AN ANNOTATED ANALYSIS OF LOGIC IN THE 1992 REPORT, "THE ORIGIN AND HISTORY OF ALTERATION AND CARBONATIZATION OF THE YUCCA MOUNTAIN IGNIMBRITES," BY J.S. SZYMANSKI

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ABSTRACT

A systematic analysis of logic required in arguments posed and conclusions reached in the 1992 report, "The Origin and History of Alteration and Carbonatization of the Yucca Mountain Ignimbrites" by J.S. Szymanski, is presented. The validity of arguments and accuracy of premises is determined. This analysis examines the current geodynamic configuration of the Yucca Mountain, the surface exposure and rock core evidence, and geochemical, mineralogic, and isotopic evidence of hydrothermal and auxiliary gas-assisted processes, as proposed by Szymanski (1992), to see if the evidence presented will support his assertions. The majority of the Szymanski (1992) report focused on the field evidence of mineralization, and attempted to argue that pedogenic deposits were formed by hypogene processes and that supergene processes cannot explain the existence of these deposits.

The analysis of logic identified several flawed premises used by Szymanski (1992) in his arguments for a hypogene origin for the alteration and carbonatization of the ignimbrites. Of greater importance is the identification of distinct areas of current scientific uncertainty, which directly influence the strength of the arguments posed by Szymanski (1992). These areas of scientific uncertainty, if resolved, could provide the necessary information to unambiguously conclude between competing premises/models. The critical incorrect premises used by Szymanski include:

- Yucca Mountain is part of the Great Basin magmatic province.
- Fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition are not expected characteristics of supergene pedogenic processes.
- Solids dissolved into infiltrating fluids are only derived from ionic exchange reactions with ignimbrites.
- K-Ar dates of clinoptilolites are ages of crystallization.

These assumptions have broad implications for many of Szymanski's (1992) arguments and conclusions. By inferring that Yucca Mountain is part of the Great Basin magmatic province, Szymanski (1992) asserted the importance of asthenospheric mantle dynamics (thin lithosphere, hot crust, and asthenospheric source for basaltic magma) on the history of magmatism at Yucca Mountain. Current tectonic and petrologic models of the Yucca Mountain area indicate that this area is part of the Western Great Basin and is associated with a thick cold lithosphere and lithospheric mantle source for basaltic magma. Szymanski (1992) used the second incorrect premise to refute the supergene origin of pedogenic deposits. Laboratory experiments and models of supergene pedogenic processes clearly and abundantly indicate that fluctuating chemical composition of fluids (primarily due to evaporation and precipitation) and fluctuating conditions of mineral deposition (non steadystate conditions) are expected for supergene pedogenic processes. Third, Szymanski (1992) incorrectly assumed that only ordinary ionic exchange reactions with the ignimbrites can contribute dissolved solids to infiltrating fluids which allowed him to infer the only source for calcium (Ca) and magnesium (Mg) found in the subsurface and pedogenic deposits must be from the underlying Paleozoic carbonates. Both a preliminary mass balance of the carbonate dust to the surface of the Yucca Mountain area combined with geochemical measurements and models of subsurface fluids indicate that the infiltrating fluid contain quantities of Ca in excess of that which can be supplied by ordinary ionic exchange with ignimbrites. Finally, Szymanski (1992) erroneously inferred that the K-Ar dates of clinoptilolites are crystallization ages of the zeolites. He attached geologic significance to data the authors emphatically argued had no geochronologic significance (the dates are not formation ages). He subsequently strongly depended upon the zeolite formation ages to infer a long history of hypogene alteration in the subsurface at Yucca Mountain.

The technical uncertainties include:

- A clear understanding of the evolution of the thermal structure of the mantle and crust in the Yucca Mountain area is lacking.
- The extent and importance of dry surface deposition of Ca and Mg (carbonate) is not fully known.
- There is an inadequate understanding of the history, mechanisms and rates of recharge to the Alkali Flat/Furnace Creek groundwater system.
- The degree to which non steadystate processes (climate) may control the formation of pedogenic and subsurface geochemical features is not well constrained.
- The history of faulting and zeolitic alteration at Yucca Mountain is not sufficiently known.
- The conditions under which zeolitic alteration occurred at Yucca Mountain are poorly understood.

In addition to these areas of scientific uncertainty, two other conclusions were derived from this systematic analysis of logic. First, there has been an insufficient degree of integration of scientific measurements and data. In many instances only single types of measurements have been performed on individual mineral or fluid samples. Without performing multiple types of analyses (isotopic, fluid inclusion, chemical) on the same mineral or fluid sample it is difficult to correlate or derive geochemical/isotopic/temperature relationships between nearby but distinct samples. There is abundant evidence that spatial variability of mineralization, particularly along fractures, is extreme and may reflect a complicated history of formation under quite distinct conditions. Inadequate integration of geologic and geochemical data compromises attempts to develop and evaluate conceptual models of the Yucca Mountain region and its history of alteration. Second, rapid assessment of geologic models would be facilitated by use of integrated databases. Many of Szymanski's arguments relied on data presented in his figures. These figures were derived from published tabular data. The veracity of his arguments relied on the correct and complete presentation of the published data and the only way to affirm the veracity of the presentation was to cross reference the published data with that presented in the figure. Timely evaluation of complicated geologic and geochemical arguments presented during both the pre-licensing and licensing periods will require computerized technology, such as that available in a geographic information system (GIS).

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1 INTRODUCTION

There has been considerable controversy generated by the consideration of alternate conceptual geodynamic models of the Yucca Mountain area (National Research Council, 1992; Archambeau, 1992; Archambeau and Szymanski, 1993), and there have been several efforts completed in an attempt to resolve the controversy (National Research Council, 1992; Everden, 1992). Early efforts to review the conceptual model depicted in Szymanski (1989) primarily focused on the theoretical and mathematical aspects of the proposed model (Powers et al., 1991; Archambeau and Price, 1991; Wescott, 1990). The absence of consensus regarding the magnitude of the expected long-term hydrologic effects of a tectonically-driven hydrologic system (Powers et al., 1991; Archambeau and Price, 1991) formed the motivation for a subsequent report by Szymanski (1992). Although the Szymanski 1989 document received extensive review, the 1992 document (Szymanski, 1992) has not. Only one review (Everden, 1992), released subsequent to the National Resource Council report (National Resource Council, 1992), has examined some of the ideas and evidence contained within Szymanski (1992). The purpose of the Everden (1992) report was to evaluate the Minority report of Archambeau and Price (1991) and did not explicitly address Szymanski's 1992 effort.

A valid criticism offered by Szymanski and colleagues (Archambeau and Szymanski, 1993) has been that the efforts to evaluate his conceptual model of the Yucca Mountain region, in particular the 1992 National Research Council Report, have not addressed all the geologic data from the area which have been used by him and which must be explained by any conceptual model of the geodynamics of this region. This important point is strongly emphasized in Szymanski's 1992 report and has broad implications for the use of results of analyses presented in the National Research Council Report (National Research Council, 1992). In essence, Szymanski has argued (Archambeau and Szymanski, 1993) that conceptualizations of the history of the Yucca Mountain region (National Research Council, 1992) must include all data that the conceptual model is dependent upon as well as be able to logically explain these data. In addition, he argued (Szymanski, 1992; Archambeau and Szymanski, 1993) that by not including all critical and relevant information for the area in the development of a conceptual model of the history of the region (National Research Council, 1992), the model and subsequent analyses derived from conceptualization will be flawed.

The purpose of the 1992 report (Szymanski, 1992) was to comprehensively evaluate the geologic data from the Yucca Mountain area to examine for evidence of past upward flow of water and its consequent mineral deposition. The logic behind this approach is as follows: if there is geological evidence of alteration and mineralization which could have only been derived from past intermittent upwelling of hypogene fluids, then regardless of the exact mechanism or its perceived possible magnitude, upwelling fluids pose a significant risk to the proposed repository site at Yucca Mountain. Alternatively, if it can be unambiguously concluded based upon geological evidence that intermittent emplacement of deep-seated fluids has not occurred, then the scenario envisioned by Szymanski (1989, 1992) or any other possible upwelling scenario would be untenable. The existence of pedogenic deposits and other geologic evidence used by Szymanski (1992) to conclude that intermittent upwelling of hypogene fluids occurs in the Yucca Mountain area may be explained by two competing models. One model espoused by Szymanski (1992) argues that pedogenic deposits (calcretes, bedrock veins, and mosaic breccias) and the spatial and temporal history of subsurface alteration recorded in the cores from the Yucca Mountain area were formed via intermittent upwelling of hypogene fluids. The alternative model requires that the history of hydrothermal alteration in this region was associated with the Timber Mountain caldera activity and was restricted both temporally (> 10 Ma) and spatially (never reached the surface). In addition, the alternative model requires that subsequent supergene pedogenic processes have created the near-surface deposits and altered the subsurface rocks via interaction with descending fluids.

The 1992 report of Szymanski, "The Origin and History of Alteration and Carbonatization of the Yucca Mountain Ignimbrites," is the basis for this study. The purpose of this document is to provide a systematic analysis of the logic used by Szymanski (1992) to support his conclusion that at Yucca Mountain hydrothermal and auxiliary gas-assisted processes pose a significant hazard for time spans measured in 10^4 years. The principal product of this task was requested to be an annotated logic diagram with an accompanying report providing additional justification and annotation of the arguments used by Szymanski (1992). However, in the course of completing the systematic (bottom up approach) analysis of the Szymanski report (Szymanski, 1992), it became clear the most beneficial (in terms of the overlying motivation of the report, see discussion in next paragraph) and principal product of such an analysis should be the actual analysis of the logic as provided by the justification and annotation presented in this document. This conclusion was derived from the following two observations: (i) the numbers of arguments and their degree of interconnection which exists in Szymanski's report (1992) would result in a logic diagram, if it contained each argument and sufficient annotation (premises involved, their accuracy, and resultant analysis) to allow clear interpretation of the argument, too large to be practical (an estimated figure on the order of 8 m^2); and (ii) a more rigorous, comprehensive, and defensible result could be achieved by producing logic diagrams which corresponded directly to the major lines of reasoning presented in the individual chapters in Szymanski (1992). These seven diagrams, representing the seven chapters in Szymanski (1992) which outline his seven main lines of reasoning, are minimally annotated and require referral to this document (further discussion of the diagrams and their relationship to the text is presented in Section 1.1 of this report). The resulting diagrams for each chapter of this report are used to derive a final logic diagram which includes the seven different arguments used by Szymanski (1992) to assert that hydrothermal and gas-assisted processes pose a significant hazard to the proposed candidate repository site at Yucca Mountain.

The motivation for this report is not to prove or disprove Szymanski's assertion (1992), but rather to systematically analyze the logic used in his arguments. If a systematic approach is used to analyze his logic, then this decreases the possibility that a critical line of evidence or possible mechanism is overlooked. It might also provide insight into the issues which are not presently resolved, or into areas where evidence is equivocal and our understanding is incomplete. Analysis of the logic consists of two separate issues: the logical form (validity) of the argument, and an evaluation of the premises (truth) used to support the conclusion of the argument. Truth is a feature relevant only to the premises and conclusions of arguments (Barker, 1989), while validity is a feature of the whole argument and has to do with how tightly the premises are connected to the conclusion. If a deductive argument is of an invalid form, then the conclusion — although it may be true — should not be accepted based upon the argument presented. If the argument has been constructed using a valid form (i.e., a valid argument), then it is necessary to determine the accuracy of each premise used in the argument prior to accepting the conclusion of the argument. From a conservative point of view, if a premise cannot be demonstrated to be false, then it should be tentatively accepted as true, especially if the hypothesis is plausible and could have serious detrimental consequences for the repository. A critical portion of the analysis of logic in this document includes the evaluation of each premise used by Szymanski (1992) to build his arguments. This crucial task requires evaluation of the geological evidence that is used to support each individual premise.

Based upon the previous discussion it can be concluded that this letter report is:

- a comprehensive logical analysis of the arguments presented by Szymanski (1992).
- intended to be a conservative evaluation of the logic used by Szymanski (1992).
- only one possible analysis of the arguments presented by Szymanski (1992).
- an evaluation of the evidence used by Szymanski (1992) to support his arguments.
- designed to be used in conjunction with Szymanski (1992).
- included with minimally annotated logic diagrams of Szymanski's arguments which must be used in conjunction with the text of this report.
- provided with a summary of critical assumptions used by Szymanski (1992).
- provided with a list of important and potentially consequential conclusions which were derived from this analysis.

This letter report is not:

- a review of Szymanski (1992).
- intended to prove or disprove Szymanski's (1992) assertions.
- the only possible interpretation of arguments presented in the text and figures supplied by Szymanski (1992).

1.1 ORGANIZATION AND CONTENT OF REPORT

The organization of this document follows that presented by Szymanski (1992), with chapters in this document addressing the arguments presented in the same chapter of Szymanski (1992). Szymanski (1992) subdivided his document into three parts: (i) current geodynamic configuration of the Yucca Mountain region (Chapter 2); (ii) direct field examinations of surface outcrops (Chapter 3) and rock cores (Chapter 4); and (iii) geochemical, mineralogic, and isotopic evidence for the origin of vadose interstitial fluids (Chapter 5), the origin and age of mosaic breccias (Chapter 6), the origin and age of alteration of Yucca Mountain zeolitic and montmorillonitic alteration (Chapter 7), and the origin and age of the Yucca Mountain carbonization (Chapter 8). The actual form of this document is different from most reports generated by the Center for Nuclear Waste Regulatory Analyses (CNWRA) in that it represents an annotated analysis of the logic used by another scientist. As an annotated logical analysis, the document structure reflects the general logical construction of arguments and, in particular, the arrangement of arguments presented by Szymanski (1992). Each chapter is subdivided into sections which individually reflect major lines of reasoning (one or several related arguments) championed by Szymanski (1992).

Within each section, three different areas (premises, arguments, and analysis) are addressed. In each section the premises used to construct the argument are explicitly stated. Every premise is numbered sequentially in each section (e.g., P1, P2, etc.). The author's assessment of the accuracy of each premise is listed in parentheses at the end of each assertion. The three possible outcomes regarding accuracy of each premise are: (i) the premise is true (T) as stated; (ii) the premise is false (F) as stated; and (iii) insufficient information is known or presented to determine accuracy of the premise (?). Determination of the accuracy of each premise is addressed in the third part of each section (analysis). In addition, in some cases the exact argument has been imprecisely expressed by Szymanski (1992), and some premises have been inferred. Discussion of these inferred premises is presented in the final segment of each section (analysis).

The second area addressed in each section is the argument presented by Szymanski (1992). Each argument is numbered sequentially in each section (e.g., A1, A2, etc.). In a few cases the exact argument has been imprecisely expressed by Szymanski (1992) and the argument presented reflects the most likely interpretation of Szymanski's (1992) ideas as pieced together by an interpretation of what is written in the document (Szymanski, 1992). The purpose of interpreting incompletely developed arguments and presenting them is not to misconstrue his ideas but to provide an explicit basis upon which reasoned argument may proceed. Thus, if a misinterpretation of his argument exists, a reassessment of the logical analysis of the misrepresented argument can only proceed, and be accepted, once inaccuracy of the interpretation has been explicitly addressed. For each argument presented by Szymanski (1992) the form of the argument is determined, the premises used to construct the argument are placed in the logical order required by the argument with the appropriate conditional conjunctions, and the argument is explicitly stated. At the end of each argument an assessment of the logical form of the argument (IV = invalid and V = valid) and an assessment of the conclusion of the argument is presented (T = true or F = false). This assessment of the conclusion of the argument is determined and dependent upon accuracy of the premises and the validity of the logical construction of the argument. It is explicitly explored in the final portion of each section (analysis). An example argument would be: If P1 and P2, then conclusion (V and T). This is to be interpreted as a validly constructed argument (V). The conclusion can be accepted as being proved by the argument (T) and requires that in this case, based upon the construction of the argument, each of the premises are true.

The final portion of each section is the annotated analysis of the logical construction of the argument and the accuracy of each premise used in the argument. The purpose of the annotation is to try to provide a concise objective analysis of the logic used by Szymanski (1992). To keep the annotation to a minimum, only minimal discussion of evidence used to support premises that are generally accepted is provided. Controversial premises, or premises that are necessary to construct the arguments which have been inferred from the text of Szymanski (1992), are discussed in sufficient detail to: (i) frame the controversial aspects; (ii) outline issues where insufficient information is known to determine accuracy of the premise; or (iii) discuss some of the simple logical physical consequences required if a premise is accepted to be true.

In addition to evaluating the accuracy of each premise, the logical form of the argument posed by Szymanski (1992) is evaluated with regard to its validity (IV or V) as an acceptable form of deductive argument. In geology, however, not all logical constructions are deductive in nature, many are examples of inductive reasoning. While a valid deductive argument is demonstrative, that is, if the premises are true, the conclusion must necessarily be true also, an inductive argument has a conclusion embodying empirical conjectures that do not follow deductively what its premises say — in an inductive argument the conclusion is not wholly contained in its premises (Barker, 1989). In an inductive argument the truth of the premises cannot absolutely ensure the truth of the conclusion and the argument cannot be demonstrative in the way valid deduction is (Barker, 1989). If the reasoning is good and the premises of an inductive argument are true, then it is reasonable to believe the conclusion; the conclusion is probably true (Barker, 1989). An inductive argument is a valid argument if the degree of probability claimed for its conclusion is indeed a reasonable degree of probability to that conclusion, relative to the available evidence. The argument is *non sequitur* (an invalid argument) if it claims for its conclusion a degree of probability that is unreasonable to attribute to that conclusion, relative to the available evidence (Barker, 1989). For those arguments presented by Szymanski (1992) which are reflective of inductive reasoning, a discussion of the strength of this reasoning is presented. Additional discussions in the analysis sections are limited to referring to the other sections of the report which use the same arguments just analyzed, and alert the reader to the consequences of the analyses.

As a means of summarizing the resultant logical analyses, a logic diagram for each chapter is presented at the end of each individual chapter. The diagram uses the following notation to provide a convenient manner to reference text in the chapter: S = section of the chapter, A = argument, P = premise, V= valid, IV = invalid, T = true, F = false, and ? = insufficient information to determine truth. An example logic diagram is presented as Figure 1-1.

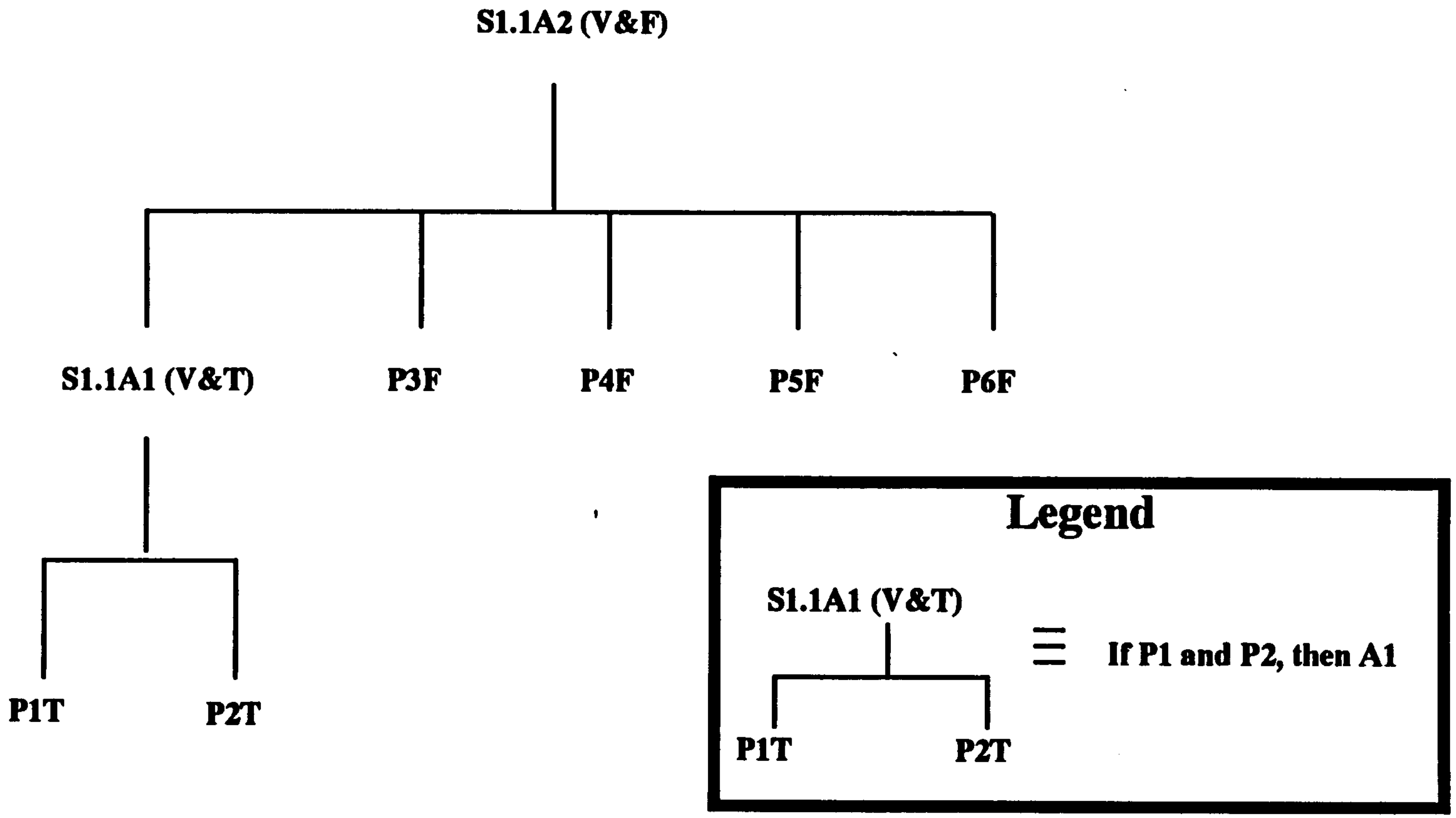


Figure 1-1. Example logic diagram

2 GEODYNAMIC PROCESSES

A review of volcanism is presented in this section of the report by Szymanski (1992) to provide a background and perspective for interpreting geophysical and geochemical evidence which he used to develop arguments that fairly young, ephemeral, conductively-replenished, hydrothermal systems have been active in the Yucca Mountain region. Four lines of geologic and petrologic evidence are combined with theoretical models of basaltic and silicic volcanism to assert that the diminishing degree of partial melting of mantle matter contained in a rising asthenospheric diapir results in thermal conditions requiring conductively-replenished convective heat flow (geothermal systems). The history and geochemistry of mafic volcanism within a radius of 50 miles of Yucca Mountain was used in Section 2.1 to infer that there has been a time-progressive decrease in the degree of partial melting. The silicic volcanism history within a radius of 75 miles of Yucca Mountain was used to argue that both the eruptive volume and eruptive frequency appear to have been diminishing with time (Section 2.2). In Section 2.3, the spatial-temporal coexistence of both magmatic suites was used to argue that volcanism in the Yucca Mountain region is a result of advective ascent of asthenospheric mantle. Conclusions from arguments presented in Sections 2.2 and 2.3 were used in Section 2.4 to postulate that in the contemporary shallow magma source region the solidus temperature is relatively high and the degree of partial melting is relatively low.

The conceptual model for the contemporary geodynamic configuration of the Yucca Mountain region developed in arguments outlined in Sections 2.1 through 2.4 of this report was asserted to be tested by geophysical techniques in Section 2.4 of Szymanski (1992). Three separate lines of evidence were used by Szymanski (1992) to test the contemporary geodynamic configuration. First, the P-wave velocity in the uppermost mantle was used to assert that the uppermost mantle remains in a quasi-stable state of incipient-partial melting (Section 2.5). Seismic reflection survey results were used in a second argument (Section 2.6) to infer that the temperatures in the lower crust are sufficiently high to produce near-solidus thermal conditions. The final geophysical argument developed by Szymanski (1992) to test the present geodynamic configuration of the Yucca Mountain region was based upon large-scale seismic heterogeneity in the lower crust (Section 2.7).

Implications of the contemporary geodynamic configuration of the Yucca Mountain region developed and tested in arguments outlined in Sections 2.1 through 2.7 of this report were used by Szymanski (1992) in his Section 2.5 to predict the expected geothermal conditions in the Yucca Mountain region. Five specific stated implications of the contemporary geodynamic configuration are: (i) the average flux of terrestrial heat is high at the base of the Yucca Mountain hydrologic system (Section 2.8); (ii) terrestrial heat input at the base of the Yucca Mountain hydrologic system lacks spatial uniformity (Section 2.9); (iii) convective heat flow is of widespread importance in the Yucca Mountain region due to the evolving thermodynamic state of the crust (Section 2.10); (iv) convective circulation of fluids is required (Section 2.11); and (v) the present geodynamic configuration results in intermittent and spatially restricted hydrothermal activity (Section 2.12).

2.1 MAFIC VOLCANISM

2.1.1 Premises

P1: Basaltic magmatism at Yucca Mountain is derived from asthenospheric mantle source (F). P2: Mafic volcanism has persisted for the last 10 m.y. (T). P3: Fairly young basalts are scattered all around Yucca Mountain (F). P4: There has been a decrease of mafic magmatism within the last

4 m.y. (T?). P5: Eruption frequency has remained fairly constant during the last 4 m.y. (T?). P6: Basaltic volcanism is more mafic (based on SiO_2 content) with decreasing age (T). P7: Progressive changes in trace element concentrations reflect a time-progressive decrease in the degree of partial melting (F).

2.1.2 Arguments

A1: If P1, P2, P4, P5, P6, and P7, then there is a decreasing degree of partial melting of asthenospheric mantle with time in the Yucca Mountain region (IV and F).

2.1.3 Analysis

The argument A1 is invalid and is an example of *petitio principii* (Barker, 1989) since it takes for granted what it is supposed to prove (i.e., there is a decreasing degree of partial melting due to the evolution of an asthenospheric mantle magma source). Asthenospheric mantle was suggested by Szymanski (1992) in Section 2.1 of his report to be the general source for basaltic magma. Szymanski (1992) assumed that basaltic volcanism at Yucca Mountain can only be derived from asthenospheric mantle (P1). Although much of the early petrologic studies of basaltic volcanism in the Yucca Mountain region called upon an asthenospheric mantle source (Crowe et al., 1983; Vaniman et al., 1982), there is substantial geochemical evidence to suggest that basaltic magma in the Yucca Mountain region has a lithospheric mantle signature and cannot be derived from asthenospheric mantle or extensive crustal contamination (Crowe, 1990; Fitton et al., 1991; Livaccari and Perry, 1993). Thus, P1 cannot be assumed to be true. Dated basaltic volcanic features in the Yucca Mountain region span a range of age from 10 Ma to about 100 ka (Crowe, 1990; Crowe et al., 1992), therefore, P2 is true. Premise P3 was loosely written and allows a broad translation; however, the area of basaltic volcanism is not random or as areally widespread as Szymanski (1992) implied. For example, Crowe (1990) clearly pointed out that basaltic volcanism is spatially limited and follows certain geographic trends, thus P3 cannot be assumed to be true. The eruptive volumes of basaltic magma during the last 4 m.y. in the Yucca Mountain region may suggest the rate of basaltic volcanism has decreased (Perry and Crowe, 1992; Crowe et al., 1986), and P4 appears to be true. Similarly, if only the last 4 m.y. are examined, the eruption frequency has remained fairly constant (Crowe et al., 1986), hence, P5 may be true. Alternative statistical analyses of the time-volume basaltic magmatism relationships for the last 10 m.y. in the Yucca Mountain region (Hill, 1993) indicate the magma supply rate may be steadystate during this timeframe, and eruption frequency has increased (with smaller volumes) during the last 2 m.y. These observations suggest some ambiguity is associated with premises P4 and P5. Except for the Buckboard Mesa basalt and basaltic andesite (2.8 Ma), during the last 4 m.y. basaltic volcanism was more mafic with decreasing age (Crowe, 1990). This is sufficient evidence to assert that P6 is true. Finally, premise P7, which asserts that progressive changes in element concentrations reflect a time-progressive decrease in the degree of partial melting, cannot be assumed to be true. Early workers on the petrogenesis of the Yucca Mountain region basaltic rocks (Vaniman et al., 1982; Crowe et al., 1983) suggested that geochemical trends could be explained by a time-progressive decrease in the degree of partial melting; however, this interpretation assumed an asthenospheric mantle source for the basaltic magma. As has been pointed out above, more recent petrologic models suggest a lithospheric mantle source for the basaltic magmas (e.g., Farmer et al., 1989; Livaccari and Perry, 1993). In addition, different petrogenetic hypotheses are possible which could explain the reported progressive changes in trace element concentrations (Fitton et al., 1991; Connor and Hill, 1993; Connor et al., 1993; Hill, 1993). For these reasons premise P7 is false.

2.2 SILICIC VOLCANISM

2.2.1 Premises

P1: The word local implies an area surrounding Yucca Mountain with a 75-mile radius (T). P2: Within the local area of Yucca Mountain, silicic volcanism persisted to the end of the Pliocene (T?). P3: The eruptive volume of silicic volcanism in the Yucca Mountain region has been decreasing with time (F?). P4: The eruptive frequency of local silicic volcanism has been decreasing with time (T).

2.2.2 Arguments

A1: If P1, P2, P3, and P4, then the silicic volcanism trend (eruptive volume and frequency diminishing with time) parallels that associated with local mafic volcanism (IV and F).

2.2.3 Analysis

Argument A1 is invalid since there is an insufficient and inaccurate connection between premises and conclusion. A1 does not compare the result for basaltic and silicic volcanism at equal scales, and thus is not true. Although Szymanski (1992) implied he is comparing basaltic volcanism within 75 miles of Yucca Mountain to silicic volcanism within 75 miles of Yucca Mountain, this is clearly not the case as he neglected to consider the Quaternary basaltic volcanism in Death Valley, Lunar Crater, and Coso (Bacon et al., 1984). It is important to note there is no evidence for silicic volcanism during the last 6.3±0.8 m.y., at a distance comparable to that used for the analysis of the history of basaltic volcanism (Szymanski, 1992). Premises P3, and P4 are strictly true only if the silicic volcanism at distances greater than 50 miles from Yucca Mountain is included in the analysis (Crowe et al., 1983; Szymanski, 1992).

2.3 RELATIONSHIP BETWEEN SILICIC AND MAFIC VOLCANISM

2.3.1 Premises

P1: Basaltic and silicic magmatism are spatially and temporal coexistent (F). P2: Basaltic and silicic magmatism are clearly related (F). P3: The origin of basaltic magma in the Yucca Mountain region is from the asthenosphere (F). P4: Rhyolites in the local area of Yucca Mountain are a result of emplacement into the crust of basaltic magma derived from asthenospheric mantle (F).

2.3.2 Arguments

A1: If P1, P2, P3, and P4, then the locally observed bi-modal magmatism expresses a convective or advective ascent of matter from the asthenosphere (V and F).

2.3.3 Analysis

Szymanski (1992) clearly tried to make the case that basaltic and silicic volcanism are related in the Yucca Mountain local area, however, his arguments are suspect. First, within 50 miles of Yucca Mountain, basaltic and silicic volcanism can only be spatially related for the period of time between 10 to 8.5 Ma (Crowe et al., 1983, 1986). Second, there has been no silicic volcanism for the past

6.3±0.8 Ma in the same area where basaltic volcanism has persisted from 10 Ma to about 100 ka (Crowe et al., 1992). Premise P1 is clearly not true based upon these two observations. Premise P3 was already shown to be suspect in Section 2.1 of this report, and thus P4 which requires that P3 be true must necessarily be false. Using these arguments, basaltic and silicic volcanism for the last 8.5 m.y. in the Yucca Mountain region are not clearly related, and P2 is false. Although A1 is a valid argument, since all premises are false, the conclusion of his argument A1 is false. The reader should refer to Bacon et al. (1984) for a clear example of a case (Coso volcanic field) where spatial and temporal coexistence of basaltic and silicic volcanism are indicative of the petrogenetic origin espoused by Szymanski (1992).

2.4 DEGREE OF PARTIAL MELTING

2.4.1 Premises

P1: Decline of silicic volcanism reflects the decreasing influx of asthenospheric mantle-derived mafic magma into the crust (F). P2: There is a diminishing degree of partial melting of mantle matter contained in the rising asthenospheric diapir (F). P3: The diminishing degree of partial melting may reflect the diminishing availability of H_2O (F). P4: A time-progressive ascent of the upper thermal boundary layer of a sub-lithospheric convective system may be responsible (F).

2.4.2 Arguments

A1: If P1, P2, P3, and P4, then, in the contemporary shallow source region of basaltic magmatism, solidus temperature is relatively high and the degree of partial melting is relatively low (IV and F).

2.4.3 Analysis

Argument A1 is invalid as it takes for granted what it is supposed to prove (i.e., premise becomes conclusion). As was demonstrated in Sections 2.1 and 2.2, basaltic magma in the Yucca Mountain local area is not derived from an asthenospheric mantle (Livaccari and Perry, 1993). Thus, P1 is false. A diminishing degree of partial melting of mantle matter contained in the rising asthenospheric diapir was required by Szymanski (1992) to explain the observed mineralogic and petrologic trends in the basaltic volcanic rocks exposed in the area. Since asthenospheric mantle is probably not the source for the basaltic magmas in this region and different petrogenetic hypotheses are possible which could explain the reported progressive petrogenetic changes (Fitton et al, 1991; Connor and Hill, 1993; Connor et al., 1993; Hill, 1993), then P2 is false. Since P1 and P2 are false, and P3 requires that P1 and P2 are true, then P3 is false. If P1, P2, and P3 were absolutely true, then P4 would be true, but since the first three premises are false, then so too is P4.

The contemporary geodynamic configuration envisioned by Szymanski (1992) was based upon many false, or certainly less than certain, assumptions. This geodynamic configuration, the asthenospheric mantle and its evolutionary ascent and consequent petrogenetic evolution of volcanic rocks for the Yucca Mountain region, is a vital and necessary condition for generation of hydrothermal alteration as described by Szymanski (1992); see analysis in Sections 2.8 through 2.12 of this report) subsequent to Timber Mountain caldera hydrothermal activity.

2.5 UPPER MANTLE P-WAVE VELOCITY

2.5.1 Premises

P1: The local presence of small-scale Quaternary mafic magmatism implies that the upper mantle is in a quasi-stable state of incipient-partial melting (T?). P2: Regions of incipient-partial melting must be associated with abnormally low velocities of P-waves (T?). P3: P-wave velocity in the uppermost mantle is abnormally low in the Yucca Mountain region (T).

2.5.2 Arguments

A1: If P1, P2, and P3, then the material comprising the uppermost mantle in the Yucca Mountain region remains in a quasi-stable state of incipient-partial melting (IV and T?).

2.5.3 Analysis

The argument A1 is invalid and somewhat misleading. There is an insufficient and inaccurate logical connection between the stated premises (Szymanski, 1992) and the conclusion. Szymanski (1992) appeared to presume that all P-wave low velocity zones require a partial-melt; however, this is not true (Evans and Smith, 1993). The low velocity of P-waves in the uppermost mantle is only suggestive and not conclusive evidence for the presence of mafic partial melts in the upper mantle in the Yucca Mountain region (Evans and Smith, 1993). The weakness of the low velocity anomaly is also permissive of subsolidus interpretations (Evans and Smith, 1993). As pointed out by Livaccari and Perry (1993), where alkalic basalts have a lithospheric mantle isotopic signature (Crater Flat basalts), the lithosphere must be at least 50 to 70 km thick. Thus, even if the low P-wave velocity zone in the uppermost mantle is partial melt, in the past 4 Ma the melt has had a lithospheric mantle signature and does not represent asthenospheric mantle partial melt (Livaccari and Perry, 1993). As is discussed in Evans and Smith (1993), premises P2 and P3 appear to be true. The conclusion of this argument is true if, and only if, the upper mantle is in a quasi-stable state of incipient-partial melting (P1 is true). Since P1 may be true, then the conclusion of A1 can be tentatively accepted.

2.6 NEAR-SOLIDUS CONDITIONS IN LOWER CRUST

2.6.1 Premises

P1: Based upon a seismic reflection survey, there is a bright spot in the local lower crust in the Amargosa Desert (T). P2: The bright spot in Amargosa Desert is similar to the lower crust spots in Death Valley and the Rio Grande Rift (F). P3: The Death Valley and the Rio Grande Rift bright spots have been attributed to reflections from thin and discontinuous magma chambers (F).

2.6.2 Arguments

P1: If P1, P2, and P3, then temperatures in the lower crust in some portions of the Yucca Mountain region are sufficiently high to produce near-solidus thermal conditions (V and F).

2.6.3 Analysis

If each of the premises were true, the conclusion of argument A1 would logically follow. It is clear there is a lower crustal bright spot image on the AV-1 line in the Amargosa Desert (Brocher et al., 1993), making P1 true. As Brocher et al. (1993) discussed, the three bright spots most likely do not have the same origin; thus, P2 is false. Finally, only the Rio Grande Rift crustal bright spot can be unequivocally attributed to a mid-crustal magma body (Brocher et al., 1993), implying that P3 must be false. Additional discussion and data presented by Brocher et al. (1993) indicate the lower crustal 8.4 sec bright spot in the Amargosa Desert is most likely due to focusing of energy reflected from the mid-crust by low-velocity basin fill lying above the bright spots. Therefore, the conclusion that temperatures in the lower crust in some portions of the Yucca Mountain region are sufficiently high to produce near-solidus thermal conditions is not supported by published interpretations of the AV-1 seismic line.

2.7 LOWER CRUSTAL LATERAL HETEROGENEITY

2.7.1 Premises

P1: Lateral P-wave velocity gradients in the lower crust around Yucca Mountain are surprisingly large (T). P2: Relative to high velocity areas, low velocity areas are necessarily hotter (T?). P3: Near-solidus thermal conditions prevail within the hotter low velocity areas (T?). P4: There are large areas of low velocity crustal material in the Yucca Mountain region (T). P5: Low velocity areas of the lower crust alternate with areas of high velocity (T). P6: Lateral compositional differences in the lower crust are not the sole factor expressed by the P-wave velocity image (T?). P7: The P-wave velocity image of the lower crust expresses the effects of laterally varying temperature on the elastic properties of the lower crust (T?).

2.7.2 Arguments

A1: If P1, P2, P3, P4, P5, P6, and P7, then the lateral distribution of crustal temperatures is spatially heterogeneous and follows the local P-wave velocity image (V and T?).

2.7.3 Analysis

The information presented in Szymanski (1992) and in Evans and Smith (1993) is adequate to imply that premises P1, P4, and P5 are true. It should be noted, however, that inferences drawn from a single seismic parameter, in this case compressional-wave velocity perturbations, are inherently ambiguous, because many properties of the rock can have similar seismic effects (Evans and Smith, 1993). With this in mind, differences in velocity do not necessarily have to reflect differences in temperature (Evans and Smith, 1993), so P2 may not be strictly true. Although P4 and P5 are true, P6, which is derived from these two premises and the assumption that P2 is true, is not required to be true. The one area where sufficient spatial resolution is available to test this assertion, the Crater Flat/Yucca Mountain immediate area (Evans and Smith, 1993), does not provide an unequivocal answer. The results of Evans and Smith (1993) are not conclusive and indicate that the weak, middle and lower crust, low velocity anomaly beneath Crater Flat may be caused by many phenomena. Premise P3 was supported by Szymanski (1992) using the Amargosa Desert bright spot coincidence within an extensive low velocity anomaly and the spatial association of all locally known (within 75-mile radius) post-Timber Mountain Tuff silicic magmatism with lower velocity areas in the lower crust. As was argued in Section 2.6, the

Amargosa Desert bright spot does not necessarily reflect near-solidus thermal conditions (Brocher et al., 1993), hence, this line of evidence used by Szymanski (1992) is at least partially negated. The spatial association of all locally known (within 75-mile radius) post-Timber Mountain Tuff silicic magmatism with lower velocity areas in the lower crust may be considered to be permissive evidence that not all of the lower crust P-wave velocity image is due to lateral compositional differences in the lower crust. At present, there is inadequate evidence to analyze this line of evidence since the resolution necessary to image small mid-crustal silicic magma chambers (Evans and Smith, 1993) has not been completed for all the areas within a 75-mile radius of the proposed candidate repository site. As discussed in the justification of premise P2 in this argument and from results of the analysis of P6, premise P7 is not required to be true. Thus, the conclusion of argument A1, that the lateral distribution of crustal temperatures is spatially heterogeneous and follows the local P-wave velocity image, should not be considered to be necessarily true. Evidence to date which refutes the conclusion of Szymanski (1992), that the lateral distribution of crustal temperatures is spatially heterogeneous, is not strong. Until further seismic and tectonic characterization of the local and regional structure of the crust and upper mantle in the Yucca Mountain vicinity can be completed, it may be prudent to allow that lateral distribution of crustal temperatures is spatially heterogeneous. However, results from the seismic reflection and tomographic studies, combined with petrologic arguments indicating less than 5 Ma basaltic volcanism in the Yucca Mountain area does not have an asthenospheric isotopic signature, imply the overall geodynamic configuration envisioned by Szymanski (1992) is most likely inaccurate. Although Szymanski (1992) asserted that the conceptual understanding of the geodynamic configuration of the Yucca Mountain region has been formulated and successfully tested, analyses presented in this report clearly indicate that neither the formulation (Sections 2.1 to 2.4) nor the testing of the configuration (Sections 2.5 to 2.7) is adequate to support his idea of the contemporary geodynamic configuration of the Yucca Mountain region.

2.8 HIGH AVERAGE FLUX OF TERRESTRIAL HEAT

2.8.1 Premises

P1: Lithospheric thickness is 30 to 50 km in the Great Basin (T). P2: Yucca Mountain is part of the Great Basin (F). P3: Lithospheric thickness is 30 to 50 km in the Yucca Mountain region (F). P4: Heat flow in regions where lithospheric thickness is 30 to 50 km is as high as 80 to 100 mW/m^2 [2.0 to 2.5 heat flow units (HFU)] (T).

2.8.2 Arguments

A1: If P1, P2, P3, and P4, then the average flux of terrestrial heat is fairly high (heat flow in the Yucca Mountain region is as high as 2.0 to 2.5 HFU) at the base of the Yucca Mountain hydrologic system (V and F).

2.8.3 Analysis

If each premise used in argument A1 was strictly true, the conclusion would follow logically and be necessarily true. The premise (P1) that lithospheric thickness is 30 to 50 km in the Great Basin is partially supported by published data (Livaccari and Perry, 1993) and can be accepted as true. Szymanski (1992) inferred, by an analogy to regions of comparable lithospheric thickness, that Yucca Mountain is part of the Great Basin. The Yucca Mountain area is part of the Western Great Basin magmatic province (Connor et al., 1993; Connor and Hill, 1993; Hill, 1993; Livaccari and Perry, 1993) and not part of the Great Basin magmatic province — thus, P2 is false. As pointed out by Livaccari and Perry (1993), where alkalic basalts have a lithospheric mantle isotopic signature, the lithosphere must be at least 50 to 70 km thick. Crater Flat basaltic rocks less than 5 Ma have a lithospheric mantle isotopic signature (Livaccari and Perry, 1993), therefore, the lithosphere in the Yucca Mountain region must be at least 50 to 70 km thick, and P3 is necessarily false. Finally, the premise (P4) that heat flow in regions where lithospheric thickness is 30 to 50 km is as high as 2.0 to 2.5 HFU appears to be fairly strongly supported (U.S. Department of Energy, 1988) and must be considered true. However, Yucca Mountain is at the southern end of the Eureka Low (an area with HFU < 1.5) (U.S. Department of Energy, 1988). Since P2 and P3 are false, and P2 and P3 must be true if the conclusion of the argument posed by Szymanski (1992) is to be accepted as true, his conclusion should not be accepted.

2.9 TERRESTRIAL HEAT INPUT HETEROGENEITY

2.9.1 Premises

P1: There is upwelling upper mantle in the Yucca Mountain region (F). P2: Heat flow over ascending limbs of mantle plumes is increased relative to descending limbs of the plume (T). P3: Upwelling mantle plumes are of fairly small size in the Yucca Mountain region (F). P4: Thin and discontinuous magma chambers in the lower crust are expected to be present around Yucca Mountain (F). P5: Introduction of a body of mafic magma in the lower crust produces a transient heat pulse in the lower crust (T). P6: There is a scarcity of free fluids deep (> 15 km) within the crust (?). P7: Convective flow is effectively inoperative in the deep crust (> 15 km) if there is a lack of free fluids (T).

