CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
520-770-3500
http://www.azgs.az.gov
inquiries@azgs.az.gov

The following file is part of the

James Doyle Sell Mining Collection

ACCESS STATEMENT

These digitized collections are accessible for purposes of education and research. We have indicated what we know about copyright and rights of privacy, publicity, or trademark. Due to the nature of archival collections, we are not always able to identify this information. We are eager to hear from any rights owners, so that we may obtain accurate information. Upon request, we will remove material from public view while we address a rights issue.

CONSTRAINTS STATEMENT

The Arizona Geological Survey does not claim to control all rights for all materials in its collection. These rights include, but are not limited to: copyright, privacy rights, and cultural protection rights. The User hereby assumes all responsibility for obtaining any rights to use the material in excess of "fair use."

The Survey makes no intellectual property claims to the products created by individual authors in the manuscript collections, except when the author deeded those rights to the Survey or when those authors were employed by the State of Arizona and created intellectual products as a function of their official duties. The Survey does maintain property rights to the physical and digital representations of the works.

QUALITY STATEMENT

The Arizona Geological Survey is not responsible for the accuracy of the records, information, or opinions that may be contained in the files. The Survey collects, catalogs, and archives data on mineral properties regardless of its views of the veracity or accuracy of those data.

KERR-McGEE CORPORATION
KERR-McGEE CENTER • OKLAHOMA CITY, OKLAHOMA 73125

June 21, 1985

Rec'd Jun 24, 1985 FOTG

Fleetwood Koutz
Asarco, Inc.
P.O. Box 5747
Tucson, AZ 85703

Dear Fleet:

Apparently I have been "volunteered" by FTG

Maurice Chaffee and I wish to thank you for agreeing to serve as an observer on the Continental Scientific Drilling Committee Ad Hoc Task Group for Red Mountain. A directory of Task Group members and observers is attached.

The first meeting of the Task Group is to be held at Red Mountain on July 24. At that time we plan to tour the mountain, introduce the group to the core storage facility, and outline a program of study for Red Mountain.

The tour on July 24 will start from the Sheraton Pueblo Inn at 350 S. Freeway in Tucson at 8:00 a.m. To help with planning we would appreciate it if you would complete and return the attached form at your convenience. We also need your signature on the attached confidentiality agreement and liability release.

Again, thanks and I am looking forward to seeing you on July 24.

Sincerely yours,

Jim

James J. Quinlan
Senior Staff Geologist
Minerals Exploration Division

JJQ:bw

Attachments

CONTINENTAL SCIENTIFIC DRILLING PROGRAM
CONFIDENTIALITY AND LIABILITY AGREEMENT
WITH THE KERR-McGEE CORPORATION

Red Mountain
Santa Cruz County, Arizona

The Kerr-McGee Corporation has granted to the Continental Scientific Drilling Committee (CSDC) permission to use its Red Mountain, Arizona property as a study and possible drill site. In addition, the company has agreed to make available to the project basic geologic data and cores resulting from previous drilling. As with all outside studies of this nature, the company does not warrant any of the material or data furnished.

In consideration of the above, and to protect Kerr-McGee's interest in the property and the company from any contingent liability resulting from the project, Kerr-McGee requires all representatives or members of CSDC participating in the Red Mountain project to agree to the following:

1. Analyses and geologic information provided by Kerr-McGee or developed under the study will be treated as proprietary information. It will be restricted in distribution within the project group to those directly involved and none released to the public prior to approval by the Ad Hoc Task Group for the Red Mountain Project and Kerr-McGee.

2. Kerr-McGee has no objection to the public release of general geologic and scientific data resulting from the project. However, prior to public release, including the publishing or placement of theses resulting from project work in university libraries, Kerr-McGee reserves the right to review and comment on data, papers, manuscripts or proposed publications pertaining to the finds, descriptions or determinations resulting from the project.

3. All unused materials, including samples, rock chips, petrographic slides and work documents will be returned to Kerr-McGee upon completion or termination of the project. This shall not preclude arrangements with Kerr-McGee to place special samples or materials in repositories or archives.

4. The undersigned, as a representative or member of the Continental Scientific Drilling Committee, by acceptance of the terms and conditions of this Agreement does indemnify and save harmless Kerr-McGee Corporation of and from any and all liability for injuries to or death of the undersigned, or for loss or damage to his or her property, and further, the undersigned shall and hereby save harmless from any and all liabilities, claims, demands, suits, actions, losses, damages recoveries, judgments, costs or expenses in any manner arising out of or in connection with your activities on the Kerr-McGee premises.

ACCEPTED THIS 24 day of JUNE, 1985

by Stephen R. King

Title GEOLOGIST

ASARCO INC, SWED - TUCSON

CONTINENTAL SCIENTIFIC DRILLING COMMITTEE
PANEL ON MINERAL RESOURCES
AD HOC TASK GROUP MEETING
Red Mountain, Arizona

July 24, 1985

☒ I plan to attend the Ad Hock Task Group Meeting for Red Mountain on July 24, 1985.

☐ I will be unable to attend the Ad Hock Task Group Meeting for Red Mountain on July 24, 1984.

☐ I would like you to reserve a room at the Sheraton Pueblo Inn in Tucson for July _____ (date or dates).

Signature

Return to: J. J. Quinlan
Kerr-McGee Corporation
P.O. Box 25861
Oklahoma City, Oklahoma 73125

CONTINENTAL SCIENTIFIC DRILLING COMMITTEE
PANEL ON MINERAL RESOURCES
AD HOC TASK GROUP FOR
RED MOUNTAIN ARIZONA

	Address	Phone
Co-Chairmen		
James J. Quinlan	Kerr-McGee Corporation P.O. Box 25861 Oklahoma City, OK 73125	(405) 270-3975
Maurice A. Chaffee	US Geological Survey Box 25046 M.S. 973 Federal Center Denver, Colorado 80225	(303) 236-1855
Members		
George D. Christiansen	Kerr-McGee Corporation P.O. Box 25861 Oklahoma City, OK 73125	(405) 270-3971
Paul I. Eimon	Pioneer Nuclear, Inc. P.O. Box 151 Amarillo, TX 79189	(806) 373-6054
Frederick T. Graybeal	Asarco, Inc. 180 Maiden Lane New York, NY 10038	(212) 510-2000
Richard H. Merkil	Arco Exploration P.O. Box 5540 Denver, CO 80217	(303) 293-1118
Charles Meyer	P.O. Box 2607 Sedona, AZ 86336	(602) 282-2287
Roland B. Mulchay	2732 Wren Road Salt Lake City, UT 84117	(801) 277-2722

	Address	Phone
Observers		
George H. Brimhall	Department of Geology and Geophysics University of California Berkley, CA 94720	(415) 642-5868
C. Wayne Burnham	Pennsylvania State University 207 Deike Building University Park, PA 16802	(814) 865-6711
George Davis	Department of Geosciences University of Arizona Tucson, AZ 85721	(602) 621-6024
Fleetwood Koutz	Asarco, Inc. P.O. Box 5747 Tucson, AZ 85703	(602) 792-3010
Albert S. Johnson	Anaconda Minerals 7805 Windfont Row Parker, CO 80134	(303) 841-0192
Spencer R. Titley	Department of Geosciences University of Arizona Tucson, AZ 85721	(602) 621-6018

JDS

CONTINENTAL SCIENTIFIC DRILLING COMMITTEE
PANEL ON MINERAL RESOURCES
AD HOC TASK GROUP MEETING
Red Mountain, Arizona

July 24, 1985

[X] I plan to attend the Ad Hock Task Group Meeting for Red Mountain on July 24, 1985.

[ ] I will be unable to attend the Ad Hock Task Group Meeting for Red Mountain on July 24, 1984.

[ ] I would like you to reserve a room at the Sheraton Pueblo Inn in Tucson for July _____ (date or dates).

Signature

Return to: J. J. Quinlan
Kerr-McGee Corporation
P.O. Box 25861
Oklahoma City, Oklahoma 73125

CONTINENTAL SCIENTIFIC DRILLING COMMITTEE
PANEL ON MINERAL RESOURCES
AD HOC TASK GROUP FOR
RED MOUNTAIN ARIZONA

	Address	Phone
Co-Chairmen		
James J. Quinlan	Kerr-McGee Corporation P.O. Box 25861 Oklahoma City, OK 73125	(405) 270-3975
Maurice A. Chaffee	US Geological Survey Box 25046 M.S. 973 Federal Center Denver, Colorado 80225	(303) 236-1855
Members		
George D. Christiansen	Kerr-McGee Corporation P.O. Box 25861 Oklahoma City, OK 73125	(405) 270-3971
Paul I. Eimon	Pioneer Nuclear, Inc. P.O. Box 151 Amarillo, TX 79189	(806) 373-6054
Frederick T. Graybeal	Asarco, Inc. 180 Maiden Lane New York, NY 10038	(212) 510-2000
Richard H. Merkil	Arco Exploration P.O. Box 5540 Denver, CO 80217	(303) 293-1118
Charles Meyer	P.O. Box 2607 Sedona, AZ 86336	(602) 282-2287
Roland B. Mulchay	2732 Wren Road Salt Lake City, UT 84117	(801) 277-2722

	Address	Phone
Observers		
George H. Brimhall	Department of Geology and Geophysics University of California Berkley, CA 94720	(415) 642-5868
C. Wayne Burnham	Pennsylvania State University 207 Deike Building University Park, PA 16802	(814) 865-6711
George Davis	Department of Geosciences University of Arizona Tucson, AZ 85721	(602) 621-6024
Fleetwood Koutz	Asarco, Inc. P.O. Box 5747 Tucson, AZ 85703	(602) 792-3010
Albert S. Johnson	Anaconda Minerals 7805 Windfont Row Parker, CO 80134	(303) 841-0192
Spencer R. Titley	Department of Geosciences University of Arizona Tucson, AZ 85721	(602) 621-6018

Kara : JDS

CONTINENTAL SCIENTIFIC DRILLING PROGRAM
CONFIDENTIALITY AND LIABILITY AGREEMENT
WITH THE KERR-McGEE CORPORATION

Red Mountain
Santa Cruz County, Arizona

The Kerr-McGee Corporation has granted to the Continental Scientific Drilling Committee (CSDC) permission to use its Red Mountain, Arizona property as a study and possible drill site. In addition, the company has agreed to make available to the project basic geologic data and cores resulting from previous drilling. As with all outside studies of this nature, the company does not warrant any of the material or data furnished.

In consideration of the above, and to protect Kerr-McGee's interest in the property and the company from any contingent liability resulting from the project, Kerr-McGee requires all representatives or members of CSDC participating in the Red Mountain project to agree to the following:

1. Analyses and geologic information provided by Kerr-McGee or developed under the study will be treated as proprietary information. It will be restricted in distribution within the project group to those directly involved and none released to the public prior to approval by the Ad Hoc Task Group for the Red Mountain Project and Kerr-McGee.

2. Kerr-McGee has no objection to the public release of general geologic and scientific data resulting from the project. However, prior to public release, including the publishing or placement of theses resulting from project work in university libraries, Kerr-McGee reserves the right to review and comment on data, papers, manuscripts or proposed publications pertaining to the finds, descriptions or determinations resulting from the project.

3. All unused materials, including samples, rock chips, petrographic slides and work documents will be returned to Kerr-McGee upon completion or termination of the project. This shall not preclude arrangements with Kerr-McGee to place special samples or materials in repositories or archives.

Apr
24 Sep 85

4. The undersigned, as a representative or member of the Continental Scientific Drilling Committee, by acceptance of the terms and conditions of this Agreement does indemnify and save harmless Kerr-McGee Corporation of and from any and all liability for injuries to or death of the undersigned, or for loss or damage to his or her property, and further, the undersigned shall and hereby save harmless from any and all liabilities, claims, demands, suits, actions, losses, damages recoveries, judgments, costs or expenses in any manner arising out of or in connection with your activities on the Kerr-McGee premises.

ACCEPTED THIS 27 day of July, 1985

by [signature]

Title Exploration Geologist - ASARCO, Inc

FLEETWOOD R. KOUTZ

7-29-85

Fleet:

Here is a copy of the Confidentiality and Liability Agreement you signed.

It was good to have you along on the tour but more important I welcomed the opportunity to discuss the situation in our phone conversation today. Thanks

Best regards

Jim

JIM QUINLAN

Rec'd 7/31/85

FTG: 1) FKK say OK to send in revised copy agreement to Jim Greenlie DOSCC? True? (Correct)

2) Also say Greenlie & you have gotten over the miles posted as to your notice via results — check holes for seamless log etc.? True? (Do). 3-R TR TM TM-13

3) We should start TM-14 hole this week. Have not get received sample cloth back — asked for (25K) but then letter signed by K-M released the seam to FKK which I will spend.

12 July

Gec 17?

6 miles N of Gatchell (Gold fields) 23 miles

TDV Rent

Amref.

x

Mon. 29 July 85

Mary: Notes for JDS when he calls in. - No need to type
Just leave this in his box after you give him the INFO.

Thunder Mtn: Joy mobilizing July 29, for TM-14
- FTG said (7/26) that we have $25,000 (your original request for TM-14) rather than only $19,000 even though Kenn McGee did agree to claim reduction. Nothing has yet come to this office in writing concerning amount approved.

TM-TR: Re your phoned-in memo of July 26 concerning TR+TM data for Quinlan. Quinlan received what he needed over the phone from FTG in May and as of 24 July needed no more data. You may remember that TM-13 went into altered limestone @ depth with 2' of massive limestone replacement mineralization. Quinlan has the monthly drill map showing this hole and the assays but it doesn't specifically say limestone-hosted. There is no reason to let him know any more about this unless specifically requested.

Red Mtn - Trip went well: Quinlan hadn't received confidentiality slip so I signed another. Will write short note on trip. Told FTG 7/26 of Trip - meeting discussions.

JRM

Read to JDS over phone 7/29/85

PRELIMINARY SCIENTIFIC INVESTIGATIONS
CONTINENTAL SCIENTIFIC DRILLING PROGRAM

Kurz

RED MOUNTAIN, ARIZONA

September, 1985

September 6, 1985

Fleet:

For your files. I also sent a copy to Fred.

Thanks for your interest and support. Hope to see you soon.

Best regards,

Rec'd 9 SEPT 85

Jim

JIM QUINLAN

P.O. Box 25861
Oklahoma City, OK 73125
September 5, 1985

Dr. Francis G. Stehli, Chairman
Science Advisory Committee
DOSECC, Inc.
College of Geosciences
University of Oklahoma
Norman, Oklahoma 73019

Re: Preliminary Scientific Investigations for Continental Scientific Drilling Program Red Mountain, Arizona

Dear Dr. Stehli:

Enclosed you will find a report describing the preliminary scientific investigations needed to site proposed Continental Scientific Drilling at Red Mountain, Arizona. The report has been prepared by the Panel of Geoscientists identified by the Ad Hoc Task Group for Red Mountain of the CSDC's Panel on Mineral Resources (PMR) to develop a program for Red Mountain. A directory accompanying this letter identifies members of the Panel of Geoscientists, the Ad Hoc Task Group for Red Mountain and the Panel on Mineral Resources of the CSDC.

Red Mountain, Arizona was selected by the CSDC as the drilling target most likely to reveal scientific information about deep crustal processes attending the emplacement of porphyry copper and related deposits (CSDC, 1984, Minerals Resources: Research Objectives for Continental Scientific drillings, p 23-28.) The Preliminary Scientific Investigations Report represents the culmination of nearly four years of consideration, effort and work by PMR to bring the project to the proposed investigative stage.

Kerr-McGee Corporation, owner of the property, has made the property, drill cores and basic geologic record resulting from its investigation available to the Continental Scientific Drilling Program. This includes cores resulting from 185,000 feet of drilling in 72 holes. Twenty-five holes are over 5,000 feet deep, the deepest being 5,790 feet. The scientific community is fortunate that Kerr-McGee has made this core available; and we should take advantage of this unique opportunity.

The report outlines a comprehensive scientific investigative program of geology, geochemistry and geophysics to site proposed deep drilling at Red Mountain. In accomplishing the siting objective, the studies are expected to add materially to the scientific understanding of hydrothermal processes within the continental crust.

We trust the Science Advisory Committee to DOSECC will favorably consider and support the program recommended in the report.

Yours truly,

For the Ad Hock Task Group for
Red Mountain

James J. Quinlan, Co-Chairman

Maurice A. Chaffee, Co-Chairman

For The Panel on Mineral Resources
Continental Scientific Drilling Committee

J. James Eidel, Chairman

Charles Meyer, Member

JJQ:bw

Enclosure

cc: G.A. Barber
W.W. Hay
Barry Raleigh

CONTINENTAL SCIENTIFIC DRILLING COMMITTEE
PANEL AND GROUP DIRECTORY
FOR
RED MOUNTAIN, ARIZONA

Panel on Mineral Resources of CSDC

James J. Eidel - Illinois State Geological Survey, Chairman

G. Arthur Barder - DOSECC, Inc.
Philip M. Bethke - U.S. Geological Survey, Reston
George H. Brimhall, Jr. - University of California, Berkeley
C. Wayne Burnham - Pennsylvania State University
Robert O. Fournier - U.S. Geological Survey, Menlo Park
William C. Kelley - University of Michigan
J. David Lowell - Private Consultant (until May 1984)
Charles Meyer - University of Arizona
John H. Schilling - Nevada Geological Survey (until June 1982)
Brian J. Skinner - Yale Univesity
Richard K. Traeger - Sandia National Laboratories
Donald E. White - U.S. Geological Survey (until June 1982)

Ad Hoc Task Group for Red Mountain

Maurice A. Chaffee - U.S. Geological Survey, Denver, Co-Chairman
James J.Quinlan - Kerr-McGee Corporation, Co-Chairman

George D. Christiansen - Kerr-McGee Corporation, Member
Paul I. Eimon - Pioneer Nuclear, Inc., Member
Frederick T. Graybeal - Asarco, Inc., Member
Richard H. Merkil - Arco Exploration, Member
Charles Meyer - University of Arizona, Member
Roland B. Mulchay - Private Consultant, Member

George H. Brimhall, Jr. - University of California, Berkeley, Observer
C. Wayne Burnham - Pennsylvania State University, Observer
J.D. Corbett - University of Utah Research Institute, Observer
George H. Davis - University of Arizona, Observer
Fleetwood Koutz - Asarco, Inc., Observer
Albert S. Johnson - DOSECC, Inc., Observer
Spencer R. Titley - University of Arizona, Observer

Panel of Geoscientists for Red Mountain

Robert J. Bodnar - Virginia Polytechnic Institute
George H. Brimhall, Jr. - Univeristy of California, Berkeley
C. Wayne Burnham - Pennsylvania State University
R. F. Butler - University of Arizona
Maurice A. Chaffee - U.S. Geological Survey
J.D. Corbett - University of Utah Research Institute
Paul E. Damon - University of Arizona
George H. Davis - University of Arizona
Kevin Furlong - Pennsylvania State University
Charles Meyer - University of Arizona
Hiorshi Ohmoto - Pennsylvania State University
James J. Quinlan - Kerr-McGee Corporation
Spencer R. Titley - University of Arizona

PRELIMINARY SCIENTIFIC INVESTIGATIONS FOR LOCATIONS OF DEEP DRILL HOLES

CONTINENTAL SCIENTIFIC DRILLING PROGRAM

RED MOUNTAIN, ARIZONA

by

R. J. Bodnar, G. H. Brimhall, Jr., C. W. Burnham, R. F. Butler,
M. A. Chaffee, J. D. Corbett, P. E. Damon, G. H. Davis, K. P. Furlong
C. Meyer, H. Ohmoto, J. J. Quinlan, S. R. Titley

September, 1985

TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
RECOMMENDATIONS	1
LOCATION AND PROPERTY STATUS	3
ENVIRONMENTAL CONSIDERATION	3
GEOLOGY	3
RESEARCH OBJECTIVES	4
PROPOSED PROGRAM	5
Regional Studies including Paleomagnetic Studies	5
Surface Mapping and Drill Core Fracture Studies	6
Geochronology	7
Petrography, Petrology, and Mineral Chemistry	7
Fluid Inclusion Studies	8
Isotope Studies	8
Thermal Modeling	10
Applied Geochemical Studies	10
Geophysics and Remote Sensing	11
Management, Synthesis and Hole Siting	12
TIME AND COST ESTIMATE	13
SCHEDULE	15
REFERENCES	16
ILLUSTRATIONS	Follows Report
APPENDIX A	Follows Report

INTRODUCTION

The porphyry copper deposit at Red Mountain, Arizona was selected by the Panel on Mineral Resource (PMR) of the Continental Scientific Drilling Committee (CSDC) as the drilling target most likely to reveal scientific information about deep crustal processes attending emplacement of porphyry copper deposits (CSDC, 1984). It was recognized by PMR that the unmined deposit at Red Mountain has received less scientific attention than many better known and productive porphyry copper deposits. This deficiency, however, could be remedied by a detailed scientific investigation prior to siting of deep drill holes to study the deep portions of the system.

