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NEVADA BUREAU OF MINES AND GEOLOGY

Arthur Baker III, Acting Director

BULLETIN 82

FORECASTS FOR THE FUTURE - MINERALS

By

Arthur Baker III
N.L. Archbold
W.J. Stoll

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MACKAY SCHOOL OF MINES
UNIVERSITY OF NEVADA
RENO, NEVADA
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BAKER, ARCHBOLD, and STOLL

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FOREWORD

This report, Nevada Bureau of Mines and Geology Bulletin 82, "Forecasts for the Future–Minerals," was originally prepared for the Division of Water Resources, Nevada Department of Conservation and Natural Resources, as one segment of the State water planning effort. In a series of similar reports by the Division, all of the fields of man's activity that involve the use of water in Nevada are being reviewed, and water needs projected, by specialists in each field. Copies of the reports are being distributed by the Division to many interested Nevada citizens and agencies, primarily to those who can be expected to benefit from the water data presented. The very nature of the subject matter, however, implies a more widespread readership for many of the reports than is usual for documents issued by the Division. This report should be of considerable interest to the mining industry.

The estimates of mineral industry water needs, herein, are the basic reason for the report and the study that led to it, but the Division of Water Resources recognized that developing these estimates would require developing allied information on other subjects, which could be included in the report to expand its usefulness greatly with a relatively small amount of additional work. It directed, therefore, that estimates of future mineral industry employment and production be included in the report. Further, the Division recognized that the value of estimates is enhanced greatly if they are accompanied by a description of the steps by which they were reached, so that the reader can form his own opinion of their validity. For this reason it directed that a descriptive text accompany the estimates. Mineral deposits are a part of the geology of the area in which they occur, and are brought into production partly on the basis of their competitive position with similar deposits and partly on the basis of mineral treatment techniques that are applicable. The descriptive text, then, inevitably developed into a description of the geology of the State, the geology of the various kinds of ore deposits, and the economics and technology of the mineral industry.

The report, therefore, may well be of use to a number of individuals and organizations whose interests are in minerals or geology rather than in water, but who may not become aware of its availability through the Division. In particular, the projections of future mineral production may be of interest to professionals in the mineral industry, while the text may be useful to non-professionals who are interested in a general, overall view of Nevada's geology and mineral deposits. The Division of Water Resources, therefore, generously granted the request of the Nevada Bureau of Mines and Geology to purchase additional copies for issuance as a Bureau Bulletin.

Arthur Baker III, *Acting Director*
Nevada Bureau of Mines and Geology

January, 1973
Mackay School of Mines
University of Nevada, Reno

State of Nevada

WATER PLANNING REPORT

WATER

FOR NEVADA

Prepared by the State Engineer's Office, and
the Nevada Bureau of Mines and Geology,
Mackay School of Mines,
University of Nevada, Reno

JANUARY 1973

FORECASTS FOR THE FUTURE — MINING

4

REPORT NO.

ELMO J. DeRICCO
Director

STATE OF NEVADA
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
DIVISION OF WATER RESOURCES
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ROLAND D. WESTERGARD
State Engineer

In reply refer to
No.

Address All Communications to
the State Engineer, Division
of Water Resources

TO THE CITIZENS OF THE STATE OF NEVADA

As a part of the development of the State Water Plan, the Division of Water Resources is estimating the need for water and related land resources for the coming fifty-year period. The years 1970 (Base Year), 1980, 2000, and 2020 have been selected by the Division to serve as markers in tracing the estimated water requirements for the next half-century.

Agreements have been made with several Federal and State agencies to assist the Division in the preparation of estimates of future usage for particular activities. Such an agreement was made with the Nevada Bureau of Mines and Geology to estimate future water requirements for the mineral industry in Nevada. The principal authors of this report are Arthur Baker III, N. L. Archbold and W. J. Stoll. James C. Perkins, Division of Water Resource's Special Projects Engineer was a major contributor. Ingrid Klaich, Division cartographer, assisted in the compilation of the report. B. J. Vasey, Planning Engineer with the Division, supervised its preparation and production.

This Planning Report is the first of a series of reports related to the projection phase of the State Water Planning effort. Estimates of future water needs for Nevada's mineral production are presented for each of the States' fourteen hydrographic regions and its seventeen counties. A summary by commodity for the entire state is also given. Future mineral production is forecast for some thirty-five commodities ranging from gold and silver to sand and gravel.

In addition to the estimates of production by commodity, and the associated water requirements, the Report also presents estimates of employment needs and value of production.

The conclusions presented in this report summarize at least some of the future conditions and problems related to future water requirements for the mineral industry that may well have an important impact on the lives of all the people of this State, both those now living and those of future generations.

Respectfully,

Roland D. Westergard
State Engineer

TABLE OF CONTENTS

List of Figures . . . . . *Page ix*

List of Maps . . . . . *x*

List of Tables . . . . . *xii*

PART I General Considerations

Chapter

1 Introduction *1*

2 Technology and Water Needs of the Mineral Industry *5*

Mineral Exploration Technology *9*

Mining Technology *11*

Concentration Technology *15*

Refining Technology *19*

3 History of Mining in Nevada *20*

4 Assumptions *26*

5 General Geology of Nevada *29*

Distribution of Rock Types *31*

Intrusive Rocks *32*

Pre-Tertiary Non-intrusive Rocks *32*

Tertiary Volcanic Rocks *33*

Deep Cover *33*

Shallow Cover *33*

Geologic History *35*

Distribution of Mineralization *37*

6 Classification of Nevada Mineral Commodities *38*

Category 1: Commodities in Non-economic Concentrations *39*

Category 2: Byproduct Commodities *41*

Category 3: Metallic Mineral Commodities *42*

Category 4: Industrial Rock and Mineral Commodities *43*

Category 5: Miscellaneous Mineral Commodities *44*

7 Comparison with a Similar Study *44*

Chapter

PART II Metallic Mineral Commodities

8 Future Metallic Mineral Deposits: General Considerations 50

9 Antimony (SIC No. 1099*) 52

10 Beryllium (SIC No. 1099*) 56

11 Copper (SIC No. 1021*) 59

12 Gold and Silver (SIC No. 104*) 64

13 Iron (SIC No. 1011*) 72

14 Lead and Zinc (SIC No. 1031*) 77

15 Manganese (SIC No. 1062*) 83

16 Mercury (SIC No. 1092*) 86

17 Molybdenum (SIC No. 1069*) 92

18 Tungsten (SIC No. 1064*) 94

19 Uranium (SIC No. 1094*) 99

20 Vanadium (SIC No. 1094*) 102

PART III Industrial Rock and Mineral Commodities

21 Future Industrial Rock and Mineral Deposits: General Considerations 106

22 Barite (SIC No. 1472*) 108

23 Clays (SIC No. 145*) 112

24 Diatomite (SIC No. 1499*) 118

25 Fluorspar (SIC No. 1473*) 121

26 Refractories (SIC No. 1459*) 125

27 Sand, Industrial (SIC No. 1446*) 129

28 Sand and Gravel ,Construction (SIC No. 1442*) 134

29 Stone (SIC No. 142*) 140

30 Talc, Soapstone and Pyrophyllite (SIC No. 1496*) 146

31 Vermiculite (SIC No. 1499*) 150

32 Zeolites (SIC No. 1499*) 152

PART IV Miscellaneous Mineral Commodities

33 Future Miscellaneous Mineral Deposits: General Considerations 156

Chapter

34 Gem and Semiprecious Stones (SIC No. 1499*) 157

35 Geothermal Resources (SIC No. 4911*) 162

36 Petroleum and Natural Gas (SIC No. 1311*) 168

37 Saline Playa Deposits (SIC No. 28*) 171

38 Total-rock Components (SIC No. 10*) 177

PART V. Estimated Mineral Production and Associated Water and Employment Needs in Nevada, 1970 to 2020, Counties, by Commodities 182

PART VI. Estimated Mineral Production and Associated Water and Employment Needs in Nevada, 1970 to 2020, Hydrographic Regions, by Commodities 200

PART VII. Estimated Mineral Production and Associated Water and Employment Needs in Nevada, 1970 to 2020, Entire State 216

References 223

*Standard Industrial Classification Number for the mining of this commodity, as established by the United States Bureau of the Budget.

LIST OF FIGURES

Figure 1-1. Bassett Lake, a recreational lake stocked with game fish . . . . . Page 2

Figure 2-1. Typical large Nevada open-pit mine. 6

Figure 2-2. Geyser erupting in geothermal area near Beowawe. 12

Figure 2-3. Concentrator at Gabbs. 15

Figure 2-4. Flotation cells concentrating copper ore at McGill. 18

Figure 3-1. A mine crew in 1898. 20

Figure 3-2. Graph showing annual value of Nevada's mineral production since 1860. 21

Figure 3-3. Inside Sutro Tunnel. 23

Figure 3-4. Power shovels and huge trucks move ore from modern open-pit mine 26

Figure 4-1. Alfalfa field. 27

Figure 5-1. Baker Lake in the Wheeler Peak area of White Pine County 30

Figure 5-2. Geologic time divisions and major events in Nevada 34

Figure 5-3. Diagrammatic representation of geologic structure in the Basin and Range Province 36

Figure 5-4. High altitude photo looking southwest across Basin and Range terrain in White Pine County 36

Figure 6-1. Cinder cone formed by volcanic action about one hundred thousand years ago 40

Figure 6-2. Empire, Washoe County 43

Figure 11-1. Heap leaching 62

Figure 24-1. Photomicrograph of a diatom 118

Figure 28-1. Paradise Ponds, Reno 136

Figure 34-1. Nevada gemstones 158

Figure 35-1. Geothermal area near Wabuska, Lyon County 165

Figure 37-1. Cross section through a saline Playa 172

Figure V1-1. Flume carrying water to a mine of the early 1900's 199

Figure V1-2. Collection pond for recovery of water used in leaching of copper from mine dumps 210

LIST OF MAPS

Map

5-1 Modified Geologic Map of Nevada . . . . . *In Pocket*

9-1 Distribution of Known Antimony Occurrences and Production 53

10-1 Distribution of Known Individual Beryllium Occurrences 57

11-1 Distribution of Known Copper Occurrences and Production 61

12-1 Distribution of Known Occurrences and Production 65

12-2 Distribution of Known Silver Occurrences and Production 67

12-3 Distribution of Known Gold-Silver Occurrences and Production 69

13-1 Distribution of Known Iron Occurrences and Production 73

14-1 Distribution of Known Lead Occurrences and Production 78

14-2 Distribution of Known Zinc Occurrences and Production 79

14-3 Distribution of Known Lead and Zinc Occurrences and Production 81

Map

15-1 Distribution of Known Manganese Occurrences and Production 85

16-1 Distribution of Known Mercury Occurrences and Production 87

17-1 Distribution of Known Molybdenum Occurrences and Production 91

18-1 Distribution of Known Tungsten Occurrences and Production 95

19-1 Distribution of Known Uranium Occurrences and Production 99

20-1 Distribution of Known Vanadium Occurrences and Production 103

22-1 Distribution of Known Barite Occurrences and Production.....109

23-1 Probable Distribution of Clay Deposits.....113

24-1 Distribution of Known Diatomite Occurrences and Production 117

25-1 Distribution of Known Fluorspar Occurrences and Production 123

26-1 Probable Distribution of Refractories Deposits 127

27-1 Probable Distribution of Industrial Sand Deposits 131

28-1 Distribution of Sand and Gravel for Construction 135

29-1 Probable Distribution of Stone Deposits 141

30-1 Distribution of Known Talc, Soapstone and Pyrophyllite Occurrences and Production.....147

31-1 Distribution of Known Vermiculite Occurrences and Production 151

32-1 Probable Distribution of Zeolite Deposits 153

34-1 Distribution of Gem and Semiprecious Stones 159

35-1 Distribution of Known Hot Springs 163

36-1 Distribution of Petroleum and Natural Gas Drilling Through 1970 169

37-1 Distribution of Pleistocene Lake.....173

38-1 Probable Distribution of Total-rock Component Deposits 179

LIST OF TABLES

Table

2-1 *Water and Manpower Requirements for Mineral Processing* ..... *Page* 7

5-1 *Generalized Rock Groupings in Nevada* 32

6-1 *Classification of Nevada Mineral Commodities* 39

6-2 *Commodities in Noneconomic Concentrations* 39

6-3 *Byproduct Commodities* 42

6-4 *Metallic Mineral Commodities* 43

6-5 *Industrial Rock and Mineral Commodities* 43

6-6 *Miscellaneous Mineral Commodities* 44

7-1 *Comparison of Value and Water Need Estimates for Nevada Mineral Production, Great Basin Study and This Study* 46

7-2 *Comparison of Adjusted Value and Water Need Estimates for Nevada Mineral Production, Great Basin Study and This Study* 48

9-1 *Estimated Future Antimony Statistics, by County* 55

9-2 *Estimated Future Antimony Statistics, by Hydrographic Region* 55

10-1 *Estimated Future Beryllium Statistics, by County* 58

10-2 *Estimated Future Beryllium Statistics, by Hydrographic Region* 59

11-1 *World Copper Production, 1968* 60

11-2 *Estimated Future Copper Statistics, by County* 63

11-3 *Estimated Future Copper Statistics, by Hydrographic Region* 64

12-1 *World Gold Production, 1969* 68

12-2 *World Silver Production, 1969* 70

12-3 *Estimated Future Gold and Silver Statistics, by County* 71

12-4 *Estimated Future Gold and Silver Statistics, by Hydrographic Region* 72

13-1 *World Iron Ore Production, 1968, and Reserves of Iron Ore* 74

13-2 *Estimated Future Iron Ore Statistics, by County* 75

13-3 *Estimated Future Iron Ore Statistics, by Hydrographic Region* 76

14-1 *World Lead Mine Production, 1968* 77

14-2 *World Zinc Mine Production, 1968* 80

Table

14-3 Estimated Future Lead and Zinc Statistics, by County 82

14-4 Estimated Future Lead and Zinc Statistics, by Hydrographic Region 83

15-1 World Manganese Production, 1968 84

15-2 Estimated Future Manganese Statistics by County 84

15-3 Estimated Future Manganese Statistics by Hydrographic Region 86

16-1 Domestic Consumption of Mercury, 1969 88

16-2 Estimated Future Mercury Statistics, by County 89

16-3 Estimated Future Mercury Statistics, by Hydrographic Region 90

17-1 Estimated Future Molybdenum Statistics, by County 93

17-2 Estimated Future Molybdenum Statistics, by Hydrographic Region 94

18-1 World Tungsten Production, 1968 96

18-2 Estimated Future Tungsten Statistics, by County 97

18-3 Estimated Future Tungsten Statistics, by Hydrographic Region 98

19-1 Estimated Future Uranium Statistics, by County 101

19-2 Estimated Future Uranium Statistics, by Hydrographic Region 102

20-1 Estimated Future Vanadium Statistics, by County 105

20-2 Estimated Future Vanadium Statistics, by Hydrographic Region 105

22-1 Estimated Future Barite Statistics, by County 110

22-2 Estimated Future Barite Statistics, by Hydrographic Region 111

23-1 Estimated Future Clay Statistics, by County 114

23-2 Estimated Future Clay Statistics, by Hydrographic Region 115

24-1 Estimated Future Diatomite Statistics, by County 119

24-2 Estimated Future Diatomite Statistics, by Hydrographic Region 120

25-1 Estimated Future Fluorspar Statistics, by County 122

25-2 Estimated Future Fluorspar Statistics, by Hydrographic Region 124

26-1 Estimated Future Refractories Statistics, by County 128

26-2 Estimated Future Refractories Statistics, by Hydrographic Region 128

27-1 Estimated Future Industrial Sand Statistics, by County 132

27-2 Estimated Future Industrial Sand Statistics, by Hydrographic Region 133

28-1 Sand and Gravel Consumption in the United States, 1968 134

28-2 Estimated Future Sand and Gravel Statistics, by County 137

Table

28-3 Estimated Future Sand and Gravel Statistics, by Hydrographic Region 139

29-1 Materials Considered as Stone 140

29-2 Uses of Crushed Stone in the United States during 1968 142

29-3 Stone Production in Nevada during 1970 143

29-4 Estimated Future Stone Statistics, by County 144

29-5 Estimated Future Stone Statistics, by Hydrographic Region 145

30-1 Estimated Future Talc, Soapstone and Pyrophyllite Statistics, by County . . . 148

