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TRANSMITTAL OF UNPUBLISHED PEER REVIEW REPORT

As requested in your letter of May 24, 1990, a copy of the following unpublished report is being transmitted herewith: "Report of the Peer Review Panel on the Proposed Program of Studies of the Calcite and Opaline-Silica Deposits in the Yucca Mountain Area, Nevada," by Gilbert N. Hanson, et al., June 18, 1987.

Carl P. Gertz, Project Manager
Yucca Mountain Project Office

YMP:DCD-3521

Enclosure:
Peer Review Report

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June 19, 1987

Dr. Maxwell B. Blanchard, Chief
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Dear Max:

Enclosed is the Report of the Peer Review Panel on the Proposed Program of Studies of the Calcite and Opaline-Silica Deposits in the Yucca Mountain Area. If you have any questions, I can be reached at Stony Brook until early September, after which I will be at the

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Best regards,

Gil

Gilbert N. Hanson
Professor

GNH:AR
Enc.

cc: S. R. Mattson

REPORT OF THE PEER REVIEW PANEL

ON THE

PROPOSED PROGRAM OF STUDIES OF THE

CALCITE AND OPALINE-SILICA DEPOSITS

IN THE YUCCA MOUNTAIN AREA

NEVADA

Gilbert N. Hanson, Chairman

Victor R. Baker

Philip M. Bethke

Peter J. Hudleston

Glenn R. Roquemore

June 18, 1987

Introduction

The members of the peer review panel of the proposed program of studies of the calcite and opaline-silica deposits located along faults in the Yucca Mountain area after reading the "Proposal for Study of Hydrogenic Deposits", observing some of these deposits in the field, listening to oral presentations of the proposed studies, and reading literature appropriate to this study present this unanimous report:

Several models have been suggested for these deposits in the proposal and in the workshop reports. These can be grouped into four main categories:

1. Pedogenic: meteoric waters flowing down through the soil have selectively deposited the calcite and opaline silica along fractures formed by faulting.

2. Cold Spring: cold ground waters ($T<30^{o}C$) have moved up along the faults depositing the calcite and opaline silica near the surface as spring deposits.

3. Hydrothermal: hot waters ($T>>30^{o}C$) of several possible origins have moved up along the faults depositing the calcite and opaline silica near the surface.

4. Seismic Pumping: hot or cold waters moved up along a fault as a direct result of faulting.

The data available for the veins at Trench 14 are not adequate to allow us to evaluate whether any one of these models is the correct one. Four major periods of silica and/or carbonate introduction have been recognized in Trench 14:

1. Chalcedony/opal linings of vugs in the non-welded Ranier Mesa tuff.
2. Drusy quartz and chalcedony lining vugs and fractures in the Tiva Canyon welded tuff.
3. Silica-cemented breccia.
4. Calcite and opaline-silica veins.

The silica-filling vugs and fractures in the Tiva Canyon and Ranier Mesa tuffs predate the breccia and vein fillings and are very likely products of the devitrification of the tuffs or later deposition from ground water. Such silica fillings are common in volcanic rocks the world over (e.g. thunder eggs). Similar occurrences can probably be found in each of the units at locations on the Test Site remote from faulting. Although these silica deposits cannot be ignored in the context of the proposed program, the panel recommends that their characterization be given lower priority than that of the silica-cemented breccia and the calcite and opaline-silica veins.

The silica-cemented breccia cut by the calcite and opaline-silica veins probably represents a different and earlier form of silica and carbonate introduction along the fault zone. On the basis of field inspection it may reasonably be interpreted as a hydrothermal eruption breccia. The peer reviewers feel that, because this is more likely to be of hydrothermal origin, it needs particular attention.