PMR approached the Kerr-McGee Corporation, owner of the deposit, regarding the availability of the property to the CSDC. Kerr-McGee agreed to make the property available for study and as a possible drill site. The Company has made available split core, assay pulps and basic geologic and assay data resulting from its investigation of the deposit which includes completion of 72 drill holes totaling 55 km (185,000 ft) of drilling. Twenty-five of the drill holes are deeper than 1.5 km (5,000 ft), the deepest being 1.75 km (5,790 ft).

An Ad Hoc Task Group for Red Mountain appointed by CSDC reviewed and inspected the materials made available by Kerr-McGee on July 24, 1985. This review confirmed PMR initial interest and the attractiveness of the proposed deep drilling target. A program to accomplish the initial scientific investigation and drill hole siting at Red Mountain was outlined. Principal investigators to accomplish the proposed program were identified. This report discusses the proposed Red Mountain project and contains proposals and cost estimates prepared by the principal investigators to target properly and site deep drilling at the study area.

RECOMMENDATIONS

The Panel of Geoscientists, charged by PMR of CSDC to evaluate and undertake scientific studies at Red Mountain, recommend that deep drilling to test the deep portions of the porphyry copper system at Red Mountain be given a high priority by the CSDC and DOSECC.

The Panel of Geoscientists also recognizes a need to refine and enlarge the geological, geochemical, and geophysical base of information at Red Mountain in preparation for locating the proposed deep drill holes. The following program to accomplish this objective is recommended:

1. Regional Studies including Paleomagnetic Studies
   Principal Investigators: G.H. Davis, University of Arizona (Regional Studies); R.F. Butler, University of Arizona (Paleomagnetic Studies)

   Time: 2 years Cost: $48,000

2. Surface Mapping and Drill Core Fracture Studies
   Principal Investigator: S. R. Titley, University of Arizona

   Time: 2 years Cost: $76,000

3. Geochronology Studies (25 dates)
   Principal Investigator: P.E. Damon, University of Arizona

   Time: 1 year Cost: $18,000

4. Petrography, Petrology and Mineral Chemistry
   Principal Investigator: G. H. Brimhall, Jr., University of California, Berkeley

   Time: 2 years Cost: $172,000

5. Fluid Inclusion Studies
   Principal Investigator: R. J. Bodnar, Virginia Polytechnic Institute

   Time: 2 Years Cost: $80,000

6. Isotope Studies
   Principal Investigator: H. Ohmoto, Pennsylvania State University

   Time: 2 years Cost: $238,000

7. Thermal Modeling
   Principal Investigator: K. P. Furlong, Pennsylvania State University

   Time: 2 years Cost: $80,000

8. Applied Geochemistry
   Principal Investigator: M. A. Chaffee, USGS

   Time: 2 years Cost: $140,000

9. Geophysics and Remote Sensing
   Principal Investigator: J.D. Corbett, University of Utah Research Institute

   Time: 2 years Cost: $140,000

10. Management, Synthesis and Deep Hole Siting

    Principal Investigator: J.J. Quinlan, Kerr-McGee Corporation

    Time: 2 years Cost: $ 70,000

TOTAL COST $1,062,000

LOCATION AND PROPERTY STATUS

The Red Mountain property is located in the Harshaw Mining District, Santa Cruz County, Arizona, Figure 1. The property lies at the north end of the Patagonia Mountains, 80 km (50 miles) south of Tucson, Arizona and 3 km (2 miles) south of Patagonia, Arizona.

The Kerr-McGee property consists of 36 patented and 524 unpatented lode mining claims. These claims cover an area of 3,625 hectares (14 square miles) and center on Red Mountain, Figure 2. The peak at Red Mountain is at an altitude of 1,942 m (6,371 ft) and lies in Section 20, T.22S., R.16E.

Other claim and land owners in the area include Asarco, Inc., and Commonwealth International. Representatives from these companies; i.e., Fred Graybeal and Fleetwood Koutz of Asarco; and Paul Eimon, Commonwealth International are members of, or observers for, the Ad Hoc Task Group for Red Mountain.

The Kerr-McGee property and others lie within an area managed by the U.S. Forest Service, pursuant to Forest Service Regulation 36 CFR. The regulation is reasonable and no problems have been encountered, nor are any anticipated in conducting scientific investigations or drilling operations at Red Mountain.

ENVIRONMENTAL CONSIDERATION

Scientific research or deep drilling at Red Mountain should present no unusual or significant environmental problems.

Mining in the area predates the Spanish conquest of Mexico in the sixteenth century (Schrader, 1915). Asarco operated the Trench mine as recently as 1960. Kerr-McGee has carried on drilling operations since 1961. In recent years numerous other companies have conducted drilling and geologic mapping programs in the region surrounding the deposit.

GEOLOGY

The geology and base-metal occurrences at Red Mountain have been intermittently studied since 1915 (Schrader, 1915; Drewes, 1971a,b, 1972a,b; Simons, 1971, 1974). More recent efforts have focused on data provided by the Kerr-McGee drilling program (Corn, 1975; Bodnar and Beane, 1980; Quinlan, 1981). Surface geochemical sampling by the U.S. Geological Survey surrounding Red Mountain was summarized by Chaffee et al. (1981). Copies of these papers are attached as Appendix A.

The Red Mountain deposit is part of the Harshaw district, which is a part of the greater Patagonia district and a part of the southwestern North America porphyry copper province. Its lateral and genetic position relative to nearby vein and replacement deposits can be studied.

The geological setting of Red Mountain includes an altered complex of flat-lying volcanic and intrusive rocks of Cretaceous and early Tertiary age. Three layered volcanic units are present. These include an upper rhyolite and dacite tuff unit of 730-m (2,400 ft) maximum thickness, a middle andesite as much as 900 m (3,000 ft) thick, and a basal felsite-latite unit that is at least 550 m (1,800) ft) thick. Porphyritic intrusive rocks ranging in composition from granodiorite to quartz monzonite cut the layered volcanic rocks.

Silicate alteration, described in detail by Quinlan (1981) and Corn (1975), varies with rock types and depth. Alteration assemblages (i.e., argillic, phyllic, and potassic) typical of porphyry copper deposits (Lowell and Guilbert, 1970; Rose, 1970) are present. The alteration zoning pattern can be explained by a deep ore-stage alteration system superimposed on an earlier, larger, and essentially copper-barren alteration system. Argillic and phyllic alteration at the surface are parts of the large, early stage system. Strong potassic and phyllic alteration at depth are parts of the deep-level porphyry copper emplacement.

Sulfide mineral zoning appears to be related to the deep-level porphyry copper-stage alteration. Lead and zinc generally occur in the upper portions of the deposit, and small amounts of molybdenum are present throughout. Chalcopyrite is the predominant copper mineral. Enargite occurs in the upper levels, and minor amounts of bornite are present at depth. Chalcocite occurs as a secondary mineral in the upper parts of the deposit.

Breccia pipes crop out at the surface and a "blind" pipe is recognized in several deep drill holes. This deep-level breccia pipe is within the potassic core of the main copper deposit and may be the deepest copper-molybdenum breccia pipe known in the world. Strong quartz-sericite-pyrite alteration is recognized at the top of this pipe, and to a lesser extent at its margins. This phyllic type alteration in the pipe clearly cuts strong biotite-magnetite-orthoclase alteration in the core area of the main deposit. A zone of copper, molybdenum, and silver enrichment is situated near the margins of the pipe. This pipe presents a unique environment permitting insight into vertically zoned mineral deposits in relation to other major elements of such deposits. It also provides an opportunity to compare high-level and deep-level breccia pipes in a porphyry copper environment.

Understanding of the structural evolution of this district could aid in the interpretation of other mineral deposits that represent single phases of the multi-staged process at Red Mountain.

RESEARCH OBJECTIVES

The Red Mountain district represents an unusual opportunity for increasing the scientific understanding of important criteria in hydrothermal mineral genesis, geochemistry, geophysics and paleohydrology.

The district presents a number of unique features that are scientifically attractive. The deposit does not appear to have been tilted,

and neither has it been extensively faulted or deeply eroded. However, more work is needed to verify these conditions. The deposit seems to be of moderate size so its root system is likely to be within reach of present drill technology. Classic mineralogical and geochemical zoning can be studied at the well-exposed present surface and by means of the drill core resulting from 55 km of drilling by the Kerr-McGee Corporation. Thus, sampling and scientific study of a nearly complete vertical system is possible.

The combination of these and other desirable features were judged by the PMR of CSDC to make the Red Mountain deposit a unique opportunity to study the movement and chemical evolution of aqueous fluids in the deep continental crust as they interacted with a large localized source of heat and chemical components related to subvolcanic processes.

PROPOSED PROGRAM

Based on present information, the Ad Hoc Task Group and Panel of Geoscientists for Red Mountain are considering two deep drill holes. One hole should be located specifically to test the breccia pipe and its downward extension, and a second hole to test below the main porphyry copper sulfide body. Both holes may be drilled to a depth as great as 5 km (16,000 ft) to explore the bottom of the potassic alteration zone. These holes should penetrate the lower limit of fluid circulation and provide data on fluid transport, paleopermeability and temperatures. They should provide data regarding existing hypotheses on metal source and mobilization as well as alteration in the roots of the system. Preliminary estimates indicate that each hole would take about a year to drill and each would cost $3 million. An additional $2 million to $3.0 million would be needed to complete scientific studies of the core and add-on experiments in the proposed holes.

The Ad Hoc Task Group and the Panel of Geoscientists for Red Mountain recognize a need to refine and enlarge on the geologic, geochemical and geophysical base at Red Mountain in order to site properly the proposed deep drill holes. A program of geological, geochemical, and geophysical research is proposed to accomplish this objective. This preliminary scientific investigation as designed should also provide much new data on porphyry copper deposits in general and a better understanding of the processes of formation. Whereas the overall program as outlined in the section on Recommendations represents a consensus of the Ad Hoc Task Group and Panel of Geoscientists for Red Mountain, details and costs for individual parts of the program have been prepared by the principal investigator responsible for each area.

Regional Studies including Paleomagnetic Studies

Principal Investigators: G.H. Davis, University of Arizona (Regional)
R.F. Butler, University of Arizona (Paleomagnetic)

Time: 2 years Cost: $48,000

The Red Mountain mineralized system is located within a part of Arizona where Laramide, mid-Tertiary, and younger Tertiary tilting and low-angle displacement have been reported (Davis, 1979, 1981; Dickinson, 1984). Although tilting and lateral transport at Red Mountain have not been recorded, except for studies of Pliocene tectonics and stratigraphy in the Sonoita Creek Basin (Menges, 1981), no evidence exists to indicate that such a possibility has been reviewed or studied. Except for strike dip plots shown in the volcanic rocks of Red Mountain (Huckins, 1976) there is little information available to assess the possible present attitude of the Red Mountain hydrothermal system. An investigation focused on this problem is of paramount importance. The siting of a drill hole based upon surface data with a purpose of testing a deep target (e.g., 5 km or 16,000 ft) will be strongly influenced by correct projections of that target. For example, a 6° inclination of the system will result in a 500 m (1,600 ft) lateral displacement at a 5 km depth, a 15° inclination will result in 1300 m (4,160 ft) of lateral displacement from the vertical.

Regional mapping and structural analysis of Mesozoic, Laramide, and younger Tertiary rocks are therefore a prerequisite to drilling. From such studies, which must be integrated with a thorough sampling of rocks for radiometric age-dating (See Geochronology section) and with a paleomagnetic study as a supplement, the faulting and tilting history of the system may be assessed. A sound basis of peripheral mapping and structural interpretation exists from which to build and extend. Further, paleomagnetic studies (Barnes and Butler, 1980; Kluth et al, 1982; Calderone and Butler, 1984) provide a working basis for additional studies in the Red Mountain system.

Surface Mapping and Drill Core Fracture Studies

Principal Investigator: S.R. Titley, University of Arizona
Time: 2 years Cost: $76,000

Distribution of flow in hydrothermal systems such as Red Mountain is chiefly controlled by an extensive interlocking network of fractures, evolved as a direct consequence of emplacement and cooling of igneous magmas. Thus the distribution of fractures is a guide to limits of fluid flow. The evolution and distribution of fractures has been detailed for a few hydrothermal porphyry-centered systems (e.g. Silver Bell: Kanbergs, 1980; Norris, 1981; Sierrita: Haynes and Titley, 1978; Titley et al., 1985, in press). Initial surface studies have been carried out over Red Mountain (Kistner, 1984).

A principal and necessary objective of the interim science project at Red Mountain is to extend the surface study of fracture distribution and abundance to the limits of fracture occurrence, and to integrate the surface information with abundance and distribution data from drill core. Such a study is a fundamental requirement for the more basic purpose of the drilling project. Information developed provides the only basis for determining the locus of most intense flow and the patterns of peripheral flow in any genetic interpretations advanced and provides an important basis for siting the drilling to be done. Further, as the study of the sequence of fractures is diagnostic of the evolution of alteration, the results will provide the only basis for understanding the chemical-thermal evolution of the system (Titley and Beane, 1980; Preece and Beane, 1982).

Fracture density data will be collected at the surface by techniques described elsewhere (Haynes and Titley, 1980; Titley et al, 1985, in press) and integrated with paragenetic studies and fluid inclusion data. Drill core fracture data will be collected by a fracture area/core volume technique in drill core and will be supplemented by petrographic studies of alteration mineralogy and fluid inclusions.

Geochronology

Principal Investigator: P.E. Damon, University of Arizona
Time: 2 years Cost: $18,000

The stratigraphic succession at Red Mountain is relatively well-established. However, the chronology of rocks and events is unknown except for scattered dates on region-wide units and a few plutonic rocks. A K-Ar or Rb-Sr chronology is required for volcanic and intrusive rocks as well as for mineralization-alteration events to verify the age, succession, and duration of thermal and geological events in this system. Such a study is especially critical to the regional tectonic analysis. It is important to establish the time of tilting of the Red Mountain system if such has occurred.

Abraco stands here for the [illegible] which is dated!

THIS A LOT!

A minimum of twenty-five dates are projected as required to date the pre-, inter- and post-ore rocks and to date the hydrothermal event(s) as measurable in the alteration assemblages.

Petrography, Petrology, and Mineral Chemistry

Principal Investigator: G. H. Brimhall, Jr., University of California, Berkeley
Time: 2 years Cost: $172,000

Objectives of the petrologic study will be to define better the deep drilling target and the petrographic and compositional criteria for recognizing the parent intrusive to be penetrated during the deep drilling phase of the Red Mountain program. Identification of this source of heat, magmatic fluids, and metals is the most critical part remaining in completing the description and analysis of this magmatic-hydrothermal system. Compositions of hydrothermal and igneous biotite from core samples expressed in terms of OH, F, Cl, Mg, Fe, Ti, Al, Si, Mn, K, and Na mole fractions in specific crystallographic sites will provide a sound basis for comparison of biotite in the breccia and in potassic alteration zones of the volcanics with drilling samples of intrusives encountered at depth during the deep drilling phase. Such results can be interpreted in terms of magmatic fluid composition and temperature at the point of release of these aqueous fluids from the magma body. This mineral chemistry will be used to define the thermal and chemical evolution of magmatic fluids from purely igneous to hydrothermal processes during breccia formation, hydrofracturing, and alteration-mineralization. During the deep drilling phase, wall rocks can be analyzed using mass balance principles to assess the relative contributions of magmatic input of metals in relation to leaching these metals from adjacent protores.

It is proposed here to use a combination of mapping (core logging) and mineral chemistry to define the locus of early-stage mineral assemblages, and to deduce fluid composition and the temperature field during the initial stages of fluid circulation. The composition of biotite is ideally-suited for this purpose as its composition and petrographic relationships clearly reflect the thermal and chemical environments of formation, including transition from magmatic to hydrothermal conditions. Biotite crystallizes both during magmatic crystallization as well as during high-temperature hydrothermal processes, making its composition an ideal monitoring device over this range in physical and chemical processes, including breccia formation and fluid-rock interaction during alteration.

Fluid Inclusion Studies

Principal Investigator: R.J. Bodnar, Virginia Polytechnic Institute
Time: 2 years Cost: $80,000

The purpose of the fluid inclusion study at Red Mountain is to provide a data base on the thermal and chemical characteristics of hydrothermal fluids in the system in time and space. These data will be combined with other available information to generate a predictive model for fluid evolution in a magmatic-hydrothermal environment. The final product would be a set of criteria based on fluid inclusion characteristics that could be used to predict where one is in a particular hydrothermal system and, more importantly, the direction and distance to the center of activity.

The proposed study includes detail petrographic work to determine the temporal and spatial distribution of fluid inclusion types in the hydrothermal system, and correlation of various inclusion types with specific episodes of alteration and mineralization. During this stage of the investigation, the limits of immiscibility (boiling) in time and space and relationships between boiling and mineralization would be defined. Outlining the boiling zones may provide a relatively simple means of distinguishing the epithermal from the deeper magmatic environment.

The petrographic phase of the study would be followed by microthermometric analyses of fluid inclusions to determine the temperatures and bulk salinities of the fluids and, more importantly, how these properties vary in time and space within the hydrothermal system. Raman microprobe analyses of these same inclusions would be conducted to determine the types and amounts of volatile components in the fluids. Considerable emphasis will be placed on the volatile analyses because the gas content of inclusion could prove to be the best indication of where one is in the system and probably is one of the major controls in metal transport and deposition.

Isotope Studies

Principal Investigator: H. Ohmoto, Pennsylvania State University
Time: 2 Years Cost: $238,000

Three major mutually related problems on the genesis of porphyry copper deposits are: (1) the sources of various components of the

ore-forming fluids, especially H_2O, metals and sulfur; (2) the hydrology of the ore-forming systems; and (3) the mechanisms of sulfide and sulfate deposition.

Oxygen and hydrogen isotope studies of minerals and fluid inclusions in porphyry copper deposits (e.g., Taylor, 1979) have revealed that two types of waters, magmatic and meteoric, were involved in the formation of most porphyry copper deposits. The sulfur isotopic data at hand also suggest that a significant proportion of sulfur in most porphyry copper deposits is magmatic in origin (e.g. Ohmoto and Rye, 1979).

Some of the major unresolved questions concern: the changes with respect to time and space in the relative importance of magmatic and meteoric waters; their effect on the mineralogical and elemental characteristics of porphyry copper deposits; and the exact nature of physical and chemical interaction between magmatic fluids and meteoric water. Specific questions include the following: Did the sulfide and sulfate minerals precipitate from magmatic fluids, and only locally redistributed by circulating meteoric water? Or, was a significant proportion of metals and sulfur derived from the surrounding country rocks by circulating meteoric water or magmatic water? How did the geometries of the two fluid systems (magmatic and meteoric) change with time? Did the two fluid systems operate independently, and the dominant system in the ore zone change from pure magmatic to pure meteoric at some state in the mineralization history? Or, was the magmatic fluid system diluted continuously by meteoric water through time? If fluid mixing was an important process for changing the chemical nature of the hydrothermal system, did the mixing take place at the site of sulfide deposition, or at the peripheral or deeper parts of the plumbing system?

If a significant proportion of metals and sulfur in these deposits is found to be magmatic in origin, a question that follows concerns the mechanism through which the magmas acquired these elements. Did the magmas acquire these elements through the partial melting of source rocks in the upper mantle or the lower crust, or did they acquire them through selective assimilation of the upper crustal rocks during magma emplacement?

The mechanism of hydrothermal mineral precipitation in porphyry copper deposits remains unresolved. The possible processes include: a simple decrease in P and T; an increase in the activity of H_2S and SO_4 (caused by the hydration of SO_2 during cooling); an increase in pH due to chemical reactions with wall rocks; mixing or unmixing of magmatic fluids; and mixing of magmatic fluids with meteoric water.

The main reason that the previous studies were unable to answer any of the above questions quantitatively was because essentially the previous isotopic studies on porphyry copper deposits were reconnaisance in nature. A detailed investigation of the temporal and spatial changes in the oxygen, hydrogen, carbon, and sulfur isotopic compositions of minerals and fluid inclusions in a well selected system can solve all of the above problems, if the isotopic study is coordinated with other geochemical studies (e.g., fluid inclusion, mineralogic, and major-and trace-element studies). The Red Mountain porphyry system seems to be one of the best localities to solve these problems on porphyry copper deposit genesis because the bottom and the sides as well as the top of a porphyry system can be sampled.

The research plan is to investigate systematically the oxygen, hydrogen, sulfur and carbon isotopic compositions of minerals and fluid inclusions from drill core samples, on which various other geochemical studies will be pursued by other members of the Red Mountain Research Panel. Approximately 200 to 500 samples, representing both mineralized and barren intrusive and country rocks, will be investigated. The study will be carried out by a post-doctoral fellow and graduate assistant under the direction of the principal investigator.