30-2 Estimated Future Talc, Soapstone and Pyrophyllite Statistics, by Hydrographic Region. 149

31-1 Estimated Future Vermiculite Statistics, by County 150

31-2 Estimated Future Vermiculite Statistics, by Hydrographic Region 152

32-1 Estimated Future Zeolite Statistics, by County 154

32-2 Estimated Future Zeolite Statistics, by Hydrographic Region 155

33-1 Miscellaneous Commodities 156

34-1 Estimated Future Gem and Semiprecious Stones Statistics, by County 160

34-2 Estimated Future Gem and Semiprecious Stones Statistics, by Hydrographic Region 161

35-1 Estimated Future Geothermal Resources Statistics, by County 166

35-2 Estimated Future Geothermal Resources Statistics, by Hydrographic Region 167

36-1 Estimated Future Petroleum and Natural Gas Statistics, by County 170

36-2 Estimated Future Petroleum and Natural Gas Statistics, by Hydrographic Region. 171

37-1 Estimated Future Saline Playa Product Statistics, by County 175

37-2 Estimated Future Saline Playa Product Statistics, by Hydrographic Region . 176

38-1 Estimated Future Total-rock Component Product Statistics, by County 180

38-2 Estimated Future Total-rock Component Product Statistics, by Hydrographic Region 180

V-1 Carson City Estimated Future Mineral Production Statistics 182

V-2 Clark County Estimated Future Mineral Production Statistics 183

V-3 Churchill County Estimated Future Mineral Production Statistics 184

V-4 Douglas County Estimated Future Mineral Production Statistics 185

V-5 Elko County Estimated Future Mineral Production Statistics 186

Table

V-6 Esmeralda County Estimated Future Mineral Production Statistics 187

V-7 Eureka County Estimated Future Mineral Production Statistics 188

V-8 Humboldt County Estimated Future Mineral Production Statistics 189

V-9 Lander County Estimated Future Mineral Production Statistics 190

V-10 Lincoln County Estimated Future Mineral Production Statistics 191

V-11 Lyon County Estimated Future Mineral Production Statistics 192

V-12 Mineral County Estimated Future Mineral Production Statistics 193

V-13 Nye County Estimated Future Mineral Production Statistics 194

V-14 Pershing County Estimated Future Mineral Production Statistics 195

V-15 Storey County Estimated Future Mineral Production Statistics 196

V-16 Washoe County Estimated Future Mineral Production Statistics 197

V-17 White Pine County Estimated Future Mineral Production Statistics 198

VI-1 Hydrographic Region 1 Estimated Future Mineral Production Statistics 200

VI-2 Hydrographic Region 2 Estimated Future Mineral Production Statistics 201

VI-3 Hydrographic Region 3 Estimated Future Mineral Production Statistics 202

VI-4 Hydrographic Region 4 Estimated Future Mineral Production Statistics 203

VI-5 Hydrographic Region 5 Estimated Future Mineral Production Statistics 205

VI-6 Hydrographic Region 6 Estimated Future Mineral Production Statistics 206

VI-7 Hydrographic Region 7 Estimated Future Mineral Production Statistics 207

VI-8 Hydrograhpic Region 8 Estimated Future Mineral Production Statistics 208

VI-9 Hydrographic Region 9 Estimated Future Mineral Production Statistics 209

VI-10 Hydrographic Region 10 Estimated Future Mineral Production Statistics . . .211

VI-11 Hydrographic Region 11 Estimated Future Mineral Production Statistics . . .213

VI-12 Hydrographic Region 12 Estimated Future Mineral Production Statistics . . .213

VI-13 Hydrographic Region 13 Estimated Future Mineral Production Statistics . . .214

VI-14 Hydrographic Region 14 Estimated Future Mineral Production Statistics . . .215

VII-1 State of Nevada, by Commodity, Estimated Future Mineral Production Statistics 216

VII-2 State of Nevada, by County, Estimated Future Mineral Production Statistics .219

VII-3 State of Nevada, by Hydrographic Region, Estimated Future Mineral Production Statistics 221

amount of minerals. Estimates on a State-as-a-whole basis are obviously inadequate because neither water nor mineral production is uniformly distributed through out the State. In order to make the figures more rational in terms of local availability, estimates are presented for each of the State's fourteen hydrographic regions. (The hydrographic regions are water source and supply areas delineated by the Division of Water Resources on the basis of topography and water availability.) In addition, estimates are also presented on a county basis because the State's seventeen counties are understood as both political and geographic units by most citizens of Nevada. We consider it important that the non-specialist citizen be able to understand the conclusions presented in this report because they summarize at least some of the future conditions and problems that may well have an important impact on the lives of all the people of this State, both those now living and those of future generations.

In producing this report the authors found that the most challenging problem was the necessity to (1) generate estimates of future mineral production on a scientifically sound basis and (2) present them in a form usable by the Division of Water Resources, as well as by other planning agencies and individuals. The two aspects of this requirement were not easy to reconcile. Reporting conclusions concerning future mineral production in terms of specific counties and hydrographic regions requires that we attempt to predict almost the very site of that future production, something which calls for a degree of precision that modern geological science is not capable of achieving. Certainly, within recognized limits, it is geologically reasonable to define favorable areas of Nevada in which deposits of a particular commodity are likely to be found. These are usually large areas which include all or parts of several counties and hydrographic regions. (See, for example, Map 9-1.) The present state of the geological science also permits us, though with a lesser degree of certainty, to conclude that a given number of deposits of the commodity will be found and mined in those favorable areas within the next half century. But it is extremely difficult to pinpoint the precise area in which production will occur – to locate it within both a partiular county and hydrographic region – when, theoretically, all parts of the larger geologically favorable area are equally reasonable choices. How, then, and on what basis could the sites be pinpointed as required?

No really satisfying solution to this problem exists. The final determinations are based principally on the judgment of the authors, who have had considerable field experience with the mineral deposits of Nevada. We have applied as best we can our knowledge of geological principles and processes to our knowledge of Nevada's unique geological structure and conditions in making the assessments. In addition, we have consulted with other geologists who have had extensive experience with particular commodities and with the areas under consideration. Some of our conclusions have been easy to make: a few metallic deposits and many nonmetallic deposits are known that await only the appropriate economic climate for exploitation. Other judgments were more difficult: many lesser prospects of both metallic and nonmetallic minerals are known, and we have had to conclude which ones will likely become productive in the next fifty years. Such decisions as these, of course, are influenced by our conceptions of economic, technologic, and social factors, including various explicit or implicit assumptions. Finally, other judgments were extremely hard to make. For instance, our best guides to possible ores beneath the great expanses that are covered by gravels or lava flows were, first, proximity to known deposits and, second, projections of known favorable structures.

The need to estimate the future production of a particular mining operation also presented difficulties. Will the size of "typical" mining operations tend to increase, remain the same, or decrease, as time progresses? In dealing with this problem we made the assumption that individual mining operations in the future will tend to be somewhat larger than those of today.

The time frame introduced additional difficulties. Obviously, the further one reaches into the future the more difficult it becomes to estimate anything. Statements contained herein that a deposit of a given commodity will be found and put into production in an area by 1980, and that another deposit will be put into production in an area by 2000 or 2020, are only estimations. In addition, there is no reliable way of knowing which deposits will remain productive through any given length of time. Estimates of these matters are based primarily on past performances and present conditions. Thus, conclu-

sions that specific kinds of mines will be operating at given levels of production in specific hydrographic regions and counties at specific times must be viewed only as our best estimates of what we believe is likely or possible. They do not pretend to be anything more.

Now, after the warnings and disclaimers, we wish to state that we believe the general conclusions of this report are valid and that, overall, our production estimates will prove to be reasonably accurate. We have attempted to maintain a rational balance between optimism and pessimism concerning the estimates presented. It will be obvious to the reader that the approach used has been that of the regional exploration geologist attempting to determine what minerals are likely to occur in economic quantities and where the deposits are likely to be found. We have left the problems of actual discovery, production, and marketing to the future.

For the State as a whole, we feel that future mineral production might range from as low as 75 percent to as high as 200 percent of our estimates. The feeling that actual production may be as great as 200 percent of the estimate might be considered by some readers as undue optimism, or perhaps even wishful thinking; however, we believe it is reasonable, partly because, as noted in Chapter 3, in only about 20 percent of the State are the rocks exposed which historically have been the sources of most of Nevada's metallic mineral production. New exploration techniques and mining technology will greatly increase man's ability to find and tap the hidden riches in the remaining 80 percent of the State. On the smaller scale of hydrographic regions and counties, we feel our estimates of total mineral production and related water consumption are reasonably good but, of course, individually not as good as for the State as a whole. We believe also that our overall conclusions about individual commodities are reasonable — for instance, there will be no major platinum mines developed in Nevada during the next fifty years but there will be several new major copper mines.

This Report is divided into seven Parts. Part I is concerned with a generalized overview of the mineral industry in Nevada and of this study. In Chapter 2 we describe mining technology and derive the factors used in later chapters to reach our estimates of future water and manpower needs. Chapter 3 is a brief history of Nevada's mineral industry. Its purpose is to summarize for the reader major events in mining activity and to provide the perspective against which our projections of the future should be viewed. Chapter 4 presents our major assumptions concerning the variables we expect to affect the State's mineral industry during the next fifty years. Chapter 5 is a resume of Nevada's geology in which we outline the basic geologic pattern of the State with emphasis on features relevant to the distribution of mineral deposits, and also describe the general way in which we have used geology in estimating future mineral production. Chapter 6 presents our classification of mineral commodities. It was developed to take cognizance of the geological emphasis, geographical restriction, regional economic setting, diversity of commodities, and water use objectives of this study. Chapter 7 is a comparison of the estimates reached in this study with those reached in "Great Basin Region, Comprehensive Framework Study, Appendix VII, Mineral Resources," prepared under the direction of Pacific Southwest Inter-Agency Committee, Water Resources Council, June, 1971.

Parts II, III and IV are the core of this report. They are devoted, respectively, to consideration of the metallic mineral commodities, industrial rock and mineral commodities, and miscellaneous mineral commodities that we believe will be produced in Nevada during the next fifty years and will consume water in their production processes. Each Part begins with an introductory chapter in which we outline the general problems encountered and the techniques used in obtaining the commodity production estimates. The remainder of each Part consists of individual commodity chapters in which we discuss the major economic, geologic, and other factors likely to influence the rate of production. The commodity chapters include tabulations presenting by county and by hydrographic region our estimates of production for the years 1970, 1980, 2000, 2020, together with our estimates of water and manpower needs and values at 1970 prices. For 1970 we have used production figures published by the U.S. Bureau of Mines wherever possible; for commodities not reported we made estimates based on Net Proceeds of Mines reports filed with the Nevada State Tax Commission. 1970 employment figures are from "Nevada Mines, Mills and Smelters in operation as of July 1, 1970," compiled by the State Inspector of Mines, Carson City, Nevada. These chapters are also

accompanied by maps showing the distribution of indiviual commodities. Map sources are given in Chapter 5, in the introductory chapters to each Part, and in certain of the commodity chapters.

Parts V and VI consist of a series of tables which summarize the estimated mineral production, with water and manpower needs, by counties and hydrographic regions. Statistics withheld from individual commodity tabulations to prevent disclosure of confidential information are included here as aggregations, in order that these tables will present our complete estimates of water and manpower needs. Part VII consists of three tables summarizing, by commodity, by county and by hydrographic region, projected mineral production and related water and manpower needs for the entire State.

Many individuals and organizations have contributed data and ideas for this study; it is impossible to mention them by name, but we are grateful to all of them. Many of the data on which we based our estimates of water and manpower needs were taken from Holmes (1966); additional data provided to us by mining companies, particularly by those working on leaching processes, were invaluable in reaching our estimates. Discussions with numerous exploration geologists have been very fruitful, particularly those concerning areas likely to contain the ore deposits of the future, and their size and grade. Data on consumption and production of the various commodities were taken primarily from publications of the U.S. Bureau of Mines, especially Bulletin 650 (1970). Commodity specialists and editors of the Nevada Bureau of Mines and Geology critically read the manuscript and made many useful suggestions. During the progress of the work, Division of Water Resources personnel proposed many modifications of the study that expanded its applicability well beyond original expectations. Again, we are grateful to all these who helped the project. However, we alone are responsible for the conclusions reached and for the estimates of future mineral production and its associated water and manpower needs.

Chapter 2 TECHNOLOGY AND WATER NEEDS OF THE MINERAL INDUSTRY

The economic activities performed by modern man are both numerous and varied. Because of this diversity, sets of related activities are commonly grouped into categories called industries. These include mining (the preferred name today is "mineral industry"), agriculture, fishing, lumbering, construction, manufacturing and services. The mineral industry is a primary industry and it includes that set of activities related to extracting useful mineral materials from the earth and processing them into products usable principally by the agricultural, construction and manufacturing industries. The output of the mineral industry thus provides the raw materials for these other industries.

In this Chapter we describe briefly the processes that are used in the mineral industry. We hope that the descriptions will be of some assistance to the reader who is not familiar with mining, as he encounters mention of the processes in the chapters that follow, but our principal purpose here is to derive water and manpower factors for the various processes – estimates of the amount of water and manpower that will be required by each process to produce a given amount of commodity. These factors we then use in the commodity chapters to reach our estimates of total water and manpower needs of the mineral industry in the years 1980, 2000 and 2020.

The essential data required to develop a water budget for a process are the amount of new water required and the amount of water consumed. "New water" is water that must be obtained from some source such as a stream or well; it does not include water recovered at the end of the processing and reused. "Consumed water" is water used up in the processing, and for the most part is water that is evaporated, but the term also includes water that remains in the product – such as moisture in sand trucked away wet – and water that is hopelessly contaminated and can no longer be used. In general, the difference between new water and consumed water represents the amount of water either discharged into streams or that seeps into the ground; such water, of course, can be used again by some other consumer. The factors that we have determined for each process are: number of gallons of new water required to treat 1,000 tons of ore; number of gallons of water consumed in processing 1,000 tons of ore; and number of men (actually, a small fraction of one man) employed for one year to process 1,000 tons of ore. The factors are summarized in table 2-1.

Many of our water need factors are derived

Figure 2-1. Typical large Nevada open-pit mine. Eureka County. Concentrating plant in center middle ground, pit to right. Water recovery pond in lower left.

largely from data presented by Holmes (1966), but since his survey did not include all of the techniques that we discuss, we turned to various other sources for information. Little has been published on the subject of water use in mineral processing, so we relied heavily on data provided by individuals and companies. We found that even among plants using the same technique, some used twice as much water as others, or even more. Some of this difference no doubt stems from inaccuracy in measuring actual water usage, which is a difficult procedure. Much of the difference, however, is probably a matter of the amount of water available: a plant that has plenty of water available tends to use it all, while one with only limited water manages to operate with that much. Because of this, we have used estimates for new water requirement and for water consumption that are close to the low end of the examples available, reasoning that future plants will have to use water as efficiently as possible. Our estimates of manpower needs are

Table 2-1
ANNUAL WATER AND MANPOWER REQUIREMENTS FOR MINERAL TREATMENT PROCESSES

PROCESS	NEW WATER REQUIREMENT GALLONS	WATER CONSUMED GALLONS	EMPLOYMENT MEN	
Mining: Open Pit				
Large	8,000	4,000	0.07	per 1,000 tons ore
Small	8,000	4,000	0.2	per 1,000 tons ore
Mining: Underground				
Large	5,000	1,000	0.08	per 1,000 tons ore
Small	5,000	1,000	0.3	per 1,000 tons ore
Screening, incl. mining (Sand and Gravel)	150,000	40,000	0.02	per 1,000 tons ore
Magnetic — Coarse	50,000	25,000	0.03	per 1,000 tons ore
Fine	250,000	150,000	0.06	per 1,000 tons ore
Gravity — Large	250,000	150,000	0.06	per 1,000 tons ore
Small	250,000	150,000	0.3	per 1,000 tons ore
Flotation — Large	250,000	150,000	0.06	per 1,000 tons ore
Small	250,000	150,000	0.3	per 1,000 tons ore
Leaching, Vat — Large	200,000	50,000	0.09	per 1,000 tons ore
Small	200,000	50,000	0.3	per 1,000 tons ore
Leaching, In Situ	600,000	200,000	0.03	per 2,000 pound metal
Leaching, Heap	600,000	200,000	0.03	per 2,000 pounds metal
Smelting	20,000	5,000	0.005	per 2,000 pounds metal
Domestic	1,200,000	600,000	----	per employee

derived partly from Holmes (1966), partly from the various annual listing of "Nevada Mines, Mills and Smelters" published by the State Inspector of Mines, and partly from other published and unpublished sources.

