with the bedding of the sandstone host rock. Individual deposits contain from as little as a ton to many millions of tons of ore. Most deposits tend to occur in clusters, and they occur from the outcrop to as much as 1 mile below the surface.

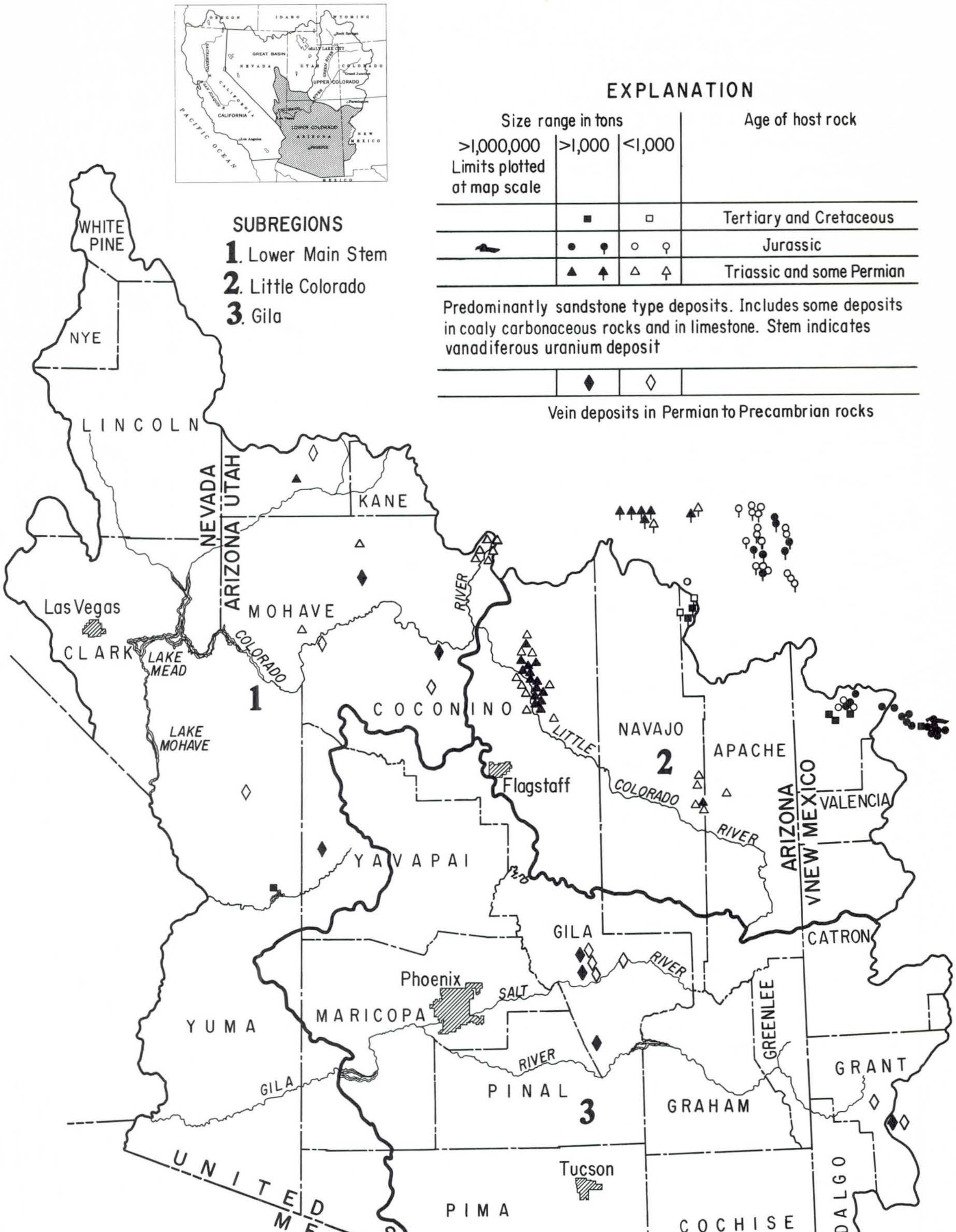


FIGURE 4. – Uranium and vanadium deposits, Lower Colorado Region.

The vein deposits are distributed in a variety of rocks and are diverse in size and form. The mineralized material in them either fills fractures or impregnates the wall rock adjacent to fractures. The largest deposit, the Orphan, in Coconino County, Ariz., consists of nearly vertical bodies of mineralized rock that generally are arcuate in plant. The arcuate bodies are partly close to the outer edge of an ovoid cylinder of collapsed and brecciated sandstone and partly in the wall of the collapse structure. Deposits in Gila County are a combination of bodies a few feet wide, less than 20 feet high, and tens to hundreds of feet long and of adjoining tabular bodies a few feet thick and nearly concordant with the bedding of the enclosing rock. Other deposits are more typical veins in a variety of host rocks, which are mostly igneous or metamorphic.

Nonmetallic Minerals

Few data are available on the significant nonmetallic mineral resources. Where data are available, they are listed and discussed. For additional information see the Congressional imprints for Arizona, Nevada, New Mexico, and Utah, which are listed under references at the end of this report.

Bentonite

Resources of bentonite, a clay that has formed from volcanic ash, reflect the distribution of tuffaceous (ash-bearing) sedimentary strata and are therefore potentially widespread through the Lower Colorado Region. Little is known, however, about the character and size of individual occurrences. Resources are probably large in the vicinity of several occurrences that have been mined, namely, in east-central Lincoln County and near Lake Mead in Clark County, Nev., and in northern Yuma County, Ariz., in Subregion 1; in the Bidahochi Formation of Pliocene age in east-central Apache County, Ariz., in Subregion 2; and in tuffaceous parts of basin fills of Cenozoic age at several localities in Yavapai County, Ariz., in Subregion 3. Also, significant resources probably could be developed at many additional localities where occurrence have merely been reported. For instance, thick beds of bentonitic material of unknown quality and extent occur in outcrops of the Chinle Formation (Triassic age) adjacent to the Little Colorado River in Navajo and Coconino Counties, Ariz.

Other materials formed as parts of volcanic terranes, such as perlite, pumice and scoria, are similar to bentonite in that they are widespread and voluminous in the region. Their recognition and evaluation as mineral commodities will come only as a demand develops.

Borates

The only significant known resources of borates occur in Clark County, Nev. (Subregion 1), where they occur principally as bedded colemanite in Tertiary rocks. These deposits may not be economically recoverable, however, because of the relative insolubility of colemanite, steep dip of the beds, and their relative thinness. Moreover, the supplies of borates at Kramer and Searles Lake, Calif., may be adequate to satisfy market needs for 50-100 years.

Halite

Halite (common salt), in amounts poorly known but potentially vast, occurs at widely scattered localities in each of the subregions. Even if not exploited as raw material for a saline industry, some of these occurrences could be significant as potential underground storage sites.

The most extensive known halite resource occurs as discontinuous lenses in the upper part of the Supai Formation (Permian) through an area of about 2,300 square miles that straddles the Little Colorado River in Navajo and Apache Counties (Subregion 2, fig. 3). This halite occurs in the subsurface in lenses as much as 400 feet thick and at depths of 600 to 2,500 feet below the surface along the length of a 55-mile, northeast-trending belt. A part of the drilling that has outlined these occurrences was done to explore an irregular zone of associated potassium salts.

The significant halite deposits of Subregion 1 are subsurface occurrences known from sparse drill penetrations in the floors of Detrital and Hualapai valleys of northern Mohave County, and subsurface and exposed occurrences in eastern Clark County. At one locality in Hualapai valley halite more than 1,200 feet thick, and apparently fairly free of impurities, was penetrated at depths between 1,400 and about 2,600 feet below the surface. Farther to the northwest in Detrital valley, near Lake Mead, halite occurs in thicknesses of 500 to 700 feet under an area of several square miles at depths of 300 to 800 feet below the surface. These deposits apparently are encompassed within Pliocene(?) basin fill deposits. Farther north and east in Clark County "thick sections of salt" have been reported from scattered wells, and comparable occurrences crop out for a length of 10 miles along cliffs on the western side of the Virgin River.

In Maricopa County about 20 miles west of Phoenix, appreciable halite was found recently in two wells about 1 mile apart in basin fill of Tertiary(?) age. In one hole, below a depth of 880 feet, more than 3,000 feet of solid halite was penetrated. Additional occurrences may be discovered in this vicinity.

Gypsum

Gypsum deposits that possibly compose extensive resources occur throughout the Lower Colorado Region in strata that range in age from Pennsylvanian to Cenozoic. Few data are available on quality, thickness, and extent of the deposits now providing gypsum, and even fewer data are available for those that are unexplored. Usable resources, however, are obviously much in excess of foreseeable demand. As future development will depend more on market demands than specific disposition of reserves, no attempt is made to tabulate the resources; but the areas where the more substantial deposits are known at the outcrop are shown in figure 3. These and others are discussed below.

Gypsum occurs in numerous deposits in Clark County, Nev., (Subregion 1) near Las Vegas and adjacent to Lake Mead. These deposits, which range from several feet to several tens of feet in thickness, are intercalated in Permian, Triassic, Cretaceous, and Pliocene(?) sedimentary rocks, and collectively form a huge resource. Many other potentially large occurrences are unexplored. Geologically equivalent though probably thinner beds of gypsum are known in northernmost Mohave County. Farther north in eastern Washington County, Utah, occurrences are numerous and commonly tens of feet thick. The deposits in the Jurassic Curtis Formation, which crops out in the northeast corner of the county, are the most extensive. Farther south in Subregion 1 few potential sources are known, but minor deposits in Permian(?) strata that have been mined in northern Yuma County could be exploited.

In Subregion 2, local thin deposits in Triassic and Permian strata have been mined and still contain appreciable gypsum resources in areas adjacent to the Little Colorado River (Apache, Coconino, and Navajo Counties). Similar occurrences in Permian strata are thicker and more extensively exposed along outcrops in southern Navajo County.

Subregion 3 contains multimillion-ton resources in Cenozoic beds of the Gila Group in the San Pedro valley, Pinal County, and similar deposits occur in the Verde Formation, Yavapai County. Additional large resources can be developed from deposits in Permian beds in eastern Pima and western Cochise Counties, Ariz., and from Permian and Cretaceous sequences in Hidalgo County, N. Mex.

Potash

Possibly significant resources of potash occur in the upper part of the Supai Formation and underlying the central part of the area that contains the halite resources in Apache and Navajo Counties, Subregion 2 (fig. 3). The potash is associated with the halite beds and occurs mainly as sylvite in an irregular bedded zone of sylvinite. This zone underlies an elongate, northeastward-trending, 300-square-mile area and ranges from 700 to 2,000 feet below the surface. The southern part extends under the Petrified Forest National Park so is closed to exploration. Figures on the quality, thickness, and tonnage are not available.

Sand and Gravel

The volume and quality of sand and gravel resources in the region are poorly known, except locally. Total resources are very large, but the distribution is spotty and locally limited, especially for gravel. In the plateau part of the region (Subregion 2, plus Coconino County and the eastern parts of Mohave and Washington Counties of Subregion 1), local stream bars and terraces contain thin and limited deposits of sand and some gravel. In the mountain belt of Subregion 3, in Arizona and New Mexico, are local supplies of gravel and sand along the stream channels and terraces, but these materials are generally of difficult access, and they contain a high ratio of gravel to sand. In the Basin and Range part of the region (most of Subregion 3 and western part of Subregion 1), the basin fills are mostly sand and silt; gravel is sparse and occurs in recoverable concentrations mainly in buried stream channels and terraces near mountain fronts. Some of the best quality gravel occurs where intermittent streams rework alluvial fans along the mountain fronts. Some coarse aggregate plant operations actually are dependent on and replenished by the periodic reworking of upstream gravels by freshets and the transport of these materials to depleted pit sites.

In addition to use depletion, available gravel supplies are becoming more limited to access because of "urban sprawl" in the denser population centers. In such areas, gravel supplies likely will be replaced gradually by other coarse rock aggregate. Abundant local sources of such aggregate generally occur along the flanks of the mountain ranges.