Thermal Modeling

Principal Investigator: F. P. Furlong, Pennsylvania State University
Time: 2 years Cost: $ 80,000

The thermal modeling part of the project is to develop constrained models of the detailed thermal evolution of the intrusive-hydrothermal system. At present, primarily as a consequence of a paucity of constraining data (and associated model simplications), models of the thermal evolution of such systems are relatively general in scope. The proposed work, in conjunction with the geological and geochemical data collected is intended to develop models which simulate the evolution of such systems, including the effects of conducted and advected heat, and heat produced via chemical reactions and phase changes (heat and crystallization). The modeling effort will be aimed at unraveling the thermal history of the system as a whole, and also at determining the local perturbations to the general pattern.

Currently, modeling algorithms allow for evaluation of the conductive aspect of the thermal evolution of intrusive systems. It is planned to adapt and improve these algorithms to allow for the evaluation of the effects of advected heat. Clearly, in systems such as Red Mountain, an important component of this advected heat is carried by fluids moving through fracture networks. Thus, to evaluate this aspect will require inclusion of data regarding the timing of formation of fracture systems, the volumes and rates of fluid flow, and the lifetime of any one fracture system, in addition to the density and geometry of the fractures. Only with the constraints provided by the geological and geochemical data gathered as a part of this project can these models be made to realistically simulate the thermal evolution of the system. This modeling will be conducted primarily on two scales. A large system-wide scale will be used to model the overall evolution, while a smaller, local-scale of modeling will be used to evaluate the variability in thermal history which can occur on such a small scale. The inclusion of these small-scale effects is a necessary component of models of the system in general.

Expected results of this work include numerical algorithms, constrained by the available data, which will allow us to simulate the thermal evolution of an intrusive-hydrothermal system. These models will provide a means of evaluating potential deep drilling sites with particular usefulness in determining the scale of local (near borehole) variability possible in the thermal history of upper crustal intrusive systems.

Applied Geochemical Studies

Principal Investigator: M.A. Chaffee, USGS
Time: 2 years Cost: $140,000

The purpose of the geochemical studies is to determine in conjunction with other geological studies, the zoning of selected elements and minerals in the Red Mountain system. This zoning will be a primary means of establishing the history and geometry of the presently drilled part of the overall mineralized system and will thus be a valuable method for locating drill sites and targets.

Samples of drill core, as well as outcrop, soil, and mine dumps, will be collected and analyzed for as many as 40 elements. Both single and multi-element plots of the raw analyses, as well as of derived parameters such as element ratios and values created by factor analysis and other statistical techniques, will be evaluated. Selected samples will be studied to determine the mineral residences of elements shown to be zoned in the study area.

The analyses will be used to establish the abundances and distributions of ore and lithologically-related elements. The analyses, and the parameters derived from the analyses, will be used to define the 3-dimensional zoning within the presently drilled out area as well as in the area immediately surrounding the known extent of the mineralized system. The analytical data will also be used to help correlate the structurally separated geologic units mapped during the project. The mineral residences of selected elements will be determined to identify those minerals that are diagnostic of specific lithologic and (or) hydrothermal zones within the system. The zoning model will help in determining the timing, location, and intensity of mineralizing pulses in the system and will therefore help to define the geometry of the system and thus suggest possible sites for deep drilling.

The distributions and abundances of the selected elements will also assist in determining the effects and extent of supergene alteration and the possible sources of the elements associated with the mineralizing processes.

Geophysics and Remote Sensing

Principal Investigator: J.D. Corbett, University of Utah Research Institute

Time: 2 years Cost: $140,000

Very little detailed geophysical data are know for the Red Mountain porphyry copper system. Geophysical studies, particularly aeromagnetic and gravity surveys, will provide a three-dimensional physical property model of the depth, lateral extent and transitional variations of both the intrusive rocks and the near-surface host-rock lithologies of the Red Mountain area. Susceptibility contrasts are known within the host rocks; densities and density contrasts between rock types can be determined from surface and drill core specimens. Geologic data and extrapolations from known outcrops or borehole intercepts will add significant control for geophysical interpretation of the third dimension of the Red Mountain deposit and siting of deep drill holes. A surface induced polarization test and borehole geophysical logging will provide additional physical property data to assist research study of the geological and mineralogical features of a hydrothermal porphyry copper system and its peripheral epithermal deposits.

A detailed helicopter-base aeromagnetic survey is proposed to cover the zone of alteration and peripheral mineralization with extensions well out into fresh unaltered rocks and background magnetic field values. A tight line spacing of about 250 m (800 ft) at a draped survey terrain clearance of 90 m (300 ft) is recommended. The survey should be completed early in the geologic mapping sequence for optimum utilization and could be completed in six months after a contract is approved.

Detail gravity across the rugged terrain of the Patagonia Mountains will require extensive surveying and terrain-effect corrections. A study of the density of the several types of surface rocks and diamond drill core is a necessary preliminary step to the survey.

Specific studies of the electrical properties (chargeability and resistivity) of the alteration zone will be undertaken. With large electrode separations this study would probe the limits of the deep sulfide mineralization to the west where erosion largely has removed the upper level sulfide zone. Short-spaced electode lines would determine the electrical parameters on the near-surface alteration zones of both Red Mountain and the peripheral mineralized environments. Selection of line placement would be based upon host-rock lithology, alteration type and extent, and culture interference.

Remote sensing data needs to be updated and integrated as a part of this study. The alteration halo associated with the Red Mountain deposit was delineated using spectral reflectance data, acquired by Landsat, a field spectrometer, and NASA's Bendix 24-channel Multispectral Scanner (MSDS) (Abrams and Siegal, 1977). These data should be recovered and integrated with the airborne geophysical data and detailed geologic mapping proposed in the preliminary investigation. Further ratioing and creation of additional contour maps and/or false-color ratio composites are recommended. The budget requirements to upgrade the previous data base should be minimal assuming the data and programs from JPL are available.

Management, Synthesis and Hole Siting

Principal Investigator: J.J. Quinlan, Kerr-McGee Corporation

Time: 2 years Cost: $70,000

Provision is made here to manage and coordinate project work during the life of the project and to synthesize data at the end of the project so as to site the proposed deep drill holes.

TIME AND COST ESTIMATE

The following time and cost estimate has been prepared from details furnished by the principal investigators of individual studies. Proposed work will be accomplished using existing equipment and facilities at the institutions of the principal investigator or will be contracted. No funds are requested or allowed for the purchase of new equipment or facilities.

1.	Regional Studies including Paleomagnetic Studies	
	Regional Studies	
	2 years, with 1/2 time R.A. = 1 R.A. year @ $16,000/yr	$ 16,000
	Transportation and Field Expenses	2,500
	Indirect Costs	8,000
	Palemagnetic Studies	
	1 year with 1/2 time R.A. = 1/2 R.A.year at $16,000/yr	8,000
	1 month Faculty Expense	5,000
	Transportation and Field/Lab Expenses	2,500
	Indirect Costs	6,000
	Subtotal	$ 48,000
2.	Surface Mapping and Drill Core Fractures Studies	
	2 years with 1 1/4 times R.A.=2 1/2 R.A.yrs.@ $16,000/yr	40,000
	2 months Faculty Expense	10,000
	Transportation and Field/Lab Expenses	3,500
	Indirect Costs	22,500
	Subtotal	$ 76,000
3.	Geochronologic Studies	
	1 year with 1/4 time R.A. = 1/4 R.A.year @$16,000/yr	$ 4,000
	25 Age dates @ $500 ea., less $4,000	8,500
	Indirect Costs	5,500
	Subtotal	$ 18,000
4.	Petrography, Petrology and Mineral Chemistry	
	2 years with 2 R.A. = 4 R.A. years @$16,000/yr	$ 64,000
	+ part time technician at 20% of R.A. time	12,800
	2 months Faculty Expense	11,200
	Transportation and Field/Lab Expenses	32,000
	Indirect Costs	52,000
	Subtotal	$172,000
5.	Fluid Inclusion Studies	
	Time: 2 years with R.A. = 2 R.A. years @$16,000/yr	$ 32,000
	2 months Faculty Expense	10,000
	Transportation and Field/Lab Expense	15,000
	Indirect Costs	23,000
	Subtotal	$ 80,000

6.	Isotope Studies	
	2 years with Proj. Assoc. = 2 P.A. years at $33,500/yr	$ 67,000
	1/2 time R.A. = 1 R.A. year @ $16,000	16,000
	Secrectary and Technician	18,000
	3 months Faculty Expense	30,000
	Transportation and Field/Lab Expense	36,000
	Indirect Costs	71,000
	Subtotal	$238,000
7.	Thermal Modeling	
	2 years with 1 R.A. = 2 R.A. years @$15,000/yr	$ 30,000
	2 months Faculty Expense	10,000
	Transportation and Lab Expense	17,000
	Indirect Costs	23,000
	Subtotal	$ 80,000
8.	Applied Geochemistry	
	2 years with 1-GS-5 = 2 GS-5 years @ $15,000/yr	$ 30,000
	Analysis - 2500 samples @ $20 ea.	50,000
	Transportation and Field Expense	20,000
	Indirect Costs	40,000
	Subtotal	$140,000
9.	Geophysics and Remote Sensing	
	Aeromagnetic, includes interpretation	$ 50,000
	Gravity	25,000
	Electrical Method	20,000
	Remote Sensing Update	5,000
	Indirect Costs	40,000
	Subtotal	$140,000
10.	Management, Synthesis and Hole Siting	
	2 years Administration, etc.	50,000
	Indirect Costs	20,000
	Subtotal	$ 70,000
	GRAND TOTAL	$1,062,000

SCHEDULE

Work can be scheduled so funds requirements are as follows:

		Year 1	Year 2	Total
1.	Regional and Paleomagnetic Studies	$ 34,000	$ 14,000	$48,000
2.	Surface Mapping and Drill Core Fracture Studies	38,000	38,000	76,000
3.	Geochronologic Studies	18,000		18,000
4.	Petrography, Petrology and Mineral Chemistry	86,000	86,000	172,000
5.	Fluid Inclusion	40,000	40,000	80,000
6.	Isotope Studies	114,000	124,000	238,000
7.	Thermal Modeling	40,000	40,000	80,000
8.	Applied Geochemistry	70,000	70,000	140,000
9.	Geophysics & Remote Sensing	100,000	40,000	140,000
10.	Management, Synthesis and Hole Siting	20,000	50,000	70,000
	TOTAL	$560,000	$502,000	$1,062,000

REFERENCES

Abrams, M.J., and Siegal, B.S., 1977, Detection of alteration associated with a porphyry copper deposit in southern Arizona: NASA Tech. Memo 33-810, 5 p.

Barnes, A.E., and Butler, R.F., 1980, A Paleocene paleomagnetic pole from the Gringo Gulch Volcanics, Santa Cruz Co., Arizona: Geophys. Res. Ltrs., v.7, p. 545-548.

Bodnar, R.J., and Beane, R.E., 1980, Temporal and spatial variations in hydrothermal fluid characteristics during vein filling in preore cover overlying deeply buried porphyry copper-type mineralization at Red Mountain, Arizona: Econ. Geol. v. 75, p. 876-893.

Brimhall, G.H., Jr., 1977, Early fractured-controlled disseminated mineralization at Butte, Montana: Econ. Geol., v. 72, p. 37-59.

Brimhall, G.H., Jr., Agee, C., and Stoffregen, R., 1985 (in press), Hydrothermal conversion of hornblende to biotite: Canadian Mineral.

Brimhall, G. H., Jr., and Ague, J., 1984, Halogen and transition metal chemistry of ferromagnesian minerals from the Sierra Nevada Batholith: Trans. Amer. Geophys. Union, v. 65, no. 45, p. 1124.

Brimhall, G.H., Jr., Gilzean, M., and Burnham, C. Wayne, 1983, Magmatic source region protoliths and controls on metallogenesis: Mica halogen geochemistry: Trans. Amer. Geophys. Union, v. 64, no. 45, p. 884.

Burnham, C.W. 1967, Hydrothermal fluids at the magmatic stage. in Barnes, H.L., ed., Geochemistry of hydrothermal ore deposits: Holt, Rinehart and Winston, Inc., New York, p. 34-76.

Burnham, C.W., 1979, Magmas and hydrothermal fluids, in Barnes, H.L., ed., Geochemistry of hydrothermal ore deposits: 2nd. ed, New York, Wiley, p. 71-136.

Burnham, C.W., and Ohmoto, H., 1980, Late-stage processes of felsic magmatism, in S. Ishihara and S. Takenouchi, eds., Granitic magmatism and related mineralization: Mining Geology Spec. Issue No. 8, Soc. Mining Geologists of Japan, p. 1-12.

Calderone, G., and Butler, R.F., 1984, Paleomagnetism of Miocene volcanic rocks from southwestern Arizona; tectonic implications: Geology, v. 12, p. 627-630.

Chaffee, M.A., Hill, R.H., Sutley, S.J., and Watterson, J.R., 1981, Regional geochemical studies in the Patagonia Mountains, Santa Cruz County, Arizona: J. Geochem. Explor., v. 14, p. 135-153.

Continental Scientific Drilling Committee, 1984, Mineral resources: research objectives for continental scientific drilling: National Academy Press, Washington D.C., p. 23-27.

Corn, R.M., 1975, Alteration-mineral zoning, Red Mountain, Arizona: Econ. Geol., v. 70, p. 1437-1447.

Davis, G.H., 1979, Laramide folding and faulting in southeastern Arizona: American Journal of Sci., v. 279, p. 543-569.

Davis, G.H., 1981, Regional strain analysis of the superposed deformations in southeastern Arizona and the eastern Great Basin, in Dickinson, W.R., and Payne, W.D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Tucson, Ariz.: Geol. Soc. Digest XIV, p. 155-172.

Dickinson, W.R., 1984, Reinterpretation of Lime Peak thrust as a low-angle normal fault: Implications for the tectonics of southeastern Arizona: Geology, v. 12, p. 610-613.

Drewes, H., 1971 a, Geologic map of the Mount Wrightson Quadrangle, southeast of Tucson, Santa Cruz and Pima Counties, Arizona: U.S. Geol. Surv. Misc. Geol. Inv. Map I-614.

Drewes, H., 1971 b, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Surv. Prof. Paper 658-C.

Drewes, H.,1972 a, Cenozoic rocks of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Surv. Prof. Paper 746.

Drewes, H., 1972 b, Structural geology of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Surv. Prof. Paper 748.

Gilzean, M. and Brimhall, G. H., Jr., 1983, Alteration biotite chemistry and nature of the deep hydrothermal system beneath Silverton District, Colorado: Geol. Soc. Amer., Abs. with programs, v. 15, no. 16, p. 533.

Haynes, F.M., and Titley, S.R., 1980, The evolution of fracture-related permeability within the Ruby Star Granodiorite, Sierrita porphyry copper deposit, Pima County, Arizona: Econ. Geol., v. 75, p. 673-683.

Huckins, D.L.E., 1976, Progress report, surface mapping, Red Mountain, Patagonia, Arizona: Private Report to the Kerr-McGee Corp., January 5, 1976, 22p.

Kanbergs, K., 1980, Fracturing along the margins of a porphyry copper system, Silver Bell district, Pima County, Arizona: Tucson, Univ. Ariz. unpub. M.S. Thesis, 90p.

Kistner, D.J., 1984, Fracture study of volcanic lithocap, Red Mountain porphyry copper prospect, Santa Cruz County, Arizona: Tucson, Univ. Ariz. unpub. M.S. Thesis, 75p.

Kluth, C.F., Butler, R.F, Harding, L.E., Shafiqullah, M., and Damon, P.E., 1982, Paleomagnetism of late Jurassic rocks in the northern Canelo Hills, Southeastern Arizona: Jour. Geophys. Res., v. 87, p. 7079-7086.

Lowell, J.D., and Guilbert, J.M., 1970, Lateral and vertical alteration-mineralization zoning in porphyry ore deposits: Econ. Geol., v. 65, p. 373-408.

Menges, C.M., 1981, The Sonoita Creek Basin; implications for late Cenozoic tectonic evolution of basins and ranges in southeastern Arizona: Tucson, Univ. Ariz. unpub. M.S. Thesis, 239p.

Munoz, J., and Swenson, A., 1981, Chloride-hydroxyl exchange in biotite and estimation of relative HCl/HF activities in hydrothermal fluids: Econ. Geol., v. 76, p. 2212-2221.

Norris, J.R., 1981, Fracturing, alteration, and mineralization in Oxide Pit, Silver Bell mine, Pima County, Arizona: Tucson, Univ. Ariz. unpub. M.S. Thesis, 72 p.

Ohmoto, H. and Rye, R.O., 1979, Isotopes of sulfur and carbon, in Barnes, H.L. ed., Geochemistry of hydrothermal ore deposits: 2nd ed., New York, Wiley, p. 509-567.

Parry, W. and Jacobs, D., 1975, Fluorine and chlorine in biotite from Basin and Range plutons: Econ. Geol., v. 70, pp. 554-558.

Preece, R.K. III, and Beane, R.E., 1982, Contrasting evolutions of hydrothermal alteration in quartz monzonite and quartz diorite wall rocks at the Sierrita porphyry copper deposits, Arizona: Econ. Geol., v. 77, p. 1621-1641.

Quinlan, J.J., 1981, Geology and silicate sulfide alteration zoning at the Red Mountain porphyry copper deposit, Santa Cruz County, Arizona, in Arizona Geological Society and University of Arizona Field Trip Guidebook: Trip #8, Patagonia-Red Mountain-Hardshell Deposits, p. 4-25.

Rose, A.W., 1970, Zonal relations of wallrock alteration and sulfide distribution of porphyry copper deposits: Econ. Geol., v. 65, p. 920-936.

Schrader, F.C., 1915, Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona, with contributions by J.M. Hill: U.S. Geol. Surv. Bull. 582, 373 p.

Simons, F.S., 1971, Mesozoic stratigraphy of the Patagonia Mountains and adjoining area, Santa Cruz County, Arizona: U.S. Geol. Survey Prof. Paper 658-E, 23 p.

Simons, F.S., 1974, Geologic map and sections of the Nogales and Lochiel quadrangles, Santa Cruz County, Arizona: U.S. Geol. Survey Map I-762.

Taylor, H.P., Jr., 1979, Oxygen and hydrogen isotope relationships in hydrothermal mineral deposits, in Barnes, H.L., ed., Geochemistry of hydrothermal ore deposits: 2nd ed., New York, Wiley, p. 236-277.

Titley, S.R., and Beane, R.E., 1980, Alteration zoning as related to fracture evolution in porphyry copper systems: Int. Geol. Congr., 26th, Paris, Abs. V. III, p. 1020.

Titley, S.R., Thompson, R.C., Haynes, F.M., Manske, S.L., Robison, L.C., and White, J.L., 1985, Evolution of fractures and alteration in the Sierrita-Esperanza hydrothermal system, Pima County, Arizona: Econ. Geol. (In Press).