We have used these factors to convert our estimates of future mineral production into the estimates of future water and manpower needs that are the basic objective of this study; all of these estimates are presented in the tables that accompany each commodity chapter. To make the conversions the following steps were taken for each commodity in each of the checkpoint years and in each county or hydrographic region. First, we estimated the average grade of ore — the quantity of the commodity in each ton of ore — that will be mined, and used this to determine how many tons of ore must be processed to produce the estimated amount of the commodity. Then we estimated what proportion of the ore will be treated by what methods — in one case, for instance, we concluded that a million tons of ore will be mined by open pit methods but half of this ore will then be treated by flotation and the other half by leaching. Finally, we multiplied the number of tons treated with each process by the factor for new water requirement derived here in Chapter 2, and added the resultant quantities to reach the total quantity of new water required to produce the estimated amount of commodity. This final step also was repeated with the factors for water consumption and manpower to reach totals for those needs.

In another study being made by the Division of Water Resources, estimates of population are being made for each county and hydrographic region in the years 1980, 2000 and 2020. Those estimates are based on statistical projection of population changes, and do not take into account population changes that will result from erratic developments such as the opening of a new large mine, which could easily result in doubling the population of one of the rural counties: new towns will be built, or existing towns greatly enlarged. In order to account for the substantial quantities of domestic water that will be required by such populations, we have included in our total water estimates an estimate of domestic water needs. We have used an average factor of 1,200,000 gallons new water requirement per employee and 600,000 gallons water consumption per employee. These are based on estimates of annual new water requirement of 150,000 gallons per person and water consumption of 75,000 gallons per person, and an estimate that each mining employee will be responsible for the presence of 7 additional persons in the area — his family, and service workers. Small mines and treatment plants require relatively large labor forces for the amount of material produced (see table 2-1). As a result, our water estimates are very high for such operations, because estimated domestic water needs are as much as three or four times greater than estimated water needs for actual treatment of the ore.

The calculations used in reaching the water and manpower estimates for the one beryllium mine estimated for 1980 (see table 10-1) serve as an example of the way in which all of our estimates were reached. We concluded that 50,000 tons of ore would have to be mined and treated to produce the 100 tons estimated beryllium production, and that this tonnage would come from a small underground mine and be concentrated by flotation. We then calculated the following:

	New Water Requirement	Water Consumed	Employment
MINING: 50 thousand X appropriate factor for small underground mine from table 2-1	250,000 gal.	50,000 gal.	15 men
CONCENTRATION: 50 thousand X appropriate factor for small flotation process from table 2-1	12,500,000 gal.	7,500,000 gal.	15 men
DOMESTIC: 30 employees X factor for domestic water per employee from table 2-1	36,000,000 gal.	18,000,000 gal.	
TOTALS	48,750,000 gal.	25,550,000 gal.	30 men
Rounded Totals to table 10-1	49 million gal.	26 million gal.	30 men

Domestic water needs are much greater than water needs for actual ore treatment in this case, because of the low tonnage-to-manpower ratio in this small mine. In estimating molybdenum production in year 2000 (see table 17-1), large underground mines and large flotation plants were assumed, both of which have relatively high tonnage-to-manpower ratios, and as a result in that case domestic water needs are about

one-half water needs for ore treatment.

Mineral industry activities can be classified into four categories: exploration, mining, concentrating and refining. Before a mineral material can be extracted from the ground, it must be found. This first step in all mining ventures is sometimes known by its older name, prospecting, but in the industry today it is referred to as mineral *exploration*. *Mining* is the actual removal of the ore containing the valuable commodity from the ground. In theory, although by no means in practice, mining is a relatively simple process: rock is extracted from a hole in the ground. There are only a few basic techniques by which this may be done, and one or another of these ways is applicable to any mineral commodity. *Concentration* is the process of separating the valuable commodity from the ordinary rock minerals present in virtually all ores and again, there are only a few basic techniques that can be used. This operation is usually performed near the mining site in order to save the cost of shipping unwanted rock material. *Refining*, as the term is used here, includes the additional processing that may be necessary to prepare the commodity in the form required by the purchaser.

Some refining processes are considered part of the mineral industry, and some are considered manufacturing. The cause of this ambiguity, of course, stems from the very nature of refining: it is a transition stage between the actual extraction of the material from the earth and its fabrication into a finished product. As a general rule, refining is considered part of the mineral industry if it is done at or close to the mine, perhaps as an additional step in the concentrating process, and is considered part of the manufacturing industry if the raw material is shipped away from the mining-concentrating site before refining.

For the purposes of this report we shall include as part of the mineral industry all of the exploration, mining, concentrating and refining of mineral material that takes place before the material is either sold to the user or shipped out of the State of Nevada.

Most human activities produce distinctive land use patterns. For example, the patterns imposed on land devoted to agricultural activities are easily recognizable. Mining, too, has its distinctive pattern of land use. Every mine is marked by a hole in the ground. At the surface this hole may be a tremendous excavation, it may be simply the 6 by 18 foot opening or collar of the shaft through which the underground excavation is reached, or it may be only a 12 inch drill hole from which a fluid is pumped. Almost all mines are also marked by piles of waste, the valueless rock that has to be removed in order to reach the valuable ore. The size of the waste piles, or dumps, varies depending on the type of mine. Additionally, there are the buildings, roads and work areas needed for the men and equipment. At some mines, such as borrow pits for construction gravel, there are no other installations because the material is shipped away just as it comes out of the mine. At or close to many mines, however, there is also a treatment plant called the mill or the concentrator, where the concentration process is carried out. The valuable product of this process is known usually as concentrate, while the useless material is called tailings. Piles of ground-up tailings are another characteristic feature of many mines. Refining carried out at the mine site is usually only a matter of adding extra steps to the concentration process, and the additional buildings or tailings — if there are any — are not usually noticed by the casual observer.

In the remainder of this chapter we will outline the principal techniques used in mineral exploration, mining, concentration and refining — particularly with respect to their water-use aspects in Nevada — and will outline also some of the changes that we foresee during the next fifty years. In most of the individual commodity chapters that comprise Parts II, III and IV of this report, the water and manpower estimates are calculated using the factors we derive for the technology outlined here.

Mineral Exploration Technology

Finding new ore deposits today is an increasingly difficult matter because the easily found deposits have already been discovered, and with each new discovery the number remaining to be found is reduced. As a result, more and more sophisticated technology is being applied to mineral exploration in an attempt to improve the effectiveness of the search.

Basically, mineral exploration is a two-stage process. The first stage consists of finding a deposit of mineral material by means of actual searching or prospecting. The second stage consists of determining whether or not the deposit can be mined profitably.

It is a matter of extensively testing the deposit to measure its size and quality, as well as investigating the many other factors that bear on profitability — essentially, the problems that will be encountered in the mining, concentration and refining stages, as well as the problems that may be encountered in marketing the product.

The difficulty involved in finding a mineral deposit varies greatly, depending on the kind of material sought. In general, deposits of the metals are hardest to find, partly becuase they are rare accidents of geology, and partly because of the success of earlier seekers after metals (especially the "traditional" metals — gold, silver, copper, lead and zinc, as well as some others). Generally, deposits of the nonmetals, or industrial minerals, are easiest to find, partly because many of them are relatively common materials and partly because their markets have developed only relatively recently so all of the more easily found deposits have not yet been developed and mined out. This does not mean that finding a *valuable* industrial mineral deposit is easy; indeed, the second stage of mineral exploration — determining the value of a particular deposit — may be greatly complicated by the fact that there are many deposits that must be investigated to determine which one is best for the purpose.

Each of the two stages of mineral exploration is ordinarily approached in such a manner that the investigator begins with the least expensive work and progresses through increasingly expensive steps. In this way, if early evidence indicates that there is no valuable deposit present, the project can be abandoned with the least possible expense. In the search stage the first step is usually a geological evaluation: largely on the basis of geological mapping and reasoning, the geologist decides whether an area theoretically should or could contain a hidden deposit of the material sought. If the conclusion is favorable, the area is geologically mapped in detail and tested with various geophysical and geochemical techniques in an effort to pinpoint places where the ore deposit may be located. Testing techniques include measuring variations in the electrical conductivity of the ground, the strength of magnetism or gravity, and the distribution of trace amounts of certain elements or minerals. If target areas are pinpointed, the next step is actual physical investigation of the ground either by digging, or more commonly, by drilling. If the reasoning has been correct, these holes should intersect the deposit and recover samples to demonstrate conclusively that the desired material is present. This is approximately the end of the first stage of mineral exploration: a deposit has been found.

The second stage is a matter of determining whether the material found is actually ore in the technical sense of the word — material that can be mined and processed to be sold at a profit. In the case of metals or other mineral materials for which a ready market is available, this is primarily a matter of additional sampling, usually by drilling, to establish the size of the deposit and the average content of metal or other material in it. With this information, the entrepreneur can calculate by fairly standardized methods the gross value of the deposit and the gross cost of producing the material in it, and thus reach a decision as to whether or not it is worth mining.

In the case of many nonmetallic minerals, the second stage is much more complex because marketing conditions impose rigid specifications on the material to be produced. As an example, the mineral sericite added to plaster to make it more workable must not only be nearly pure sericite, but it must contain very small amounts of certain other minerals as impurities in order that the resulting plaster will have the proper consistency; it must be a certain shade of tan; it must be very fine grained in order to minimize grinding costs (but must not be too fine grained because that would spoil the plaster); and the deposit itself must be inexpensive to work so the product can successfully compete with similar materials. Frequently, material from industrial mineral deposits must undergo very extensive testing, even including prolonged trial use in the intended application, before a decision can be reached as to whether or not the deposit is valuable. And during all this testing, the industrial minerals entrepreneur must be digging or drilling to make sure the deposit is big enough to justify his investment, and simultaneously he must be examining other deposits which might be better able to compete for his market if they were to be developed by a competitor.

Some experts claim that of 100 prospects examined by the mineral exploration geologist, only one is likely to be developed into a producing mine. Other experts claim that the ratio is closer to 1,000 prospects examined for every productive mine. In

either case, it is clear that mineral exploration is a very expensive and risky undertaking. Few companies enter the field with a budget smaller than one million dollars per year, and large ones budget several tens of millions of dollars annually for exploration. This is purely for exploration – for finding a deposit and determining whether it might be made into a mine. To put a mine into production requires additional millions or even hundreds of millions of dollars. Most of the companies in the field are mining concerns who are protecting an investment, not speculating: new deposits must be found to replace the existing ones when they are exhausted, or else the company will go out of business.

The question that naturally follows, in view of the cost of mineral exploration, is: is there then no chance for the individual prospector or the small group or company? There is a chance. In fact, the modern prospector is a vital component in the mineral exploration process although he has radically changed from the old concept of a bearded sourdough who carries his possessions on a burro and digs holes where he thinks there should be ore. The geologist employed by the mineral exploration company is a specialist in evaluating the mineral potential of ground, but it is impossible for him to see all of the mineralized areas even in a limited region such as the State of Nevada, and it is even more impossible for him to acquire a detailed understanding of the geology of each. The principal function of the modern prospector, then, is to be a specialist in the mineral occurrences of his own particular area, perhaps a single mining district or a few mining districts. By studying them in detail, he develops concepts about the geology that provide ideas as to where an ore body might lie hidden; then, having acquired title to the ground, he brings both the area and the concept to the attention of the mineral exploration company.

Water consumption in nearly all techniques of mineral exploration is minimal: in most projects, the greatest user of water is the drilling process, which may use a few truckloads of water per day. For a few commodities, however, the processes of exploration may require the extraction of large quantities of water from underground reservoirs. Geothermal power is a case in point. To determine whether a geothermal area contains enough steam to generate power for many years, wells must be drilled and allowed to "blow off" steam for a period of months, and this water is usually lost into the atmosphere. Similarly, the testing of saline brines in a dry lake may require the extraction of large quantities of water. In rare instances, if a mineral deposit must be explored by underground shafts and tunnels, water may be encountered that must be pumped out to allow work to continue.

Mining Technology

Today's mining, with a few exceptions, is a matter of removing rock that contains valuable materials, and to do this there are basically only two kinds of mines: open pits and underground mines. These account for most of the solid minerals produced in the world.

Open pit mining is, as the name implies, mining in a large hole that is open to the sky. This particular term is usually applied to metal mines; a similar mine producing some of the non-metallic commodities such as stone is usually called a quarry, and one producing coal is called a strip mine. The characteristic feature of open pit mining is big, heavy equipment: power shovels, large trucks and bulldozers that can move large quantities of rock *cheaply*. This is vital to open pit mining operations because ore bodies are surrounded and usually covered by waste rock that must be removed before the ore itself can be reached. At most open pits, three or four tons of waste must be hauled out of the mine for each ton of ore, and in some mines the ratio is as great as ten tons of waste to each ton of ore. The techniques of mining are similar in all open pits. First, if it is hard the rock must be broken by drilling and blasting. In softer rock large teeth mounted on bulldozers may be used to rip the material loose, or perhaps it may be soft enough to dig with a power shovel or front-end loader without preliminary loosening. The material is then loaded into trucks and hauled out of the pit. The actual operation of an open pit is of course infinitely more complex than this grossly simplified outline would indicate: digging a hole a mile long, half a mile wide and a quarter of a mile deep requires a great deal of careful planning and constant scheduling, and even a small open-pit, one no larger than a football stadium, must be carefully designed and operated if it is to be worked efficiently.

Water usage in open pit mining is quite small: most is used in dust control on roads or at working

Courtesy Nevada State Highway Dept.

Figure 2-2. Geyser erupting in geothermal area near Beowawe.

places, some is used for drinking and washing by the crew, and some is used for cooling and cleaning equipment. We estimate that the factor for new water requirement is 8,000 gallons and the factor for consumed water is 4,000 gallons per 1,000 tons of ore produced. Employment in open pit mines varies widely, depending mostly upon the size of the mine, but to some extent also on the kind of material being mined and the selectivity that must be exercised in the mining. We estimate that large mines will use manpower at the rate of 0.07 man per 1,000 tons of ore produced annually, and that small mines will use manpower at the rate of 0.2 man per 1,000 tons of ore.

Underground mining is far more varied than open pit mining, in both techniques and equipment. The principal reason for this is that the easy access to an open pit makes it practical simply to dig a big hole, taking away both ore and waste as necessary; whereas, the need to support the overlying and surrounding rock in an underground mine requires that the holes be kept quite small. In mining large ore bodies underground, equipment comparable to open-pit equipment may be used, but the openings in which men work usually cannot be much wider than an ordinary large highway tunnel.

All underground mines must, of course, have an opening to the surface, which may be a vertical shaft in which an elevator-like mechanism lowers men and equipment and raises the ore produced, or it may be an inclined shaft perhaps with a gentle enough incline to permit trucks to haul the ore out, or it may in some cases be a horizontal tunnel driven from a valley to reach ore in the mountain above.