The calcite-opaline veins clearly cut the silica-cemented breccia, and are, therefore, the highest priority for study. There is some indication from the stable isotope data that the calcite and opal samples analyzed so far were deposited from water of less than 30°C, which would favor models 1 or 2. More data, however, are essential. Episodic expulsion of hot or cold water from depth as a consequence of faulting (seismic pumping) would produce effects similar to processes 2 and 3 above, and might not be distinguishable in the nature of the deposits. In the case of seismic pumping the laminae in the deposits will represent discrete fracturing events related to faulting. In the case of normal ground water flow the laminae may also describe faulting events, but they may in part reflect non-fault related changes in the character of ground water flow (e.g. climatic control). The members of the peer review were not able to suggest any model for the origin of the deposits not considered in the material presented to us.

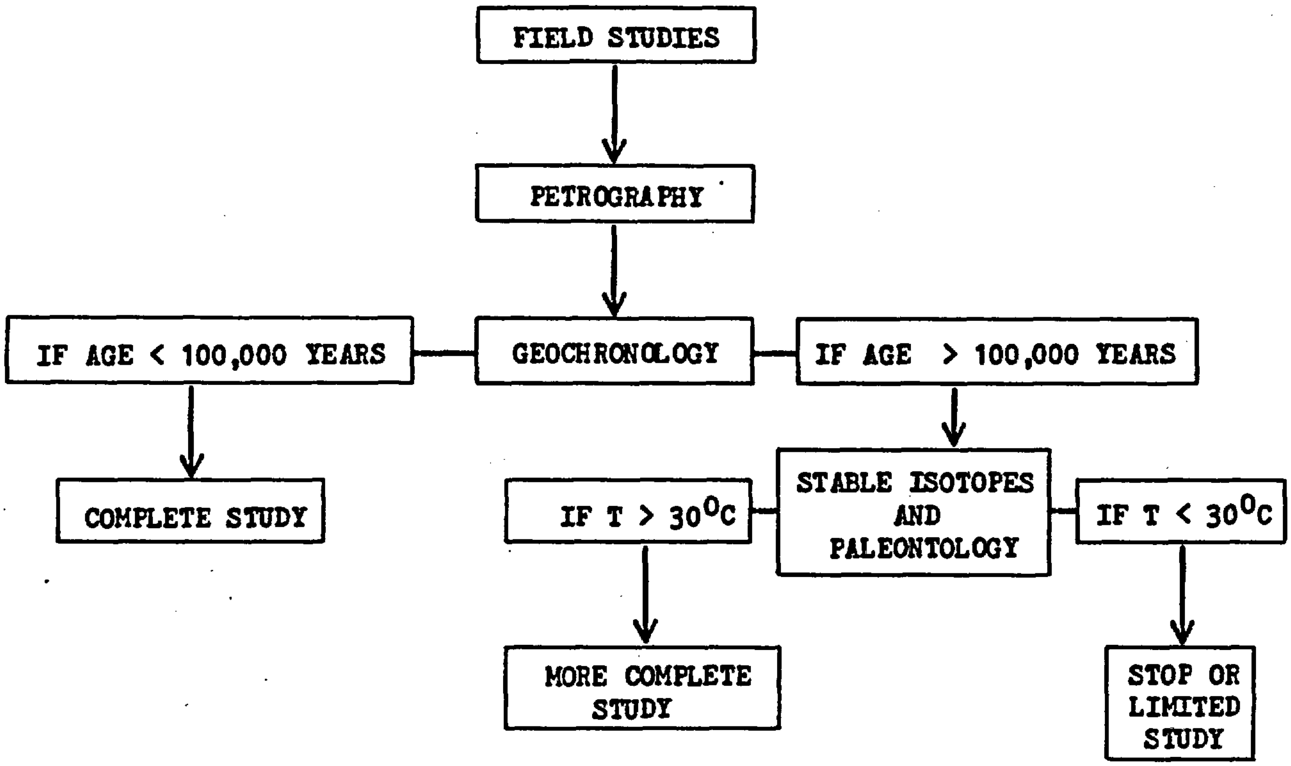
The present data are inadequate for determining the age of the vein formation.

Calcite and opaline-silica veins are common in faults in the Basin and Range. While a pedogenic origin has generally been assumed for these veins, no careful study, of the kind proposed, has really addressed their origin. Considering the ramifications of the effect of large volumes of waters derived from depth on a nuclear repository, it is essential that their origins be clarified. Thus, we strongly recommend that the study begin and recognize that the data collected so far has to be ignored due to inadequacies of quality assurance.