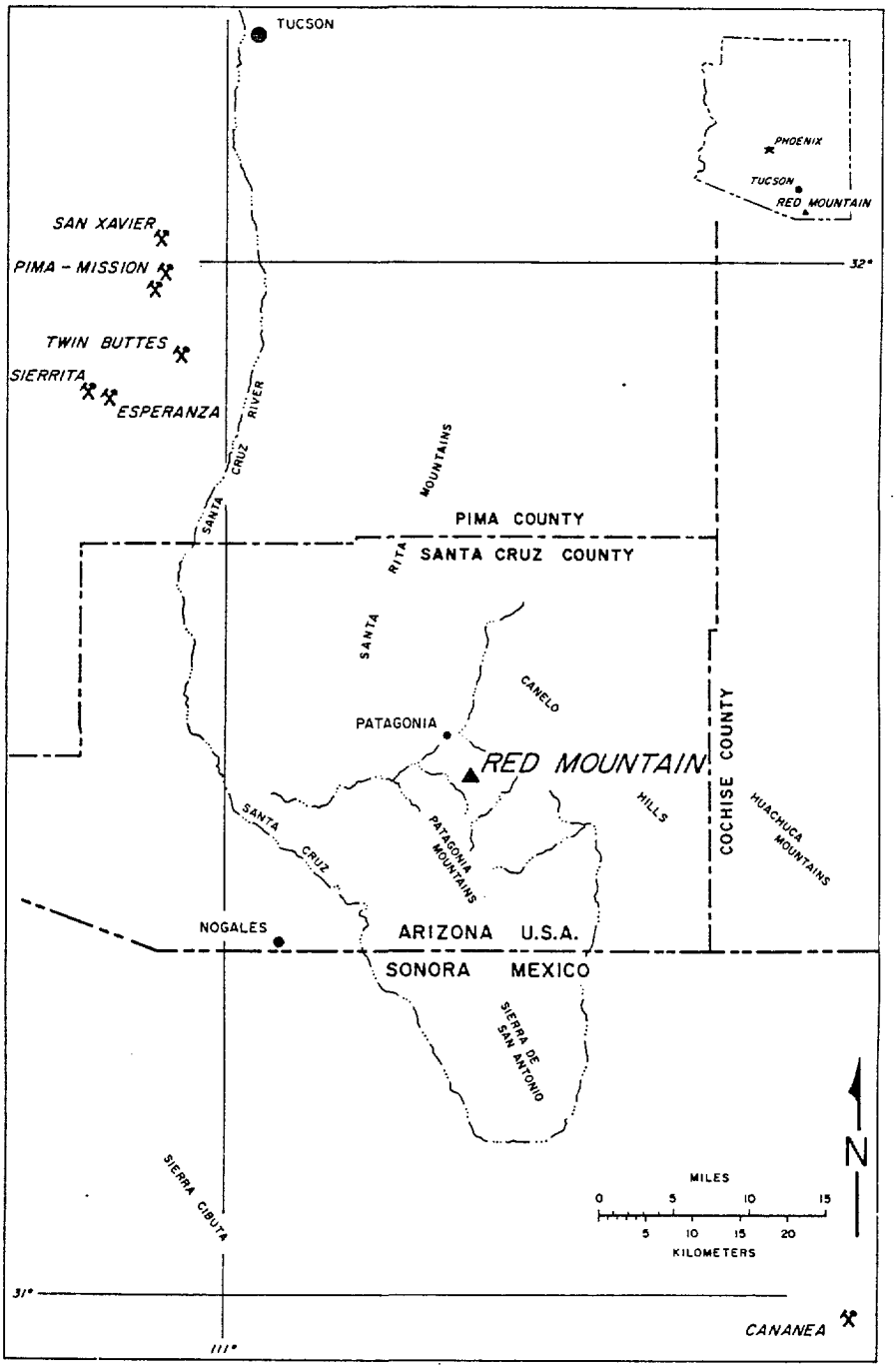
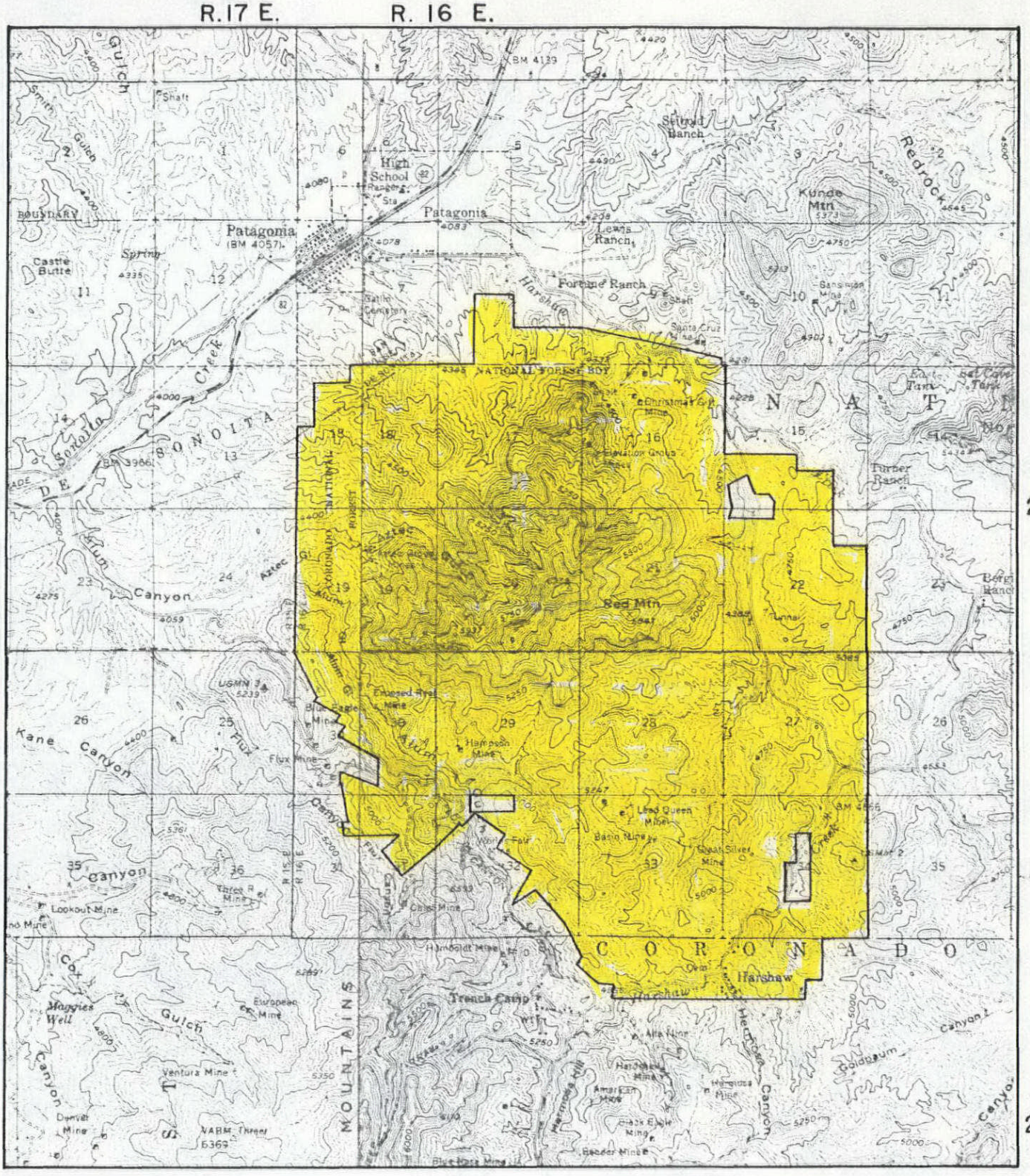


Fig. 1. Index map showing the location of the Red Mountain porphyry copper deposit. After R.M. Corn, Economic Geology, Vol. 70, No. 8, Dec. 75



EXPLANATION

KERR-McGEE PROPERTY

RED MOUNTAIN PROPERTY MAP

SANTA CRUZ COUNTY, ARIZONA

SCALE 1:62,500

TOPOGRAPHIC BASE FROM USGS 15' QUADRANGLE MAPS
ELGIN (1958), LOCHIEL (1958), NOGALES (1958), MT. WRIGHTSON (1958)

FIGURE 2

13

United States Senate

WASHINGTON, D.C. 20510

March 24, 1986

Mr. William L. Kurtz
Manager, Exploration
S.W. Exploration Division
ASARCO
P. O. Box 5747
Tucson, Arizona 85703

Dear Mr. Kurtz:

Knowing of your interest in scientific drilling of the continental crust, I am pleased to report that the Senate Committee on Energy and Natural Resources has scheduled a hearing on the Continental Scientific Drilling and Exploration Act, S. 1026, on July 24. This hearing represents a major step forward in our effort to establish a national policy and program on exploration of the earth's crust. Details on the hearing and S. 1026 are discussed in the enclosure.

Interest in the Continental Scientific Drilling Program (CSDP) continues to increase. However, the success of our efforts to develop this program depend on gathering as much support as possible from other members of the Senate, particularly those serving on the Energy and Natural Resources Committee. I urge you to make your support known. It is also important that the hearing include a thorough discussion of the various aspects and benefits of the drilling program. Your support and suggestions are an important contribution to eventual passage of this legislation and implementation of this important program.

As you may know, DOSECC is sponsoring a general CSDP workshop at the South Dakota School of Mines and Technology in Rapid City, South Dakota on June 12-14, 1986. I have told Dr. Papike that I hope to attend at least one day of the conference in order to discuss the July hearing, the legislation, and other Congressional efforts regarding CSDP. I look forward to seeing you at that time.

Sincerely,

Larry Pressler

Larry Pressler
United States Senator

LP/bsd
Enclosure

United States of America

Congressional Record

PROCEEDINGS AND DEBATES OF THE 99th CONGRESS, FIRST SESSION

Vol. 131 WASHINGTON, FRIDAY, APRIL 26, 1985 No. 51

Senate

FRIDAY, APRIL 26, 1985

(Legislative day of Monday, April 15, 1985)

By Mr. PRESSLER:

S. 1026. A bill to direct the cooperation of certain Federal entities in the implementation of the Continental Scientific Drilling Program; to the Committee on Energy and Natural Resources.

CONTINENTAL SCIENTIFIC DRILLING AND EXPLORATION ACT

Mr. PRESSLER. Mr. President, I am extremely pleased today to introduce the Continental Scientific Drilling and Exploration Act of 1985. This legislation represents an early step in a scientific program which I believe parallels in importance our efforts in space over the past three decades—but at a tiny fraction of the cost. Its scientific value and potential for resolving heretofore unanswered questions about the development and management of the planet on which we live is inestimable.

By increasing our basic understanding of the Earth, an effective Continental Scientific Drilling Program [CSDP] has practical day-to-day applications in areas dealing with energy and mineral development, natural hazards such as earthquakes and volcanic eruptions, disposal of hazardous wastes, water resource management, and a host of other areas.

Mr. President, this legislation calls for the implementation of the Continental Scientific Drilling Program joint resolution which I introduced last year, and was signed into law by the President on October 12, 1984. The legislation represents an effort to define in greater detail some policy goals and objectives of the U.S. Continental Scientific Drilling Program, and calls on the Interagency Coordinating Group to prepare and submit to the Congress a study outlining those detailed goals and objectives, and recommend a plan of action.

The Interagency Coordinating Group consists of an outstanding group of scientists that were brought together as a result of an interagency accord on continental scientific drilling signed by the Department of Energy, the U.S. Geological Survey and the National Science Foundation.

Much work has already been done in this important area. Years of dedication and work have already been invested in the program. We are now on the threshold of an exciting new scientific era in basic Earth sciences research and application, but we need to take the next step by beginning sincere congressional inquiry into this area and carefully assessing our need to make a commitment toward CSDP. I firmly believe this is one of the most important scientific programs this body has considered in some time.

I have been astounded by the Scientific community's tremendous interest in and support for this legislation. For example, in an effort to make the legislation as substantive and technically correct as possible, I circulated a draft bill to approximately 130 top scientists from around the country. The response was tremendous. We received substantive, detailed comments from nearly 50 percent of the scientists. All were generally supportive and enthusiastic about the legislation. The comments and recommendations I received were, to the extent possible, incorporated in the bill I am introducing today. I believe it is a good piece of legislation and encourage my colleagues to join me as cosponsors.

It is important to get this bill passed in a timely fashion. The program is already going forward. Indeed, the National Science Foundation is sponsoring a meeting of a large group of distinguished scientists and engineers who will gather in Houston, TX, next week to lay groundwork for what I hope we will develop into a truly national, long-term Continental Scientific Drilling Program.

I might just pause here to take a moment to recognize the dedication and cooperative spirit of the individuals and Government agencies involved in this program. It is heartening to witness people and agencies so truly devoted to a worthy common goal.

My interest and involvement in this program is relatively recent, and stems from the potential role that the South Dakota School of Mines and Technology could and should play in CSDP. But the more I study the program, its goals and what it could mean for the United States, the more enthusiastic I become and the more certain I am that we must go forward on a national scale.

There is much yet to learn about the Earth. I am convinced that our understanding of this fascinating planet will be the key to a liveable, prosperous future for generations to come. The Continental Scientific Drilling Program is an extremely important element in gaining a better fundamental understanding of and insight into our Earth. Space is not the final frontier. Much closer, just as mysterious, and probably more beneficial is the inside of our own planet. A thorough exploration of this important frontier, I am certain, will reap great rewards. I again ask you to join me in support of this effort and support passage of this important legislation. The text of the bill itself goes a long way toward explaining the thrust of my legislation. I commend it to my colleagues' attention and ask unanimous consent that a copy of the bill be printed in the RECORD at this point.

There being no objection, the bill was ordered to be printed in the RECORD, as follows:

S. 1026

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled. That this Act may be cited as the "Continental Scientific Drilling and Exploration Act".

PURPOSES

SEC. 2. The purpose of this Act is to—

(1) implement section 323 of the joint resolution entitled "Joint Resolution making continuing appropriations for the fiscal year 1985, and for other purposes", approved October 12, 1984 (Public Law 98-473; 98 Stat. 1875) which supports and encourages the development of a national Continental Scientific Drilling Program;

(2) enhance fundamental understanding of the composition, structure, dynamics, and evolution of the continental crust, and how such processes affect natural phenomena such as earthquakes, volcanic eruptions, transfer of geothermal energy, distribution of mineral deposits, the occurrence of fossil fuels, and the nature and extent of acquifers;

(3) advance basic earth sciences research and technological development;

(4) obtain critical data regarding the earth's crust relating to isolation of hazardous wastes; and

(5) develop a long-range plan for implementation of the Continental Scientific Drilling Program.

FINDINGS

SEC. 3. Congress finds that—

(1) because the earth provides energy, minerals, and water, and is used as a storage medium for municipal, chemical, and nuclear waste, an understanding of the processes and structures in the earth's crust is essential to the well being of the United States;

(2) there is a need for developing long-range plans for a United States Continental Scientific Drilling Program; and

(3) the Continental Scientific Drilling Program would enhance—

(A) understanding of the crustal evolution of the earth and the mountain building processes;

(B) understanding of the mechanisms of earthquakes and volcanic eruptions and the development of improved techniques for prediction;

(C) understanding of the development and utilization of geothermal and other energy sources and the formation of and occurrence of mineral deposits;

(D) understanding of the migration of fluids in the earth's crust for evaluation of waste contamination and the development of more effective techniques for the safe subsurface disposal of hazardous wastes;

(E) understanding and definition of the size, source, and more effective use of acquifers and other water resources; and

(F) evaluation and verification of surface geophysical techniques needed for exploring and monitoring and earth's crust.

IMPLEMENTATION OF CONTINENTAL SCIENTIFIC DRILLING PROGRAM

SEC. 4. The Secretary of the Department of Energy, the Secretary of the Department of the Interior through the United States Geological Survey, and the Director of the National Science Foundation shall implement the policies of section 323 of the joint resolution entitled "Joint Resolution making continuing appropriations for the fiscal year 1985, and for other purposes", approved October 12, 1984 (Public Law 98-473; 98 Stat. 1875) by—

(1) taking such action as necessary to assure an effective, cooperative effort in furtherance of the Continental Scientific Drilling Program of the United States;

(2) taking all reasonable administrative and financial measures to assure that the Interagency Accord on Continental Scientific Drilling continues to function effectively in support of such program;

(3) assuring the continuing effective operation of the Interagency Coordinating Group to further the objectives of such progam;

(4) taking such action to assure that the Interagency Coordinating Group receives

appropriate cooperation from any Federal agency that can contribute to the objectives of such program, without adversely affecting any program or activity of such agency; and

(5) acting through the Interagency Coordinating Group, preparing and submitting to the Congress, within one hundred and eighty days after the enactment of this Act a report describing—

(A) long and short-term policy objectives and goals of the United States Continental Scientific Drilling Program;

(B) projected schedules of desirable scientific and engineering events that would advance United States objectives in the Continental Scientific Drilling Program;

(C) to the extent and for the duration that the Interagency Coordinating Group deems practicable, maximum, minimum, and intermediate levels of resources and funding that would be required by each participating Federal agency to carry out events pursuant to subparagraphs (A) and (B) at the various levels of effort;

(D) the scientific, economic, technological, and social benefits expected to be realized through the implementation of such program at each level described in subparagraph (C);

(E) a recommended course for interaction with the international community in a cooperative effort to achieve the goals and purposes of the Act;

(F) the extent of participation or interest shown to date in the Continental Scientific Drilling Program by—

(i) any other governmental agency;

(ii) any academic institution;

(iii) any organization in the private sector; and

(iv) any governmental or other entity in the international community;

(G) a plan to develop benefical cooperative relationships among the entities mentioned in subparagraph (F), to the extent that the Interagency Coordinating Group deems practicable; and

(H) any other information or recommendations that the Interagency Coordinating Group deems appropriate.

JOHN C. DANFORTH, MISSOURI, CHAIRMAN

BOB PACKWOOD, OREGON
BARRY GOLDWATER, ARIZONA
NANCY LANDON KASSEBAUM, KANSAS
LARRY PRESSLER, SOUTH DAKOTA
SLADE GORTON, WASHINGTON
TED STEVENS, ALASKA
BOB KASTEN, WISCONSIN
PAUL S. TRIBLE, JR., VIRGINIA

ERNEST F. HOLLINGS, SOUTH CAROLINA
RUSSELL B. LONG, LOUISIANA
DANIEL K. INOUYE, HAWAII
WENDELL H. FORD, KENTUCKY
DONALD W. RIEGLE, JR., MICHIGAN
J. JAMES EXON, NEBRASKA
ALBERT GORE, JR., TENNESSEE
JOHN D. ROCKEFELLER IV, WEST VIRGINIA

W. ALLEN MOORE, CHIEF COUNSEL AND STAFF DIRECTOR
RALPH B. EVERETT, MINORITY CHIEF COUNSEL AND STAFF DIRECTOR

United States Senate

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

WASHINGTON, DC 20510

March 3, 1986

The Honorable James A. McClure, Chairman
Committee on Energy and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Jim:

The purpose of this letter is to thank you for scheduling a hearing on S. 1026, the Continental Scientific Drilling and Exploration Act. I understand the hearing will be held July 24, 1986 at 10:00 a.m. before the Subcommittee on Natural Resources Development & Production.

As I said when I introduced S. 1026, this legislation represents an early step in a scientific program which I believe parallels in importance our efforts in space over the past three decades—but at a tiny fraction of the cost. Its scientific value and potential for resolving heretofore unanswered questions about the development and management of the planet on which we live is inestimable.

The Continental Scientific Drilling Program will enhance our understanding of the natural processes which have led to the evolution of the chemical and physical structures, and properties of the Earth's continental crust. At the present time, little is known about the crystalline rock that underlies most of the North American continent. Petroleum exploration, currently the chief means of subsurface exploration, is confined only to the overlying layer of sedimentary rock.

According to an interagency agreement developed by the Department of Energy, the Department of the Interior, and the National Science Foundation, the Continental Scientific Drilling Program would "contribute directly to the solution of serious national problems such as ensuring adequate supplies of energy, water and mineral resources, safe isolation of wastes, protection against the hazards of earthquakes and volcanic eruptions, and national defense." The agreement goes on to state that the program "is an especially important tool for the scientific exploration of the Earth's crust."

The United States has much work to do in order to "catch up" in this field. The Soviet Union and many of our European counterparts are far ahead of us in this important scientific technnology. It is imperative that we forge ahead as a nation in this program. The hearing scheduled before the Subcommittee on Natural Resources Development & Production is a crucial step in making this program a reality.

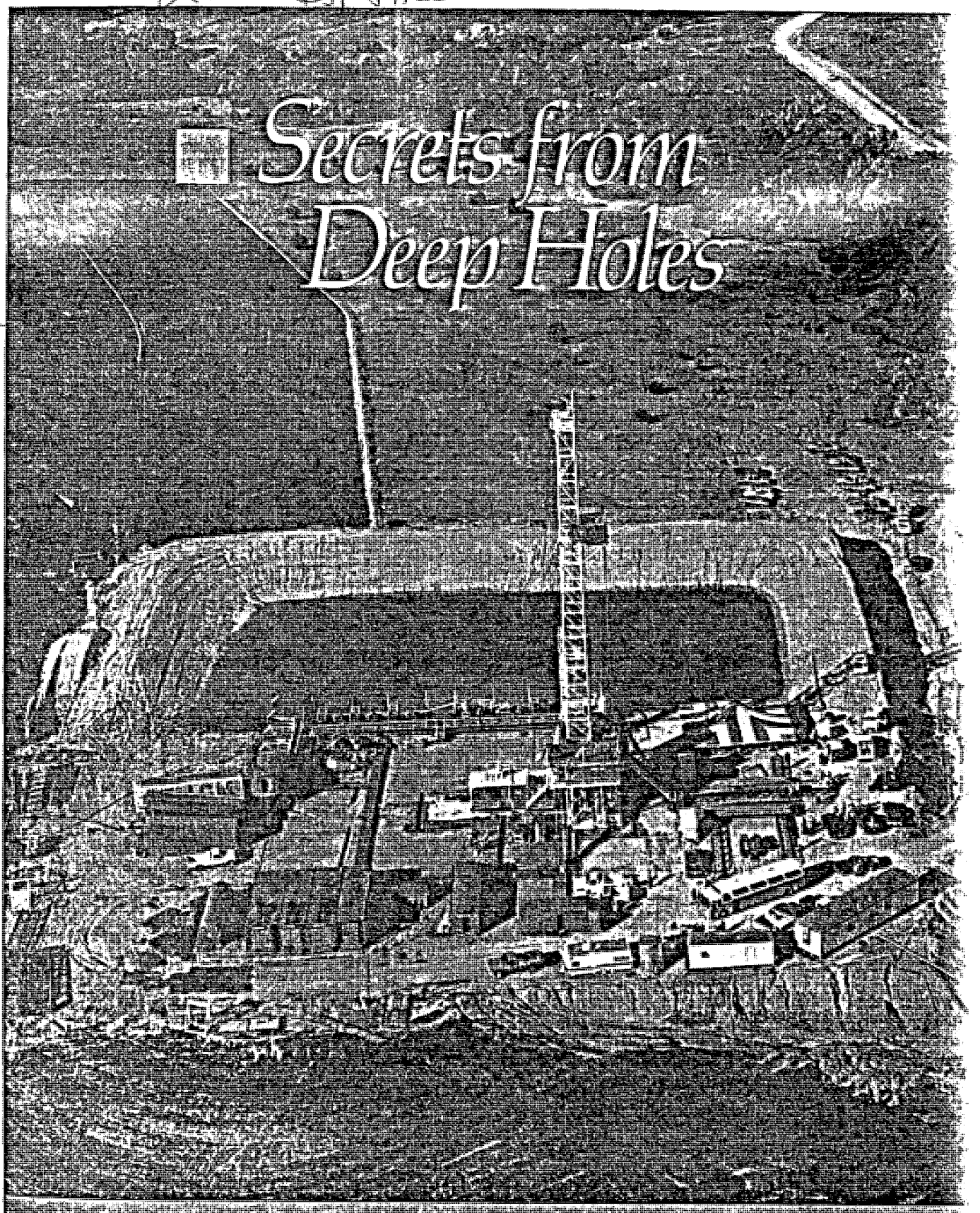
Sincerely,

Larry Pressler
United States Senator

LP/bsp

JUN 16 1986

Secrets from Deep Holes



Among the deepest mobile land drilling rigs for production work is this 1500 Series triplex unit that can drill to 16,000 feet with 4½-inch drill pipe. It is the largest drill rig made by IRI International, Pampa, Tex., and can be found in many fields throughout the world. The mast, substructure, draw works with power and rotary drive can be moved in five loads. It is engineered so that rig-up and rig-down can be done quickly; typically such a rig can be drilling at one site one day, and be operational at another the following day.