Because of the need to keep the openings small, plus the difficulty in disposing of waste, the workings of underground mines are kept within the ore body as much as possible, and various techniques have been developed to work ore bodies with particular shapes. The three general shapes that dictate the techniques used in mining are: 1) steeply inclined ore bodies that are long and narrow; 2) flat-lying, broad or elongate, rather thin ore bodies; and 3) ore bodies that are large in all dimensions: height, width and breadth. Steep, narrow ore bodies are commonly mined by some form of overhand stoping. (Stoping is the miner's term for the actual removal of ore, as opposed to driving the tunnels necessary to get to the ore; the excavation produced by the removal of the ore is a stope.) A typical ore body of this kind might be nearly vertical, 1,000 feet from top to bottom, 5 feet to 50 feet wide, and 500 feet long. A vertical shaft is sunk beside the ore body, and horizontal tunnels are driven out along the length of the ore at vertical intervals of about 150 feet. The ore is mined upward from each of these tunnels or levels, dropping to the tunnel floor as it is blasted, to be picked up, hauled to the shaft, and hoisted to the surface. One of the problems with this technique is to keep the walls of the stope from caving in after the ore has been removed, and this is usually done by filling the stope below where the miners are working, leaving only a few holes through which the ore drops to the tunnel. Today the most common practice is to fill the stope with a slurry of the tailings of the concentrating process; as the water drains down to the tunnel, the sandy material packs tightly.

In flat-lying, pancake-like ore bodies, such as one that is half a mile in diameter and 20 feet thick, front-end loaders and trucks are often used to handle the ore after it has been broken by blasting. The technique is known as room and pillar mining, and the end result is a series of tunnels or rooms perhaps

15 feet wide and as high as the ore, separated by pillars of solid rocks also perhaps 15 feet wide that have been left to hold up the overlying rock. Obviously such a method is wasteful, because it means leaving as much as one half of the ore in the ground as pillars, but often the pillars can be safely "robbed" to much smaller dimensions just before the mine is abandoned. Some flat-lying ore bodies can be mined by removing a strip of ore about 10 feet wide along one edge, and allowing the overlying rock to cave into the opened strip, then mining the adjacent strip and allowing it to cave in, and so on until the entire ore body has been removed.

Ore bodies that are large in all dimensions, such as some of the low-grade copper deposits that are half a mile in diameter and many hundreds of feet thick, are mined by a technique known as block caving. A network of tunnels is driven beneath a block a few hundred feet on each side, and then the entire block is undermined on a level perhaps 50 feet above the network of tunnels. When the undermining is completed (pillars left to hold up the block are all blasted simultaneously as the final step of undermining) the ore crumbles and caves in of its own weight and is drawn out through holes into the tunnels on the level below to be sent to the shaft for hoisting. Usually the ore does not extend all the way to the surface (if it did, it probably would have been mined by open pit methods) and the stope is abandoned when all of the ore has been drawn out and the material that reaches the level is waste. Since so much material has been withdrawn, the caving action may extend all the way to the surface, producing a large depression.

As in open pit mining, underground mining by any of these techniques ordinarily uses relatively small amounts of water: a little is used by the miners themselves, somewhat more is used in the drilling machines, which use water both to cool the drill and to wash the ground up rock out of the drill holes, and some is used in dust control. Where the stopes are filled with tailings after mining, larger amounts of water are used to make the sand slurry. In most underground mines, virtually all of the water used is recovered because there is not enough air movement to evaporate much of it, and of course it cannot be allowed to accumulate or it will flood the mine. We estimate new water requirements at 5,000 gallons, and consumed water at 1,000 gallons, per 1,000 tons of ore mined by underground methods. Some underground mines as well as open pit mines must pump out water that flows into them naturally, and this water is then applied to the water needs of the mining and concentrating processes of the operation, thus eliminating the need for that amount of water from other sources. Occasionally, more water must be pumped than the ore processing consumes, and this water then is allowed to flow into the nearest stream if it does not contain pollutants, adding to the amount of surface water available for other uses. Some mines, usually the rather shallow ones, are dry, and the water brought into them seeps out of the lower workings and is added to the general ground water table below.

The manpower required in underground mining varies widely depending upon the technique used. In general, of course, the more mechanized techniques require fewer men, and mechanization is more practical in larger mines; block caving is comparable to open pit mining in efficiency of manpower use. We estimate manpower requirements at 0.08 man per 1,000 tons of ore produced annually in large mines, and 0.3 man per 1,000 tons of ore in small mines.

Some mineral products are usable as they come out of the mine, and practically all of each ton of ore produced is used. Limestone, for instance, is used in making cement just as it is mined and little effort is wasted in mining unusable rock. Many valuable minerals, however, especially metals, occur scattered in small amounts throughout rock that otherwise has no particular value. For example, the 15 pounds of copper contained in a ton of typical copper ore, when extracted and gathered together, occupy the volume of a 3½ inch cube whereas the ton of ore — the copper plus the rock through which it is scattered — occupies the volume of a cube a little more than 2 feet on a side. If that copper ore is mined from an open pit, which means that a great deal of waste rock was moved in addition to the ore itself, then a volume of rock equivalent in size to an ordinary office desk is moved to recover the 3½ inch cube of copper. Obviously, in cases such as this (and the situation is essentially the same for nearly all of the metals as well as some industrial minerals) a great deal of energy is expended handling valueless rock in order to obtain a very little metal.

This waste can be attacked in two ways: one is to find a use for the associated material rather than simply throwing it away, so that the time, money and

energy expended in moving it is put to good use. The other way is to extract the metal from the earth without moving the associated material. In varying degrees both approaches are currently being used; both are being investigated and tested intensively. The first solution does not appear very promising at most mines because of the tremendous amounts of very low-value material produced and the fact that most mines are well removed from centers of population and consumption. (But tailings that are put back underground to fill the stope below the working place, and thus support the walls, are thereby used very effectively.) The second appears much more promising, at least for some metals. Copper, for instance, is quite easily leached out of rock by acid solutions and has been recovered from mine dumps by this process for years. It seems very likely that long before the next half-century ends, copper will be extracted from many deposits without traditional mining, simply by sprinkling acidic water on the surface above and collecting it through drill holes or shafts below after it has dissolved copper from the rocks that it passes through — a process called *in situ* leaching, or leaching in place. In the future, perhaps, nuclear blasting within some deposits may be useful to shatter the rock to permit free access of the leaching water. Laboratory and pilot plant investigations suggest that at least gold, mercury, and uranium can be similarly leached from their ores. We estimate that late in the fifty-year period more than half of the metals produced in Nevada will be recovered by leaching without prior mining because the savings in money and energy will be tremendous.

Estimates of water needs for *in situ* leaching of metals are highly uncertain, because the technique is just beginning to be used. Furthermore, water needs cannot be presented in terms of tons of ore handled because the ore is not handled; for this technique we must consider water needs in terms of pounds of metal produced. Information made available to us by mining companies that are presently conducting studies of *in situ* leaching of copper ores indicate that about 5 percent of the copper content of the ore can be removed each year, and that about 20 gallons of water will be evaporated — consumed — per year for each ton of ore being leached. We assume that copper ore treated this way will contain on the average 4 pounds of copper per ton (0.2 percent), and therefore 5 tons must be treated in order to recover 1 pound of copper per year. Water consumption thus is 200,000 gallons per 2,000 pounds (one ton) of metal produced. By comparison with other techniques, we conclude that new water requirement will be three times as great as consumption, or 600,000 gallons per 2,000 pounds of metal produced. On a basis of pounds or tons of copper produced, these factors are about 10 times greater than water need factors by present methods in which the ore is removed from the ground and the copper then extracted by flotation or by leaching in vats. We estimate manpower needs for *in situ* leaching at 0.03 man per 2,000 pounds of copper produced, well below manpower needs for other techniques. Water and manpower needs for *in situ* leaching of other metals may vary widely from these estimates, partly for the reason that the quantity of metal in other ores varies widely from our assumed quantity of copper — a gold ore may contain less than one ounce of metal per ton, while a zinc ore may contain 100 pounds or more — and partly because other metals may be easier or more difficult to leach.

Mineral materials such as diatomite, barite, gypsum or gem stones, which are mined for their physical properties rather than for their metal content, must continue to be mined by actually breaking the rock and moving it to the consumer or, if it must be purified, to a concentration plant. The traditional methods of mining will continue to be used for these commodities although mechanization undoubtedly will continue progressively to replace manpower. We do not anticipate that technological developments will significantly alter water usage patterns of traditional mining methods except perhaps in isolated cases.

In addition to the rock-breaking methods of mining and the leaching in place techniques, there are other techniques applicable to certain commodities or in particular circumstances. Sulfur is mined by pumping steam through drill holes into the ore bodies; the heat liquifies the easily-melted sulfur which is then pumped to the surface. In some places salt is mined by pumping fresh water into the deposit and then pumping it out after it has dissolved as much salt as it will carry. This is, of course, a special application of leaching-in-place and, perhaps, the first one. Petroleum and natural gas represent special cases of mining wherein the desired fluids are recovered directly from underground reservoirs.

Concentration Technology

The process of concentrating valuable minerals from ores is known also as mineral beneficiation or extractive metallurgy. The objective of concentration is to separate all of the valuable mineral from the waste rock in order that subsequent processing will not be burdened with handling large amounts of valueless rock. A typical copper ore, for instance, contains only about 0.7 percent copper and it is totally uneconomical to melt a ton of rock to extract the 14 pounds of copper. The concentration process disposes of most of the rock and sends to the mill a concentrate containing 20 to 30 percent copper which can be economically smelted. In the case of nonmetals further treatment of the concentrate may or may not be needed before it is usable.

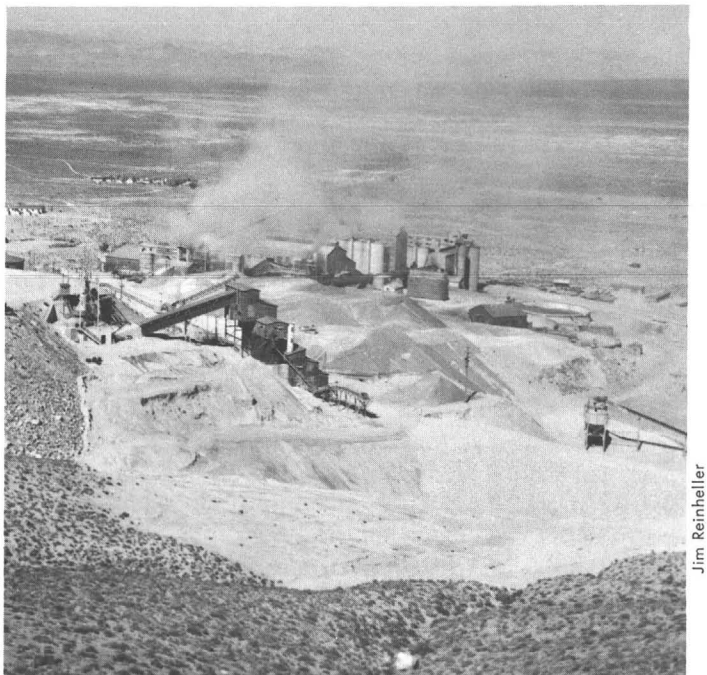
The individual techniques used in concentration are designed to take advantage of slight differences in the physical or chemical characteristics that distinguish the desired minerals from the unwanted ones. A preliminary step in many concentration processes is crushing and grinding the ore to reduce it to small fragments of fairly uniform size. The small size is required because the valuable mineral in many ores occurs as scattered individual grains the size of a pinhead or smaller, which must be broken free of the accompanying rock before they can be concentrated. In some cases crushing is required because certain techniques simply will not work on larger fragments. Uniformity of size usually is required because many techniques become ineffective if the grains vary greatly in volume, surface area, or weight.

Most mineral concentration today is done by one or another of five basic techniques: screening, magnetic separation, gravity separation, flotation, or leaching.

Screening often is not considered a technique of mineral concentration, both because it is such a well-established and widely used procedure, and because it often is preliminary to the crushing and grinding needed for other techniques. However, about two billion tons of sand, gravel and crushed stone are produced annually in the United States, and most of this is treated only by screening to separate the various size ranges. Since the separation by size ranges is necessary to make these mineral commodities saleable, the screening is truly a process of mineral concentration in its own right, and a very important one in view of the tremendous tonnage of material treated. The process is a simple one, a matter of passing the material over a wire-mesh screen or other surface having holes of the appropriate size. The oversize stays on top of the screen and is diverted into one pile, while the undersize passes through and ends up in another pile. Several screens with progressively smaller holes can be used to make several products with different size ranges. Some materials are screened dry but most sand and gravel are screened wet in order to remove extremely fine material. When water is used the process usually is called "washing" rather than "screening". New water requirement in sand and gravel washing operations is about 150,000 gallons per 1,000 tons treated, and consumption is about 40,000 gallons per 1,000 tons. The mining and treatment processes are so closely linked in most sand and gravel operations that they cannot be separated for employment estimates; employment for the two operations together is 0.02 man per 1,000 tons of material treated annually.

Magnetic concentration is a technique based on the attraction of certain iron-bearing minerals to a magnet. The strongest attraction is displayed by magnetite (Fe_3O_4), one of the more common iron ore minerals, which is concentrated by simply using an electromagnet to pull pieces of the magnetite mineral away from pieces of the unwanted minerals. Much of the iron ore presently produced in the

Figure 2-3. Concentrator at Gabbs.



Jim Reinheller

United States is concentrated by magnetic methods and most of the iron ore known to occur in Nevada is amenable to this technique. Because magnetite is so strongly attracted by the electromagnet, careful sizing is not required and some ores in which the magnetite occurs in large chunks can be concentrated in mixtures ranging in size from dust to fragments several inches in diameter. Water may or may not be used in this process. However, if the magnetite occurs intimately intergrown with waste rock, fine grinding is required to break the grains loose, and this must ordinarily be done in a water slurry. The actual concentration itself is also then done in a slurry and relatively large water usage results. Probably much of the ore of Nevada's projected iron mining industry will have to be ground before concentration, so there will be large consumption of water. Excepting magnetite, most magnetic minerals are only very weakly attracted; consequently, this technique has limited application to other ores, but it can be very effective in instances where slightly magnetic minerals must be separated from entirely nonmagnetic minerals.

Plants that use wet magnetic separation on coarsely crushed iron ore, we estimate will have new water requirement of 50,000 gallons per 1,000 tons of ore, and water consumption of 25,000 gallons per 1,000 tons. If ore must be ground fine in order to concentrate it, the process will be very similar to flotation in water needs, and we estimate for such plants new water requirement of 250,000 gallons per 1,000 tons of ore, and water consumption of 150,000 gallons per 1,000 tons. We estimate that employment will be 0.03 man per 1,000 tons of ore treated annually in the relatively small plants that we anticipate will use coarse magnetic separation, and 0.06 man per 1,000 tons in the larger plants that we expect to use fine magnetic separation.

Gravity techniques of concentration are based on the differences of specific gravity of different minerals: a pea-sized lump of gold is much heavier than a pea-sized lump of pyrite, and the lump of pyrite is heavier than a similar-sized lump of quartz. Gold, one of the heaviest minerals, has a specific gravity of 19.3, pyrite has a specific gravity of 5.02, and quartz has a specific gravity of 2.65. (That is, these minerals are the indicated number of times heavier than an equal volume of water.) Most of the metal-bearing sulfide minerals have a specific gravity close to that of pyrite, and most of the common rock minerals have a specific gravity close to that of quartz. One effect of specific gravity differences is shown when a mixture of fragments of heavy minerals and light minerals is shaken gently, especially in water that serves as a lubricating and suspending agent: the heavier minerals tend to sink to the bottom of the mix and the lighter ones to ride in a layer on top of them. Another effect can be demonstrated by kicking both a football and a cannonball; the kicks effectively separate them because of the difference in inertia that stems from the difference in their specific gravities.

Both of these effects of specific gravity have been recognized for many years, and both are used in the many different techniques of gravity separation that have been developed. A simple but effective application of gravity technique is the use of the prospector's gold pan, which depends upon the sinking action of the gold to separate it from the unwanted materials and upon its inertia to "string out the colors" around the edge as the water is swirled in the pan. Other simple applications are the old-time "long toms" and sluices that were used in earlier days to settle and catch gold from placer materials. These devices work well even on fine-grained gold that is mixed with coarse gravel because the gold has a much higher specific gravity than the gravel. When there is less difference between the specific gravities of the minerals, such as between metal-bearing sulfide minerals and common rock minerals, more sophisticated techniques must be used. Uniform sizing of the material becomes imperative and devices employed to enhance the effect of inertia supplement the utilization of the differential settling rates of the lighter and heavier minerals. The two most widely used devices are jigs, which speed up the settling process by imparting a vertical pulsating (jigging) action to the mixture, and gently sloping tables down which the mixture of minerals flows while a tapping action tends to move the heavier grains to one end of the table. Both of these techniques were developed and extensively used in the 1890's and are still used to some extent, but except in special applications, they have been largely replaced by other techniques.