2.9.2 Arguments

A1: If P1, P2, P3, or P4 and P5, then in the Yucca Mountain region there are very substantial lateral temperature gradients in the lower crust (> 15-km depth) (V and F). A2: If A1, P6 and P7, then along the base of the Yucca Mountain hydrologic system (at about 15-km depth) the terrestrial heat input lacks spatial uniformity (V and F). A3: If A2 and A1 in Section 2.8 (S2.8A1; the average flux of terrestrial heat is fairly high at the base of the Yucca Mountain hydrologic system), then convective circulation of the local intracrustal fluids (< 15-km depth), either continuous or intermittent, is a thermodynamic necessity (V and F).

2.9.3 Analysis

The logical form of argument A1 is valid; however, the conclusion that there are very substantial lateral temperature gradients in the lower crust in the Yucca Mountain region is not supported and should be considered false. Inferring that Szymanski (1992) meant upwelling asthenospheric mantle, then premise P1 is false (see analysis in Section 2.1 and Livaccari and Perry, 1993). Heat flow is increased over ascending limbs of mantle plumes (Scheidegger, 1963), thus, premise P2 is true. Szymanski (1992) inferred that local mantle plumes are fairly small in size due to the sharp P-wave velocity gradients (Evans and Smith, 1993). However, as was discussed in the analysis of Section 2.5 argument A1, interpretation of P-wave velocity gradients does not require these gradients to indicate partial-melts (Evans and Smith, 1993). Given this reservation and that upwelling mantle plumes most likely do not exist (P1 is false), then, premise P3 should be considered false. Argument A1 is equivalent in form to the argument: if A or B, then C. In this case, A is P1, P2, and P3, and B is P4 and P5. For the conclusion of A1 to be true, either P1, P2, and P3, or P4 and P5 must be true. Since both P1 and P3 are false, the only way the conclusion of A1 can be true is if both P4 and P5 are true. Premise P4 is false, since there is no evidence that thin and discontinuous magma chambers in the lower crust are present in the Yucca Mountain region (see analysis of argument A1 in Section 2.6 and Brocher et al., 1993). Emplacement of a heat source (body of mafic magma or spent nuclear fuel) into a solid produces a transient heat pulse (Scheidegger, 1963). Premise P5 is true. Since both P4 and P5 in combination are not true, then the conclusion of argument A1 that there are very substantial lateral temperature gradients in the lower crust (> 15 km depth) in the Yucca Mountain region is false.

The logical form of argument A2 is valid, and the conclusion of this argument is true if, and only if, the conclusion of argument A1 and premises P6 and P7 are true. Since the conclusion of argument A1 is false, the conclusion of argument A2, along the base of the Yucca Mountain hydrologic system (at about 15 km depth) the terrestrial heat input lacks spatial uniformity, is false. Note that Szymanski's (1992) choice of the depth of the base of the Yucca Mountain hydrologic system of 15 km appears to be arbitrary, and no relevant studies have been completed to test his assertion. The veracity of premise P6 (scarcity of free fluids deep within the crust) cannot be determined with much certainty, since this topic is at the forefront of scientific research. If there is a lack of free fluids deep within the deep crust (i.e., P6 is true), convective flow would be effectively inoperative (Scheidegger, 1963).

The logical form of argument A3 is valid, and the conclusion of this argument is true if the conclusion of argument A2 and the conclusion of argument A1 of Section 2.8 are true. Since the conclusion of argument A2 is false and the conclusion of argument A1 of Section 2.8 is false, the conclusion of argument A3, convective circulation of the local intracrustal fluids (< 15-km depth), either continuous or intermittent, is a thermodynamic necessity, is false.

2.10 EVOLVING THERMODYNAMIC STATE OF THE CRUST

2.10.1 Premises

P1: The local observed bi-modal magmatism expresses an advective ascent of matter from the asthenosphere (F). P2: There has been a decrease in the degree of partial melting of the rising asthenospheric matter (F). P3: There has been a decreasing influx of mantle-derived mafic magma (F). P4: There has been a decrease in the magma segregation depth (F). P5: There has been a concurrent increase in melting temperature (F). P6: Average crustal temperatures have been steadily increasing (F). P7: There has been a steady increase in the overall geothermal gradient (F). P8: In the Eureka Low, including part of the Yucca Mountain area, the terrestrial conductive heat flow is 1.5 HFU (T). P9: In general, excessive rise of the geothermal gradient is prevented by convective heat flow (T). P10: In the volcanic setting (Basin and Range) of the Yucca Mountain region heat flow should be greater than 1.5 HFU (F). P11: Measured P-wave velocities imply a heat flow greater than 1.5 HFU (?). P12: Local silica content of groundwaters imply a heat flow greater than 1.5 HFU (T?). P13: Effective convective crustal heat flow requires participation of crustal fluids (T).

2.10.2 Arguments

A1: If P1, P2, and P3, then the advective heat transport from the mantle and localized magmatic heating of the crust have been diminishing with time (V and F). A2: If P4 and P5, then there has been a steadily increasing conductive heat flow across the Moho discontinuity (V and F). A3: If P6, P7, P8, and P10, or P11, or P12, then excessive rise of the geothermal gradient is prevented by convective heat flow, and convective heat flow is of widespread importance for the Eureka Low and for Yucca Mountain (V and F). A4: If A3 and P13, then crustal hydrothermal circulation is important in the Yucca Mountain area (V and F).

2.10.3 Analysis

The logical form of argument A1 is valid, and the conclusion of this argument is true if, and only if, premises P1, P2 and P3 are true. Premise P1 is effectively the conclusion of argument A1 in Section 2.3 of this report. The conclusion of argument A1 in Section 2.3 was demonstrated to be false, thus the conclusion of argument A1 in this section, that advective heat transport from the mantle and localized magmatic heating of the crust have been diminishing with time, is false. Similarly, premise P2 is effectively the conclusion of argument A1 in Section 2.1 of this report. The conclusion of argument A1 in Section 2.1 was demonstrated to be false, so, the conclusion of argument A1 in this section is false. Finally, premise P3 necessarily includes premise P1 of Section 2.4 and can be considered to be the same as that premise. In the analysis of argument A1 in Section 2.4, it was concluded that P1 in that section was false — making P3 (there has been a decreasing influx of mantle-derived mafic magma) false. Since P1, P2, and P3 are false, the conclusion of Szymanski (1992) that the advective heat transport from the mantle and localized magmatic heating of the crust have been diminishing with time is false.

Argument A2 is validly constructed. The conclusion of this argument (A2) is true if premises P4 and P5 are true. Both premises P4 and P5 are based upon the petrogenetic constraints placed upon Szymanski's (1992) assumption of asthenospheric mantle derived basaltic magmatism in the Yucca Mountain region (see analysis of argument A1 Section 2.1). There is no geochemical evidence which requires involvement of asthenospheric mantle in the generation of basaltic volcanic rocks in the Yucca Mountain area (Livaccari and Perry, 1993), hence both P4 and P5 are false. Since both P4 and P5 are false, there is no reason to believe that there has been a steadily increasing conductive heat flow across the Moho discontinuity (conclusion of A2 is false).

The construction of argument A3 is of valid logic form. The conclusion that convective heat flow is of widespread importance for the Eureka Low and for Yucca Mountain requires that premises P6, P7, and P8 are true, and either P10, or P11, or P12 is true. The basis for the construction of this argument by Szymanski (1992) was that measured conductive heat flows are lower in part of the Yucca Mountain region than elsewhere in the Great Basin. Since Szymanski (1992) assumed the Yucca Mountain region is identical to the rest of the Great Basin with respect to the thickness of the lithosphere and the importance of asthenospheric mantle on geodynamic processes (basaltic volcanism and heat flow processes), he was forced to explain a perceived geothermal paradox. The contrived paradox simply stated is that according to his model (thin lithosphere and asthenospheric mantle origin for basaltic volcanism) there should be a larger conductive heat flow than is measured. Since there is not a larger conductive heat flow, the implication is convective flow of fluids is required (P9). This geothermal paradox disappears when one considers the geochemical isotopic signature of less than 5 Ma basaltic rocks in Crater Flat (Livaccari and Perry, 1993). Since these rocks have a lithospheric mantle signature, require lithospheric thickness to be greater than 50 to 70 km, and are in an area (western Great Basin) which is distinct from the rest of the Great Basin and whose preservation (lithospheric mantle source of volcanism) may have been caused by the area being anomalously cold and strong compared to the normal Basin and Range lithosphere (Livaccari and Perry, 1993), it is clear the basic premise under which Szymanski (1992) constructed his arguments was flawed. Premises P6 and P7 as constructed by Szymanski (1992), require asthenospheric mantle to drive them, and, are false. The measured conductive heat flow of Yucca Mountain, as measured in the only drill hole (total 60 drill holes) properly constructed for confident analysis of the thermal effects of natural groundwater flow, is 1.58 HFU (U.S. Department of Energy, 1988); thus, P8 can be accepted as true. Premise P10 is false since Szymanski (1992) assumed the geodynamic setting of Yucca Mountain region is the same as the rest of the Basin and Range (Livaccari and Perry, 1993). As discussed previously in Section 2.5, upper mantle P-wave velocities are suggestive that the upper mantle may remain in a quasi-stable state of incipient partial melting. However, a detailed argument was not presented by Szymanski (1992) which would allow calculation of the effect of this incipient partial melting state on the measured heat flows, therefore, the veracity of premise P11 and its possible consequences remain to be determined. Premise P12 states local silica contents of groundwaters imply a heat flow greater than 1.5 HFU. This assertion cannot be rigorously accepted and is only permissive and not conclusive evidence that heat flow is greater than 1.5 HFU (U.S. Department of Energy, 1988) — hence, P12 may be tentatively regarded as true. The conclusion of argument A3 that convective heat flow is of widespread importance for the Eureka Low and for Yucca Mountain should be considered false.

Finally, the logical form of argument A4 is valid. The conclusion of A4 that crustal hydrothermal circulation is important in the Yucca Mountain area can only be accepted if P13 and the conclusion of argument A3 (convective heat flow is of widespread importance for the Eureka Low and for Yucca Mountain) are true. Effective convective crustal heat flow requires participation of crustal fluids (Scheidegger, 1963) and (P13) can be considered true. Since the conclusion of A3 was demonstrated to be false, the conclusion that crustal hydrothermal circulation is important in the Yucca Mountain area should be considered false also.

2.11 CONVECTIVE CIRCULATION OF FLUIDS

2.11.1 Premises

P1: There is a fairly high intensity of the mean heat flow (F). P2: There is a fairly high lateral heat flow heterogeneity (F). P3: Elevated geothermal gradients are caused by the high intensity mean heat flow (F). P4: Elevated geothermal gradients introduce non equilibrium fluid density configurations at Yucca Mountain (F). P5: The fairly high lateral heat flow heterogeneity causes lateral temperature gradients (F). P6: Lateral temperature gradients assure that thermal stability limits are small (F). P7: Thermal stability limits are reached in crustal fluids due to the ongoing high heat flow input to the crust (F). P8: There is the potential for local presence of intracrustal magma bodies (?). P9: Intracrustal magma bodies result in strongly disequilibrated and sustainable "Bernard-Rayleigh" instabilities in enlarged spatio-temporal domains (T). P10: Intracrustal magma generated "Bernard-Rayleigh" instabilities are spatially stationary and temporally prolonged (T).

2.11.2 Arguments

A1: If P1 and P2, then "Bernard-Rayleigh" instabilities are intrinsic elements of the long-term behavior of the local hydrosphere (V and F). A2: If P3, P4, P5, P6, and P7, then convective circulation of intracrustal fluids occurs and unstable density configurations are dissipated (V and F). A3: If P8, P9, and P10, then magmatic center-based convective systems may remain active for a fairly long time (V and T).

2.11.3 Analysis

The logically valid construction of argument A1 requires that if, and only if, P1 and P2 are true, the conclusion that Bénard-Rayleigh instabilities (Scheidegger, 1963) are intrinsic elements of the long-term behavior of the local hydrosphere will be true. It has been assumed that Szymanski (1992) meant Bénard when he used "Bernard" in his text. Premise P1 is a restatement of the conclusion of argument A1 in Section 2.8. The conclusion of that argument, the average flux of terrestrial heat is fairly high (heat flow in the Yucca Mountain region is as high as 2.0 to 2.5 HFU) at the base of the Yucca Mountain hydrologic system, was determined to be false, thus P1 is false. Similarly, premise P2 is a partial restatement of the conclusion of argument A1 in Section 2.7 (S2.7). The conclusion of argument S2.7A1, that the lateral distribution of crustal temperatures is spatially heterogeneous, was shown to be false, requiring that premise P2 be assumed false. The conclusion that Bénard-Rayleigh instabilities are intrinsic elements of the long-term behavior of the local hydrosphere (A1) is false.

The construction of argument A2 is a valid logical form, which requires if each of the premises are true, the conclusion of the argument will be true. Although the global translation of premises P3, P4, P5, P6 and P7 indicates these premises are true in the global sense (Scheidegger, 1963), when applied to the local Yucca Mountain region, these premises are false. As expressed by Szymanski (1992), each premise is actually stated as if it is true (premise becomes conclusion). However, these premises are only true if high intensity mean heat flow and fairly high lateral heat flow heterogeneity are present in the Yucca Mountain region. As is clear from the analysis of argument A1 in this section, neither of these underlying premises are true — so, P3, P4, P5, P6 and P7 are false, making the conclusion of argument A2, convective circulation of intracrustal fluids occurs and unstable density configurations are dissipated, also false.

Argument A3 is validly constructed and the conclusion may be accepted to be true since each of the premises used to construct the argument are true. Premise P8 as stated by Szymanski (1992) was ambiguous because he did not give qualifying information. Specifically, he did not state whether the potential for local presence of intracrustal magma bodies spatially referred to the Yucca Mountain area imaged by Evans and Smith (1993) or to the 75-mile radius from Yucca Mountain area that he used in his discussion of silicic volcanism. In addition, Szymanski did not specify whether he was referring to the present time or the time of the Timber Mountain caldera system. Since Szymanski (1992) cited the Evans and Smith (1993) reference which clearly stated that >4-km mid-crustal silicic magma chambers can be ruled out in the immediate vicinity of the Yucca Mountain repository block, I have assumed he was referring to the larger area surrounding Yucca Mountain (75-mile radius). Another reason to infer the larger spatial scale is that analysis A1 in Section 2.6 indicates that intracrustal magma bodies are absent. A similar line of reasoning can be used to infer that Szymanski (1992) meant the time of the Timber Mountain caldera system (> 10 Ma). With this broad and generous interpretation of Szymanski's (1992) writing, premise P8 is then required to be true. Premise P9 is a thermodynamic necessity of large silicic or mafic intracrustal magma bodies (Scheidegger, 1963) and can be taken to be true. Premise P10 is an amplification of P9 and should also be considered true. Therefore, the conclusion that magmatic center-based convective systems may remain active for a fairly long time should be accepted as being both globally true and, as interpreted from Szymanski (1992), locally true at Yucca Mountain.

2.12 CONDUCTIVELY REPLENISHED HYDROTHERMAL SYSTEMS

2.12.1 Premises

P1: There is substantial conductive heat input from the upwelling mantle (F). P2: There is episodic enhancement of extrinsic hydraulic conductivity by ongoing tectonic straining (?). P3: Intermittent plumes exhaust the thermal source that fuels the intermittent instability (F). P4: Ephemeral plumes are characterized by an initial eruptive burst, followed relatively rapidly by a period of decaying activity and the eventual cessation of such activity (?). P5: Heating of host rocks due to the ephemeral plumes is spatially restricted (?). P6: Accumulation of trace elements due to ephemeral plumes is low and spatially restricted (?). P7: Rapid CO_2-degassing of ascending fluids in ephemeral hydrothermal plumes causes a reduction of calcite solubility (T?). P8: Rapidly dropping fluid temperatures during rapid ascent of ephemeral hydrothermal plumes causes reduction in the solubility of silica (T?). P9: The majority of local known hydrothermal ore deposits are temporally and spatially associated with local caldera-forming magmatic centers (T). P10: There is an evolving character of local convective heat transport (F).

2.12.2 Arguments

A1: If P1, P2, and convective circulation of intracrustal fluids occurs and unstable density configurations are dissipated (Section 2.11 argument A2), then transient Bernard(sic)-Rayleigh instabilities are present and assume the form of intermittent (ephemeral) plumes (V and F). A2: If A1, P1, and P3, then conductively driven plumes are episodic (V and F). A3: If A1, P4, P5, and P6, then the geologic record of intermittent hydrothermal systems are principally expressed by accumulations of gangue minerals (opaline silica and calcite) (V and F). A4: If P7 and P8, then various textural and mineralogical forms of silica and calcite precipitate (IV and F). A5: If A3, P9 and P10, then the local geologic record should contain expressions of fairly young and distinctly more subtle hydrothermal deposits associated with intermittent conductively replenished hydrothermal systems (V and F).

2.12.3 Analysis

The assertion of argument A1 that transient Bénard-Rayleigh instabilities are present and assume the form of intermittent (ephemeral) plumes is true if, and only if, convective circulation of intracrustal fluids occurs, there is substantial conductive heat input from the upwelling mantle, and there is episodic enhancement of extrinsic hydraulic conductivity by ongoing tectonic straining. The logical form of this argument (A1) is valid. The conclusion of argument A2 in Section 2.11, convective circulation of intracrustal fluids occurs and the unstable density configurations are dissipated, is false; thus, the conclusion of argument A1 is false. The conclusion of argument A1 is also undermined since the premise (P1) that there is substantial conductive heat input from the upwelling mantle is false (see analysis of arguments in Section 2.10). The last premise that Szymanski (1992) invoked in this argument is that there is episodic enhancement of extrinsic hydraulic conductivity by ongoing tectonic straining. This controversial idea outlined in his previous report (Szymanski 1989) may in fact be supported by recent analyses [Wood and King, 1992 as cited by Archambeau and Szymanski (1993)], however, there remains much controversy. The eventual decision to conclude that this premise is true will only affect the interpretation of the conclusion of this argument if, and only if, the other premises of this argument can be shown to be true. With the current understanding of the geodynamic configuration of the local Yucca Mountain area and possible geodynamic processes, Szymanski's (1992) conclusion that transient

Bénard-Rayleigh instabilities are present and assume the form of intermittent (ephemeral) plumes should not be accepted as a true inference.

The logical form of argument A2 is valid, and the conclusion (conductively driven plumes are episodic) is true only if the conclusion of argument A1 is true and premises P1 and P3 are also true. Since P1 is false (see analyses of arguments in Section 2.10) and the conclusion of argument A1 is false, then the conclusion of Szymanski's (1992) argument that conductively driven plumes are episodic is also false. Premise P3 assumes that intermittent plumes exist, and the above analysis of argument A1 in this section clearly demonstrates this to be false. Hence, the conclusion of argument A2 is false.

Argument A3 is constructed with a valid logical form. If, and only if, the conclusion of A1 and premises P4, P5, and P6 are true, then the geologic record of intermittent hydrothermal systems is principally expressed by accumulations of gangue minerals (opaline silica and calcite). Since the assertion presented by Szymanski (1992) in argument A1 is false, the conclusion of A3, that the geologic record of intermittent hydrothermal systems is principally expressed by accumulations of gangue minerals, is false. It is not necessary to disprove premises P4, P5, and P6, since conditions necessary to produce the effects described in premises P4, P5, and P6 do not exist if conclusion A1 is false. If A1 was in fact true, the veracity of each of these premises (P4, P5, and P6) would still have to be determined and supported before the conclusion of argument A3, the geologic record of intermittent hydrothermal systems is principally expressed by accumulations of gangue minerals, could be accepted as true. Szymanski (1992) presented premises P4, P5, and P6 as statements of fact, without any geological support. In fact, premise P4 as stated by Szymanski (1992) (ephemeral plumes are characterized by an initial eruptive burst, followed relatively rapidly by a period of decaying activity and the eventual cessation of such activity) is an untested hypothesis, and perhaps an intestable hypothesis. If Szymanski (1992) had provided any support from any other geologic or historic occurrence (an analogy) for his characterization of the attributes of intermittent conductively generated hydrothermal plumes as described in this premise, there would be at least some basis to analyze the veracity of his premise. Similarly, no supporting evidence was presented by Szymanski (1992) to test the hypotheses presented in premise P5 (heating of host rocks due to the ephemeral plumes is spatially restricted) or in premise P6 (accumulation of trace elements due to ephemeral plumes is low and spatially restricted). Therefore, since premises P4, P5, and P6 cannot be assumed to be true, and since the assertion that transient Bénard-Rayleigh instabilities are present and assume the form of intermittent (ephemeral) plumes is false, there is no plausible reason to accept the conclusion that the geologic record of intermittent hydrothermal systems is principally expressed by accumulations of gangue minerals.

The construction of argument A4 is invalid since each premise assumes an unproven concept (hydrothermal plumes). While it is true that rapid CO_2-degassing of fluids causes a reduction of calcite solubility and rapidly dropping fluid temperatures causes a reduction in the solubility of silica (Henley et al., 1984), Szymanski's (1992) application of these global concepts to the specific case of ascending fluids in ephemeral hydrothermal plumes was flawed by the necessary requirement that the plumes exist. Since both premises P7 and P8 assume that ephemeral hydrothermal plumes exist, and this assertion has been shown not to be true (see discussion of argument A1), then P7 and P8 are false, and necessarily the conclusion of argument A4 is most likely false.

The construction of argument A5 is a valid logical form which requires each of the premises to be true in order for the conclusion of the argument to be true. The premises of A5 are: (i) the geologic record of intermittent hydrothermal systems is principally expressed by accumulations of gangue minerals (A3); (ii) the majority of local known hydrothermal ore deposits are temporally and spatially associated with local caldera-forming magmatic centers (P9); (iii) and the gradually evolving thermodynamic state in the Yucca Mountain region (P10, as described in Section 2.10). If these premises are true, then Szymanski's (1992) conclusion that the local geologic record should contain expressions of fairly young and distinctly more subtle hydrothermal deposits associated with intermittent conductively replenished hydrothermal systems can be accepted as true. In the analysis of argument A3 in this section, it was demonstrated that the premise that the geologic record of intermittent hydrothermal systems is principally expressed by accumulations of gangue minerals is false — so too, the conclusion of argument A5 is false. Premise P9 is adequately supported in the literature (Bish and Chipera, 1989; Broxton et al., 1987) and can be assumed to be true. Since the model upon which Szymanski (1992) builds his argument that the thermodynamic state has been gradually evolving is false (see analysis in Section 2.10), premise P10 is false.

As stated in the final paragraphs of Section 2.5 in Szymanski (1992), the rest of his document, and therefore the rest of this report, focuses on establishing whether fairly young and subtle hydrothermal deposits caused by conductively replenished hydrothermal systems exist in the Yucca Mountain area. From the discussion and analyses presented in this section of the report, it is clear there is no logical or scientific bases upon which to plausibly accept the existence of conductively replenished hydrothermal systems (characterized by intermittent ephemeral hydrothermal plumes) in the Yucca Mountain region. The conclusions for all subsequent arguments developed by Szymanski (1992) which require that conductively replenished hydrothermal systems (characterized by intermittent ephemeral hydrothermal plumes) exist in the Yucca Mountain region will be false.

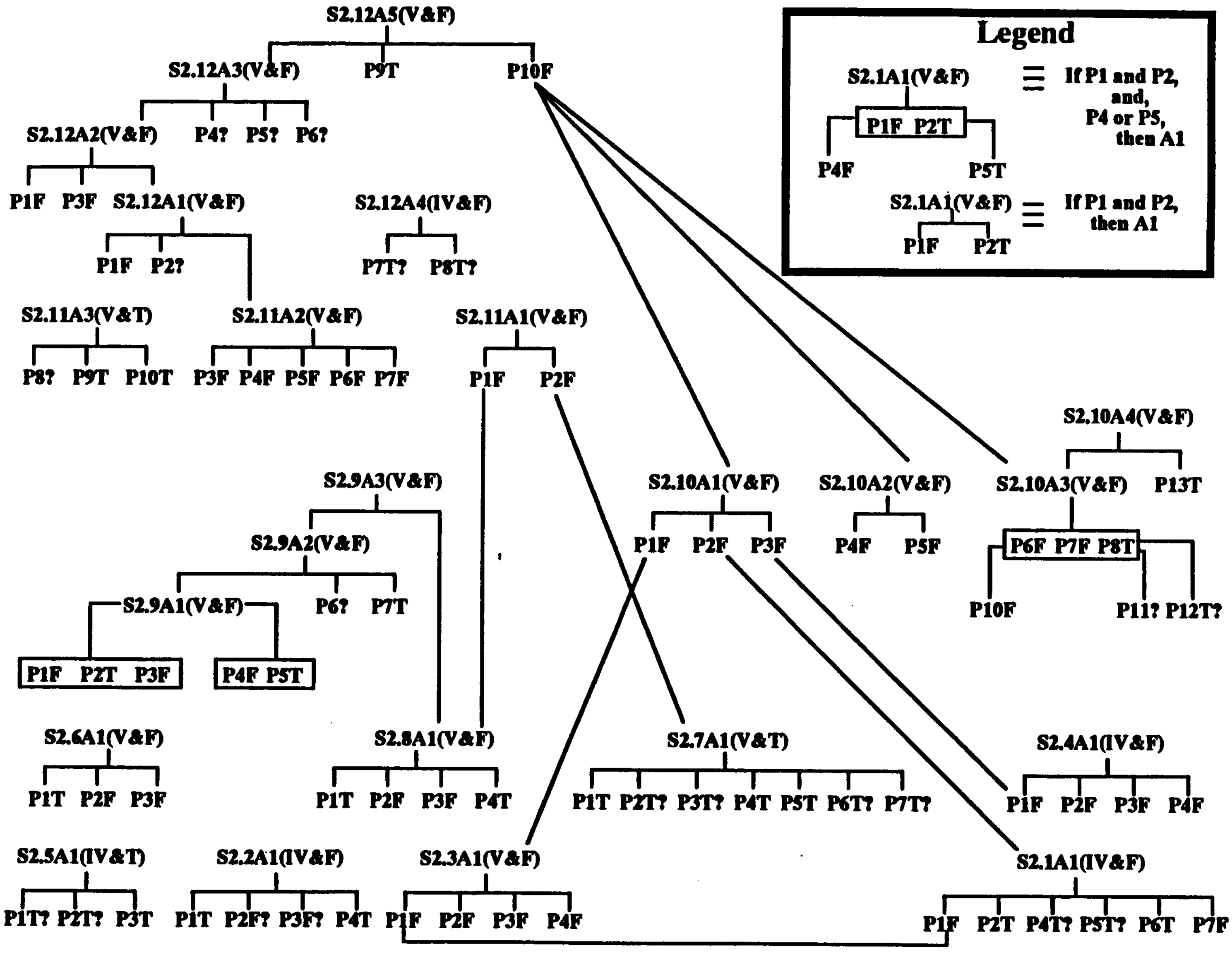


Figure 2-1. Logic diagram of arguments presented in Chapter 2

3 MINERALIZATION AND ALTERATION OF SURFICIAL DEPOSITS

In Chapter 3 of Szymanski (1992), evidence was presented and arguments were developed to convince the reader that some surficial exposures of mineralization and alteration at Yucca Mountain are epigenetic (origin later than that of enclosing rocks) and that sometime in the past hydrothermal solutions discharged at the contemporary topographic surface. Further, it was argued that some of the observed hydrothermal features appear to be fairly young (Plio-Quaternary) in age. Four different types of exposures which are reflective of mineralization and alteration at Yucca Mountain were used to develop and support these assertions. First, surficial calcrete and sinter deposits were examined with respect to their textural diversity and their compositional diversity. Separate arguments for the textural (analyzed in Section 3.1) and compositional (reviewed in Section 3.2) diversity of these deposits were developed to support the assertion that the deposits may be hypogene (formed by ascending solutions). Bedrock veins were the second type of deposit examined by Szymanski (1992) for evidence of textural and compositional diversity and purity. Separate arguments for the textural (discussed in Section 3.3) and compositional (addressed in Section 3.4) diversity of the bedrock veins and the mineralogical purity of the M-type veins (examined in Section 3.5) were developed to support the assertion that at least some of the deposits must be hypogene. The third type of surficial exposure investigated by Szymanski (1992) was the example of hydrothermal alteration found in the vicinity of Stage Coach Road, the eastern flank of Harper Valley, and in the Trench #14b exposure. Four separate arguments based upon known local epigenetic hydrothermal mineralization (considered in Section 3.6), the age of the units affected by alteration (pursued in Section 3.7), the restriction of alteration to brittle deformation features (scrutinized in Section 3.8), and the relationship of alteration to the history of faulting (studied in Section 3.9) at these sites were offered to support the assertion that these sites reflect epigenetic alteration. Mosaic breccias were the fourth type of surficial deposits examined by Szymanski (1992). Five lines of evidence were used to argue that these deposits are epigenetic and hypogene. The lack of characteristics associated with auto-breccias (explored in Section 3.10), the lack of characteristics associated with shear fragmentation as recorded by strain constraints (analyzed in Section 3.11), the presence of F-type textures (reviewed in Section 3.12), the compositional alternations in the mosaic breccias (examined in Section 3.13), and the mineralogical purity of the authigenic cement (addressed in Section 3.14) comprise the five arguments used in support of the assertion that some surficial exposures of alteration and mineralization are young, epigenetic, and hypogene.

3.1 TEXTURAL DIVERSITY OF CALCRETES AND SINTERS

3.1.1 Premises

P1: Calcretes occur in the form of five texturally distinct varieties (T). P2: GS-textured calcretes are defined as occurrences where allogenic clasts are in direct contact and authigenic cement occurs in undilated pore space (T). P3: F-textured calcretes are defined as occurrences where allogenic clasts float in authigenic cement (T). P4: M-textured calcretes are defined as occurrences where authigenic cement, either calcite or opal, constitute more than 90% of a specimen's total volume (T). P5: Intercalated M-textured calcretes are defined as occurrences where bands or laminae of calcite alternate with laminae or bands of opal (T). P6: Laminated M- and GS-textured calcretes are defined as occurrences where laminae of fine cemented and GS-textured sand separate laminae or bands of detritus-free authigenic cement (T). P7: Precipitation of calcium carbonate and/or opaline silica, as found in pedogenic (topographic surface deposition) accumulations, is the result of some combination of several factors (T).

P8: Meteoric fluids which endure run-off, infiltration, evaporation, and evapotranspiration can cause accumulations of carbonate and/or opaline silica (T). P9: Reduction of fluid temperature, reduction in CO_2 partial pressure, and changes in fluid pH can cause accumulations of carbonate and/or opaline silica (T). P10: Calcretes with clearly comparable ages exhibit textural diversity (F?). P11: Rates of supergene authigenic cement are invariant in time and space (F). P12: Supergene authigenic cement formation cannot occur both directly at the topographic surface and in pre-existing alluvial, colluvial, or aeolian deposits (F). P13: Rapid precipitation on the topographic surface causes formation of both M-textured calcretes and laminated M- and GS-textured calcretes (?). P14: F-textured calcretes form by a direct, but slower, surface precipitation process (?). P15: GS-textured calcretes are produced when the rates of formation of authigenic cement are smaller than the rates of introduction of allogenic clasts or when mineralizing fluids flow through pre-existing accumulations of various detritus (?).

3.1.2 Arguments

A1: If P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, and P15, then the textural diversity of calcretes and sinters at the topographic surface can only be formed by hypogene fluids (IV and F).

3.1.3 Analysis

This inductive argument is invalid since Szymanski (1992) claimed a degree of probability for its conclusion that is unreasonable to attribute to that conclusion, relative to available evidence. No scientific evidence (thin-section, detailed sedimentological and/or chemical analyses of deposits) was presented by Szymanski (1992) to support his premises. Several premises, P2, P3, P4, P5, and P6, are presented as definitions and can be accepted as a true definition, however as stated, these premises provide no credible support for the origin of calcretes and surface sinter deposits. Premise P1 is true as the direct consequence of the definitions offered by Szymanski (1992) in P2, P3, P4, P5, and P6. The various possible processes responsible for the precipitation of pedogenic silicious and carbonate deposits are presented in P7, P8, and P9, and can be accepted as true based upon published geochemical treatises (Klappa, 1983; Henley et al., 1984; McFadden et al., 1991). The remaining premises used by Szymanski (1992) to construct his argument were either stated as fact (P10, P13, P14, and P15) or implied based upon the physical consequences of premises P7 and P8 (P11 and P12). Regardless of their origin, none of these premises were supported by any scientific evidence by Szymanski (1992). There is substantial evidence at Yucca Mountain (Everden, 1992; Stuckless, et al., 1992; Vaniman, 1991; Vaniman et al., 1988) to suggest that P11 and P12 are false. Additionally, the mechanisms and models of supergene pedogenic authigenic cement formation suggest variable rates, both in time and space, for cementation (McFadden et al., 1991; Wang et al., 1993, Harden et al., 1991). A disregard for basic geologic principles, which was repeated throughout his analyses (Szymanski, 1992), is the temporal correlation of deposits of authigenic minerals without sufficient temporal constraints on the deposits. Calcretes or any authigenic deposits cannot have clearly comparable ages when no geochronologic data or textural or stratigraphic controls for the different deposits is presented. So, without any scientific support, other than blind assertion, Szymanski (1992) concluded that the textural diversity of calcretes and sinters at the topographic surface can only be formed by hypogene fluids. Clearly, it is unreasonable to confidently infer a hypogene origin for the calcretes. The conclusion to this inductive argument should not be accepted as true since poor reasoning was used in the argument and some premises are false. It is important to note that further arguments presented in Sections 3.3 and 3.12 of this report rely on the same faulty premises that the rates of supergene authigenic cement are invariant in time and space, and supergene authigenic cement formation cannot occur both directly at the topographic surface and in pre-existing alluvial, colluvial, or aeolian deposits.

3.2 COMPOSITIONAL DIVERSITY OF CALCRETES AND SINTERS

3.2.1 Premises

P1: Bands of alternating calcium carbonate and opal exist (T). P2: The conditions of formation of authigenic cement alternated between those favoring precipitation of opal and those favoring precipitation of micritic calcite (T). P3: Fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition are not expected characteristics of supergene pedogenic processes (F). P4: A typical feature of geothermal systems is fluctuating chemical composition of fluids (T). P5: Fluctuating conditions of mineral deposition are a typical feature of geothermal systems (T).

3.2.2 Arguments

A1: If P1 and P2, then the conditions of formation fluctuated with time (V and T). A2: If P3, P4, and P5, then the compositional diversity of calcretes and sinters at the topographic surface can only be formed by hypogene fluids (V and F).

3.2.3 Analysis

The construction of argument A1 by Szymanski (1992) is valid, and requires that both P1 and P2 be true for the conclusion to be accepted as true. Both P1 and P2 must be true since deposits which are carbonate-rich and silicious coexist (Szymanski, 1992), and this necessarily requires geochemical conditions conducive for the formation of the different minerals. Although Szymanski (1992) stated that either the parental fluid compositions or the conditions of formation fluctuated with time, the first clause is actually a special case of the more inclusive statement of alternating conditions with time, and the argument only requires that conditions of formation fluctuate with time. Argument A1 is thus validly constructed and the conclusion is true.

Argument A2 is validly constructed. Premise P3 was stated as fact by Szymanski (1992) without scientific support or reference to published models of supergene calcrete formation. Published models of calcrete formation actually demonstrate that fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition are expected characteristics of supergene pedogenic processes (Harden et al., 1991; Wang et al., 1993; Vaniman et al., 1992; Carlisle, 1983). P3 is false, and the conclusion of argument A2 should not be accepted as true. Although the broad ideas presented in premises P4 and P5 are true (Henley et al., 1984), details of the current geometrical and mineralogic relationships (grain size of calcium carbonate) indicate that hydrothermal precipitation of opal and micritic calcite is unlikely (Henley et al., 1984). Hence, the conclusion of argument A2 that the compositional diversity of calcretes and sinters at the topographic surface can only be formed by hypogene fluids, is false. It is important to note that further arguments presented in Sections 3.4 and 3.13 of this report rely on the same faulty assumption that the compositional diversity of calcretes and sinters at the topographic surface cannot be formed by supergene fluids.

3.3 TEXTURAL DIVERSITY OF BEDROCK VEINS

3.3.1 Premises

P1: There are two broadly distinct varieties of veins (T). P2: The older variety is clearly hydrothermal veins and impregnations (T). P3: The older variety of hydrothermal veins represents deuteric mineralization (T). P4: Convincing geologic field evidence at the northeastern flank of Harper Valley and across Lathrop Wells indicates that at these locations epigenetic hydrothermal veins are seen (?). P5: The younger variety consists of micritic calcite intercalated with milky opaline silica (T). P6: At least some of the calcite-opaline silica veins (Busted Butte aeolian deposits) are younger than 700 ka (T). P7: The younger veins display indisputable affinity with the local calcretes (T). P8: Rates of supergene authigenic cement formation are invariant in time and space (F).

3.3.2 Arguments

A1: If P2, P3, and P4, then at least some (northeastern flank of Harper Valley and across Lathrop Wells) older variety hydrothermal veins represent subsequent epigenetic mineralization (V and F). A2: If P5, P6, P7 and P8, then the textural diversity of bedrock veins can only be formed by hypogene fluids which have been active within the last 700 ka (V and F).

3.3.3 Analysis

The logical form of argument A1 is valid and requires that P2, P3, and P4 must be true if the conclusion is to be accepted. Although Szymanski (1992) suggested that field evidence is convincing at both the northeastern flank of Harper Valley and across Lathrop Wells, he provided no evidence (detailed geologic description or supportive analyses) for his assertion. Alternate detailed interpretations of these deposits exist (Everden, 1992; Levy, 1993). If Szymanski (1992) was correct, then he could only state that hydrothermal alteration occurred after the cooling, syndepositional devitrification and solidification of the ignimbrites.

A valid logical form was used by Szymanski (1992) to construct argument A2. Premise P5, P6 and P7 appear to be true based upon field evidence (Szymanski, 1992; Stuckless, et al., 1992; Everden, 1992). The critical assumption that Szymanski (1992) made to discount the possibility that supergene fluids could form the bedrock veins was P8. As was discussed in the analysis of Section 3.1, this premise is false. The conclusion of A2 should not be accepted.

3.4 COMPOSITIONAL DIVERSITY OF BEDROCK VEINS

3.4.1 Premises

P1: There are two broadly distinct varieties of veins (T). P2: The younger variety consists of micritic calcite intercalated with milky opaline silica (T). P3: At least some of the calcite-opaline silica veins (Busted Butte aeolian deposits) are younger than 700 ka (T). P4: The younger veins display indisputable affinity with the local calcretes (T). P5: Fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition are not expected characteristics of supergene pedogenic processes (F). P6: A typical feature of geothermal systems is fluctuating chemical composition of fluids (T). P7: Fluctuating conditions of mineral deposition are a typical feature of geothermal systems (T).

3.4.2 Arguments

A1: If P1, P2, P3, P4, P5, P6, and P7, then the compositional diversity of bedrock veins can only be formed by hypogene fluids, some of which have been present within the last 700 ka (V and F).

3.4.3 Analysis

The requirement of the validly constructed argument A1 is that all premises must be true if the conclusion can be accepted as true. As discussed in the analysis of Section 3.3 premises P1, P2, P3, and P4 are true based upon field evidence (Szymanski, 1992; Everden, 1992; Stuckless, et al., 1992). P6 and P7 are true (see analysis in Section 3.2). To infer that only hypogene deposits can form the bedrock veins, Szymanski (1992) must have implicitly assumed P5, and that assumption is false. Published models of calcrete formation demonstrate that fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition are expected characteristics of supergene pedogenic processes (McFadden et al., 1991; Harden et al., 1991). P5 is false, and the conclusion of argument A1 should not be accepted as true.

3.5 MINERALOGICAL PURITY OF M-TEXTURED VEINS

3.5.1 Premises

P1: Some veins with fairly large apertures consist of pure mineral phases (M-textured) (F). P2: The rate of supergene mineral formation is much slower than the rate of fracture opening (T?).

3.5.2 Arguments

A1: If P1 and P2, then supergene fluids cannot precipitate pure mineral phases in bedrock veins (V and F).

3.5.3 Analysis

Argument A1 is a validly constructed logical argument, however, it necessarily requires that P1 and P2 are true if the conclusion is to be accepted as true. Szymanski (1992) offered no scientific evidence of veins composed of a pure mineral phase, he simply asserted it was true. However, all published analyses of bedrock veins in the Yucca Mountain region (Everden, 1992; Stuckless et al., 1992; Vaniman et al., 1988) indicate the veins are not composed of a pure mineral, but are invariably composed of varying degrees (>30 percent) of noncarbonate material. There is no evidence to support the premise that some bedrock veins consist of pure mineral phases, and so the conclusion of A1 is not true. At least in some cases P2 is true, since some near surface veins contain basaltic ash (Vaniman et al., 1988). The general validity of P2 is questionable.

3.6 EPIGENETIC HYDROTHERMAL MINERALIZATION

3.6.1 Premises

P1: Hydrothermally altered bedrock, in the form of fracture- and fault-based alteration aureoles is found in the Yucca Mountain area (T). P2: An aureole is observed in the vicinity of Stage Coach Road (T). P3: An aureole is observed along the eastern flank of Harper Valley (T). P4: An aureole is observed along the trace of the Solitario Canyon fault (T). P5: An aureole is observed in the Trench #14b exposure (T). P6: Hydrothermally altered bedrock can form via deuteric processes (T). P7: Hydrothermally altered bedrock can form via epigenetic processes (T).

3.6.2 Arguments

A1: If P1, P2, P3, P4, P5, P6, and P7, then at least some of the hydrothermal alteration may represent epigenetic processes, some of which may be associated with the hydrothermal stage of the Timber Mountain caldera (V and T).

3.6.3 Analysis

Argument A1 is a valid inductive argument since Szymanski (1992) claimed a degree of probability for its conclusion that is reasonable to attribute to that conclusion, relative to available evidence. Szymanski (1992) applied general mechanisms of hydrothermal alteration (deuteric or epigenetic) to specific examples without supplying any supporting evidence. Some of the examples that Szymanski (1992) cited in P1, P2, P3, P4, and P5 have been examined and described in detail by Everden (1992) and Levy (1993). Levy (1993) offered abundant scientific evidence that the Harper Valley and Stage Coach Road exposures most likely reflect deuteric hydrothermal processes and provided credible evidence that hydrothermal activity associated with the Timber Mountain caldera system was not the cause for the alteration at these sites. Szymanski (1992) provided no data and only asserted that these hydrothermal alteration exposures are the result of epigenetic hydrothermal activity. Both P6 and P7 can cause hydrothermal alteration, and these premises are true in the global sense.

3.7 YOUTH OF HYDROTHERMAL ALTERATION

3.7.1 Premises

P1: Some of the hydrothermal alteration (locations cited in premises of Section 3.6) may represent epigenetic processes associated with the hydrothermal stage of Timber Mountain caldera (T). P2: There are both apparently younger calcretes and equivalent bedrock veins (T). P3: Calcretes and bedrock veins are produced by hypogene fluids (F).

3.7.2 Arguments

A1: If P1, P2, and P3, then some of the observed hypogene alteration (calcretes) is significantly younger than the Timber Mountain hydrothermal episode (V and F).

3.7.3 Analysis

The construction of argument A1 by Szymanski (1992) was valid and requires that all premises be true if the conclusion is to be accepted. In Section 3.6, P1 was demonstrated to be true. Calcretes and bedrock veins do not have to be formed by hypogene processes (P3 is false, see analyses in Section 3.1 and 3.2). Therefore, the conclusion of A1 that some of the observed hypogene alteration (calcretes) is significantly younger than the Timber Mountain hydrothermal episode should not be accepted as true.

3.8 AREALLY RESTRICTED TO BRITTLE DEFORMATIONAL FEATURES

3.8.1 Premises

P1: Devitrification of the Topopah Spring Member vitrophyre is restricted to pockets and bands centered on brittle deformational features (T). P2: Brittle deformation (fractures) cannot form until after the volcanic unit has cooled (F).

3.8.2 Arguments

A1: If P1 and P2, then at least some of the hydrothermal alteration (devitrification along fractures) represents epigenetic processes, some of which may be associated with the hydrothermal stage of the Timber Mountain caldera (V and F).