WJK / JOS → for your info
(copy sent to files at Reporter)

– All nice but I bet management / overhead from this will be around from the drill holes.

JMK

cc
Place copy in ~~library~~ plane archives and one for my files (in hanging folder) - Jim

MINERAL RESOURCES:

RESEARCH OBJECTIVES FOR SCIENTIFIC DRILLING

Panel on Mineral Resources

Continental Scientific Drilling Committee

Geophysics Research Board

Commission on Physical Sciences, Mathematics, and Resources

17 March 1983

Papers to be given at SLC GSA meeting May 1983

XC: LIBRARY 4/7/83

PANEL ON MINERAL RESOURCES*

J. James Eidel, Coastal Mining Company, Chairman
G. Arthur Barber, Anaconda Minerals Company
George H. Brimhall, Jr., University of California, Berkeley
C. Wayne Burnham, Pennsylvania State University
Robert O. Fournier, U.S. Geological Survey, Menlo Park
Richard W. Hutchinson, Western Ontario University
William C. Kelly, University of Michigan
J. David Lowell, Private Consultant
Charles Meyer, University of California, Berkeley (retired)
John H. Schilling, Nevada Geological Survey
Brian J. Skinner, Yale University
Richard K. Traeger, Sandia National Laboratories
Donald E. White, U.S. Geological Survey, Menlo Park

CONTRIBUTORS TO THE VARIOUS MINING DISTRICT SUMMARIES

Roger P. Ashley, U.S. Geological Survey, Menlo Park (Tonopah)
Paul B. Barton, Jr., U.S. Geological Survey, Reston (Creede)
John Beeder, Minerals Engineering Company (Creede)
Philip M. Bethke, U.S. Geological Survey, Reston (Creede)
Marc W. Bodine, Jr., U.S. Geological Survey, Denver (Creede)
David L. Campbell, U.S. Geological Survey, Denver (Creede)
Russell M. Corn, Private Consultant (Red Mountain)
Paul I. Eimon, Pioneer Nuclear, Incorporated (Red Mountain, Creede)
Peter W. Lipman, U.S. Geological Survey, Denver (Creede)
Richard H. Merkel, Anaconda Minerals Company (Butte, Red Mountain)
John S. Phillips, Chevron Resources Company (Creede)
James J. Quinlan, Kerr-McGee Corporation (Red mountain)
Linda K. Riddle, Sandia National Laboratories (Creede)
Malcolm M. Roeber, Homestake Mining Company (Creede)
Robert O. Rye, U.S. Geological Survey, Denver (Creede)
Thomas A. Steven, U.S. Geological Survey, Denver (Creede)
Eric M. Struhsacker, Chevron Resources Company (Creede)

Creede wins by shear force!

*John H. Schilling, member through June 1982: Donald E. White, member through January 1982

CONTENTS

I. SUMMARY AND RECOMMENDATIONS 4

II. MINERAL RESOURCE PROBLEMS TO BE ADDRESSED 6
A. GEOMETRY OF INDIVIDUAL MINERAL DEPOSIT SYSTEMS 6
B. RELATIONSHIPS AMONG MINERAL DEPOSIT SYSTEMS 7
C. PROBLEMS CONCERNING METAL SOURCE, TRANSPORT, AND DEPOSITION . 7
D. RECENT REPORTS ON MINERAL RESOURCE RESEARCH NEEDS . . . 8
E. SELECTION OF HIGH PRIORITY MINERAL DEPOSIT TARGETS . . . 9
F. CRITERIA FOR SELECTION OF DEDICATED RESEARCH TARGETS . . . 10
G. PRIORITIES FOR DEDICATED RESEARCH TARGETS 11

III. FOSSIL MINERALIZED SYSTEMS 12
A. CREEDE MINING DISTRICT, COLORADO 12
1. Research Objective 12
2. Proposed Program 13
B. TONOPAH, NEVADA 14
1. Research Objective 15
2. Proposed Program 15
C. RED MOUNTAIN, ARIZONA 17
1. Research Objectives 19
2. Proposed Program 19
D BUTTE, MONTANA 19

IV. ACTIVE HYDROTHERMAL SYSTEMS 20
A. RESEARCH OBJECTIVES 20
B. PROPOSED TARGETS 21

V. EXAMPLES OF OBJECTIVES TO BE ADDRESSED BY ADD-ON INVESTIGATIONS. . 23
A. PORPHYRY COPPER SYSTEMS 24
B. PRECIOUS METAL ENVIRONMENTS 24
C. MASSIVE SULFIDE DEPOSITS 25
D. PLATINUM GROUP METALS (PGM) DEPOSITS 25
E. MISSISSIPPI VALLEY-TYPE DEPOSITS 25
F. SEDIMENTARY ENVIRONMENTS 26
G. CHEMISTRY OF THE CRUST 26

VI. DRILLING AND DIAGNOSTIC NEEDS 27
A. DRILLING 27
B. DIAGNOSTICS 27
C. PRELIMINARY INFORMATION REQUIREMENTS 29

REFERENCES CITED 31

I. SUMMARY AND RECOMMENDATIONS

Many critical metals, including gold, silver, copper, cobalt, tin, and tungsten, are concentrated in mineral deposits formed by hydrothermal activity driven by heat from subvolcanic intrusions. The geological evolution of such deposits involves a complex of spatial, physical, and chemical changes whose duration is a function of the magnitude and timing of magmatic events and the interactions of water with hot rocks and magma. Many hydrothermal deposits originally formed at different depths in the earth's crust have ultimately been exposed at the earth's surface by a combination of uplift and erosion. Through geological and geochemical reconstructions of the environments of mineral deposition in these exposed systems, time-dependent hydrothermal models have been developed that include intervals of early growth, maturity, and dissipation, each correlative with events in an evolving magmatic system. Thus, intensive research over the last century has developed sophisticated understanding of ore-forming processes in different crustal environments.

However, the resulting knowledge is still fragmentary because the overall spatial dimensions -- particularly the depth dimension -- of ore-generating hydrothermal systems are invariably larger than that part of the systems exposed at the surface or accessible at current mining and exploration drilling depths. In a given geographic location, research has been restricted to small, accessible parts of hydrothermal systems which may or may not be related genetically to the complete system at depth. Consequently, while we now have advanced knowledge of mineralization processes and vertical zonations in shallow environments (such as epithermal, precious metal, volcanic settings) and in deeper crustal environments (such as porphyry copper and molybdenum, subvolcanic settings), we cannot address the basic question of whether these are genetically unrelated products of hydrothermal systems that originated at different crust depths, or genetically related, but vetically separated parts of a single hydrothermal system which we have not, so far, examined through its full vertical dimension. This problem of depth accessibility is fundamental and one of long standing, but it cannot be resolved until the vertical constraints on observations are removed by sampling and measurement in deep crustal drillholes in sites of well-studied mineralization. The problem is also one of obvious economic and resource implications because it is not known today whether well-known epithermal ore deposits are genetic entities in themselves or near-surface manifestations of mineralogically different, but economically important ore deposits at depth. Many other scientific problems in ore genesis require improved access to marginal parts, both lateral and vertical, of mineral deposits, but this question of vertical zonation in large hydrothermal systems is fundamental and will comprise the central theme in this report.

The Panel on Mineral Resources proposes a program to investigate deep hydrothermal fluid circulation in mineralized systems. Research will focus on heat and metal sources, fluid evolution and compositions, rock permeability, and metasomatism, and on relating features observed at various depths in the systems. Ideally, the proposed program would involve investigation of each type of epithermal system over a wide range of tectonic environments and over chemical environments ranging from the adularia-rich precious metal deposits at Cripple Creek, Colorado, through intermediate types such as found at Creede, Colorado, and Tonopah, Nevada, to the kaolinite and alunite-rich alteration at Goldfield, Nevada. However, in applying the criteria defined herein to establish priorities, the Panel recognizes the mining districts of

Creede and Tonopah as containing epithermal systems most likely to produce new scientific information through deep drilling. These systems may be near-surface parts of hydrothermal systems which evolved from disseminated and stockwork mineralization of copper and/or molybdenum at depth. Evaluation of this hypothesis by deep drilling is critical to the evaluation of partially exposed epithermal mineralized systems of similar type elsewhere. Such epithermal districts are numerous in the Western United States (including Alaska); their potential contribution of ore from deeper zones could become a substantial part of the American mining economy. The Red Mountain, Arizona, and Butte, Montana, mining districts, on the other hand, contain zones of disseminated and stockwork copper-molybdenum mineralization at depth. Superimposed vein systems contain increasing proportions of silver (and gold?) outward and upward from a central zone richer in base metals. Red Mountain may offer an opportunity to investigate the entire range of mineralization in a porphyry copper system of moderate size and vertical extent. Butte offers a potential opportunity to drill the root zone below a well-defined copper-molybdenum stockwork in a much larger granodiorite-base metal system.

The Panel on Mineral Resources has selected the Creede mining district as its highest priority target and recommends that a research drilling project be undertaken at Creede in order to examine a caldera-related silver and base metal-bearing hydrothermal mineral system. Selection of this target is based, in part, on the economic importance of the epithermal precious metal deposits, the availability of an extensive data base that includes industry drillhole data, and the existence of a comprehensive and well-documented geological-geochemical model. The proposed program will require two, 3.5 to 4.0 km drillholes, supplemented with information from active, caldera-related geothermal systems; new data gained from this program will be integrated into existing models for enhanced interpretations of the Creede system.

Tonopah, Red Mountain, and Butte are lower priority targets that offer opportunities for future research. Much like Creede, the Tonopah and Red Mountain targets would test the vertical and possible genetic relationships between epithermal and subjacent deposits, whereas drilling at Butte would address the separate question of of what may lie at the very roots of a hydrothermal system known to have formed initially at depths of at least several kilometers. Each of these targets are fossil hydrothermal systems that require additional data in order to define specific drilling requirements and sites. The Panel on Mineral Resources recommends that geological and related studies at Tonopah, Red Mountain, and Butte be continued to define possible research drilling needs of these important mineral systems at a later time.

Available data indicates that the Creede system represents a mineralized fossil analog of certain active geothermal systems associated with silicic calderas, such as the caldera complexes at Yellowstone, Wyoming, and Valles, New Mexico. A major research objective that requires drilling of active geothermal systems is the ability to interpret properly the individual stages of hydrothermal development of fossil mineral systems which are rarely well preserved in ore deposits. Typical hydrothermal mineral deposits exhibit features that formed during late stage thermal collapse and fracture followed by vein-filling events, producing major overprinting of early zonations and obscuring critical field relationships of earlier mineralization. Recognizing whether diverse types of mineral deposition in subjacent parts of the system occurred simultaneously in separate convection cells or separately in a single cell is made difficult by this overprinting. Because of the similarities between active and fossil systems, information obtainable from the deeper

portions of a presently active system should be directly applicable to the Creede system and to the construction of accurate models for epithermal mineralization in volcanic settings. The Panel on Mineral Resources therefore recommends that a research program, complementary to that proposed at Creede, be initiated in an active hydrothermal system in a silicic caldera complex. At this time, the Valles geothermal system in New Mexico is the best available target. We further recommend that a working group be established to investigate the feasibility of future research drilling at Yellowstone.

Table I gives a summary of the major research drilling objectives for the active and fossil hydrothermal systems discussed in this report.

Many critical aspects of mineral genesis and related geothermal activity can be addressed by investigations added on to current and planned government and industry drilling activities. The Panel recommends that experiments addressing significant problems of mineral genesis be designed for possible add-on investigations. Several examples are presented in this report. Such investigations involve sampling and measurements in host rocks which, though removed from mineral concentations, have played an essential role in its emplacement. Commercial mining, and drilling in mining areas, normally do not provide information on unproductive, distal portions of mineral systems. The highest priority problems will be defined by the Panel, with input from the scientific community.

A major problem that must be faced in a national continental scientific drilling program is the management of samples and other relevant data. Careful handling of and accounting for these materials is necessary to ensure that maximum benefit is gained from the effort by the greatest number of interested scientists. The Panel on Mineral Resources recommends that the CSDC and the Panel on Sample Curation and Data Management give careful attention to developing a plan for the appropriate curation of all data relevant to the research drilling program.

The Panel on Mineral Resources recommends that scientific drilling and diagnostic requirements be defined for sampling of solids and fluids, logging, and in situ measurements from slim holes [diameters of 5 inches (13 cm) or less]. For planning purposes, the Panel will compile information on capabilities and costs of slim hole logging, wire line coring, rotary drilling, and coring.

II. MINERAL RESOURCE PROBLEMS TO BE ADDRESSED

Only small portions of mineral deposit-forming systems exposed in mines are studied in detail, and little information is available from exploration or from mining on the margins of such systems. Margins of mineral deposit systems include the eroded tops, laterally adjacent areas, and roots of these systems. The source of important metals may be remote or immediate to an ore deposit. Commonly, the source and transport mechanisms of metals are unknown. The reasons are often unknown as to why many significant concentrations of metals have precipitated where they are found.

A. GEOMETRY OF INDIVIDUAL MINERAL DEPOSIT SYSTEMS

The recognition and proper interpretation of the geometric relations found in exposed portions of mineralized and altered zones or halos depend on careful observations and accurate three-dimensional models of complete mineral

deposit systems. The greatest response to a questionnaire regarding needs for mineral exploration research, distributed and compiled by the Society of Economic Geologists (SEG) Research Committee (Eidel, 1981), identified a need for bulk and trace element analytical data on the margins of ore deposit systems. The most common suggestion as to useful methods needed in future research efforts included comprehensive geological mapping and sampling, followed by correlation of the data with geochemical data on appropriate field scales. The most common criticism of published alteration-zoning studies referred to their limited geographic scope and their focus on spatially-limited "ore grade" metal concentrations, thereby precluding extrapolation to poorly exposed exploration targets. This limited understanding of mineralogical and associated chemical effects at the margins of ore deposits also hinders recognition of ore-forming signatures as distinct from background regional variations in barren terrane. Drilling into the margins of mineral deposit systems can provide critical data for relating deep mineralization/alteration patterns with the better understood shallow patterns, allowing more accurate interpretation of unexposed or partially exposed lower portions of mineral deposit systems.

B. RELATIONSHIPS AMONG MINERAL DEPOSIT SYSTEMS

Thermal energy drives convection within hydrothermal systems. In many locations this thermal energy is transferred from subcrustal depths to shallow crustal regions by upward extruding magma. Various types of mineral deposition may occur simultaneously within different, subjacent parts of hydrothermal systems and sequentially during different stages in their development. Superposition of hydrothermal activity and mineral deposition also may occur as a result of successive pulses of igneous intrusions.

In mining operations it is necessary to recognize ore-limiting features. The distinction between ore zones and weaker mineralized zones is economic, reflecting metal prices and other critical considerations, but near surface epithermal mineral deposits may be linked to deeper magma-related hydrothermal deposits containing base metals. Stacking of one type of mineral deposit above another has been inferred from partially exposed systems that commonly exhibit barren intermediate levels. No examples of complete, or nearly complete mineralized systems that show the expected transition from porphyry mineralization to epithermal vein and hot spring deposits have been yet continuously "exposed" through mining and drilling. Knowledge of the relationships between subjacent and vertically zoned mineral deposits would be useful for the design of future exploration programs. Responses to the SEG research questionnaire indicated considerable interest in the investigation of hydrothermal systems below epithermal deposits.

C. PROBLEMS CONCERNING METAL SOURCE, TRANSPORT, AND DEPOSITION

While much is known about the geometric and mineralogical relationships within mineral deposits, the mechanisms of metal transport and deposition are largely conjectural. For many classes of mineral deposits, metal sources remain unknown. Chloride-rich solutions are widely recognized as essential for the extraction of many metals from their sources and for their transport in hydrothermal systems; these solutions may not be essential in the case of metals such as molybdenum and tungsten. How and where natural fluids acquire their chlorinities are important unanswered questions. The source of the fluids themselves is an unresolved question in many cases, since the chemical and isotopic evidence is commonly lacking or ambiguous. The oxidation state in hydrothermal systems also is recognized as an important parameter in the

transport and deposition of metals, especially as sulfides. Little is known of the precise manner in which oxidation interrelates to the chloride and sulfur contents of the fluids in effecting metal transport and deposition. The association in space and time of certain metals with distinctive types of intrusive igneous rocks suggests a magmatic source for these metals, but how the magmas themselves acquired their metal-rich character is not fully understood. The source of the metal-bearing brines that produced Mississippi Valley and clastic-hosted types of deposits and various uranium deposits is still characterized by active scientific debate.

D. RECENT REPORTS ON MINERAL RESOURCE RESEARCH NEEDS

The genesis and distribution of mineral resources, recognition of the need for research that benefits society, and a better understanding of continental mineral resources have been addressed by several important studies.

In October 1976, 40 scientists involved in research and exploration for mineral deposits met at The Pennsylvania State University to consider research which could lead to the discovery of new mineral deposits. In the report of this meeting, Research Frontiers in Exploration for Non-Renewable Resources (Rose et al., 1977), the participants recommended the following urgently needed aids for mineral exploration:

1. intensive study of representative mineral districts;

2. expanded basic research on ore genesis concepts;

3. increased coverage of the U.S. by geologic maps and geophysical surveys; and

4. frequent interchanges between exploration and research personnel.

The report recognized that the most productive new direction for research should consist of an integrated program of comprehensive geological, geochemical, and geophysical studies that would focus on specific regions containing representatives of the major ore types. The report states that drilling techniques should be improved to allow cheaper, faster, and deeper drilling, and that logging methods should be developed to maximize the information from drillholes.

The Frontiers of Mining Geophysics (Ward et al., 1977) was a report of a workshop held by the National Science Foundation at Salt Lake City in December 1976 to identify subjects in the field of mining geophysics that require additional research effort. The participants of these workshops concluded that there was a need for research into both surface geophysical and downhole measurements for mineral exploration. One particular recommendation that received strong support from the participants was the design of a program to drill deep holes (15,000 to 25,000 ft - 4600 to 7600 m) to explore and characterize the roots of porphyry copper systems.

The National Academy of Sciences' Workshop on Continental Drilling for Scientific Purposes, held in Los Alamos, New Mexico, in July 1978, concluded with the principal recommendation that a continental scientific drilling program be initiated to achieve expanded knowledge and understanding of the uppermost part of the crust of the earth in the United States (U.S. Geodynamics Committee, 1979). The report of that workshop, Continental Scientific Drilling Program, identified three general areas of interest

related to mineral resources that would benefit from data provided by a continental drilling program: the fundamental geological structure and composition of the continental crust; active geothermal systems of the type that have formed mineral deposits in the past; and mineral deposits. In the Mineral Resources section of the report, the authors noted that although some deep holes will be needed for mineral resource studies, many vital scientific questions may be answered by relatively shallow drilling, to about 1500 m, provided the holes are properly located. The essential factor of the program was to provide an opportunity to study mineral-depositing processes in three dimensions at significantly increased depths, resulting in a major advance in the understanding of how mineral deposits form.

A National Academy of Sciences study, entitled Mineral Resources: Genetic Understanding for Practical Applications (Geophysics Study Committee, 1981), points out that our understanding of ore deposits may be two or three decades behind that of the interpretation of global geology. The report contained the recommendation that future research on mineral deposits should focus on the acquisition of a genetic understanding of mineralization to increase the efficiency of exploration and the accuracy of resource assessment. A significant portion of this research should consist of large, multidisciplinary studies, requiring coordination and collaboration among industry, academia, and government. Burnham and Ohmoto (p. 62-72 of the report) described the current deficiencies in understanding magmatic hydrothermal processes and concluded that there is need for focused research efforts on the numerous interrelated geological, petrological, and geochemical aspects of mineral-forming processes. Cathles (p. 105-110) stated that a strategy is necessary for increasing our knowledge of the factors controlling mineral genesis. Such a strategy would increase exploration effectiveness by quantitative modeling of the ore-forming processes of individual mineral deposit systems. Bailly, in the same report (p. 21-32), points out that "we need cost-effective improvements in drilling, sampling, and analytical techniques in order to decrease the costs of drilling and drill-sample analyses."