CHAPTER 5 - DEVELOPMENT PROJECTIONS BY SUBREGION

Projection Methods

The mineral industry data from the Lower Colorado Region for the 1947-66 interval clearly show that only a handful of mineral commodities consistently have dominated production and value statistics. Moreover, geologic evidence and inference of the resource base in the region strongly suggest that this established commodity mix will be perpetuated for many decades, although some important shifts of commodity position within the mix seem quite likely. Based upon value-of-output data, the top 10 mineral commodities produced in the region in 1950 and in base-year 1965 are listed in table 3 along with the expected commodity mix for 1980, 2000, and 2020.

Further study of production data reveals that the top five commodities listed in table 3 comprised 95 percent or more of total mineral industry output value for almost all of the years 1947-66 inclusive. Korean War-induced output of strategic metals, such as tungsten, manganese, and mercury, was an extraneous influence during the 1954-59 interval. If the value of these commodities was removed from statistical totals, the top five would dominate the mineral industry output as in other years. Figure 5 graphically illustrates the importance of the top five. The percentage distribution of value of the top five compared with all other mineral industry output value is indicated at the top of the figure, and a breakdown of the top five along with all other mineral industry in terms of dollar value is illustrated at the bottom of the figure.

Table 3 and figure 5 point up the paramount importance of copper in the region's mineral commodity mix; copper commonly comprises 80 percent or more of total annual mineral industry value of production. Moreover, if current expectations materialize, copper will maintain its commanding position in the commodity-mix through 2020, being subject to challenge only during the early 1980's when uranium output is expected to surge to a short-lived peak.

The general approach to development of projections of mineral output presented herein is briefly outlined below.

Historic value of production data for the 1947-66 interval, adjusted by use of Bureau of Mines price indexes for selected fuels, metals, and minerals, with 1957-59 = 100, were used to approach base-year 1965. Base-year data were 1965 figures as recorded or a reflection of very recent output trends if 1965 value figures were not truly representative. (For example, if output was markedly depressed in 1965--or 1964 or 1966--because of a local or industry-wide strike, an appropriate adjustment in base-year data was made.)

TABLE 3. - Ten leading mineral commodities, in order of value, produced in the Lower Colorado Region in 1950 and 1965, and estimates for 1980, 2000, and 2020

	1950	1965	1980	2000	2020
1	Copper	Copper	Copper	Copper	Copper
2	Lead-zinc	Uranium-vanadium	Uranium-vanadium	Uranium-vanadium	Uranium-vanadium
3	Sand and gravel	Sand and gravel	Petroleum1/	Petroleum1/	Sand and gravel
4	Cement	Lead-zinc	Sand and gravel	Sand and gravel	Cement
5	Lime	Cement	Lead-zinc	Cement	Petroleum1/
6	Gypsum	Lime	Cement	Lime	Lime
7	Stone	Stone	Coal	Stone	Stone
8	Bentonite	Petroleum1/	Lime	Lead-zinc	Lead-zinc
9	Asbestos	Gypsum	Stone	Coal	Gypsum
10	Manganese	Pumice	Gypsum	Gypsum	Pumice

1/ Petroleum includes crude oil, natural gas, natural gas liquids, helium, etc.

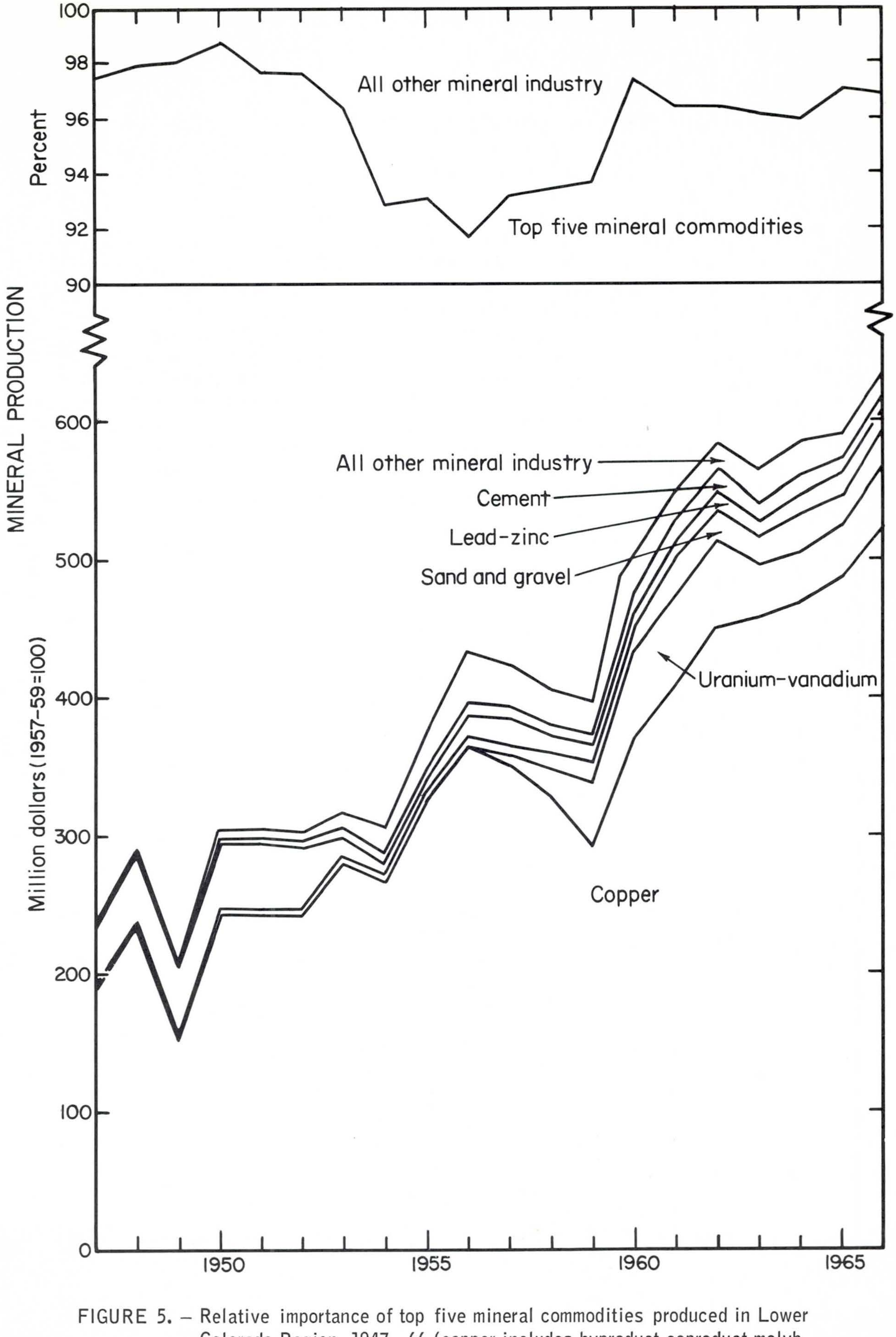


FIGURE 5. – Relative importance of top five mineral commodities produced in Lower Colorado Region, 1947 – 66 (copper includes byproduct-coproduct molybdenum, silver, and gold).

Value of production projections for the top ten mineral commodities produced in the region in base-year 1965 were developed in general as follows:

1. Value of production data for the 1947-66 interval, adjusted to 1958 dollars, were plotted on rectangular coordinate graph paper. Data points that were noticeably out of line with the other points were checked for accuracy, and, if still out of line, subsequently investigated to determine the reason for the marked departure from data trends. When justification was sufficiently sound, adjustments in the data plots were made. (Adjustment of data occasionally was found to be crucial to the development of meaningful projections. Because data as reported and recorded may be held sacred in some quarters, vindication for tampering with bits of historic data may be found in a classic example or two. For instance, in the Lower Colorado Region, the Colorado River Storage Project had a marked impact upon construction minerals output in the late 1950's and early 1960's. Construction of Glen Canyon Dam caused sand and gravel output in 1961 to increase more than 50 percent over that of 1960 on a regionwide basis. Moreover, one of the counties in the vicinity of Glen Canyon had no recorded sand and gravel output during one year of the construction project, but more than 4 million tons in the following year--the data for the particular county are held company confidential. Clearly, removal of these major one-time-only construction material needs from the 1947-66 series of statistical data is justifiable in the light of developing the most objective historic trends for subsequent development of the most purposeful future trends. However, in the same vein, the impact of the on-going Federal Interstate Highway Program upon construction materials output was ignored. The impact is most noticeable upon subregional statistical tabulations, less noteworthy on a regional basis. Basically, however, the assumption was that this major construction program is not a panacea for National highway needs, but rather, a contribution to the Nation's highway requirements of the 1950's and 60's, and that in the 1970's and 80's another bundle of National highway needs will materialize and will be relieved, in a never-ending chain of construction programs.)

2. Trend lines or channels were sketched on the graph paper so as to include all or almost all of the historic data, and projection lines were sketched lightly towards 2020.

3. The resource base (supply) was reviewed when appropriate and found or assumed to be sufficient to meet all foreseeable needs through 2020--with exceptions as noted below. Market requirements (demand) for pertinent commodities over the short term (commonly through 1975, 1980, or 1985), as estimated by various industry, private, or government groups, were reviewed for background data. For locally consumed minerals, population trends were used for projections. Regression analysis was used to explicitly define projections of these commodities believed to be somewhat susceptible to such rigid mathematical delineation.

Projection Summaries

Following the general three-step approach listed above, and in the standard fuels-metals-nonmetals sequence, projections for the top ten mineral commodities produced in the region in base-year 1965 were developed specifically as follows:

Mineral Fuels

Uranium

Forecasts of uranium needs for nuclear fuel, prepared by various government agencies and industry sources during the transitional 1960's, blanket a full spectrum of viewpoints from somber pessimism to elated optimism. The enthusiasm expressed by nuclear power partisans in the mid-60's has been tempered in the late-60's because of a mixed batch of technical, material, and manpower problems. Costly stretchouts of construction activities at a number of nuclear powerplant sites (coupled with unusually high interest rates) have triggered second thoughts about a rapid switch to nuclear fuel throughout much of the Nation's electric utility industry. Alternatives aimed at filling the developing gap between capacity output and power demands in the early 70's include expansion of established conventional powerplants, power exchanges, other efforts to increase output efficiency, and some new construction of traditional coal-, oil-, or gas-fired powerplants. Although the swing to nuclear power seems assured, the transition may require considerably more time than generally expected.

Water needs for uranium mining are known to be negligible, but water needs for milling uranium ore are substantial. It is virtually certain that hydrometallurgy will be used indefinitely in uranium milling; therefore, water needs are assumed to be required at millsites. Uranium mills will remain along the main water arteries--the San Juan, the Colorado main stem, etc.--and ore will move to the millsites.

Based upon OBE-ERS population and employment data, annual uranium output would be essentially unchanged through 2020. In contrast, a considerably more optimistic view of uranium's future is developed and included in the Modified OBE-ERS plan of development.

Petroleum

Arizona's first commercial oil well was completed in Apache County in 1958 and production began in 1958. Through most of the 1960's natural gas and helium have represented the bulk of petroleum industry value; however, in the late 1960's crude oil value has surged ahead and seems certain to remain the most important industry product in the foreseeable future.

Northeast Arizona is underlain by sedimentary rocks that are commonly a continuation of strata in the Four Corners area of Colorado, New Mexico, and Utah. Such formations have proved to be highly rewarding to petroleum industry exploration efforts in the 1950's and 1960's. Continuing exploration activity has resulted in substantial discoveries in the Four Corners area in the late 1960's, and, although in Arizona reserve data are sparse, geologic inference portends that the Lower Colorado Region should share increasingly in regional petroleum industry developments. Output is estimated to increase generally without interruption through 2000 and then decline through 2020.

Coal

Output has been very limited throughout the 1947-66 interval, and coal was not one of the top ten minerals produced in base-year 1965. However, a recent long-term commitment of coal deposits in the Black Mesa area of northwest Arizona (fig. 6) to fuel a major steam-electric powerplant in southernmost Nevada assures coal a top-ten position in 1980 and probably 2000.

Metals

Copper

In base-year 1965, copper--along with its gold, silver, and molybdenum byproducts and/or coproducts--represented 84 percent of total value of mineral output (and, as subsequently will be determined, used 91 percent of the water diverted to mineral industry, and consumed 92 percent of the water depleted by mineral industry in the Lower Colorado Region). If uranium, sand and gravel, lead-zinc, and cement are thrown in with copper, then the mineral industry is, in effect, defined because this handful of commodities in 1965 accounted for 97 percent of total value of mineral output and 98 percent of all water

FIGURE 6. – Coal-bearing Black Mesa near Kayenta, Ariz.