3.8.3 Analysis

If both P1 and P2 were true then the conclusion would be true according to the logically valid form of this argument. Premise P1 is true (Levy and O'Neil, 1989; Bish, 1993). Szymanski (1992) provided no evidence other than assertion regarding the timing of fracture growth in the Topopah Spring Member which would require that alteration had occurred after cooling of the unit. In contrast, Levy (1993) and Levy and O'Neil (1989) provided compelling evidence that P2 is false and devitrification in the lower Topopah Spring Member occurred during cooling of the pyroclastic deposit (deuteric alteration). The conclusion of A1 is demonstrably false.

3.9 ALTERATION POSTDATING FAULTING

3.9.1 Premises

P1: Hydrothermal alteration occurs in stratigraphically distinct ignimbrites across fault contacts (?). P2: Faulting substantially followed emplacement of all ignimbrites (?).

3.9.2 Arguments

A1: If P1 and P2, then at least some of the hydrothermal alteration represents epigenetic processes, some of which may be associated with the hydrothermal stage of the Timber Mountain caldera (? and ?).

3.9.3 Analysis

This argument was poorly developed by Szymanski (1992), with no reference to a location upon which premise P1 is asserted to be true. No detailed field description of the location was presented so that analysis of the validity of the premise cannot be tested. If Szymanski (1992) intended to refer to the vicinity of the Stage Coach Road area or the Harper Valley site, then the detailed description provided by Everden (1992) could be used to assess the truth of P1. Similarly, no evidence was provided by Szymanski (1992) to indicate relative timing of the faulting — so, accuracy of P2 cannot be ascertained. Some indication of the relative timing of faulting was provided by Levy (1991). She asserted that much deformation occurred between successive emplacement of the volcanic rocks — contemporaneous volcanism and deformation. However, this hypothesis has been inadequately explored to confidently conclude the truth of the premise. No conclusion about the importance of alteration postdating faulting can be derived from the inadequately developed argument A1 of Szymanski (1992).

3.10 MOSAIC BRECCIAS ARE NOT AUTO-BRECCIAS

3.10.1 Premises

P1: Peculiar looking breccias occur in the area around Stage Coach Road (T). P2: Peculiar looking breccias occur at the head of the Solitario Canyon (T). P3: Peculiar looking breccias occur in the Trench #14b exposure (T). P4: Peculiar looking breccias occur in the east and west flanks of Busted Butte (T). P5: Breccias are composed of angular to subrounded clasts of various sizes firmly cemented by opaline silica with lesser involvement of micritic calcite (T). P6: Some breccias occur in the local pyroclastic rocks (T). P7: Some breccias occur in the local sedimentary rocks (specifically the Paleozoic carbonates) (T). P8: Breccias formed in sedimentary rocks cannot be auto-breccias (T). P9: All breccias have the same origin (F).

3.10.2 Arguments

A1: If P1, P2, P3, P4, P5, P6, P7, P8, and P9, then all breccias did not form syndepositionally with the host ignimbrites (auto-breccias); some are epigenetic in origin (V and T).

3.10.3 Analysis

The inductive argument A1 is valid since Szymanski (1992) applied a reasonable probability to the conclusion relative to the available evidence. Again, Szymanski (1992) gave little or no explanation for his premises, but asserted their truth. The first seven premises are based upon field observations (Szymanski, 1992; Everden, 1992; Levy, 1993) and are true. By definition breccias formed in sedimentary rocks cannot be formed syndepositionally with the host ignimbrites and P8 is true. Without any evidence, Szymanski (1992) postulated that breccias in the ignimbrites cannot be auto-breccias, although published analyses by Levy (1993) clearly indicate otherwise. Thus, P9 is false. Although P9 is false, the remainder of the premises are true and the reasoning used by Szymanski (1992) is good; the conclusion is probably true.

3.11 MOSAIC BRECCIAS ARE NOT DUE TO SHEAR FRAGMENTATION

3.11.1 Premises

P1: Yucca Mountain breccias lack any shear fabric (T). P2: The breccias exhibit a very large volumetric strain (T). P3: Breccias occur as irregular pods and discontinuous dikes (T). P4: Breccias exhibit a volumetric strain that is remarkably isotropic (T). P5: All breccias are not auto-breccias (T). P6: Bedrock openings cannot be formed by crystallization forces of minerals (?).

3.11.2 Arguments

A1: If P1, P2, P3, P4, P5, and P6, then some of the Yucca Mountain breccias are either denudation breccias (formed through in-filling of independently formed bedrock opening by erosionally derived clasts) or explosive breccias (V and T?).

3.11.3 Analysis

A correct logical form was used by Szymanski (1992) to construct argument A1. No scientific evidence was supplied by Szymanski (1992) to support his assertion of premises P1, P2, P3, and P4. An implied premise which is required to account for all possibilities of formation of the brecciated rock is P6. To date, Szymanski has refused to acknowledge this possibility; however, workers in the area have not quantitatively supported this model either. Until the physical dynamics of the process in P6 are quantified, the formation mechanism of these brecciated zones cannot be quantitatively and firmly established. Workers, such as Everden (1992), imply that the force of crystallization of carbonate would be large enough to cause separation of the bedrock; however, no scientific evidence is offered to support the assertion. Since the argument was validly constructed and all the premises may be true, the conclusion of argument A1 may be tentatively accepted. Szymanski's conclusion of this argument allowed for two possible modes of formation for the mosaic breccia fabric, and his arguments presented in Sections 3.12, 3.13, and 3.14 are used to infer that mosaic breccias are formed via explosion.

3.12 F-TEXTURED MOSAIC BRECCIA

3.12.1 Premises

P1: Authigenic cement of the mosaic breccias is very much like the material that occurs in bedrock veins, calcretes, and sinters (T). P2: Rates of supergene authigenic cement are invariant in time and space (F). P3: F-textured calcretes (allogenic clasts floating in cement) form by a direct, but slower, surface precipitation process (?). P4: Mosaic breccias are F-textured (T).

3.12.2 Arguments

A1: If P1, P2, P3 and P4, then mosaic breccias cannot form by supergene processes and must be formed via hypogene processes (V and F).

3.12.3 Analysis

Argument A1 is a validly constructed argument, but contains at least one premise (P2 and possibly P3) which is false, requiring the conclusion of the argument not to be accepted. There is a logical break required by Szymanski (1992) if one is to believe that the mosaic breccias are caused by explosive activity. On page 3-6, Szymanski (1992) stated the formation of F-textured calcretes is presumed to be due to a slow but direct surface precipitation of carbonate, yet the mechanism required to generate the mosaic breccias by Szymanski (1992) is explosive volatilization of CO_2-rich hypogene fluids. Additionally, Szymanski (1992) used the similarity of the bedrock veins, mosaic breccia, and calcretes to create a genetic link between the deposits in P1. As was discussed in Section 3.1, there was no reason given by Szymanski (1992) to support the assertion that rates of supergene authigenic cement formation are invariant in time and space — and, there is ample evidence (McFadden et al., 1991) to indicate otherwise. Since P2 is false and P3 is not consistent (asserted to be true in Section 3.1 and incompatible with explosivity), the conclusion of argument A1 should not be accepted as true.

3.13 COMPOSITIONAL ALTERNATIONS OF MOSAIC BRECCIA

3.13.1 Premises

P1: There are compositional alternations in mosaic breccias (T). P2: Fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition are not expected characteristics of supergene pedogenic processes (F). P3: The conditions of formation of authigenic cement alternated between those favoring precipitation of opal and those favoring precipitation of micritic calcite (T).

3.13.2 Arguments

A1: If P1, P2, and P3, then the compositional diversity of mosaic breccias at the topographic surface can only be formed by hypogene fluids (V and F).

3.13.3 Analysis

The construction of A1 is a valid form and requires that each premise be true if the conclusion is to be accepted. Premise P1 is true based upon field (Szymanski, 1992) and laboratory analyses of the mosaic breccias (Stuckless et al., 1992). Premise P3 is a geochemical necessity which is dependent upon the truth of P1, and thus is also true. As was discussed in Section 3.2, Szymanski (1992) offered no documentation to the assertion that supergene formation of calcretes, bedrock vein, and mosaic breccia cements cannot result in compositionally diverse mineral deposits. Published models of near-surface authigenic cement formation in arid regions (Harden et al., 1991; McFadden et al., 1991), in fact, require fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition during supergene pedogenic processes. P2 is false and the conclusion of A1 should not be accepted.

3.14 MINERALOGICAL PURITY OF MOSAIC BRECCIA

3.14.1 Premises

P1: The authigenic cements in mosaic breccias are pure and contain no detrital contamination (F). P2: Authigenic purity of cement requires a hypogene mechanism (T?).

3.14.2 Arguments

A1: If P1 and P2, then the mosaic breccias at the topographic surface may be formed by hypogene fluids (V and F).

3.14.3 Analysis

The assertion of argument A1 that the mosaic breccias at the topographic surface may be formed by hypogene fluids requires that premises P1 and P2 be true, if the conclusion is to be accepted. Since P1 is false, the logically correct form of argument A1 requires that the conclusion not be accepted. Szymanski (1992) offered no evidence of mineralogical purity of the mosaic breccias other than pure assertion, while published analyses of the breccias indicate (Stuckless et al., 1992; Everden, 1992) they are impure (>30%).

Although Szymanski (1992) asserted the upwelling possibility can rationally explain every single field observation of calcretes, sinters, bedrock veins, and mosaic breccias, it is clear from this analysis of the logic used by Szymanski (1992) in Chapter 3 of the report, that many irrational assumptions must be made and several logical inconsistencies are present. This chapter acts as a foundation for subsequent chapters in his report (1992) and is the most poorly scientifically supported section. His style of argumentation in this chapter relies on blind assertion, without sufficient or adequate documentation, to test his premises/affirmations. Many of his most critical declarations conflict with observations and published models of supergene pedogenic mineral formation in arid regions. His foundation (calcretes, sinters, bedrock veins, and mosaic breccias may be formed via hypogene processes) for many arguments in subsequent chapters (Szymanski, 1992) was primarily based upon this assertion — not supported by available evidence — and should not be accepted as true.

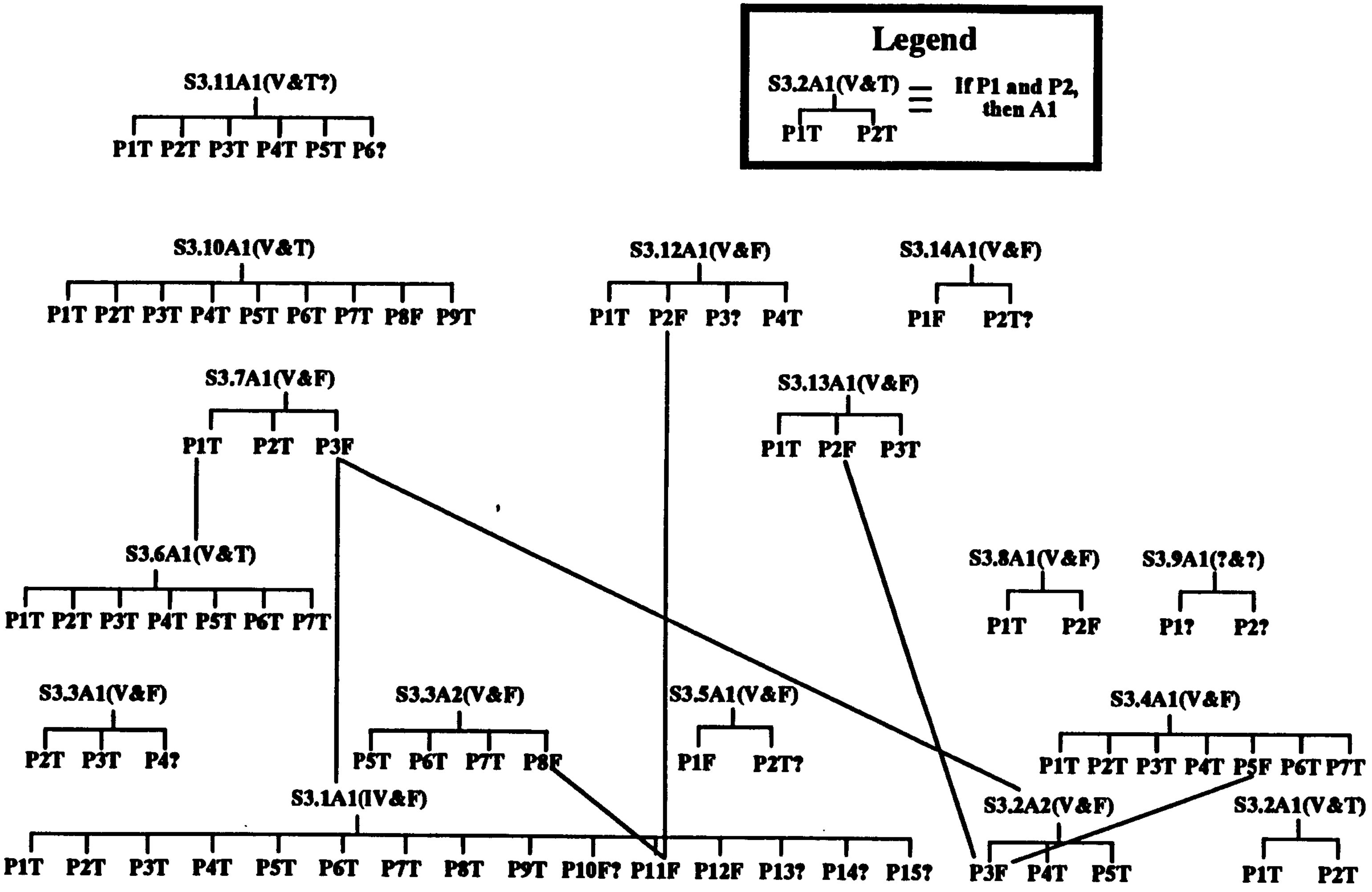


Figure 3-1. Logic diagram of arguments presented in Chapter 3

4 VADOSE ZONE ROCK CORES

Section 4 in Szymanski (1992) tried to establish through the examination of rock cores that vadose zone ignimbrites were influenced by epigenetic hydrothermal processes. Unequivocal evidence is presented that ignimbrites of the Topopah Spring Member of the Paintbrush Tuff, currently in the vadose zone in the Yucca Mountain region, were affected by epigenetic hydrothermal processes. It was argued that mineralization present in the core reflects the hydrothermal stage of activity of the Timber Mountain caldera and in part subsequent intermittent hydrothermal system activity driven by conductively replenished heat sources. The only line of reasoning presented in this section which was used to support the assertion of intermittent hydrothermal system activity was based upon relative timing of hydrothermal alteration observed in the rock cores (Section 4.1).

4.1 RELATIVE TIMING OF HYDROTHERMAL ALTERATION

4.1.1 Premises

P1: Paragenetic relationships of alteration minerals determine the relative age of formation of alteration minerals (T). P2: Paragenetic relationships indicate at least two periods of mineral formation (T). P3: Undeformed euhedral zeolites formed late in Yucca Mountain deformational history (F). P4: Calcite is the latest mineral formed (T). P5: Most vadose zone mineralization is due to hydrothermal processes (F). P6: Thermal evolution of local crust is due to a decreasing flux of mantle-derived magma (F).

4.1.2 Arguments

A1: If P1 and P2, then some of the mineralization and alteration phases in rock cores are epigenetic (V and T). A2: If A1, P3, P4, P5, and P6, then some of the observed mineralization and alteration phases are records of intermittent activity of hydrothermal systems driven by conductively replenished heat sources (V and F).

4.1.3 Analysis

Argument A1 is valid. Premises P1 and P2 are true based upon rock core descriptions (Carlos, 1985; Carlos, 1989; Carlos et al., 1990, 1991). Since both premises are true and A1 is valid, the conclusion is true.

Szymanski's (1992) construction of argument A2 was valid. Premise P4 is true and requires no further discussion. However, the faulty assumptions P3, P5, and P6 require clarification. Premise P3, as implied by Szymanski (1992) requires that euhedral zeolites formed late in the Yucca Mountain deformational history. However, formation of euhedral zeolites must occur later than faulting of the Topopah Spring Member of the Paintbrush Tuff. The absolute age of the faulting which produced the faults upon which the zeolites grow is not known. Unless the euhedral zeolite sample is dated, the age of formation of the zeolite cannot be known. It has been argued by Carlos et al. (1991) that since most of the movement at Yucca Mountain took place prior to 11.6 Ma (Levy, 1991), then zeolites may have formed during hydrothermal alteration associated with the Timber Mountain caldera eruption of the Rainier Mesa Tuff at 11.6 Ma. Premise P5 assumes that most vadose zone mineralization, including calcite formation, is due to hydrothermal processes. This premise was discussed in detail in Section 3.1

of this report and was demonstrated to be false. Finally, premise P6 requires that a decreasing flux of mantle-derived magma be generated with time. As discussed in Section 2.4, the theory that only asthenospheric magma can describe the observed basalt and silicic volcanism was argued to be false since the basaltic magmatism may not actually have an asthenospheric geochemical character (Livaccari and Perry, 1993). It should be noted that epigenetic strictly means that a deposit forms later than the enclosing rock and does not have any larger meaning with regard to absolute timing of the mineralization. The conclusion that some of the observed mineralization and alteration phases found in rock cores are records of intermittent activity of hydrothermal systems driven by conductively replenished heat sources (Szymanski, 1992) is false.

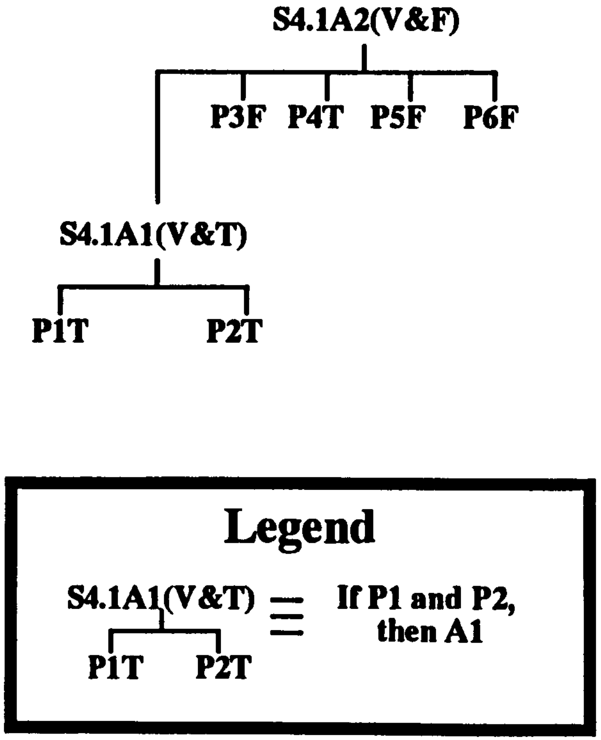


Figure 4-1. Logic diagram of arguments presented in Chapter 4

5 VADOSE ZONE INTERSTITIAL FLUIDS

The purpose of Section 5 in Szymanski (1992) is to prove that vadose zone interstitial fluids are modified deep-seated fluid phases which were injected into the vadose zone. Five lines of reasoning were offered by Szymanski (1992) in support of his assertion of a hydrothermal origin for vadose zone interstitial fluids. The pronounced oxygen isotopic shift observed in vadose zone interstitial fluids was used to support this hydrothermal origin affirmation (Section 5.1). Second, combined tritium and ^{14}C data were used to prove that vadose zone interstitial fluids are multicomponent solutions (Section 5.2). The strongly discordant geochemistry of vadose zone interstitial fluids relative to the presumed weathering of local ignimbrites (Section 5.3) was argued to require that the source of the interstitial fluids must reflect in part remnant highly evolved hydrothermal solutions. Strong geochemical affinity of the interstitial fluids to the typical calcium-magnesium fluids residing in the local Paleozoic carbonates was the fourth argument offered by Szymanski (1992) to support the hydrothermal origin of interstitial pore fluids (Section 5.4). The final geochemical line of reasoning used by Szymanski (1992) was based upon the rare earth element (REE) content of the fluids and expected fractionation of REE under high CO_2 conditions (Section 5.5).

5.1 OXYGEN ISOTOPIC SHIFT OF VADOSE ZONE INTERSTITIAL FLUIDS

5.1.1 Premises

P1: Recharge to the vadose zone occurs year-round (F). P2: Contemporary precipitation in the Yucca Mountain area yields a weighted average annual value of the δ^{18}O ranging from -11.3 to -11.7‰ relative to standard mean ocean water (SMOW) for land surface altitudes comparable to Yucca Mountain (T). P3: Vadose zone interstitial fluids are genetically related to the meteoric water line and should have δ^{18}O values of $-14.5‰_{SMOW}$ (T). P4: Vadose zone fracture-based fluids are not chemically or isotopically different than corresponding fluids immediately below water table (F). P5: Recharge of groundwater occurs only locally and vertically (i.e., precipitation should be same as meteoric water line (F). P6: Fracture-based fluids from below the water table plot on the meteoric water line and show no evidence for evaporation (T). P7: Evaporative removal of water from the vadose zone occurs (T).

5.1.2 Arguments

A1: If P1, P2, P3, and P7, then for vadose zone interstitial fluids the observed oxygen-isotopic shift is not solely due to the evaporative ^{18}O enrichment of the local surficial and year-round recharge (IV and F). A2: If A1, P4, P5, P6, and P7, then interstitial pore fluids are relict fluids which have undergone evaporative enrichment (V and F).

5.1.3 Analysis

Argument A1 is invalid since the conclusion of the argument contains a premise (P1) which Szymanski (1992) assumed was true. This argument is an example of *petitio principii* (Barker, 1989). Premise P2 is true (Szymanski, 1992). Evaporative removal of water from the vadose zone at Yucca Mountain occurs (Claassen, 1985), and P7 is true. Since evaporative removal of water occurs in the vadose zone, the measured ^{18}O values of vadose zone fluids can be used to estimate the isotopic composition of the unevaporated fluid. This calculation, completed by Szymanski (1992), indicates the unevaporated fluid in the vadose zone should have values of about $-14.5‰_{SMOW}$. Premise P3 is true. The critical assertion of argument A1 is P1 (recharge occurs year-round). Since P2 is true, if P1 is true then $\delta^{18}O$ of recharge to the interstitial pores should range from about -11.3 to $-11.7‰_{SMOW}$. By assuming P1 is true, Szymanski (1992) was able to assert that there is an isotopic discrepancy between the measured oxygen content of recharge (-11.3 to $-11.7‰_{SMOW}$) and that predicted from evaporation ($-14.5‰_{SMOW}$). Data presented by Yang (1991) clearly indicate that recharge to the vadose zone is derived mainly from winter precipitation (isotopically heavy), thus P1 is false. Szymanski (1992) conceded that if only winter precipitation infiltrates into the vadose zone (Yang, 1991), then surficial ^{18}O evaporative enrichment of winter recharge satisfactorily accounts for the observed isotopic compositions of the vadose zone interstitial fluids. Since A1 is invalid and there is sufficient information to refute Szymanski's (1992) assertion of year-round recharge, the conclusion of A1 is false.

The valid form of argument A2 requires that each premise is true if the conclusion is to be accepted as true. Premise P7 is true and P6 is true (Kerrisk, 1987), however, each of the other premises used by Szymanski (1992) to construct A2 is false. Premise P4 is false since Szymanski (1992) merely assumed it to be true without any evidence to support his assertion. Premise P5 is a combination of premise of P3 and the implied assumption that the residence time of fluids in the interstitial pores of the vadose zone is comparable to the residence time of fluids in fractures from the vadose zone. The latter assertion is unsupported and P5 can be assumed to be false. Based upon the isotopic information presented in Kerrisk (1987) and Yang (1991), it can be concluded the saturated zone waters tend to be slightly shifted to heavier isotopic compositions relative to the meteoric water line, but not as much as the vadose zone waters. Saturated zone waters tend to fall along Szymanski's (1992) postulated line, with an intercept on the meteoric water line of $\delta^{18}O=-14.5‰_{SMOW}$. This suggests that the waters have a similar origin, but saturated zone waters have undergone less evaporation, and that the recharge is isotopically light relative to average precipitation. Since several premises are false and A2 is a valid argument, the conclusion can be rejected.

5.2 INTERMIXING OF FLUID PHASES CARRYING DIFFERENT RADIOMETRIC AGES

5.2.1 Premises

P1: Downward movement of vadose zone fluids is only by porous vertical movement (F). P2: The measured values of tritium in pore fluids may be directly compared to measured values of ^{14}C at deeper depths (F).

5.2.2 Arguments

A1: If P1 and P2, then vadose zone interstitial fluids are multicomponent solutions (V and F).

5.2.3 Analysis

The basic argument approach, which was repeatedly used in Szymanski's analysis (1992), is flawed. Szymanski (1992) assumed that vadose zone pore fluid samples, collected from core samples from test holes UE-25 UZ #4 and UE-25 UZ #5 with 10's of meters of vertical separation, can be directly compared with regard to their tritium and ^{14}C contents. Argument A1 is based on alleged discrepancies between ^{14}C ages and ^{3}H ages in vadose waters at Yucca Mountain. In fact, in addressing the same data, Yang (1992) stated that, "The ^{3}H concentrations at the depth of 95.6 to 95.7 m in UE-25 UZ#4 and 103.5 to 105.2 m in UE-25 UZ#5 indicated 0 tritium units (TU) and are consistent with the ^{14}C data indicated by 1000-year and 4900-year waters." For UZ#4, the cited ^{3}H depth is 0.4 to 4.9 m above the ^{14}C depth (96 to 100.6 m). For UZ#5, the ^{3}H depth interval is 5.2 to 6.8 m above the ^{14}C depth (103.6 to 105.2 m). Therefore, there is no discrepancy. Furthermore, uncorrected ^{14}C ages would be expected to be older than ^{3}H ages because of retardation of carbon transport and dilution with dead carbon. Thus, the conclusion of argument A1 should not be accepted.

5.3 IONIC EXCHANGE OF RAINWATER AND LOCAL IGNIMBRITES

5.3.1 Premises

P1: Only ordinary ionic exchange reactions between rainwater and local ignimbrites provide dissolved constituents to vadose zone fluids (F). P2: The main source of carbon in the vadose zone fluids is the local biosphere (T). P3: Average concentrations of dissolved solids (ionic pairs $Ca^{2+}+Mg^{2+}$ and $Cl^{-}+SO_4^{2-}$) in the vadose zone interstitial fluids are a factor of about 10 higher than fracture based fluids from the local ignimbrites (T). P4: Fracture based fluids in the local ignimbrites (water in the saturated zone) is only derived locally via vertical percolation through the overlying ignimbrites (F). P5: Fracture based fluids in the local ignimbrites (water in the saturated zone) carry apparent ^{14}C ages of 3,800 to 27,000 years B.P. (T). P6: Vadose interstitial fluids contain significantly higher dissolved alkaline earth concentrations relative to fluids from the saturated zone (T). P7: Iodide and chloride concentrations in vadose zone fluids are larger by a factor of 20 to 30 than from the saturated zone (T). P8: Mo, W, La, Y, Au, Pt are significantly enriched in vadose zone fluids relative to fluids extracted from the saturated zone (T).

5.3.2 Arguments

A1: If P1, P2, P4, and P5, then fluids in the saturated zone have undergone ionic exchange reactions with local ignimbrite for a fairly long time (V and F). A2: If P1, P3, P6, P7, and P8, then vadose zone interstitial fluids appear to be composed of two genetically distinct fluid phases (V and F).

5.3.3 Analysis

Both arguments A1 and A2 in this section and many other arguments presented latter in Szymanski (1992) were critically dependent on premise P1. Premise P1 was stated as fact by Szymanski (1992). He supplied no documentation for his assertion. To accept P1 as true, it is necessary to prove that no material which could dissolve in rainwater and impart a geochemical signature different than that expected from ionic exchange with ignimbrite is present at the surface and interacts (dissolves) in rainwater. Reaction of infiltrating vadose zone fluids with soil material, including carbonate dust, provides dissolved constituents to the interstitial and fracture pore fluids (McFadden et al., 1991; Wang et al., 1993; Murphy, 1991, 1993; Stuckless, 1991; Zartman and Kwak, 1993). Premise P2 is substantially supported by published reports (Yang et al., 1993; Quade et al., 1989; White et al., 1980). The following premises are based on published data and can be accepted as true without further comment: P3, P5, P6, P7, and P8 (Szymanski, 1992; Yang, 1992; Kerrisk, 1987; Benson and McKinley, 1985). Szymanski's (1992) conceptual model for recharge to the tuffaceous regional groundwater system was demonstrated by his use of premise P4 in this section and similar premises in Sections 5.1 (P5) and 5.2 (P1). Spatially and temporally uniform (year-round precipitation and no distinct recharge zone for the

Alkali Flat/Furnace Creek groundwater system) percolation of rainwater is the primary method of recharge for the Alkali Flat/Furnace Creek groundwater system. And, this is the underlying assumption which Szymanski (1992) was required to use in construction of his geochemical arguments. Although this assumption was not expressly stated in his document (Szymanski, 1992), it is required to explain his logical treatment of the geochemical parameters of the regional groundwater and vadose zone interstitial pore fluids. Szymanski (1992) provided no evidence to support his conceptual model of regional recharge. The significant discussion of the regional groundwater system in Appendix B of the National Research Council 1992 report indicated a steadystate spatially uniform model of recharge to the Alkali Flat/Furnace Creek groundwater system is most likely inappropriate—thus, making P4 false. While premise P5 is true, Szymanski (1992) inferred in argument A1 that the apparent ^{14}C age of waters in the saturated zone reflects long periods of interaction with the ignimbrites. Again the validity of his assertion relied critically on his presumed, but not explicitly stated, model for recharge to the Alkali Flat/Furnace Creek groundwater system. The apparent ^{14}C ages determined for fluids from the Alkali Flat/Furnace Creek groundwater system have been alternatively interpreted (National Research Council, 1992) as inferring that recharge to this system occurred during the timeframe indicated by the ages (10 to 15 ka). For argument A1, while premises P2 and P5 are true, premises P1 and P4 are not supported by available evidence and should be considered false. The result of this analysis indicates that while the form of the argument is valid, conclusions should not be accepted.

Argument A2 was constructed using a valid form. However, from the discussion of P1 in the previous paragraph, it is clear that P1 is not true, and hence the conclusion of argument A2 should not be accepted. As Szymanski (1992) quoted Smith (1991), "the compositional differences . . . indicate that pore waters have evolved by significantly different processes," he inferred that the significantly different processes must reflect different sources of the fluids. Szymanski's (1992) conclusion that vadose zone interstitial fluids were composed of two genetically distinct phases, one of which was infiltrating rainwater and the other was remanent highly-evolved hydrothermal solutions, is flawed by his assumption that dissolved solid content of downward percolating interstitial fluids was derived solely from interaction of ignimbrites and rainwater. The geochemical data indicate differences in origins of the vadose zone interstitial fluids and fracture fluids. An infiltrating rainwater component is clearly indicated. The oxygen and hydrogen isotope data suggest greater evaporation of the vadose water than the saturated water (Section 5.1). Higher concentrations of Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, and trace elements in the vadose waters would be consistent with greater evaporation. Dry (or wet) deposition of carbonate, sulfate, and chloride minerals at the surface and dissolution of these salts in recharging waters is a likely source for these species (Everden, 1992; Claassen, 1985). Similar Na^+ and K^+ (and other alkali) concentrations between vadose and saturated zone waters is likely due to controls by ion exchange or mineral dissolution equilibria (Murphy, 1991; Kerrisk, 1983; Claassen and White, 1979; White and Claassen, 1980). A logically consistent and testable hypothesis for the recharge mechanisms and geochemical modification of interstitial fluids will require careful consideration/demonstration of (i) the sources of dissolved solids (is it only ignimbrites or is there carbonate material/dust) which are released by interaction with rainwater and (ii) the amounts, spatial distribution, and timing of recharge to the Alkali Flat/Furnace Creek groundwater system.

5.4 GEOCHEMICAL AFFINITY WITH CALCIUM-MAGNESIUM FLUIDS IN PALEOZOIC CARBONATES

5.4.1 Premises

P1: Vadose zone interstitial fluids contain high concentrations of dissolved alkaline earth elements relative to dissolved alkali metals (T). P2: Observed ranges of concentrations of $Ca^{2+} + Mg^{2+}$ and $Cl^- + SO_4^{2-}$ in vadose zone interstitial fluids are identical to those for Paleozoic carbonate-based fluids (T). P3: Only ordinary ionic exchange reactions between rainwater and local ignimbrites provide dissolved constituents to recharging vadose zone pore fluids (F). P4: The large concentrations of $Ca^{2+} + Mg^{2+}$ and $Cl^- + SO_4^{2-}$ in vadose zone interstitial fluids relative to saturated zone fluids require long intraformation residence time (?).

5.4.2 Arguments

A1: If P1, P2, P3, and P4, then the interstitial fluids may have acquired their dissolved solids with underlying Paleozoic carbonate rocks (V and F). A2: If A1, then the interstitial fluids preserve a epigenetic or remnant hydrothermal component (V and F).

5.4.3 Analysis

A valid form of argumentation was used by Szymanski (1992) in argument A1 to suggest that the alkaline earth element composition of interstitial vadose zone fluids required interaction with carbonate material. The critical assumption that Szymanski used in his argument, with no scientific support, was P3—dissolved constituents in the vadose zone fluids were only derived by the interaction of rainwater and the ignimbrites. He implicitly denied the possibility that there is a flux of carbonate material to the ground surface in the region (Everden, 1992), and further would require that any carbonate material at the surface does not react with rainwater to provide any alkaline earth elements to solution. P3 cannot be blindly accepted as true, however, the necessary mass balance measurements on the surface carbonate flux (dust) have not yet been made in the Yucca Mountain area. Measurements of $CaCO_3$ dust flux cited in Schlesinger (1985) for the Mojave Desert have been used by Everden (1992) in a preliminary mass balance of the carbonate system. The results of the mass balance calculation indicated the entire amount of carbonate presently seen in the alluvium can be accounted for by the input of carbonate dust to the surface (Everden, 1992). Premises P1 and P2 are true and supported by published geochemical analyses (Szymanski, 1992; Yang, 1992; Kerrisk, 1987; Benson and McKinley, 1985). Inadequate information/discussion was provided by Szymanski (1992) to evaluate whether premise P4 is true. However, it seems this premise was implicitly dependent upon on the Chebotarev geochemical evolutionary model of a regional flow system (Szymanski, 1992), which does not explicitly account for the evolution of vadose zone fluids and the possible interactions of rainwater with surface carbonate materials. There are clear similarities between regional carbonate waters and vadose waters. However, mixing of fluids in the vadose zone has not been demonstrated by the data or by Szymanski's (1992) analyses. Chemical properties of vadose waters are consistent with interactions of recharging meteoric water with surface deposits, tuffs, and evaporation (Murphy, 1991). The chemical data presented in this set of premises and arguments (Szymanski, 1992) do not, however, prove that the mixing hypothesis is false. Even though P1 and P2 are true, the conclusion of argument A1 should not be accepted as true since P3 is false.

Argument A2 is a valid logical form whose conclusion only depends upon the truth of the conclusion of argument A1. Since A1 is false, then the conclusion of A2 is false.

5.5 RARE EARTH ELEMENT ABUNDANCE PATTERN OF VADOSE ZONE INTERSTITIAL FLUIDS

5.5.1 Premises

P1: Interstitial vadose zone fluids exhibit a pronounced enrichment of heavy rare earth elements (HREE) relative to the chondrite REE pattern (T). P2: Interstitial vadose zone fluids exhibit a pronounced depletion of light rare earth elements (LREE) relative to the chondrite REE pattern (T). P3: Local ignimbrites have a chondrite normalized REE abundance pattern similar to that typical of most terrestrial rocks with a LREE enrichment and a slight HREE depletion (T). P4: Only ordinary ionic exchange reactions between rainwater and local ignimbrites provide dissolved constituents to vadose zone pore fluids (F). P5: The vadose zone interstitial fluids have a REE abundance pattern similar to CO_2-rich, highly-evolved, and concentrated hydrothermal solutions (T). P6: Solutions which contain high concentrations of complexing carbonate anions promote HREE enrichment in fluids (T). P7: The only source of carbonate in the Yucca Mountain near-surface region is from underlying Paleozoic carbonates (F).

5.5.2 Arguments

A1: If P1, P2, P3, and P4, then the REE contents of vadose zone interstitial fluids were not derived from water rock interaction with the ignimbrites (V and F). A2: If P5, P6, A1, and P7, then the interstitial fluids currently residing in the vadose zone partially represent remnant (epigenetic) hydrothermal solutions (V and F).

5.5.3 Analysis

The construction of argument A1 is valid, and the conclusion of this argument can only be true if, and only if, premises P1, P2, P3, and P4 are true. Premises P1, P2, and P3 are based upon measured geochemical parameters and are true (Szymanski, 1992; McLennan, 1989). Again the argument Szymanski (1992) has constructed critically depends on the assumption that only rainwater interaction with the ignimbrites contributes dissolved solids to fluids in the interstitial vadose zone fluids (P4). By neglecting the possibility of surficial carbonate interaction with rainwater, he was able to argue that A1 should be accepted as true. However, as discussed in Sections 5.1 through 5.4, premise P5, which stipulates that only ordinary ionic exchange reactions between rainwater and local ignimbrites provide dissolved constituents to vadose zone pore fluids, has not been scientifically supported and should be considered false. Thus the conclusion of A1 is false.

A valid logical form has been used to construct argument A2, and requires that A1, P5, P6, and P7 be true if the conclusion of A2 is to be accepted as true. Premises P5 and P6 are true and adequately supported in the literature (Smith, 1991; Gouveia et al., 1993; Leroy and Turpin, 1988; Michard et al., 1987; Prudêncio et al., 1993). It should be noted that REE fractionation occurs in a similar pattern to that suggested by Szymanski (1992) during surface weathering of igneous rocks (Leroy and Turpin, 1988; Gouveia et al., 1993; Prudêncio et al., 1993). Premise P7, which Szymanski (1992) did not explicitly discuss, must be included in the analysis of his argument of the source of dissolved solids presently found in vadose zone interstitial fluids. If, and only if, P7 is included, and is true, can it be considered that a realistic and complete interpretation of the chemical and isotopic compositions of interstitial fluids has been completed. Szymanski (1992) implicitly assumed that P7 is true and offered no evidence to evaluate the hypothesis. Everden (1992) has indicated that enough carbonate could be delivered to the surface of the Yucca Mountain area to supply all the carbonate necessary to account for its accumulation in the near-surface region. This strongly indicates that P7 should be considered to be false. Since both A1 and P7 are false there is no reason to accept Szymanski's (1992) conclusion that interstitial fluids currently residing in the vadose zone represent remnant (epigenetic) hydrothermal solutions.

5.6 SUMMARY OF GEOCHEMICAL MODEL OF VADOSE ZONE WATER

Szymanski (1992) believed that based on his arguments presented in Sections 5.1 through 5.5, he had constructed a complete and realistic interpretation of the chemical and isotopic compositions of interstitial fluids (page 5-17 in Szymanski, 1992). Two major premises that Szymanski (1992) should have included to support his interpretation of the origin of vadose zone interstitial fluids have not been adequately or even explicitly stated or evaluated by Szymanski (1992). First, he assumed that spatially and temporally uniform (year round precipitation and no distinct recharge zone for the Alkali Flat/Furnace Creek groundwater system) percolation of dissolved rainwater is the primary method of recharge for the Alkali Flat/Furnace Creek groundwater system. Although this assumption was not expressly stated anywhere in his document (Szymanski, 1992), it was required to explain his logical treatment of the geochemical parameters of the regional groundwater and vadose zone interstitial pore fluids. A steadystate spatially uniform model of recharge to the Alkali Flat/Furnace Creek groundwater system is most likely inappropriate (National Research Council, 1992). The second critical underlying and implied assumption was that the only source for dissolved solids derived from interaction of rainwater is the local ignimbrites. Szymanski (1992) neglected to consider the likelihood that carbonate material is deposited at the surface of the Yucca Mountain region via dust deposition and reacts with recharging meteoric water. Schlesinger (1985) provided evidence that the flux of carbonate dust to the surface of western U.S. desert regions is substantial and was the source for near-surface accumulations of calcium carbonate. The carbonate material could provide the necessary geochemical source for the alkaline earth elements, abnormally high concentrations of transition and noble metals (see Zartman and Kwak, 1993, and analysis in Section 6.5), and the necessary conditions to generate the unusual REE abundance pattern. Without explicitly considering these two basic premises, and proving their general truth, there is no reason to accept that the fluids which reside in the vadose zone are partially composed of a hydrothermal remnant fluid which carried a high partial pressure of CO_2.

It is only based upon his conclusion (Szymanski, 1992) that vadose zone ignimbrites were influenced by epigenetic hydrothermal processes which could have contained large quantities of dissolved CO_2 can assertions in the remaining sections be partially supported by Szymanski (1992). Since Szymanski's basic conclusion of his Section 5 (Szymanski, 1992) was flawed and cannot be accepted as true, resulting arguments which are dependent of the truth of his conclusion will also be similarly adversely affected. Also, any conclusions which relied on his assertion that vadose zone ignimbrites were influenced by epigenetic hydrothermal processes (which could have contained large quantities of dissolved CO_2) cannot be considered to be true.

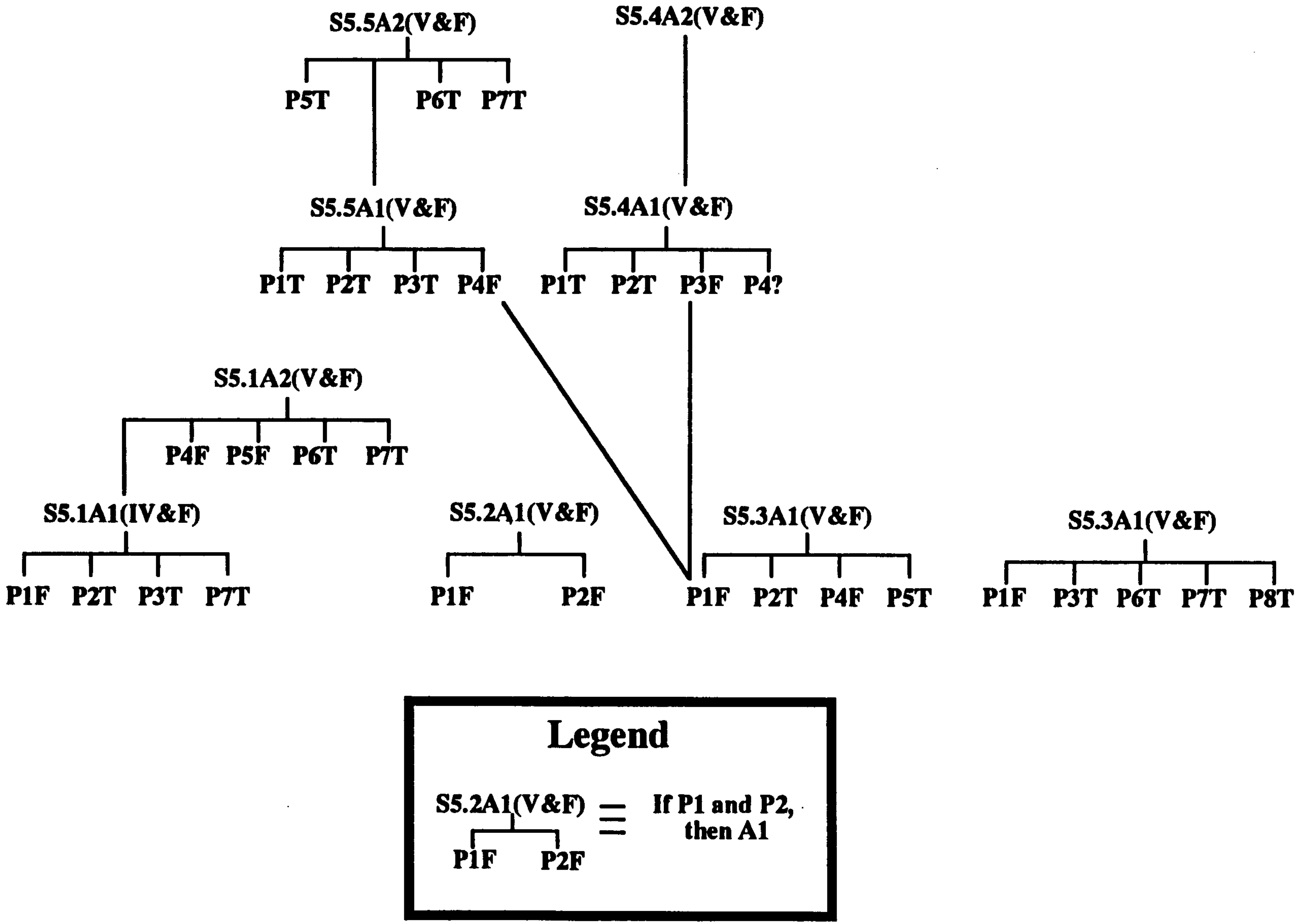


Figure 5-1. Logic diagram of arguments presented in Chapter 5

6 ORIGIN AND AGE OF MOSAIC BRECCIAS

The purpose of Section 6 in Szymanski (1992) was to establish through the examination of various characteristics of mosaic breccias the origin and age of these deposits. Specifically, Szymanski (1992) attempted to prove that the mosaic breccia deposits were the result of hydrothermal eruptions of hypogene fluids and the eruptions of these fluids have remained operational during the Plio-Quaternary time span. Eight lines of reasoning were used by Szymanski (1992) to convince the reader his conclusions concerning the mechanism and timing of the formation of the mosaic breccias should be accepted. The relative importance of mosaic breccias as a record of significant widening of the Yucca Mountain area was put forth as one line of reasoning (Szymanski 1992, Section 6.1). Two lines of evidence used by Szymanski (1992) to establish the epigenetic characteristics of mosaic breccias are addressed in Section 6.2. Further reasoning used to establish the relative timing of the formation of the breccias was based on the assertion these deposits represent polygenetic deformational phases (Szymanski 1992, Section 6.3). The compositionally diverse mineral assemblages found in the mosaic breccias were used to assert that hypogene fluids were required for the deposit's formation (Szymanski 1992, Section 6.4). Elevated and anomalous concentrations of trace and pathfinder elements in the mosaic breccias were argued to require hydrothermal hypogene fluids (Szymanski 1992, Section 6.5). The isotopic characters of carbon and oxygen incorporated in the mosaic breccias, bedrock veins, and the calcrete deposits were used to infer a hypogene origin of the cements (Szymanski 1992, Section 6.6). An argument was constructed by Szymanski (1992, Section 6.7) that the fluid compositional features recorded in the cement of mosaic breccias cannot be derived from supergene pedogenic fluids. Finally, the presence of zircons, whose fission-track ages are both older and younger than the ignimbrites, was used to construct an argument which requires that eruption of hydrothermal fluids at times significantly younger than the host rock was responsible for the presence of these minerals in the mosaic breccia cements (Szymanski 1992, Section 6.8).