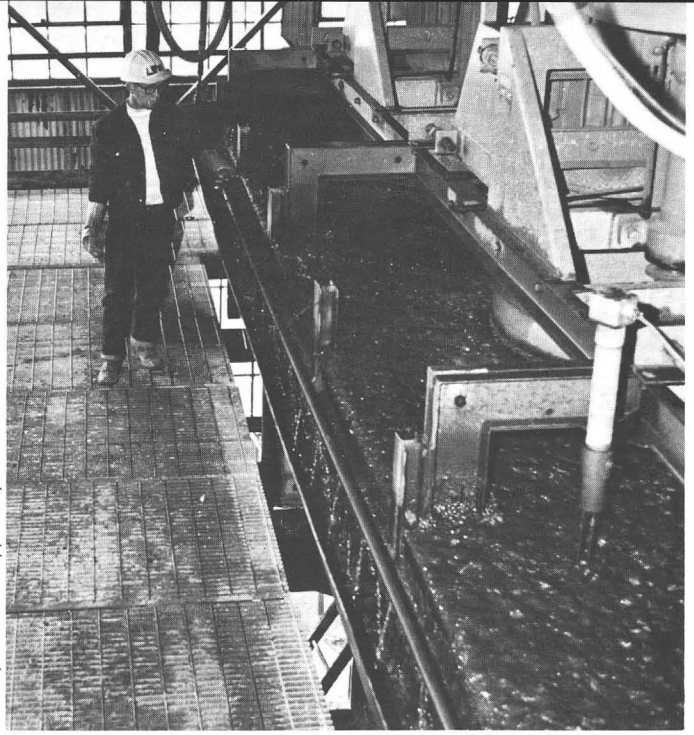
A newer gravity technique is heavy-media separation, a process which passes crushed but not ground ore through a bath of liquid or slurry that has a specific gravity intermediate between the light and the heavy minerals, causing the light minerals to float and the heavy ones to sink. For some ores this

process is a very effective preliminary step in concentration, separating fairly large pieces of material that contain no heavy minerals from those that contain abundant heavy minerals. The product may then be ground for further concentration.

For the most part, gravity concentration has been replaced by more complex, efficient processes of ore beneficiation, but there remain certain applications in which it is still the most effective technique to use. In particular, it works best on material that has been crushed and ground to the consistency of coarse sand, whereas other techniques are more effective on material that has been crushed much finer. When it is desirable to collect the valuable mineral in relatively large grains, as is the case with some nonmetals, gravity techniques are still preferred. They will no doubt continue to be used throughout the next fifty years in special applications. Water is used in most gravity techniques very much as it is used in flotation techniques, and we consider that the water needs will be about the same: new water requirement of 250,000 gallons per 1,000 tons of ore, and water consumption of 150,000 gallons per 1,000 tons. Employment, too, should be similar: 0.3 man per 1,000 tons of ore treated in small plants, and 0.06 man in large plants.

The flotation process of mineral concentration is a deceptively simple technique that was developed in the early 1900's and has been adapted for concentrating all kinds of metal ores and many kinds of industrial minerals. Probably 90 percent of the metals produced in the United States today, excluding iron and aluminum, are concentrated by flotation. The ore must first be ground in a water slurry to the consistency of very fine sand. Small amounts of chemicals and soapy oil are then added and air is bubbled through the slurry. The desired minerals cling to the air bubbles, which rise to the surface, and are scraped off as froth. The ore is very finely ground because fine grains present more surface per unit of weight than do coarser ones, and thus stick to the bubbles better. The soapy oil in the slurry produces bubbles with tough surfaces that form froth rather than burst when they reach the surface. (Burst bubbles drop their load of minerals back into the slurry.) The other chemicals cause the desired minerals to stick to the bubbles and the undesired minerals to remain in the slurry. Although the effect of the process is a mechanical one — moving particles of minerals — flotation is truly a chemical process. Chemical effects on the surfaces of the mineral particles and on the surfaces of the air bubbles are the cause of the particles adhering to the bubbles. A great deal of effort has been spent on research and experimentation to determine what chemicals will make particular minerals float or not float. Flotation operations are delicate and require continual readjustment, for minor changes in the acidity of the water or the composition of the ore can destroy the fragile, intricate relationship that exists among the minerals, chemicals and bubble surfaces, throwing the system awry and resulting in the loss of valuable minerals to the tailings pond.

For many mineral materials, flotation offers great advantages over other processes of concentration. The principal ones are efficiency — often 90 percent or more of the valuable mineral is recovered from ore — and speed — the ground-up rock spends not more than half an hour in the flotation cells and when it leaves, the valuable mineral is ready for further processing and the tailings for final disposal. Modern flotation concentrators that treat 20,000 tons of ore a day are housed in buildings the size of a large department store. The state of the product that comes out of a concentrating plant can be either an advantage or a disadvantage, for the valuable material is collected in the form of the mineral itself. This is an advantage when the entire mineral is needed by the consumer, as feldspar is needed by the glass manufacturer, but is something of a disadvantage when the mineral must be further broken down to extract part of its contents, as chalcopyrite must be broken down to remove its copper, leaving the iron and sulfur that were part of the mineral to be disposed of. To overcome this disadvantage other techniques, principally leaching, are being intensively investigated and within the next fifty years will at least partially replace flotation in the treatment of metal ores. Nonetheless, flotation will continue to be an important process of concentration. New water requirement for flotation is 250,000 gallons per 1,000 tons of ore treated, and water consumption is 150,000 gallons per 1,000 tons. The high consumption is evidently a result of the fact that tailings are carried to the disposal site as a slurry, and much water evaporates from the tailings pond before it can be recovered and reused. Employment in flotation plants is 0.3 man per 1,000 tons of ore treated



Courtesy Kennecott Copper Corp.

Figure 2-4. Flotation cells concentrating copper ore at McGill.

annually in small plants, and 0.06 in large plants.

Leaching is the process of dissolving certain constituents out of an ore while leaving others behind in the solid state, probably unchanged. In a few applications leaching is essentially a cleaning operation to remove unwanted impurities, as when a certain sandstone ore is leached with acid to remove iron stains on the sand grains because iron will impart the wrong color to glass made from the sand. In most applications, though, it is used to extract the desired metals from an ore, and here the process is two-part: first, the actual leaching of the metals from the ore and, second, the matter of getting the metals out of the resulting leach liquor. The leaching part is quite simple for some techniques. In vat leaching, copper, gold-silver or uranium ores are merely ground rather fine, placed in huge tanks, and soaked in the leaching solution for a few hours or days; the solution, which now has dissolved most of the valuable metal that was in the ore, is then drawn off and the tailings dumped. In heap leaching the ore is stacked in heaps and leaching solution is sprinkled over the surface, to trickle through the pile and be caught when it runs out at the bottom. Other applications, such as the treatment of some nickel ores, require complex heating and chemical treatment of the ore before the metal becomes leachable. The principal leaching solutions now in use are dilute sulfuric acid, sodium carbonate, and cyanide.

Extracting the metal from the solution after it has been separated from the solid tailings can be the most difficult part of the process. Copper can be extracted simply by allowing the solutions to flow through troughs filled with scrap iron, usually old "tin" cans, where the copper precipitates and iron dissolves to take its place in the solutions. However, the resulting concentrate contains a large amount of undissolved iron fragments; newer approaches are being devised to extract the copper electrolytically, but these require complex chemical engineering techniques and very careful control of the chemistry of the solutions. Similar complexities are involved in the extraction of other metals from leach solutions.

A great deal of research is presently being directed toward leaching of metal ores of all kinds. At least in theory, leaching should be more economical than other processes, partly because the ore need not be ground so fine, and partly because the product of the leaching operation should be relatively pure metal or at least a relatively simple metal compound, rather than the concentrate of metal-bearing minerals produced by gravity and flotation methods. For most metals, bypassing the step of producing mineral concentrates is an important one from the point of view of environmental protection because it is the smelting of the metal sulfides that produces the sulfur dioxide that is a major air pollutant. Additionally, researchers and the minerals industry in general look forward to the day when it will not be necessary to mine the ore before leaching it: when the concentration process can be combined with the mining process by leaching the ore in place. We have concluded that late in the fifty-year period more than half of the metals produced in Nevada will be produced by leaching without prior mining. Before that time, we estimate that leach extraction, from mined ore, will become the principal concentration process for some metals.

For vat leaching, new water requirement is 200,000 gallons per 1,000 tons of ore treated, and water consumption is 50,000 gallons per 1,000 tons. Employment in vat leaching plants is 0.3 man per 1,000 tons of ore treated annually in small plants and 0.09 man in large ones. Heap leaching is very similar to *in situ* leaching, which was described on an earlier page, both in the nature of the process and in the water and manpower requirements. The requirements cannot be presented in terms of tons of ore handled, but instead must be presented in terms of pounds of metal produced. As with *in situ* leaching, we consider that heap leaching will have new water requirement of 600,000 gallons per 2,000 pounds (one ton) of metal produced, and consumption of 200,000 gallons for the same amount of metal. Manpower needs for heap leaching will be 0.03 man per 2,000 pounds of metal produced annually.

Besides these five processes of concentration that are applicable to a variety of ores, there are numerous others that are especially adapted to only one or two minerals. Perhaps the one most widely used in Nevada is the furnacing of mercury ore to vaporize the metal it contains, which is then condensed as pure mercury. This process uses a great deal of heat energy and can be hazardous to workmen because poisonous fumes are produced. It will probably be largely replaced by leaching processes within the next twenty years. Some clays that contain sand or rock fragments are concentrated by mixing them into water, which permits the heavy particles to settle out while the clay mud is drawn off and filtered; water consumption in this process is comparable to that in vat leaching. Some soft or finely-divided industrial minerals are concentrated by a somewhat similar technique using no water, by removing hard particles during dry grinding, and some are concentrated without water by electrostatic processes.

The dividing line between concentration processes and refining processes is often a difficult one to draw, particularly in the case of many nonmetallic commodities that are concentrated and refined in a continuous sequence of operations. As nearly as possible, we have considered as concentration those processes that remove relatively large quantities of impurities from the valuable material, and we will consider as refining those processes that remove all or some of the remaining impurities, as well as processes that simply change the nature of the material itself.

Refining Technology

Smelting is the first step in the refining of most metals. In many cases it consists of first burning off the sulfur that forms part of many metal minerals, and then melting what remains and separating most of the other impurities while the entire mass is molten.

There is only one major smelter in Nevada at present, the copper smelter at McGill, which treats concentrates produced from the mines of the Ely district. The copper it produces is more than 99 percent pure, but nonetheless must be further refined before it is usable in industry. The further refining is done outside of Nevada. We consider it unlikely that new major smelters for any metals will be built in Nevada, partly because unless a mine is very large, it is more economical to ship the concentrates to existing smelters than to build a new one, and partly because the increase in leach extraction that we foresee should reduce the need for smelters. Smelting requires 20,000 gallons of new water for every 2,000 pounds of metal produced and 5,000 gallons are consumed for each 2,000 pounds of metal. Employment in smelters is estimated at 0.005 men per 2,000 pounds of metal.

When gold and silver are extracted from ore by the cyanide leaching process, the metals are precipitated from the leach liquors as a sludge, which is usually melted at the mine site to produce bullion, a mixture of whatever gold and silver was recovered. This first step in the refining of gold and silver is a very minor process, since a whole day's mining at a fair-sized gold mine produces no more than a large soup bowl full of gold, and the water consumed in the process is negligible.

The refining methods used in treating industrial minerals are nearly as varied as the minerals themselves, making an attempt to describe them by general categories impossible. Where necessary, the techniques used are described briefly in the individual commodity chapters. One generalization particularly apropos to this report can be made: most nonmetallic commodities are sold as dry products, so if water has been used in their processing, they must be dried at some stage, which costs money. For such commodities, every effort is made to develop dry concentrating and refining techniques. Some nonmetallics are subjected to heat treatment, either to drive off the natural moisture they contain, or to modify the characteristics of the mineral so that it will be suitable for specific uses.

Most of the mineral materials produced in Nevada are shipped out of the State for consumption in major population centers. Transportation is the subject of another report in the Division of Water Resources series, but one aspect of it is worth mentioning here. Modern technology has made it possible to reduce mineral materials to a thick water slurry which can be pumped through a pipeline over considerable distances at a relatively low cost. Even heavy materials, such as metal ores, are now being transported in this way. In the future, it is highly likely that some Nevada mineral products will be transported as slurries, and if the material is moved thus from one county to another, or from one

Figure 3-1. A mine crew in 1898.

Courtesy Nevada Historical Society

hydrographic region to another, then the water in the slurry must be considered entirely consumed at its point of origin, but must be added to the available supply of water at the end of its trip. If the substantial amounts of iron ore that we estimate will be produced late in the next half century are transported to California as slurries, this would constitute an export of several hundred million gallons of water from Nevada annually.

Chapter 3 HISTORY OF MINING IN NEVADA

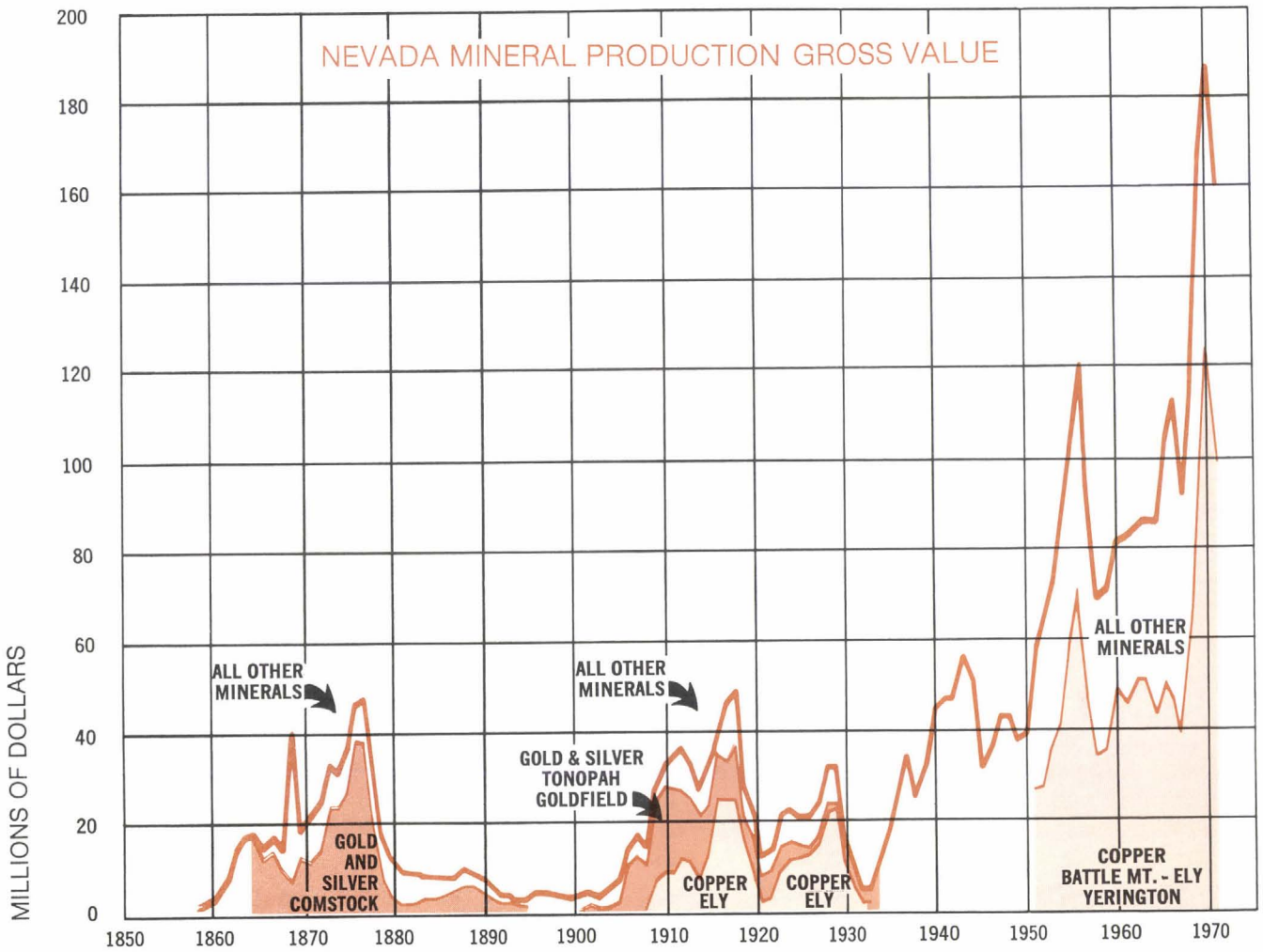
Some incidents of mining history in Nevada are known to practically all Nevadans: the Comstock boom in the 1870's and the Tonopah-Goldfield boom in the early 1900's are distinct landmarks in the history of the State. Somewhat less well known is the prolonged depression that afflicted the State between the decline of the Comstock, about 1880, and the

development of the Tonopah district, about 1905; that depression was essentially a reflection of the low ebb of mining in Nevada. Almost unknown to most Nevadans is what has happened to the mineral industry in the years since the Tonopah-Goldfield boom: the years of unspectacular, hardly noticed growth that have brought the industry to greater strength and stability than it ever had during the boom times. The graph of Nevada's mineral production, figure 3-2, portrays not only the fluctuations of the industry, but also some of its changing nature.