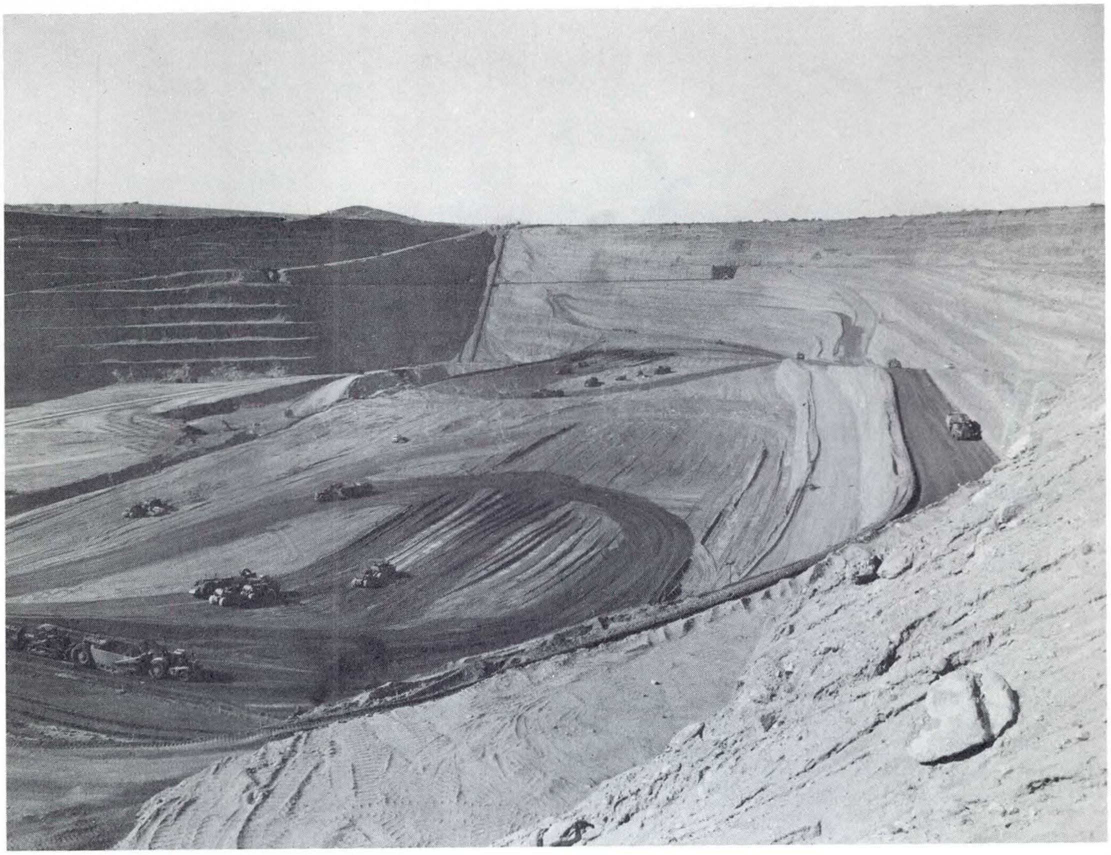
diverted and depleted by mineral industry. Projections of mineral industry water needs and land use through 2020 primarily will be based upon estimated production potential of these few commodities, plus other mineral resources that may show reasonable promise of becoming exploitable in substantial quantity between 1965 and 2020. Although nearly 50 different mineral commodities have been produced in the Lower Colorado Region in recent years, only a few of them require the bulk of the industries' activities, and copper by itself is of overwhelming importance. A meaningful projection of mineral industry activity, in effect then, hinges upon an objective analysis of the region's copper industry, and such a review follows.

As discussed under the heading, "The Mineral Resource Base," the basic assumption is made that all important mineral resources customarily produced in the Lower Colorado Region will be available in ample supply through 2020. This assumption is based on the record of past production and continuing discoveries in a geologic environment suited for further discovery. It also is based on knowledge of copper resources that, with new technology, will become economic.

It may be stated unequivocally that in the light of recent trends in mining and exploration the copper resource base in the Lower Colorado Region is sufficient to meet projected needs for copper output through 2020, providing related resource needs--primarily water and land--are reasonably accessible, and a classical free marketing system prevails (figs. 7 and 8).

Copper's recent past is pictured in figure 9, a one-shot look at 1946-66 (and preliminary 1967-68) Arizona copper production and price data as well as major internal and external factors that influenced production and price. The price of aluminum, currently copper's chief metallic competitor, also is plotted. And for a start, using the method of least squares, a copper production trendline is plotted based upon 1946-66 output. (Figure 9 does not include the steady output of copper from southwestern New Mexico and intermittent output of copper from southern Nevada during the 1946-68 interval. Readily available statistics on a statewide basis for Arizona--from which the great bulk of Lower Colorado Region copper output has been and probably will be derived--facilitate this copper review and the subsequent development of projections.)

External factors lend considerable insight to the copper production-price picture. The four recessions since World War II illustrate clearly that production and price are tied closely to the business cycle; less obvious, however, are the manifold implications of the internal factors. The following brief discussion attempts to thread objectively through the important internal factors--price and production controls, labor-management and personnel problems, profits, and taxes--factors



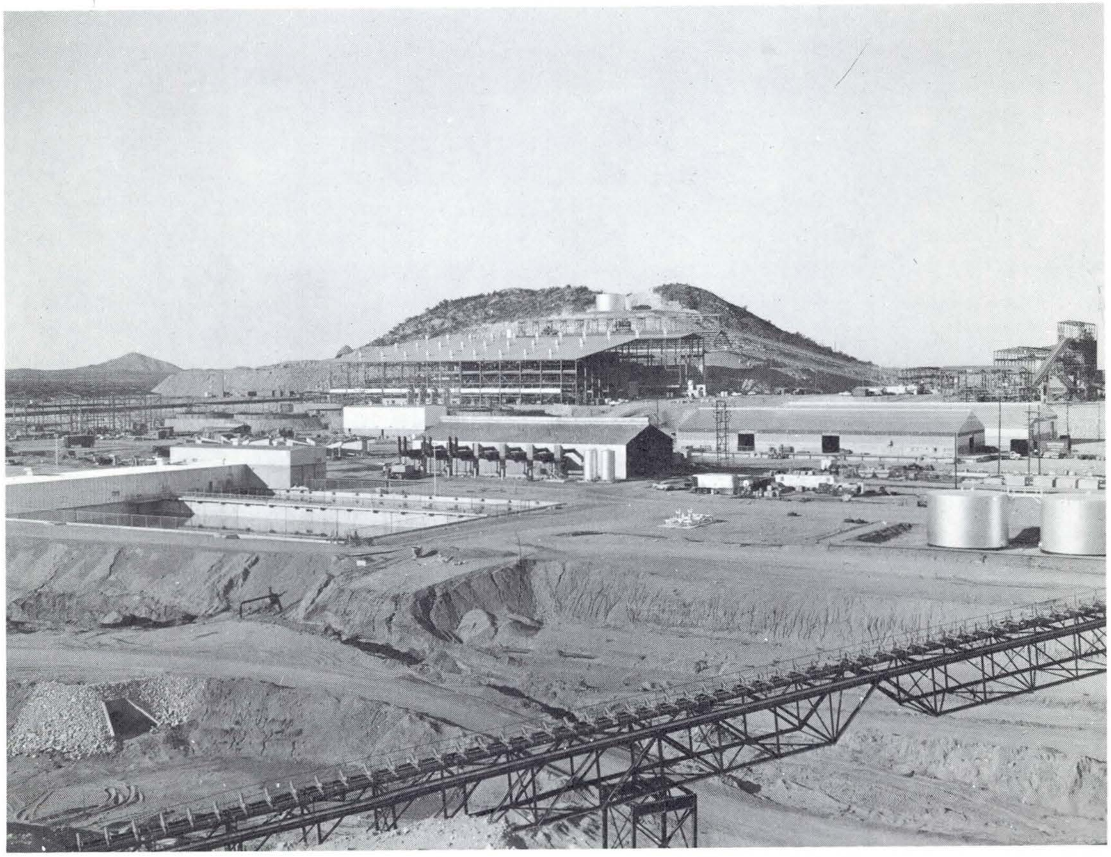
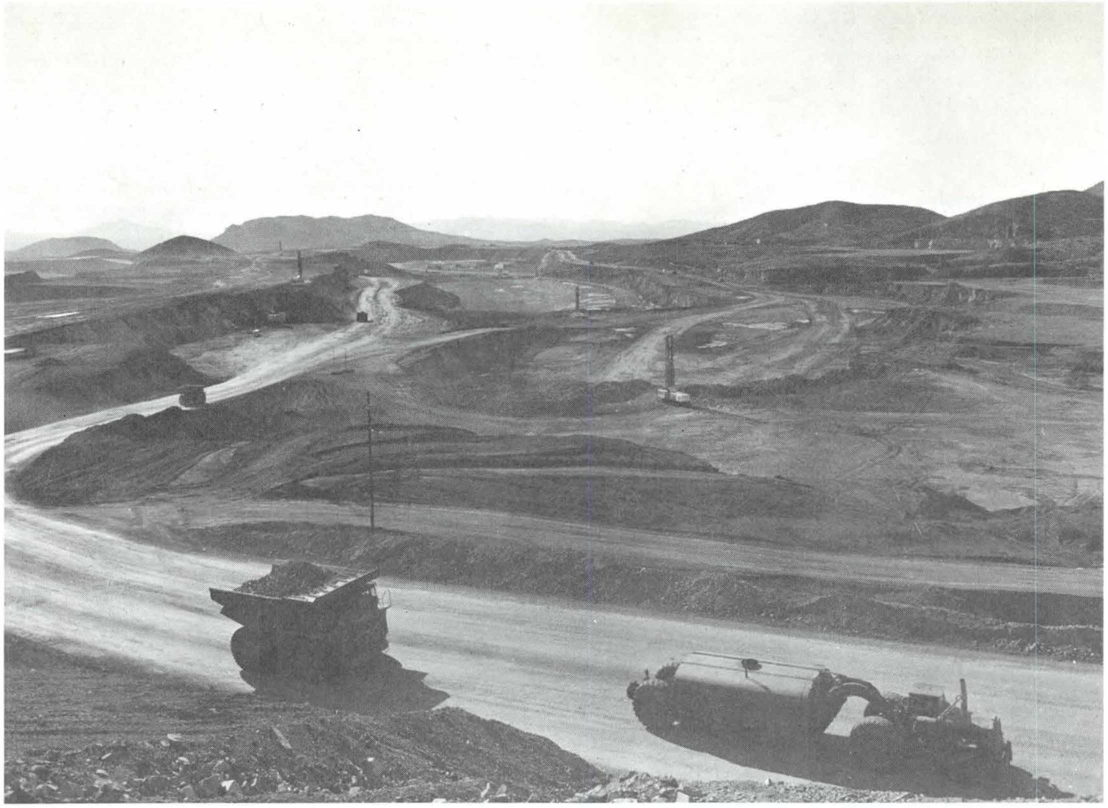


FIGURE 7. – The Anaconda Company's Twin Buttes mine and millsite, approximately 20 miles southwest of Tucson, Ariz. Milling of copper ore from the pit at a rate of 30,000 tons per day was attained in late 1969.