6.1 ACCRETIONARY STRAIN ESTIMATE

6.1.1 Premises

P1: Mosaic breccias occur along five local faults (T). P2: The combined thickness of mosaic breccias is as large as 2 km in 14 km explored area (?). P3: The cement is 10 percent of the volume in the mosaic breccia zones (?). P4: The volumetric strain can be equated to the volume of cement (?).

6.1.2 Arguments

A1: If P1, P2, P3, and P4, then the mosaic breccias record a significant widening (1.5 percent) of the Yucca Mountain area (V and T?).

6.1.3 Analysis

The construction of argument A1 is valid, and the conclusion of this argument is true if premises P1, P2, P3, and P4 are true. Based upon the minimally described locations presented in Szymanski (1992), it may be assumed that P1 is true and represents mosaic breccias at the Windy Wash, Solitario Canyon, Bow Ridge, Paintbrush Canyon, and the Fran Ridge Faults. Premise P2 may be true, however, no supporting evidence (e.g., maps of each location indicating degree to which mosaic breccias are present) was presented by Szymanski (1992) to support the declaration. Additional description of the techniques used to derive the thickness of mosaic breccias might better allow truth of the assertion to be tested. Similarly, P3 was poorly supported by Szymanski (1992) and can only be presumed to be true. Again, additional documentation of the techniques used to derive the volumetric estimate of cement in the mosaic breccia areas would have allowed a more robust determination of the accuracy/truth of P3. Premise P4 was stated by Szymanski (1992) as a fact, without any qualifying statements of support or evidence. If conservatively, P2, P3, and P4 are accepted as true, then the conclusion of argument A1 may be tentatively accepted as true. This would provide an estimate of the amount of extension in the Yucca Mountain region, 1.5 percent. The acceptance of this conclusion does not bear on subsequent arguments used by Szymanski (1992) regarding either the origin or age of mosaic breccia deposits.

6.2 EPIGENETIC DEFORMATIONAL PHASES

6.2.1 Premises

P1: There are two distinct types of mosaic breccias: CTM (crushed-tuff-matrix) and AMC (authigenic-mineral-cement) (T). P2: Both types of mosaic breccia contain brecciated fragments of minerals produced during deuteric vapor phase mineralization (T). P3: Both mosaic breccia types are not bound to a single ash-flow unit (they transgress stratigraphic boundaries) (F). P4: Both mosaic breccia types are not restricted to the pyroclastic complex (they also occur in the Paleozoic carbonates) (F?). P5: AMC mosaic breccias contain allogenic zircons (T). P6: Zircons yield a wide spectrum of fission-track ages (59.7±12.0 to 4.8±2.5 Ma) (T). P7: Fission-track ages of the zircons are strongly discordant with the age of host ignimbrites (T). P8: Part of the Topopah Spring Member is still vitric (T). P9: CTM breccias contain clasts with and without devitrification textures (T). P10: Some clasts in the CTM breccias contain devitrified fringes surrounding vitric interior portions (T). P11: Devitrification of these fringed clasts occurred after the cooling and syndepositional devitrification of the Topopah Spring Member (F).

6.2.2 Arguments

A1: If P1, P2, P3, and P4, then the formation of both types of breccia occurred subsequent to the cooling and syndepositional devitrification of the host ignimbrites (V and F). A2: If P5, P6, and P7, then AMC mosaic breccias are epigenetic (V and T). A3: If P3, P8, P9, P10, and P11, then CTM mosaic breccias are epigenetic, formed after deuteric processes were complete, and epigenetic processes are responsible for the devitrification fringes observed in the clasts (V and F).

6.2.3 Analysis

If each of the premises were true, then the conclusion of argument A1 would logically follow. A discussion of the two types of mosaic breccias was presented by Szymanski (1992) based upon the unpublished work of Levy and Naesser (1991). That there appears to be two genetically distinct types of mosaic breccias can be considered to be true (P1 is true) based upon published descriptions (Levy, 1993). Similarly, P3 can be presumed to be true for AMC type breccias, based upon unpublished work cited in Szymanski (1992). However, evidence presented by Levy (1993) indicated that CTM breccias do not transgress stratigraphic boundaries, rather, they are restricted to certain stratigraphic layers of the ignimbrites—making P3 false. Both AMC and CTM breccias must transgress stratigraphic boundaries if P3 is to be true. Inadequate documentation by Szymanski (1992) of the assertion of P2 and the published work of Levy (1993) suggests that P2 may be provisionally accepted as true. Although Szymanski (1992) did not explicitly state that both types of mosaic breccias occur in Paleozoic carbonate, the conspicuous absence of the qualifying adjective AMC in the statement of P4 implicitly links the genesis of mosaic breccias in Paleozoic carbonates to the genesis of CTM breccias found in the ignimbrites. No substantiated evidence was presented by Szymanski (1992) to support his assertion, and P4 should tentatively be considered false. Since P2 and P4 are not true, then the conclusion that both types of mosaic breccias (CTM and AMC) formed subsequent to the cooling, syndepositional devitrification of the host ignimbrites is incorrect.

A2 is a validly constructed argument whose conclusion may be accepted since each of the premises of the argument is true. Premise P5 is an uncontested fact (Szymanski, 1992; National Research Council, 1992). The genetic implications of premise P6 are a contentious issue (Archambeau, 1992) and will be discussed fully in Section 6.8. Regardless of the implications of this observation, zircons yield a wide spectrum of fission-track ages (59.7±12.0 to 4.8±2.5 Ma) and premise P6 can be accepted as true. Finally, P7 is true since the measured fission-track ages, as reported in Szymanski (1992), of two zircons (Samples HD-74-2-5 and HD-41-4-9) are significantly older than the host ignimbrites (assuming a 2 sigma error), while two zircons (Samples HD-74-2-3 and HD-74-2-12) are significantly younger than the host ignimbrites (assuming a 2 sigma error). Thus, the conclusion of A2, that the AMC mosaic breccia are epigenetic, should be accepted as true. It should be remembered that epigenetic only requires that the origin of the deposit is later than the enclosing rocks and carries no significance with regard to the origin of the deposit (i.e., epigenetic does not imply hypogene or supergene).

The logical form of argument A3 is valid, and requires that if premises P3, P8, P9, and P10 are true, then the conclusion of this argument is true. Premises P8, P9, and P10 can be accepted as true since published descriptions substantiate them (Levy, 1993). Remember P3 was demonstrated to be false with respect to CTM breccias (Levy, 1993). P11 was not expressly stated by Szymanski (1992), however, it is a physical requirement if the CTM formed epigenetically. Since this premise was implied without any support, it is necessary to understand the physical implications of the mechanism. Szymanski (1992) allowed the possibility that devitrification textures in the CTM breccias indicate that some of the brecciation occurred while devitrification of the tuff was active. He argued the available evidence does not require that CTM breccia phases must have been formed exclusively during the syndepositional devitrification of the Topopah Spring Member. If devitrification of CTM occurred after deuteric processes were over (i.e., epigenetically) as implied by P11, and if as Szymanski (1992) continually asserted they were explosively formed, then it would strongly suggest that pieces of the underlying formation should be incorporated within the CTM breccia. Direct examination of this hypothesis in the CTM breccias indicated no evidence for fragments from the underlying formations (Levy, 1993). This observation strongly suggests that P11 is false. Since P2 and P11 are false, then the conclusion that CTM mosaic breccias are epigenetic and epigenetic processes are responsible for the devitrification fringes observed in the clasts, should not be accepted as true.

6.3 POLYGENETIC DEFORMATIONAL PHASES

6.3.1 Premises

P1: AMC breccia specimens contain solidified plant remains (T). P2: CTM breccia specimens do not contain solidified plant remains (T). P3: CTM breccias were formed below the biological root zone (F). P4: Subsequent erosion has exposed the CTM breccias at the surface (T?). P5: CTM breccias display evidence of having formed with the involvement of moderate-temperature fluid phases (T). P6: AMC breccias do not exhibit any indications of having formed under elevated geothermal conditions (T).

6.3.2 Arguments

A1: If P1, P2, P3, and P4, then the Yucca Mountain mosaic breccias are composed of polygenetic deformational phases (V and F). A2: If P5 and P6, then the Yucca Mountain mosaic breccias are composed of polygenetic deformational phases (V and T).

6.3.3 Analysis

If each premise of argument A1 is true, then the conclusion of this argument should be accepted since this a consequence of the valid logical construction of the argument. Both premises P1 and P2 are true based upon published descriptions of the AMC and CTM breccias (Stuckless et al., 1992; Levy, 1993). Both premises P3 and P4 were asserted by Szymanski (1992) to be true without any substantiation. The only logical conclusion which can be reached from the absence of plant remains in CTM breccias is that they formed under conditions where biological (plant) activity was absent. Premise P3 is not the only possible explanation. Another substantiated hypothesis is that CTM breccias formed during deuteric processes (Levy, 1993). These conditions would be incompatible with abundant plant activity. If P3 was true then P4 would have to be true to allow the present exposure of CTM breccias. Since P3 cannot be ascertained to be true by any method presented by Szymanski (1992), it is fair to question its validity as a premise. This line of reasoning used by Szymanski (1992) does not support his assertion that the Yucca Mountain mosaic breccias are composed of polygenetic deformational phases.

The construction of argument A2 is valid. The conclusion of this argument can only be true if, and only if, premises P5 and P6 are true. Premise P5 is supported by published descriptions of the CTM breccia (Levy, 1993) and should be accepted. The importance of P6 cannot be stated strongly enough. Szymanski (1992) clearly required this premise for this argument to be accepted, yet throughout the rest of the report he argued that AMC breccias exhibit indications they were formed under elevated geothermal conditions. This direct contradiction was perpetuated throughout the rest of this chapter, especially in Section 6.8. Abundant evidence has been provided by Stuckless et al. (1992) that indeed the AMC mosaic breccias do not exhibit indications that they formed under elevated geothermal conditions. Thus, P5 and P6 are true and the conclusion that the Yucca Mountain mosaic breccias are composed of polygenetic deformational phases should be accepted. Further, any subsequent argument offered by Szymanski (1992) which requires that AMC mosaic breccias have indications of having formed under elevated geothermal conditions can be logically rejected.

6.4 MINERAL ASSEMBLAGE DIVERSITY

6.4.1 Premises

P1: AMC breccias are cemented by a compositionally diverse mixture of minerals species (T). P2: AMC breccias are cemented by a texturally diverse mixture of minerals species (T). P3: AMC breccia cements are composed of calcite, silica and sepiolite (T). P4: Mineral species are clearly demarked from neighboring mineralogically distinct species (T). P5: Hypogene solutions emerging from faults and fissures would have substantial variations in CO_2 partial pressure, fluid chemistry, and temperature (T). P6: Fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition are not expected characteristics of supergene pedogenic processes (F).

6.4.2 Arguments

A1: If P1, P2, P3, and P4, then the mineral precipitation environment was undergoing substantial fluctuations (V and T). A2: If A1, P5, and P6, then the observed compositional and textural diversity of AMC cement must be caused by hypogene fluids (V and F).

6.4.3 Analysis

The valid constructional form of the inductive argument A1 requires that if, premises P1, P2, P3, and P4 are adequately supported, then the conclusion will be true. Published descriptions of AMC breccias (Stuckless et al., 1992) support premises P1, P2, P3, and P4, and they may be considered true. Since each premise of the inductive argument appears to be true, the conclusion of A1 can be accepted as true.

Argument A2 is a valid deductive argument requiring the conclusion of A1 and premises P5 and P6 to be true if the conclusion is to be accepted as being supported by the argument. P5 is a generally accepted description of hydrothermal fluid effusion at the surface (Henley et al., 1984). The final premise of this argument has been thoroughly discussed in Chapter 3 of this report, and from the analysis therein, this premise may be dismissed purely as unsubstantiated and unsupported. Models of supergene pedogenic mineral deposition in arid environments amply refute P6. Since P6 is false, the conclusion of this argument that the observed compositional and textural diversity of AMC cement must be caused by hypogene fluids should not be accepted.

6.5 TRACE AND PATHFINDER ELEMENTS

6.5.1 Premises

P1: AMC breccias from the Trench #14 exposure contain elevated concentrations of trace and pathfinder elements (T). P2: Brecciated and cemented ignimbrites (AMC) in Trench #14 contain elevated concentrations of trace and pathfinder elements relative to stratigraphically equivalent ignimbrites (T). P3: AMC breccias from the Trench #14 are substantially younger than the age of the late-stage cooling of pyroclastic units (T). P4: Trench #14 breccias are epigenetic (T). P5: Isotopic characters of carbon and oxygen incorporated in the Trench #14 breccia authigenic cement are comparable to those contained in the late Quaternary calcretes (T). P6: The only source of dissolved solids reacting with meteoric water is the ignimbrites (F). P7: Elevated concentrations of metals can be found in hydrothermal fluids (T). P8: The anomalous samples could represent a very distant halo around a concentration of base metals in the deep subsurface (?).

6.5.2 Arguments

A1: If P3, then Trench #14 concentrations of some metals are not related to late-stage cooling pyroclastic units (V and T). A2: If P1, P2, P4, P5, P6, and P7 or P8, then the observed elevated concentrations of trace and pathfinder elements in AMC breccias from Trench #14 cannot be because of supergene pedogenic processes and must necessarily be reflective of hydrothermal hypogene explosive fluids (V and F).

6.5.3 Analysis

Argument A1 only requires that P3 is true if the conclusion is to be accepted. This validly constructed argument is elementary and the conclusion can be accepted since the analysis of argument A2 in Section 6.2 clearly supports P3.

The validly constructed argument A2 requires that P1, P2, and P4 through P6, and either P7 or P8 is true if the conclusion is to be accepted. Premises P1 and P2 were adequately supported by Szymanski (1992) and appear to be true. The acceptance of P4 as a true affirmation is a result of the definition of epigenetic and the acceptance of the conclusion of A1. The adequately documented isotopic characteristics (Stuckless et al., 1992; Szymanski, 1992) of pedogenic deposits requires that P5 be true. The recurring and unsupported hypothesis of Szymanski (1992) that carbonate dust is not important in providing a source of dissolved solids required P6 be assigned sufficient uncertainty that it can be considered false. It is important to re-emphasize that at present a mass balance of carbonate and dissolved solids which may be derived from the interaction of dust with rainwater has yet to be completed. It is also necessary to realize that although comparative analyses of Everden (1992) suggest that carbonate dust probably can support the formation of the near-surface carbonate deposits, P6 has not yet been quantitatively proven to be false. Even if P6 is true, if either P7 or P8 is true, then the AMC breccias in Trench #14 are required to have characteristics which directly contradict Szymanski's (1992) declaration that AMC breccias do not exhibit any indications they formed under elevated geothermal conditions. Premise P8 is not supported and is probably an intestable hypothesis. Premise P7 is in fact true and the basis for economic geology and ore deposits (Henley et al., 1984). Thus, Szymanski (1992) concluded that the AMC deposits in Trench #14 must be hydrothermal in origin, yet not exhibit any indications of having formed under elevated geothermal conditions. Clearly, this is an untenable position. The conclusion of Szymanski's (1992) argument that the observed elevated concentrations of trace and pathfinder elements in AMC breccias from Trench #14 cannot be due to supergene pedogenic processes and must necessarily be reflective of hydrothermal hypogene explosive fluids cannot be rationally accepted.

6.6 CARBON AND OXYGEN ISOTOPIC CONTENT

6.6.1 Premises

P1: The relative concentrations of ^{13}C and ^{18}O incorporated in the authigenic breccia cements are similar to those contained in samples of local calcretes and associated bedrock veins (T). P2: The $\delta^{13}C$ versus $\delta^{18}O$ fields indicate these compositionally and texturally equivalent lithofacies were precipitated from common solutions (T). P3: The isotopic character of breccia cement at Trench #14 can be compared to that at Busted Butte, and similarly, vein fillings and calcretes can be compared at the two sites (T). P4: Evaporative enrichment of ^{18}O occurs in the parent solution during the precipitation process in a evaporating fluid (T). P5: Diffusional enrichment of ^{13}C occurs in the aqueous phase during the precipitation process while CO_2 degases (T). P6: The lithofacies are of hypogene origin (F). P7: The hottest fluid first passed through locations presently occupied by mosaic breccias and precipitated cement (F). P8: Hypogene fluid then precipitated cement in more topographically exposed bedrock veins (F). P9: Hypogene fluid then precipitated cement in the most distal and topographically exposed locations (calcretes) (F). P10: Diffusional enrichment of ^{13}C occurs in the aqueous phase as a result of degassing of CO_2 from hypogene fluids (T). P11: Cement precipitated at larger distances from the source was derived from fluid which had degassed larger quantities of CO_2 (F). P12: Cement precipitated at larger distances from the source was derived from fluid which had undergone larger amounts of evaporation (F). P13: Cement precipitated at larger distances from the source was derived from fluid that had lower temperatures (F).

6.6.2 Arguments

A1: If P6 and P10, then P7, P8, P9, P11, P12, and P13 (V and F). A2: If P1, P2, P3, P4, P5, and A1, then the isotopic characters of carbon and oxygen incorporated in the authigenic breccia cements from both the Trench #14 and Busted Butte exposures indicate a hypogene origin of these cements (IV and F).

6.6.3 Analysis

Prior to discussing the validity of the arguments presented by Szymanski (1992), accuracy of the various premises will be addressed. Premises P1 and P2 are clearly supported by published data (Whelan and Stuckless, 1990). In order for the rest of the argument to be developed, Szymanski (1992) had to demonstrate the isotopic characteristics for each lithofacie are different. This should have been done with appropriate use of statistics. However, neither accuracy nor uncertainty of the measurements were considered by Szymanski (1992) in his determination of the average values for each lithofacie. It is unlikely, considering the spread of data in each lithofacie and the accuracy and precision of the data, that P3 is necessarily true. The isotopic data generally, but fuzzily, suggest isotopic increase in mass in the sequence: breccia cement, vein, and calcrete. The argument is reasonably made that this sequence would be typical of material precipitating from a cooling and evaporating hydrothermal fluid that progressively flows from the breccia to the veins to the calcretes. This argument doesn't prove the hypothesis of hypogene fluids, but it is a true premise if viewed as part of an overall inductive argument for hypogene origin. Premise P4 is a simple statement based upon isotopic and geochemical principles and is true. Premise P5 is a simple statement based upon isotopic and geochemical principles and is therefore also true. It should be noted that CO_2 degassing is only one process which can cause ^{13}C enrichment (Quade and Cerling, 1990).

The most critical premise for this argument is P6. Szymanski (1992) clearly stated he assumed this statement was true. The analyses presented in this document and in Everden (1992) clearly indicate that Szymanski (1992) has not provided adequate evidence to support this assertion. It was only by assuming an upwelling origin for the different lithofacies could he invent a geometric model (topographic exposure) which may allow attribution of the correct isotopic characteristics for the different lithofacies. Szymanski (1992) stated that the isotopic pattern is incompatible with a pedogenic origin in which the water flow would be in the opposite direction. Calcites that precipitate at the surface as calcretes are generally associated with water that evaporates completely (McFadden et al., 1991). Water that manages to recharge is more likely less evaporated because recharge requires a large flux of water. These observations suggest that Szymanski's (1992) assertion that the isotopes are incompatible with a supergene origin is false. Since P6 is false, then premises P7 through P9 and P11 through P13 are also false. Note that each of these latter premises are blind assertions with no quantitative evidence presented by Szymanski (1992) to support them, and they are mainly intestable hypotheses.

Argument A1 is validly constructed, and the conclusions strictly rely on the truth of P6. Since P6 is false, then each of the conclusions (P7 through P9 and P11 through P13) need not be accepted. Argument A2 constructed by Szymanski (1992) is invalid. This is a classic example of an argument in which the premise (hypogene origin of these cements) appears both in the conclusion and as a required statement (circular reasoning) and cannot be considered a valid argument. This argument appears to have no supporting evidence presented by Szymanski (1992). If the scenario is to be properly supported, then documentation from analogous systems should have been presented by Szymanski (1992), however, he provided no such data and simply relied on assertion to support his premises. It is important to note that Szymanski's (1992) argument that hypogene fluids could precipitate carbonate of appropriate carbon and oxygen isotopic signature is permissible. However, Szymanski's (1992) statement cannot be considered conclusive for the hypogene origin of the mosaic breccia, bedrock veins, and calcretes.

In order to strengthen his declaration, it will be necessary that Szymanski prove by construction of a mass balance and use of analogous systems that the amount of Ca found in the pedogenic deposits, and most importantly the impurity of the carbonates, can be balanced and formed from a hypogene fluid. Everden (1992) completed a preliminary mass balance calculation for Ca in the Yucca Mountain area and carefully looked at appropriate analogs with regard to purity of the carbonate deposits. His preliminary quantitative conclusions indicated the amount of hypogene fluid necessary to account for the pedogenic carbonate would require conditions (saturation of surface for extended periods of time) which are not recorded in deposits at sites (Stuckless et al., 1992) which Szymanski (1992) insisted formed from hypogene fluids. Further, Everden (1992) illustrated that the flux of rainwater Ca is of the right order of magnitude to account for the measure of calcium carbonate content of the stratigraphic column in which deposits are found. Additionally, deposition of carbonate dust (Everden, 1992) in the Yucca Mountain area could supply even a larger amount of Ca than is delivered by rainwater. From a mass balance standpoint, the preliminary calculations completed by Everden (1992) indicated that hypogene fluids could not supply enough Ca to the surface without causing significant evidence for saturated conditions to be left in the record of these deposits. Rainwater and dust deposition can supply sufficient amounts of Ca to balance the amount of calcium carbonate recorded in these deposits. Everden (1992) summarized textural and compositional characteristics of a variety of possible analogs to the pedogenic deposits at Yucca Mountain and conclusively demonstrated that the general characteristics (composition and textural purity and diversity) of the Trench #14 deposits and those at Busted Butte cannot be ascribed to a hydrothermal system, or to any system that remains saturated for any length of time (standing water or palustrine conditions).

Thus, the permissible evidence for a hypogene origin derived, but unsupported, by Szymanski (1992) from the carbon and oxygen isotopic signatures of the mosaic breccias, calcretes, and bedrock veins does not require that the deposits were formed from hypogene fluids. Likewise, the explanation developed by Quade and Cerling (1990) that the carbon and oxygen isotopic characteristics of these deposits infer a supergene origin is permissible evidence. However, their findings do not require that the deposits were formed from supergene fluids. It is only in combination with detailed laboratory and mineralogical characterization of the major characteristics of these deposits and analog sites that the controversy over origin of these deposits will be concluded. Everden's (1992) approach and treatment of the data (Ca mass balance with detailed analysis of the lithologic character of all possible analog deposits) strongly argued the only rational conclusion with regard to origin of the calcretes, mosaic breccias, and bedrock veins is that they are supergene. It is important to note that Szymanski (1992) did not seriously evaluate the possibility that supergene processes could supply the necessary flux of Ca to the surface of the Yucca Mountain region. Even more telling—a subsequent analysis of Everden's report (1992) by Szymanski and colleagues (Somerville, 1993) completely ignored the strongest lines of evidence presented by Everden (1992). Calcium mass balance and textural and compositional characteristics (impurity) of all relevant analog pedogenic deposits, presented by Everden (1992), indicate that mosaic breccias, calcretes, and bedrock veins are derived from supergene fluids. However, until further characterization of the sources and geochemical and isotopic characteristics and the quantification of the flux of dust and Ca to the surface in the Yucca Mountain area are completed, some concerns remain. These concerns are the Sr isotopic signature (discussed in Section 8.14), a more rigorous mass balance of Ca and other elements (trace metals), and determination that rainwater interaction with surface materials, including dust, can account for characteristics recorded in the pedogenic deposits.

6.7 FLUID COMPOSITION RESPONSIBLE FOR MOSAIC BRECCIA

6.7.1 Premises

P1: The local carbon isotopic system is in equilibrium with regard to all phases containing carbon (gas, dissolved HCO_3^- and calcium carbonate) (F). P2: The carbon isotopic signature incorporated in carbonate cement is invariant in time (F). P3: The isotopic character of carbon incorporated in AMC cements may be calculated assuming isotopic equilibrium of the carbon system (T). P4: Fluctuating chemical composition of fluids and fluctuating conditions of mineral deposition are not expected characteristics of supergene pedogenic processes (F). P5: AMC cements have $\delta^{13}C$ ratios identical to those incorporated in carbonate gangue associated with known hydrothermal deposits (T). P6: Calcium-Magnesium (Ca-Mg) fluid phases were heavily involved in the formation of authigenic cements (T). P7: Dissolved solids in vadose zone interstitial fluids are only derived by interaction of rainwater and the ignimbrites (F). P8: Ca-Mg fluid phases are metasomatic (T). P9: Authigenic breccia cements are inferred to precipitate at rates larger than fractions of a gram per cm^2 per 10^3 years (T). P10: Explosive hypogene upwelling fluids which brecciated ignimbrites provided conditions supportive to plant life (F).

6.7.2 Arguments

A1: If P1, P2, and P3, then the isotopic character of carbon incorporated in AMC from both the Trench #14 and Busted Butte locations is different than that expected to be dissolved in local supergene pedogenic fluids (V and F). A2: If A1, P4, P5, P6, P7, P8, P9, and P10, then there is no factual evidence to support that mineral cementation of AMC breccias is required to be supergene in origin (V and F).

6.7.3 Analysis

The construction of argument A1 is valid. The conclusion of this argument can only be true if premises P1, P2, and P3 are true. Quantitative analyses presented by Yang et al. (1993) and Quade and Cerling (1990) abundantly show that P1 and P2 are false. Since an equilibrium calculation can be made from the available information as Szymanski (1992) indicated, P3 is a true statement. The important point to remember is that the results of an equilibrium calculation have geochemical significance, and would support Szymanski's (1992) geochemical argument, if the system can be shown to be in equilibrium. Thus, since P1 and P2 are false, the results of Szymanski's (1992) calculations do not support his argument. The conclusion of argument A1, that the isotopic character of carbon incorporated in AMC from both the Trench #14 and Busted Butte locations is different than that expected to be dissolved in local supergene pedogenic fluids, is false and should not be accepted.

Argument A2 is a validly constructed inductive argument. Acceptance of the conclusion of an inductive argument requires the strength of the conclusion be reflective of the strength of the premises (Barker, 1989). From the analyses presented in earlier sections of this report, premises P4 (Section 3.1) and P7 (Section 5.3) can be dismissed as false assertions. Premise P5 appears to be adequately supported by Szymanski (1992), but is only permissive evidence that the $\delta^{13}C$ of the AMC cements are analogous to values measured in carbonate gangue associated with known hydrothermal deposits. Ca-Mg bearing fluids have to be involved in the formation of authigenic cements since they are primarily Ca-Mg bearing, thus, P6 and P8 are true. It should be noted that metasomatic only describes the allogenic nature of the fluid and its constituent elements (Bates and Jackson, 1980) and does not necessarily imply hypogene or hydrothermal conditions. As Schlesinger (1985) eloquently demonstrated, precipitation of supergene pedogenic calcium carbonate deposits is certainly not a steadystate process with formation rates of fractions of a gram per cm^2 per 10^3 years, but is characterized by more episodic deposition with rates much larger than fractions of a gram per cm^2 per 10^3 years. P9 is true, but cannot be used as Szymanski (1992) intended to indicate that supergene processes would be too slow to account for the pedogenic deposits. Finally, it has been interpreted that Szymanski (1992) intended to argue that the presence of plant roots only requires conditions conducive for plant growth. Since elsewhere in his document (page 6-2) Szymanski (1992) argued that the hypogene fluids would be explosively delivered to the surface, the implication from this line of reasoning argues that explosive eruption of hydrothermal hypogene fluids would necessarily involve conditions which are also conducive to plant life. This is an example of the illogical reasoning used by Szymanski (1992) to assert that hypogene conditions are the source for the fluids for pedogenic deposits. Several lines of evidence presented by Stuckless et al. (1992) and Everden (1992) argued against this assertion, in particular the absence of any fauna indicating persistent saturated conditions at the Trench #14 and Busted Butte sites. In summary, Szymanski's (1992) strongest attempt to discredit the supergene origin hypothesis was thwarted by available documentation. The conclusion of inductive argument A2 is not supported enough by the available evidence to conclude it is true, and should be considered false.

6.8 DIFFERENTIALLY HEATED SOURCE

6.8.1 Premises

P1: Fission-track ages of zircons contained within AMC mosaic breccia deposits at Trench #14 and Busted Butte have ages significantly older and younger than the K/Ar ages of the host ignimbrites (T). P2: There is a fairly young source (4.8±2.5 Ma) of either primary or thermally reset zircons (T). P3: The age of formation of some AMC breccias must be younger than 4.8±2.5 Ma (T). P4: Prior to or during emplacement, some of the enclosed zircon crystals were heated sufficiently to cause fission-track annealing (F?). P5: The Ca-Mg fluid phases must have ascended with sufficient velocity to carry high density zircons (F?).

6.8.2 Arguments

A1: If P1, P2, and P3, then the AMC breccia cements can form by supergene processes in which zircons introduced by wind or runoff action are incorporated into the cement (V and T). A2: If P2, P3, P4, and P5, then hypogene Ca-Mg fluids have brought zircons from a deep substratum and were incorporated in the AMC breccias (V and F). A3: If A1 or A2, then anomalous fission-track zircons can be incorporated into AMC breccia deposits (V and T).

6.8.3 Analysis

The construction of inductive argument A1 is valid, and the conclusion of this argument should be true if premises P1, P2, and P3 are true. Premise P1 has been adequately documented in Szymanski (1992) and discussed in Section 6.2 and is true. Rhyolitic pumice from Crater Flat dated by fission-track method on a zircon (Carr, 1982) indicated an age of 6.3±0.8 Ma for this rhyolite bed. This age is not significantly different than that determined for the one zircon in the AMC breccia cited by Szymanski (1992) and requires that P2 be accepted as true. Since P2 is true, then P3 must be true by superposition principles. This is a permissible argument, but further support for each of the premises should be sought (specifically the evidence for primary fission-track ages versus annealed ages) since this remains one of the strongest arguments (Szymanski, 1992; Somerville, 1993) which can be raised against the supergene origin of pedogenic deposits.

Argument A2 is inductive and constructed using a valid format. Premises P2 and P3 were shown to be true in the preceding paragraph. If indeed the zircons were brought to the surface by hypogene fluids then one of two possibilities must have been attained by the zircons prior to eruption to the surface. The first possibility is that the zircons were derived from Tertiary volcanic pile and that fluids, traveling with sufficient velocity to erode and carry the zircons upward, were in great excess of 250 °C. This is required because the annealing or partial annealing of zircons requires long periods of time at relatively high temperatures (>175 °C). Alternatively, the zircons were derived from the Precambrian rocks at great depths (>6 km, assuming a Basin and Range geothermal gradient of about 30 °C/km) and were almost completely annealed (>99 percent of all the tracks annealed). Additionally, this scenario requires that 90 percent of the annealed zircons analyzed in the AMC breccia cements fortuitously have the same age as the ignimbrites, and that the fluids traveled at a high enough velocity to erode and transport the zircons to the surface. Detailed textural characterization of the mosaic breccias cited in Everden (1992) and Stuckless et al. (1992) indicates the preservation of delicate features in the cements which would undoubtedly have been destroyed by these explosive fluids. From this discussion of the physical requirements necessary to explain the assumptions engendered in P4 and P5, these two premises should be considered false, and the conclusion of argument A2 should not be accepted.

Based upon the valid logical construction of argument A3, only the truth of arguments A1 or A2 must be ascertained before the conclusion can be accepted as true. As was demonstrated in the analysis of argument A1, the conclusion of that argument indicated it could be accepted, and thus the conclusion of A3 can be accepted. The result of the analysis of logic used by Szymanski (1992) indicated there is no conclusive evidence which may be solely derived from the presence of dated zircons in the AMC breccias regarding origin of pedogenic deposits. Since the hypogene fluids would have to be traveling at large enough speeds from great depths (>8 km for 30 °C/km geothermal gradient), provided to carry the zircons, it is remarkable that the evidence of destruction of these explosive fluids is not preserved in the deposits (Stuckless et al., 1992; Everden, 1992). It should become more clear if supergene pedogenic processes can cause the incorporation of anomalous (discordant) zircons when further characterization of the detrital dust flux is completed. Nevertheless, the more likely scenario for the incorporation of zircons into pedogenic deposits is by supergene processes.

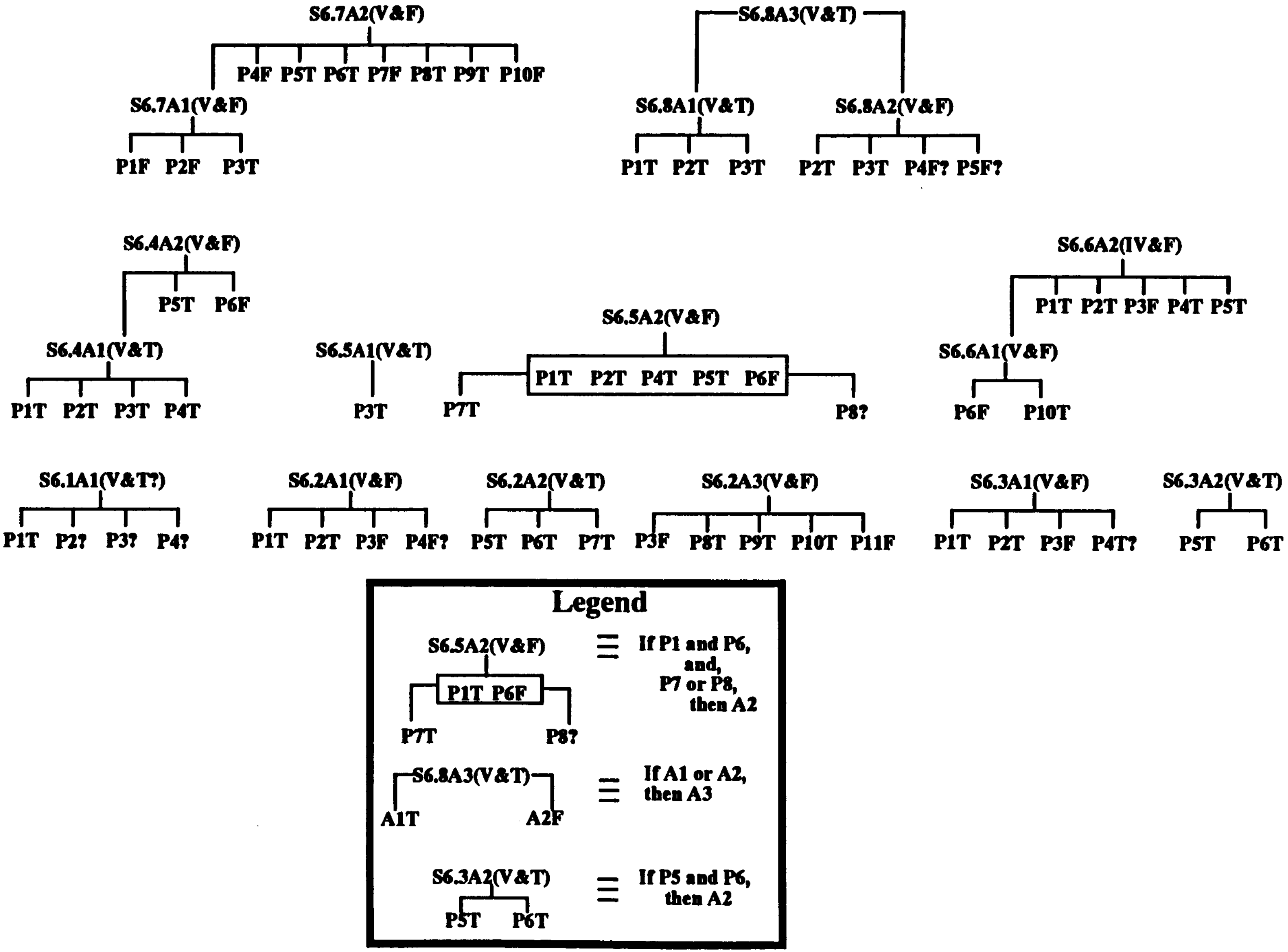


Figure 6-1. Logic diagram of arguments presented in Chapter 6

7 ORIGIN AND AGE OF ZEOLITIC AND MONTMORILLONITIC ALTERATION

In Chapter 7 of Szymanski (1992) geochemical, mineralogic, and geochronologic information relevant to understanding the origin and history of zeolitic and montmorillonitic alteration in the Yucca Mountain area was presented. Data were used by Szymanski (1992) to conclude that metasomatic formation of epigenetic clinoptilolites has been an intermittent process involving two spatio-chemically distinct types of hydrothermal systems. This conclusion was developed from three major ideas: (i) conditions of formation of pro-grade zeolitic and montmorillonitic facies; (ii) spatial distribution of alteration facies (mineralogic and geochemical evidence); and (iii) timing of the alteration (geochronologic data). Szymanski (1992) first presented evidence and developed arguments which stipulate the conditions of formation of pro-grade zeolitic and montmorillonitic facies. These arguments are addressed in Section 7.1.

Next, Szymanski (1992) presented geochemical and mineralogical data regarding the spatial distribution of the alteration facies. From these data he developed seven main arguments which were used to assert at least two spatio-chemically distinct hydrothermal alteration aureoles exist at Yucca Mountain: one situated in the northwestern sector of Yucca Mountain associated with the Timber Mountain caldera hydrothermal system; and the second situated in the southeastern sector of Yucca Mountain, centered near the NE striking trace of the Stage Coach Road fault. The lack of discrete zoning in the depth distribution of alteration minerals beneath the surface of Yucca Mountain was the first argument used by Szymanski (1992) to indicate the polygenetic nature of zeolitic and montmorillonitic alteration and is addressed in Section 7.2. The second argument presented by Szymanski (1992) is that isogradal surfaces from both the zeolitic (analcime) and montmorillonitic facies lack a consistent relationship to the local stratigraphic boundaries. This argument, analyzed in Section 7.3, was used to imply that higher grade alteration minerals are not the result of deuteric alteration, but must represent epigenetic hydrothermal metamorphism, and that alteration is also expressed in the present day local vadose zone. Section 7.4 reviews Szymanski's (1992) argument that the lack of a consistent relationship between the volcanic glass-free zone and the contemporary water table implies lower grade alteration minerals (glass to zeolite transition) require an epigenetic hydrothermal explanation. The high degree of chemical diversity exhibited by the clinoptilolites was used by Szymanski (1992) to infer that two chemically distinct fluid phases were involved in formation of these minerals; this topic is evaluated in Section 7.5. The Ca-Mg nature of some of the zeolites was hypothesized by Szymanski (1992) to require that the hypogene fluids which formed these minerals acquired their geochemical signature, in part, through the dissolution of the underlying Paleozoic carbonates. Additionally, he inferred hypogene fluids invaded the area occupied by the contemporary vadose zone. This two-part argument is considered in Section 7.6. The metasomatic nature of the conversion process of glass to zeolite, reviewed in Section 7.7, was argued by Szymanski (1992) to require that the alkaline earth alteration cannot be attributed to a supergene-diagenetic origin. Finally, Szymanski (1992) stated that the spatial distribution of the higher grade alteration minerals can be interpreted to infer a planar distribution of alteration temperatures which would require the presence of two alteration aureoles in the Yucca Mountain area. This final argument based upon the spatial distribution of geochemical and mineralogical properties associated with the zeolitic and montmorillonitic alteration is analyzed in Section 7.8

Finally, Szymanski (1992) presented radiometric analyses of the Yucca Mountain alteration minerals. From this information he developed nine arguments which he used to support his conclusion that metasomatic formation of epigenetic clinoptilolites has been an intermittent process involving two spatio-chemically distinct types of hydrothermal systems. The strongly discordant K/Ar ages of the Yucca Mountain clinoptilolites and their range of ages in a given stratigraphic unit are the two ideas developed in Szymanski's (1992) first argument which concluded that zeolitization does not only reflect deuteric alteration, but must be polygenetic in origin. These ideas and this argument are considered in Section 7.9. Szymanski (1992) used the similarity of K/Ar ages of clinoptilolites and montmorillonitic clays in the deeper parts of the Yucca Mountain ignimbritic complex to infer that at least some clinoptilolites are suitable for K/Ar geochronometric analyses. He also inferred that the hydrothermal activity of the Timber Mountain system was long-lived (11-9.5 Ma) and was clearly recorded in the northwestern segment of Yucca Mountain. His use of K/Ar ages in this manner is analyzed in Section 7.10. An evaluation is provided in Section 7.11 of Szymanski's (1992) argument that the increasing K/Ar clinoptilolite ages with increasing depth below the topographic surface implies the availability of ignimbritic matter in the vitric state seems to have been a factor which controlled the timing and duration of the low grade zeolitization. The mixed age nature of the K/Ar ages of the younger clinoptilolites and their spatial distribution were used by Szymanski (1992) to infer that there has been a depthward diminishing overprinting of the young clinoptilolites and a depthward increasing rate of paleo-depletion of the vitric reservoir. The major consequence of this argument, according to Szymanski (1992), was that the latest episode of low grade zeolitization was less than 2 Ma. These ideas, the argument constructed by Szymanski (1992), and the consequence are discussed in Section 7.12. Based upon the geochemical and radiometric analyses of the zeolites, Szymanski (1992) argued that at least four chemico-temporally distinct sets of clinoptilolites exist at Yucca Mountain—this issue is addressed in Section 7.13. Conclusions derived from the previous argument (Section 7.13) were combined (Szymanski, 1992) with the observation that the decrease of clinoptilolite age with increasing concentration of alkaline earth elements to infer that fluids responsible for the formation of various chemico-temporally distinct sets of zeolites have become more Ca-Mg rich with decreasing age. This argument is analyzed in Section 7.14. In Section 7.15 the assertion (Szymanski, 1992) that different types of hydrothermal processes have been responsible for the formation of the spatio-chemically distinct alteration aureoles is considered. The hypothesis (Szymanski, 1992) that space-differential overprinting of the northwestern alteration aureole (Timber Mountain caldera activity) by the subsequent southeastern aureole (fault-based hydrothermal system) was responsible for observed spatial distribution of the K/Ar ages and concentrations of the alkaline earth elements is examined in Section 7.16. Finally, in Section 7.17, the coincidence of the K/Ar history of hypogene zeolitic and montmorillonitic alteration with the history of local magmatism was used by Szymanski (1992) to infer that K/Ar ages of the epigenetic clinoptilolites adequately reflect timing of the main episodes of hypogene alteration and that low grade metasomatic zeolitization expresses intermittent hydrothermal metamorphism.