The studies should emphasize a detailed investigation of the veins and silica-cemented breccia in the fault at Trench 14 (near field studies). The results of the near field studies should be compared to less detailed investigations (far field studies) of the veins and breccia found at the sand ramps exposed on Busted Butte, veins exposed in trenches crossing other faults in the vicinity of Yucca Mountain, veins found in drill cores obtained in the vicinity of Yucca Mountain, and deposits found in hot and cold springs in and near the Nevada Test Site. We do not recommend extensive analytical studies of deposits outside of this area as analogs. The information available in published reports should be adequate for comparing the modes of formation. Comparisons should be made in collaboration with experts on such deposits. If necessary, limited analytical studies of such deposits should be made, again in collaboration with appropriate experts.

We recommend that field, petrographic, geochronological, stable isotope, and paleontological studies be undertaken at each site. Table 1 shows a plan for studies at each site. These studies are most important for: (1) helping to determine the age of the vein and breccia deposits associated with faulting; (2) placing constraints on time intervals between fault movements on a given fault assuming new veins are introduced at, or near, the time of faulting; (3) determining the temperature of waters responsible for the vein deposits; and (4) determining the origin of the veins and breccia. If the veins are young (i.e., less than 100,000 years old), a more complete study, including mineralogy; fluid inclusions; major, minor, and trace element; and tracer isotopes studies will be required. If the veins are old (i.e., greater than 100,000 years) and formed from cold waters, no further studies may be warranted. If the veins or breccias are old (i.e., greater than 100,000 years) and from hot waters, some limited mineralogical and geochemical studies may be warranted.

TABLE 1. FLOW PLAN FOR INVESTIGATIONS OF THE CALCITE AND OPALINE-SILICA VEINS



The personnel proposed to be involved in the study are highly quaified scientists, but the panel notes a lack of experience in vein petrology. Because of the fundamental importance of vein petrography (as discussed in a later section of this report) in developing a sampling base for required detailed studies the panel recommends that a geoscientist experienced in the detailed study of epithermal veins be added to the study group and be given the responsiblity for vein and breccia petrography. The USGS employs a number of individuals highly qualified to conduct such studies.

Field Investigations

Introduction

The field investigation phase of the study provides base-line data for the further analysis of the calcite and opaline-silica deposits. The primary investigations will be near-field, concentrated on the Trench 14 site. The existing trench exposures should be used, as well as expansion of the existing exposures and the excavation of new sites. During the course of the investigation a careful and methodical approach should be taken in sample collection and cataloging.

Far-field investigations need to be conducted that will attempt to compare the features of the calcite and opaline-silica veins in Trench 14 to those of other sites throughout Yucca Mountain, both along faults and at the colluvium-bedrock contact away from faults. The regional comparison should include those deposits in the sand ramps at Busted Butte as well as samples found in the deep cores close to the repository location. Local springs of all types should be investigated for correlatives to the Trench 14 site and a careful review of the open literature should be conducted to locate possible analogs throughout the world. If the literature search proves limited, field studies of analogs outside of the State of Nevada should be permitted.

Near Field Investigations

Systematic Exploratory Trench Logging

Trench 14 contains an extremely complicated mass of calcite and opaline-silica vein infilling. It is evident from field observation, trench logs and photography that cross-cutting relationships exist in the exposed trench walls. These cross-cutting relationships could have a bearing on the origin of the vein filling and possibly on fracture-opening events, presumably faulting events. Through careful small scale mapping procedures*

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*A newly developed procedure of trench logging involves gridding the entire trench wall and numbering the grids in a convenient manner. The wall is then photographed at an equal distance from the wall. A monorail is often used to slide the camera mount on. Overlap is taken in the photographs for stereo viewing. A stereo-zoom transfer scope is used to map the photographs on graph paper. This procedure allows for extremely detailed mapping of the trench wall at various scales and for registration of samples and documentation of sampling procedures.

combined with mapping polished slabs, as discussed in the section on Mineralogy-Petrography, it may also be possible to construct a vein filling history. This history would provide a basis for detailed sampling, and information about the origin of the vein filling by showing growth patterns that could be associated with cold or hot water spring deposition from below, growth patterns that might be associated with the opening of fractures by faulting events followed by the downflow of water, or growth associated with episodic expulsion of water from depth during faulting.