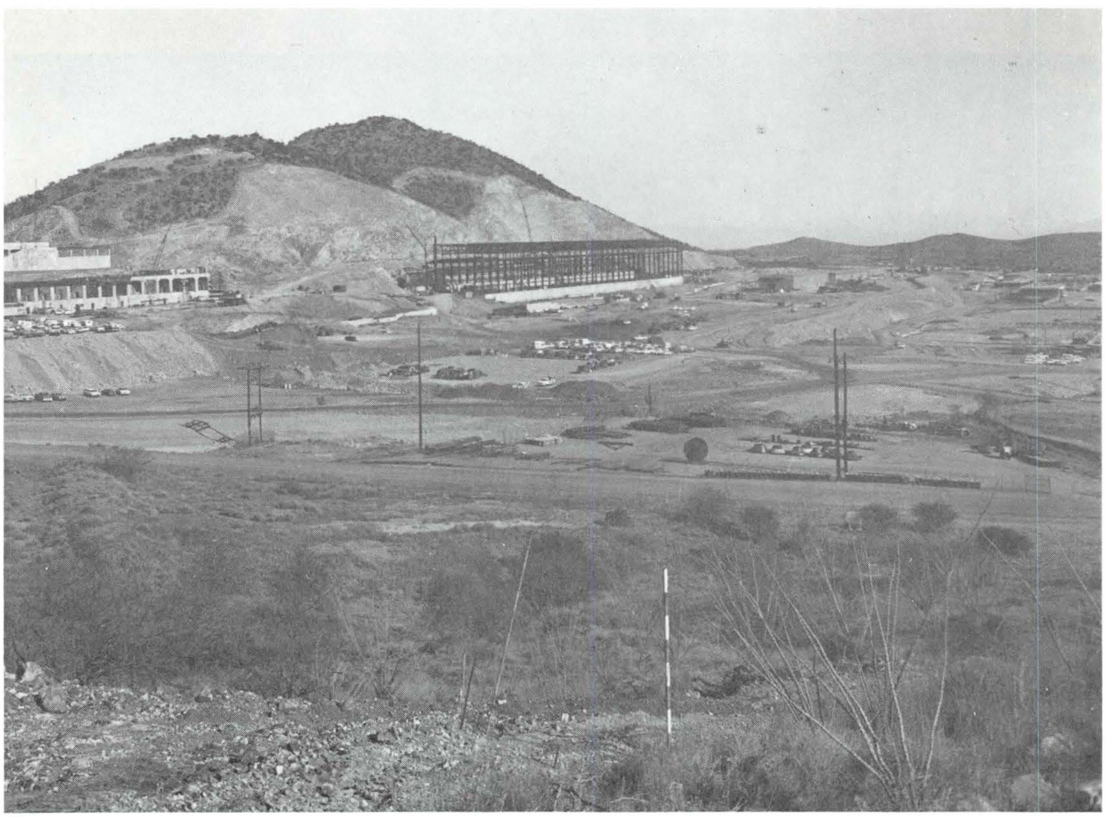


FIGURE 8. – Panorama of Duval Corp.'s Sierrita mine and mill development 30 miles southwest of Tucson, Ariz. The Sierrita mine is the largest of several new Arizona mines which by 1972 will increase the State's annual copper capacity to 989,000 short tons––21 percent over 1968 capacity. By the mid-70's Sierrita copper output will represent about 7 percent of the State's total.

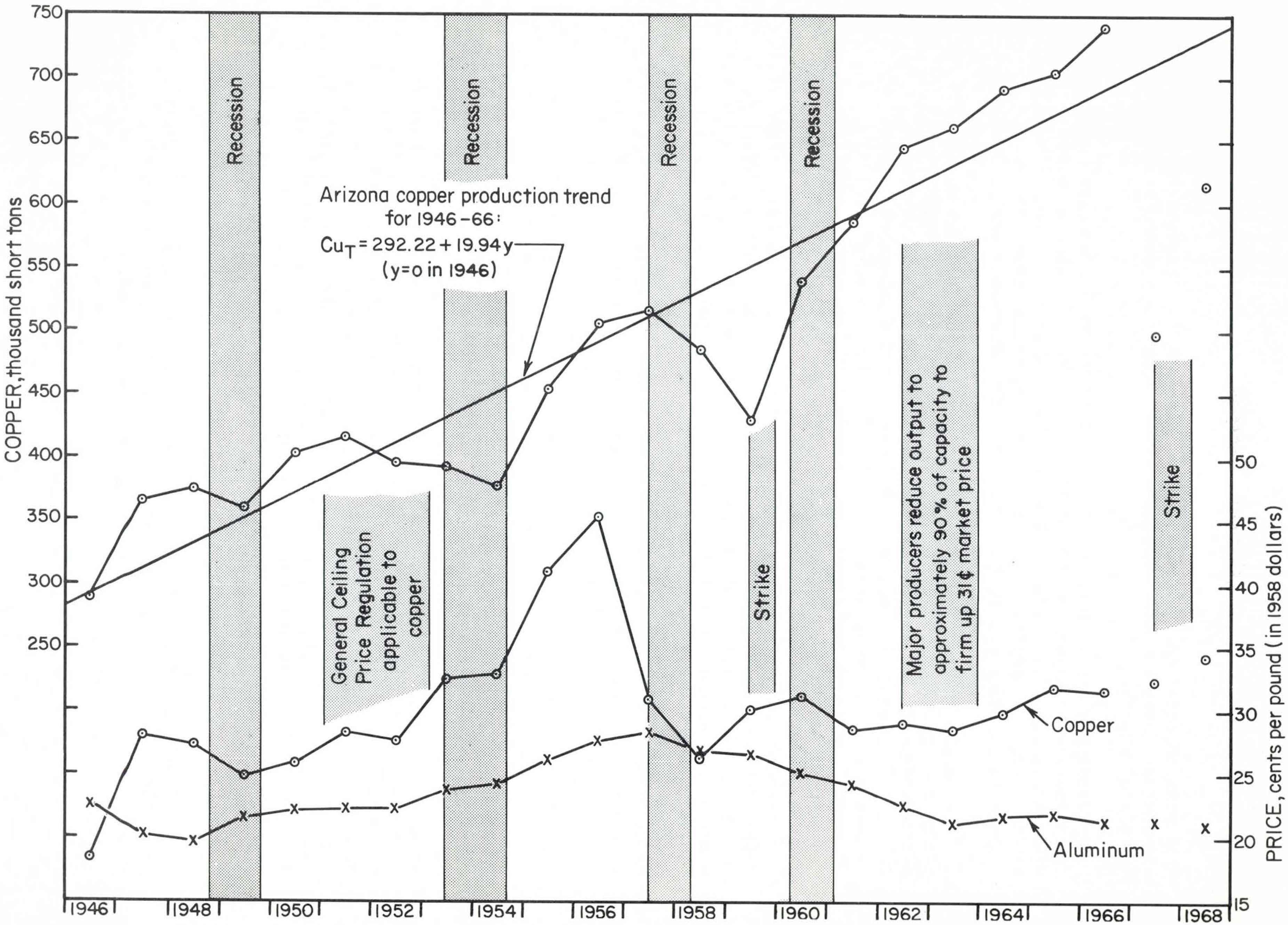


FIGURE 9. – Arizona annual mine production of copper, annual average price of copper and aluminum, and major external and internal factors that influenced copper production and price, 1946 – 68.

that have affected the fabric of copper industry developments during the postwar years and seem destined to influence the pattern of future industrial growth.

Copper was one of many commodities affected by the General Ceiling Price Regulation enacted early in the Korean War. Despite a short labor strike in 1951, copper output peaked in that year. Thereafter, it declined for the remainder of the war period, while major producers managed to increase equity and generally maintain prewar profit levels.

A drastic decline in capital investment by the industry marked the second postwar recession (1953-54), a move which subsequently added impetus to soaring copper prices during the 1955-57 expansion. The 1955-57 period of price volatility triggered a substantial loss of copper markets to aluminum. It also stimulated a surge of in-house exploration activity, and attracted several extraneous capital-rich industries into the search for copper.

Copper's bubble deflated with the economy during the precipitous third postwar recession. Massive layoffs of personnel and an abrupt decline in copper price marked this period of contraction. The subsequent short-lived economic recovery was marred by the prolonged strike during the second half of 1959. (The entire 1946-68 interval was riddled by labor-management unrest; however, the 1959 strike seems to have had the most far-reaching consequences, particularly in consolidating the formerly bitterly divided labor union structure that existed through the 1950's.)

Depleted copper inventories were replenished through the fourth postwar recession while consumer demands for copper were relatively slack. By mid-62 excess stocks were beginning to exert downward pressure on price, and major producers made efforts somewhat reminiscent of previous attempts to control output and price. Some producers announced a 5- to 10-percent cutback in output, and as customary, operators at most open-pit mines turned to higher grade ore and reduced stripping ratios, thereby maintaining copper output, profit levels, and uninterrupted records of productivity. (The initial cutbacks were announced in July 1962, and average output was as follows: for the first six months, 55,000 tons per month; the July-September quarter, the customary vacation interval, 50,000 tons per month; and the final quarter, 55,000 tons per month. Average monthly output by quarters in 1963 were 55,000 tons, 55,000 tons, 51,000 tons, and with production cutbacks removed in the fourth quarter as demand intensified, 59,000 tons.)

Expansionary tax policies at the National level in 1964-65 enhanced the 1961-63 economic recovery and are reflected in copper production and price statistics. With the clear-cut improvement in the economy, copper output restrictions had been abandoned late in 1963, but with essentially all high-grade ore mined out during the previous 18 months, and a burdensome backlog of waste material on the immediate horizon, the industry failed to fully meet demands--waste removal and ore production surged, but copper output only inched higher. (Based upon Bureau of Mines Minerals Yearbook data, the change in 1963-65 output at 11 open-pit mines, representing the bulk of copper output, was as follows: waste- and leach-material removal up 22.3 percent, ore production increased 8.2 percent, and copper output up 4.2 percent.)

With copper in tight supply during most of 1964, all of 1965, and most of 1966, price began an upward spiral. In 1964 price went from 31 to 34 cents per pound; in 1965 from 34 to 38 cents, then, in response to Government suasion, back to 36 cents; in 1966 the 36-cent price remained firm; and in 1967 copper greeted the new year with a 38-cent price. At the advent of the July 1967 strike, price skyrocketed: by year-end spot prices reportedly approached one dollar a pound in a turbulent copper market.

Incident to the generally increasing price level during the 1964 to mid-67 interval, the industry experienced a return to a prolonged period of profitable operation, with reported profits going from the approximate 10- to 15-percent range to the 15- to 25-percent level. Such returns brought an influx of exploration teams from petroleum, construction, chemical, and other industrial sectors ordinarily foreign to the copper industry. In addition to higher prices, there were substantial increases in output with only negligible increases in labor needs through increased utilization of capital equipment. (For example, according to data in Bureau of Labor Statistics Bulletin No. 1370-3, copper industry labor needs in Arizona increased from 10,400 to 14,200, a 36.5-percent increase during the 1949-65 interval, whereas copper output jumped from 359,000 to 703,000 tons, a 95.8-percent increase. For the more recent 1960-65 interval the positive increments are 9.2 percent for labor and 30.4 percent for copper output.) Still another element in the higher profits is the low cost of mining manpower. It is frequently pointed out that copper industry wages top most other wage scales in Arizona; however, the other major sectors of Arizona's economy are agriculture and services related to tourism, thus the comparison is not realistic. When compared with the other industrial sectors (petroleum, construction, chemical) that recently have invested in the copper industry, the cost of mining manpower--both wage earners and salaried technical personnel--is found to be lower. Table 4 lists selected average hourly earnings of production workers in Arizona and surrounding States for 1965.

Along with the low cost of mining manpower, productivity changes in the copper industry are of interest. The labor-productivity index for copper mining production workers was 136.1 in 1965, with 1957-59 = 100. An elementary indication of increased productivity from 1949 (the year of earliest records) to 1965 is indicated in table 5.

TABLE 4. - Average hourly earnings of production workers in selected industries for 1965

	Copper mining (SIC 102)	Mining	Quarrying and nonmetallic mining (SIC 14)	Crude petroleum and natural gas (SIC 13)	Contract construction	Industrial chemicals (SIC 281)
Arizona ..	$3.25	NA	NA	NA	$4.31	NA
California	NA	NA	$3.76	$3.46	4.94	$3.33
Nevada ...	NA	$3.25	NA	NA	5.14	NA
New Mexico	NA	3.02	NA	NA	3.51	NA
Utah	NA	3.15	NA	NA	3.89	NA

NA = not available
Source: Employment and Earnings Statistics for States and Areas 1939-65, Bulletin No. 1370-3, United States Department of Labor, June 1966.

TABLE 5. - Changes in selected Arizona copper industry statistics between 1949 and 1965

	1949	1965	Increase (percent)
Total employees	10,400	14,200	37
Average hourly wage	$1.50	$3.25	117
Copper output (tons)	359,000	703,000	96
Copper price (per ton)...........	$400	$720	80
Copper output per employee (tons)	34.5	49.5	43
Value of output per employee	$13,800	$35,640	158

Source: Bureau of Mines Minerals Yearbook, 1949 and 1965. Employment and Earnings Statistics for States and Areas 1939-65, Bulletin No. 1370-3, United States Department of Labor, June 1966.