7.1 ALTERATION MINERALS TEMPERATURES OF FORMATION

7.1.1 Premises

P1: The thermal stability limits of pro-grade alteration facies (zeolitic and montmorillonitic) may be estimated based on the results of studies of appropriate contemporary analogs elsewhere (T). P2: The extent of the smectite to illite transformation in the montmorillonitic facies is related to the alteration temperature (T). P3: The randomly interstratified (R0) to allevardite type of interstratification (R1) transformation occurs in the temperature range from 130 to 150 °C for reaction times less than 1 Ma (T). P4: Clinoptilolite can form over a range of temperatures, from as low as 25 to 60 °C, up to 140 °C (T). P5: The glass to zeolite reaction temperature is a function of fluid chemistry (T?). P6: The thermal stability and conditions of formation for calcic and alkalic clinoptilolites are different (T?).

7.1.2 Arguments

A1: If P1, P2, and P3, then the degree of intrastratification (degree of smectite to illite transformation) of illites in the subsurface at Yucca Mountain can be used to infer the conditions of the montmorillonite alteration (V and T). A2: If P1, P4, P5, and P6, then the distribution of zeolites in the subsurface at Yucca Mountain and their chemical composition can be used to infer the conditions of the zeolitic alteration (V and T).

7.1.3 Analysis

Argument A1 is a valid argument whose logical form requires the conclusion be accepted since each premise is true. Premise P1 is true based upon the many published accounts of the conditions of formation of zeolites and montmorillonites (Bish, 1989; Bowers and Burns, 1990; Tschernich, 1992; White et al., 1980). Adequate documentation of premises P2 and P3 is presented in Bish (1989) to justify the truth of these assertions.

Similarly, A2 is a valid argument requiring the conclusion be accepted since each premise is true. Based upon this discussion, P1 is true. Szymanski's (1992) use of the phrase appropriate contemporary analogs is important, and he considered an appropriate contemporary analog for the conditions of formation of zeolites to be primarily restricted to hydrothermal systems. Yet even his direct quotation (Szymanski, 1992) of Tschernich (1992), clearly indicated that silica-rich heulandite (clinoptilolite) commonly crystallizes at surface temperatures in volcanic tuff beds. Sufficient evidence has been presented by Bowers and Burns (1990) and Bish (1989) to accept P4 and P5 as true statements. Although Szymanski (1992) did not expressly state premise P6—that he implicitly acknowledged the importance of this concept is clear from his discussion of P4 (Szymanski, 1992). Premise P6 is an extremely important concept whose implications directly impact subsequent arguments offered by Szymanski (1992). Equilibrium model calculations of zeolite stability fields and a discussion of field evidence from an appropriate contemporary analog (active seepage through zeolitized Rainier Mesa, Benson, 1976; White et al., 1980) by Bowers and Burns (1990) indicate calcic clinoptilolites are in equilibrium with fluids which reside in the Tertiary ignimbrites at temperatures near 25 °C. Further, Bowers and Burns (1990) suggest that the clinoptilolite stability field decreases with increasing temperature and K-rich clinoptilolites have an increased stability field. However, it has been argued that the thermal stability fields for clinoptilolites are poorly constrained (Murphy, 1991).

7.2 DEPTH DISTRIBUTION OF ALTERATION MINERALS

7.2.1 Premises

P1: The observed depth distribution of low grade alteration minerals overlaps the distribution of equivalent "higher grade alteration minerals" (T). P2: Mineral species representing low grade zeolitization (clinoptilolite, heulandite, and mordenite) appear to be ubiquitous (F). P3: Mineral species representing low grade montmorillonitization (smectite) appear to be ubiquitous (T). P4: Local occurrences of "higher grade alteration minerals," such as analcime, laumontite, albite, allevardite clay, Kalkberg clay and discrete illite are intermixed with the ubiquitous low grade alteration background (F). P5: Lower grade mineral species appear to have been produced both prior to and after formation of higher grade alteration minerals (T).

7.2.2 Arguments

A1: If P2 and P3, then the low grade alteration background is ubiquitous (V and F). A2: If P1, A1, P4, and P5, then the low grade alteration is polygenetic, and the corresponding low grade alteration minerals (zeolites and smectites) must have been formed via deuteric and hypogene or supergene processes (IV and T).

7.2.3 Analysis

Szymanski (1992) argued (A1) the distribution of low grade alteration assemblages is ubiquitous. The valid constructional form of the argument requires that P2 and P3 must be true if the conclusion is to be accepted. Premise P3 is almost a direct quotation by Szymanski (1992) of Bish (1989; Bish stated smectites are present in virtually all units, while Szymanski used ubiquitous). This observation is based upon the work in Bish (1989) and in Bish and Chipera (1989), and can be accepted as true. However, Szymanski (1992) neglected to include or even consider the rest of Bish's statement. Bish (1989) also noted the distribution of zeolites (mordenite, clinoptilolite and analcime) in Yucca Mountain was stratified, clearly indicating that the distribution of the low grade zeolite minerals is not ubiquitous. Information presented in Bish and Chipera (1989) and figures 7-6a through 7-6l in Szymanski (1992) clearly indicates that premise P2 is false. Thus, the conclusion of A1 is not strictly true. If the assertion had been that the low grade smectite alteration is ubiquitous, this would be true.

Although the conclusion to A2 is true, Szymanski's (1992) argument was *non sequitur* and invalid (Barker, 1989). Analyses of alteration mineralogy of the subsurface of the Yucca Mountain area (Bish and Chipera, 1989; Bish, 1989; Broxton et al., 1986, 1987) indicate that premise P1 is true. Argument A1 was demonstrated to be false. P4 requires that A1 be true in order for P4 to be true, since Szymanski (1992) again equated distribution of low grade zeolites to the distribution of low grade montmorillonites (smectite). A1 is false, hence, P4 is false. Szymanski (1992) asserted lower grade mineral species appear to have been produced both prior to and after that of "higher grade alteration minerals," however, he provided no evidence to support the first clause (prior to). Evidence of early deuteric formation of lower grade mineral species (clinoptilolite and smectite) preceding the formation of higher grade alteration minerals was presented by Levy and O'Neil (1989). Bish (1989) clearly stated that lower grade mineral species (smectite) formed after that of higher grade alteration minerals. Thus, the conclusion that A2 is true is based upon the observations of deuteric alteration (Levy and O'Neil, 1989), later Timber Mountain hydrothermal alteration (Broxton et al., 1987; Broxton, 1992), and subsequent smectite formation (Bish, 1989).

7.3 ISOGRADAL SURFACES AND STRATIGRAPHIC BOUNDARIES

7.3.1 Premises

P1: The top of the analcime zone is situated: within the Prow Pass Member of the Crater Flat Tuff in boreholes J-13, USW G-1, and G-2; in the underlying Tram Member in boreholes UE-25p#1 and 25a#1; and below the Crater Flat Tuff within the Lithic Ridge Tuff in USW G-3 (T). P2: Analcime occurs above the water table at a depth of 608 ft in the Tiva Canyon Member of the Paintbrush Tuff (T?). P3: The top of the authigenic albite zone occurs within the Tram Member of the Crater Flat Tuff in boreholes UE-25a#1 and USW G-2, and within the Lithic Ridge Tuff in borehole USW G-1 (T). P4: The R0/R1 interface occurs within the Bullfrog Member of the Crater Flat Tuff in borehole USW G-2, in the

Lithic Ridge Tuff in borehole USW G-1, and within pre Lithic Ridge Tuff units in borehole UE-25p#1 (T). P5: The first presence of Kalkberg clays is within the Tram Member of the Crater Flat Tuff in USW G-2 and much deeper in borehole USW G-1 (pre Lithic Ridge Tuff) (T).

7.3.2 Arguments

A1: If P1, P3, P4, and P5, then the "higher grade alteration minerals" are not the result of deuteric alteration (V and T). A2: If P1, P3, P4, P5, and S7.1P3, then the "higher grade alteration minerals" (analcime, authigenic albite, R1-type illite, and Kalkberg-type illite) are not the products of supergene-diagenetic processes (IV and ?). A3: If A1 and A2, then the higher grade alteration minerals must have been formed in response to hypogene epigenetic hydrothermal metamorphism (V and ?). A4: If P2 and A3, then higher grade metamorphism is not confined to deeper parts of the stratigraphic sections and is also expressed in the local vadose zone (V and T?).

7.3.3 Analysis

Argument A1 is clearly and validly constructed with adequate support provided by Szymanski (1992) and others (Bish, 1989; Bish and Chipera, 1989) to accept each premise (P1, P3, P4, P5, and P6) as true, and thus the conclusion is true.

Argument A2 is an invalid inductive argument and an example of a *non sequitur*. The equivalence of the terms diagenesis and supergene by Szymanski (1992, page 7-3) is misleading as there is no universally accepted definition of diagenesis and no delimitation associated with the term (such as boundary with metamorphism, maximum range for diagenesis is from 100 to 300 °C, Bates and Jackson, 1980). In addition, grouping of the minerals analcime, authigenic albite, R-1 type illite, and Kalkberg-type illite as higher grade (temperature) alteration minerals is inappropriate. Only R-1 type and Kalkberg-type illites are exclusively higher grade alteration minerals (Bish, 1989; Broxton et al., 1986; Tschernich, 1992), while analcime and authigenic albite can also form at lower temperatures. By combining these minerals as higher grade alteration minerals, Szymanski's (1992) argument becomes *non sequitur* and the conclusion can be neither accepted nor rejected. Premises P1, P3, P4, P5, and P6 are true (Bish, 1989; Bish and Chipera, 1989). Premise P3 from Section 7.1 of this report is also true. The evidence cited by Szymanski and the terms used by him do not allow acceptance or rejection of the non-supergene/diagenetic hypothesis for the origin of the "higher grade alteration minerals" at Yucca Mountain.

Although the logical form of A3 is valid and A1 is true, the truth of A2 cannot be determined from the evidence and arguments presented by Szymanski (1992). The conclusion of A3 cannot be determined true or false based upon the premises of the argument. The conclusion of A3 has been argued to be true by Bish (1989). Szymanski (1992) repeatedly used this conclusion in subsequent arguments detailed in this chapter.

The final argument in this section concerns the occurrence of higher grade alteration minerals in the vadose zone. Since A3 may be true, and the argument was constructed (Szymanski, 1992) using a valid form, acceptance of the conclusion as true depends on the truth of premise P2. It is only on the basis of single, possibly suspect, occurrence of analcime at a depth of 608 ft (page 147, Appendix G of Broxton et al., 1986) in borehole J-13 that Szymanski (1992) inferred the presence of "higher grade alteration minerals" in the vadose zone. There is some ambiguity as to the correct identity of the sample cited by Szymanski (1992). Broxton et al. (1986) list three chemical analyses of analcime collected from a depth of 608 ft in the Tiva Canyon Member of the Paintbrush Tuff. In Bish and Chipera (1989), which is the Los Alamos National Laboratory's revised summary of the subsurface three-dimensional distribution of minerals in the Yucca Mountain area, there is no reference to the Broxton et al. (1986) work. There is no sample listed for a depth of 608 ft; only a sample for 607 ft which contained no zeolites, analcime, or higher grade alteration minerals (Bish and Chipera, 1989). However, they (Bish and Chipera, 1989) noted the highest occurrence of analcime in J-13 was at a depth of 608 m (1995 ft) in the Prow Pass Member, where almost 45 percent of the sample was analcime. It should also be noted Broxton et al. (1986) listed six chemical analyses for analcime samples from 1995 ft (608 m) from borehole J-13. Without proper documentation or further clarification from Broxton or Bish, it is impossible to place high confidence in premise P2, and thus the presence of higher grade alteration minerals in the vadose zone may not be true. However, based upon Broxton et al. (1986), the conclusion of argument A4 is tentatively accepted as true.

7.4 DISTRIBUTION OF VOLCANIC GLASS RELATIVE TO THE WATER TABLE

7.4.1 Premises

P1: Vitric ignimbrites are preserved well below the contemporary water table in boreholes J-13, USW VH-2, and UE-25a#1 (T). P2: Preserved glasses in boreholes J-13 and USW VH-2 represent the dense vitrophyre of the Topopah Spring Member (T). P3: Preserved glasses in boreholes J-13 and UE-25a#1 represent unwelded tuffs of Calico Hills and unwelded Prow Pass Member of the Crater Flat Tuff, respectively (T). P4: Conditions beneath the water table are presently characterized by low ambient temperature, near neutral Ph, and low concentrations of dissolved cations and are considered to be ordinary (T). P5: Both the dense vitrophyre and unwelded tuffs of Calico Hills and Prow Pass Member of the Crater Flat Tuff have sufficient permeability to allow fluid-glass interaction to be considered ordinary (F). P6: Hypogene processes involve warmer and chemically more complex fluids than present groundwaters (T).

7.4.2 Arguments

A1: If P1, P2, P3, P4, and P5, then under ordinary conditions the conversion of glass to zeolite proceeds at exceedingly low rates (V and F). A2: If A1 and P6, then conditions associated with hypogene processes are required to speed up the conversion of glass to zeolite at Yucca Mountain (V and F). A3: If A2 and S7.3A4, then the lower grade alteration minerals encountered in the vadose zone are related to epigenetic hydrothermal metamorphism (V and F).

7.4.3 Analysis

Argument A1's valid construction requires that P1, P2, P3, P4, and P5 are true if the conclusion is to be accepted as true. Szymanski (1992) asserted that P1, P2, and P3 are true, although he did not provide proper reference (Carr and Parrish, 1985) for the evidence he presented from borehole VH-2 to support premises P1 and P2. Subsurface mineralogical characterization of drill cores (Bish and Chipera, 1989; Bish, 1989) provided adequate documentation to accept P1, P2, and P3 as true statements. Kerrisk (1987) gave support for acceptance of P4. Although Szymanski (1992) did not explicitly state P5, his inference in terms of ordinary conditions and fluid rock interactions required that fluid react with rock surfaces (sufficient permeability). Szymanski (1992) implied that the preservation of glass beneath the water table was the ordinary and expected condition. This is clearly not true based upon discussions presented by Bish and Chipera (1989) and Broxton et al. (1987), who concluded glass was rarely preserved beneath the static water table. The densely welded nature of the vitrophyre at the bottom of the Topopah Spring Member was used by Bish and Chipera (1989) to infer that glass preservation may be coupled to rock permeability—implying insufficient permeability exists in this unit to allow conversion of glass to zeolite. Inadequate evidence has been presented to understand the isolated local preservation of vitrophyric glass beneath the static water table in boreholes J-13, VH-2, and UE-25a#1. Additionally, the preservation of glass in the unwelded tuffs beneath the static water table in boreholes J-13 and UE-25a#1 has been incompletely examined. Premise P5 should be considered false, and the conclusion of argument A1 should not be accepted as being adequately supported.

Premises P6 and A1 must be true if the conclusion of A2 is to be accepted. The conclusion of this validly constructed argument (Szymanski, 1992) is false since A1 is false. Premise P6 is a true statement (Henley et al., 1984; Kerrisk, 1987; Tien et al., 1985). The error in Szymanski's logic was that he assumed all units were equally permeable (A1) and glass preservation is only a function of the temperature of the surrounding fluids. It is true that increased temperatures promote the conversion of glass to zeolite (Bowers and Burns, 1990), however, without considering the effect of permeability, it is unreasonable to conclude that hypogene fluids were required to convert glass to zeolite at Yucca Mountain.

Argument A3, as I have presented it, was a series of rhetorical questions in Szymanski (1992) and really should not be construed as a formal argument (Barker, 1989). However, he used his own conclusion to these rhetorical questions as bases for arguments in many of the subsequent sections (e.g., Section 7.7). Thus, analysis of the logic of these questions which form the premises of this argument should be completed. A3 is a validly constructed argument which demands the conditions associated with hypogene processes are required to speed up the conversion of glass to zeolite at Yucca Mountain and higher grade metamorphism is not confined to deeper parts of the stratigraphic sections to be true before acceptance of the conclusion of A3. Clearly from the discussion of argument A4 in Section 7.3 and in the preceding paragraph (A2), the conclusion cannot be strictly accepted as being proved by the argument and the truth of the premises. These rhetorical questions (Szymanski, 1992) were used to offer an alternative to the interpretation by Levy (1991). The choice of Levy (1991) to use the term diagenetic was construed by Szymanski (1992, page 7-3) to infer that various investigators associated with the Yucca Mountain Site Characterization Project advocate exclusively a supergene origin for the younger and lower grade alteration minerals, particularly those in the vadose zone. Levy (1991) and Broxton et al. (1987) argued zeolitization in most of the Prow Pass Tuff took place before the Topopah Spring Tuff was deposited, while zeolitization of the Calico Hills and Topopah Spring Member of the Paintbrush Tuff was finished by the time of deposition of the Rainier Mesa Tuff (11.6 Ma). Levy and O'Neil (1989) document that at least some of the zeolitization of Topopah Spring Member of the Paintbrush Tuff was due to post-emplacement cooling of a pyroclastic unit (deuteric processes). However, as Bish (1989) and Broxton (1992) clearly stated, the presence of lower grade alteration minerals in the vadose zone and their distribution at Yucca Mountain is partially the result of hydrothermal activity associated with the Timber Mountain caldera system affecting the pre-existing zeolites.

7.5 HIGH DEGREE OF CHEMICAL DIVERSITY OF ZEOLITES

7.5.1 Premises

P1: In the upper parts of the stratigraphic section at Yucca Mountain, clinoptilolites contain fairly large concentrations of alkaline earth elements (Ca+Mg) (T). P2: In deeper parts of the northwestern section of the Yucca Mountain area (boreholes USW G-1, G-2, G-3, USW H-4, and H-5) clinoptilolites contain fairly high concentrations of alkali metals (Na+K) (T). P3: In deeper parts of the southeastern section of the Yucca Mountain area (boreholes J-13, UE-25p#1, 25a#1, 25b#1, and USW G-4), clinoptilolites contain fairly high concentrations of alkaline earth elements (T). P4: Vadose zone clinoptilolites in the western segment are predominantly sodic-potassic in composition (T). P:5 Vadose zone clinoptilolites in the eastern segment are predominantly calcic-magnesic in composition (T). P6: Calcic clinoptilolite-bearing intervals (boreholes J-13, UE-25p#1, 25a#1, and USW G-4) also contain other zeolites from the calcic series (T).

7.5.2 Arguments

A1: If P2, P3, P4, P5, and P6, then the low grade alteration minerals were produced with a spatially selective involvement of two chemically distinct fluids phases (V and T). A2: If A1, then one of these fluid phases must have been carrying relatively high concentrations of dissolved alkaline earth elements (V and T).

7.5.3 Analysis

Argument A1 was constructed (Szymanski, 1992) with a valid logical form. This argumentation form stipulates that if each of the premises is true, then the conclusion of the argument has been adequately supported by the argument and the premises, and can be accepted as true. The spatial and chemical variations of zeolitized tuff in the Yucca Mountain area have been well documented (Broxton et al., 1986, 1987; Vaniman et al., 1984; Bish and Chipera, 1989; Carlos, 1985, 1989). Compositions of zeolites contained in fractures of the ignimbrites have also been described (Carlos et al., 1991; Carlos, 1985, 1989). These descriptions adequately support premises P2, P3, P4, P5, and P6. Since each of these premises is true and the argument is of a valid form, the conclusion that low grade alteration minerals were produced with a spatially selective involvement of two chemically distinct fluids phases is true. Although P1 was not used in the argument, Szymanski (1992) acknowledged the concept. With only the exception of borehole UE-25p#1, the uppermost chemical analysis reported for each borehole indicated that the zeolites, whether in fractures or in discretely zeolitized tuff, are Ca+Mg rich (Broxton et al., 1987). Although this observation was not incorporated into Szymanski's (1992) arguments, it is suggestive evidence that Ca-containing fluids may be transported downward from the surface. In addition, Szymanski (1992) neglected to include boreholes G1, G2, and G3 into premise P6. Carlos et al. (1991) clearly demonstrated that other calcic zeolites occurred in these boreholes and also indicated the abundance of these calcic zeolites was greater in the northern parts of the Yucca Mountain area (G-2 and G-1). By selectively presenting only the data from the eastern boreholes (J-13, UE-25p#1, 25a#1, and USW G-4), Szymanski (1992) was able to lead the reader into arguments presented later which infer upwelling of calcium bearing fluids in the eastern portion of Yucca Mountain.

Based upon the valid logical form of argument A2, if the conclusion of A1 is true, then the conclusion that one of the fluid phases responsible for formation of the zeolites must have been carrying relatively high concentrations of dissolved alkaline earth elements is true. The necessity of at least some involvement of Ca-bearing fluids in the eastern portion of the Yucca Mountain area has been previously argued (Broxton et al., 1987; Broxton, 1992). Since A1 is true, then the conclusion of A2 is true.

7.6 CALCIUM ZEOLITES AND PARENTAL FLUIDS

7.6.1 Premises

P1: Vadose interstitial fluids have a hydrothermal component (F). P2: Parental fluids of the mosaic breccia cements contain Ca+Mg (T). P3: Ca+Mg fluid phases are responsible for the conversion of the Na+K glass to Ca+Mg clinoptilolite (T).

7.6.2 Arguments

A1: If P1, P2 and P3, then the parental fluids (Ca+Mg) have acquired their chemical composition, in part, through the dissolution of the underlying Paleozoic carbonates (IV and T). A2: If A1 and S7.5P5, then the contemporary vadose zone was inundated by hypogene fluids (V and T).

7.6.3 Analysis

Argument A1 is invalid since Szymanski (1992) inferred a hypogene origin as a premise, and this is part of the conclusion. As was discussed in Section 5.6, there is no unequivocal evidence that the vadose zone fluids have a hydrothermal component. From that information, premise P1 should be interpreted as false. The requirement that Ca+Mg fluids are responsible for formation of mosaic breccia is true (Section 6.4; Vaniman et al., 1992). However, the source of the Ca+Mg fluids is not required to be hypogene as Szymanski (1992) asserted (e.g., analyses in Sections 6.4 and 6.5). The necessity of at least some involvement of Ca-bearing fluids derived from the Paleozoic carbonates in the eastern portion of the Yucca Mountain area has been previously suggested (Broxton et al., 1987; Broxton, 1992). This indicates that although P1 is false, the conclusion can still be accepted as a true statement. Premise P3 is adequately supported (Broxton et al., 1986, 1987) and should be accepted.

If the parental fluids have acquired their chemical composition in part through dissolution of underlying Paleozoic carbonates and if vadose zone clinoptilolites in the eastern segment are predominantly calcic-magnesic in composition, then the valid logical form of argument A2 requires the conclusion be true. Szymanski (1992) inferred that the hypogene fluids resided either in the Paleozoic carbonates or in the underlying Precambrian basement. Since he offered no support for his assertion of Precambrian basement involvement, it should not be accepted. However, the involvement of Ca+Mg fluids, which resided in Paleozoic carbonates, in the formation of Ca+Mg zeolites has been previously postulated for the eastern portion of the Yucca Mountain area (Broxton et al., 1987; Broxton, 1992). Since both arguments A1 and S7.5P5 are true, then the contemporary vadose zone was inundated by hypogene fluids. Several qualifying statements are necessary to clarify this conclusion. Spatial and depth distribution of alteration minerals and chemical composition of zeolites located in the eastern region of Yucca Mountain were argued (Broxton et al., 1987; Broxton, 1992) to indicate that conditions of zeolite formation were most likely due to low temperature regional groundwaters. The conditions (temperature and timing) under which the Ca-enriched waters, possibly derived from the Paleozoic carbonates, interacted with the ignimbrites and formed calcic zeolites has not been adequately explained (Broxton, 1992). Further insight into the timing of the calcic zeolites formation in the eastern portion of Yucca Mountain is discussed in Sections 7.9 and 7.10.

7.7 CONVERSION OF GLASS TO ZEOLITE MINERALS

7.7.1 Premises

P1: At least in part, the glass to clinoptilolite conversion is clearly metasomatic (T). P2: Presently, the altered Yucca Mountain ignimbrites contain fairly significant concentrations of alkaline earth elements relative to the locally preserved glass (T). P3: Large volumes of the local ignimbrites have been affected by the alkaline earth enrichment (T). P4: Supergene processes cannot provide the amount of alkaline earth elements to cause alkaline earth enrichment of the local ignimbrites (F).

7.7.2 Arguments

A1: If P1, P2, P3, and P4, then there has been metasomatic introduction of large quantities of alkaline earth elements via epigenetic hydrothermal processes (V and F).

7.7.3 Analysis

If P1, P2, P3, and P4 are true, then the valid logical form of argument A1 requires the conclusion of A1 to be true. The nature of the conversion process of glass to zeolite was reviewed in Section 7.4. Premise P1 is unquestionably true. It should be remembered that the term metasomatic does not imply a hypogene origin for fluids. Both premises P2 and P3 are adequately documented in published literature (Broxton et al., 1986, 1987; Broxton, 1992) and should be accepted as true statements. Premise P4 was simply asserted to be true by Szymanski (1992), without any attempt to support his assertion. Everden's (1992) Ca mass balance suggests P4 is false. Since P4 is false, argument A1 cannot be used to support the conclusion that there has been hypogene metasomatic introduction of large quantities of alkaline earth elements. Recent work by Broxton (1992) placed the alkaline earth element enrichment noted for the central Yucca Mountain area into a larger regional description of the mobility of alkali earth and alkaline earth elements associated with Timber Mountain caldera hydrothermal system.

7.8 SPATIAL DISTRIBUTION OF HIGHER GRADE ALTERATION MINERALS

7.8.1 Premises

P1: The first occurrence of an alteration mineral with increasing depth may be assigned a temperature of alteration (T?). P2: Temperatures of alteration for different minerals can be combined to determine paleo-temperature gradients for each borehole (F).

7.8.2 Arguments

A1: If P1 and P2, then the spatial distribution of the higher grade alteration minerals appears to be systematic (V and F). A2: If A1 and S7.5A1, then there are at least two spatio-chemically distinct alteration aureoles (V and F). A3: If A2 and S7.5A1, then one aureole is situated in the northwestern sector near the southern margin of the Timber Mountain caldera and in deeper parts is associated with the predominantly sodic-potassic clinoptilolites (boreholes USW G-1, G-2, G-3, USW H-4, and H-5) (IV and T). A4: If A2 and A3, then the other alteration aureole is situated in the southeastern sector of Yucca Mountain, centered near the northeast striking trace of the Stage Coach Road fault, and is associated with calcic clinoptilolites (V and F).

7.8.3 Analysis

The arguments in this section are based upon Szymanski's (1992) use of spatial distribution of the "higher grade alteration minerals" (analcime, albite, and illite), his assignment of distinct temperatures associated with formation of the respective minerals, and his estimated paleo-geotherms derived from those two parameters. Each of the arguments he constructed was based upon the truth of premise P2. In A1 the valid logical form of the argument and the truth of P1 and P2 would be sufficient to accept the conclusion as true. Szymanski (1992) assigned a temperature to the first occurrence of each of the higher grade alteration minerals: analcime (about 100 °C); R1/Allevardite clays (about 140 °C); Kalkberg clays (about 175 °C); albite (about 180 °C); and illite (about 260 °C). These assignments of alteration temperatures to specific minerals were based upon the conditions of formation discussed in Section 7.1. Although the exact temperatures he chose for each mineral were not justified, the relative temperatures of formation for the different minerals may be appropriate (Bish, 1989; Bowers and Burns, 1990). Temperature is not the only factor determining existence of a particular alteration mineral, since composition of the water, kinetics, grain size, and openness of the system may also play critical roles. In some sedimentary environments, the same sequence (through albite) occurs along flow paths in silicic volcanic sediments (Tschernich, 1992). Premise P1 can be accepted conditionally as true based upon the published understanding of the temperatures of formation for different alteration minerals. Szymanski (1992) then attempted to derive a paleo-geotherm for each borehole based upon the depth of the first occurrence of each higher grade alteration mineral and its temperature of formation. Only for boreholes G-1 and G-2 in the northwestern portion of Yucca Mountain is there sufficient data (Bish, 1989) to estimate paleo-geotherms using more than two points. For the southeastern portion of the Yucca Mountain area there are only sufficient data to estimate a paleo-geotherm for borehole UE-25p#1 using two points (Szymanski, 1992). The only other borehole in which paleo-geotherm might be estimated is from G-3, where a maximum paleo-geotherm could be derived from the reported presence of analcime (about 100 °C) at a depth of 1199.8 m (Bish and Chipera, 1989) and the lack of R1 clays (about 140 °C) at a depth of 1513.1 m (Bish, 1989). All other paleo-geotherms presented by Szymanski (1992) are hypothetical and have no scientific support. Thus, the planar distribution of alteration temperatures derived by Szymanski (1992) from the spatial distribution of the higher grade alteration minerals is suspect, and P2 is false. Since P2 is false, then the conclusion of argument A1, spatial distribution of the higher grade alteration minerals appears to be systematic, is not supported by the premises. Nevertheless, depth of the first occurrence of analcime in boreholes J-13 and UE-25p#1 is significantly shallower than observed in other boreholes from the Yucca Mountain area. Since other workers (Broxton et al., 1987) have argued that the presence of analcime is a reflection of the replacement of previously formed clinoptilolites at increased temperatures, the relatively shallow analcimes in boreholes J-13 and UE-25p#1 are at least suggestive that temperatures of about 100 °C occurred at shallower depths in the southeastern area of Yucca Mountain than elsewhere in the Yucca Mountain region. It is important to note there is no mineralogical evidence (if one neglects the disputed 608 ft analcine sample in J-13; Broxton, et al., 1986) that 100 °C temperature fluids invaded the contemporary vadose zone in the southeastern area of Yucca Mountain since the first presence of analcime is about 304.8 m below the static water level in this region (Carlos, 1989; Benson and McKinley, 1985).

Szymanski (1992) constructed his argument (A2) with a valid form which required that each premise be true if the conclusion of the argument is to be accepted as supported by both argument and premises. The conclusion of Section 7.5A1, which forms one of the premises of this argument, is true. Since argument A1 is false, based upon the premises used by Szymanski (1992), the conclusion of A2 is not supported by his argument. The inclusion by Szymanski (1992) of the concept of distinct alteration aureoles is not adequately supported or explained. Certainly, the concept of an alteration aureole is applicable when discussing a hydrothermal system driven by a magmatic source (Henley et al., 1984). However, there is insufficient understanding (due to a lack of data) of the southeastern region of Yucca Mountain to assert the presence of a distinct alteration aureole.

Argument A3 is invalid since there is not a sufficient logical connection between the premises and the conclusion. The conclusion of Section 7.5A1, which forms one of the premises of this argument, is true. The other premise, the conclusion of argument A2, is false. Argument A3 is not supported by the premises used by Szymanski (1992). However, the conclusion of A3 is generally accepted as true (Broxton et al., 1987; Broxton, 1992).

The valid logical form of argument A4 requires that each premise be true if the conclusion is accepted as being adequately supported by the premises. Since the conclusion of argument A2 is false and the conclusion of A3 is true, Szymanski's (1992) conclusion that there is an alteration aureole situated in the southeastern sector of Yucca Mountain centered near the northeast striking trace of the Stage Coach Road fault which is associated with calcic clinoptilolites, is not adequately supported and should be considered false. Lack of documentation necessary to confidently assert the presence of an alteration aureole in the southeastern region of Yucca Mountain and the present dearth in understanding the genesis of calcic clinoptilolites in this area is a result of the absence of information (boreholes). Without a better comprehension of the spatial/chemical/temporal distribution of alteration minerals in this region, it will be difficult to confidently refute any assertion of the existence of an upwelling zone in the area.

7.9 DISCORDANT K-Ar DATES OF CLINOPTILOLITES

7.9.1 Premises

P1: For a given stratigraphic unit there is a wide range of K/Ar ages of clinoptilolites (F). P2: The oldest ages of the local clinoptilolites are significantly younger than the corresponding K/Ar ages of the ignimbrites (F).

7.9.2 Arguments

A1: If P1, and P2, then the K/Ar ages of clinoptilolites are strongly discordant with respect to the ignimbrites (IV and F). A2: If P1 and A1, then the low grade zeolites are polygenetic (formed during repeated or intermittent episodes of alteration) (IV and T).

7.9.3 Analysis

The underlying premise of this section and each subsequent section which utilized arguments based upon K/Ar ages (Szymanski, 1992) is that the K/Ar measurements presented in WoldeGabriel et al. (1992) as K/Ar dates can be interpreted with geologic significance in terms of geologic ages. The only instance in which the K/Ar dates may have geological significance and possibly be considered crystallization ages is for the few occurrences of equivalent K/Ar dates of illites/smectites (Bish, 1989) and clinoptilolites (WoldeGabriel et al., 1992) which will be more fully analyzed in Section 7.10. Szymanski's (1992) use of the term K/Ar age for the clinoptilolite data was improper and not scientifically supported or justified (WoldeGabriel et al., 1992). The K/Ar dates generated by WoldeGabriel et al. (1992) should be considered exploratory for a variety of reasons, including: K/Ar measurements were determined on multimineral assemblages rather than high-purity mineral separates, the systematics and theoretical basis for K/Ar dating of zeolites is poorly established, and the conditions of preservation of the K/Ar signature reflective of crystallization conditions are unknown. Thus, any premise used by Szymanski (1992) containing K/Ar ages of clinoptilolites will be false, and any argument constructed by Szymanski (1992) which relies on premises or results in conclusions containing K/Ar ages of clinoptilolites will be invalid.

For the reasons outlined, argument A1 is invalid and premises P1 and P2 are false. The conclusion of A1 cannot be accepted as true or even supported by the argument. However, there is a wide range of K/Ar dates of clinoptilolites for a given stratigraphic unit (WoldeGabriel et al., 1992), and the oldest dates of the local clinoptilolites are significantly younger than the corresponding K/Ar ages of the ignimbrites (WoldeGabriel et al., 1992). As a result of these two observations, the K/Ar dates of clinoptilolites are strongly discordant with respect to age of formation of the ignimbrites.

Argument A2 is invalid and both premises P1 and A1 are false. The conclusion of A2 (low grade zeolites are polygenetic) cannot be accepted as true or even supported by the argument. However, the possibility low grade zeolites are polygenetic cannot be summarily dismissed. The strongly discordant K/Ar dates of clinoptilolites might be explained as the result of dissolution of older clinoptilolites and crystallization of more clinoptilolite, as well as new phases such as mordenite (WoldeGabriel et al., 1992). If this mechanism controls the measured K/Ar dates, then low grade zeolites may be polygenetic. Specifically, the original formation of the zeolites most likely occurred under saturated conditions (Broxton et al., 1987), while subsequent dissolution of older clinoptilolites and the crystallization of more clinoptilolite seemed to occur in unsaturated conditions (WoldeGabriel et al., 1992). This liberal interpretation of the term alteration used by Szymanski (1992) suggests the conclusion of argument A2 may be true.

7.10 EQUIVALENCY OF K-Ar DATES FOR ILLITE AND CLINOPTILOLITE

7.10.1 Premises

P1: The K/Ar ages of clinoptilolites in the deeper parts of Yucca Mountain are equivalent to the K/Ar ages of the montmorillonitic clays (F). P2: At least some of the Yucca Mountain clinoptilolites are suitable for the purpose of K/Ar geochronometric analysis (T). P3: Clinoptilolites retain their K and Ar contents adequately (F). P4: Fluid ionic exchanges with the clinoptilolites do not appear to be causing loss of radiogenic argon (F). P5: Montmorillonitic clays are indisputable products of hydrothermal metamorphism (T).

7.10.2 Arguments

A1: If P1, P2, P3, and P4, then some of the sodic-potassic clinoptilolites are not deuteric and not supergene-diagenetic (IV and T). A2: If A1 and P5, then in the deeper parts of the northwestern segment of Yucca Mountain both the montmorillonitic clays and sodic-potassic clinoptilolites record the prolonged activity of a hydrothermal system driven by the Timber Mountain caldera (V and T).

7.10.3 Analysis

Argument A1 is invalid since it relies on a premise (P1) containing the concept of a K/Ar age of clinoptilolites. In an invalid argument there is no logical connection between the premises and the conclusion, and the conclusion cannot be accepted or rejected based upon the truth of the premises. Szymanski (1992) misquoted WoldeGabriel et al. (1992) by asserting (P1) the deeper clinoptilolites K/Ar dates were ages. The interpretation provided by the investigators (WoldeGabriel et al., 1992) was that K/Ar dates may be crystallization ages and were similar to published illite/smectite ages from USW G-1 and G-2 (Bish, 1989). Additionally, Szymanski (1992) asserted that the montmorillonitic clays which were dated using the K/Ar method were spatially correspondent (although they are separated by vertical distance of greater than 701 m) to clinoptilolites which yield equivalent K/Ar ages. Yet, K/Ar dates of montmorillonitic clays which occur in the same boreholes as clinoptilolite samples, and at closer vertical distances (less than 213.4 m) to the clinoptilolites, have non equivalent dates (Szymanski, 1992). Thus, it is inappropriate to unequivocally equate the K/Ar dates of the deeper clinoptilolites as K/Ar ages—hence, P1 is false. Premise P2 was used by Szymanski (1992) to further his opinion that at least some of the K/Ar dates can be considered to be ages. Regardless whether K/Ar measurements of clinoptilolites can be used to determine ages or dates, they are useful for geochronometric analyses. K/Ar measurements and the calculated dates provide some information about the diagenetic history of clinoptilolites. If formation of the clinoptilolites was substantially complete prior to the initiation of the Timber Mountain caldera hydrothermal system event, about 10.5 Ma (Levy, 1991; Broxton et al., 1987), all younger K/Ar dates reflect either loss of Ar, growth of new clinoptilolites, or addition of K by ion exchange after this time (WoldeGabriel et al., 1992). Thus, P2 is true. Premise P3 is absolutely false. WoldeGabriel et al. (1992) provided strong evidence (mordenite content and permeability) that the clinoptilolite K/Ar results were affected by fluid chemistry and availability of fluid pathways. Similarly, P4 can be considered to be false based upon arguments presented by WoldeGabriel et al. (1992). The youngest K/Ar dated clinoptilolite (WoldeGabriel et al., 1992) provides some insight into the importance of precipitation of new clinoptilolites, ion exchange of cations, and the loss of argon due to dissolution of the original clinoptilolites. Duplicate measurements of a sample at 475.8 m from borehole USW G-1 indicate a K/Ar date of about 2.1 Ma (WoldeGabriel et al., 1992) and an approximate mole percent exchangeable cations (Broxton et al., 1986) of Ca+Mg (5 percent), K (55 percent), and Na (40 percent). If the zeolites originally formed prior to the Timber Mountain caldera event (10.5 Ma), then their young age may primarily reflect loss of argon or addition of K since their original formation. Ion exchange of extremely potassic rich fluids could drive the age younger (WoldeGabriel et al., 1992). There is no evidence of K-rich fluids in the vadose zone (Szymanski, 1992). All other ion exchanges with fluids in which K was lost from the clinoptilolite would result in older ages than the crystallization age (WoldeGabriel et al., 1992). If precipitation was important for this sample, this could affect the overall K/Ar measurement. Thus, dissolution of clinoptilolites and loss of radiogenic argon may play a crucial role in the discordant K/Ar dates. Clearly, a better understanding of the K/Ar systematics of clinoptilolites is necessary before unequivocal interpretation of the K/Ar results can be concluded. Even though the argument is invalid, and premises P1, P3, and P4 are false, the conclusion is true. The conclusion of argument A1, some of the sodic-potassic clinoptilolites are not deuteric and not supergene-diagenetic, seems to be supported by the results by Broxton et al. (1987) and by the preliminary K/Ar dates of the deeper clinoptilolites of WoldeGabriel et al. (1992), and may be accepted as a true statement.

Argument A2 is a valid logical assertion whose premises are true requiring that the conclusion be accepted as true. The conclusion of argument A1, some of the sodic-potassic clinoptilolites are not deuteric and not supergene-diagenetic, is true (see discussion previous paragraph). Premise P5 was adequately supported by Szymanski (1992) and is documented in Section 7.1. Discussion by Bish (1989) also supports the assertion that higher grade montmorillonitic clays are the result of hydrothermal activities. The K/Ar dates of illites/smectites (Bish, 1989) and clinoptilolites (WoldeGabriel et al., 1992) and the spatial distribution of the chemical character of altered ignimbrites (Broxton, 1992) support the conclusion of argument A2 that the hydrothermal activity of the Timber Mountain system was long-lived and clearly recorded in the northwestern segment of Yucca Mountain.

7.11 K-Ar DATES INCREASE WITH STRATIGRAPHIC DEPTH

7.11.1 Premises

P1: The youngest clinoptilolite ages (2.0 to 8.5 Ma) occur higher in the stratigraphic section (F). P2: Deeper clinoptilolites have older ages (9.5 to 10.6 Ma) (F). P3: The oldest K/Ar ages of the deep and clearly epigenetic clinoptilolites indicate that fairly high temperatures associated with the Timber Mountain caldera system persisted for a fairly long time at depths of > 1.0 km (T). P4: Prolonged and pervasive alteration of the deep ignimbrites completely depleted the vitric reservoir and arrested further low grade zeolitization (T). P5: The Timber Mountain caldera system episode was much more subtly expressed higher in the stratigraphic column (F). P6: Higher in the stratigraphic column, the rate of vitric reservoir depletion was substantially lower and much vitric matter survived (T). P7: Subsequent alteration events consumed some of the remaining glass to produce younger clinoptilolites (T?). P8: The newly produced clinoptilolites seem to have grown over the older clinoptilolites (T?).

7.11.2 Arguments

A1: If P1 and P2, then the availability of ignimbritic matter in the vitric state seems to have been a factor which controlled timing and duration of the low grade zeolitization (IV and T). A2: If P3, P4, P5, P6, and P7, then the availability of ignimbritic matter in the vitric state seems to have been diminishing differentially in time and space (IV and T). A3: If P8 and A2, then the depth variant K/Ar ages is the result of radiometric age overprinting (IV and F).

7.11.3 Analysis

Since A1 relies on premises which are not logically connected to the argument, the argument A1 is invalid. As discussed in Section 7.9, the use of K/Ar ages is inappropriate and premises P1 and P2 are false. Determination of the truth of the conclusion of argument A1 must rely on other information. The relationships between K/Ar dates of clinoptilolites and their stratigraphic location was addressed by WoldeGabriel et al. (1992). In essence, they argued (WoldeGabriel et al., 1992) progressive sealing of permeable zones by mordenite crystallization with depth within the unsaturated zone results in progressively less dissolution of the clinoptilolites and precipitation of mordenite with depth. This relationship/explanation is inadequately supported at present. Szymanski (1992) asserted without adequate scientific evidence that the availability of ignimbritic matter in the vitric state seemed to have been a factor which controlled timing and duration of low grade zeolitization. By making this assertion, Szymanski (1992) implied that zeolite formation continued up to 2.0 Ma, yet this is not supported by any geochemical or chronological arguments (WoldeGabriel et al., 1992; Section 7.10). In general, however, zeolites form from glass—therefore, the presence of glass affects formation of zeolites. Absence of glass arrests zeolite formation. Thus, the generalized conclusion of A1 is true, however, quantification of the process through the use of K/Ar ages is inappropriate.