Expanded Exploratory Investigation

The existing trench exposures should provide a vast amount of information; however, the 3-dimensionality of the site should be expanded. Trench 14 should be deepened at least to the intersection point of the three prominent veins. The potential for additional cross-cutting relationships exists at this intersection and such relationships may provide information on the recurrence of faulting events and on vein-filling history. A series of shallow trenches that expose the major vein infilling in the tuff should be placed along strike of the fault. The lateral characteristics of the vein infilling, the relationship of the platy calcrete to the fracture filled veins, and the relationship of the overlying soils to the vein filling should be investigated. If it appears that the exploratory trench investigations lack the required information, it might be important to conduct a shallow drilling program. The drill holes should begin up slope of the existing fault trace and continue down slope perpendicular to the fault trace. The holes should be cored and extend through the vein filling or until a depth limit is reached. The panel felt that deep drilling at Trench 14 may not yield useful information. One problem with drilling is that many vein systems are discontinuous leading to uncertainties in interpretation if veins are absent in the drill core.

Field Sampling

For the purpose of detailed petrographic and geochemical studies it is suggested that oriented and registered block samples be taken from the calcite and opaline-silica veins and from the silicified breccia. The blocks taken from the vein material should include the entire vein with some tuff as well. This procedure will simplify the record-keeping of sample locations for several experiments that could be conducted on the block. The block(s) and other samples should be filed in a manner similar to the core library procedure. The trench wall should be gridded to closer intervals than 1 meter. Within the grids, sample locations should be carefully marked and transferred to a sample log at a scale equal to the trench log and photographed. A grid numbering system could be established that is based on a standard water well numbering convention.

Another important aspect to the sample collecting procedures is that they should be conducted with input from all disciplines that expect to be conducting experiments on sample material. This will unify the record keeping and library utilization of the samples.

Far Field Investigations

Regional Exploratory Trenching

The far field studies will expand the relationships from the Trench 14 site to other areas within Yucca Mountain. Each far field site will not require the detail of Trench 14 but will serve to investigate the potential for a uniform process of vein filling, site specific processes, or a combination of processes throughout the repository area. Obvious targets for the far field investigations should include known, mapped faults and the colluvium-bedrock contact where shallow bedrock is available. The sand ramp area of Busted Butte displayed a vastly different field relationship in vein filling character than the Trench 14 site. The bedrock exposed below the sand ramps at Busted Butte should be trenched to explore for Trench 14-like vein filling.

The problem at hand involves the mobility of water through the repository site and the implications of water-deposited materials discovered in Trench 14. Vein filling has been seen in deep (below the repository level) drill core. The nature of these deep, vein-filling materials must be compared to all surface samples taken in the near field study. The correlation or lack of correlation of these two source areas is very important to conclusions that can be drawn from the surface information alone.

Local analogs of spring activity could be characterized by the investigation of presently operating spring activity on and around the Nevada Test Site. It may be possible to study cold, warm, fault related and non-fault related spring activity that could be used to correlate various modes of vein infilling back to Trench 14 and other sites as well.

It should be possible to locate far field analogs from the available open literature. This procedure should be conducted by experts skilled in spring water deposition, hydrothermal deposition, and seismically-induced water flow. If the literature search does not reveal sufficient information, it may be required to conduct research on these topics using sites not only in Nevada, but in other states as well.

Mineralogy - Petrography

The Panel recommends that Section 3.2 (Mineralogy) of the Proposal be expanded to include Petrographic Studies. Such studies are implied, but not explicitly identified, in the Proposal.