Value of output per employee would be up 173 percent rather than the 158 percent listed in table 5 if byproduct molybdenum, silver, and gold were included (value would be $37,680 in 1965). In 1949 no molybdenum was recovered, and substantial values of silver and gold were recovered from lode and placer mines outside the copper industry; therefore, a meaningful comparison is not readily determinable. Nevertheless, using the copper values alone, the marked increase in value of output per employee is most impressive.

Finally, the most conclusive evidence of a marked improvement in industry profitability is the return on invested capital data listed in table 6.

TABLE 6. - Return on invested capital for copper producers, mining industry, and all industry, 1960-66

	Big three United States copper producers (percent)	Two major Arizona copper producers (percent)	United States mining industry (percent)	All United States industry (percent	Mining industry rank (among 22 industries)
1960	7.7	14.5	9.4	9.1	10
1961	6.8	12.8	9.3	8.3	7
1962	7.2	12.3	9.6	8.9	8
1963	6.4	12.2	9.6	9.1	11
1964	7.8	18.3	11.8	10.5	8
1965	10.3	19.2	13.9	11.8	6
1966	13.1	22.4	16.2	12.7	2
1960-63	7.0	13.0	9.5	8.9	9
1964-66	10.4	20.0	14.0	11.7	5

Source: Fortune, June or July issues, 1961-67.

Clearly, excellent profits characterized Arizona's huge copper industry during the economically robust 1964-66 interval. An important consequence of the 1964-66 profit situation is the copper industry's developing excess capacity that is virtually certain to materialize by the early 1970's and plague the industry for as long as a decade. Coupled with worldwide increases in copper capacity--through expansion of established operations and development of newly discovered ore bodies--a copper glut seems probable; however, because most foreign copper is produced in Latin American and African nations racked by political, economic, and social uncertainties, and because of the internal problems in the domestic copper industry, the forthcoming excess capacity for copper probably will be significant only periodically in the marketplace.

Labor-management strife dominated the mid-1960's as shown in figure 9. In anticipation of the probable advent of an extended strike starting in mid-1967, stockpiling and speculative demands coupled with heavy current demands in 1965-66 resulted in a strong surge of copper output up to the July 1967 strike. Monthly output averaged 58,600 tons in 1965, 60,900 tons in 1966, and 65,400 tons during the first six months of 1967. Following the July strike, output averaged 14,700 tons monthly during the last five months of 1967. The copper price structure became chaotic; domestic quotations were suspended; foreign prices peaked out near 60 cents per pound; and some domestic cash sales were reportedly close to one dollar a pound.

Throughout most of the early postwar years the domestic copper industry made only token efforts to maintain its established markets and to compete with other metals and plastics for newly developing markets. Results have been as might be expected and seem to foreshadow the copper industry's limited prospects for near-term improvement in the marketing arena. Copper and aluminum price in cents per pound (in 1958 dollars) for the 1946-68 interval is plotted in figure 9. In 1955-56 when copper was in short supply and price shot up into the 45-cents-per-pound area, aluminum made marked inroads into copper's traditional markets. Copper's renewed short supply and upward-creeping price in the mid-60's has triggered some additional loss of markets to aluminum and, to a lesser extent, to other low-cost metals and plastics that are distinguished by more orderly marketing standards. The July 1967 to March 1968 strike and its resultant temporary one-dollar-per-pound copper price for immediate delivery must surely have increased copper users' commodity-substitution efforts in the 1960's.

Copper may now hold the line in its damaged marketing arena through the 1970's for two important reasons. First, because of copper's excess capacity that seems certain to materialize in the early 70's--in Arizona, the Nation, and the world--weakness in copper's price is virtually certain to appear by 1970 and remain a short-term factor, possibly until the late 1970's. (However, as indicated by figure 9, for short-term periods through 1980 or so, abnormally volatile changes in output and price will remain "normal" for the copper industry.) Second, as a hedge against persistent competition from aluminum, the copper industry has traveled most avenues of entry into the aluminum industry; major copper producers in the late 1960's control, directly or indirectly, more than 10 per-cent of domestic primary aluminum capacity. Control ranges from fully integrated operations to those companies with long-term contracts for aluminum from primary aluminum producers.

Figure 10 illustrates the more rapid growth of new aluminum consumption over that of new copper consumption in the United States since World War II. Aluminum's attractive historic growth rate and favorable expectations (Bureau of Mines estimates a 7.1-percent average annual growth rate through 1980 in contrast to only 1.7 per-cent for copper), copper's impending excess capacity, and the copper industry's healthy financial status and advantageous tax features (depletion and depreciation benefits that tend to stimulate succeeding investment) all suggest further copper industry penetration of the aluminum industry. Objectively, this would augment domestic aluminum capacity, but the specter of in-house copper-aluminum competition does not auger well for a long-term minimal price structure.

The Lower Colorado Region has no extractive aluminum industry and negligible potential for the development of such an industry. However, if market competition between copper and aluminum is substantially reduced because of the probable continuance of the heterogenous trend in the minerals industry, then the traditional long-term dampening effect that the relatively stable aluminum price has had on copper's volatile price is likely to be undermined. Thus, if copper-aluminum pricing becomes somewhat more harmonious--in effect, if copper and aluminum prices climb sympathetically--the near-term impact upon Arizona's copper industry would tend to be stabilizing, but the long-term effect would be contractionary because of inevitable competition from other low-cost metals and plastics as well as further expansion of the increasingly lucrative (and aesthetically beneficial) secondary recovery (scrap metal) market for copper and aluminum. Although price and production volatility have been undesirable trademarks of the copper industry, the industry's obvious preoccupation with influencing price to the detriment of production seems to have been shortsighted policy. Evidence is readily at hand. A pointed example: the first underground commercial power line that made use of the low-cost metal sodium was installed in July 1967--in Litchfield Park, Ariz. Another possible trend indicator: in November 1968, with copper and aluminum in relatively plentiful supply and priced at 42- and 26-cents per pound, respectively, Appalachian Power Co. installed an underground 34,500-volt sodium line in Groundhog Mountain, Va.--at a cost estimated to be 25 percent less than a comparable aluminum line.

Because of a deeply intrenched, traditional manner of operation in the copper industry, short-term future trends are subject to relatively precise definition. From year to year actual output and price may fluctuate violently, but by developing a 3-, 4-, or 5-year moving average, short-term trends are closely approximated. However, projecting output and price over the long-term for a commodity such as copper, in the light of the industry's turbulent history, is exceedingly hazardous. Almost any major change in the industry's manner of operation

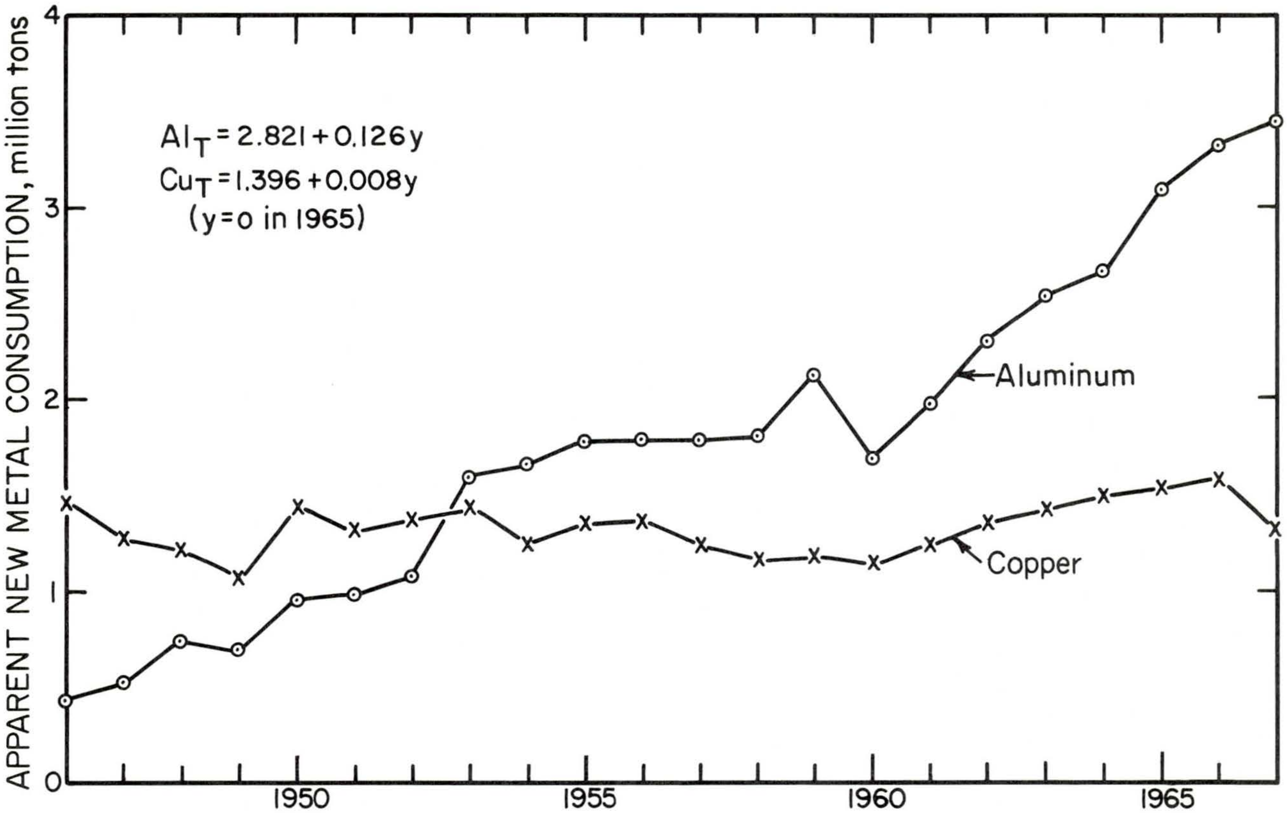


FIGURE 10. – United States apparent consumption of new aluminum and copper (secondary consumption of scrap aluminum and copper omitted.)

could substantially alter price and production trends, but such change in the industry is not foreseen: industry's traditional manner of operation in the Lower Colorado Region is virtually assured through 1980. As previously pointed out, a 13-percent return on investment in slack years and 20 percent in robust years for Arizona's copper producers is not a very stimulating climate for increasing financial returns by improved copper recovery through applied research and development efforts.

Research, almost an unheard of term in the mining phase of the copper industry, seems virtually certain to remain stagnant. Negligible research in the milling phase of the industry and the resultant waste--the traditional loss of about one-seventh of the copper mined--likely will remain an essentially unchanged hallmark of the industry. The loss of another 3 percent or so of copper in the research-barren smelting phase probably will persist indefinitely. (It is customarily pointed out by copper mining operators, some with decades of experience at the same mine, that once the mining-milling procedures are developed there is little need for further evaluation and sophisticated supervision because in most ore bodies the copper mineralization and the type of host rock are fairly consistent.) Thus, with a high degree of ore control in the mine, recovery is 90 to 95 percent of the ore. About 90 percent of the copper is recovered from ore in the milling process and 98 percent from concentrates in the subsequent smelting process.

In summary, it is exceedingly difficult to visualize any important change in the copper industry in the Lower Colorado Region that would result in any worthwhile increase in copper and associated metal recovery, or in operating efficiencies, that would be reflected in reduced water needs or in meaningful change in land use and conservation.

Table 7 summarizes mine production of recoverable copper in the United States during the 1960-66 interval. With the exception of the 1964 Utah production figure, the data are free of important local internal and external influences and seem indicative of future trends in domestic copper output--probably through 1980.

It is noteworthy that only Arizona and New Mexico have unbroken uptrends throughout the 1960-66 interval. Also, a new maximum production record was posted by Arizona in each succeeding year since 1960 and by New Mexico since 1962 (New Mexico's previous record output was 80,100 tons in 1942). Furthermore, based upon on-going developments there is strong reason to believe these growth trends will be maintained and the Arizona-New Mexico copper output will continue to comprise 60 to 65 percent of total domestic copper production at least through 1980 and probably through 2020.