Argument A2 is invalid since no logical connection exists between premises and conclusion. The truth of the conclusion of the argument cannot be determined by the truth of the premises. Premise P3 is actually an argument whose conclusion is that fairly high temperatures associated with the Timber Mountain caldera system persisted for a fairly long time at depths of > 1.0 km. The first clause of the sentence is a premise which is false (dependent on K/Ar age) and is not logically connected to the conclusion of the statement. The conclusion of premise P3 is a recapitulation of S7.10A2 and is true. Premise P4 was asserted by Szymanski (1992) without any documentation. If all glass was consumed during zeolitization, then further low grade zeolitization would be arrested, and P4 can be accepted as true. Evidence of origin of zeolitization has been previously presented (Levy, 1991; Broxton et al., 1987), and the significance of the tectonic history of Miocene faulting on the spatial cross-cutting relationship of zeolites with respect to ignimbrites is neglected by Szymanski (1992). Premise P5 was asserted by Szymanski (1992) with inadequate support. Broxton et al. (1987) argued that the present zonation (depth in each borehole) of the higher grade alteration minerals (analcime) reflected thermal overprinting of the Timber Mountain caldera activity onto the previously formed zeolites. Premise P5 is false. P6 is true based upon published evidence of the distribution of vitric material (Levy, 1991; Broxton et al., 1987; Bish, 1989). Szymanski (1992) asserted the truth of P7, but provided no substantiated proof which would allow evaluation of alternate models of interpretation of the spatial distribution of K/Ar dates with depth (WoldeGabriel et al., 1992). Premise P7 cannot be accepted unconditionally as true based upon the information presented by Szymanski (1992). However, his explanation may still be true. Since Szymanski (1992) constructed an invalid argument, with some of the premises being false, it is not possible to accept his conclusion that the availability of ignimbritic matter in the vitric state seems to have been diminishing differentially in time and space. His conclusion to argument A2 amounted to an unsubstantiated and unsupported assertion. Although the conclusion of A2 cannot be accepted as true on the basis of the premises and the argument constructed by Szymanski (1992), the conclusion should still be accepted as true based upon the thermodynamic principles associated with the glass to zeolite conversion. Finally, Szymanski's (1992) logic required that zeolitization in the upper stratigraphic section throughout the Yucca Mountain area, including K-rich zeolites near the surface of borehole USW G-1, is the result of Ca+Mg fluids overprinting the earlier formed zeolites. As discussed in Section 7.10, this scenario is unlikely since it would not generate zeolites with appropriate chemical and K/Ar signatures required by the shallow borehole USW G-1 zeolites. In addition, hydrothermal fluids required by his hypothesis would have presumably generated higher grade alteration minerals (illites/smectites) with K/Ar dates substantially younger than the Timber Mountain caldera hydrothermal system activity; yet, no young K/Ar dates for Kalkberg clays or illites have been reported (Bish, 1989).

Szymanski's (1992) final argument (A3) was also invalid as he did not develop a logical connection between premises and his conclusion. Both P8 and the conclusion of argument A2 are not supported by Szymanski (1992), and P8 is refuted by WoldeGabriel et al. (1992). There is no logical or scientific reason to accept his assertion that the depth variant K/Ar ages are the result of radiometric age overprinting. Discussion in Section 7.10 adequately documents alternative explanations for the depth variant K/Ar dates (WoldeGabriel et al., 1992).

7.12 MIXED AGES OF ZEOLITES

7.12.1 Premises

P1: Clinoptilolites deep in the stratigraphic section record the waning stages of the Timber Mountain caldera hydrothermal system (T). P2: The relative proportion of younger clinoptilolites is small deep in the stratigraphic section (F). P3: Higher in the stratigraphic section low grade zeolitic alteration appears to be an intermittently active process (F). P4: Relative proportions of the younger clinoptilolites vary as a function of distance below the contemporary base of the vitric zone (F). P5: It is not possible to reliably specify an upper age limit of the latest episode of the low grade zeolitization (T).

7.12.2 Arguments

A1: If P1, P2, P3, and P4, then there is a depthward diminishing overprinting by the young clinoptilolites (IV and F). A2: If P1, P2, P3, and P4, then there is a depthward increasing rate of paleo-depletion of the vitric reservoir (IV and F). A3: If P3, P5, and S7.11P8, then the latest episode of the low grade zeolitization must be younger than about 2 Ma (IV and F).

7.12.3 Analysis

Argument A1 is invalid since there is no logical connection between the premise (K/Ar ages) and the conclusion. The conclusion of A1 is not supported by premises P1, P2, P3, or P4 and there is no proof for the conclusion based upon the published understanding of K/Ar systematics of clinoptilolites (WoldeGabriel et al., 1992). P1 is sustained by mineralogical studies and is true (Broxton et al., 1986, 1987; Broxton, 1992). P2 is false since the K/Ar measurements may not be reflective of a closed system with respect to Ar loss (WoldeGabriel et al., 1992). Thus, K/Ar dates cannot be equated to an age of formation of the zeolites. P3 is false for the same reason. Similarly, P4 is false. WoldeGabriel et al. (1992) provided an explanation for depthward diminishing influence of open system behavior (Ar loss during dissolution, Section 7.9) that appears to be supported by the limited data available. There is no scientific or logical reason to accept the conclusion of argument A1 as a true statement.

For the same reasons that argument A1 was considered to be invalid, argument A2 can be considered an invalid argument. Szymanski (1992) stated the truths of premises P1, P2, P3, and P4 supported his assertion of a depthward increasing rate of paleo-depletion of the vitric reservoir. Since all the same premises in argument A1 are used in A2, the result of the analysis of A1 holds for A2—P1 is true (Broxton et al., 1992); P2 is false (WoldeGabriel et al., 1992); P3 is false (WoldeGabriel et al., 1992); and P4 is false (WoldeGabriel et al., 1992). There is no scientific or logical reason to accept the conclusion of argument A1 as a true statement.

There is no rational connection between the premises of argument A3 and its conclusion—thus, it is invalid. Premise P3 is false based upon the analysis of argument A1. From the incomplete understanding of the K/Ar systematics in zeolites, it is not possible to assess an age limit. At least some of the younger zeolite ages most likely reflect open system behavior (WoldeGabriel et al., 1992). Thus, P5 is true. From the data presented in Section 7.11.3, it was determined that P8 is false. K/Ar dates and the description of the K/Ar analyses of WoldeGabriel et al. (1992) provide no scientifically defensible evidence to be allowed to claim that the K/Ar dates of the clinoptilolites can be equated to an age of formation of the zeolites; yet, this is exactly what Szymanski (1992) assumed. All samples used in

WoldeGabriel et al. (1992) were from strongly zeolitized horizons. There is no documentation that strong zeolitization of ignimbrites occurred any time after the Timber Mountain caldera hydrothermal system waned. Coexisting geochemical analyses (K-rich zeolites) and K/Ar measurements (dates of K-rich zeolites in borehole USW G-1 of 2.0 Ma) directly conflict with Szymanski's (1992) envisioned episodic low grade Ca+Mg zeolitization. Szymanski's (1992) declaration that the latest episode of the low grade zeolitization must be younger than about 2 Ma is false. The only information derived from the results of WoldeGabriel et al. (1992) was that the loss of Ar or K addition is the most likely mechanism for the discordant K/Ar dates, and the degree of discordance is highest for the shallowest clinoptilolites.

7.13 FOUR CHEMICAL/TEMPORAL DISTINCT ZEOLITE SETS

7.13.1 Premises

P1: Epigenetic clinoptilolites formed during the Timber Mountain hydrothermal episode are sodic-potassic in composition, yield K/Ar ages ranging from 9.5 to 10.6 Ma, and are encountered in deeper segments of boreholes USW G-1, G2, and G-3 (T). P2: Clinoptilolites in deeper segments of boreholes UE-25p#1 and USW G-4 in the southeastern sector of Yucca Mountain are calcic-magnesic in composition and yield K/Ar ages from 7.3 to 8.4 Ma (F). P3: Predominantly sodic-potassic clinoptilolites with K/Ar ages ranging from 3.8 to 7.0 Ma occur higher in the stratigraphic section in boreholes USW G-1 and USW G-4 (F). P4: Clinoptilolites with ages from 2.0 to 4.7 Ma occur high in the stratigraphic section in boreholes USW G-1, G-2, and G-3 and are mainly calcic-magnesic clinoptilolites (F).

7.13.2 Arguments

A1: If P1, P2, P3, and P4, then the Yucca Mountain clinoptilolites consist of at least four chemico-temporally distinct sets (IV and F).

7.13.3 Analysis

There is no logical connection between premises P2, P3, and P4, and the conclusion of argument A1, since each of these premises requires that K/Ar dates are equal to K/Ar ages of formation of clinoptilolites. In addition, simply different chemical/temporal conditions could explain the spatial distribution of the characteristics of the zeolites. Thus, A1 is invalid and the conclusion is not supported by the premises. Premise P1 is a restatement of two earlier premises (S7.11P3 and S7.12P1) and these premises were demonstrated to be true (Broxton et al., 1987; Bish, 1989; WoldeGabriel et al., 1992). Premises P2, P3, and P4 are false since Szymanski (1992) equated K/Ar dates with the age of the formation of the zeolites. Without any temporal constraints, this argument then becomes a recapitulation of Section 7.5A1. Additionally, P4 is false since the shallowest K/Ar dated zeolite in USW G-1 is K-rich. There is no scientific evidence to support Szymanski's (1992) assertion that there were at least four chemico-temporally distinct sets of zeolites in the Yucca Mountain region. Yet, there is some evidence which refutes his assertion (WoldeGabriel et al., 1992).

7.14 YOUNGER ZEOLITES WITH INCREASING CONTENT OF ALKALINE EARTH ELEMENTS

7.14.1 Premises

P1: The most alkalic clinoptilolites (containing 10 to 15 percent Ca+Mg cations) yield an average K/Ar age of about 7.8 Ma (F). P2: Chemically intermediate clinoptilolites (containing 20 to 25 percent Ca+Mg cations) yield an average K/Ar age of about 5.8 Ma (F). P3: The most calcic clinoptilolites (containing 30 to 45 percent Ca+Mg cations) yield an average K/Ar age of about 4.7 Ma (F). P4: One end-member clinoptilolite type consists predominantly of Na+K clinoptilolites (F). P5: Deeper in the stratigraphic section, Na+K clinoptilolite formation was initiated and terminated during the Timber Mountain caldera hydrothermal episode (F). P6: The production of alkalic clinoptilolites higher in the stratigraphic section continued to approximately 4.0 Ma (F). P7: Formation of alkalic clinoptilolites required fluids to have elevated dissolved alkali metals (T). P8: Elevated alkaline earth concentrations for both whole-rock altered ignimbrites and separated clinoptilolites exist (T). P9: The other end-member of the clinoptilolite type consists of the predominantly calcic clinoptilolites (F). P10: Production of the calcic zeolites required almost exclusive involvement of Ca-Mg fluid phases (T). P11: The occurrence of calcic clinoptilolites is spatially accompanied by other species from the calcic zeolitic series (T). P12: Calcic zeolitization was initiated at or after 8.5 Ma (F). P13: Calcic zeolitization has continued throughout the Pliocene, and most probably into the Quaternary (F). P14: The older predominantly alkalic clinoptilolites display clear spatio-temporal association with the Timber Mountain caldera hydrothermal system (T?). P15: Overprinting of earlier alteration by formation of younger calcic zeolites was produced by allogenic Ca-Mg fluid phases (F). P16: Some K/Ar ages of calcic clinoptilolites are less than 4.8 Ma (F).

7.14.2 Arguments

A1: If P1, P2, and P3, then clinoptilolites become younger with increasing concentration of alkaline earth elements (IV and F). A2: If P1, P2, and P3, then at Yucca Mountain clinoptilolites are polygenetic mixtures of two compositionally distinct end-members (IV and F). A3: If P4, P5, and P6, then development of the alkalic end-member was a multiple stage process (IV and F). A4: If P7 and P8, then formation of predominantly alkalic zeolites was produced by intermixing sodium-potassium fluid phases (from the alkalic ignimbrites) with calcium-magnesium fluid phases (from the underlying Paleozoic carbonates) (IV and F). A5: If P9, P10, P11, P12, and P13, then the development of calcic zeolites was a multiple stage process (IV and F). A6: If P10, then the chemical character of the calcic zeolites must have been acquired from outside the ignimbrites (V and T). A7: If A1 and A6, then most of the low grade zeolitization is the result of epigenetic (hypogene) hydrothermal metamorphism (IV and F). A8: If P14, P15, and A7, then the observed metasomatic overprinting is readily attributable to intermittent ascent of deep-seated and Ca-Mg fluid phases either from the Paleozoic carbonates or from the underlying Precambrian basement (IV and F). A9: If P16 and S6.8A2, then there has been ascent of Ca-Mg fluids during the last 4.8 Ma (IV and F).

7.14.3 Analysis

Arguments developed by Szymanski (1992) and presented in this section incorporated conclusions derived from Section 7.13 (distinct chemical-temporal sets of zeolites) and were combined with his interpretation (Szymanski, 1992) that the ages of the clinoptilolites decrease with increasing concentration of alkaline earth elements. From these arguments he inferred (Szymanski, 1992) that fluids responsible for formation of the various chemico-temporally distinct sets of zeolites have become more Ca-Mg rich with decreasing age. It should be remembered there is no scientifically defensible reason to equate K/Ar dates as ages of clinoptilolite formation (WoldeGabriel et al., 1992).

Argument A1 is invalid since it relies on concepts (K/Ar age of clinoptilolites) which cannot be logically related to the conclusion. Since the K/Ar dates cannot be equated to a K/Ar age of formation, each premise (P1, P2, and P3) is false. In addition, the most alkalic zeolites (sample USW G-1 1561; Ca+Mg=5 mole percent exchangeable, Broxton et al., 1986, page 79) dated by WoldeGabriel et al. (1992) yielded replicate K/Ar dates of 2.2 and 2.0 Ma (sample USW G-1 1561)—thus, premise P1 is inaccurate. It should be noted that all arguments developed by Szymanski (1992) which relied on chemical and K/Ar analyses of clinoptilolites (Szymanski, 1992; Figure 7-28) are suspect, since almost half of the chemical analyses of the clinoptilolites from Broxton et al. (1986) were misquoted by Szymanski [e.g., for sample USW G-1 1561, Szymanski (1992) used Ca+Mg=30 mole percent, while in Broxton et al. (1986), Ca+Mg=5 mole percent is cited]. There is no evidence to suggest clinoptilolites become younger with increasing concentration of alkaline earth elements, so the conclusion of A1 is false.

For the same reasons noted in the analysis of A1, argument A2 should be considered as an invalid assertion, and the conclusion not accepted as true. There is no scientific data to support Szymanski's statement that at Yucca Mountain clinoptilolites are polygenetic mixtures of two compositionally distinct end-members. Evidence presented in WoldeGabriel et al. (1992) is in opposition to Szymanski's (1992) conclusion. Thus, the conclusion to argument A2 is false.

Szymanski's (1992) reliance on his interpretation of the K/Ar dates as K/Ar ages requires that argument A3 be considered an invalid argument. The conclusion of A3 is not logically supported by the premises used by Szymanski (1992). Information provided in WoldeGabriel et al. (1992) was sufficient to reject P6. Data contained in Broxton et al. (1987) and Levy (1991) suggest zeolitization ended before miocene uplift and rotation was completed. These authors (Levy, 1991; Broxton et al., 1987) argued that most of the zeolite formation in the Yucca Mountain area occurred between 11.3 and 13.9 Ma. This is sufficient to reject P5. However, information presented by Broxton (1992) indicated some substantial amount of zeolitization must have happened during the Timber Mountain caldera hydrothermal episode. Clearly, the timing and conditions of formation of zeolites in Yucca Mountain is inadequately known. The use of end-member populations of zeolites (e.g., Na+K clinoptilolites) by Szymanski (1992) was a bit contrived, since the work of Broxton et al. (1987) and Broxton (1992) indicated chemical composition of alteration minerals in Yucca Mountain was a strong function of their distribution in space with respect to the Timber Mountain caldera. P4 should be considered false. From the discussion presented, it is clear there is no support for Szymanski's (1992) statement that development of the alkalic end-member was a multiple stage process—the conclusion of argument A3 is, therefore, false.

Premises in argument A4 were inadequately logically linked (Szymanski, 1992) to the conclusion resulting in an invalid argument (Barker, 1989). Formation of alkalic clinoptilolites requires alkali-rich fluids (Bower and Burns, 1990). Premise 7 is thus supported and can be accepted as true. Broxton et al. (1987) provided sufficient scientific data to accept P8 as true. Even though both premises are true, they do not infer the conclusion. Szymanski (1992) provided no evidence to support his conclusion of this argument. Adequate documentation of the formation conditions of the alkalic zeolites has been presented (Broxton et al., 1987; Broxton, 1992) to reject the conclusion of argument A4. There may be no need to require intermixing of Ca-bearing fluids and alkali-rich fluids during zeolitization since the alkaline earth enrichment throughout the ignimbritic pile of Yucca Mountain might just be a reflection of the downward transport of surface derived (carbonate dust) carbonate/alkaline earth elements.

The invalid nature of argument A5 is the result of Szymanski's (1992) reliance upon the assumption of K/Ar formation ages of the zeolites. Since there is no logical link between premise and conclusion, determination of veracity of the conclusion must rely on other evidence. There is none to support Szymanski's (1992) declaration, and the conclusion of A5 should be considered false. Use of end-member populations of zeolites (e.g., Ca+Mg clinoptilolites) by Szymanski (1992) was contrived, thus, P9 is false. Premise 10 is true based upon published models of zeolite formation (Tschernich, 1992). Premise P11 is a recapitulation of S7.5P6 and is true (Carlos et al., 1991). Both P12 and P13 are false since there is no scientific support to accept that K/Ar dates reflect crystallization age of zeolites, except possibly for the deepest zeolites (WoldeGabriel et al., 1992).

Szymanski's (1992) argument A6 is valid. Argument A6 is only dependent upon the truth of P10, and P10 is true. The truth of P10 has no implications for the source of Ca+Mg bearing fluids if zeolite formation is allowed to occur at low temperatures. Zeolites, specifically clinoptilolites, can form at near surface temperatures (Tschernich, 1990). Since P10 is true, the conclusion of A6 can be accepted.

Argument A7 is based upon Szymanski's (1992) affirmation that Yucca Mountain low grade zeolitization was the result of epigenetic hydrothermal processes, and this has already been suggested to be false. This is a case of a *petitio principii* (begging the question) argument (Barker, 1989), and A7 is an invalid argument. In addition, there is substantive evidence that K/Ar dates do not increase as a function of increasing alkaline earth concentration (see analysis of argument A1 in this section). The conclusion of A6 is true. There is no reason to accept Szymanski's (1992) assertion that most of the low grade zeolitization is the result of epigenetic (hypogene) hydrothermal metamorphism. Broxton et al. (1987) provided evidence relevant to this declaration, which allows rejection of A7.

Equating K/Ar dates (WoldeGabriel et al., 1992) to crystallization ages (Szymanski, 1992) causes argument A8 to be invalid. Premise P14 is probably true (Broxton et al., 1987) and is simply a restatement of S7.13P1. Discussion presented in WoldeGabriel et al. (1992) was sufficient to reject P15. There is no evidence to suggest there was an overprinting of zeolites, thus, P15 is false. Argument A7 was demonstrated to be false. Again, Szymanski (1992) used the term metasomatic to infer hypogene conditions. The definition of metasomatic does not imply hypogene conditions (Bates and Jackson, 1980), and the lack of scientific evidence for hypogene conditions implies Szymanski's usage of metasomatic was incorrect. Clearly there has been an addition of alkaline earth elements to the surface and subsurface of Yucca Mountain. This addition can be characterized as metasomatism (Murphy, 1993). Thus, there has been metasomatic overprinting of zeolites. The rest of the conclusion of A8 (intermittent ascent of deep-seated and Ca-Mg fluid phases either from the Paleozoic carbonates or from the underlying Precambrian basement) is simply a statement by Szymanski (1992) and can be rejected due to the general and specific lack of proof supplied by Szymanski (1992).

The invalid argument A9 is the result of Szymanski's (1992) insistence on equating K/Ar dates to K/Ar crystallization ages of the clinoptilolites. Both premises in this argument are false. P16 is false since there is no reason to accept the K/Ar dates as K/Ar ages of formation (WoldeGabriel et al., 1992). Premise S6.8A2, hypogene Ca-Mg fluids have brought zircons from the deep subsurface and incorporated them into the AMC breccias, was demonstrated in Section 6.8.3 to be false. Szymanski's (1992) assertion that there has been ascent of Ca-Mg fluids during the last 4.8 Ma cannot be logically supported by his arguments, and cannot be scientifically documented by any published analyses.

7.15 DIFFERENT HYDROTHERMAL PROCESSES

7.15.1 Premises

P1: The northwestern segment of the Yucca Mountain alteration aureole (USW G-1, G-2, G-3, H-4, and H5) contains three suites of alteration minerals (higher grade montmorillonitic clays, predominantly sodic-potassic clinoptilolites, and higher grade minerals from the alkali zeolitic series) (T). P2: The alteration minerals in the northwestern aureole have K/Ar ages from 9.5 to 11.0 Ma (T). P3: Alteration temperatures diminish with increasing distance from the southern margin of the Timber Mountain caldera (T). P4: The southeastern segment of Yucca Mountain alteration aureole (USW G-4, J-13, UE-25p#1, UE-25a#1, and 25b#1) contains three suites of alteration minerals (possibly allevardite clays, predominantly calcic clinoptilolites, and higher grade zeolites from the calcic series) (F). P5: The K/Ar ages for these minerals range from 2.0 to 8.5 Ma (F). P6: Alteration in the southeastern aureole is not pervasive and is fairly low grade (T?). P7: Alteration temperatures diminish with increasing northwestern distance away from the trace of the Stage Coach Road fault (F). P8: There is a planar distribution of inferred alteration temperatures in the southeastern alteration aureole (F).

7.15.2 Arguments

A1: If P1, P2, and P3, then the northwestern alteration aureole expresses and records prolonged activity of the hydrothermal system driven by a Timber Mountain caldera heat source (V and T). A2: If P4, P5, and P6, then the causative hydrothermal alteration processes of the southeastern aureole did not operate continuously (IV and F). A3: If P4, P7, and P8, then the southeastern alteration aureole is fault based and rooted in the Stage Coach Road fault zone (V and F). A4: If A1, A2, and A3, then the spatio-chemically distinct alteration aureoles formed at different times, most probably in response to broadly different hydrothermal processes (IV and F).

7.15.3 Analysis

Statements presented by Szymanski (1992) in this section relied heavily on previously constructed rationales. For instance, A1 is a restatement of arguments S7.8A3 and S7.10A2. Both of these assertions were demonstrated to be true (Broxton et al., 1987; Bish, 1989; Broxton, 1992), and the conclusion of A1 should be likewise accepted as true. Each of the premises (P1, P2, and P3) used to construct this argument are true (see discussions in Sections 7.8.3 and 7.10.3 and Broxton et al., 1987) and logically support its conclusion. A1 is a valid argument.

Szymanski's (1992) insisted on equating WoldeGabriel et al. (1992) K/Ar dates to the time of formation of zeolites and this resulted in a logical flaw and an invalid argument. The conclusion of argument A2 is not supported by the premises (P4, P5, and P6). Premise P4 is a restatement of Section 7.8 argument A4. Discussion in Section 7.8.3 indicated there is insufficient evidence to accept this premise as a true statement. Data from WoldeGabriel et al. (1992) require that premise P5 be rejected. Information presented in Section 7.8.3 suggests use of the term alteration aureole for the southeastern region is not reasonable. Findings by Szymanski (1992), derived from reports by Bish (1989), Broxton et al. (1986), and Bish and Chipera (1989), support the idea of fairly low grade alteration in the southeastern region of Yucca Mountain. Premise P6 can be tentatively accepted as true. Arguments analyzed in Section 7.14 indicate the conclusion of argument A2, causative hydrothermal alteration processes of the southeastern aureole did not operate continuously, should not be accepted as a true statement.

Argument A3 is valid, but its conclusion is false since all the premises used to construct the argument are not true. All premises used by Szymanski (1992) to construct this argument appear to be false. As was discussed in Section 7.8.3, there is too little evidence to assert that alteration temperatures diminish with increasing northwestern distance away from the trace of the Stage Coach Road fault. Thus, premises P7 and P4 are false. Premise P8 is a restatement of Section 7.8 argument A1, and is false. Justification for this assessment of P8 can be found in Section 7.8.3. There is insufficient evidence to conclude that there is an alteration aureole situated in the southeastern sector of Yucca Mountain centered near the northeast striking trace of the Stage Coach Road fault, and A3 should be considered false. Lack of support necessary to confidently assert the presence of an alteration aureole in the southeastern region of Yucca Mountain and the present dearth in understanding the genesis of calcic clinoptilolites in this area is a result of the absence of information (boreholes). A better comprehension of the spatial/chemical/temporal distribution of alteration minerals in this region will be necessary to confidently refute any assertion of the existence of an upwelling zone in the area.

The premises used to construct argument A4 (Szymanski, 1992) were the conclusions of the three previous arguments. Since arguments A1 and A2 are both fallacious assertions and based on false ideas (K/Ar dates=K/Ar ages), argument A4 is not logically supported by the premises and is therefore invalid. Since A4 is erroneous, truth of the conclusion of spatio-chemically distinct alteration aureoles formed at different times, most probably in response to broadly different hydrothermal processes, must be derived from alternative arguments or evidence. Szymanski (1992) did not offer any unambiguous or easily supported information which may be used to support his statement. Thus, there is, at present, insufficient evidence to conclude the presence of a conductively replenished hydrothermal system rooted in the Stage Coach Road fault zone.

7.16 SPACE-DIFFERENTIAL ALTERATION OVERPRINTING

7.16.1 Premises

P1: In a magmatic hydrothermal system, prolonged circulation of fluids is controlled by a fairly uniformly-distributed intrinsic hydraulic conductivity (T). P2: For a magmatic center-based alteration aureole, the isogradal surfaces are fairly uniform (T). P3: For a magmatic center-based alteration aureole, the isogradal surfaces reflect both the proximity to the topographic surface and proximity to the causative magmatic heat source (T). P4: For a magmatic center-based hydrothermal system, the upward fluid flux is spatially extensive and fairly uniformly distributed about the causative magmatic heat source (T). P5: A fault-based hydrothermal system is controlled by the *in-situ* stress field developed around a yielding, and soon to be unstable, fault (F). P6: The *in-situ* stress field and extrinsic hydraulic conductivity structure is space-variant prior to fault rupture and ascent of deep-seated fluids (F). P7: Near the soon-to-be ruptured fault system, the *in-situ* stress enhancement (extrinsic) of hydraulic conductivity is relatively deep and large (F). P8: The depth extent and amount of conductivity enhancement diminish gradually away from the fault (F). P9: The expected fluid flux increase from a fault-based hydrothermal system is restricted to a ruptured fault and a few adjacent fractures (F). P10: The fluid flux increase is narrowly focused around the parent fault and forms an upwelling center elongated along the fault strike (F). P11: The development of alkaline earth metasomatism is spatially-selective (F).

7.16.2 Arguments

A1: If P1, P2, P3, and P4, then the northwestern alteration aureole has characteristics associated with a magmatic-based hydrothermal system (V and T). A2: If P5, P6, P7, and P8, then the lateral diffusion of ascending fluids away from the parent fault in a fault-based hydrothermal system is controlled by the spatial distribution of the extrinsic hydraulic conductivity (IV? and F?). A3: If P9, P10, and P11, then for a fault-based hydrothermal system there is not a spatially extensive and uniform increase in the upward fluid flux (IV? and F?). A4: If S7.15A3 and A3, then Ca-Mg fluid phases responsible for the observed metasomatic zeolitization were ejected in the southeastern segment of Yucca Mountain (IV and F). A5: If A3, P9, and P10, then the fluid diffusion paths were controlled by the deformation-induced gradients of extrinsic hydraulic conductivity (IV? and F?).

7.16.3 Analysis

Arguments presented in this section by Szymanski (1992) were predominantly based upon his hypothetical model of a fault-based hydrothermal system. They were primarily unsupported by physical evidence and insufficiently explained by Szymanski (1992) to be rigorously assessed. The theoretical basis for his model of a fault-based hydrothermal system was developed previously (Szymanski, 1989). Analysis of his model has been presented by Powers et al. (1991), Archambeau and Price (1991) and Wescott (1990). It should remembered that logic behind Szymanski's approach (1992) was that if there is geological evidence of alteration and mineralization which could have only been derived from past intermittent upwelling of hypogene fluids, then, regardless of the exact mechanism or its perceived possible magnitude, upwelling fluids pose a significant risk to the proposed repository site at Yucca Mountain. Alternatively, if it can be unambiguously concluded, based upon geological evidence, that intermittent emplacement of deep-seated fluids has not occurred, then the scenario envisioned by Szymanski (1989, 1992) or any other possible upwelling scenario would be untenable. This concept will be used to analyze arguments A2, A3, A4, and A5 in this section.

Argument A1 addresses the evidence for a magmatic-based hydrothermal system in the Timber Mountain caldera, and is a valid assertion. Although premises P1, P2, P3, and P4 are rather broadly qualified descriptions of a magmatic-based hydrothermal system, there is sufficient support (Henley et al., 1984) to accept each premise as a true statement. Since each premise is true and the logical form of the argument is valid, the conclusion can be accepted as true. Abundant documentation supports the assertion that the northwestern alteration aureole has characteristics associated with a magmatic-based hydrothermal system (Broxton et al., 1987; Bish, 1989; Broxton, 1992).

Argument A2 cannot be rigorously evaluated in terms of its logical form and the truth of its conclusion. There has been much controversy concerning the assessment of the validity of the model outlined in premises P5, P6, P7, and P8 (Powers et al., 1991; Archambeau and Price, 1991). If these ideas are valid concepts, then the argument could be valid; however, it is just as likely that these cannot be logically related to the conclusion (Powers et al., 1991). An assessment of the truth of each of these premises was the partial goal of previous studies (Powers et al., 1991; Archambeau and Price, 1991). Lack of consensus with regard to their acceptance as true statements suggests that each of the premises may not be true. The conclusion of argument (A2), lateral diffusion of ascending fluids away from the parent fault in a fault-based hydrothermal system is controlled by the spatial distribution of the extrinsic hydraulic conductivity, may or may not be true. There is insufficient theoretical and scientific support to accept this as a true statement.

Logical analysis of argument A3 is similar to that of A2. The argument as presented by Szymanski (1992) may be valid, or it may be invalid. Similarly, each of the supporting premises of this argument should be considered false due to inadequate scientific and theoretical support. The conclusion of argument A3, that for a fault-based hydrothermal system there is not a spatially extensive and uniform increase in the upward fluid flux, should not be accepted as proven by the arguments presented by Szymanski (1992).

Argument A4 is invalid since there is not a logical connection between premises and conclusion. The conclusion of A3 was suggested to be false. Based upon a lack of scientific evidence, premise S7.15A3 is false. Szymanski's (1992) conclusion, Ca-Mg fluid phases responsible for the observed metasomatic zeolitization were ejected in the southeastern segment of Yucca Mountain, is not supported, but reflects his assertion. Therefore, it cannot be accepted as a true statement.

Argument A5 is similar to arguments A2 and A3 in that it is difficult to determine the validity of the argument presented by Szymanski (1992). The truth of premises P9 and P10 cannot be rigorously proven (Powers et al., 1991; Archambeau and Price, 1991). The assertion that the fluid diffusion paths were controlled by the deformation-induced gradients of extrinsic hydraulic conductivity cannot be proven true based on truth of the premises or by the logical form of the argument. Szymanski (1992) provided a model which remains intestable. This has no relevance to the present analysis of the logic of arguments based on field evidence. As stated previously, if there is no field evidence for hypogene hydrothermal upwelling of fluids, then there is no reason to believe any possible model ever operated which could generate appropriate fluids.

7.17 ZEOLITE FORMATION CORRELATIVE TO LOCAL MAGMATISM

7.17.1 Premises

P1: Both the montmorillonitic clays and the older alkalic clinoptilolites are temporally correlative with the late Timber Mountain magmatic stage (T). P2: The younger calcic clinoptilolites are temporally correlative with subsequent local magmatic episodes (F).

7.17.2 Arguments

A1: If P1 and P2, then the K/Ar ages of the epigenetic clinoptilolites adequately reflect timing of the main episodes of hypogene alterations (IV and F). A2: If P1 and P2, then the low grade metasomatic zeolitization expresses and records episodically-continuous or intermittent hydrothermal metamorphism (IV and F).

7.17.3 Analysis

Argument A1 is invalid since it relies on a concept which cannot be logically supported (K/Ar dates=K/Ar ages). Results of WoldeGabriel et al. (1992), as used by Szymanski (1992), were inappropriate. The K/Ar dates generated from varying impurity mineral assemblages determined by WoldeGabriel et al. (1992) strongly indicated Ar loss during zeolite dissolution and did not allow the analyses to be used as formation ages of the sample. Any argument which relies on a premise that asserts a K/Ar age of formation for a zeolite cannot be logically or scientifically supported. Thus, the K/Ar ages of the epigenetic clinoptilolites do not at all reflect timing of the main episodes of hypogene alterations.

Premise P1 is true (Bish, 1989; WoldeGabriel et al., 1992; Broxton et al., 1987). P2 is false since the zeolite analyses do not reflect their age of formation. Szymanski (1992) asserted that the age of formation of the zeolites was temporally correlative to local magmatic history. Szymanski's (1992) interpretation of the term local meant any magmatic activity within 100 miles of Yucca Mountain. The logical inconsistent nature of this definition was presented in Section 2.2.3. In conclusion, there is no reason to believe Szymanski's (1992) assertion that the K/Ar ages of the epigenetic clinoptilolites adequately reflect the timing of the main episodes of hypogene alterations.

Since argument A2 relies on the same premises as A1, the same analysis of logic may be used. Argument A2 is invalid, premise P1 is true, P2 is false, and there is no logical reason or scientific evidence which can be used to support Szymanski's (1992) assertion that the low grade metasomatic zeolitization expresses and records episodically-continuous, or intermittent hydrothermal metamorphism. At this point it can be concluded that any further arguments developed by Szymanski (1992) which rely on premises that include inferences on K/Ar ages of clinoptilolites may be summarily dismissed.

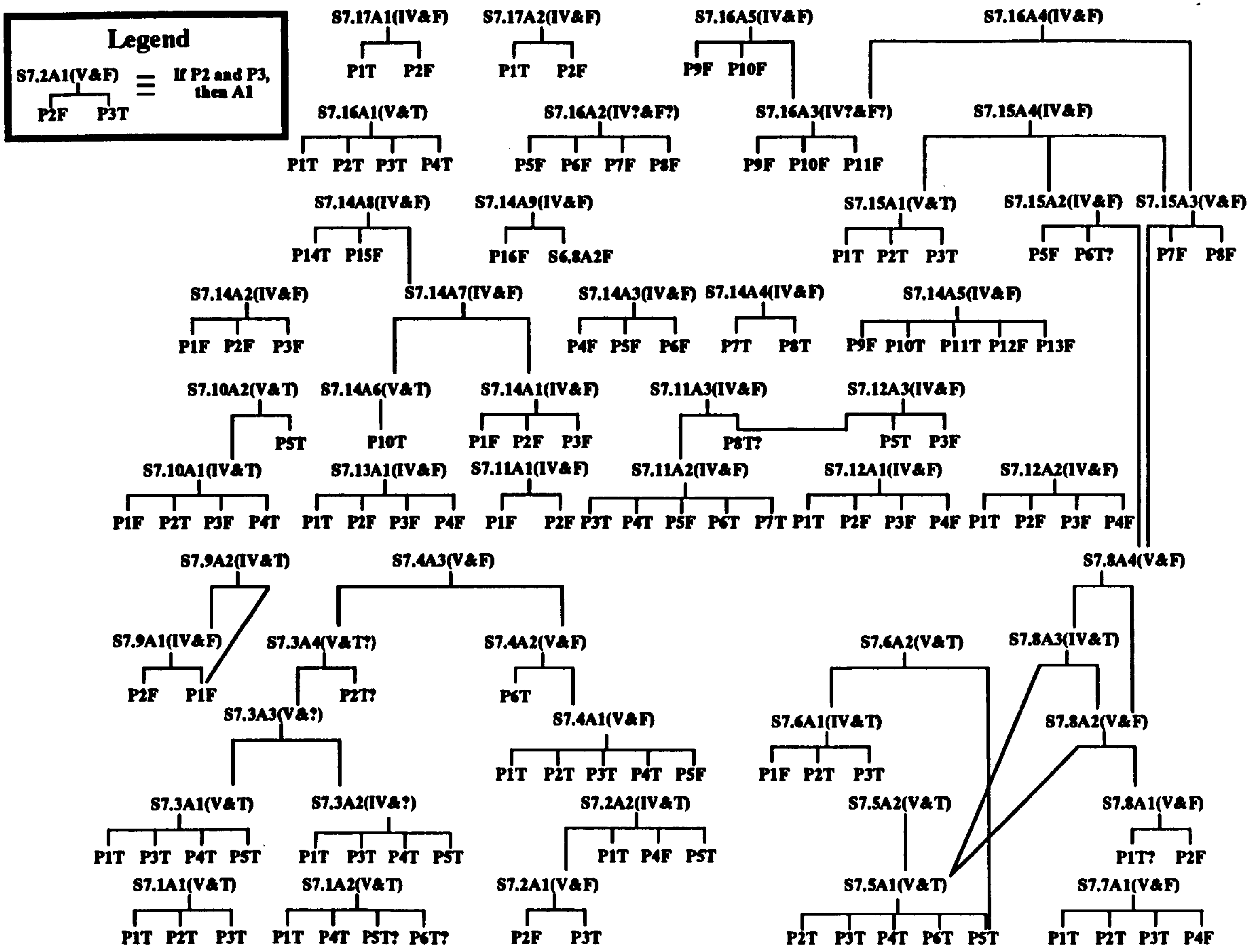


Figure 7-1. Logic diagram of arguments presented in Chapter 7

8 AGE AND ORIGIN OF CARBONATIZATION

The purpose of Chapter 8 in Szymanski (1992) was to establish through the examination of various characteristics of carbonate deposits, particularly the isotopic signatures, the origin and age of Yucca Mountain carbonatization. Specifically, Szymanski (1992) attempted to prove all of the observed textural and paragenetic varieties of calcite (see Section 3.1) are hypogene in origin. He asserted that observed sparry calcites, especially those associated with barite and fluorite, express the prolonged activity of a hydrothermal system driven by the Timber Mountain caldera system, while subsequent micritic calcites express the intermittent activity of a fault-based hydrothermal system driven by conductively replenished heat sources. In addition to offering arguments in support of his contentions, Szymanski (1992) attempted to discredit/disprove four isotopically-based statements offered by United States Geological Survey (USGS) workers for the supergene origin of micritic carbonate deposits. His efforts to address these USGS conclusions are analyzed in Section 8.1.

Having attempted to demonstrate the four arguments as false, Szymanski (1992) re-examined the isotopic data. His investigation was presented in five parts. Comparative isotopic analyses of uranium, carbon, and oxygen isotopes and paleo-geothermal reconstructions based upon the oxygen isotopic evidence comprised the first part. The isotopic characters of uranium, carbon, and oxygen incorporated in samples of Yucca Mountain calcretes and calcites in the subsurface in the vadose zone and below the contemporary water table were presented by Szymanski (1992) in his Section 8.2. Based upon this isotopic evidence, he developed arguments concerning the isotopic equivalency of surface and near-subsurface deposits and the relative concentrations of ^{13}C in deep calcites, which he concluded indicated the presence of two generations of calcite. These contentions are addressed in Section 8.2. Next, Szymanski (1992) argued the analogous U, C, and O isotopic characters of Yucca Mountain calcites relative to hypogene analogs provide a permissible interpretation that the Yucca Mountain calcites are hypogene in origin (Section 8.3). In Section 8.4, documentation presented concerning sources of carbon incorporated in calcites and the interpreted carbon isotopic discordancy of parental fluids and calcites is discussed. Szymanski (1992) then asserted the isotopic character of oxygen incorporated in the Yucca Mountain calcites is not consistent with or supportive of a supergene origin for the calcites. His use of paleo-geotherms derived from the oxygen isotopic evidence is evaluated in Section 8.5. Finally, Szymanski (1992) attempted to refute the supergene origin of some of the Yucca Mountain calcites based upon a presentation of uranium, carbon and oxygen isotopic data. His contentions of the carbon isotopic signature expected in an evolving magmatic region and his refutation of the supergene origin hypothesis are reviewed in Section 8.6.

The second part of Szymanski's (1992) re-examination consisted of an interpretation of the paragenetic relationships derived from consideration of five different sets of data. These are: (i) spatial distribution of the alteration minerals; (ii) K/Ar ages of clinoptilolites; (iii) structural settings of the calcites in question; (iv) isotopic characteristics of oxygen and carbon incorporated in these calcites; and (v) homogenization temperatures of fluid inclusions contained in spatially associated calcites. Szymanski (1992) contended that there are three structural settings of carbonates reflective of three different generations of calcite formation: (i) in-fillings of lithophysal cavities (deuteric); (ii) interstitial impregnations and replacement of phenocrysts (long-lived hydrothermal activity of the Timber Mountain caldera system); and (iii) discrete veins (intermittent activity of a fault-based hydrothermal system driven by conductively replenished heat sources). His support of this statement forms the basis of the discussion in Section 8.7. The postulated isotopic conditions (Szymanski, 1992) of formation for the three facies of epigenetic calcites are evaluated in Section 8.8. The spatial association of elevated homogenization temperatures of fluid inclusion with both ^{13}C enriched and ^{13}C depleted calcites was used by Szymanski (1992) to assert the hypogene origins of the ^{13}C depleted calcites. This argument is examined in Section 8.9. Finally, the spatial distribution of the isotopic characters of carbon incorporated in the epigenetic calcites, the chemical composition of clinoptilolites, and the K/Ar ages of clinoptilolites were combined by Szymanski (1992). From his combination of information, Szymanski (1992) inferred epigenetic carbonatization related to intermittent activity of a fault-based hydrothermal system rooted in the Stage Coach Road fault system has overprinted the alteration associated with the Timber Mountain caldera hydrothermal system. These contentions are reviewed in Section 8.10.

Strontium isotopic data were presented as the third part of Szymanski's (1992) re-exploration of the isotopic information. The strontium isotopic data were used (Szymanski, 1992) to test his independently inferred origin of the Yucca Mountain calcites and the interpreted paragenetic relationships (analyzed in Chapter 7, Sections 8.6 and 8.10 of this report). Four different tests of the interpreted paragenetic relationships were derived by Szymanski (1992) from the carbon and strontium isotopic database. Anticipated conditions predicted by Szymanski (1992): (i) the isotopic characters of dissolved carbon and strontium associated with Timber Mountain hydrothermal metamorphism should be distinct from subsequent hydrothermal metamorphism since the respective fluids acquired C and Sr from isotopically different sources and reservoirs; (ii) contemporary mature Ca-Mg fluids should have distinct isotopic signatures which differ from the Paleozoic carbonates; (iii) early allogenic paleo-fluids ought to display clear isotopic affinity with the Paleozoic carbonates; and (iv) allogenic fluids responsible for calcic zeolitization and corresponding ^{13}C depleted carbonatization ought to be analogous to those of contemporary Ca-Mg fluids. Five interpretations were offered in support of these predictions, and these lines of evidence are analyzed in the next five sections. First, pervasive strontium metasomatism of ignimbrites at Yucca Mountain and lateral variability of Sr concentrations was argued (Szymanski, 1992) to require that the fluids responsible for calcic zeolitization and the late ^{13}C depleted carbonatization had elevated concentrations of total dissolved strontium. This argument is dissected in Section 8.11. Szymanski (1992) then asserted the observed space-differential strontium metasomatism developed sequentially in response to two distinct fluids, with fluids associated with the subsequent fault-based hydrothermal system derived from the Precambrian basement. The strontium isotopic data used by Szymanski (1992) to support this statement is reviewed in Section 8.12. The bimodality of the $^{87}Sr/^{86}Sr$ ratios with spatially corresponding bimodality of the $\delta^{13}C$ ratios supports an evolutionary path consistent with a postulated increased depth of circulation with time (Szymanski, 1992). This contention is analyzed in Section 8.13. Szymanski's (1992) use of the conclusion of this argument as unequivocal evidence in support of his first test of the inferred origin of calcite at Yucca Mountain is also evaluated. The isotopic signatures of contemporary mature Ca-Mg fluids were presented (Szymanski, 1992) as distinctive from the isotopic signatures expected for fluids which solely derive their isotopic signature from Paleozoic carbonate. This was Szymanski's (1992) fourth line of evidence and was used by him to support his second test. These assertions are evaluated in Section 8.14. Finally, Szymanski's (1992) fifth contention was used to support his third and fourth tests for the inferred origin of Yucca Mountain calcites. These contentions and the evidence from which they are derived are assessed in Section 8.15.