Near Field Studies

Petrography

Petrographic studies at the hand specimen and microscopic scale of samples from Trench 14 are needed for the following proposes: (1) determination of the history of vein filling, (2) the location of fluid inclusions, and (3) the location of microfossils. Methodology should include polished slab mapping of fracture filling, and petrographic microscopic studies including cathode luminescence (luminoscope) and ultraviolet fluorescence examination.

Mapping of fracture filling on polished slabs is an extension of trench logging to the hand specimen scale, and is required to determine the number of episodes and sequence of fracture filling. The maps prepared in this phase of the study will provide the basis of sampling for geochronology and subsequent geochemical, mineralogical and paleontological tests. They are thus fundamental to the program and need to be prepared as soon, and with as much care, as possible. The techniques of slab mapping are standard and have been used by ore deposit geologists in numerous studies of hydrothermal ore deposits. There is a lack of experienced personnel in this critical area.

Petrographic microscopic study extends fracture mapping to a microscale, and is often needed to clarify relations between minerals or mineral assemblages. It may provide information on replacement of one mineral, or mineral assemblage, by another, and may provide textural information that will allow correlation of depositional stages. Microscopic petrography may serve to locate fluid inclusions and microfossils. It also provides guidance for subsequent electron microprobe or other micro-sampling techniques. Methods of petrographic microscopy are well established, and several of the proposed investigators are expert in them.

Cathode luminescence and ultraviolet fluorescence examination of vein material is recommended. The luminescence and fluorescence characteristics of the various layers of opaline silica or calcite may be sufficiently different to provide a basis of correlation for the relative timing of fracture filling events. They may also elucidate textural features (particularly growth textures) that are not apparent in transmitted or reflected visible light.

Mineralogy

Mineralogical studies of materials from Trench 14 fall into two categories of the Project Flow Sheet (Table 1); they are needed in support of the petrographic study and are principal elements in the characterization at the vein fillings. Mineralogical studies in support of petrography are principally those of mineral identification (including the different forms of opal). It is possible, but not considered probable, that changes in mineral chemistry will help in the correlation of depositional units. The methodology needed is petrographic microscopy and X-ray diffraction, and possibly electron microprobe and microchemical studies. These techniques are standard and the investigators are expert in their application.

Detailed mineralogical characterization studies are needed to: (1) compare the different types of fracture (or breccia) filling in Trench 14, (2) compare the mineralogy of each type to that reported in the literature for possible analogs of known origin, and (3) provide a basis for selection of samples for geochemical study, and for the interpretation of the results of such study.

Mineralogical characterization should include: (1) the form of silica, (2) the chemical composition (including trace elements) of silica and carbonate minerals, and (3) the identification and, possibly, chemical composition of other minerals found in the vein fillings.

Methodologies needed in the mineralogical characterizations include: (1) X-ray diffraction, (2) electron microprobe and/or analytical scanning electron microscopy, (3) transmitted and, possibly, reflected light microscopy, and (4) chemical analytical techniques such as INAA on mineral separates. In many cases sampling for chemical analysis may need to be done on a microscale within one depositional interval. The required methodologies are available to the investigators, and they are expert in their use.

Materials to be Studied

Materials from Trench 14 requiring mineralogic-petrographic characterization include: (1) banded calcite and opaline-silica fracture fillings, (2) silica-cemented breccia (with some matrix calcite) cut by (1) above, (3) sub-horizontal, platy calcite masses in the platy petrocalcic horizon (Unit 3) overlying bedrock and cut by the apparently latest stages of calcite-opal veining, and (4) drusy quartz in cavities in the Tiva Canyon ash flow tuff. Characterization, comparison, and determination of relative ages of the first three materials is of much higher priority than study of the drusy quartz. This is so because the drusy quartz does not occur as fracture filling, and is probably not related to the veining of interest.

Far Field Studies

Mineralogical-petrographic studies similar to those performed on materials from Trench 14, but of much more limited scope, are recommended for calcite-silica deposits at sites removed from Trench 14. These include: (1) vein and breccia filling, uncovered by additional trenching, (2) calcite and/or silica vein fillings in drill core from Yucca Mountain including those close to, and, particularly, below the repository horizon, and (3) precipitations at local springs in and around the NTS. The scope of these studies should be limited by selection of materials and techniques shown to be important by the comprehensive study of material from Trench 14.