E. SELECTION OF HIGH PRIORITY MINERAL DEPOSIT TARGETS

It is the purpose of this report to identify and address specific mineral deposit systems that are both suitably accessible and geometrically complete in the sense that no portion of the deposit has been removed by faulting or erosion.

The following classes of mineral deposits occur within the continental United States:

1. porphyry copper and molybdenum;
2. epithermal gold-silver (antimony, mercury);
3. volcanogenic massive sulfides (lead, zinc, copper, silver);
4. magmatic nickel-copper-platinum;
5. granite-related tin and tungsten;
6. Mississippi Valley type (carbonate-hosted) lead, zinc, copper, silver;
7. clastic-hosted copper, lead, zinc, uranium;
8. sedimentary iron;
9. sedimentary phosphate;
10. lateritic nickel; and
11. evaporite minerals and elemental sulfur.

Critical data can be acquired in most cases by the acquisition and study of

existing drill samples, by further scientific investigations added on to government and industry drilling activities, and by dedicated shallow exploratory holes drilled for purely scientific objectives. The study of spatial and genetic relationships involving base-metal veins and epithermal precious metal mineralization and underlying igneous intrusive rocks, however, requires dedicated drilling to depths of 2 to 5 km.

This report addresses two methods of access to drilling samples and measurements: (a) drillholes dedicated to broad scientific objectives; and (b) investigations added-on to industry and government drilling activities.

The Panel on Mineral Resources recommends emphasis on research drilling be directed toward epithermal gold-silver and porphyry-type deposits for the following reasons:

1. Sources of metals and heat for generation of epithermal systems need to be identified by research drilling and thereby be genetically related to deeper, porphyry-type mineralization.

2. Such research will provide important data for our understanding of: (a) how fluids, derived from and/or mobilized by a magmatic source, evolve in different portions of a vertically extensive hydrothermal system; (b) how and where in the systems these fluids mix with heated, convecting meteoric waters; and (c) the effects of different degrees of mixing on the wallrock alteration, metal transport, and deposition.

3. Epithermal gold-silver and porphyry-type fossil geothermal systems represent end-stage examples for comparison with active geothermal systems; they provide the opportunity to study the chemical, thermal, and hydrologic evolution of geothermal systems, whereas active geothermal systems provide the opportunity to study a similar system at a specific instant. From the standpoint of the development of genetic models of ore deposition, comparative studies of active and fossil geothermal systems are essential for the understanding of the genesis of porphyry copper and epithermal gold-silver ore deposits.

4. Successful exploration for both epithermal gold-silver and porphyry-type deposits requires a better understanding of the origin and evolution of the deposits in order to maintain our ability to discover unexposed or poorly exposed reserves.

5. Increased discovery and extraction of metals from United States' deposits should have a positive impact on the currently depressed minerals industry and mining districts.

6. Technology for core drilling, sampling, and logging is available for drillhole depths of 15,000 ft (4600 m) and temperatures of 100° to 200°C. Developments of instrumentation are needed to upgrade existing instruments for use in high temperature active geothermal systems; such developments can best be tested in deep holes to study fossil mineral systems.

F. CRITERIA FOR SELECTION OF DEDICATED RESEARCH TARGETS

The Panel on Mineral Resources reevaluated the mineral resource objectives formulated at a Workshop on Continental Drilling for Scientific Purposes in Los Alamos, New Mexico, in 1978. Achievement of scientific goals proposed in Appendix C of the report of this workshop, Continental Scientific Drilling

Program, was evaluated from a point of view of drilling holes dedicated to broad scientific objectives and investigations added on to holes drilled for specific missions by government agencies and industry. The Panel unanimously agreed that drillholes dedicated to present research needs in mineral resources represent the only viable approach to study of targets in active and fossil hydrothermal-magma systems for the near future. However, objectives for investigations added on to project-oriented industry and government drilling activities may be addressed by defining research priorities and recognizing and coordinating research in identified 'holes of opportunity'.

The Panel established ten criteria for use in assuring that the dedicated drillhole targets selected would maximize scientific and technological returns in the 1980's.

1. The research objectives must address fundamental scientific problems with potentially broad impact on the understanding of mineral resources.

2. The objectives should be sufficiently broad to address research relevant to national needs (e.g., mineral resource inventory, enhanced exploration techniques, geothermal energy development, and radioactive and chemical waste isolation).

3. The targets should represent a broad classes of mineral deposits so that the scientific results may be applied to exploration for mineral resources in other areas.

4. Previous studies of the area should be in an advanced stage, allowing selection of specific research drill sites within a reasonable time frame.

5. Targets should be as specific as possible to maximize the value of data obtained and to ensure achievement of the scientific objectives with minimum expenditure of time and funds.

6. The target should be unique in the sense that data sought are rarely available from continuous, uninterrupted rock sequences in the United States.

7. Geological models should be well defined, utilizing near-surface data to derive substantiated geometric relationships.

8. Results of geophysical field studies should be integrated with surface and near-surface geological and geochemical data.

9. The location should be accessible to scientists and suitable for surface geological, geochemical, and geophysical studies. If the site is in a mining district, workings should be accessible and required subsurface data should be available.

10. The site should be on property providing no insurmountable environmental difficulties, and studies on the site should be compatible with the interests of land and mineral-rights owners.

It should be noted that Criteria 9 and 10, although not generally scientific in nature, do influence the establishment of priorities for selected research drilling targets because of practical matters that must be addressed on a case-by-case basis.

G. PRIORITIES FOR DEDICATED RESEARCH TARGETS

The highest priority for dedicated research is given to determining the complete range in hydrothermal activity related to relatively shallow (less than 5 km) silicic magmatic intrusions in both space and time. This requires studies in both fossil and active hydrothermal systems.

Based on the criteria described previously, the first recommended target area for determining the relationships of shallow epithermal mineralization and possible deep silicic igneous activity is at Creede. Other hydrothermal systems of significant merit as potential research targets include Tonopah, Red Mountain, and Butte.

The deeper portions of an active hydrothermal system in a silicic volcanic complex should be drilled to bridge the gaps in our knowledge about the interactions of shallow hydrothermal activity with igneous intrusives at or near magmatic temperatures. The Valles caldera is given a high priority because it presents an environment geologically similar to Creede, and each system should provide information useful for interpreting the other. Active hydrothermal systems that should also be considered for research include Yellowstone, The Geysers, the Salton Sea, and Long Valley.

III. FOSSIL MINERALIZED SYSTEMS

A. CREEDE MINING DISTRICT, COLORADO

The Creede mining district in the San Juan Mountains, Colorado, has been in almost continuous production for over 90 years. A research drilling program is proposed in this silver/base-metal district which represents a fossil analogue to modern geothermal systems in silicic volcanic terranes.

1. Research Objective. The objectives of a research program are to investigate the roots of the Creede mineral concentration and relate the deep data to the known parameters nearer to the surface and the top of the system. A quantitative model of the Creede system that integrates geological, hydrological, geophysical, and geochemical parameters would be developed. The importance of such an integration lies not only in its application to the Creede district, but in its application to the understanding of hydrothermal ore deposits related to silicic volcanic centers and calderas. Once the physical relationships between the upper and lower portions of the fossil Creede system are understood, hydrothermal systems exposed at the surface elsewhere may be interpreted accordingly. The proposed program objectives address national needs, as an improved understanding of the Creede mineral-forming system could represent a major contribution to the development of precious metal exploration techniques and the conceptual framework of epithermal vein/bulk silver-gold deposits. The study would also address hydrothermal systems relevant to geothermal energy, in that fossil systems such as Creede record the evolution of a geothermal system in time, a parameter that cannot be studied in active systems.

In summary, selection of the Creede district a high priority research target is based on the following factors:

a. growing economic importance of this class of epithermal silver ore deposits (Eimon, 1981; Buchanan, 1981; Berger and Eimon, 1982);

b. similarity to modern geothermal systems (Wetlaufer et al., 1979; Bethke, 1980);

c. the relative simplicity of the geometry and geological setting of the Creede District; and

d. extensive available background data, particularly quantitative information, on the geology, geochemistry, geophysics, and ore fluid chemistry and isotopy from investigations by the U.S. Geological Survey (Steven and Ratte, 1965; Steven and Eaton, 1975; Steven and Lipman, 1976; Barton, Bethke, and Roedder, 1977; Bethke et al., 1976; Bethke and Rye, 1979; and Roedder, 1965 and 1977) on which to interpret the new data.

2. Proposed Program. It is proposed that four, continuously-cored holes be drilled, two to depths of approximately 1 km to test the caldera, moat-filling lake sediments as a source of water, salinity, and sulfur, and two to approximately 5 km, sited in the central part of the Creede District to test the roots of the hydrothermal system. These holes would provide data regarding:

a. the nature of the heat source for the ore-forming hydrothermal system;

b. information concerning the source rocks from which the chemical and isotopic components of the Creede mineral concentrations were derived; and

c. the physical and chemical conditions and rock-water interactions in the roots of the hydrothermal system.

Heat Source: Steven and Eaton (1975) postulated the existence of a stock emplaced some 3 to 5 km below the present mineral deposits, lying below the center of the Creede District. Their main evidence was that the maximum displacement on the mineralized faults defining the Creede graben was located in the center of the district, and diminished to the north and south. Supporting evidence is derived from subtle gravity and magnetic anomalies based on regional scale geophysical studies. This conclusion is widely accepted; however, other geothermal systems in the Western U.S. appear to be related to abnormally high regional thermal gradients rather than to local magmatic heat sources. Bethke et al. (1976) have shown that mineralization followed the last known igneous event in the central San Juan caldera complex by 1 to 2 Ma. This presents the question as to whether the postulated stock is part of the eruptive cycle of the Creede caldera and, therefore, caldera-related, or a high-silica rhyolitic stock of the younger bimodal basalt-rhyolite sequence, and therefore unrelated to the caldera evolution. This question is of fundamental importance in evaluating the role of calderas in epithermal mineral formation.

Source Rocks: Doe et al. (1978) have shown that the lead isotopic composition of Creede minerals is more radiogenic than any of the volcanic rocks in the San Juan Mountains. They suggest that this is due to substantial additions of radiogenic lead from the Precambrian basement. Steven and Friedman (1968) have postulated that the isotopic composition of the travertine mounds in the moat of the Creede caldera indicates that the CO_2 was derived by decarbonation reactions of Mesozoic limestones at depth below the Creede District. The high salinity (4 to 12 wt % NaCl equivalent) of

fluid inclusions in the Creede minerals suggests that chloride content may be due to mechanisms other than leaching of the underlying volcanics. Bethke and Rye (1979) have suggested that, based on the oxygen and hydrogen isotopic composition of the Creede mineral fluids, these fluids were of meteoric origin and were derived from the interstitial waters in the lacustrine sediments filling the moat of the Creede caldera. Rye, Barton and Bethke (U.S. Geological Survey, unpublished data) have suggested that the oxygen and sulfur isotopic composition of the barite requires that the sulfate gained its isotopic signature by biogenic sulfate reduction in a lacustrine environment and that the sulfur isotopic data on hoter barite and sulfide minerals imply that approximately ten times as much sulfur exists elsewhere in the system than in the known ores. This sulfide may exist as pyrite or pyrrhotite disseminated in the underlying volcanics. Alternatively, the sulfide may reside in a deep porphyry-type system from which the known mineral concentrations were derived by hypogene leaching at depth and redeposition at the top of the system, as suggested for Creede by Barton, Bethke, and Roedder (1977) and postulated for Butte by Brimhall (1979, 1980). All of these hypotheses have profound bearing on our concept of the Creede system and can be tested by drilling in the mineralized portion of the moat-filling sediments.

Roots of the Hydrothermal System: The final objective of the Creede research program is to gain a quantitative knowledge of the physical and chemical conditions in the roots of the hydrothermal system. Specifically, temperatures and salinities of fluids from fluid inclusions trapped deep in the system are needed, together with estimates of the controlling chemical parameters based on mineral assemblages and of metasomatism analogous to alteration at the top of the system. Estimates of both the nature and magnitude of the permeability at the bottom of the system are essential for quantitative definition of the hydrologic parameters of the ore-forming system.

B. TONOPAH, NEVADA

The Tonopah Mining district is located in west-central Nevada. Almost 2 million ounces of gold and 175 million ounces of silver have been produced from epithermal precious metal veins hosted by a complex of igneous flows, tuffs, intrusions, and breccias, ranging in composition from andesite to rhyolite. Mineralization at Tonopah has been dated at 17-20 Ma (Silberman et al., 1979).

The epithermal mineralization at Tonopah may have been related to a porphyry molybdenum system at depth. In the western part of the Tonopah district, intrusive breccias may represent the uppermost parts of a shallow hypabyssal molybdenum-bearing porphyry complex. Although molybdenum is not abundant in Tonopah precious metal ores, molybdenum values increase in the western and deeper parts of the productive zone. Indications that the Tonopah district may be the top of a porphyry molybdenum system include: (a) changes from gold-silver to copper-lead-zinc to lead-zinc-molybdenum mineralization with depth; (b) presence of a host igneous complex of nearly contemporaneous andesitic, dacitic, and rhyolitic rocks; and (c) presence of intrusive breccia bodies.

Tonopah was selected as a research target for the following reasons:

a. Considerable production of silver and gold in the western United States has come from epithermal deposits in volcanic rocks. Mining companies are interested in applying new conceptual models and exploration techniques in the search for additional deposits of this type in the western United States.

b. The epithermal system at Tonopah, as at Creede, is similar to active geothermal systems in many ways.

c. The district is compact in size, intensely mineralized, relatively undisrupted by faults in the mineralized interval, and simple in overall geometry. After appropriate preliminary studies, drill holes can be sited to test desired targets.

d. Intrusive breccias and molybdenum-bearing outcrops in the district suggest a high likelihood of intersecting a contemporaneous underlying system with porphyry mineralization or, alternately, of observing results of remobilization of an earlier mineralization in the roots of an epithermal system.

1. Research Objective. One to three preliminary shallow holes and one or two deeper holes are proposed to explore the possibility that a different, related mineralization may exist below the epithermal precious metal deposits. The sequence might include epithermal mineralization overlying anomously high molybdenum with possible tungsten values, in turn overlying porphyry molybdenum mineralization in an intrusive complex. Research at Tonopah could demonstrate that epithermal deposits, intrusive breccias, and geochemical anomalies such as are found at Tonopah may be upward extensions of porphyry molybdenum systems.

2. Proposed Program. The regional geology and detailed geochronology of the Tonopah district are described in a number of studies (Bonham and Garside, 1979; Silberman et al., 1979). The distribution of veins, orebodies, and structures observed underground during exploration of the district are well documented (Nolan, 1935). A museum collection assembled by Nolan has been used for fluid inclusion and stable isotope studies (Fahley, 1982; Taylor, 1973). Additional unpublished data pertinent to this drilling program have been acquired by mining companies in recent years, particularly by Houston International Minerals Corporation (HIMC). In order to effectively site the proposed drillholes, the following studies are needed:

a. Inventory and analysis of data and samples held by HIMC, including core, core logs, and geochemical data from the HIMC drilling program in the western part of the district, geochemical data from surface and underground samples, and low-level aeromagnetic data. The main objective of this step is to confirm that the increase in molybdenum values with depth in the western part of the district are coincident with the occurrence of intrusive breccias. The HIMC drill core would also provide material for chemical analyses needed to determine whether the possible intrusive complex has alkaline affinities, as is typical of major known fluorine-rich molybdenum porphyry systems. Existing geochemical data and additional analyses of unoxidized mineralized material will better define the minor element suite associated with molybdenum. This information may also make it possible to predict whether the anomalous molybdenum is related to a deeper molybdenum system or was mobilized from older mineralized rocks.

b. Examine materials available from core, surface exposures and existing HIMC and museum collections to see if recent fluid inclusion work of Fahley (1981) can be extended spatially. This information could provide a better understanding of the paleohydrology of the mineralizing system that is needed for drillhole site selection.

c. A detailed study of oxygen and hydrogen isotopic variations should be undertaken to extend the earlier reconnaissance study of Taylor (1973), which established that the mineralizing hydrothermal system was meteoric-water dominated.

d. Undertake detailed gravity and magnetic studies to help establish the existence and location of the main intrusive mass at depth that gave rise to the intrusive breccias.

f. Consider detailed seismic reflection work over the entire Tonopah-Divide area to detect any low-dipping faults or detachment surfaces.

The proposed research program would begin with one to three 1- to 2-km drillholes designed to confirm the molybdenum and base metal bearing character of epithermal mineralization at depth, to develop further and refine the known geometry of the epithermal system and the geometry of the breccia bodies, and to detect any low-dipping faults that may seriously disrupt or offset the lower parts of the system.

Geometry of the Epithermal System: The work of Nolan (1935) revealed that the productive zone at Tonopah is an approximately symmetrical elongate shell 200 to 600 ft (60 to 180 m) thick that is concave downward. Taylor's (1973) oxygen data for whole rocks show maximum shift over the highest part of the productive zone. The symmetrical productive zone and coincident isotopic pattern could be explained by upward fluid flow beneath the center of the district, giving way to dominantly lateral flow away from this upwelling center at about the level of the productive zone. Fahley (1981), however, found the highest fluid inclusion temperatures (260°C) in the western part of the district; evidence of boiling was found in the center. Fluids thus may have come up the Tonopah Fault, a major low-dipping mineral-controlling structure that forms the west side of the shell, and discharged above the center of the district. Taylor's data are also consistent with the idea that the center of the district was a high-discharge area. A 900- to 1800-m hole should be drilled west of the westernmost productive veins to intersect the area through which upward-flowing hydrothermal fluids may have entered the Tonopah Fault zone.

Geometry of the Intrusive Complex: Intrusive breccias in the district, the West End Rhyolite and the Extension Breccia, are exposed only in mine workings as sills which intrude along the Tonopah Fault. Where the Tonopah Fault is occupied by intrusive rock, ore bodies occur at the intrusive contacts, indicating that hydrothermal fluids moved up along these contacts and into the fault zone. Both units contain abundant fragments, largely from local units below the Tonopah Formation. The units appear just west of the center of the district and thicken to the west, indicating that the dikes or plugs that fed the sills from a deeper multiple-phase stock are probably located just west of the district. The first hole proposed above may locate these feeders, which should overlie the inferred molybdenum-bearing stock. An additional 900- to 1800-m hole somewhat farther west might be required.

Low-Dipping Faults: Low-dipping, or detachment faults were not recognized by Bonham and Garside (1979) in their mapping of the Tonopah district and surrounding area. Such faults have been recognized in several other parts of western Nevada. Horizontal distension and associated shingle faulting was recognized by Ashley (1974) at Goldfield, only 40 km south of Tonopah. Faulting similar in age to that at Goldfield would predate mineralization at

Tonopah. The Tonopah Fault may be part of a low-dipping fault system of premineralization age. If a detachment fault is found, the project would have to be re-evaluated, depending upon the depth at which the detachment fault is encountered and the displacement involved.

The shallower holes proposed for this program should be cored throughout. If the shallower holes successfully intercept the downward pipe- or dike-like portions of the breccia bodies or confirm anomalous molybdenum and base metals, as well as confirming the absence of detachment or other major faults, a deeper hole (2 to 5 km) should be drilled. This deep hole, cored most of its length, would penetrate the bottom of the epithermal system, the deeper parts of the intrusive complex, and the porphyry molybdenum or basement rock source of the molybdenum.

The research would provide information to address fundamental uncertainities similar to those being addressed in the Creede district: nature of the heat source; nature of the source rocks that supplied the mineral components; and conditions in the roots of the system. Comparison of the results of these programs could explain the fundamental influences of intermediate versus silicic rock systems on related mineral systems, leading to a more accurate and applicable epithermal-hypothermal deposit model.

C. RED MOUNTAIN, ARIZONA

The Red Mountain mineral deposit, located approximately 40 miles (64 km) southeast of the Pima-Twin Buttes district in southeastern Arizona and approximately 40 miles (64 km) northwest of the Cananea district in northern Sonora, Mexico, is suggested as a research site to examine a complete porphyry copper system in terms of geochemistry and paleohydrology.

The Patagonia Mountains, of which Red Mountain is a part, offers an environment in which a series of epithermal deposits may be spatially and genetically related to the Red Mountain porphyry copper system. Additional geological, geochemical, and geophysical studies supplementing the proposed drilling program could measurably add to the knowledge of epithermal and porphyry copper/molybdenum system relationships.

The proposed study of the Red Mountain district represents an unusual opportunity for increasing scientific understanding of important criteria in hydrothermal mineral genesis. The district presents a number of unique features that are scientifically attractive, including the basic simplicity of the geological setting and an apparently vertical, structurally undisturbed porphyry copper system encompassing an unusually large vertical interval, which is as great or greater than all major, extensively mined porphyry copper systems. Because of the undisturbed nature of the deposit is unmined, sampling of the complete vertical system is possible.