Uranium-thorium ages of the late micritic calcites were considered together with the K/Ar ages of the youngest local volcanic rocks by Szymanski (1992) as the fourth part of his re-examination. Since a magmatic source was asserted (Szymanski, 1992) to be necessary to explain the ^{13}C depleted calcites at Yucca Mountain, Szymanski (1992) devised an independent testing scheme based upon the U/Th ages of carbonates in the area and the local history of igneous events to evaluate this conclusion. First, Szymanski (1992) argued the open system behavior of Yucca Mountain calcites with respect to uranium and thorium bearing calcites effectively explains the apparent uranium isotopic discrepancy between near-surface carbonates at Yucca Mountain and submerged calcites in the Devil's Hole vein. This novel interpretation is appraised in Section 8.16. Second, the open system nature of Yucca Mountain calcites was argued by Szymanski (1992) to infer that U/Th ages may be accepted, but would be positively biased (U/Th ages older than true age). This contention is reviewed in Section 8.17. A consistent episodic history of formation of local calcretes derived from the U/Th isotopic data was presented by Szymanski (1992). Szymanski's (1992) argument that only calcites formed at about 30 ka, 75 ka, and 280 ka are preserved at the surface, while an additional period of carbonate formation at 170 ka is preserved in the subsurface, is assessed in Section 8.18. Finally, the depositional history of calcites as determined from U/Th isotopic measurements was claimed (Szymanski, 1992) to be correlative with local magmatic activity. His argument and the conclusion that the calcites in the Yucca Mountain area are of hypogene origin and related to the magmatic history of the area is evaluated in Section 8.18.

Finally, the fifth part of Szymanski's (1992) re-examination of the isotopic evidence at Yucca Mountain consists of his overall conclusions. This section of his report did not contain any new information, and hence, no discussion is presented.

8.1 REFUTATION OF SUPERGENE ORIGIN OF MICRITIC CALCITES

Szymanski (1992) attempted to show that the supergene hypothesis is false by analyzing four arguments which he suggested accurately reflected logic used by USGS investigators. He noted some scientists associated with the Yucca Mountain Site Characterization Project proposed that the overall carbonatization represents a combination of temporally distinct processes, ranging in origin from hypogene to supergene. He stated these investigators inferred the calcite, barite, and fluorite mineral assemblage in the saturated zone reflected epigenetic mineralization (Timber Mountain caldera activity), while the calcite and fluorite assemblage in the vadose zone was deuteric, and the calcretes and micritic veins were supergene deposits.

Szymanski (1992) stated that four lines of evidence have been used by these scientists to support the supergene interpretation. It is interesting to note Szymanski (1992) claimed this evidence is based on isotopic data. As is obvious in many other chapters of this report (Chapters 3, 6, and 7 in particular), there are other lines of proof which more directly support a supergene origin than the isotopic arguments. The four conclusions derived by Szymanski (1992) from the published work of other investigators are: (i) similar isotopic characteristics of bedrock veins and calcretes indicate a supergene origin (discussed in Section 8.1.1); (ii) different uranium and strontium isotopic signatures in fluids and micritic calcites require a supergene origin (discussed in Section 8.1.2); (iii) the clear bimodal distribution of the carbon isotopic character in calcites demonstrates a supergene origin (discussed in Section 8.1.3); and (iv) strontium isotopic gradients with depth of whole-rock ignimbrites and spatially corresponding calcites demand a supergene origin (discussed in Section 8.1.4). Unlike the logical analyses presented previously in this document, the focus of the following four analyses will be actual construction of the arguments by Szymanski (1992). This approach was used, since Szymanski (1992) analyzed the validity of the logic and not the truth of the premises in this section of his report. Without providing adequate documentation, Szymanski (1992) forced the reader to accept his construction of conclusions which he asserted were presented by others. Evidence in support of the arguments/premises will be provided in more detail later in this chapter when Szymanski (1992) identified the isotopic evidence used to construct the statements.

8.1.1 Similar Isotopic Characteristics of Bedrock Veins and Calcretes

8.1.1.1 Premises

P1: The Yucca Mountain calcretes and sinters are of supergene origin (?). P2: For a given area all supergene deposits carry equivalent isotopic signatures (T).

8.1.1.2 Arguments

A1: If P1 and P2, then ". . . 'because the calcretes and the bedrock veins do carry equivalent isotopic signatures, both of these deposits are of supergene (pedogenic) origin'(sic)" (IV and ?).

8.1.1.3 Analysis

The premises and the argument are exact statements as provided by Szymanski (1992). As he constructed the argument, it is invalid. The major premise appears in P1 and in the conclusion of the argument, which represents circular logic and invalid scientific reasoning. Szymanski (1992) derived this rationale from evidence in Stuckless et al. (1991a). In fact, a rearrangement of the presentation of the premises and what Szymanski (1992) inferred to be the conclusion culminates in a valid affirmation. The premises and arguments follow:

P1: For a given area, all demonstrably supergene/pedogenic deposits carry equivalent isotopic signatures (T). P2: Calcretes at Yucca Mountain have the same isotopic signature as supergene/pedogenic deposits (T). P3: Bedrock veins at Yucca Mountain have the same isotopic signature as calcretes (T)

A1: If P1 and P2, then calcretes at Yucca Mountain are supergene in origin (V and T?). A2: If P3 and A2, then bedrock veins are supergene (V and T?).

Evidence supporting P1 and P2 was provided in Quade and Cerling (1990), while P3 was maintained by Whelan and Stuckless (1991). By incorrectly defining the arguments used by USGS investigators and others, Szymanski (1992) was able to assert that invalid reasoning was being used by these scientists to sustain the supergene origin of the calcretes and bedrock veins. Thus, his attempt to discredit the logic of the supergene origin proponents based upon the argument of similar stable and radiogenic isotopes in the compositionally and texturally equivalent calcretes and bedrock veins is unfounded. Even these reformulated premises and arguments do not require that calcretes and bedrock veins at Yucca Mountain are of supergene origin. An unstated and unproven premise is that all materials with a given isotopic signature are pedogenic.

8.1.2 Uranium and Strontium Isotopes in Fluids and Micritic Calcites

8.1.2.1 Premises

P1: The isotopic characteristics of uranium and strontium dissolved in the local fluids were both time- and depth-invariant for the last 2 Ma. Consequently, the parent fluids for any hypogene deposits must have been isotopically similar to those currently observed within 0.5 to 1.5 km of the topographic surface (?). P2: Both the calcretes and isotopically equivalent veins must be either of supergene origin or of hypogene origin (?).

8.1.2.2 Arguments

A1: If P1 and P2, then ". . . 'because the isotopic characteristics of the radiogenic elements dissolved in the subsurface fluids are dissimilar to those incorporated in calcites, the calcites cannot possibly be of hypogene origin and, therefore, must be of supergene origin'(sic)" (IV? and ?).

8.1.2.3 Analysis

Again, the premises and the argument presented here are the exact words provided by Szymanski (1992). As he constructed his contention, it is invalid and not an adequate characterization of the statements presented by proponents of the supergene origin of the pedogenic deposits. First, Szymanski (1992) implied that those investigators invoked time and depth invariability of the isotopic characteristics for a period of 2 m.y. for the local fluids (Alkali Flat/Furnace Creek flow system). He was incorrect on two separate points. First, Stuckless et al. (1991b) clearly stated the possible long-term temporal isotopic variations in the groundwater system beneath Yucca Mountain cannot be constrained directly, but must be inferred from the long-term behavior of the major flow system adjacent to the east of Yucca Mountain (Ash Meadows system). Second, from their analysis of the isotopic evidence from the Ash Meadows system (Stuckless et al., 1991b), the long-term isotopic stability of that system could be demonstrated for the period of 60 ka to 600 ka, not 2 Ma. Stuckless et al. (1991b) were forced to argue by analogy for the long-term (60 ka to 600 ka) isotopic stability of the Alkali Flat/Furnace Creek flow system. Szymanski (1992) asserted P1 required the factors which control the isotopic characteristics of shallow fluids (fluid circulation depth, fluid fluxes, conditions of isotopic exchange reactions) to have remained invariant for 2 Ma. He further contended (Szymanski, 1992) this required that the corresponding position of the water table has been invariant for the same amount of time. However, based upon the isotopic evidence presented by Stuckless et al. (1991b) and the structure of the regional groundwater system (National Research Council, 1992; Winograd and Szabo, 1985), the analogy between stability of the Ash Meadows groundwater system and Alkali Flat/Furnace Creek groundwater system can be accepted as true. Note the isotopic stability of the Ash Meadows system does not necessarily provide any information about the stability of the groundwater table, but does directly assess the impact of possible variability of isotopic sources with time (see detailed discussion in Section 8.15). Thus, Szymanski's (1992) conclusion that different uranium and strontium isotopic signatures in saturated zone fluids and micritic calcites cannot require a supergene origin was inaccurate as well as based on an incorrect interpretation of the material presented in Stuckless et al. (1991b) together with incomplete understanding of the implications of arguments provided by them (Stuckless et al., 1991b).

8.1.3 Bimodal Distribution of Carbon Isotopes in Calcites

8.1.3.1 Premises

P1: At Yucca Mountain, the locally circulating carbon originates exclusively from two sources: (i) a biogenic source, providing isotopically light carbon; and (ii) an inorganic source (Paleozoic carbonates), providing isotopically heavy carbon (?). P2: At Yucca Mountain, hypogene calcites contain exclusively isotopically heavy carbon (derived from the inorganic source) and supergene calcites contain both isotopically light carbon (derived from the biogenic source) and isotopically heavy carbon (light biogenic carbon dioxide modified via diffusional ^{13}C enrichment) (?).

8.1.3.2 Arguments

A1: If P1 and P2, then "... 'because the calcites in question contain isotopically 'light' carbon these calcites cannot possibly be of hypogene origin and, therefore, must be of supergene origin'(sic)" (? and ?).

8.1.3.3 Analysis

The premises and argument presented here are the exact statements provided by Szymanski (1992). His attempt to rebut this interpreted argument relied on two assertions. First, Szymanski (1992) maintained that circulating carbon in magmatically active regions (Yucca Mountain) consisted of three sources, including biogenic, inorganic (Paleozoic carbonates), and a deep-seated igneous source. In support of his declaration, Szymanski (1992) referred to isotopic data presented in literature sources which indicate carbon from deep-seated magmatically active area would be similar to that associated with rhyolitic hydrothermal caldera. These conditions would be similar to that expected during the Timber Mountain caldera episode. Present conditions do not indicate a magmatically active area equivalent to a caldera system (Szymanski, 1992, Chapter 2). He continued (Szymanski, 1992) with this inappropriate analogy to infer that the isotopic character of dissolved carbon derived from igneous sources of carbon ranged from light through intermediate to heavy. Second, Szymanski (1992) incorrectly inferred that the presence of isotopically heavy hypogene carbonates in magmatically active regions required inclusion of magmatic carbon dioxide. In his attempt to discredit the hypothesis of only two sources of carbon at Yucca Mountain, Szymanski (1992) cited the work of White et al. (1990) at the Long Valley caldera. That work indicated isotopically heavy hypogene carbonates (White et al., 1990), from which Szymanski (1992) contended the presence of a magmatic carbon dioxide source. However, White et al. (1990) unequivocally stated the most likely source for the heavy carbon is from subsurface metamorphosed Paleozoic basement rocks (see also discussion in Section 8.12). Clearly, Szymanski's (1992) choice of evidence to refute the possibility of only two sources of carbon (biogenic and Paleozoic carbonates) in the Yucca Mountain area calcretes and bedrock veins was inappropriate. Thus, Szymanski's (1992) attempt to refute this hypothesis was inadequately supported. Further discussion of additional evidence to the contrary of that presented by Szymanski (1992) will be discussed in Sections 8.12 and 8.13.

8.1.4 Depth Gradient of Strontium Isotopes

8.1.4.1 Premises

P1: For the whole-rock ignimbrites, the $^{87}Sr/^{86}Sr$ ratio versus depth gradient was established prior to, and independently of, the corresponding gradient for the calcites (T). P2: During descent, supergene solutions acquire their dissolved strontium through ionic exchange reactions with the whole-rock ignimbrites and, at the same time, are involved in development of authigenic veins and resulting transfer of the strontium isotopic signal from the ignimbrites to the authigenic calcites (?).

8.1.4.2 Arguments

A1: If P1 and P2, then "... 'because the late micritic calcites yield a $^{87}Sr/^{86}Sr$ ratio versus depth gradient which is equivalent to that obtained from the whole-sample ignimbrites, these calcites are of supergene origin'" (? and ?).

8.1.4.3 Analysis

Again, the premises and argument are exact verbiage used by Szymanski (1992). He derived argument A1 from information presented in Peterman et al. (1991 and 1992b). Analysis of Szymanski's (1992) attempt to discredit this argument is limited, since he bluntly stated there was no factual evidence to verify premise P1. In contrast, there is substantial chemical data in support of this premise (Peterman et al., 1991, 1992b, 1993). This information will be addressed later in Section 8.12, in the review of Szymanski's (1992) attempt to discredit this argument based upon his interpretation of the chemical evidence. In addition, Szymanski (1992) asserted alteration overprinting was spatially correlative with both strontium isotopic gradients. This would effectively refute P1. However, he provided no documentation to invalidate P1. Thus, by not presenting any scientific evidence to negate A1, Szymanski (1992) claimed he had proven that the strontium isotopic data do not support a supergene origin. An analysis of his logic and a discussion of the scientific data for strontium isotopes are formally presented in Sections 8.11 through 8.15.

8.2 Isotopic Equivalency of Surface and Subsurface Deposits

8.2.1 Premises

P1: Isotopically equivalent (uranium, carbon, and oxygen isotopes) calcites are present in three settings including the topographic surface, within the vadose zone, and below the contemporary water table (F?). P2: The isotopically similar calcites in each setting are young and owe their existence to the same carbonatization process (F?). P3: There is a population of calcites which is not represented at the topographic surface (T). P4: These deeper calcites are older and have $\delta^{13}C$ from about -2.0 to about $+5.0$‰ relative to Peedee Formation belemnite (PDB) (T?). P5: Spatially, chemically, and temporally distinct hydrothermal alteration aureoles exist in the Yucca Mountain area (F).

8.2.2 Arguments

A1: If P1, P2, P3, and P4, then there are two distinct different generations of calcite present at Yucca Mountain (IV and F). A2: If A1 and P5, then the two different generations express two different stages of hypogene carbonatization (V and F).

8.2.3 Analysis

Argument A1 is invalid. The conclusion of this statement cannot be accepted based upon constructional form. Truth of the conclusion of the argument cannot be ascertained from the premises. Szymanski (1992) asserted there are two different generations (temporal) of calcites without providing any scientific support. However, he was correct in his affirmation that there may be two genetically distinct groups of carbonates. Based upon the distinction between genetic origin and temporal differences, argument A1 is false. It is somewhat unclear what Szymanski (1992) meant in the first premise. If he meant that some calcites were isotopically equivalent in each setting—this is true. Based upon construction of the argument (Szymanski, 1992), it is inferred he meant all calcites are isotopically equivalent and some of these calcites occur beneath the water table. The majority of carbonate deposits in the Yucca Mountain area have $^{234}U/^{238}U$ activity ratios between 1 to 1.5 (Szabo and O'Malley, 1985; Szabo et al., 1981; Szabo and Kyser, 1990; Stuckless et al., 1991a, 1991b) for the carbonate fraction of the deposit; however, the carbonate spring deposits at the south end of Crater Flat have distinctly different ratios

(>2.6, Paces et al., 1993). Carbon isotopic data indicate that P1 can be tentatively accepted (Whelan and Stuckless, 1991, 1992; National Research Council, 1992; Szabo and Kyser, 1990). Oxygen isotopic data indicate that calcites at the topographic surface within the vadose zone and below the contemporary water table are not isotopically equivalent (Whelan and Stuckless, 1990, 1992; National Research Council, 1992; Szabo and Kyser, 1990). Additional isotopic information is available to evaluate the claim of isotopically equivalency among calcites from different settings. Strontium isotopic data indicate that pedogenic calcite and unsaturated zone fracture calcite have overlapping $^{87}Sr/^{86}Sr$ valves which are distinctly different from saturated zone fracture calcite and from the Quaternary discharge sites at the southern end of Crater Flat (Marshall et al., 1993). Lead isotope information is too limited to draw a conclusion about isotopic equivalency among the different settings of carbonate deposits (Stuckless, 1991; Zartman and Kwak, 1993). Thus, premise P1 may or may not be true, however, based on U and Sr isotopic data from the only paleontologically and sedimentologically confirmed Quaternary sites of surface discharge in the Yucca Mountain area (Paces et al., 1993; Marshall et al., 1993), it can be concluded that P1 should not necessarily be accepted. Premise P2 is not supported based upon the discussion for P1, as well as by the unsubstantiated assertion that the calcites are young (Szymanski, 1992). The majority of carbonates in the vadose zone analyzed by Szabo and Kyser (1985, 1990) were beyond the limit of the $^{230}Th/^{234}U$ dating technique (>400 ka) and provided no support for the assertion of a young age. However, Szymanski's (1992) contention that the calcites in each setting owe their existence to the same carbonatization process may be true for carbonate deposits (except for the Crater Flat spring deposits) (National Research Council, 1992; Everden, 1992; Stuckless, 1991). Although the calcites in each setting may owe their existence to the same carbonatization process, there is no evidence to support their youth, and P2 should be tentatively considered false. Premise P3 is true (Whelan and Stuckless, 1992). Although there is no strong support for Szymanski's claim that the deeper calcites are older (Szabo and Kyser, 1985, 1990), premise P4 also may be tentatively accepted as true.

Argument A2 was constructed using a valid logical form, but its conclusion cannot be accepted as a true statement since each of the premises is false. A1 is false since Szymanski (1992) inferred a temporal difference between the distinct groups of carbonates. Premise P5 is equivalent to Section 7.15 Argument A4 and is false based upon the analysis presented therein.

8.3 HYPOGENE ANALOGS

8.3.1 Premises

P1: The Amargosa Basin-Furnace Creek Wash travertine veins are known to be of hypogene origin (T). P2: The Amargosa Basin-Furnace Creek Wash travertine veins are an appropriate U-series isotopic analog to the late Yucca Mountain calcites (F). P3: The isotopic character of incorporated uranium in calcretes and the vadose zone veins is identical to that incorporated in the Amargosa Basin-Furnace Creek Wash travertine veins (F). P4: The isotopic character of carbon incorporated in all locally known calcites at Yucca Mountain is identical to that incorporated in carbonate gangue associated with various hydrothermal ores (T). P5: The isotopic character of carbon incorporated in all locally known calcites at Yucca Mountain is identical to that incorporated in travertines and hydrothermal veins from the Long Valley caldera (T). P6: The hydrothermal carbonate gangue and travertines and hydrothermal veins from the Long Valley caldera are an appropriate carbon isotopic analog to the late Yucca Mountain calcites (F). P7: The isotopic character of oxygen incorporated in all locally known calcites at Yucca Mountain is identical to that incorporated in the Amargosa Basin spring deposits (F). P8: The isotopic character of oxygen incorporated in all locally known calcites at Yucca Mountain is identical to that incorporated in the Carlin-Cortez disseminated gold deposits (T). P9: The Amargosa Basin spring deposits and the Carlin-Cortez disseminated gold deposits are appropriate oxygen isotopic analogs to the late Yucca Mountain calcites (F). P10: Hypogene carbonates in magmatically active areas, formed during periods when the dominant source of carbon is magmatic carbon, are depleted in ^{13}C and carry values of δ^{13}C from -3.0 to as low as $-10‰_{PDB}$ (T?). P11: Hypogene carbonates in magmatically active areas, formed during periods when the dominant source of carbon is inorganic carbon (marine limestones), are enriched in ^{13}C and carry values of δ^{13}C from $0.0 \pm 2.0‰_{PDB}$ (T?).

8.3.2 Arguments

A1: If P1, P2, and P3, then uranium isotopic evidence supports a hypogene origin for the Yucca Mountain calcretes and vadose zone carbonate veins (V and F). A2: If P4, P5, and P6, then carbon isotopic proof supports a hypogene origin for the Yucca Mountain calcretes and vadose zone carbonate veins (V and F). A3: If P7, P8, and P9, then oxygen isotopic evidence supports a hypogene origin for the Yucca Mountain calcretes and vadose zone carbonate veins (V and F). A4: If A1, A2, and A3, then the observed close multiple element isotopic affinity indicates that even for the most ^{13}C depleted calcites at Yucca Mountain a hypogene origin is clearly a permissible interpretation option (V and F). A5: If A4, P10, and P11, then the varying carbon signature of calcites at Yucca Mountain reflects variable input of magmatic carbon dioxide to the carbon system therein (IV and F).

8.3.3 Analysis

If each of the premises of argument A1 were true, then the conclusion could be accepted as a true statement since A1 was constructed validly (Szymanski, 1992). However, not all the premises are true, and hence, the conclusion is false. P1 is true (Szymanski, 1992), but it should be noted Furnace Creek Wash calcites are much purer (>97 percent calcite) than the calcretes in the Yucca Mountain area (Szabo and O'Malley, 1985; Everden, 1992). In addition, the present uranium isotopic signature of half the Amargosa Basin carbonate samples (79-3-7P and 80-10-20-F) used by Szymanski (1992) in his hypogene analogy may not reflect the isotopic signature of the fluid responsible for their formation (Szabo and O'Malley, 1985) since these deposits have been interpreted to have been recrystallized. The other two samples (81-3-19F and AM-9) used by Szymanski (1992) in his hypogene analogy indicate that initial ^{234}U/^{238}U ratios of the Amargosa Basin carbonates were probably between 2.5 and 3.0, similar to the ratio observed for the Paleozoic carbonate reservoir during the period 60 to 566 ka (Zielinski and Rosholt, 1978; Szabo and O'Malley, 1985; Ludwig et al., 1992; Winograd et al., 1988). Szymanski (1992) argued the Furnace Creek Wash-Amargosa Basin carbonates were an appropriate U-series isotopic analog to the late Yucca Mountain calcites since these deposits are above the water table and are exposed to the leaching (of ^{234}U) influence of rainwater, which would lower the ^{234}U/^{238}U ratio similar to that hypothesized for the Yucca Mountain calcites (see discussion Section 8.17). Based upon the isotopic information presented, the Amargosa Basin carbonates are inappropriate uranium isotopic analogs to the Yucca Mountain calcites since they do not show unequivocal evidence for open behavior and leaching of ^{234}U. The Furnace Creek Wash sample's ^{234}U/^{238}U activity ratios are lower than the vertical veins (Paleozoic fluids, Winograd et al., 1985) which they crosscut (Szabo and O'Malley, 1985; Winograd et al., 1985). In addition, the ^{230}Th/^{234}U dates of the samples are much younger than any of the dated vertical veins (Szabo and O'Malley, 1985; Winograd et al., 1985). The low ^{234}U/^{238}U activity ratios may reflect open system behavior; however, the concordant dates (4 samples) determined by Szabo and O'Malley (1985) do not support this interpretation. Use of Furnace Creek Wash carbonate (travertine) deposits as an analog to the Yucca Mountain calcretes is inappropriate since the mineralogical and sedimentological evidence (Szabo and O'Malley, 1985; Vaniman et al., 1988) did not support the depositional (hypogene) analogy. Thus, P2 is false. Premise P3 is false since the isotopic character incorporated in the Amargosa travertines was different ($^{234}U/^{238}U > 2.6$) than that incorporated in the Yucca Mountain calcretes ($^{234}U/^{238}U < 1.5$, except for Crater Flat spring deposits, Szabo et al., 1981; Paces et al., 1993) and vadose zone veins (only one sample $^{234}U/^{238}U > 1.5$, Szabo and Kyser, 1990). The uranium isotopic character of the Furnace Creek Wash carbonates appears to be similar to that observed for Yucca Mountain carbonate deposits. The only carbonate deposits in the Yucca Mountain area assigned an unequivocal hypogene origin are the spring deposits at the southern end of Crater Flat (Paces et al., 1993; Marshall et al., 1993) and these deposits have uranium isotopic signatures ($^{234}U/^{238}U > 2.8$) unlike the rest of the calcretes and vadose zone carbonate veins. Since premises P2 and P3 are false, it cannot be concluded that uranium isotopic evidence supports a hypogene origin for the Yucca Mountain calcretes and vadose zone carbonate veins.

As constructed by Szymanski (1992), A2 is a valid argument. If each premise were true then the conclusion would be true. Premise P4 is true based upon information presented in Szymanski (1992). The $\delta^{13}C$ range of values for hydrothermal carbonate deposits at Long Valley caldera is similar to that measured for Yucca Mountain carbonates (Whelan and Stuckless, 1991; White et al., 1990). This implies P5 is true. Although Szymanski (1992) compared the carbon isotopic signature of hydrothermal fluids at Long Valley caldera to the mature fluids at Yucca Mountain (Benson and McKinley, 1985; White and Chuma, 1987), his attempt to create an analogy between the Long Valley caldera and the Yucca Mountain area was flawed. Premise P6 is false for two different reasons. The use of analogy requires the two systems being compared are similar. Szymanski (1992) suggested that Long Valley caldera, an active magmatically driven hydrothermal system, was comparable to an intermittently active conductively driven hydrothermal system which he postulated existed at Yucca Mountain. This is an insupportable use of the idea of an analogous hydrothermal system. More importantly, Szymanski (1992) asserted that the Long Valley caldera system is a carbon isotopic analog of carbon isotopes found in carbonate deposits at Yucca Mountain. This analogy is critically flawed since he postulated that diffusional enrichment of ^{13}C (CO_2 degassing) in the vadose zone and at the surface at Yucca Mountain produced carbonates with $\delta^{13}C$ values of about -3 to $-10‰_{PDB}$ (Whelan and Stuckless, 1991), while CO_2 degassing at the Long Valley caldera produced carbonates with $\delta^{13}C$ values of about -0.3 to $+3.5‰_{PDB}$ (White et al., 1990), even though the parental fluids had comparable carbon isotopic contents $\delta^{13}C$ values of -2.3 to $-9.0‰_{PDB}$ for Yucca Mountain (Benson and McKinley, 1985; White and Chuma, 1987) and $\delta^{13}C$ values of -1.5 to $-9.7‰_{PDB}$ for Long Valley (White et al., 1990). Clearly, the carbon isotopic signatures of surface carbonates at the two systems are not comparable, the analogy untenable (Talma and Netterberg, 1983), and premise P6 is false. Since P6 is false, the conclusion that the carbon isotopic evidence supports a hypogene origin for the Yucca Mountain calcretes and vadose zone carbonate veins is also false.

Similar to arguments A1 and A2, A3 is valid but its conclusion is false since not all of its premises are true. Premise P7 is false since Yucca Mountain carbonates have $\delta^{18}O$ of 4.2 to $20.3‰_{SMOW}$ (Standard Mean Ocean Water) while Amargosa Basin calcium carbonates have $\delta^{18}O$ of 15 to $22‰_{SMOW}$ (Szymanski, 1992). The range of ^{18}O content in carbonates at Amargosa Basin is only comparable to vadose zone and surface carbonates at Yucca Mountain. Premise P8 is approximately true since the Carlin-Cortez disseminated gold deposits $\delta^{18}O$ only range from 8 to $24‰_{SMOW}$ (Szymanski, 1992). Szymanski (1992) insisted the oxygen isotopic analogy between all the calcites at Yucca Mountain and the Carlin-Cortez disseminated gold deposits and the Amargosa Basin deposits was appropriate, yet premise P9 is false since the isotopic data from these systems are not comparable and conditions of formation are not the same (Vaniman et al., 1988; Szabo and O'Malley, 1985; Winograd et al., 1985, 1988, 1992). Since both P7 and P9 are false, there is no scientific or logical reason to accept Szymanski's

(1992) conclusion that the oxygen isotopic evidence supports a hypogene origin for the Yucca Mountain calcretes and vadose zone carbonate veins.

The valid logical construction of argument A4 requires the conclusions of arguments A1, A2, and A3 be true if A4 is to be accepted as logically supported by the premises. Since each of the premises is false, the conclusion is false and there is no reason to accept Szymanski's (1992) contention that even for the most ^{13}C depleted calcites at Yucca Mountain a hypogene origin is clearly a permissible interpretation option.

Finally, argument A5 is invalid as there is not a sufficient logical connection between the stated premises (Szymanski, 1992) and the conclusion of the argument. The conclusion of A4 is one of the premises of this argument, and A4 is false. Premise P10 is inferred to be true by Szymanski (1992); however, the discussion of the carbon isotopic data from Long Valley caldera (White et al., 1990) clearly indicated his postulated mechanism of CO_2 degassing of upwelling fluids hydrothermal fluids would not produce carbonates with the appropriate isotopic signature. In addition, Szymanski's (1992) insistence of a magmatic origin for the carbon isotopic signature of hydrothermal fluids at the Long Valley caldera ignores the author's discussion which argued convincingly against the magmatic origin of carbon in this system (White et al., 1990). Premise P11 appears to be true (Szymanski, 1992). The conclusion of argument A5, that the varying carbon signature of calcites at Yucca Mountain reflect variable input of magmatic carbon dioxide to the carbon system there, cannot be accepted as a true statement based on the truth of the premises. The conclusion is not logically supported by the argument.

8.4 SOURCES OF CARBON AND CARBON ISOTOPIC DISCORDANCY

Szymanski (1992) asserted the carbon isotopic compatibility of the Yucca Mountain calcites with hypogene hydrothermal fluids (discussed in Section 8.3). In addition to trying to prove this compatibility with hydrothermal fluids, Szymanski (1992) attempted to demonstrate a discordancy between the expected carbon isotopic character of local supergene fluids and the carbon found in the Yucca Mountain calcites. To obtain the expected carbon isotopic character of supergene parental fluids to the calcretes, Szymanski (1992) relied on five different inferences (possible sources/processes for carbon incorporation in supergene fluids) which are analyzed in the following five sections. The first estimate (Szymanski, 1992) of the carbon signature of supergene fluids relied on the assertion that parent fluids for hypothetical supergene carbonates acquired their carbon solely through dissolution of the locally produced biogenic CO_2 (Section 8.4.1). The second inference (Szymanski, 1992) assumed parent fluids for hypothetical supergene carbonates acquired their carbon through dissolution of the CO_2 gas known to be residing in the vadose zone (Section 8.4.2). The third estimate (Szymanski, 1992) of the carbon signature of supergene fluids was calculated assuming parent fluids for hypothetical supergene carbonates are similar to local contemporary fluids occurring immediately below the topographic surface (Section 8.4.3). The fourth inference (Szymanski, 1992) was based on the assumption that parent fluids carbon isotopic signature was similar to interstitial fluids residing in the Yucca Mountain vadose zone (Section 8.4.4). The final estimate (Szymanski, 1992) of the carbon signature of supergene fluids assumed parent fluids for hypothetical supergene carbonates acquired their carbon through dissolution of pre-existing soil carbonates (Section 8.4.5).

8.4.1 Biogenic Carbon

8.4.1.1 Premises

P1: Biogenic CO_2 dissolves at an ambient temperature of about 15 °C (T). P2: During residence in the soil horizon, biogenic CO_2 does not undergo any isotopic modification (F). P3: The $\delta^{13}C$ of biogenic CO_2 can be estimated based on the results of a plant survey conducted in the Yucca Mountain area (T).

8.4.1.2 Arguments

A1: If P1, P2, and P3, then parental local fluids would have a dissolved $\delta^{13}C$ of about $-15‰_{PDB}$ (V and F).

8.4.1.3 Analysis

The valid logical construction of argument A1 requires that each premise be true if the conclusion is to be accepted. Premises P1 and P3 are true based upon published work (Quade and Cerling, 1990; Quade et al., 1989). P2 is false as was amply demonstrated by Quade et al. (1989). Atmospheric exchange of CO_2 strongly affects the isotopic signature generated during plant respiration (Quade and Cerling, 1990; Quade et al., 1989). Thus, the estimated $\delta^{13}C$ of parental fluids derived assuming no isotopic modification of biogenic CO_2 will be too light, making the conclusion of A1 false.

8.4.2 Dissolution of Vadose Carbon Dioxide Gas

8.4.2.1 Premises

P1: A mean value of $\delta^{13}C$ of CO_2 gas residing in the vadose zone is $-18.36‰_{PDB}$ at Yucca Mountain and $-20.0‰_{PDB}$ at Amargosa Narrows (T). P2: A mean value of $\delta^{13}C$ of CO_2 gas residing in the vadose zone at various locations in the Nevada Test Site is $-20.5‰_{PDB}$ (T). P3: Temperature for formation of surficial carbonates at Yucca Mountain is 15 °C (F).

8.4.2.2 Arguments

A1: If P1, P2, and P3, parental supergene pedogenic fluids may be expected to have $\delta^{13}C$ values ranging from -9.36 to $-11.5‰_{PDB}$ (IV and F).

8.4.2.3 Analysis

Argument A2 was invalidly constructed by Szymanski (1992). His logical structuring of the data required that conditions of formation of surficial calcretes were similar to present day situations—this premise was not evaluated by him. By not considering this factor, A1 becomes invalid. Premises P1 and P2 are true (White and Chuma, 1987; Thorstenson, 1993; Yang et al., 1993). For temperatures appropriate to the elevation of the surface carbonates at Yucca Mountain, the expected fractionation factor between soil CO_2 and soil carbonate is close to 11‰ (Quade et al., 1989). If precipitated today, this would result in $\delta^{13}C$ values in carbonates ranging from -7.36 to $-9.5‰_{PDB}$, slightly lighter than that measured for the surface carbonates (Whelan and Stuckless, 1992). As was inferred by Quade and Cerling

(1990), calcretes in Trench 14 most likely precipitated under conditions unlike today, and the conclusion of argument A1 should not be accepted as true.

8.4.3 Local Infiltrating Water

8.4.3.1 Premises

P1: A mean value of $\delta^{13}C$ of young fluids from shallow alluvium is $-11.3‰_{PDB}$ around Amargosa Narrows (T). P2: A value of the $\delta^{13}C$ of young fluids in the shallow tuff pile in the Yucca Mountain borehole UE-29 a#2 is $-13.0‰_{PDB}$ (T).

8.4.3.2 Arguments

A1: If P1 and P2, then parental supergene pedogenic fluids may be expected to have $\delta^{13}C$ values ranging from -11.3 to $-13.0‰_{PDB}$ (IV and F).

8.4.3.3 Analysis

Argument A1 is invalid, since there is an insufficient logical connection between the stated premises and the conclusion. Similar to A1 in Section 8.4.2, Szymanski (1992) assumed carbonates at Yucca Mountain would precipitate under conditions similar to today. Premises P1 and P2 are true (White and Chuma, 1987; Benson and McKinley, 1985). Yang et al. (1993) clearly showed that soil carbonates are not in isotopic equilibrium with either soil CO_2 or soil HCO_3^-. This proves the statement Szymanski (1992) implicitly made (equilibrium conditions) is incorrect and hence the conclusion of A1 is not supported.

8.4.4 Interstitial Fluids

8.4.4.1 Premises

P1: The value of $\delta^{13}C$ of interstitial fluids from the vadose zone is -20.05 to $-26.70‰_{PDB}$ at Yucca Mountain (T).

8.4.4.2 Arguments

A1: If P1, then parental supergene pedogenic fluids may be expected to have $\delta^{13}C$ values ranging from -20.05 to $-26.70‰_{PDB}$ (IV and F).

8.4.4.3 Analysis

There is an insufficient logical connection between the stated premises and the conclusion, thus argument A1 is invalid. Similar to A1 in Section 8.4.3, Szymanski (1992) presumed the carbonates at Yucca Mountain would precipitate under conditions similar to today. Yang et al. (1993) clearly demonstrated that soil CO_2 is not in isotopic equilibrium with soil HCO_3^-, hence premise P1 is not true. In addition, soil HCO_3^- ^{13}C values do not indicate that carbonate dissolution is active (Yang et al., 1993). These factors demonstrate the assumption Szymanski (1992) implicitly made (equilibrium conditions) was incorrect, and the conclusion of argument A1 is not supported.

8.4.5 Pre-Existing Soil Carbonates

8.4.5.1 Premises

P1: Laboratory soil-leaching experiments released carbon only from pre-existing soil carbonates (F?). P2: A value of $\delta^{13}C$ of fluids derived from laboratory leaching of Nevada Test Site soil is $-12.0‰_{PDB}$ (T).

8.4.5.2 Arguments

A1: If P1 and P2, then parental supergene pedogenic fluids may be expected to have $\delta^{13}C$ value of $-12.0‰_{PDB}$ (IV and F).

8.4.5.3 Analysis

Szymanski's (1992) fifth inference (argument A1) for the possible carbon isotopic signature of parental fluids of the caliche at Yucca Mountain is invalid. A simple interpretation of the leaching experiments is not possible since the results would depend on the water-rock ratio of the experiment. In addition, if the leaching dissolves all the carbonate then the carbonate $\delta^{13}C$ is recorded, not the equilibrium fractionation between the fluid and the carbonate. Although P2 is true (Szymanski, 1992), premise P1 may not be true. Yang et al. (1993) stated if dissolution of caliche or calcite was occurring at Yucca Mountain, resultant pore water $\delta^{13}C$ would tend to move toward the range of -4 to $-8‰_{PDB}$. This suggests that leaching conditions used in the experiments cited by Szymanski (1992) may have also released carbon from organic matter. Since not all of the premises are true, the conclusion that parental supergene pedogenic fluids may be expected to have $\delta^{13}C$ value of $-12.0‰_{PDB}$ should not be accepted.

8.4.6 Carbon Isotopic Discordancy

8.4.6.1 Premises

P1: Parental local fluid's carbon isotopic signature, derived from biogenic CO_2, would have a dissolved $\delta^{13}C$ of about $-15‰_{PDB}$ (F). P2: Parental supergene pedogenic fluid's carbon isotopic signature, derived from dissolution of vadose zone CO_2, may be expected to have $\delta^{13}C$ values ranging from -9.36 to $-11.5‰_{PDB}$ (F). P3: Parental supergene pedogenic fluid's carbon isotopic signature, derived from local infiltrating water, may be expected to have $\delta^{13}C$ values ranging from -11.3 to $-13.0‰_{PDB}$ (F). P4: Parental supergene pedogenic fluid's carbon isotopic signature, derived from vadose zone interstitial fluids, may be expected to have $\delta^{13}C$ values ranging from -20.05 to $-26.70‰_{PDB}$ (F). P5: Parental supergene pedogenic fluid's carbon isotopic signature, derived from leaching of pre-existing soil carbonates, may be expected to have $\delta^{13}C$ value of $-12.0‰_{PDB}$ (F). P6: Parental fluids of calcretes and surficial veins had a $\delta^{13}C$ value from about -5.0 to about $-10.0‰_{PDB}$ (T). P7: Parental fluids of subsurface veins had a $\delta^{13}C$ value from about 2.7 to about $-11.3‰_{PDB}$ (T). P8: Precipitation of carbonates occurred during a glacial maximum (T?). P9: Biogenically derived CO_2 is the main source of dissolved carbon (T). P10: Rates of precipitation of micritic calcites are high (F?). P11: The fractionation factor between HCO_3^- and $CaCO_3$ under fast precipitation conditions is smaller than for slow precipitation conditions (T).

8.4.6.2 Arguments

A1: If P1, or P2, or P3, or P4, or P5, P6, and P7, then relative to the isotopic character expected in local supergene fluids, the isotopic character interpreted for parent fluids of the Yucca Mountain calcites is strongly discordant (IV and F). A2: If A1, P8 and P9, then paleo-fluids during the glacial maximum would be 2 to 3‰ lighter and the isotopic discordancy larger (IV and F). A3: If A1, P10 and P11, then the fractionation factor between HCO_3^- and $CaCO_3$ is 1‰ and the isotopic discordancy would be larger (V and F). A4: If A1, A2, and A3, then the carbon isotopic discord calculated assuming climatic conditions similar to today and fast precipitation conditions predicted by the micritic texture represents a minimum (V and F). A5: If A1 and S8.3A2, then the calcites cannot be of supergene origin (V and F).

8.4.6.3 Analysis

The construction of argument A1 requires only the truth of one of the first five premises, together with the truths of premises P6 and P7 to result in the conclusion being logically supported by the argument. Szymanski (1992) incorrectly inferred that all calcitic deposits beneath the surface are the result of supergene processes. By making this assumption (P7) he was able to construct an argument which required the conclusion to be accepted if P6 and one of the other premises can be demonstrated to be true. Due to his illogical connection of supergene processes to the presence of all calcites beneath the surface, argument A1 is invalid. Premises P1, P2, P3, P4, and P5 are false (see discussion in Sections 8.4.1 through 8.4.5). Premise P6 is true as stated by Szymanski (1992). As was pointed out by previous investigators, the heavy ^{13}C values in the subsurface above the present water table are from lithophysal deposits of calcite and do not reflect deposition of calcite during supergene processes (Whelan and Stuckless, 1992; Everden, 1992; Hays, 1993). Thus, P7 is false and there is no reason to accept his conclusion that relative to the isotopic character expected in local supergene fluids, the isotopic character interpreted for the parent fluids of the Yucca Mountain calcites is strongly discordant.

Argument A2 is invalid and the conclusion of the argument is false. Szymanski (1992) did not include all the necessary premises to form a valid argument. Szymanski (1992) must have implicitly assumed rates of soil respiration and other rates of processes associated with the carbon system remained constant and similar to today. The work of Quade et al. (1989) clearly demonstrated this assumption is false. Although P8 and P9 may be accepted as true statements, the conclusion does not logically result from the acceptance of just these two premises, since the third premise, A1, is false. There is no reason to expect a greater (or any) isotopic discordancy between the postulated parental fluids carbon isotopic signature and that required by the carbon isotopic signature of the carbonates (Quade et al., 1989; Quade and Cerling, 1990).

Based upon the valid logical construction of argument A3, if each of the premises were true, then the conclusion could be accepted as logically supported by the argument and the premises (Barker, 1989). A1 is false. Premise P11 is true (Szymanski, 1992, and references therein). Premise P10 has been asserted to be true by Szymanski (1992) without any reference or support (see discussion in Chapter 3) and cannot be assumed to be true. Since two of the premises used to construct this argument are false, the conclusion is not supported.

Argument A4 is a valid argument and requires the truth of each premise prior to acceptance of the conclusion. Each of the premises is false and Szymanski's (1992) conclusion that the carbon isotopic discord calculated assuming climatic conditions similar to today and fast precipitation conditions predicted by the micritic texture represents a minimum discordancy is incorrect.

Each premise of A5 must be true if the conclusion of this validly constructed statement is to be demonstrated to be logically supported by the argument. Premise A1 is false. The second premise, S8.3A2, carbon isotopic evidence supports a hypogene origin for the Yucca Mountain calcretes and vadose zone carbonate veins, is also false. Since A5 is valid, and each premise is false, there is no reason to accept Szymanski's (1992) conclusion that the calcites cannot be of supergene origin.

8.5 PALEO-GEOTHERMS AND OXYGEN ISOTOPIC EVIDENCE

8.5.1 Premises

P1: Oxygen isotopic analyses of late micritic calcites were used to construct $\delta^{18}O$ versus depth gradients (T). P2: Only samples that are the most enriched in ^{18}O were used in the reconstructions (T). P3: For these samples, corresponding calcite precipitation temperatures were at their relative minimum (F). P4: Paleo-geothermal gradient reconstructions may be made in relative terms of the ^{18}O character of micritic calcites (T). P5: For spatially distinct calcite specimens, the parent fluids were carrying the same $\delta^{18}O$ or the $\delta^{18}O$ variability is both known and constant (T?). P6: During formation of the specimens considered, nonequilibrium fractionation effects were either absent or, relative to the equilibrium fractionation curve, maintained a known relationship (T?). P7: Assuming nonequilibrium fractionation factors were either absent or depth-invariant, and for a constant depth, the observed $\delta^{18}O$ variability is about 3‰, reflecting the $\delta^{18}O$ fluctuations in the parent solutions (T?). P8: The fractionation factor is a known function of temperature (T). P9: Contemporary geothermal gradients range from about 20 to 24 °C/km (F). P10: For shallow specimens, the combined fractionation effects exceeded equilibrium effects and the difference was depth variant (T?). P11: For a constant depth, the observed range of values for $\delta^{18}O$ expresses the variability in the parent solutions and the combined fractionation effects (T?). P12: The combined fractionation effects were smaller than the equilibrium effects and the difference was depth-variant (F).

8.5.2 Arguments

A1: If P2 and P3, then reconstructed geothermal gradients will represent the mildest geothermal conditions prevailing during the formation of the Yucca Mountain veins (IV and F). A2: If P1, P4, P5, P7, and P8, then the reconstructed paleo-geothermal gradient (about 35 °C/km) is considered to be the most conservative and reliable (V and T?). A3: If P1, P4, P6, P10, and P11, then the value of the paleo-geothermal gradient was about 33 °C/km (V and T?). A4: If P1, P4, P6, P12, then the value of the paleo-geothermal gradient was about 58 °C/km (IV and F). A5: If A1, P9, and A2, or A3, or A4, then paleo-geothermal gradients were at least 10 °C higher than contemporary geothermal gradients in the vadose zone (IV and F). A6: If A5, then intermittently warm hypogene fluids ascend into the vadose zone (IV and F). A7: If A5, then the epigenetic calcites, together with metasomatic zeolites and young thermally reset zircons, record intermittent ascent of warm hypogene fluids into the vadose zone (IV and F).