In addition to the above, samples of wind-blown dust should be characterized mineralogically. The specifics of methodology will depend on the mineral content. Perhaps X-ray diffraction analysis will be sufficient.

Geochronology

Certain of the geochronology studies are absolutely essential to the Project and those involved are highly expert at such studies. These studies should be completed as soon as possible in order to constrain the number and types of other investigations. Critical in this regard is the establishment of a minimum age for the calcite and opaline-silica vein fillings. Four analyses can be used for this purpose, as follows: (1) Uranium-series dating of the youngest calcite vein fillings (as determined by field/petrographic criteria); (2) Uranium-trend dating of the argillic B horizon (Unit 2) of the paleosol developed in the colluvium; (3) Uranium-series dating of the platy petrocalcic horizon (Unit 3) of the paleosol developed on the colluvium; and (4) Potassium-Argon dating of the magnetic black ash filling veins that cut all units older than Unit 2.

Although some of the above dating may not be wholly satisfactory, it is likely that a minimum age will be sufficiently designated to determine if the age of the calcite and opaline-silica vein fillings is either (1) less than 100,000 years or (2) greater than 100,000 years. In case (1) a much more extensive geochronology study will have to be undertaken in relation to the more extensive geochemical characterization. In either case geochronology will have to be used to establish the absolute age relationships for the calcite and opaline-silica vein fillings.

If the age of the deposits is less than 400,000 years, Uranium-series dating will be of major use in establishing the complex history of fracturing and vein filling with calcite and opaline silica. This method will also be critical in the correlation of Trench 14 history to other sites of calcite and opaline-silica accumulation in fault zones.

The proposed fission-track measurements from wall-rock and tuff materials will mainly be useful in checking for annealing of apatite as a paleo temperature tool. This result should resolve the hydrothermal hypothesis. However, ages of the wall rock, including the silica-cemented breccias will be of low priority if sufficient antiquity (greater than 100,000 years) can be demonstrated for the calcite and opaline-silica vein fillings. If the latter prove to be relatively young, then a high priority must be placed on dating the relationship of the calcite and opaline-silica veins to the silica-cemented breccias.

For this particular project the electron spin resonance dating seems of low-priority in comparison with other methods. The panel finds this project scientifically interesting and suggests that it may be of broader applicability to other geochronological concerns in relation to the Nevada Nuclear Waste Storage Investigations Project.

One stated objective of the isotopic dating studies was to determine absolute ages of spring, lake and pedogenic deposits at and near the Yucca mountain area. This objective only becomes important if the calcite/opaline silica veins of fault zones turn out to be relatively young, i.e. less than 100,000 years old.

Stable Isotopes

A comprehensive stable isotope study of the materials from Trench 14 (and less comprehensive study of far-field deposits) offers considerable promise in determining the origin of the calcite and opaline-silica veins and associated breccia-fillings. The principal investigator is top-notch, and the analytical and interpretive methodologies are well established. A very large data base exists on the stable isotopic systematics of potential analog environments, and it is supported by a solid body of theory.

The oxygen and carbon isotopic composition of calcite, the oxygen isotopic composition of opal, and the hydrogen isotopic composition of inclusion fluids (if such can be documented as primary) can be used in combination to estimate the source of water, its thermal history, and the temperature of mineral deposition. If primary clay minerals are present and can be analyzed, their hydrogen and oxygen isotopic composition can aid the interpretation.

The discussion of stable isotope studies in the proposal leaves a few worries, but the panel feels that all can be addressed:

1. The oxygen isotopic composition of fluid inclusions in oxygen-bearing minerals (particularly calcite) cannot be used to define the oxygen isotopic composition of the depositing water unless it can be independently demonstrated that the fluid was trapped at near-ambient temperatures. This is because of the potential for continued exchange with the host during the cooling history. This is well recognized by the principal investigator and should be no concern. If the proposal is written into a work plan, this aspect should be omitted or qualified.