Nevada's modern mining history began in the 1850's with the discovery of lead, zinc, and silver deposits at Goodsprings, and the silver-gold deposits of the Comstock Lode. By the time the news of these discoveries had spread, the mining boom in California had passed its peak and the tide of miners turned to the Territory of Nevada. In 1875, as the Comstock boom approached its peak, Virginia City and the other towns along the Lode were producing gold and silver valued at $26,000,000 annually and had a population of more than 20,000, while many lesser mining districts had also been discovered and were supporting small communities.

Statehood came to Nevada partly as a result of the Union's need for the precious metals of the Comstock to finance the Civil War. Another effect of early mining activities was widespread development

Figure 3-2. Graph showing annual value of Nevada's mineral production since 1860. Red sections represent production of gold and silver, light red represents copper, white includes all other minerals. (See text).



of water resources to provide domestic water and, more importantly, water for the treatment of the ores that the mines produced. An interesting observation is that a large proportion of the mining districts discovered during this era are in or close to fairly well wooded and well watered mountain ranges: most of the mines of this era obtained their water from nearby streams. This was not true of all the mines, though. The population of the Comstock towns was too large for the local supply so water had to be brought in from the Sierra through a 7-mile pipeline that was one of the engineering marvels of its day. Candelaria was similarly supplied through a pipeline that was 27 miles long, though it involved less ingenuity in its construction.

In the 1870's and 80's, mining in Nevada was faced with a good many problems. One of the greatest was the poorness of transportation, which made mining of the more common metals impractical: essentially, only gold and silver were worth the high cost of transportation to market areas. Another problem was the primitive metallurgical practices of the day, which for the most part could be applied effectively only to rich ores, so that even a large deposit could not be worked unless it were high grade. Unfortunately, rich gold and silver ore bodies are rare and hard to find, and usually small; at about the same time that the ores of the Comstock were exhausted, so too were most of the smaller deposits of other districts. By about 1880 the ores that could be treated profitably were exhausted and the drastic decline of the mining industry resulted. During the 25 years that followed, there were no major changes in the transportation system that would allow development of base metal ores, nor were there major changes in the concepts and techniques of prospecting to find new, rich, precious metal deposits. New developments were made in ore processing but they were not applied to Nevada ores. Most of the boom camps fell into decay and most of the abandoned water systems deteriorated, though some served as the basis for agricultural water supplies.

With the advent of the Tonopah-Goldfield boom, beginning about 1905, the mining situation in Nevada was fundamentally altered. Prospecting techniques and concepts changed: the high-grade silver ore at Tonopah, first of the discoveries of this boom, was in inconspicuous veins that had been largely overlooked in previous years and the realization that this kind of deposit could be rich in precious metals opened whole new regions to the prospector. The immediate result was the discovery of more deposits of the same type: Goldfield, Rawhide, Rhyolite, Fairview, Wonder, and others. A more subtle result was the realization, elsewhere in the country and the world, that Nevada did contain numerous and varied valuable minerals, so that investment capital became available to search for and develop new mines.

During the years between booms existing metallurgical techniques had been improved and new ones invented. One of the new techniques was particularly well suited for treating the kinds of ores found in the new bonanza camps. This was the cyanidation process for extracting gold and silver from ores by dissolving them away from the accompanying rock. It could not be used to treat base metal minerals, like those of Eureka or Pioche, but it worked well on Tonopah-type ores in which most of the silver and gold occurred as free grains in a mass of quartz. This process, coupled with improved and large-scale crushing equipment, made it profitable to mine and process relatively low grade ores, which ultimately accounted for much of the production from Tonopah. About 1915 another new metallurgical process, flotation, was introduced that had even more widespread application and importance than cyanidation. In the flotation process, particles of ore minerals cling to air bubbles rising through a slurry of ground ore and are skimmed off in the resulting foam as rich concentrates to be shipped to the distant smelter while the waste rock is disposed of as tailings. This process was soon adapted to treat a wide variety of precious and base metal ores, and in the 1920's dozens of mills were built to treat ore from deposits that had been found in the preceding 50 years but had not been exploitable until the development of an economical recovery process.

Many of the new districts brought into production during the boom period of 1905-1920 were in arid parts of the State where surface water from springs or streams was very limited. The cyanidation and flotation processes and the fine grinding that they required involved the use of large quantities of water, and although some very long pipelines were laid to carry water from distant springs to the vicinity of the mines, it was necessary to drill wells to supply the water for some mills. These wells plus the water that was pumped from the mines themselves repre-

Courtesy Mackay School of Mines

Figure 3-3. Inside Sutro Tunnel. Nearly four miles long, the Sutro Tunnel was driven under mountains from neighboring valley in the 1870's to drain water from the deeper levels of the Comstock mines.

sented the beginning of today's overall dependence upon ground water for mineral processing.

Probably the most important difference between the Comstock boom and the Tonopah-Goldfield boom was in the matter of transportation. Even in the early days of Tonopah and Goldfield, automobiles were on the scene; by the early 1920's they were common and trucks had to a large extent supplanted horsedrawn wagons for short hauls. Railroads had been well established by the end of the Comstock boom, but the only ones in Nevada were the transcontinental lines crossing the northern part of the State with their few short branch lines. The Tonopah-Goldfield boom sparked an equally wild boom in railroad building and within a few years there was a network of lines serving many of the new camps. For the most part these lasted only a short time, but while they were operative they provided relatively easy and inexpensive transportation for people, goods and ores. In spite of their short lives and their lack of economic success, they opened up the country; some towns that they linked persisted after the railroads died, serving not only as supply centers but also as nodes in the highway network that was developing in that part of the State that had been almost pathless.

Like the ores of the Comstock, the ores of Tonopah and Goldfield were unusually rich and offered the hope for quick and fabulous profits that is the basis for any boom. It was the rich ores or the hopes of finding them that paid for the exploration and initial development of the mines, the building of the mills, and the construction of the roads and railroads. After the rich ores in Tonopah were exhausted the mines continued working — though much less profitably — on lower grade ores, using the installations that were already amortized by the earlier operations. In contrast to Tonopah, Goldfield had little low-grade ore and when the high grade was worked out the district was essentially finished. In some of the other camps the expectations of finding high grade ore were never fulfilled, although some metal was won from low grade ores. But in many of the boom camps little or no ore was found and all of the effort and expense was wasted.

The "boom-and-bust" aspect of Nevada's mining industry ended around 1920. Some of the mines and towns that were started during the boom days continued, but after that date there were very few of the "rushes" that characterized the boom period — the swarming of prospectors and miners to newly discovered (or newly advertised) camps that probably would last only a few months or a year. The principal reason for this was that the intensive prospecting during the boom times had found virtually all of the rich metal deposits that could be found by the simple techniques and tools available to individual prospectors of the time, and also had delineated virtually all of the exposed mineralized areas. Almost all of the presently-known metal mining districts in Nevada were found before 1920 and marked for the future by prospect pits and exploratory shafts and adits.

At the same time that Tonopah and Goldfield were approaching their peak, another — and ultimately much more important — camp came into production: the Robinson district, more commonly known today as the Ely district. This was one of the districts that had been recognized as a mineralized area long before 1900 but it was not developed because there was little or no rich gold and silver ore. Developments in transportation and metallurgy of the early 1900's, together with the new approach of open-pit mining using heavy equipment, made the extremely large, low grade copper deposits economically mineable. During World War I, the output of the Ely mines accounted for half of Nevada's mineral production

(see figure 3-2), and for some three decades after that the district continued to dominate the State's production. The most significant point about Ely, however, is not the amount of its copper production but rather the fact that it was the forerunner of the mines that typify the industry today: mines working very large deposits of low grade ore that are capable of sustaining production over a very long period of time.

Another long-range development in the State's mineral history also was initiated during the Tonopah-Goldfield era with the beginning of industrial minerals and rocks production — gypsum near Gerlach in Washoe County, and gypsum, limestone, and silica in the Las Vegas region. These were not, of course, the first industrial minerals operations. Salt was harvested from playas in the earliest days of the State to be used in the Washoe process for extracting silver from the Comstock ores, building stone was quarried for construction purposes, and other nonmetallics were mined for local consumption. The developments in the 1920's, though, were much more important because they were aimed primarily at wide markets, California in particular. Their significance is similar to that of the Ely deposits because they are large enough to support mining and manufacturing operations for many years. Unlike the Comstock and Tonopah mines, they are not short-lived, passing through a cycle of boom and exhaustion in 25 years or less.

During the Depression years mining activity in the State declined greatly, paralleling much industrial activity throughout the Nation. In the early 1930's, mineral production fell almost to the depths of the hungry years of the 1890's. There was, however, an important difference between the two depression periods. The decline of mining between 1880 and 1905 was caused largely by a lack of ore: the bonanza ore bodies of the Comstock and the other early camps had been worked out and no new ones had been found to replace them. The decline in the 1930's was not a matter of lack of ore, but lack of market: there was plenty of copper in the ground at Ely, lead-zinc-silver at Pioche, and gypsum near Arden — but no buyers. Mineral production in the State regained its earlier magnitude as the national economy recovered and from that time onward has continued to increase erratically.

The period from the mid-1930's through about the mid-1950's was characterized by the operation of many small to medium-sized metal mines (at least by 1972 size standards) in the State. Numerous gold mines were active during the later part of the Depression but these were abruptly closed by government order in 1942 to free miners to produce metals more directly needed for the World War II military effort. For some 20 years thereafter, precious metal production was relatively minor. Copper — much of it from Ely — continued to be the principal metal, but major amounts of tungsten, lead-zinc-silver, and mercury were produced, and the nonmetallics operations slowly grew.

The decade of the 1950's was an eventful one in the fields of prospecting and of mine development, though there was little organized exploration by major mining companies. The prospecting was on nearly the same scale as during the Tonopah-Goldfield days, but with comparatively little of the hectic promotion that characterized the boom times. Tungsten was the target of the first surge of prospecting, in the early 50's, and uranium was the target of a second surge in the middle of the decade. Important amounts of tungsten had been produced in Nevada during World War II, much of it from Mill City but much also from several other districts. In the early 1950's, however, a government buying program offered very high prices for tungsten and at about the same time the use of the ultraviolet lamp as a prospecting tool became common. The principal tungsten mineral, scheelite, is very inconspicuous, greatly resembling quartz, but it is one of the few minerals that glows a brilliant white when subjected to ultraviolet radiation, or "black light." Using portable ultraviolet lamps, prospectors combed the hills and found numerous deposits of scheelite. Many of the deposits, although too small to support substantial mining operations, were nonetheless rich enough to be very profitable operations for individuals or small companies. The price was sufficiently high to encourage such production until the program ended in 1957. The uranium prospecting boom also was stimulated by a Federal buying program, and was facilitated by the widespread use of the geiger counter and the scintillometer, which were able to detect very small amounts of uranium and other radioactive elements. Prospecting in Nevada for uranium was markedly less successful than it had been for tungsten: a few mines produced a little uranium

but no substantial deposits were found. These latter-day booms differed from earlier booms in that prospecting was largely a local affair: some prospectors came to Nevada from elsewhere, but the greater part of the prospecting was done by Nevadans within a fairly small radius of their home towns. These booms were also different in that no new towns were established, other than company-owned housing projects built at some of the more isolated mines. Two important mine developments of the 1950's were the beginning of major open pit copper mining in Yerington and the beginning of iron ore production in the State. The Yerington mine was important because it demonstrated that Ely was not the only large metal deposit in Nevada and helped to stimulate the extensive exploration for such deposits that began a few years later. Iron ore production (mostly for Japanese markets), likewise, stimulated prospecting that led to discovery of additional deposits including the Yerington iron deposit that will have great importance in the future.

Despite efforts by individual prospectors, exploration by major mining companies remained at a low level in 1950's. During much of the decade only one company maintained an exploration office in the State. In the 1960's, however, this situation changed and by the latter part of that decade some two dozen companies had exploration crews based in Reno alone, and geologists were carefully investigating mineralized areas throughout the State. Several new deposits – notably those at Battle Mountain, Carlin, and Cortez – were discovered and opened, and others were found but held for better economic or technologic conditions in the future. Among the latter that have been publicly announced are a major molybdenum deposit north of Tonopah and the tremendous iron-copper deposit of Pumpkin Hollow near Yerington. Rumors speak of others that have been found and evaluated but not publicly announced. Most are big, low-grade deposits that can be mined by mechanized techniques, whether open pit or underground. By 1970 virtually all of Nevada's mines were highly mechanized; only half a dozen small underground mines continued to use high-labor methods.

The nature of Nevada mining in the next half-century can be predicted reasonably well on the basis of patterns of the past, not only the radical change in pattern of the last few years, but also the more slowly developing pattern of the past century. The more recent developments make it clear that big, mechanized mines will be the major producers of tomorrow, although it is already apparent that a new and versatile breed of small mining companies is developing, to occupy the vacuum left by the larger companies and work the small deposits that inevitably are discovered. In the near future, open pit mines will dominate the scene, but it seems certain that before the fifty years is out, deposits shallow enough to be extracted this way will be unable to supply the demand for metals, and deeper-lying metal deposits will have to be mined by underground methods.