TABLE 7. - Mine production of recoverable copper in the United States, with production of maximum year, cumulative production from the earliest record to end of 1966, and percent distribution for the top six States and Arizona-New Mexico

(Short tons)

State	Maximum production		Production by years							Total production from earliest record through 1966
	Year	Quantity	1960	1961	1962	1963	1964	1965	1966	
Arizona	1966	739,569	538,605	587,053	644,242	660,997	690,988	703,377	739,569	21,221,597
Utah	1943	323,989	218,049	213,534	218,018	203,095	199,588	259,138	265,383	9,537,281
Montana	1916	176,464	91,972	104,000	94,021	79,762	103,806	115,489	128,061	8,205,099
New Mexico	1966	108,614	67,288	79,606	82,683	83,037	86,104	98,658	108,614	2,798,936
Michigan	1916	136,846	56,385	70,245	74,099	75,262	69,040	71,749	73,449	5,784,459
Nevada	1942	83,663	77,485	78,022	82,602	81,738	67,272	71,332	78,720	3,112,400
All others	-	-	30,485	32,695	32,756	29,295	29,982	31,991	35,356	2,985,960
Total	1966	1,429,152	1,080,269	1,165,155	1,228,421	1,213,186	1,246,780	1,351,734	1,429,152	53,645,732

Percent distribution		1960	1961	1962	1963	1964	1965	1966	Total
	Top six States	97.2	97.2	97.3	97.6	97.6	97.6	97.5	94.4
	Arizona-New Mexico 1/	56.1	57.2	59.2	61.3	62.3	59.3	59.3	44.8

1/ Essentially all New Mexico copper output is from Grant and Hidalgo Counties in the Lower Colorado Region; therefore, Arizona-New Mexico copper output is, in effect, Lower Colorado Region copper output.

Based upon the foregoing brief review and analysis of the copper industry in Arizona, dominant both in the region and the nation, the most realistic outlook of regional copper output seems to be a linear projection based upon 1948-66 value of production. By the least squares method, the value of copper output in 1958 million dollars is defined as Cu$ = 480 + 17.4y, with y = 0 in base-year 1965. This straight line is plotted in figure 11 and value of output is noted for the years 1980, 2000, and 2020. (It should be recalled that copper value includes byproduct molybdenum, silver, and gold values, too. For any given year after 1966 the value distribution is estimated to be approximately as follows: copper 94.5 percent, molybdenum 3.2 percent, silver 1.3 percent, and gold 1.0 percent.) A projection of recoverable copper in the region also is plotted in figure 11. Its straight line formula is $Cu_T = 760 + 22.5y$, with copper noted in thousand short tons, and with y = 0 in base-year 1965.

Lead-zinc

Value of lead-zinc production has fluctuated erratically between $8 and $53 million annually in the 1947-66 interval. Output has been responsive to the volatile prices of these commonly geologically associated metals. Prices, in turn, have been strongly influenced by the business cycle (peaks in value of output are clearly in evidence for 1951-52 and 1956-57, with pronounced troughs noted in 1954 and 1958-59). Since 1960, output values have been less erratic on an annual basis, with some signs of a modest rate of growth through 1966 data. Historic lead-zinc data provide little insight to future levels of output. On the assumption that the more recent stable levels of output in the 1960's reflect a taming of the business cycle to the extent that only business "fluctuations" subsequently will prevail, and a recognition of the stabilizing influence of the increased market value of byproduct silver and gold that has materialized in the late 1960's, arbitrarily it is estimated that annual lead-zinc output will hover about the $20 million mark through 2020.

Nonmetals

Sand and gravel

Data for 1961 were adjusted to eliminate the impact of the one-time-only sand and gravel need (worth $8 million) for Glen Canyon Dam. An adjustment in 1964 data also was made to eliminate the influence of a major construction project in southern Nevada; however, no adjustment was made because of the on-going interstate highway building program. Year-to-year data were reviewed and correlated with available population data for select years; no meaningful trend was observed. Using the least squares method, a projection was developed and judged

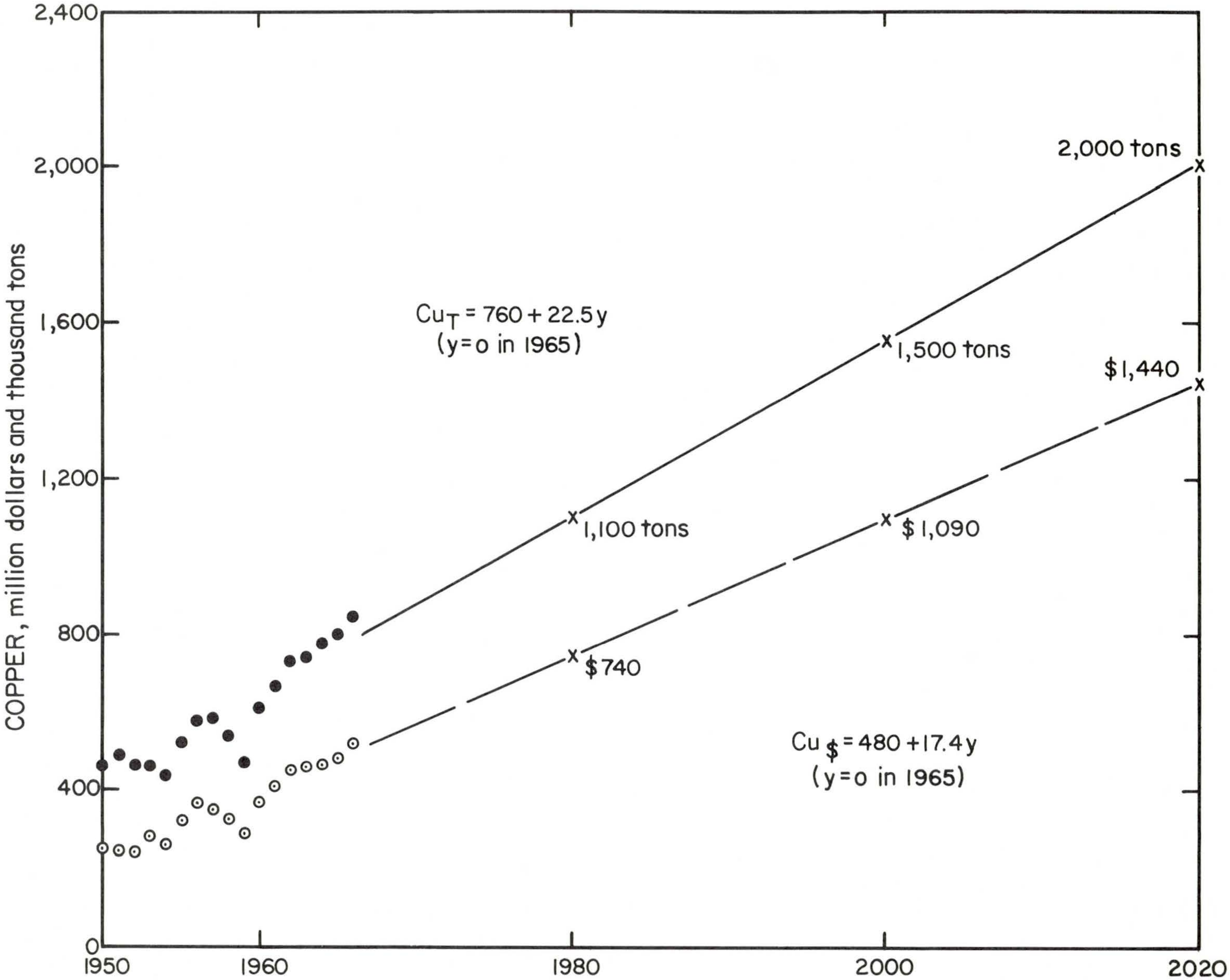


FIGURE 11. – Value of copper plus byproducts, and quantity of copper produced in the Lower Colorado Region 1950 through 1966, with projections to 1980, 2000, and 2020.

to be satisfactory when the 1959-67 data were used. The equation of line is $S\&G_{\$} = 23.32 = 1.10y$, with $y = 0$ in base-year 1965 and $S\&G_{\$}$ in million 1958 dollars. Value of output would be about $40 million in 1980, $62 million in 2000, and $85 million in 2020.

Cement

Cement output for the 1950-67 interval has been exceptionally erratic. A surge in output was recorded in the late 1950's during the home building boom in central Arizona. The early 1960's posted an even greater surge in production to meet the needs of the Colorado River Storage Project. Because of the close relationship between sand and gravel use and cement, the adjusted sand and gravel data were used to estimate by proportion the future output of cement. For the select years the projected values are as follows: $19 million in 1980, $29 million in 2000, and $41 million in 2020.

Lime

In the Lower Colorado Region approximately 80 to 85 percent of the lime produced is used by the copper industry in ore concentrating and copper smelting. In effect, then, future lime output mostly will be a function of copper industry growth. More pointedly, lime needs will be influenced increasingly by the declining grade of copper ore. In 1960 average grade of copper ore in the region was about 0.8 percent. Future grades of copper ore for select years are estimated as follows: 0.7 percent in 1980, 0.6 percent in 2000, and 0.55 percent in 2020. Using these slight declines in grade of copper ore results in a moderate upturn in lime needs through 2020 when compared with a least-squares-derived, straight-line projection. Lime values of product are estimated to be $14 million in 1980, $23 million in 2000, and $34 million in 2020.

Stone

Output of stone has been quite erratic through the 1950's and 1960's; nevertheless, a fairly well defined uptrend--actually an upchannel in plotted data--is apparent. Projections were developed by the least squares method using 1950-66 data and 1950-64 data. A downturn in output recorded in 1965 and 1966 could not be fully reconciled; therefore, the data for these years were held suspect and the 1950-64 interval was used. The equation of the line is $Stn\$ = 7.5 + 0.4y$, where value of stone is in million 1958 dollars and $y = 0$ in 1965. Value of stone output would be approximately $14 million in 1980, $22 million in 2000, and $30 million in 2020.

Gypsum

Production of gypsum has been in a well defined uptrend since the early 1950's. Using the least squares method for the 1952-64 interval, the equation of the line in Gyp$ = 3.17 + 0.16y, where gypsum value is recorded in million 1958 dollars and y = 0 in base-year 1965. In round numbers, then, values for the select years would be $5.5 million in 1980, about $9 million in 2000, and $12 million in 2020.

Pumice

Although value of pumice output has leveled off in the 1960's, a long-term uptrend in output prevails. Using the least squares method for the 1954-66 interval, the equation of the line is Pum$ = 1.85 + 0.14y, where pumice value is read in million 1958 dollars and y = 0 in 1965. Values, then, for the select years would be about $3.9 million in 1980, $7 million in 2000, and $10 million in 2020.

Value of mineral production in the Lower Colorado Region and its Subregions for base-year 1965, with projections to 1980, 2000, and 2020, are listed in table 8. Value data include the top 10 commodities briefly reviewed above, their coproducts and byproducts, and several other commodities (such as feldspar, mica, clays, iron ore, etc.) of local importance that do not merit individual reviews.

TABLE 8. - Value[1/] of mineral production for the OBE-ERS level of development in the Lower Colorado Economic Region and Subregions for 1965, with projections to 1980, 2000, and 2020

(million dollars)

	Commodity group	1965	1980	2000	2020
Main Stem Subregion	Fuels	$3	$3	$3	$3
	Metals	22	33	48	62
	Nonmetals	18	32	50	72
		43	68	101	137
Little Colorado Subregion	Fuels	37	99	119	73
	Metals	-	-	-	-
	Nonmetals	3	6	8	10
		40	105	127	83
Gila Subregion	Fuels	-	-	-	-
	Metals	486	728	1,063	1,403
	Nonmetals	37	61	95	132
		523	789	1,158	1,535
Lower Colorado Region	Fuels	40	102	122	76
	Metals	508	761	1,111	1,465
	Nonmetals	58	99	153	214
		606	962	1,386	1,755

1/ Values are adjusted by use of Bureau of Mines price indexes for selected fuels, metals, and minerals, with 1957-59 = 100. (See Bureau of Mines Minerals Yearbook, Volume I, 1966, page 54.)