2. In low temperature environments (specifically travertines) the carbon and oxygen isotopic composition of calcite is controlled by kinetic fractionation factors, i.e., their composition is a function of rate of precipitation. This has been well documented in the literature. These fractionations are regular, however, and the composition of carbonates falls along linear trends on C-13 - O-18 diagrams, the slope of the trend being a function of the rate of precipitation. At sufficiently slow rates the values fall along an equilibrium fractionation trend. Therefore, the degree of approach to equilibrium can be estimated in such systems if a sufficient range of C-13 and O-18 values is found. This, too is well recognized by the principal investigator, and needs only acknowledgement.

3. There is not yet sufficient knowledge of the thickness or isotopic homogeneity of individual bands in the banded calcite and opaline silica or in the breccia filling to warrant purchase of a laser sampling system. The principal investigator is a master at obtaining and running small samples. Preliminary analysis based on the detailed vein mapping may well provide such justification in the future, and if so such a system could prove very important to the study.

The general opinion of the Panel is that stable isotopes hold real promise for the resolution of the problem of origin of the calcite-opal veins, that the principal investigator is the right person to get the most out of the study, and that the sampling must be very closely tied to the history of the vein-filling.

Fluid Inclusions

The possible utility of fluid inclusions in evaluating the origin of the Trench 14 calcite opaline silica veins is discussed in the proposal, but few specifics are supplied as to either the methods to be employed or the materials to be studied. This is no doubt due to the fact that two-phase fluid inclusions have been found only in drusy quartz, and only a few of them were large enough to allow measurement of homogenization temperature on a heating-freezing stage. None were large enough to allow determination of freezing point depression. In the opinion of the panel it is unlikely that fluid inclusion studies of any type will prove of value, but some feasibility studies are probably warranted.

Fluid inclusions trapped at temperatures below about 70°C usually do not nucleate a vapor bubble on cooling. Lack of the optical contrast between the vapor bubble and surrounding liquid makes such inclusions hard to see in minerals of low refractive index, and particularly in those of high birefringence. The problem is seriously compounded by fine grain size. The vein calcites very likely contain many such "cryptic" inclusions. This can be determined by opening the inclusions by thermal decrepitation or by crushing, both in vacuo, and by collecting the water in a cold trap. If many cryptic inclusions are present, it suggests that the temperature of trapping was below 70°C, and suggests that it may be possible to analyze the contents of the inclusions. Another method of recognizing the presence of "cryptic" fluid inclusions (and estimating their size) is by examination of polished surfaces of calcite. Pits due to the opening of fluid inclusions can usually be distinguished from those resulting from sample preparation, particularly if the nature of their walls is examined by scanning electron microscopy.

Both the gas chemistry and aqueous solutes can be analyzed for bulk samples of fluid inclusions by techniques briefly described in the proposal. However, no really satisfactory method of analyzing aqueous solutes has yet been developed. Those methods employing the opening of the inclusions by thermal decrepitation or crushing in vacuo followed by leaching of the residue have been particularly disappointing. Charge balances typically disagree by more than 20%! The problem appears to be in the leaching process. The panel sees no value in attempting such analyses on material from the calcite-opal veins.

Determination of gas chemistry of fluid inclusions is, in general, a very promising technique, but is still in the developmental stage. It is being developed, principally, in three laboratories in the United States: Dave Norman's lab at New Mexico Tech, Colin Barker's lab at the University of Oklahoma, and Gary Landis' lab at the USGS in Denver. It is far from a standard technique, but many labs are rushing to acquire the instrumentation because of its promise. The data base on the gas chemistry of fluid inclusions from various environments is very small, so that even general interpretation of results is difficult. The panel is of the opinion that the potential value of the gas chemistry of fluid inclusions is sufficiently small that only a reconnaissance study of calcite should be attempted, and only if such analyses can be accomplished in one of the three principal laboratories, or if other facilities are being developed for other purposes within one of the participating groups. In the latter event, advice and continuing guidance should be sought from at least two of the operators of the principal laboratories because each of the three has custom-developed his methodology and each methodology differs from the others in significant ways. This is a tough game, and there is a real danger of substantial misinterpretation. A further concern has to do with the analysis of inclusions whose integrity cannot be checked optically. This is recognized in the proposal, but no strategy of verification is presented.