The historical pattern, as partly indicated by figure 3-2, provides insight into the economic future of mining in Nevada. The most significant part of the pattern is the change in the sources of mineral wealth in the State through the years. In the earliest period of major production, from 1860 to 1880, more than 80 percent of the mineral value was in gold and silver, and came from a single mining district, the Comstock Lode. In the second period, from 1905 to about 1930, gold and silver were important at first, then gave way to copper, but three districts – Tonopah, Goldfield and Ely – produced about 75 percent of the total value. In the most recent period, from about 1950 to the present, one metal, copper, still dominates mineral production. But now it is produced in major quantities from three districts, Ely, Yerington and Battle Mountain, and accounts for only about 60 percent of the State's total mineral production. The point is, of course, that the mineral industry in Nevada is no longer dependent upon the fortunes of one or two districts or one or two metals: it is a quite thoroughly diversified industry, and thereby a far more stable one than it was 50 to 100 years ago. A point of particular interest in this respect, which does not appear on figure 3-2, is the increasing importance of industrial minerals and rocks. These were too minor even to be considered in early production summaries, but their value has increased from almost nothing in 1920 to about one fourth of the total in 1970. They add special stability because they go to different markets than do the metals – to local and regional consumers, rather than competing in worldwide markets – and thus respond to different economic changes. As a result, while Nevada production of one or more metals might be depressed by

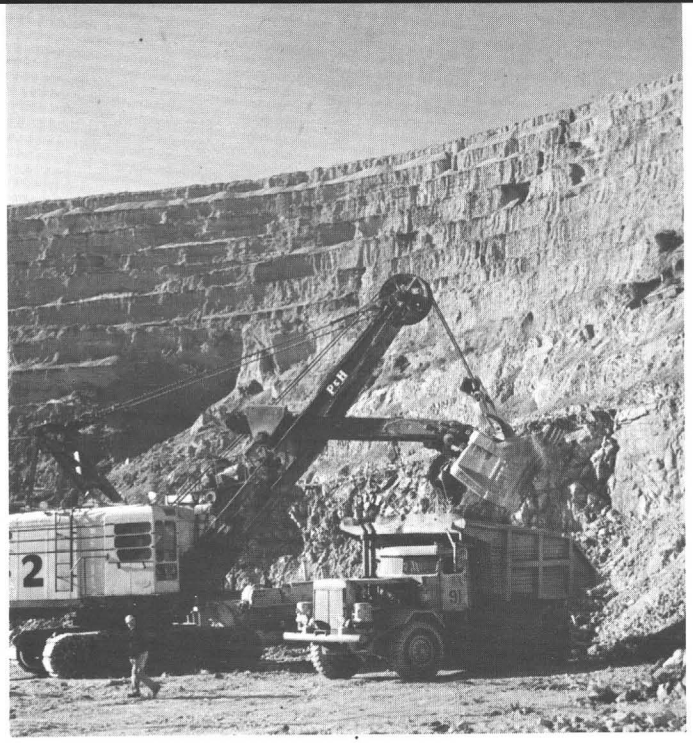


Figure 3-4. Power shovels and huge trucks move ore from modern open-pit mine. Lyon County. Horizontal steps in background are "benches," each about 20 feet high, the remains of levels worked as mine was deepened.

new mine discoveries or political actions in foreign countries, nonmetallic production would probably remain unaffected. Conversely should local or regional economic events depress the market for nonmetallics, metals might well remain strong on the world market. Present indications of continuing industrial development on the West Coast suggest that the historic trend toward increasing production of industrial minerals and rocks in Nevada will continue, perhaps at a higher rate than in the past.

The future changes in Nevada mining that the history of the past and the technology of the present foretell will bring about substantial increases in water needs. For the State as a whole, growing mineral production — and production more than tripled in the last thirty years — automatically means overall increasing need for water. The increasing size of individual mines, clearly foreseeable, means each mine will need more water from the local supply, even if today's technology is used with no change in the amount of water used per ton of ore treated; some of the techniques being developed, such as leaching ore without first mining it, substitute water for manpower and thus increase the amount of water needed still further. Finally, growing concern about environmental damage dictates that antipollution equipment will be part of the design of future mineral treatment plants, and nearly all such devices, whether aimed at dust or gaseous pollutants, use water as a collection agent. It requires no careful study to conclude that that mineral industry of the future will require greatly increased amounts of water — doubling or tripling present needs provides a conservative estimate.

Chapter 4 ASSUMPTIONS

In every study of the kind reported here the authors approach and carry out their work with sets of preconceptions and assumptions which have a significant impact on the research strategy and, more importantly, on the results themselves. Our study is no exception.

Many of the assumptions and preconceptions which we brought to bear on our work were consciously selected or at least were knowingly permitted to influence our reasoning and procedures. On the other hand, some of them — at least initially — operated on a subconscious level and, at times almost unknowingly, they influenced us as we worked. Such assumptions and preconceptions, of course, we have attempted to expose and examine, not just to be able to present them in this chapter for the reader's examination but, more importantly, so that we might better handle the techniques and procedures that led us to the numerous conclusions that we have drawn and which are presented in the other sections of this report.

In this chapter we discuss many of the assumptions that have influenced our thinking, particularly those which are relevant to the study as a whole or to major parts of it. Those which apply only to specific commodities or groups of commodities are usually mentioned in the appropriate chapters. Inevitably, some of our assumptions and preconceptions are discussed neither here nor in the appropriate commodity chapters. This happens because either we felt they were not of sufficient importance for our purposes to merit discussion or they were unrecognized or overlooked. We would much prefer the reader to select the first alternative, of course, but in those instances in which the second alternative must apply, we ask the reader's indulgence.

In choosing our assumptions we very consciously sought to maintain a reasonable balance between gloomy pessimism and undue optimism. As an extreme example, we could have assumed a set of conditions making obsolete all of the mineral raw materials that Nevada can supply, which would totally destroy the State's mineral industry. On the other hand, we could have assumed a set of circumstances that would have made Nevada the principal world supplier of many major mineral commodities. Both examples, of course, are ridiculously improb-

able. We sought, instead, a middle ground that reflects our understanding of world and national conditions; of the role and speed of technological change in our own country; and of important social, economic and political trends. The total effect of the assumptions which we applied was to produce a hypothetical future not greatly unlike the present, at least insofar as the mineral economy of the nation and the world is concerned. This future that we envision forces us to conclude that Nevada's mineral inudstry can and will expand markedly to help meet the demand for raw materials.

In examining our assumptions we found that they tended to fall into four broad categories: economic, demographic, technologic, and a group that for convenience we think of as politics and regulations. Few of the individual assumptions fit completely into any single category. Rather, they tend to overlap into two or more, and a rigid system of classification or organization would force us to improperly focus on one aspect of an assumption to the neglect and detriment of its other parts. For this reason we have not divided the chapter into sections.

One of the most important assumptions we have made is that the American economy will suffer no long-term, serious dislocations and that its growth and development during the next half century will be at a rate comparable to that from the post-World War II period to the 1970's. This, coupled with the assumption that mankind's apparently insatiable demand for goods of all kinds will not slacken, means that our standard of living will continue to rise at about the same pace as at present (a rate, incidentally, that is greater than population growth) and that a not altogether dissimilar assortment of goods and services will be produced.

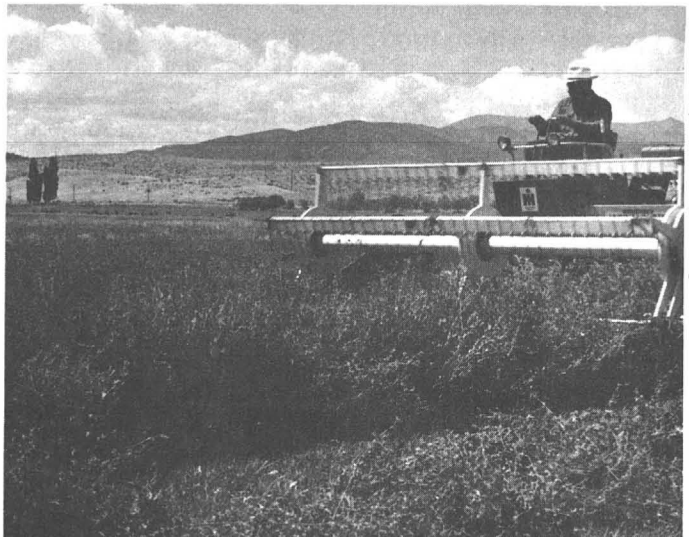
We have, of course, assumed that "zero population growth" will not be achieved during the coming half-century but that the size of the population of the United States will continue to increase even though the rate of growth may become substantially lower than during the past decade or two. In recent years the American public has tended to spend a smaller proportion of its income on manufactured goods. We feel this trend will continue but the increasing size of our population and the generally rising standard of living will require the continued expansion of the manufacturing sector and the primary industries on which it depends for raw materials.

Growth of population is important but for the purposes of this study, distribution of population is also of great significance. We expect that the American West will continue to attract large numbers of people and that, responding to market considerations, a growing percentage of American industry will be located in this region as time progresses. Such a development will favor Nevada's mineral industry.

Growing population in the West — mostly in states other than Nevada — will require the areal expansion of land devoted to housing and industry, to roads, parks, and other facilities, which will have an important impact on Nevada's mineral industry. These competing uses for the land will locally make continued resource exploitation difficult and expensive. Partly as a result of such developments and partly simply because of resource depletion, local production of various kinds of building and construction materials, especially in the larger metropolitan areas of the region, will prove no longer sufficient to meet demand. Producers of such materials will be forced to move to more remote areas and some of them will come to Nevada for mineral commodities.

There has been rapidly increasing concern in the United States with the problems of pollution and environment, and the health and safety of workers. New standards to protect the environment and workers are being established on both a national level and by various States, including Nevada. In all parts of the country there will be some mining operations

Figure 4-1. Alfalfa field. This crop could not be grown without mineral fertilizers, and could not be harvested without machinery made of metals.



Courtesy International Harvester Co.

that will be unable to operate profitably after the new controls are applied. We are presuming that mining in the State will be no more adversely affected by the application of these regulations than similar operations elsewhere and that generally, as a whole, Nevada's mineral industry will neither gain nor lose in reference to its present competitive position because of pollution and environmental controls.

Another matter of current public concern is the question of procedures for acquisition of mineral rights. The mining law of 1872, which presently regulates practices of locating mining claims, is being increasingly criticized by various groups and it seems certain that it will soon be replaced by new legislation. Some of the alternatives now being considered impose such stringent restrictions on mineral acquisition and production that they will undoubtedly remove much of the incentive to seek new mineral deposits and, consequently, will ultimately strangle the mining industry in the United States. We assume that whatever the provisions of the new legislation, it will not fundamentally alter the status of the minerals sector of the economy of the country: either the new legislation will be as encouraging to mineral exploration and exploitation as the 1872 law; or else, if it proves truly damaging, public pressure will demand its amendment.

Taxation is a vitally important governmental activity that can have profound impact on any industry. As in the case of environmental and safety regulations, a number of mining operations will no doubt be forced out of business by what we consider to be inevitable tax increases. Mining operations in Nevada are no more vulnerable to Federal tax increases than similar activities elsewhere; therefore, we believe Nevada's general competitive position will not be seriously affected by Federal taxation policies. State taxation policies, however, can operate in a manner to either encourage or discourage industry by providing an investment climate that is favorable or unfavorable compared to other states. In the past Nevada's taxation policy as it affects the mineral industry has been similar to that of most other states and has, therefore, neither especially encouraged nor especially discouraged mining activity. We presume that this condition will continue.

Since the period of World War II, the federal government has intermittently supported the domestic production of certain mineral materials to insure that in case of national emergency there would be a supply of the commodity on hand as well as a reservoir of domestic skill and production capability that could serve as a nucleus for expansion. Some of these programs have had a significant impact on the production of certain minerals in the State. For example, in the early 1950's the federal government supported a stockpile program for tungsten and by 1955 there were approximately 700 producing mines and Nevada was the leading supplier of that metal. However, shortly thereafter government support was withdrawn and by 1958 there were only two mines in production. For the most part it has been the production of metals which in the past the government has subsidized. Metals are the class of commodities which historically has been the mainstay of Nevada's mineral industry and which we believe will continue to be of greatest importance to the State; consequently, government programs affecting the production of these commodities would probably have a very marked effect on Nevada's economy. It is our belief that the government in the future will continue at least sporadically to pursue this policy and that it will tend to encourage further development of Nevada's mineral industry. However, we have not attempted to pinpoint the areas or commodities affected.

A very important assumption concerns the distribution of kinds of rocks. As described in Chapter 5, older rocks are exposed only in about 20 percent of the State, chiefly in the mountain ranges. These rocks contain most of the important metal deposits that have been found and many of them have proven to be very rich. From the more than 200 mining districts in which the ore bodies occur in older rocks there have been recovered metals valued at more than five billion dollars, as measured in today's dollar values. The known districts contain at least another five billion dollars worth of known ore waiting to be extracted and, without doubt, they contain much additional ore that has not yet been discovered. In the remaining 80 percent of the State the same older rock formations are covered by varying thicknesses of gravels, lava flows, and other younger rocks and, therefore, have never been explored for metal deposits. There is every reason to believe that these covered older rocks are, unit-for-unit, as rich as the exposed ones. They are a tremendous reservoir of mineral wealth. We assume that during the coming half-century tech-

niques will be developed to discover and mine the deposits in this yet-unexplored ground.

Many of our assumptions concerning the technology of mining operations are discussed in Chapter 2 but one important assumption is worthy of note at this point: the present trend toward larger and larger mines will continue in order to take advantage of the economies offered by bulk handling methods. Small mines will still be needed, however, for certain commodities that either have only small markets or occur only in small deposits. (By "large" we mean mines that produce tens of thousands of tons of ore per day, and by "small" we mean ones that produce hundreds of tons of ore per day.) A subsidiary assumption is that open-pit mining will be used very extensively, but that as shallower deposits are found and mined out, large underground mines will become more numerous than at present. Another subsidiary assumption is that the grade or quality of most metal ores that will be mined in the future will be lower than those of today: this trend, too, is already clearly established. These lower grade ores will probably require greater amounts of water per ton of final product.

Our estimates of future mine development and production, presented in the tabulations that accompany each commodity chapter, take into account only the principal and continuing mines that we anticipate. For some commodities these will be large mines in terms of our definition above, but for other commodities small mines will be the rule. We do not take into account the very small, sporadic development and mining operations undertaken by individuals and small companies that will exist during the next 50 years as they have during the past. These operations will not contribute a significant proportion of Nevada's mineral production, nor will they consume a significant amount of water. They will continue to be highly significant to the growth of the industry, nonetheless, in that many of them will undoubtedly be the forerunners of the exploration and development that leads to major mines.

We have also concluded that coproduct and byproduct recovery will become increasingly important in the future. From some ores many more components will be recovered, including very unlike products. For example, materials such as quartz for glassmaking and pyrite for sulphur and iron content will be recovered from copper ores. This development will help offset higher anticipated mining costs and make profitable ores that are of lower grade or quality.

In considering technologic advancement it has been apparent that some of the mineral commodities produced in Nevada will become obsolete. We conclude, however, that the other side of this coin will outweigh this effect — that many new uses for Nevada's materials will be found. We therefore assume that technological developments will not render useless the mineral commodities that Nevada can produce.

Improvements in transportation technology and extension of transportation networks — especially within Nevada — will be made, we believe, and will work to the benefit of the State's mineral industry. This will be particularly important to the low-value, bulky, nonmetallic commodities.

As we considered factors of an international nature, we saw a number of possible future developments that could have a significant influence on Nevada's mineral economy. On the one hand, some foreign developments could seriously damage the domestic mineral industry. For example, it is certain that there will be important overseas mineral discoveries that will result in large-scale importation of some commodities into the United States. Less certainly, for political reasons foreign countries will occasionally "dump" a particular commodity that will sell at extremely advantageous prices in the United States. On the other hand, opposite conditions can develop. Our balance-of-payment problems, domestic unemployment, the ugly apparition of economic nationalism, to mention but a few, can strongly favor domestic mineral production. We have decided to assume that these and the many other eventualities of foreign developments are countervailing and over the long run will be self-cancelling, with the result that the State's overall production of mineral commodities will not be seriously affected by international forces or events. Certain contrary assumptions that affect individual commodities are discussed in the appropriate chapters.

Chapter 5 GENERAL GEOLOGY OF NEVADA

The geology of Nevada is only partially mapped at present; however, reconnaissance mapping is com-

Jim Reinheller

Figure 5-1. Baker Lake in the Wheeler Peak area of White Pine County. In background are flat-lying Prospect Mountain quartzite beds, of Cambrian age. The depression in which the lake lies was gouged out of the rock by a glacier about ten thousand years ago.

pleted for most of the state. The complex geology revealed by the mapping indicates that Nevada is a favorable region in which to search for new mineral deposits, but it makes a generalized description subject to oversimplification.

Except for a small section in the extreme northern part of the State, Nevada lies within the Basin and Range Physiographic Province. Topographically, this province is characterized by numerous, subparallel mountain ranges that trend in a north-

south direction. Individual ranges are from 40 to 80 miles in length and 5 to 15 miles in width. Broad, flat valleys 15 to 20 miles wide separate the mountain ranges. Surficial drainage in the province ends in the valleys, and material eroded from the mountains is deposited in the valleys rather than being carried away to the sea by major streams.