CHAPTER 6 - WATER REQUIREMENTS OF MINERAL INDUSTRY

Projection Methods

Mineral industry water-use data for 1962 were accumulated by the Bureau of Mines in a nationwide water canvass in 1963. Subsequently, water requirements and use studies were made in several western States--specifically Arizona, New Mexico, Nevada, Wyoming, and Montana. A number of water-use studies have been performed and published by western universities and by leading national research organizations that contain substantial sections on mineral commodity and mineral industry water use. All of these sources of information have been consulted in the determination of base-year water use and the estimation of future water needs by mineral industry; however, the heart of the subject and the basic source of essentially all data used in development of projections were the raw data in the Bureau of Mines water canvass files.

Water canvass responses were reviewed and considerably thinned out so as to upgrade the quality of the data. Major effort was directed to developing the most meaningful factors for those mineral commodities having the most pressing current and probable future demands for water resources. As a general rule the most reliable data were found to be provided by major producers, and the responses of questionable quality were commonly provided by smaller or intermittent operators. Fortunately, the volume of water needs closely parallels the quality of water canvass responses--major producers ordinarily expressing substantial demands, whereas small operators commonly indicate negligible, if any, demands. Also, as a general rule, the mining process usually involves only a small demand for water whereas the milling process commonly involves more significant if not extremely heavy demands for water.

Two factors--a diversion factor and a depletion factor--were developed for all important mineral commodities in each subregion. Each factor indicates water needs in gallons per (1958) dollar value of mineral output. Subsequently, the volume of water required was converted into acre-feet; and all water needs in this report are expressed in terms of acre-feet.

Uranium mining and milling posed a special problem because integrated mine-mill operations have been rare in the industry. Much of the uranium ore, particularly in Colorado and Utah, has been produced from small mines and shipped to custom mills for processing, and frequently this means that two or more counties are involved (and sometimes two or three States) in the overall uranium recovery process. Value of uranium output is credited to the county in which the ore was mined. Uranium mining ordinarily requires only negligible water supplies; in contrast, uranium milling is very demanding of water resources. Uranium ore reserves are relatively negligible (simply because there has not been any sound economic reason to search for and develop reserves in the absence, until the late 1960's, of a promising market for the uranium); thus, in working up projections of uranium output, it has been necessary to make generalized assumptions regarding future uranium production and to assume that uranium ore will continue to move from a number of mines to a centralized custom mill situated adjacent to any one of the region's major rivers or tributaries. In summary, future uranium ore output is assumed to come from established mining districts and contiguous areas underlain by the same type of host rocks, and to be processed at a handful of conveniently located mills.

More than likely there will be some shifting of uranium mining activity and quite possibly some relocation of uranium mills within subregions through 2020, but these movements will not materially affect estimates of future subregional water needs.

In the course of the study it became apparent that a conversion of the regional data to hydrologic boundaries would be more useful to some participants; therefore, county areas markedly affected by hydrologic boundaries were reviewed in order to determine the possible impact upon data of using hydrologic rather than political boundaries. Where justification was deemed to be sufficient, the data were reworked so as to convert the estimates to a hydrologic delineation. As a whole the Lower Colorado Hydrologic Region thus loses a substantial fraction of the estimated value of production and water needs through 2020, although this shift of value data involves only five counties. Estimates of output and water needs for Apache and Navajo Counties, Arizona, and McKinley County, New Mexico, are partially allocated to the Upper Colorado Hydrologic Region, and estimates for Grant, Hidalgo, and McKinley Counties, New Mexico, are partially allocated to the Rio Grande Hydrologic Region. By far the greater fraction of this transfer of data is to the Rio Grande Hydrologic Region. Specifically, this represents the substantial uranium output from the Rio Grande portion of McKinley County and the significant output of copper from the Rio Grande portion of Grant County.

Inasmuch as possible this important shift of data from a political to hydrologic basis, which commonly involved 20 to 30 percent of total county production and water needs estimates, was based upon historic and current production records, and upon proven on-coming operations--particularly the soon-to-be-in-operation major copper developments in Grant County. Lacking meaningful geologic data, other projected mineral production and water needs data were redistributed on a proportional basis between hydrologic divisions of counties.

However, as pointed out elsewhere herein, ore bodies are neither created nor defined mathematically, but rather are developed by specific, unique, complex geologic conditions that are rarely fully decipherable by the most competent earth scientists--even after an ore body has been completely exploited. Earth sciences applied to mineral exploration and development are, by nature, inexact sciences. Thus the presumption that the conversion of data from political to hydrologic definition may in some manner enhance the quality of the data must be completely discounted. Projecting future mineral production and related water needs--or at least indicating the direction of change in production and water needs as much as 50 years into the future--by elementary statistical methods probably has meaningful value when the subject area is of significant size, such as the Pacific Southwest, or the State of Arizona, or the Colorado Plateau.

Tables 9 through 24 list value of mineral production in 1958 dollars for base-year 1965, estimates of value of mineral production for target years 1980, 2000, and 2020, and estimates of mineral industry water use (diverted and depleted) for the base and target years. Data are tabulated on both a State and Subregion basis. Tables 9 through 16 are built upon OBE-ERS data, tables 17 through 24 are based upon Modified OBE-ERS data.

Source material for tables 10 and 12 have been reorganized into the three basic mineral commodity groups--fuels, metals, and nonmetals--and used to estimate value of mineral production per acre-foot of water diverted and depleted on a subregional basis in base-year 1965. Since base-year data have been adjusted where appropriate to allow for unusual influences, such as labor-management strife, unique supply-demand problems, etc., the data listed in table 25 are believed to be representative of mid-1960's value and water use relationships.

TABLE 9. - Estimated value of mineral production by States for the OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Economic Region

State	Value of mineral production (thousand 1958 dollars)			
	1965	1980	2000	2020
Arizona	$490,179	$790,300	$1,150,000	$1,458,300
Nevada	13,075	22,300	33,700	47,500
New Mexico	102,795	150,400	201,900	251,600
Utah	174	300	400	500
Lower Colorado Economic Region	606,223	963,300	1,386,000	1,757,900

TABLE 10. - Estimated value of mineral production by Subregions for the OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Economic Region

Subregion	Value of mineral production (thousand 1958 dollars)			
	1965	1980	2000	2020
Lower Main Stem ..	$43,412	$68,400	$101,300	$137,100
Little Colorado ..	40,088	104,000	126,700	81,800
Gila	522,723	790,900	1,158,000	1,539,000
Lower Colorado Economic Region	606,223	963,300	1,386,000	1,757,900

TABLE 11. - Estimated water use for minerals by States for the OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Economic Region
(acre-feet)

State	1965		1980		2000		2020	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Arizona	102,360	50,010	153,800	76,400	225,200	111,600	295,800	144,700
Nevada	1,470	640	2,800	1,400	4,300	2,100	5,800	2,900
New Mexico	17,430	9,670	26,900	14,200	38,000	19,900	49,100	25,300
Utah	30	10	40	10	50	20	80	20
Lower Colorado Economic Region	121,290	60,330	183,500	92,000	267,600	133,600	350,800	172,900

TABLE 12. - Estimated water use for minerals by Subregions for the OBE-ERS level of development 1965, 1980, 2000, and 2020, Lower Colorado Economic Region
(acre-feet)

Subregion	1965		1980		2000		2020	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Lower Main Stem ..	6,380	2,590	9,900	4,300	14,600	6,400	19,400	8,500
Little Colorado ..	3,160	2,060	5,700	4,500	6,400	5,000	4,300	2,700
Gila	111,750	55,680	167,900	83,200	246,600	122,200	327,100	161,700
Lower Colorado Economic Region	121,290	60,330	183,500	92,000	267,600	133,600	350,800	172,900

TABLE 13. - Estimated value of mineral production by States for the OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Hydrologic Region

State	Value of mineral production (thousand 1958 dollars)			
	1965	1980	2000	2020
Arizona	$489,087	$781,000	$1,142,000	$1,462,600
Nevada	8,268	22,300	33,700	47,500
New Mexico	13,075	64,200	102,900	116,400
Utah	174	300	400	500
Lower Colorado Hydrologic Region	510,604	867,800	1,279,000	1,627,000

TABLE 14. - Estimated value of mineral production by Subregions for the OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Hydrologic Region

Subregion	Value of mineral production (thousand 1958 dollars)			
	1965	1980	2000	2020
Lower Main Stem ...	$43,412	$68,400	$101,300	$137,100
Little Colorado ...	10,894	66,500	93,700	48,900
Gila	456,298	732,900	1,084,000	1,441,000
Lower Colorado Hydrologic Region	510,604	867,800	1,279,000	1,627,000

TABLE 15. - Estimated water use for minerals by States for the OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Hydrologic Region
(acre-feet)

State	1965		1980		2000		2020	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Arizona	102,260	49,920	153,500	76,200	225,000	111,500	295,700	144,600
Nevada	1,470	640	2,800	1,400	4,300	2,100	5,800	2,900
New Mexico	1,340	930	12,300	6,400	20,300	10,200	25,500	13,000
Utah	30	10	40	10	50	20	80	20
Lower Colorado Hydrologic Region	105,100	51,500	168,600	84,000	249,600	123,800	327,100	160,500

TABLE 16. - Estimated water use for minerals by Subregions for the OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Hydrologic Region
(acre-feet)

Subregion	1965		1980		2000		2020	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Lower Main Stem .	6,380	2,590	9,900	4,300	14,600	6,400	19,400	8,500
Little Colorado .	1,010	590	3,700	3,100	4,300	3,600	2,200	1,400
Gila	97,710	48,320	155,000	76,600	230,700	113,800	305,500	150,600
Lower Colorado Hydrologic Region	105,100	51,500	168,600	84,000	249,600	123,800	327,100	160,500

TABLE 17. - Estimated value of mineral production by States for the Modified OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Economic Region

State	Value of mineral production (thousand 1958 dollars)			
	1965	1980	2000	2020
Arizona	$490,179	$908,300	$1,259,000	$1,565,600
Nevada	13,075	37,000	52,000	56,000
New Mexico	102,795	222,000	388,000	823,000
Utah	174	300	500	800
Lower Colorado Economic Region	606,223	1,167,600	1,699,500	2,445,400

TABLE 18. - Estimated value of mineral production by Subregions for the Modified OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Economic Region

Subregion	Value of mineral production (thousand 1958 dollars)			
	1965	1980	2000	2020
Lower Main Stem ..	$43,412	$141,000	$171,600	$197,800
Little Colorado ..	40,088	224,100	304,100	480,000
Gila	522,723	802,500	1,223,800	1,767,600
Lower Colorado Economic Region	606,223	1,167,600	1,699,500	2,445,400

TABLE 19. - Estimated water use for minerals by States for the Modified OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Economic Region
(acre-feet)

State	1965		1980		2000		2020	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Arizona	102,360	50,010	161,400	79,600	232,300	114,700	302,800	147,600
Nevada	1,470	640	4,600	2,300	6,600	3,400	6,900	3,500
New Mexico	17,430	9,670	27,600	17,900	55,000	38,400	100,400	75,200
Utah	30	10	40	10	100	30	100	30
Lower Colorado Economic Region	121,290	60,330	193,600	99,800	294,000	156,500	410,200	226,300

TABLE 20. - Estimated water use for minerals by Subregions for the Modified OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Economic Region
(acre-feet)

Subregion	1965		1980		2000		2020	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Lower Main Stem ..	6,380	2,590	17,000	6,200	21,700	8,600	25,300	10,000
Little Colorado ..	3,160	2,060	12,600	9,800	16,800	13,500	28,200	23,300
Gila	111,750	55,680	164,000	83,800	255,500	134,400	356,700	193,000
Lower Colorado Economic Region	121,290	60,330	193,600	99,800	294,000	156,500	410,200	226,300

TABLE 21. - Estimated value of mineral production by States for the Modified OBE-ERS level of development, 1965, 1970, 2000, and 2020, Lower Colorado Hydrologic Region

State	Value of mineral production (thousand 1958 dollars)			
	1965	1980	2000	2020
Arizona	$489,087	$896,000	$1,248,000	$1,554,600
Nevada	8,268	37,000	52,000	56,000
New Mexico	13,075	83,000	153,500	323,000
Utah	174	300	500	800
Lower Colorado Hydrologic Region	510,604	1,016,300	1,454,000	1,934,400

TABLE 22. - Estimated value of mineral production by Subregions for the Modified OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Hydrologic Region