In general, the fluid inclusion section of the proposal suggests a lack of experience in fluid inclusion studies, although the principals presumably involved are first class scientists.

Geochemistry

The geochemistry program presented in the proposal emphasizes analytical techniques rather than addressing the more important problem of how the geochemical data will be used to place constraints on the origin of the hydrogenic deposits. The investigators should present well thought-out arguments as to which elements may be the most useful, including a description of the approach necessary to evaluate the data. It would seem more appropriate to analyze a limited number of well characterized samples for those elements that most low-temperature geochemists would agree could help in such a discrimination rather than analyze a large number of elements on a large number of samples. Using strictly a fingerprinting approach for evaluating the data may not be useful because it may not allow the investigators to account for variations in water chemistry due to factors such as, for example, the extents to which the various waters have reacted with a variety of host rocks before precipitating the calcite and opaline silica. It is not clear from the proposal whether the investigators have sufficient experience with trace elements in low-temperature, vein deposits to make adequate evaluations.

Tracer Isotopes

The tracer isotope studies as presented are well thought out and worthwhile. The analysts will produce first-rate isotopic data. It is essential that these studies be integrated at a very early stage with the major, minor, and trace element studies on the same material.

Paleontology

Although some very generalized age information is provided, the main purpose of the paleontological studies is in providing paleoenvironmental information. This information is complementary to information provided by geochemical techniques, notably the stable isotope studies. Thus, the paleontological studies should proceed regardless of the initial geochronology results, that is whether or not the age of the calcite and opaline-silica vein fillings exceeds 100,000 years.

The paleontological studies must be tied closely to the sampling strategy that is keyed to critical field relationships and petrography. It is essential that the paleoenvironmental interpretations be tied to key, dated horizons. Moreover, the strategy of collecting from modern analog environments is a sound one, quite necessary to establishing the paleoenvironmental connections. The investigator is a recognized expert in such paleontological studies.

Hydrologic Studies

The hydrologic studies proposed as part of this Project are all in a sense derivative. Models of past groundwater flow in the vicinity of the Bow Ridge Fault and Trench 14 will depend on parameters and information that are provided by the other parts of the Project. There are no studies proposed which have a direct bearing on the age or origin of the calcite and opaline-silica deposits, nor do we believe there are any such appropriate studies.

Studies of the chemistry of water from active springs in the Test Site area are proposed, and these will provide data to help assess the relative merits of the various models being considered for the origin of the calcite-opaline silica deposits. They should proceed as planned.

The hydrological studies are thus peripheral to the main concerns of the Project. They are, however, obviously central to other aspects of site characterization.

Data Integration

It is very clear that close cooperation among all researchers is essential at all stages of this Project, both because there is interdependence among the various approaches to be used and because the later parts of the research will depend on the results of the earliest and most important studies (see Table 1). Most obviously, if the calcite and opaline-silica veins turn out to be young (less than 100,000 years) a great deal more effort will be needed to determine their origin and the path of movement of the water that deposited them than would be the case if they are old.

Data integration in one sense should be a continuous process that occurs simultaneously with data collection. This is recognized in the proposal by the plan that the group of experts who will be responsible for the analytical work will also be responsible for the sampling, and that this will be done in a coordinated way. We feel this is very important. The proposal to hold formal workshops on the results six months and one year after the project is initiated is a good way of facilitating data integration.

A prime example of the importance of continuous data integration is the close tie-in needed between field investigations to determine the vein-filling history in Trench 14, the petrography which helps determine that history, and the geochronology that needs to be done selectively on parts of the veins to find the ages of vein filling. An essential element in the analytical program is that all studies be carefully tied in to the temporal and spatial frame established by field and petrographic work.