Structurally, the valleys and ranges are blocks of the earth's crust that have been tilted, uplifted, or dropped along major breaks or faults. Subsequent erosion has stripped large amounts of rock from the mountains and deposited it in the valleys. Older rocks that contain metallic ore deposits are exposed in the ranges, but in the valleys the same rocks are generally covered by as much as several thousand feet of younger eroded material. Because of the thick cover, the valleys have not been prospected for metal deposits. However, the geologically young valley fill that covers the older rocks is the host material for deposits of many valuable nonmetallic commodities.

Processes of erosion in arid regions such as Nevada result in the formation of pediments along the base of some mountain ranges. These pediments are bedrock surfaces that slope gently toward the valleys. They may be a mile or more wide and are commonly covered by only a thin layer of recently deposited sand and gravel. Pediments thus are areas where the older, possibly metal-bearing rocks lie under a shallow cover. Exploration efforts are now being directed to these pediments because they offer promise of containing mineral deposits that may be discovered by combined geochemical and geophysical surveys.

Distribution of Rock Types

Map 5-1, Modified Geologic Map of Nevada, is a rather unconventional presentation of the surficial geology of the State compiled from the point of view of the economic geologist, and is intended to show the distribution of the rocks in which various kinds of mineral deposits may occur. On the map, the many geological units of the State are generalized into only five groups. Three of these groups are actual rock units: intrusive rocks, pre-Tertiary non-intrusive rocks, and Tertiary volcanic rocks. The other two groupings are not conventional rock types, but show shallow or deep accumulations of unconsolidated or geologically young sands and gravels that have been designated "cover." Generally, cover fills the valleys, while the true rocks are exposed as mountains; however, very young volcanic flows are also classed as cover because they contain no metal ores.

The five groupings are logical in terms of mineral deposits, although geologically there is some overlap in age between groups and each group contains rocks of diverse origin and petrographic type. The intrusive rocks are shown because many metallic ore deposits are genetically related to intrusive bodies and occur within or close to them. The other pre-Tertiary rocks serve as hosts for deposits of most metallic minerals and many industrial minerals such as barite and fluorite. The Tertiary volcanic rocks can serve as hosts for some kinds of metallic deposits, such as gold, silver, and mercury, but commonly they cover up older metallic deposits in underlying pre-Tertiary rocks; thus, they can be either host rocks for metal deposits or form a cover over other metal-bearing rocks.

The categories of cover have two very important economic consequences. First, they cover the older rocks that are the hosts for most metallic mineral deposits (hence the name), making present-day discovery and mining of these deposits difficult or impossible. Second, and equally important, they are the hosts for deposits of many nonmetallic minerals such as sand and gravel, diatomite, saline brines, and clays. Cover is divided into two categories, shallow cover that is less than 1,000 feet thick, and deep cover that is from 1,000 feet to 5,000 feet or more thick. We have drawn this distinction because we expect any metallic mineral deposits present under deep cover to remain inaccessible until early in the 21st century while deposits under shallow cover will become accessible much sooner, and indeed, some are already being exploited.

The rock groupings are listed in table 5-1, together with the approximate age range of each grouping and the percentage of area of the State in which each is exposed. (The percentages are taken from more detailed tables printed on Map 5-1.) The table reveals that in 59 percent of the State older rocks of the kind known to contain metallic deposits lie under either deep or shallow cover. In an additional 22 percent of the State only Tertiary volcanic rocks are exposed and, consequently, the underlying potentially metal-bearing rocks are virtually unexplored. We know of no reason to believe that unexposed older rocks contain fewer or smaller

Table 5-1
GENERALIZED ROCK GROUPINGS IN NEVADA

	Approximate Age in millions of years	Percentage of exposure in State
Shallow cover	10 to 0	30.1
Deep cover	10 to 0	28.5
Tertiary volcanic rocks	40 to 3	22.1
Pre-Tertiary non-intrusive rocks	600+ to 60	16.5
Intrusive rocks	160 to 12	2.8

metallic deposits than the exposed ones; hence, extrapolating from experience with exposed rocks we consider it extremely likely that future exploration of older rocks under covered areas will reveal the existence of numerous important metal ore bodies.

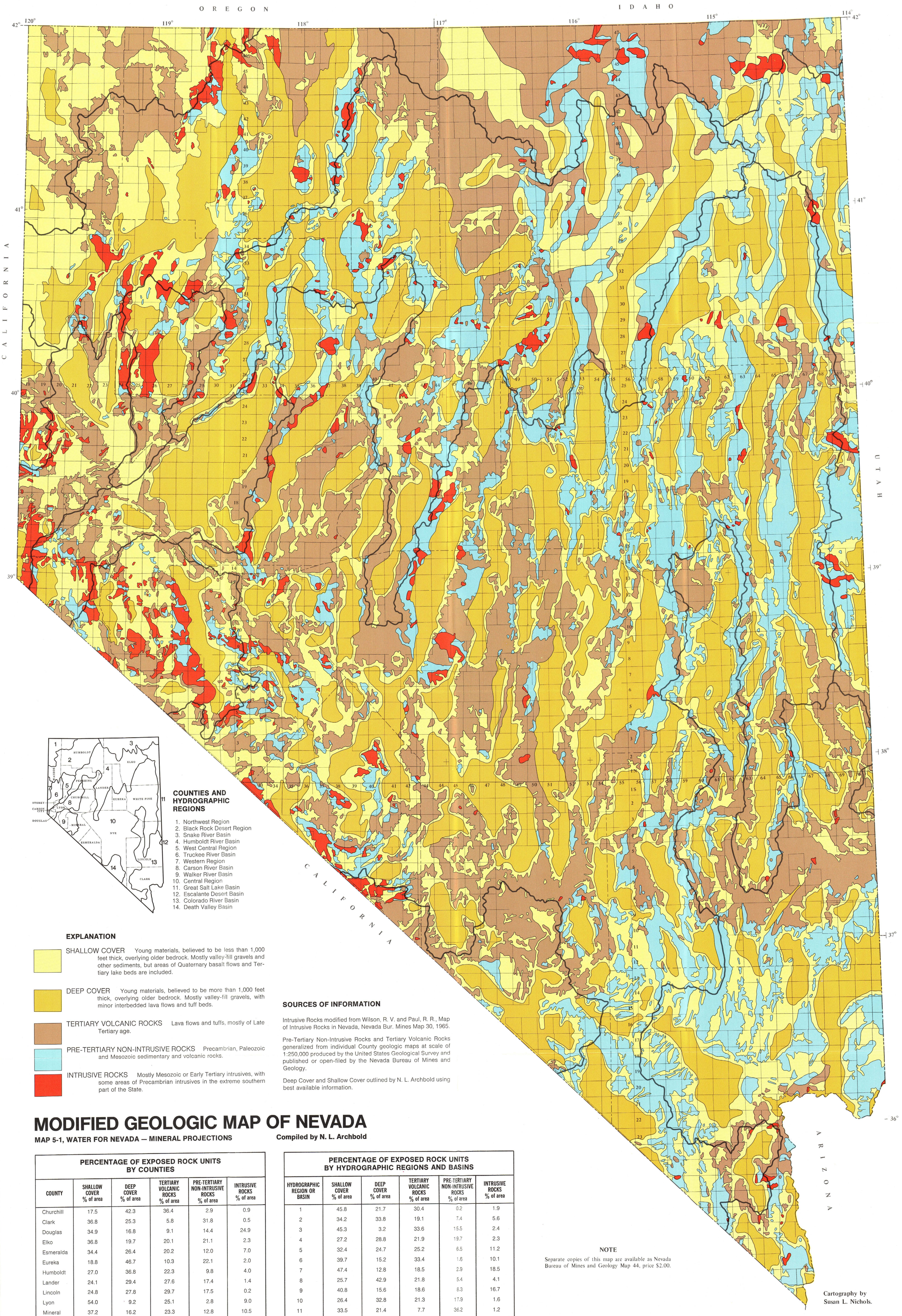
Intrusive Rocks. Most igneous intrusive rocks in the State were formed in Mesozoic or Tertiary time, between about 160 and 12 million years ago; however, a few intrusives in Clark County are Precambrian and are probably older than 1,200 million years (see geologic column, figure 5-2). In general, the actual ages of the intrusives decrease from the western toward the eastern side of the State. The percentage of area underlain by intrusive rock is greatest along the western side where the density doubtless reflects both proximity to the Sierra Nevada batholith and a greater depth of erosion than in the east. Many of the intrusives fall within the composition range of granite, quartz monzonite, granodiorite, or quartz diorite although other varieties have been recognized. Many of the major metallic deposits in Nevada occur within or adjacent to intrusive rocks. Relationships to intrusions are displayed by copper deposits at Ely, Battle Mountain, and Yerington; tungsten deposits at Mill City, Nightingale, and Tempiute; and iron deposits near Yerington and in the Buena Vista Hills.

Pre-Tertiary Non-intrusive Rocks. This grouping includes the geologically old rocks of the State, ranging from very old Precambrian schists through less old Paleozoic and Mesozoic sediments and volcanics. All of these rocks were subjected to greater or lesser degrees of deformation during the Laramide orogeny, a period of mountain-building that occurred near the end of the Mesozoic Era (about 60 or 70 million years ago) and during which a great many of the major metallic ore deposits of the western United States were formed. Some of the older rocks were subjected to earlier periods of mountain-building, and perhaps were mineralized then, but we consider the Laramide orogeny and its associated mineralization to be the unifying feature of this grouping.

The Precambrian rocks (more than 600 million years old) consist of metamorphic and clastic sedimentary rocks that crop out in southern Clark County, eastern White Pine County, south-central Elko County, Esmeralda County, and southern Nye County. Locally, the time boundary between these and overlying pre-Tertiary rocks (lower Cambrian) is not distinct. For the most part, Precambrian rocks in Nevada have not yielded major mineral production, partly because they are exposed only over a very small total area. Minerals that might be produced from Precambrian rocks are essentially the same as those that might be produced from other pre-Tertiary rocks.

The Paleozoic rocks (225 to 600 million years old) in Nevada grade from one type to another across the State. Those in the eastern third of the State consist mainly of the carbonates, limestone and dolomite, which are hosts for lead-zinc-silver deposits such as those at Pioche and Eureka, and for the disseminated gold deposits at Carlin and Cortez. These carbonate rocks are commonly called the "eastern assemblage." Westward, the carbonate rocks grade to interbedded shale, chert, limestone and dolomite. Because of their intermediate nature and position between the eastern and western rocks, these rocks have been referred to as the "transitional assemblage." The Paleozoic rocks in the western part of the State are cherts, shales and rocks of volcanic derivation. They are usually referred to as the "western assemblage." During the Antler orogeny, a mountain building period that occurred about 350 million years ago, rocks of the western assemblage slid or were pushed many miles eastward over rocks of the transitional and eastern assemblages so that today we find the western assemblage overlying either of the other two throughout much of central Nevada.

Mesozoic rocks (70 to 225 million years old) in Nevada are much less extensively exposed than the Paleozoic rocks although there are small patches of them in many parts of the State. Those in the northwest constitute the most extensive exposures. The early Mesozoic rocks in northwestern Nevada consist of volcanic rocks and volcanic-derived sedi-



COUNTIES AND HYDROGRAPHIC REGIONS

1. Northwest Region
2. Black Rock Desert Region
3. Snake River Basin
4. Humboldt River Basin
5. West Central Region
6. Truckee River Basin
7. Western Region
8. Carson River Basin
9. Walker River Basin
10. Central Region
11. Great Salt Lake Basin
12. Escalante Desert Basin
13. Colorado River Basin
14. Death Valley Basin

EXPLANATION

SHALLOW COVER — Young materials, believed to be less than 1,000 feet thick, overlying older bedrock. Mostly valley-fill gravels and other sediments, but areas of Quaternary basalt flows and Tertiary lake beds are included.

DEEP COVER — Young materials, believed to be more than 1,000 feet thick, overlying older bedrock. Mostly valley-fill gravels, with minor interbedded lava flows and tuff beds.

TERTIARY VOLCANIC ROCKS — Lava flows and tuffs, mostly of Late Tertiary age.

PRE-TERTIARY NON-INTRUSIVE ROCKS — Precambrian, Paleozoic and Mesozoic sedimentary and volcanic rocks.

INTRUSIVE ROCKS — Mostly Mesozoic or Early Tertiary intrusives, with some areas of Precambrian intrusives in the extreme southern part of the State.

SOURCES OF INFORMATION

Intrusive Rocks modified from Wilson, R. V. and Paul, R. R., Map of Intrusive Rocks in Nevada, Nevada Bur. Mines Map 30, 1965.

Pre-Tertiary Non-Intrusive Rocks and Tertiary Volcanic Rocks generalized from individual County geologic maps at scale of 1:250,000 produced by the United States Geological Survey and published or open-filed by the Nevada Bureau of Mines and Geology.

Deep Cover and Shallow Cover outlined by N. L. Archbold using best available information.

MODIFIED GEOLOGIC MAP OF NEVADA

MAP 5-1, WATER FOR NEVADA — MINERAL PROJECTIONS

Compiled by N. L. Archbold

PERCENTAGE OF EXPOSED ROCK UNITS BY COUNTIES

COUNTY	SHALLOW COVER % of area	DEEP COVER % of area	TERTIARY VOLCANIC ROCKS % of area	PRE-TERTIARY NON-INTRUSIVE ROCKS % of area	INTRUSIVE ROCKS % of area
Churchill	17.5	42.3	36.4	2.9	0.9
Clark	36.8	25.3	5.8	31.8	0.5
Douglas	34.9	16.8	9.1	14.4	24.9
Elko	36.8	19.7	20.1	21.1	2.3
Esmeralda	34.4	26.4	20.2	12.0	7.0
Eureka	18.8	46.7	10.3	22.1	2.0
Humboldt	27.0	36.8	22.3	9.8	4.0
Lander	24.1	29.4	27.6	17.4	1.4
Lincoln	24.8	27.8	29.7	17.5	0.2
Lyon	54.0	9.2	25.1	2.8	9.0
Mineral	37.2	16.2	23.3	12.8	10.5
Nye	23.0	34.6	32.6	8.9	0.8
Ormsby	23.8	7.7	19.2	22.7	26.6
Pershing	26.8	32.5	9.7	22.9	8.1
Storey	28.3	—	69.8	1.2	0.7
Washoe	53.7	15.2	24.6	1.4	5.2
White Pine	24.8	31.0	9.1	34.3	0.8
STATE	30.1	28.5	22.1	16.5	2.8

PERCENTAGE OF EXPOSED ROCK UNITS BY HYDROGRAPHIC REGIONS AND BASINS

HYDROGRAPHIC REGION OR BASIN	SHALLOW COVER % of area	DEEP COVER % of area	TERTIARY VOLCANIC ROCKS % of area	PRE-TERTIARY NON-INTRUSIVE ROCKS % of area	INTRUSIVE ROCKS % of area
1	45.8	21.7	30.4	0.2	1.9
2	34.2	33.8	19.1	7.4	5.6
3	45.3	3.2	33.6	15.5	2.4
4	27.2	28.8	21.9	19.7	2.3
5	32.4	24.7	25.2	6.5	11.2
6	39.7	15.2	33.4	1.6	10.1
7	47.4	12.8	18.5	2.9	18.5
8	25.7	42.9	21.8	5.4	4.1
9	40.8	15.6	18.6	8.3	16.7
10	26.4	32.8	21.3	17.9	1.6
11	33.5	21.4	7.7	36.2	1.2
12	23.8	25.9	50.2	—	—
13	29.5	26.8	19.9	23.6	0.3
14	28.4	23.8	35.1	9.7	3.0
STATE	30.1	28.5	22.1	16.5	2.8

DIVISION OF WATER RESOURCES
STATE ENGINEER'S OFFICE
Prepared as a part of the Nevada State Water Plan

NOTE

Separate copies of this map are available as Nevada Bureau of Mines and Geology Map 44, price $2.00.

Cartography by Susan L. Nichols.

Scale 1:1,000,000

0 10 20 30 40 50 100 Kilometers

0 10 20 30 40 50 100 Miles