Drilling by Kerr-McGee Corporation from 1961 to 1974 explored the porphyry copper system over a vertical range of 6500 ft (2000 m). Existing data are derived from 71 drillholes, totaling approximately 180,000 ft (55 km) and including 24 holes over 5000 ft (1500 m) deep. The deposit is interpreted to consist of at least three distinct zones representing a broad spectrum of hydrothermal mineralization and alteration.

The upper portion of the deposit consists of: (1) a relatively thin chalcocite-enrichment blanket developed from chalcopyrite-enargite-bearing material within high level phyllic and argillic alteration patterns; (2) a

deeper porphyry copper sulfide deposit 3500 ft (1100 m) below the chalcocite blanket; and (3) a copper-molybdenum breccia pipe near the center of the porphyry sulfide deposit.

The major purpose of the research program would be to define the limits of the hydrothermal system in terms of geological and mineralogical features of porphyry copper deposits. Transitions in physical rock properties at great depths would be of prime interest. Collectively, these factors relate to the understanding of the vertical and horizontal limits of hydrothermal fluid circulation and paleo-permeability variations over a 4300-m interval. Because of economic limitations, these depths are not commonly explored, but they represent regions critical to the complete understanding of porphyry copper-molybdenum systems. Conversely, root zones exposed in other districts may not be recognized as being the lower portions of eroded porphyry copper systems.

A research program at Red Mountain would provide an opportunity to acquire basic data regarding mineral deposition and metasomatic zoning. Although recent advances in isotope geochemistry have provided insight into various water sources, the specific source of metals and sulfur, and the controlling transport processes, remain targets for scientific pursuit.

The geology and base metal occurrences at Red Mountain have been intermittently studied since 1915 (Schrader, 1915; Drewes, 1971a, 1971b 1972a, and 1972b; Simons, 1971 and 1974). More recent efforts have focused on data by the Kerr-McGee drilling program (Corn, 1975; Bodnar and Beane, 1980; Quinlan, 1981), and comparisons with postulated generic models of porphyry copper deposits (Lowell and Guilbert, 1970; Rose, 1970). Surface geological sampling by the U.S. Geological Survey surrounding Red Mountain is summarized by Chaffee (19XX).

The geological setting of Red Mountain consists of an altered complex of flat-lying volcanic and intrusive rocks of Cretaceous and early Tertiary age. Three layered volcanic units have been described, including an upper rhyolite and dacite tuff unit [2400 ft (730 m) maximum thickness], an underlying andesite 3000 ft (900 m) thick, overlying a basal felsite-latite unit. Porphyritic rocks ranging in composition from granodiorite to quartz monzonite cut the layered volcanic rocks.

Silicate alteration at Red Mountain, described in detail by Quinlan (1981) and Corn (1975), varies with rock types and depth. The central portions of the system within the tuff unit are altered to quartz-sericite-pyrite-kaolinite-alunite. Sericite content increases with depth as the content of kaolinite and alunite decreases. At depth, a quartz-sericite-chlorite-pyrite alteration passes through a biotite-magnetite-pyrite assemblage to a biotite-orthoclase-anhydrite-magnetite-chalcopyrite environment within both the intrusive porphyries and andesite. With the addition of quartz, this assemblage persists within the felsite-latite unit. The transition from the upper level quartz-sericite-pyrite alteration to deeper potassic alteration takes place within an interval of about 1500 ft (460 m).

Mineralization zoning typical of porphyry copper deposits is strongly developed, both vertically and laterally. Lead and zinc generally occur in the upper portions of the deposit, and small amounts of molybdenum are present throughout. Chalcopyrite is the predominant copper mineral. Enargite occurs in the upper levels, and minor amounts of bornite are present at depth in the potassic core of the deposit. The proportion of bornite increases with depth.

The formation of irregular intrusive breccias has been interpreted to be the youngest hypogene mineralization event. These breccia masses may be the deepest copper-molybdenum breccia pipes known in the world; there is evidence to suggest that the breccia pipes may be continuous from near the surface to the deepest drilling intersections. A zone of copper, molybdenum, and silver enrichment is situated near the margins of the largest breccia pipe. The breccia pipe presents a unique environment permitting insight into vertically zoned mineral deposits in relation to other major elements of such deposits and providing a unique opportunity to compare high level and deep level breccia pipes in a porphyry copper environment. The structural evolution of this district could aid in the interpretation of other mineral deposits which represent single phases of the multi-staged process at Red Mountain.

1. Research Objectives. Studies of the alteration and mineralization patterns at Red Mountain have not been as intensive as those at other mining districts in the Western United States. Geochronology research to determine the ages of alteration assemblages is recommended.

The prime purpose of the research program would be to explore the root systems of the deposit, particularly the extent to which metals have been leached from lower portions. Deep alteration of fresh wall rock may have liberated trace elements which are not included in the primary ores. Additional research would provide mineralogical zoning data relating to the vertical interval over which metals and particular alteration processes have been concentrated.

2. Proposed Program. Although coring at Red Mountain has provided samples over a considerable vertical interval within the large porphyry copper deposit, additional geological work in the district is needed to refine the understanding of mineralization and alteration relationships of the Red Mountain system with the spatially associated epithermal deposits. Geological mapping, geochemical sampling, and comprehensive analysis of drill-core for cross-cutting relationships, alteration products, and fluid inclusions should precede selection of specific drilling sites. Existing geophysical data requires supplemental gravity and aeromagnetic surveys. These predrilling studies will provide a better three-dimensional model for validation and modification by dtat obtained by the proposed research drilling.

A minimum of two research drillholes is proposed, based on the known geometry of the district zonation; i.e., the breccia pipe and bulk sulfide deposit. One drillhole should be located specifically to test the breccia pipe and its downward extension, and a second hole should test depths below the known sulfide body at 2400 to 3000 m. Both holes may be drilled to depths of up to 4300 m to explore the bottom of the potassic alteration zone.

Such depths should penetrate the lower limit of fluid circulation where a test of the nature of fluid transport could be conducted and paleo-permeability estimates could be made. Paleotemperature isotherms would be generated through fluid inclusion and mineralogical studies. Gradients in permeability, paleotemperature, and fluid composition would improve the present understanding of the relationship of magmatic heat supply, fluid convection, and composition of hydrothermal fluids. Research drill holes in these environments would also provide data regarding the existing hypotheses of metal remobilization and alteration in root systems.

D. BUTTE, MONTANA

Scientific research studies of the mineral deposits at Butte, Montana,

could provide additional data regarding mineral deposition/metasomatism, including the possibility of subjacent mineral systems. Although recent advances in isotope geochemistry have provided insight into water sources in mineral deposits, direct sources of metals and sulfur and transport mechanisms remain frontiers for scientific pursuit.

Large copper-silver-zinc veins are superimposed upon an extensive copper-molybdenum stockwork. The zoning may have been generated in a one- or two-stage cycle. Extensions of the Butte base metal veins above the present surface may have included higher precious metal concentrations if zoning upward had been similar to the silver-zinc concentrations now surrounding the copper deposits.

One of the principal objectives of research drilling at Butte would be to determine the extent to which the metals may have been leached from the lower portions of the deposit, to be reprecipitated in veins at higher elevations.

It is possible that entirely new holes would not have to be drilled in a research program at Butte. In the past 5 years, the Anaconda Minerals Company has drilled a series of holes up to depths of 7000 ft (2100 m), and the possibility exists for re-entry and deepening of one or more of these holes. Sampling requirements, because of the possibility of hole re-entry, could be satisfied by slim hole coring. The core would be studied petrographically for vein and alteration types, fluid inclusions (including pressure corrections), veinlet inclinations and intersections, and stable isotopes. Following logging of the core, it would be split and analysed.

Although published information describing the Butte deposit would indicate that it should be considered as a possible site for future research drilling, limited access to the mining properties and the proprietary nature of existing data precludes consideration of this target at the present time, at least until new information about the zoning at Butte is published.

IV. ACTIVE HYDROTHERMAL SYSTEMS

A. RESEARCH OBJECTIVES

Present knowledge of hydrothermal mineral deposits and active geothermal systems demonstrates the importance of interaction of shallow, dilute meteoric water and deeper brines. The origin and character of these deep brines is poorly understood. Fluid inclusions in mineralized copper-molybdenum porphyry systems contain both high salinity and moderate to dilute fluids. Highly concentrated brines thus far encountered in active hydrothermal systems have come from environments in which the waters may have interacted with evaporites (e.g., Salton Sea, California; El Tatio, Chile; Cesasano, Italy). Highly saline, as well as moderately concentrated brines may evolve from a magma depending on the initial water and chloride contents and depth of crystallization (Burnham and Ohmoto, 1982; Fournier, 1983). Highly concentrated brines may also develop from dilute meteoric waters as a result of boiling, for example, at the bottom of a vapor-dominated system (White and Truesdell, 197X). The primary objective of the proposed research drilling as related to the objectives of the Panel on Mineral Resources is to investigate the origin, evolution, and geometric relations of brines in an active silicic volcanic center, uncomplicated by a sedimentary section containing evaporites. Specific elements of the objective include:

1. What are the sources of the waters in the hydrothermal system and how did they acquire their salinities?

2. What is the variation in temperature and chemical and isotopic composition from the top to the bottom of an active hydrothermal system at a given time? Do less saline waters form separate convecting cells above more saline convecting cells? If so, mineral deposition of different types and intensities might occur simultaneously in various parts of the system. Mineral deposition is particularly likely to occur at fluid interfaces where different fluids mix.

3. What is the origin of metals and sulfur in hydrothermal systems, what is their concentration, how are they transported, and how and where are they deposited?

4. How do porosity and permeability change with depth in an active hydrothermal system?

5. To what extent does self-sealing take place at tops, roots, and lateral extensions of hydrothermal convection cells? If more than one convection cell is present, will each tend to be self-sealed? In subjacent mineralized zones, barren silicified rock might represent the separation of mineral concentrations formed from different brines.

6. Is there a change from hydrostatic to lithostatic fluid pressures in the vicinity of shallow magmatic intrusives, possibly caused by self-sealing through deposition of minerals from an evolved magmatic fluid? If so, drastic changes in fluid pressure may occur from time to time if the seal is broken by tectonic movements or pressure buildup derived from magmatic fluid, with major implications for mineral deposition (Fournier, 1983).

7. How do partial pressures of gases and oxidation states of the system change with depth? What is the origin of the gases in active systems? What are the relative contributions from the mantle, shallow magmatic bodies, and metamorphic reactions?

The broad objective in studying an active hydrothermal system is to gain information about the evolution of hydrothermal systems and mineral genesis. A hole drilled into an active system that does not encounter ore can answer many of the questions enumerated above. It is equally important to understand why many shallow magmatic systems apparently have no associated economic mineral deposits.

B. PROPOSED TARGETS

With the above questions in mind, we conclude that important concepts relating to mineral deposit formation could be developed through research of active hydrothermal systems. A deep hole should be drilled into a presently active system within a silicic caldera complex in which rock temperatures of 500°C at a depth of about 5 to 7 km are likely to exist. Many hydrothermal ore deposits are spatially and genetically related to such caldera complexes, and an investigation of an active system would directly relate to a study of a fossil system in a similar geologic environment. The above factors and those outlined by the Panel on Thermal Regimes in their report indicate that the Yellowstone caldera as the best of the active hydrothermal system candidates for research drilling. However, because accessibility of the Yellowstone

caldera as a drill site is uncertain because of environmental considerations, we recommend the Valles caldera system as an alternative site for this research.

Extensive studies of the Yellowstone silicic caldera complex have provided abundant geological, geophysical, and geochemical data with which models can be formulated. However, the deepest drillholes are relatively shallow [maximum of 1088 ft (332 m)], so there is little subsurface data that can be used to test models. Judging by the currently available geophysical data, there probably is an extensive body of high temperature rock (magma?) within 3 to 10 km of the surface beneath much of the Yellowstone caldera. This hot rock may come closest to the surface (within 3 km) beneath the northeast part of the caldera, where a research drillhole would provide scientific information about the roots of hydrothermal systems. Before attempting any research involving drilling in an ecologically and politically sensitive area such as Yellowstone National Park, drilling techniques into rocks approaching magmatic temperature, and possibly with high fluid pressures, should be in an advanced stage.

The Valles caldera system also has been extensively studied and has the additional advantage of about 25 existing industry-financed intermediate-depth wells down to depths of 3200 m that provide information about the chemical and physical nature of the upper parts of the hydrothermal system. At present, there is no direct evidence for the existence of magma beneath the Valles system at a depth accessible by drilling. However, the geological evidence indicates that the system is still hot, the heat source is large, and the hydrothermal system is well developed. We consider the Valles caldera as an excellent target to gain information about depth-temperature-pressure-salinity conditions in a relatively simple hydrothermal system that has evolved above a shallow silicic magma. The similarities between the geological environments at the Valles caldera and at Creede are striking. A comparison between the active system at Valles and the fossil hydrothermal system at Creede will yield interpretations that are beneficial to the understanding of each system.

The Long Valley silicic caldera system is geologically similar to the Valles caldera system, but it has been investigated by a limited number of intermediate-depth drillholes. A major drawback to research at Long Valley is the distinct possibility that the underground thermal regime and hydrothermal system are changing at a rapid rate owing to upward movement of magma. Recent uplift of the caldera floor, local seismic activity (spasmodic tremors), and increased hot-spring and fumarole activity have prompted the U.S. Geological Survey to issue in May 1982 a notice of potential volcanic hazard. If magma is currently rising within or near the Long Valley caldera, it should greatly perturb the subsurface thermal regime and could alter the chemical and physical nature of the hydrothermal system. This would make it difficult to interpret drilling data. Research at Long Valley might be more appropriately directed toward answering questions about the early stages of development of a hydrothermal system related to a younger magmatic intrusion. While the early stages of development of a hydrothermal system related to a magmatic intrusion are of great interest to the Panel, the later, "mature" stage is likely to provide more useful information for modeling hydrothermal ore depositing systems.

The Geysers/Clear Lake geothermal system appears to be related to a moderately well-defined magmatic body present at a shallow depth which could serve as a source of sulfur as well as heat. The evolution of any brine that might be found in the deep part of the system could be related to factors

other than interaction with evaporite deposits because there are no known or inferred halide deposits in the sedimentary rocks in the immediate area. However, hot spring waters flowing from the Great Valley sequence rocks in the region generally do contain much more chloride than do hot spring waters flowing from Franciscan rocks. A boiling brine may exist beneath the vapor-dominated zone at The Geysers. If so, present day mineral deposition could be occurring there. From the point of view of relating an active system to studies of similar fossil systems, The Geysers/Clear Lake system is ranked lower in priority than the Valles caldera. Current industry interest in drilling deeper and closer to the inferred magmatic body at The Geysers should be monitored for possibilities of add-on investigations in holes of opportunity.

The Salton Sea geothermal system appears to have limited direct application in terms of mineral concentrating processes because, while the salinity and dissolved metal concentrations in the brine are very high, the origin of that brine appears to be the result of a special circumstance; i.e., the presence of halide evaporite deposits in the sedimentary section. A low concentration of dissolved sulfur may account for the high metal contents. Considerable information is available concerning the rocks and high-temperature fluids in the upper parts of this system. By deeper drilling the hydrothermal system in the Salton Sea, we would obtain information about the metamorphism of an initially relatively uniform pile of sediments and the consequent changes in porosity and permeability. We might also obtain information about how deeply the brine circulates and whether there are changes in salinity, sulfur, and metal content of the brine with depth. The above information might be obtained most economically through add-on investigations, including deepening of existing or planned industry drillholes, rather than by a program of drilling dedicated holes. The Salton Sea remains the best onshore target for add-on investigations that address the problems of mineral concentation related to spreading centers.

V. EXAMPLES OF OBJECTIVES TO BE ADDRESSED BY ADD-ON INVESTIGATIONS

Numerous scientific objectives, considered by the Panel on Mineral Resources to be of importance equal to the specific objectives of the proposed dedicated drilling projects, can be accomplished by scientific investigations in holes and on core material available from industry or government agencies in and adjacent to mineralized fossil and active geothermal regions. Existing holes may be deepened or otherwise used to provide access to untested lower horizons and peripheral portions of mineralized systems normally inaccessible to sampling. The concept of "add-on investigations" to such holes of opportunity requires establishment of a dialogue between industry, government, and the scientific community, such as through the Continental Scientific Drilling Committee's DEW (Drilling Early Warning) NEWSLETTER, in which both specific research needs and the availability of pertinent mission-oriented holes can be identified.

The acquisition, maintenance, and deepening of selected holes will allow studies of mineral deposits and related active hydrothermal systems for which available data relates only to the immediate vicinity of "ore" grade mineralization. The exploration of peripheral relationships, the reactions of ore deposit systems with marginal facies, and the interpretation of zonal relationships that may be guides to ore would also require access to holes of opportunity. Geological and geochemical studies of the margins, both lateral and vertical, of ore-deposit systems constitute the principal area of

recommended research by those who responded to the Society of Economic Geologists (SEG) Research Committee questionnaire. The scientific benefits of add-on investigations are high in comparison with their costs.

Specific add-on investigations would include:

1. whole rock and mineralogical sampling for petrologic, bulk and trace element geochemistry, fluid inclusions, and isotopic and geochronological studies;

2. geophysical experimentation to establish response and continuity of mineralization and/or mineral-related facies; and

3. determination of micropore and microfracture densities.

The following ore deposit types are cited as examples that should be considered in selecting areas of existing drillholes for further study. By publishing these objectives in the CSDC DEW NEWSLETTER and in geoscience society and industry publications, a dialogue would be established to better define the overall scientific goals and requirements of the Panel on Mineral Resources, and allow recommendations for modification of these goals and requirements by interested investigators.

A. PORPHYRY COPPER SYSTEMS

There are few porphyry copper systems for which the marginal or lateral characteristics associated with mineralization have been studied adequately. The definition and study of the margins of these systems may not require deep holes such are as proposed for the dedicated research drilling. Research on abandoned holes in the margins of such systems would allow studies of lateral dimensions of porphyry copper systems, of complete hydrologic systems associated with porphyry copper and molybdenum concentrating processes, of related skarn processes, and of basic elemental abundance based on comparisons of selective metal contents within and outside of the production centers. Cores from the margins of porphyry copper systems are needed for bulk and trace metal geochemistry, fluid inclusion, and isotopic studies.

Numerous requests for the study of such systems on a district-wide regional scale were made by the Society of Economic Geologists' members who replied to the Society's Research Committee Questionnaire. The rationale for extending the studies of porphyry copper systems was that exploration geologists would be better able to recognize the margins of porphyry copper systems if more scientific attention was paid to them. Such studies are partially dependent on add-on investigations, including deepening of existing holes.

B. PRECIOUS METAL ENVIRONMENTS

The dedicated holes for Creede and Tonopah are focused upon epithermal precious metal mineralization and its relationships with deeper parts of those particular systems. This emphasis is not intended to overlook significant scientific problems connected with other types of gold-silver mineralization.

The current intense effort directed toward the discovery of epithermal vein gold-silver deposits and related "invisible" gold-silver disseminated in carbon- and/or sulfide-bearing host rocks is accompanied by a myriad of drill holes that are potential candidates for add-on investigations and deeper

drilling to explore the "bottoms" of these systems. The spatial and temporal relationships of these gold-silver-bearing systems to silicic caldera systems and to deeper seated base metal-bearing systems should be better understood. For instance, at Creede, there still is not a thorough understanding of the "invisible" disseminated silver mineralization in the lake sediments that may represent a leakage of the vein fluids upward into the sedimentary cover. Add-on investigations are recommended, in part to investigate the vertical relationship of mineral systems that have undergone multiple boiling episodes.

C. MASSIVE SULFIDE DEPOSITS

Many of the key questions pertaining to the origin of massive sulfide deposits can only be answered by study of wall rocks beyond the limits of ore *per se*. There is increasing interest in the comparison of wallrock alteration patterns associated with such deposits with hydrothermal alteration developed around currently active sulfide-forming vents in active rift systems on the modern sea floor. A rapidly developing line of investigation is directed at the interaction of massive sulfides with host rocks during regional metamorphism, an interaction involving sulfide-silicate reactions that tend to obscure primary mineral assemblages and thus the origin of the mineralization. In both of the cases cited, the research requires access to samples that may be barren, but are nevertheless scientifically informative. Once the opportunities for extension of drill holes planned by industry are identified by the Panel, scientific add-on investigations would provide a cost-effective means for probing these mineral-forming systems in their entirety. Clearly, the success of such an add-on program will depend upon development of an efficient mechanism for communication of the scientific needs to industry and the coordinated development of drilling programs that might satisfy those needs.