Subregion	Value of mineral production (thousand 1958 dollars)			
	1965	1980	2000	2020
Lower Main Stem ...	$43,412	$141,000	$171,600	$197,800
Little Colorado ...	10,894	131,800	162,100	154,000
Gila	456,298	743,500	1,120,300	1,582,600
Lower Colorado Hydrologic Region	510,604	1,016,300	1,454,000	1,934,400

TABLE 23. - Estimated water use for minerals by States for the Modified OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Hydrologic Region
(acre-feet)

State	1965		1980		2000		2020	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Arizona	102,260	49,920	161,000	79,200	231,800	114,300	302,400	147,200
Nevada	1,470	640	4,600	2,300	6,600	3,400	6,900	3,500
New Mexico	1,340	930	12,300	7,400	21,400	13,800	50,200	35,600
Utah	30	10	40	10	100	30	100	30
Lower Colorado Hydrologic Region	105,100	51,500	177,900	88,900	259,900	131,500	359,600	186,300

TABLE 24. - Estimated water use for minerals by Subregions for the Modified OBE-ERS level of development, 1965, 1980, 2000, and 2020, Lower Colorado Hydrologic Region
(acre-feet)

Subregion	1965		1980		2000		2020	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Lower Main Stem .	6,380	2,590	17,000	6,200	21,700	8,600	25,200	10,000
Little Colorado .	1,010	590	7,600	6,500	10,300	8,900	13,900	11,800
Gila	97,710	47,840	153,300	76,200	227,900	114,000	320,500	164,500
Lower Colorado Hydrologic Region	105,100	51,500	177,900	88,900	259,900	131,500	359,600	186,300

TABLE 25. - Value of Lower Colorado Economic Region mineral industry production in 1965 per acre-foot of water diverted and depleted

	Water use (acre-feet)		Value of production (thousand 1958 dollars)	Average value per acre-foot	
	Diversions	Depletions		Diverted	Depleted
Lower Main Stem	6,400	2,600	$43,412	$6,800	$16,700
Fuels	280	50	3,080	11,000	61,600
Metals	3,950	1,680	22,037	5,580	13,120
Nonmetals	2,140	860	18,295	8,550	21,270
Little Colorado	3,200	2,100	40,088	12,500	19,100
Fuels	2,720	1,920	37,177	13,670	19,360
Metals	-	-	-	-	-
Nonmetals	440	150	2,911	6,620	19,410
Gila	111,800	55,700	522,723	4,700	9,400
Fuels	-	-	-	-	-
Metals	106,470	54,800	485,754	4,560	8,860
Nonmetals	5,310	890	36,969	6,960	41,540
Lower Colorado Region	121,400	60,400	606,223	5,000	10,000
Fuels	3,000	1,970	40,257	13,400	20,400
Metals	110,420	56,480	507,791	4,600	9,000
Nonmetals	7,890	1,900	58,175	7,400	30,600

CHAPTER 7 - LAND REQUIREMENTS OF MINERAL INDUSTRY

Projection Methods

Land use in connection with (1) discovering and with (2) producing minerals is so categorized in order to highlight the mineral land requirements and the interrelationships with land requirements for other land uses.

Exploration-inventory control land use includes land owned, leased, or temporarily occupied for exploration.

An estimated 223,000 acres will be in active mineral production in the year 2020, but only if many times that number of acres are prospected and reprospected by a host of men and mechanized equipment. Approximately 11 percent of the region's lands are withdrawn from mineral exploration or otherwise restricted by present use or decision of owners. The balance of the land in the region must support the discovery of deposits for eventual active production land use.

The effect of this prospecting and land acquisition for future production has a profound effect upon the use of these and adjacent acres for other pursuits. This is discussed further in Appendix VI, Land Resources & Use.

Active production land use refers explicitly to land actively occupied and used by the mineral industry in producing minerals on an annual basis. This category includes access roads and mill sites, but does not include subsurface lateral development for extraction of minerals. For example, land use at an underground coal mine refers only to the surface-plant needs--not to the surface area controlled by, or "subsurface area" mined by a company.

Mineral industry land-use data are not canvassed by the Bureau of Mines in its annual survey of mineral industry activities. However, land-use data have been included in descriptions of mineral properties presented in many Bureau publications, some reports and maps of the U.S. Geological Survey, and some technical journals. These data have served as the basis for estimating land use at the larger mineral industry operations in base year 1965.

Surface land use for active production at the numerous small mineral industry operations was estimated. Minerals recovered from vein-type deposits usually involve only negligible land use whereas, in contrast, sedimentary mineral deposits recovered by surface-mining methods commonly require a substantial land area even for relatively small operations. Based upon prior studies, oil and gas wells were estimated to occupy an average of one-third acre per well.

Estimates of mineral industry total active production land use in base year 1965 and 1980, 2000, and 2020 are listed in Table 26 for OBE-ERS level of development and in Table 27 for modified OBE-ERS level of development.

Economics of Land (and Water) Use for Mineral Production

Economic, social, and environmental impacts are fundamental considerations in land and water resources development programs. In both the public and private sectors, when major land and/or water developments are proposed, benefits commonly are stressed, costs usually are soft-pedalled, and both benefits and costs (particularily those related to social and environmental factors) are subject to a disconcertingly wide range of economic interpretation. However, firm numerical data concerning value of product, employment and wages, taxes generated, etc., usually are available and may be used to illustrate quite explicitly the importance of the various sectors in the region's economy. Furthermore, these firm data should be used by basin planners to weigh the substantial variations in the value of land and water used in alternative ways. Particularly in the arid areas, such as the Lower Colorado Region, it has become imperative to assign scarce water resources to their highest uses, those which will yield maximum social returns.

Comparable data for major land- and water-using sectors of the region's economy are not readily available on a subregional basis. However, Arizona is the one State fully within the economic boundary of the Lower Colorado Region, and thus its statewide statistical data are available and will serve to illustrate several important points.

Value of Lower Colorado Region mineral industry production in base-year 1965 per acre of active production land used is presented in table 28.

In the competition for limited land and water resources, mineral industry value-of-product data generally head the list of raw materials produced per unit of water diverted and depleted. Table 29 illustrates this point, showing the marked spread between value of land and water in alternate uses--in this instance, between Arizona agriculture and mining, and between cotton and copper, the leading products of those industries.

The importance of mineral industry in the Lower Colorado Region has been indicated in table 28, and table 29 points up relative contributions to Arizona's economy. Table 30 presents pertinent facts concerning cotton and copper from a still broader viewpoint, that of national requirements, production, and prices, and Arizona's relative importance as a supply source for these commodities.

TABLE 26. - Estimates of mineral industry active production land use in Lower Colorado Region for 1965, 1980, 2000, 2020 OBE-ERS level of development[1/]

	Total active production land use (acres)			
	1965	1980	2000	2020
Lower Main Stem	5,410	6,190	7,690	8,890
Little Colorado	7,460	13,110	15,240	9,820
Gila	62,900	77,570	95,610	107,370
Lower Colorado Region	75,770	96,870	118,540	126,080

1/ Estimates apply to both the economic region and the hydrologic region.

TABLE 27. - Estimates of mineral industry active production land use in the Lower Colorado Region for 1965, 1980, 2000, 2020 Modified OBE-ERS level of development[1/]

	Total active production land use (acres)			
	1965	1980	2000	2020
Lower Main Stem	5,410	9,000	10,000	11,000
Little Colorado	7,460	28,000	41,000	84,000
Gila	62,900	78,000	105,000	128,000
Lower Colorado Region	75,770	115,000	156,000	223,000

1/ Estimates apply to both the economic region and the hydrologic region.

TABLE 28. - Value of Lower Colorado Economic Region mineral industry production in 1965 per acre of active production land used

	Mineral industry land use (acres)	Value of mineral production (1958 dollars)	Value per acre of land used (1958 dollars)
Lower Main Stem	5,410	$43,412,000	$8,020
Little Colorado	7,460	40,088,000	5,370
Gila	62,900	522,723,000	8,310
Lower Colorado Region	75,770	606,223,000	8,000

TABLE 29. - Arizona agriculture-mining and cotton-copper value of product data for 1965

	Land use (acres)	Water depletion (acre-feet)	Value of product (1958 dollars)	Value of product	
				per acre used	per acre-ft depletion
Agriculture 1/	1,600,000	6,300,000	$265,496,000	$229	$42
Mining 2/	58,350	49,520	475,713,000	8,153	9,606
Cotton	339,000	2,200,000	120,018,000	354	55
Copper	54,870	48,490	433,132,000	7,894	8,932

Source: University of Arizona "Arizona Agriculture" and Bureau of Mines.
1/ Principal crops only: alfalfa, citrus, cotton, grains, and vegetables.
2/ Top commodities only: copper, sand and gravel, lead-zinc, cement, and lime.

TABLE 30. - United States and Arizona cotton and copper production and price, 1950-65

	Cotton				Copper			
	Production (thousand 500-lb bales)		Arizona production as a percent of U.S.	Price per pound (current dollars)	Production (thousand short tons)		Arizona production as a percent of U.S.	Price per pound (current dollars)
	U.S.	Arizona			U.S.	Arizona		
1950	10,000	440	4.4	$0.40	909	395	43.5	$0.21
1955	14,700	728	5.0	.32	999	454	45.4	.37
1960	14,300	835	5.8	.30	1,080	539	49.9	.32
1965	15,000	787	5.2	.28	1,352	703	52.0	.35

Source: U.S. Department of Agriculture and U.S. Bureau of Mines.

TABLE 31. - Average annual wage payments to covered employees in Arizona
(current dollars)

Industry	1960	1965	Percent increase
Mining	$6,452	$7,878	22.1
Construction	6,223	7,136	14.7
Manufacturing	5,722	6,551	14.5
Transportation and utilities	5,340	6,512	21.9
Finance, insurance, real estate	4,863	5,603	15.2
Wholesale and retail trade	3,922	4,375	11.6
Services and miscellaneous	3,590	4,096	14.1
Arizona average	4,894	5,506	12.5

Source: Arizona Statistical Review, Research Department, Valley National Bank, Phoenix, Twenty-second Annual Edition, Sept. 1966.

Finally, some recent data on wage scales in leading sectors of Arizona's economy are noteworthy. Annual wage payments data are listed in table 31.

Data compiled on a subregional basis will become available upon completion of the Type I Comprehensive Framework Study and will afford an opportunity to develop more specific analyses of economic returns from land and water resources in alternative uses. Consideration of the many factors involved in subregional development programs, including an objective measurement or estimate of social benefits and costs, may assure optimum returns in line with accepted conservation principles to the region and the Nation.

CHAPTER 8 - CONCLUSIONS

Projections of mineral production and related land and water needs herein represent two possible levels of regional mineral resource development. These projections primarily are based upon regional and national population growth expectations through 2020 as set forth by OBE-ERS and Modified OBE-ERS criteria.

Tables 9 through 24 summarize projections through 2020 of value of mineral production and water needs. Projections of important mineral commodity output through 1980 generally are compatible with those prepared by a number of private and government sources, including the Bureau of Mines. Projections beyond 1980 herein admittedly are hypothetical and considerably less harmonious with the few long-range forecasts that have been prepared elsewhere. However, prolonged, unbending, upward-inclined trendlines eventually tumble under the inexorable pressures of change and progress, in part perhaps because both arithmetic and geometric progressions possess the seeds of their own downfall. A case in point: at a recent urban mass-transit seminar in Denver one seer suggested that if the worldwide rate of growth in use of internal combustion engines continues its recent trend, then by 2030 the world's internal-combustion-engine population annually could consume all the oxygen in the atmosphere.

For various reasons, some mineral commodities, too, must drop out of their established growth trends. However, there is no objective reason to believe that any of the important mineral commodities customarily produced in the Lower Colorado Region could be depleted physically through 2020. In contrast, there are numerous factors--primarily of an ecologic, economic, or technologic nature--that appear virtually certain to modify the traditional approach to mineral resources development.

Multiple advantages and benefits from domestic mineral resources development--like all resources development--are countered by some negative impacts upon the environment. The 1965-2020 interval surely will see the term "scarce natural resources" increasingly applied to essentially all natural resources in the region. Thus, truly objective weighing of real costs--including a realistic evaluation of the usually neglected bundle of social costs--against real benefits from resource development will be crucial if the people of the Lower Colorado Region and the Nation are to maximize utilization of regional resources potential.

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