D. PLATINUM GROUP METALS (PGM) DEPOSITS

Recent research on the layered mafic complexes of the world has advanced our understanding of the thermodynamic concentration and temperature control of sulfur saturation in gabbroic magmas which in turn has led to various models for the generation of PGM-enriched sulfide layers in the Bushveld and Stillwater complexes. Further evaluation of such models will require continued laboratory research aimed at development of criteria for recognition of local and/or temporal sulfur saturation in the magmatic chamber, and a better understanding of melt-solid and solid-solid partitioning of the PGM elements as crystallization proceeds. Even given such improved understanding of the experimental systems, the recognition of the concentrative processes that were operative, as opposed to being merely possible, will require access to samples that most likely can only be provided by drilling. In the Stillwater Complex, for example, it becomes essential to determine the actual solid-melt partitioning of the PGM elements in the basal sulfide-free cumulate zone if mechanisms for generation of the PGM-enriched zones are to be defined. For the Stillwater complex, such research might be accomplished by add-on studies of existing holes and cores.

E. MISSISSIPPI VALLEY-TYPE DEPOSITS

Mississippi Valley-Type ore deposit systems are considered in an add-on category because many of the genetic problems associated with these systems can be addressed by experiments added on to industry drilling in intracratonic basins. Although this important type of mineralization has been intensely studied for decades, many of the basic questions such as the age of

mineralization and the source, mode of transport, and precipitation mechanisms for the metals remain unsolved. As with all of the mineral deposits considered in this report, it is essential to study the entire mineral-forming system of which the ore deposit itself may comprise an economically important but volumetrically trivial part. In the case of Mississippi Valley Type deposits, this requires access to the deeper parts of the basins where the metallizing brines were probably generated. One can visualize numerous situations in which add-on investigations would permit needed studies of water-rock reactions and isotopic exchange, of shale filtration mechanisms, of diagenetic vs mineral-related carbonate facies and their possible relations to fluid interfaces or mixing zones, and of metal partitioning between brines and host rocks at various depths. In some instances, it would be critical to extend existing drill holes into genetically significant but economically unrewarding ground; for example, studies of solution collapse mechanisms, and of the relationships between rock matrix (karst) and superimposed mineral matrix (hydrothermal) breccias often hindered or precluded by inaccessibility to the full stratigraphic section involved. It is anticipated that many add-on investigations of the Mississippi Valley Type environment will require in situ temperature measurements and sampling of any gases and/or brines encountered during exploration and/or mining.

F. SEDIMENTARY ENVIRONMENTS

The question of why more significant metal concentrations have not been found in black shale or "red bed" environments within the United States has been raised by both industry and academic groups. A number of university scientists have studied these carbonate and clastic environments, and a few industry research programs are oriented toward discovery of base metals in sedimentary environments. Add-on investigations to holes of opportunity represented by present and future drilling activities should be conducted to acquire samples and measurements from sedimentary basins. In addition, an examination of drilling repositories should be made to determine the availability of existing samples and measurements. Exchange of information can be made through the DEW NEWSLETTER and incorporated in the data acquisition system of the Department of Energy drilling data base at Lawrence Livermore National Laboratory (Pawloski et al., 1982).

Further investigations of sedimentary iron-manganese facies is required in, for example, the Animikie Basin. Studies of down-dip manganese distributions, iron-manganese ratios, and iron-manganese formations in the Animikie Basin in general, and in the Cuyuna Range of northern Minnesota specifically, are recommended. Such projects could possibly be considered as add-on investigations to holes proposed by the CSDC Panel on Basement Structures and Deep Continental Basins.

interest to the studies of mineral resources. Precambrian sedimentary basins contain a large portion of the world's mineral resources; they are poorly studied in this country.

G. CHEMISTRY OF THE CRUST

Significant subsurface data relating to metallogenic provinces could be obtained from a series of deep drill holes in the Southwest porphyry copper province. Such holes would provide a cross-section of a significant crustal region which characterizes critical features of the copper belt. It is unlikely that the question of whether a metallogenic province represents an inheritance of metals from an anomalous crustal section would be answered in a

few drillholes. However, the information produced would supplement existing drillhole well logs and core descriptuons.

Given the current level of petroleum exploration, it may also be possible to identify future oil company test sites for cooperative add-on geochemical experiments. The geochemical setting of Mid-Continent basement magnetic and gravity anomalies is of considerable interest to investigators of the Mississippi Valley-Type base metal sources. These metallogenic considerations could also be addressed as add-on investigations to holes proposed by the CSDC Panel on Basement Structures and Deep Continental Basins.

VI. DRILLING AND DIAGNOSTIC NEEDS

Scientific objectives for research investigations in drillholes will present unique requirements and constraints on drilling, logging, and downhole measurements. Although state of the art equipment will provide much of the information needed, needs for accurate determination of physical and chemical parameters encountered in drilling may require the development of special tools and sensors. Each research activity, whether an add-on investigation or a carefully planned drillhole dedicated to broad scientific objectives, will evolve specific requirements to attain its desired goal.

Although the focus of the Panel on Mineral Resources is on the scientific aspects of mineral deposit systems, technology development in drilling and diagnostics will also impact other aspects of the mineral resource base of the nation. Technologies developed for use in deep, hard, and possibly hot formations could result in lower exploration costs. Knowledge generated on fluid pressures and formation permeability in deep holes will be critical for technology in hydrofracturing and solution mining, anticipated methods of mineral extraction in the decades ahead. Technological requirements for scientific studies of fossil mineralized systems at depth will be less demanding than requirements for studying hot, over- or underpressurized, active hydrothermal-magma systems.

A. DRILLING

Continental scientific research drilling requirements include such factors as: (1) recovering extensive core and fluid samples; (2) using completion techniques that allow *in situ* experiments; and (3) maintaining an open hole for a number of years for continuous monitoring and future scientific research.

Drilling techniques need refinement to improve sample recovery and downhole studies. Advanced technology is also needed for systems involving excessively hot, active hydrothermal formations. Geothermal drilling has provided wells and completions at temperatures to 300°C, with limited capabilities to 400°C. Coring and sampling equipment is currently limited to environments below about 200°C.

Continuous coring, needed for most of the holes, may include the use of specialized wireline deep-coring rigs that can bore holes up to 11 cm in diameter and cut cores up to 5.4 cm in diameter. Current wireline rigs have the capability to drill to depths of about 4.5 km; conventional rotary rigs would probably be required for deeper or significantly larger diameter bore holes.

B. DIAGNOSTICS

Scientific data from these holes will be derived cores, fluid samples, and well logs and other downhole measurements. Environmental parameters such as the following will need to be determined from the collected data:

a. orientation, spacing, and apertures of fractures;

b. fluid inclusions in vein fillings;

c. structures and/or textures indicative of hydrothermal leaching and precipitation;

d. vein and alteration mineral assemblage studies for estimates of chemical parameters;

e. isotopic (sulfur, oxygen, carbon, hydrogen) studies of solid and fluid phases; and

f. brine zones and compositions;

g. distribution of *in situ* temperature, pressure, and geophysical properties (magnetic, electrical, seismic, gravity, mechanical) with depth; and

h. near-hole properties (determined by hole-to-hole and hole-to-surface measurements).

Sampling and Sample Analysis. Samples of fluids from various depths, as localized and uncontaminated as possible, must be obtained from the boreholes to define the origins of potential fossil ore fluids or contributors to the ore fluid system. Equipment development will be needed for research proposed by individual scientists as specific experiments are proposed. A limited but effective analytical capability at the drill site is required to provide real-time research input to the drilling and field logistics. Analyses needed (e.g., fluids and solids, petrographic, scanning electron microscopy with X-ray fluoresence) are currently available. Operational facilities will be defined when research requirements are specified.

In Situ Experiments. Geophysical and geochemical, downhole, hole-to-hole, and hole-to-surface measurements are needed to extrapolate data from core and log analyses to the far field, to aid interpretation of surface geophysical exploration techniques, to identify major structural changes, and to study temporal chemical and physical changes. Specific downhole experiments include measurements of *in situ* stress, petrochemical analysis, application of seismic and electrical techniques for formation studies by frequency sweeps, effect of potential fields on chemical processes, identification of permeation routes *via* tracer studies, and isotopic or fluid chemistry changes with time.

Hole-to-hole seismic, electrical, and tracer studies can be used to determine structural and stratigraphic discontinuities and anomalies, identify permeable paths, evaluate the uniformity of a given volume with respect to the surface geophysical data, and confirm mineral deposit models.

Hole-to-surface measurements are critical to separate the effects of near surface geology in the interpretation of geophysical exploration data. Specific experiments would include hole-to-surface or surface-to-hole seismic

studies to understand quantitatively the effect of weathering, faults, and fractured structures on refraction and reflection seismic data. Similar electrical resistivity data are needed to confirm theoretical analyses on the effect of layered conductors on geophysical data interpretations.

Long term experiments are required to identify permeabilities and permeable paths by injection of tracers into the formation and monitoring appearance of the tracer in the drill hole. In situ teleseismic measurements would be used to distinguish deep crustal structure without signal loss by attenuation and dispersion in the fractured upper crust. In situ temperature measurements to define undisturbed thermal gradients and fluid motion in the formation. Equilibrium thermal properties of the formation are needed to validate models of the heat sources and transport. Electrical measurements, hole-to-hole or hole-to-surface, would be used to evaluate the effect of climatic cycles on the formation response to geophysical measurements.

Geophysical logging: Geophysical logs will be run in all boreholes, whether or not core is recovered. Such logs provide vital quantitative information on intervals where core-recovery is incomplete due to fracturing or dissolution, identify specific regions for detailed coring or repeat logging analysis, and provide information on variations near the drillhole. Geophysical logs also provide essential ancillary information on continuity of rock properties that is difficult or impossible to obtain from core by laboratory measurement. Drill logs may indicate which core sections and which laboratory measurements should be done in more detail and which may be omitted. Geophysical logs of a properly-sited borehole may also be used to calibrate, and thereby substantially improve the precision of interpretation of regional geophysical work. Analyses are expected to suggest new geophysical strategies to address scientific questions raised by the research drilling project.

The variety of experimental and developmental logging tools afforded by university, government, and industry laboratories, many of which have been designed specifically for small-diameter holes should be used. For example, the U.S. Geological Survey (USGS) Branch of Petrophysics and Remote Sensing has developed a suite of experimental and developmental logging tools designed specifically for small-diameter holes (3 to 4.5 inches - 7 to 11 cm) in hard rock.

Logging tools for hot, active hydrothermal systems are limited by insulation capabilities and cable degradation. New commercial tools with cable are useable to about 300°C. Special systems could be developed for high temperature use when specific scientific needs are identified. Diagnostics and technologies needed for logging in such hostile environments are being addressed by the Panel on Thermal Resources.

C. PRELIMINARY INFORMATION REQUIREMENTS

Drilling and diagnostic technology requirements will be modified to meet the scientific goals as specific sites are selected and as details of experiments are developed. Issues that need to be addressed include:

1. models of the down-hole environments should be developed by each task group for a dedicated drilling target;

2. identification of specific geological data and data accuracy requirements needed by researchers; and

3. definition of down-hole experiment requirements, including in situ chemistry and property measurements, data and operational constraints, hole-to-hole experiments, and provisions to keep holes open when required.

Logistics and costs for research operations obviously will be determined by the specific sites and experiments. The following information should be acquired to support research planning:

1. compilation of contract drilling and coring capabilities, costs, and limitations;

2. estimation of costs of staging, workover rigs, and other field related operations; and

3. category and comparison of types, dimensions, and capabilities of slim hole logging tools.

REFERENCES CITED

Ashley, R. P. 1974. Goldfield mining district, p. 49-66. In Guidebook to the geology of four Tertiary volcanic centers in central Nevada. Nevada Bureau Mines and Geol. Rep. 19, Reno, Nv.

Barton, P. B., Jr., P. M. Bethke, and E. Roedder. 1977. Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado: Part III. Progress toward interpretation of the chemistry of the ore-forming fluid for the OH vein. Econ. Geol. 72:1-24.

Berger and Eimon, 1982. NEED REFERENCE.

Bethke, 1980. NEED REFERENCE.

Bethke, P. M., P. B. Barton, Jr., M. A. Lanphere, and T. A. Steven. 1976. Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado: II. Age of mineralization. Econ. Geol. 71:1006-1011.

Bethke, P. M., and R. O. Rye. 1979. Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado: Part IV. Source of fluids from oxygen, hydrogen, and carbon isotope studies. Econ. Geol. 74:1832-1851.

Bodnar, R. J., and R. E. Beane 1980. Temporal and spatial variations in hydrothermal fluid characteristics during vein filling in preore cover overlying deeply buried porphyry copper-type mineralization at Red Mountain, Arizona. Econ. Geol. 75:876-893.

Bonham, H. F., Jr., and L. J. Garside 1979. Geology of the Tonopah, Lone Mountain, Klondike, and northern Mud Lake quadrangles, Nevada, p. XXX - XXX. In Nevada Bureau Mines and Geol. Bull. 92. 142 p.

Brimhall, G. H., Jr. 1979. Lithologic determination of mass transfer mechanisms of multiple-stage porphyry copper mineralization at Butte, Montana: Vein formation by hypogene leaching and enrichment of potassium-silicate protore. Econ. Geol. 74:556-589.

Brimhall, G. H., Jr. 1980. Deep hypogene oxidation of porphyry copper potassium-silicate protore at Butte, Montana: A theoretical evaluation of the copper remobilization hypothesis. Econ. Geol. 75:384-409.

Buchanan, 1981. NEED REFERENCE.

Committee on Mineral Resources and the Environment (COMRATE). 1975. Mineral resources and the environment. Commission on Natural Resources, National Academy of Sciences-National Research Council, Washington, DC. 348 p. [NOT CITED!]

Corn, R. M. 1975. Alteration-mineral zoning, Red Mountain, Arizona. Econ. Geol. 70:1437-1447.

Doe et al., 1978. NEED REFERENCE.

Drewes, H. 1971a. Geological map of the Mount Wrightson Quadrangle, southeast of Tucson, Santa Cruz and Pima Counties, Arizona. U.S. Geol. Survey Misc. Geol. Inv. Map I-614.

Drewes, H. 1971b. Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona. U.S. Geol. Survey Prof. Paper 658-C.

Drewes, H. 1972a. Cenozoic rocks of the Santa Rita Mountains, southeast of Tucson, Arizona. U.S. Geol. Survey Prof. Paper 746.

Drewes, H. 1972b. Structural geology of the Santa Rita Mountains, southeast of Tucson, Arizona. U.S. Geol. Survey Prof. Paper 748.

Eidel, J.J. 1981. Preliminary results of the SEG Research Questionaire. Econ. Geol. 76:542-543.

Eimon, 1981. NEED REFERENCE.

Fahley, 1981. NEED REFERENCE.

Geophysics Study Committee. 1981. Mineral resources: Genetic understanding for practical applications. Geophysics Research Board, National Academy of Sciences Press, Washington, DC. 119 p.

Lowell, J. D., and J. M. Guilbert. 1970. Lateral and vertical alteration-mineralization zoning in porphyry ore deposits. Econ. Geol. 65:373-408.

Nolan, T. B. 1935. The underground geology of the Tonopah mining district, Nevada. Univ. Nevada Bull. 29(5). 49 p.

Pawloski, G. A., N. Howard, G. Hage, M. L. Higuera, and W. Richardson. 1982. The Continental Scientific Drilling Program data base. Lawrence Livermore National Lab. Rpt. UCRL-53284, Livermore, CA. 89p.

Quinlan, J. J. 1981. Geology and silicate-sulfide alteration zoning at the Red Mountain porphyry copper deposit, Santa Cruz County, Arizona, p. XXX - XXX. In Arizona Geological Society Field Trip Guidebook to Red Mountain District, Arizona.

Roedder, E. 1965. Evidence from fluid inclusions as to the nature of the ore-forming fluids, p. 375-384. In Symposium on problems of postmagmatic ore deposition, Prague 1963. Czechoslovakia Geol. Survey, Prague, vol. 2.

Roedder, E. 1977. Changes in ore fluid with time, from fluid inclusion studies at Creede, Colorado, p. 179-185. In Proc. Internat. Assoc. Genesis of Ore Deposits, 4th Symposium, Varna, Bulgaria, 1974. Sofia, Bulgaria, IAGOD, vol. 2.

Rose, A. W. 1970. Zonal relations of wallrock alteration and sulfide distribution of porphyry copper deposits. Econ. Geol. 65:920-936.

Rose, A. W., H. L. Barnes, C. W. Burnham, and H. Ohmoto. 1977. Research frontiers in exploration for non-renewable resources. The Penn. State Univ. Rep. NSF/RA-770031, University Park, Pa. 164 p.

Schrader, F. C. 1915. Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona, with contributions by J. M. Hill. U.S. Geol. Survey Bull, 582.

Silberman, M. L., H. F. Bonham, Jr., L. J. Garside, and R. P. Ashley. 1979. Timing of hydrothermal alteration-mineralization and igneous activity in the Tonopah mining district and vicinity, Nye and Esmeralda Counties, Nevada, p. XXX - XXX. In Papers on mineral deposits of North America, The International Association on the Genesis of Ore Deposits Fifth Quadrennial Symposium Proceedings, Vol. 2. Nevada Bureau Mines and Geol. Rep. 33:119-126.

Simons, F. S. 1971. Mesozoic stratigraphy of the Patagonia Mountains and adjoining area, Santa Cruz County, Arizona. U.S. Geol. Survey Prof. Paper 685-E.

Simons, F. W. 1974. Geologic map and sections of the Nogales and Lochiel Quadrangle, Santa Cruz County, Arizona. U.S. Geol. Survey Misc. Inv. Series I-762.

Steven, T. A., and J. C. Ratte. 1965. Geology and structural control of ore deposition in the Creede district, San Juan Mountains, Colorado. U.S. Geolog. Survey Prof. Paper 487. 90p.

Steven and Friedman, 1968. NEED REFERENCE.

Steven, T. A., and G. P. Eaton. 1975. Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado: I. Geologic, hydroligic, and geophysical setting. Econ. Geol. 70:1023-1037.

Steven, T. A., and P. W. Lipman. 1976. Calderas of the San Juan volcanic field, southwestern Colorado. U.S. Geolog. Survey Prof. Paper 958. 35p.

Taylor, H. P. 1973. O^{18}/O^{16} evidence for meteoric-hydrothermal alteration and ore deposition in the Tonopah, Comstock Lode, and Goldfield mining districts, Nevada. Econ. Geol. 68:747-764.

U.S. Geodynamics Committee. 1979. Continental scientific drilling program. Geophysics Research Board, National Academy of Sciences-National Research Council, Washington, DC. 192 p.

Ward, S. H., R. Campbell, J. D. Corbett, G. W. Hohmann, C. K. Moss, and P. M. Wright. 1977. The Frontiers of mining geophysics. Dept. of Geology and Geophys., Univ. of Utah, Salt Lake City, UT. 309 p.

Wetlaufer, P. H., P. M. Bethke, P. B. Barton, Jr., and R. O. Rye. 1979. The Creede Ag-Pb-Zn-Cu-Au District, Central San Juan Mountains, Colorado: A fossil geothermal system, p. 159-164. In J. D. Ridge (ed) Papers on mineral deposits of Western North America. Proc. IAGOD 5th Quadrennial Symposium, vol. II. Nevada Bur. Mines and Geology Rpt. 33, Reno.

FIGURE BY LOWELL, FOURNIER, AND BETHKE THAT WAS DRAFTED AT THE OCTOBER 21, 1982, MEETING OF THE PANEL

TABLE I: RESEARCH DRILLING SUMMARY

LOCATION	MAJOR MINERAL RESOURCE OBJECTIVES	ANTICIPATED DRILLING NO OF HOLES	ANTICIPATED DRILLING DEPTH PER HOLE KM
Fossil Systems			
Creede, CO	- test Creede formation as source of water, sulfur, and salinity of mineral fluids.	2	1
Creede, CO, and Tonopah, NV	- quantify physical and chemical nature of source rock system; investigate rock-hydrothermal interactions at depth; determine nature of heat source driving the hydrothermal system; construct comprehensive model of epithermal mineral-forming system.	2	5
Tonopah, NV	- refine epithermal and breccia geometries; confirm base-metal-bearing characterization of epithermal mineralization; detect low-dipping faults.	1 - 3	1 - 2
	- define bottom of epithermal system, intrusive complex, and source of molybdenum.	1 - 2	2 - 5
Red Mountain, AZ	- examine zone between shallow epithermal(?) silver-gold and top of porphyry copper mineralization - continue to bottom of potash alteration zone.	1	3 - 5
	- test relationship of mineralized breccia to main porphyry body and related alteration zones.	1	3 - 5
Butte, MT	- examine copper-molybdenum deposit and host porphyry interface.	2	3 - 4
	- determine extent of deep mineralized breccia and relation to mineralized porphyry.	2	2 - 3
Active Systems			
Valles Caldera, NM Yellowstone, WY Long Valley, CA Salton Sea, CA The Geysers/ Clear Lake, CA	For all active mineral systems: - understand temperature, composition, and source of fluids as a function of depth. - define source of high salinity. - study role of boiling in mineral deposition. - determine permeability variations and extent of self-sealing processes.	2	3 - 6