8.5.3 Analysis

Szymanski (1992) derived three separate estimates of the paleo-geothermal gradient in the present day vadose zone. These are reflected in arguments A2, A3 and A4 and required different assumptions (premises) regarding the importance of equilibrium fractionation factors in the precipitation of calcites. The truths of these suppositions (P6, P7, P10, and P11) were difficult to ascertain, and conservatively they will be excepted as true (T?).

Szymanski (1992) constructed A1 in what seems a logical manner, however, embedded into his argument in premise P3 is the assumption that evaporative enrichment of ^{18}O in the fluids which precipitated surface carbonates did not occur. Without explicitly including this as a separate premise, argument A1 is invalid. Premise P2 appears to be true (Whelan and Stuckless, 1992). Premise P3 is false since Szymanski (1992) included the most ^{18}O enriched surficial carbonates, which may have been influenced by evaporation of parental fluids (National Research Council, 1992; Whelan and Stuckless, 1992). Thus, A1 is invalid and Szymanski's (1992) conclusion that reconstructed geothermal gradients will represent the mildest geothermal conditions prevailing during the formation of the Yucca Mountain veins is inaccurate and not supported by the argument.

Argument A2 appears to be valid, and its conclusion may be true. Premise P1 seems to be true (Whelan and Stuckless, 1992); however, it should be noted that Szymanski (1992) could only assume the youth of calcitic veins which have ^{230}Th/^{234}U dates in excess of 400 ka (Szabo and Kyser, 1990). By including several generations of calcites (Szabo and Kyser, 1990) which may have formed under different conditions (different initial isotopic contents of parental fluids), it is difficult to create a meaningful paleo-geothermal gradient. Similarly, by including the oxygen isotopic information from several different cores, Szymanski (1992) determined a geothermal gradient which may not be directly comparable for all boreholes since even at present day there is spatial variability of geothermal gradients (U.S. Department of Energy, 1988). With this caveat in mind, P4 can be tentatively accepted as true. Premises P5 and P7 are merely assertions made by Szymanski (1992) and are difficult to analyze with respect to their truth. Present day aquifer fluids have a δ^{18}O spatial variability of about 1.5‰ (Benson and McKinley, 1985), while the actual variability may be larger. For a given observation station over a period of a few years, fluctuations are known to be as large as 5.0‰ (Lyles et al., 1990). In addition, for observation periods of a few 100 ky, the known δ^{18}O fluctuations range from 2.7 to about 4.0‰ (Winograd et al., 1988). These observations indicate the relative insensitivity of the measured oxygen isotopic of calcites in unambiguously determining a temperature of formation. Premise P5 has been tentatively accepted as true. Szymanski (1992) hypothesized (P7) the 3‰ variability in oxygen isotopic content of calcites at a constant depth only reflects variability in the parental fluid isotopic signature. This may not be true. However, without any way to evaluate this assertion, a conservative approach would require acceptance of this premise. Premise P8 is true (Szabo and Kyser, 1990; Szymanski, 1992). With the conservative acceptance of these premises (P1, P4, and P7) the conclusion of this argument, that reconstructed paleo-geothermal gradient (about 35 °C/km) is considered to be the most conservative and reliable, may be accepted as being supported by the logic of the argument and the truth of the premises.

The valid construction of argument A3 requires truth of several premises which might not be true. Szymanski (1992) assumed (P10) depth variant nonequilibrium fractionation due to a hypothesized rapid and depth variant escape of CO_2 from the parent solution during formation of the calcites (the CO_2 degassing rate decreases depthward). Although this scenario is unlikely, premise P10 will be tentatively accepted as true since this is the scenario Szymanski (1992) asserted was responsible for formation of the mosaic breccias (Chapter 6). Premises P1 and P4 may be true. Premise P6 is not explicitly addressed by Szymanski (1992) and he gave no reason for selecting the exact depth variability in the fractionation factor which he chose. Given the known relationship Szymanski (1992) presented in his Figure 8-11c, premise P6 will be tentatively accepted as true. Finally, P11 can only be accepted as true based upon Szymanski's contention. With the tentative conservative acceptance of each of the premises and the logically valid form of the argument, the conclusion (value of the paleo-geothermal gradient was about 33 °C/km) can be demonstrated to be a true characterization.

By Szymanski's (1992) own admission there is little reason to accept the accuracy of his third reconstruction of the paleo-geothermal gradient. Argument A4 is invalid since there is no logical connection between the premises and the conclusion of this argument. Premises P1, P4, and P6 may be true, however, acceptance of P12 would refute his primary hypothesis of rapid degassing of CO_2 which is necessary to create the mosaic breccias. Thus, P12 is false. The conclusion of argument A4, the value of the paleo-geothermal gradient was about 58 °C/km, is not logically or scientifically supported and should be discarded.

Construction of argument A5 requires that both premises A1 and P9 are true, as well as one of the other premises—A2, A3, or A4, if the conclusion is to be demonstrated true. Based upon the invalid nature in which A1 was derived, A5 is also an invalid contention. Argument A1 was demonstrated to be false. Szymanski (1992) quoted a geothermal gradient (22 °C/km) for borehole UE-25a#1 which is inaccurate (Szabo and Kyser, 1990, quoted a gradient for depths up to 470 m as 36 °C/km). Although arguments A2 and A3 may be true, A4 is false. Since both A1 and P9 are also false, Szymanski's (1992) critical conclusion that paleo-geothermal gradients were at least 10 °C higher than contemporary geothermal gradient in the vadose zone is unsupported both logically and scientifically.

There is an insufficient logical connection between the premise of A6 and its conclusion. Argument A6 is invalid and the conclusion that intermittently warm hypogene fluids ascend into the vadose zone is not supported by the sole premise of the argument (A5 is false) and should be considered false.

Similarly, argument A7 relies on A5, and there is an inadequate logical connection between conclusion and sole premise. A7 is invalid. The conclusion that epigenetic calcites, together with metasomatic zeolites and young thermally reset zircons, record intermittent ascent of warm hypogene fluids into the vadose zone is false.

8.6 REFUTATION OF A SUPERGENE ORIGIN FROM U, C, AND O ISOTOPES

8.6.1 Premises

P1: There are uranium, carbon and oxygen isotopic affinities between hypogene analogs and the Yucca Mountain calcites (F). P2: There is a carbon isotopic discord between hypothetical supergene fluids and parent fluids of the Yucca Mountain calcites (F). P3: There is a discrepancy between the present geothermal gradient and the paleo-geothermal gradient (F). P4: ^{13}C enriched calcites record circulation either during subdued stages of hydrothermal activity or during waning stages of igneous activity (F). P5: The ^{13}C depleted calcites record deeper circulation, either during youthful stages of igneous activity or during invigorated hydrothermal circulation (F). P6: The parent fluids of the ^{13}C

enriched calcites acquired dissolved carbon from local Paleozoic carbonates (F). P7: The parent fluids for the ^{13}C depleted calcites acquired dissolved carbon from a local igneous source (the inferred CO_2 dissolution temperature ranges from 200 to 250 °C) (F).

8.6.2 Arguments

A1: If P1, P2, and P3, then the uranium, carbon, and oxygen isotopic data do not provide any factual basis for supporting the proposed supergene origin of some of the Yucca Mountain calcites (V and F). A2: If P4, P5, P6, and P7, then the observed range of $\delta^{13}C$ could be explained by and attributed to hypogene processes (V and F).

8.6.3 Analysis

If each of the premises were true, then based on the valid construction of argument A1, the conclusion would be true. Discussion of the scientific basis for Szymanski's (1992) construction of argument A1 was presented in Sections 8.3, 8.4, and 8.5. Analyses of arguments presented in those sections indicated that each premise in this argument is false. In essence, P1 is equivalent to Section 8.3 argument A4 (false), P2 is equivalent to Section 8.4.6 argument A1 (false), and P3 is equivalent to Section 8.5 argument A5 (false). Since each of the premises of this logically valid argument are false, the conclusion that the uranium, carbon, and oxygen isotopic data do not provide any factual basis to support the proposed supergene origin of some of the Yucca Mountain calcites is incorrect.

Argument A2 was constructed by Szymanski (1992) using conclusions derived from arguments based on analogies (Section 8.3). This assertion (A2) is valid. The truth of the premises used by Szymanski (1992) to construct A2 can be ascertained from discussions presented in Section 8.3 of this report. Analyses of the analogy-based statements in Section 8.3 (Szymanski, 1992) indicate that premises P4, P5, P6, and P7 are false. Since these premises are false and the argument is valid, the conclusion that the observed range of $\delta^{13}C$ can be explained and attributed to hypogene processes is false. This important conclusion adversely impacts any subsequent arguments constructed by Szymanski based on the carbon isotope system. In effect, the conclusion of any valid argument which contains a premise relying on interpretation of the carbon isotopic signature as reflective of a magmatic source or caused by intermittently active conductively replenished hydrothermal system, will be false. If the conclusion of any subsequent argument includes the same interpretation of the carbon isotopic content of the calcites, then that argument will be invalid and the conclusion false, since this would be an example of a *petitio principii* (Barker, 1989).

8.7 STRUCTURAL SETTINGS OF CARBONATES CONSTRAIN PARAGENESIS

8.7.1 Premises

P1: Subsurface calcites represent three different structural settings: in-fillings of lithophysal cavities; interstitial impregnations and replacement of phenocrysts; and discrete veins (T). P2: In-fillings of lithophysal cavities represent deuteric carbonatization (T). P3: Interstitial impregnations and replacements record prolonged hydrothermal exposure of calcite-bearing rocks (T?). P4: At least some of the discrete veins, particularly those associated with barite, fluorite, and pyrite and which are sparry in texture, are related to the Timber Mountain caldera carbonatization (T?). P5: The discrete micritic veins associated with opal-CT and sepiolite record intermittent activity of a fault-based hydrothermal system driven by conductively replenished heat sources (F).

8.7.2 Arguments

A1: If P2, P3, P4, and P5, then the corresponding $\delta^{13}C$ versus $\delta^{18}O$ fields ought to be somewhat distinct (IV and F). A2: If P2, P3, P4, and P5, then corresponding $\delta^{13}C$ versus $\delta^{18}O$ field ought to be explicable within the context of the presumed paragenesis (IV and F). A3: If P3 and P4, then the early epigenetic calcites ought to be spatially correlative with the Timber Mountain alteration minerals (V and T). A4: If P2, P3, P4, and P5, then the late epigenetic calcites ought to be spatially correlative with the late metasomatic (calcic) zeolites (V and F).

8.7.3 Analysis

Since the conclusion of this argument presupposes, based on carbon isotopic information of calcites, that late epigenetic calcites may be explained in terms of hypogene processes, argument A1 is invalid. In essence, this argument is a *petitio principii*, and fails to prove anything because it takes for granted what it is supposed to prove (Barker, 1989). Premise P2 is true (Levy, 1993; Whelan and Stuckless, 1992; Bish and Chipera, 1989; Hays, 1993). Premise P3 is true (Broxton et al., 1987; Bish and Chipera, 1989; Bish, 1989). Premise P4 also is true (Bish and Chipera, 1989; Bish, 1989). Premise P5 is false (Vaniman, 1993; Vaniman et al., 1988; Wang et al., 1993). The presence of opal-CT and sepiolite associated with the micritic carbonate veins effectively refutes a hydrothermal origin. Since P5 is false and the argument is invalid, there is no reason to believe the conclusion of A1 is true.

Argument A2 was constructed by Szymanski (1992) using the same premises as A1 and also presupposes carbon isotopic evidence for hypogene origin of calcites. Argument A2 is invalid. The conclusion is false since P5 is false.

Based on the valid logical construction of argument A3, if each premise was true, then the conclusion would be supported by the argument and could be accepted as true. Both premises P3 and P4 are true. Since A3 is valid and P3 and P4 are true, the early epigenetic calcites ought to be spatially correlative with the Timber Mountain alteration minerals.

Argument A4 was constructed (Szymanski, 1992) in a similar manner as A1, with the exception that it does not rely on carbon isotopic information from calcites in any of the premises and does not incorporate isotopic assertions in the conclusion. Because of these factors, A4 is a valid argument. Nonetheless, logical analysis of A1 indicates Szymanski's (1992) conclusion that late epigenetic calcites ought to be spatially correlative with the late metasomatic (calcic) zeolites is false.

8.8 THREE ISOTOPIC FACIES CONSTRAIN PARAGENETIC HISTORY

8.8.1 Premises

P1: Parent fluids of deuteric calcites were isotopically similar to magmatic fluids (T?). P2: Deuteric calcite precipitation temperatures ranged from 200 to 250 °C (T?). P3: Parent fluids of deuteric calcites were carrying igneous carbon with $\delta^{13}C$ ranging from -8.0 to about $-5.0‰$ (T?). P4: Parent fluids of deuteric calcites were variably enriched in ^{13}C via the diffusional ^{13}C enrichment mechanism

(CO_2 degassing) (T?). P5: Calcite precipitation temperature associated with a magmatic hydrothermal system are generally 100-200 °C (T?). P6: Local meteoric fluids associated with the hydrothermal system at Timber Mountain had $\delta^{18}O$ of about −4.0‰ (F?). P7: There is a trend toward isotopically heavy carbon with the evolution of the Timber Mountain magmatic center from 13 to 9.5 Ma (F?). P8: During the waning stages of activity of the caldera-forming magmatism, the earlier igneous source of carbon was replaced by an inorganic source of carbon, specifically, the Paleozoic carbonates (F). P9: The conductively replenished hydrothermal system was active for shorter periods of time relative to the magmatic based hydrothermal system (F). P10: The conductively replenished hydrothermal system is expressed at shallower depth west of the Stage Coach Road fault relative to the magmatic based hydrothermal system (F). P11: The conductively replenished hydrothermal system was associated with a greater depth of fluid circulation relative to the magmatic based hydrothermal system (F). P12: Epigenetic calcites formed during rapid degassing of CO_2 (F).

8.8.2 Arguments

A1: If P1, P2, P3, and P4, then the observed ranges of $\delta^{18}O$ (14.0 to about 17.0$‰_{SMOW}$) and $\delta^{13}C$ (−8.0 to about 5.0$‰_{PDB}$) in lithophysal in-fillings of calcite were produced by deuteric processes (IV and F?). A2: If P5, P6, P7, and P8, then the observed ranges of $\delta^{18}O$ (4.0 to about 12.0$‰_{SMOW}$) and $\delta^{13}C$ (−2.0 to about 4.5$‰_{PDB}$) in calcite interstitial impregnations and replacements of phenocrysts and discrete vein calcite were produced by prolonged hydrothermal activity associated with the Timber Mountain caldera episode (IV and F?). A3: If P9, P10, P11, and P12, then the observed ranges of $\delta^{18}O$ (13.0 to about 20.0$‰_{SMOW}$) and $\delta^{13}C$ (−3.0 to about −9.5$‰_{PDB}$) in epigenetic, mainly micritic, vein calcite were produced by the activity of an intermittently active conductively replenished hydrothermal system (IV and F). A4: If A1, A2, and A3, then the combined carbon and oxygen isotopic data for calcites represent three clearly distinct facies (IV and F?).

8.8.3 Analysis

Argument A1 as constructed by Szymanski (1992) is invalid. There is an insufficient logical connection between premises and conclusion. The lithophysal calcites do not have to represent deuteric alteration. Szymanski (1992) provided no evidence to support his assertions of the conditions of formation of deuteric calcite. Each premise in this argument may be true, however, there is inadequate support to assume this. The only relevant isotopic data which can address Szymanski's premises is that of Whelan and Stuckless (1992). Whelan and Stuckless (1992) provided an alternative geochemical model for the origin of the lithophysal calcites which involved precipitation of the calcite in the unsaturated zone. Additional evidence (Vaniman, 1993) based on the trace element and REE content of the calcites indicates that lithophysal calcites may have precipitated via the mechanism proposed by Whelan and Stuckless (1992). Although each of the premises may be true, there is no logical connection between the available evidence, and Szymanski's (1992) assumption that lithophysal calcites are deuteric in origin should not be accepted.

The invalid nature of argument A2 is the result of an insufficient logical connection between the premises and the conclusion. Similar to his development of A1, Szymanski (1992) gave no evidence to support his assertions (premises P5, P6, P7, and P8) of the conditions of formation of hydrothermal calcite in the Yucca Mountain area. Premise P6 is particularly suspect since modern precipitation and meteoric fluids have a substantially different isotopic signature. There was no justification presented by Szymanski (1992) for the apparent 10‰ discrepancy. The meteoric fluids $\delta^{18}O$ of about −4.0‰ asserted by Szymanski (1992) would have required much warmer climatic conditions. Whelan and Stuckless (1992) argued that the measured $\delta^{13}C$ values of the calcites in the saturated zone, those attributed a hydrothermal origin by Szymanski (1992), most likely formed under conditions (temperatures of 25 to 60 °C) in which fluids of the Paleozoic aquifer were infused into the Tertiary aquifer. Since the premises of this argument are not supported by any scientific proof and there is strong evidence of an alternate mechanism, there is no plausible reason to accept Szymanski's (1992) conclusion that the interstitial impregnations and replacements of phenocrysts and discrete vein calcite most likely formed under hydrothermal conditions.

Argument A3 is invalid and the conclusion of this argument is false. This succinct analysis is derived from the discussion presented in Section 8.6.

Similarly, A4 is invalid (see Section 8.6) and there is no logical or plausible scientific reason to accept Szymanski's (1992) conclusion that the combined carbon and oxygen isotopic data for calcites represent three clearly distinct facies. Any subsequent argument developed by Szymanski (1992) which infers the presence of distinct isotopic facies associated with deuteric, hydrothermal, and intermittently active conductively replenished hydrothermal processes will be invalid, since it will be a *petitio principii*.

8.9 FLUID INCLUSIONS AND ISOTOPES CONSTRAIN PARAGENESIS

8.9.1 Premises

P1: The ^{13}C enriched calcites may be associated with the fluid inclusion homogenization temperatures ranging from 94 to 240 °C (T?). P2: These temperatures are similar to those inferred from the spatially corresponding occurrences of the higher grade alteration minerals (T). P3: Some of the shallower ^{13}C depleted calcites from borehole USW GU-3 may also be associated with fluid inclusion homogenization temperatures ranging from 101 to 227 °C (T?). P4: Both of the shallow sampling sites in borehole USW GU-3 from which the fluid inclusion temperature samples were collected are associated with a hydrothermally altered fault zone (F). P5: The alteration aureole is centered and narrowly restricted to the fault zone itself (T). P6: Both the alteration aureole and the shallow fluid inclusion sampling sites in borehole USW GU-3 occur within three different stratigraphic members of the Paintbrush Tuff (F).

8.9.2 Arguments

A1: If P1 and P2, then the Yucca Mountain fluid inclusion homogenization temperatures may provide an adequate representation of the paleo-geothermal environment (V and T). A2: If P1 and P2, then the ^{13}C enriched calcites in the northwestern portion of Yucca Mountain were formed contemporaneously with higher grade alteration minerals and are related to the Timber Mountain hydrothermal metamorphism (V and T). A3: If P5 and P6, then these features are epigenetic (V and F). A4: If P3, P4, and A3, then these ^{13}C depleted calcites are epigenetic hydrothermal in origin (V and F).

8.9.3 Analysis

Argument A1 was validly constructed by Szymanski (1992) and the conclusion of the argument is true since each of the premises used to form the argument is true. Fluid inclusion temperatures measured by Bish (1989) for deeper parts of borehole USW G#2 closely correspond to the alteration mineralogy [e.g., chlorite at a depth of 1756 m; Bish and Chipera, (1989)]. The carbon isotopic measurements of Whelan and Stuckless (1992) support premise P1. Although results from the only three coincident fluid inclusion and isotopic samples available from the deep subsurface (> 1000 m) were used to develop this argument, there are major implications associated with the conclusion of this argument. First, the low temperature (25 to 60 °C) scenario envisioned (Whelan and Stuckless, 1992) for the carbon isotopic signature of calcites presently in the saturated zone must be at least partly incorrect. Second, it is only the coincidence of the fluid inclusion temperatures with the higher grade alteration minerals in the same sample which allows an unambiguous acceptance of the elevated temperatures during formation of these calcites.

Since premises P1 and P2 are true, and argument A2 was constructed validly by Szymanski (1992), then the conclusion that ^{13}C enriched calcites in the northwestern portion of Yucca Mountain were formed contemporaneously with the higher grade alteration minerals and are related to the Timber Mountain hydrothermal metamorphism is true. Again, the conclusion of this argument appears to be strongly in conflict with the postulated (Whelan and Stuckless, 1992) conditions of formation of some of the saturated zone calcites.

If both premises P5 and P6 were true, then the conclusion could be accepted since A3 is a valid argument. Information presented by Szymanski (1992) indicated P5 is true (see his figures 8-21a through 8-21d). However, these same figures and published mineralogic summaries (Bish and Chipera, 1989) indicate that P6 is false. The fluid inclusion calcite samples (Bish, 1989) referred to by Szymanski (1992) are not located in the altered fracture zone, but are some meters away from the altered fracture zone. Spatial mineralogical variability in the subsurface of Yucca Mountain is extreme (Bish and Chipera, 1989; Carlos et al. 1990, 1991, 1993), and it is scientifically indefensible to infer spatial/genetic associations even over distances of a meter. Since P6 is false, the conclusion of argument A3 should not be accepted.

Argument A4 is a valid deductive argument. The conclusion of A3 was demonstrated to be false. Premise P3 may be true (Szymanski, 1992), however, the wide range of temperatures recorded for single locations of calcites (45 °C for the sample from 131 m; 125 °C for the sample from 31 m) and the lack of any other zeolitic or higher grade alteration minerals associated with these locations (Bish and Chipera, 1989; Bish, 1989) suggest that fluid inclusion analyses are suspect. Although Szymanski (1992) argued that the lack of other alteration minerals associated with the calcites was not a convincing reason to reject the analyses, postulated hydrothermal fluids (Szymanski, 1992) would be the same fluids (high relative concentrations of alkaline earth elements) which were required by him to form Ca-Mg zeolites (Szymanski, 1992, Chapter 7). There is no mineralogical evidence for zeolites at the locations of the calcites; the closest zeolites within boreholes are found some 400 to 500 m deeper in the borehole (Bish and Chipera, 1989). Careful examination of the information provided by Szymanski (1992, figures 8-21a through 8-21d) and mineralogical analyses (Bish and Chipera, 1989) indicate P4 is false. Since A4 is valid and at least one of the premises is false, there is no plausible reason to accept that ^{13}C depleted calcites are epigenetic hydrothermal in origin. Further studies which combine multiple measurements (fluid inclusion, chemistry, stable isotopes, and U-series isotopes) on single samples would perhaps clarify the origin of the calcites. As Vaniman (1993) suggested, there is not likely to be a single model of calcite precipitation which will be adequate to explain the origins of all the calcites in the Yucca Mountain region.

8.10 SPATIAL DISTRIBUTION OF CARBON ISOTOPIC OVERPRINTING

8.10.1 Premises

P1: Older and predominantly sodic-potassic clinoptilolites are spatially correlative with the ^{13}C enriched calcites (F). P2: The measured K/Ar dates of the associated clinoptilolites are K/Ar ages of formation (T?). P3: Subsequent and strongly metasomatic clinoptilolites (fairly large mole percentage of Ca+Mg cations) are spatially correlative with the ^{13}C depleted calcites (F). P4: The measured K/Ar dates of the associated strongly metasomatic clinoptilolites are K/Ar ages of formation (F). P5: ^{13}C depleted calcites occur within the vadose zone, some 80 to 400 m above the contemporary water table in the northwestern segment of Yucca Mountain and throughout the 520 m thick vadose zone, as well as throughout the uppermost 320 m of the saturated zone in the southeastern region of Yucca Mountain (T). P6: There is a set of calcitic veins in the southeastern region of Yucca Mountain whose age remains uncertain (T). P7: The ^{13}C enriched calcites have acquired their dissolved carbon from nearby Paleozoic carbonates (T?). P8: Yucca Mountain ignimbrites have been carbonatized in association with three different hypogene processes (F). P9: There has been an increase in the depth of circulation associated with the conductively replenished hydrothermal system with time (dominantly in Paleozoic carbonates until 5 Ma, and subsequently in the Precambrian rocks) (F).

8.10.2 Arguments

A1: If P1 and P2, then it can be concluded these calcites represent epigenetic carbonatization related to the prolonged activity of a hydrothermal system driven by the Timber Mountain heat source (IV and F). A2: If P3 and P4, then these calcites represent epigenetic carbonatization related to intermittent activity of fault-based hydrothermal system driven by conductively replenished heat sources (IV and F). A3: If A1, A2, and P5, then ^{13}C depleted calcites appear to be hypogene in origin and confirm the expected concurrent development of metasomatic zeolitization associated with hypogene carbonatization (V and F). A4: If P6 and P7, then precipitation of these veins could have occurred during early stages of activity of a fault-based hydrothermal system when circulation was confined to the Paleozoic carbonates, or, during periods of subdued activity (thermal source depletion) of the fault-based hydrothermal system (IV and F). A5: If A2, P8, and P9, then carbonatization was initiated about 8.5 Ma and has continued intermittently until at least 2.0 Ma, and is directly attributable to the intermittent activity of a fault-based hydrothermal system driven by conductively replenished heat sources (IV and F).

8.10.3 Analysis

Argument A1 is invalid since there an inconsistency between the premises and the conclusion. Premise P2 may be true (WoldeGabriel et al., 1992). Szymanski (1992, figure 8-24) argued there is a clear spatial correlation between the ^{13}C enriched calcites and the sodic zeolites, however, once the calcite samples are correlated to the zeolite locations in the same borehole (Bish and Chipera, 1989), it is clear no spatial correlation exists. The apparent general lack of spatial coexistence of the calcites and zeolites was previously documented by Broxton et al. (1987). Thus, P1 is false and the conclusion of A1 should not be accepted.

The invalid nature of argument A2 is the result of Szymanski's (1992) assumption that the K/Ar dates of WoldeGabriel et al. (1992) reflected formation ages, and his assumption that intermittent activity of a fault-based hydrothermal system driven by conductively replenished heat sources occurred. Information provided by both Szymanski (1992) and Bish and Chipera (1989) indicated premise P3 is false. P4 is also false (see discussions in Chapter 7). The conclusion of A2, that calcites represent epigenetic carbonatization related to intermittent activity of fault-based hydrothermal system driven by conductively replenished heat sources, is false and not scientifically or logically supported.

Although A3 is a valid argument, the conclusions of A1 and A2 are false requiring the conclusion of A3 to be regarded as false. Premise P5 is true and simply reflects measurements presented in Whelan and Stuckless (1992).

Argument A4 is invalid since it presupposes that a fault-based hydrothermal system exists. Premise P6 is true; there is no published geochronological data for calcites presently located in the saturated zone. Szymanski (1992) offered P7 without any justification except the relative distance to the Paleozoic rocks. Even though P7 may be true, there is no logical basis to accept the conclusion of A4. Since the conclusion of A4 requires that fault-based hydrothermal systems exist, and their existence has not been proven, the conclusion of argument A4 should be rejected.

There is an insufficient logical connection between the premises and the conclusion, hence, argument A5 should be considered invalid. Both P8 and P9 are presented by Szymanski (1992) as assertions of the truth, however, he has not provided requisite evidence to justify his contentions. The conclusion of A2 was demonstrated to be false and there is no logical reason to accept the conclusion of A5.

8.11 PERVASIVE STRONTIUM METASOMATISM

8.11.1 Premises

P1: Unaltered Yucca Mountain alkali ignimbrites have low concentrations of strontium (about 20 ppm) (T). P2: Altered Yucca Mountain alkali ignimbrites have large but highly erratic concentrations of strontium (10 to about 700 ppm Sr) (T). P3: Relative to the devitrified interior of the Topopah Spring ash-flow sheet, the epigenetically altered vitrophyre exhibits substantial gains in both calcium and strontium (T). P4: For a given stratigraphic unit the average concentrations of strontium vary laterally (T). P5: The highest average concentration of strontium occurs in the vadose zone in the southeastern region of Yucca Mountain (T).

8.11.2 Arguments

A1: If P5, then the parent fluids responsible for both calcic zeolitization and the late ^{13}C depleted carbonatization carried elevated concentrations of total dissolved strontium (V and T?). A2: If P1, P2, P3, and P4, then the spatially differential strontium metasomatism may be related to the same hydrothermal processes responsible for calcic zeolitization and the ^{13}C depleted calcites (IV? and F?).

8.11.3 Analysis

Argument A1 is valid. Premise P5 is supported by strontium measurements presented by various authors (Spengler and Peterman, 1991; Peterman et al., 1991, 1993). Since A1 is valid and P5 is true, the conclusion of A1, that parent fluids responsible for both the calcic zeolitization and the late ^{13}C depleted carbonatization carried elevated concentrations of total dissolved strontium, is most likely true.

The invalid nature of A2 is caused by the inadequate logical connection between the premises and the conclusion of the argument. Premises P1, P2, P3, and P4 appear to be true (Spengler and Peterman, 1991; Peterman et al., 1991, 1993). The construction used by Szymanski (1992) for the conclusion of A2 is invalid since it required that hydrothermal processes were responsible for calcic zeolitization. Discussions presented in various sections of Chapter 7 indicated this was not the likely condition of formation for the zeolites. Benson (1976) provided evidence that zeolite formation is probably occurring under present conditions. Geochemical modeling of possible waters in the unsaturated zone suggests the fluids would be in equilibrium with the Ca-zeolites (Murphy, 1991, 1993). Thus, there is no reason to believe that spatially differential strontium metasomatism is related to hydrothermal processes responsible for the calcic zeolitization and the ^{13}C depleted calcites.

8.12 SEQUENTIAL STRONTIUM METASOMATISM REQUIRES TWO FLUIDS

8.12.1 Premises

P1: Ignimbrites altered during the Timber Mountain hydrothermal metamorphism have low present day values of the $^{87}Sr/^{86}Sr$ (less than 0.7100) and initial ratios from 0.7083 to no more than 0.7101 (T?). P2: For ignimbrites altered during the subsequent intermittent hydrothermal metamorphism present-day values of the $^{87}Sr/^{86}Sr$ ratios range from 0.7095 to 0.7202 (F?). P3: The corresponding initial ratios range from 0.7104 to 0.129 (T). P4: Locally, the appropriately radiogenic strontium is incorporated in only one primary reservoir, which is the Precambrian basement (F).

8.12.2 Arguments

A1: If P1, then fluids responsible for the Timber Mountain hydrothermal metamorphism had $^{87}Sr/^{86}Sr$ ratios from 0.7083 to no more than 0.7101 (V and T?). A2: If P2 and P3, then a conservatively representative value of the $^{87}Sr/^{86}Sr$ ratio in the allogenic fluids associated with a fault-based hydrothermal system is 0.7119 (IV and F?). A3: If A1 and A2, then the observed space-differential strontium metasomatism was developed sequentially in response to two distinct allogenic fluids, each having definite strontium isotopic characteristics (V? and T?). A4: If S8.10P9, P4, and A3, then the clearly evident bimodality of the strontium isotopic characteristics is compatible with an increasing depth of fluid circulation with time (IV and F?).

8.12.3 Analysis

Argument A1 is valid, the premises used by Szymanski (1992) appear to be true (Peterman et al., 1991, 1993; Spengler and Peterman, 1991) and the conclusion may be accepted as true.

Although the numerical values of present-day and initial strontium isotopic ratios cited by Szymanski (1992) are accurate (Peterman et al., 1991, 1993), he invalidly assumed in P2 that the values reflected intermittent hydrothermal metamorphism. Argument A2 is invalid since it presupposes that hydrothermal alteration is necessary to explain the strontium isotopic signature. Since A2 is invalid and P2 is false, there is no reason to accept Szymanski's (1992) hypothesis that a conservatively representative value of the $^{87}Sr/^{86}Sr$ ratio in the allogenic fluids associated with a fault-based hydrothermal system is 0.7119.

The conclusion of A1 is true, while the conclusion of argument A2 is false. Since A3 appears to be a valid argument, it follows that the conclusion should be false. However, Szymanski (1992) did not provide enough detail to reasonably determine if A3 is valid. The conclusion seems to be supported by the available data (Peterman et al., 1991, 1993; Marshall et al., 1992, 1993) and is tentatively accepted as true.

Argument A4 is invalid since there is an insufficient logical connection between premises and conclusion. Premise P4 was asserted to be true by Szymanski (1992) based upon evidence presented in Goff et al. (1991). However, both arguments in Everden (1992) and the isotopic measurements of Marshall et al. (1993) prove P4 false. Premise P9 from Section 8.10 (Szymanski, 1992) is unsubstantiated and false. There is no logical reason to accept the conclusion of A4 and no plausible scientific information which could support Szymanski's (1992) contention.

8.13 BIMODALITY OF CARBON AND STRONTIUM ISOTOPIC RATIOS

8.13.1 Premises

P1: The ^{13}C enriched calcites are spatially correlative with the ^{87}Sr depleted calcites (T). P2: The ^{13}C depleted calcites are spatially correlative with the ^{87}Sr enriched calcites (T). P3: The $\delta^{13}C$ versus $^{87}Sr/^{86}Sr$ field reconstructed for the Timber Mountain calcites is clearly distinct from the field reconstructed for the subsequent epigenetic calcites (T).

8.13.2 Arguments

A1: If P1, P2, and P3, then the subsequent epigenetic calcites were precipitated from solutions bearing both low relative concentrations of ^{13}C and high relative concentrations of ^{87}Sr (V and T). A2: If A1, then the observed evolutionary path is consistent with the postulated increased depth of circulation, with the resulting substitution of both the reservoirs of strontium (Paleozoic carbonates then Precambrian basement) and the sources of carbon (Paleozoic carbonates then igneous sources) (IV and F?).

8.13.3 Analysis

The valid construction of argument A1 and the truth of premises P1, P2, and P3, require that the conclusion of A1 be accepted as true. Premises P1 and P2 are true (Whelan and Stuckless, 1992; Peterman et al., 1991; Marshall et al., 1992). Although there are distinctive $\delta^{13}C$ versus $^{87}Sr/^{86}Sr$ fields found in the calcites of Yucca Mountain, the reason supplied by Szymanski (1992) for this difference, which is incorporated within P3, is not necessarily true. Since each premise is true and A1 is valid, the conclusion that epigenetic calcites were precipitated from solutions which were bearing both low relative concentrations of ^{13}C and high relative concentrations of ^{87}Sr, is true.

There was no logical connection supplied by Szymanski (1992) to adequately tie together the premise to the conclusion of A2. Thus, A2 is an invalid argument. Szymanski (1992) completely neglected the possibility that the radiogenic strontium could be derived from dissolution of radiogenic material at the surface of Yucca Mountain.

8.14 CARBON AND STRONTIUM ISOTOPES IN FLUIDS AND PALEOZOIC ROCKS

8.14.1 Premises

P1: Contemporary Paleozoic carbonate-based fluids are strongly enriched in both radiogenic ^{87}Sr (^{87}Sr/^{86}Sr of 0.7120 to 0.7190) and isotopically light carbon ($\delta^{13}C = -5.0‰_{PDB}$) (T). P2: Hypothetical fluids equilibrated with marine limestones of Paleozoic age would have ^{87}Sr/^{86}Sr of 0.7088 and $\delta^{13}C = 0.0 \pm 2.0‰_{PDB}$ (T). P3: The only source for radiogenic strontium and isotopically light carbon is from a deeper substratum (F). P4: With increasing maturity of fluids in both the Tertiary and Paleozoic aquifers, the δ^{13}C versus ^{87}Sr/^{86}Sr fields evolve to more radiogenic and heavy conditions (T?).

8.14.2 Arguments

A1: If P1 and P2, then the isotopic characters of carbon and strontium dissolved in contemporary Ca-Mg fluids are different from those incorporated in the host Paleozoic carbonates (V and T). A2: If A1 and P3, then the contemporary Ca-Mg fluids are being contaminated (intermixed) with deeper fluids (IV and F?). A3: If P4, then ^{13}C deleted calcites (light) are incompatible with local infiltrating chemically immature fluids (IV and F).

8.14.3 Analysis

Argument A1 is valid, both premises P1 and P2 are true. The conclusion of A1 that the isotopic characters of carbon and strontium dissolved in contemporary Ca-Mg fluids are different from those incorporated in the host Paleozoic carbonates is true. Both P1 and P2 are supported by published data (Stuckless, 1991; Marshall et al., 1990; Stuckless et al., 1991a, 1991b; Everden, 1992; Ludwig et al., 1992, 1993).

Szymanski (1992) incorrectly assumed the only radiogenic reservoir of strontium is from deeper Precambrian rocks. This is not true (Marshall et al., 1993). Additionally, he presumed that isotopically light carbon must be derived from deeper stratum, however, discussions presented earlier in this chapter clearly indicated the fallacy of this assumption. Thus, P3 is false. There were insufficient premises supplied by Szymanski (1992) to concretely tie the stated premise of A2 to its conclusion, and A2 is an invalid argument. Since A2 is invalid and P3 is false, there is no logical reason to accept the truth of the conclusion of A2. The idea that contemporary Ca-Mg fluids are being contaminated (intermixed) with deeper fluids is both illogical and unsubstantiated.

Previously in this chapter it was demonstrated that ^{13}C depleted calcites are not incompatible with local infiltrating chemically immature fluids. Premise P4 is based upon Szymanski's (1992) speculations and cannot be demonstrated to be true. Hence, argument A3 is invalid and the conclusion of A3 is false.

8.15 PARENTAL FLUID CARBON AND STRONTIUM ISOTOPIC AFFINITY

8.15.1 Premises

P1: For the parent fluids of the Timber Mountain calcites (vein set I) the reconstructed $\delta^{13}C$ versus $^{87}Sr/^{86}Sr$ field is compatible with that expected for fluids isotopically equilibrated with marine limestones of Paleozoic age (T?). P2: Diffusional ^{13}C enrichment explains the slight difference in values of ^{13}C (F?). P3: For the parent fluids of the late epigenetic calcites (vein set I) the reconstructed $\delta^{13}C$ versus $^{87}Sr/^{86}Sr$ field is compatible with contemporary Ca-Mg fluids (T?). P4: The small differences in the values of the $\delta^{13}C$ ratio is attributable to degassing of CO_2 (F). P5: Relative to contemporary fluids, parent fluids for the late epigenetic calcites may be presumed to have been ascending with much higher velocities (F).

8.15.2 Arguments

A1: If P1 and P2, then early allogenic paleo-fluids ought to display clear isotopic affinity with the Paleozoic carbonates (IV and F?). A2: If P3 and P4, then the subsequent allogenic fluids ought to be analogous to those for the contemporary Ca-Mg fluids (IV and F?). A3: If S8.12A3, then the spatial distribution of the whole-rock alteration and the corresponding zeolites is the result of overprinting of the Timber Mountain alteration aureole by a subsequent fault-based, strongly metasomatic aureole (IV and F?). A4: If S8.12A3, then the spatial distribution of the isotopic character of carbon incorporated in the epigenetic calcites does reflect the independently-known alteration overprinting (IV? and F?). A5: If S8.13A2, then for both of the identified isotopic and textural varieties of epigenetic calcite, differences in relative concentration of ^{13}C are directly attributable to differences in depth of fluid circulation, with resulting substitutions of carbon sources (V? and F?).

8.15.3 Analysis

Argument A1 is invalid since there is no clear or plausible connection between the premise and the conclusion. Although P1 appears to be true (Peterman and Stuckless, 1993; Peterman et al., 1991, 1992a, 1992b, 1993), premise P2 was offered by Szymanski (1992) without any motivation. It is logically inappropriate to accept that the early allogenic paleo-fluids ought to display clear isotopic affinity with the Paleozoic carbonates.

The invalid nature of argument A2 is demonstrated by the illogical and unsubstantiated hypotheses Szymanski (1992) made. Premise P5 is pure speculation and should be considered false. Premise P3 may be true (White and Chuma, 1987; U.S. Department of Energy, 1988; Claassen, 1985; Stuckless et al., 1991c), however, P4 is false (White et al., 1990). The conclusion of A2 is not supported by the argument or the premises and should be considered false.

Argument A3 is invalid. There was an insufficient logical connection made (Szymanski, 1992) during its development. The analysis of argument A3 in Section 8.12 (Szymanski, 1992) indicated that the conclusion was probably true. The conclusion of A3, that spatial distribution of the whole-rock alteration and the corresponding zeolites is the result of overprinting of the Timber Mountain alteration aureole by a subsequent fault-based, strongly metasomatic aureole cannot be supported by the logical structure of this argument. There is no reason to indicate the conclusion is true, and it is most likely false.

Similarly A4 is invalid. The truth of the conclusion of argument A3 in Section 8.12 (Szymanski, 1992) does not require acceptance of the conclusion of A4. Although Szymanski (1992) asserted the spatial distribution of the isotopic character of carbon incorporated in the epigenetic calcites does reflect the independently-known alteration overprinting, he has not adequately demonstrated that the alteration overprinting is independently known. In addition, he (Szymanski, 1992) has not sufficiently developed the scientific and logical connection between the strontium and carbon isotope systematics at Yucca Mountain. For these reasons, A4 is most likely false.

Finally, argument A5 appears to be valid. Since the conclusion of argument A2 of Section 8.13 (Szymanski, 1992) was false, the conclusion of A5 is false. A5 stated that both of the identified isotopic and textural varieties of epigenetic calcite and differences in relative concentration of ^{13}C are directly attributable to differences in depth of fluid circulation, with resulting substitutions of carbon sources. The different sources envisioned by Szymanski (1992) are not the same as most investigators have demonstrated (Stuckless, 1991; Winograd et al., 1985, 1988; Ludwig et al., 1992, 1993).

8.16 OPEN SYSTEM BEHAVIOR OF URANIUM IN YUCCA MOUNTAIN CALCITES

8.16.1 Premises

P1: The measured values of the $^{230}Th/^{234}U$ activity ratio exceeds asymptotic secular equilibrium for a few samples of calcite (F?). P2: Measured values for the vadose zone calcites are consistently lower than those for the submerged DH-2 vein (F).

8.16.2 Arguments

A1: If P1 and P2, then the Yucca Mountain calcites seem to exhibit open system behavior with respect to uranium isotopes (V and F?). A2: If A1, then the vadose zone calcites are leached by rainwater (V and T).

8.16.3 Analysis

Both premises P1 and P2 are false (Paces et al., 1993; Schlesinger, 1985; Stuckless et al., 1991a, 1991b; Rosholt et al., 1985; Whitney and Muhs, 1991). Since argument A1 is valid and the premises are false, the conclusion of A1 may be rejected. However, at least some of the calcites do exhibit open system behavior (Szabo et al., 1981; Szabo and Kyser, 1985; Szabo and O'Malley, 1985).

Argument A2 is valid and the conclusion is true since some of the calcites are open with respect to uranium isotopes.

8.17 SELECTIVE MOBILIZATION OF URANIUM-234

8.17.1 Premises

P1: The selective mobilization of ^{234}U atoms has the effect of diminishing the ^{234}U/^{238}U ratio, while at the same time enhancing the ^{230}Th/^{234}U activity ratio (T?). P2: Coexisting carbonates from the Eagle Mountain area of Mojave Desert have U/Th ages which are consistently older than the corresponding ^{14}C ages (F).

8.17.2 Arguments

A1: If P1 and P2, then selective mobilization of ^{234}U atoms renders U/Th ages to old by about 30 percent for 20 ka carbonates (IV and F).

8.17.3 Analysis

Argument A1 is invalid since the premises are not logically tied to the conclusion. Premise P1 is true (Ku and Liang, 1984), however, P2 is clearly false (Schlesinger, 1985; Ku and Liang, 1984). Since there is no logical reason to believe the conclusion of A1 and no scientific evidence to support Szymanski's (1992) assertion, then selective mobilization of ^{234}U atoms does not render U/Th ages to old by about 30 percent for 20 ka carbonates.

8.18 HISTORY OF FORMATION OF LOCAL CALCRETES

8.18.1 Premises

P1: There are three temporally discrete depositional sequences of calcretes at Busted Butte that are younger than the Bishop Ash (700 ka) (T?). P2: U/Th ages of the late epigenetic calcites indicate that there have been four generations of calcites (30, 75, 170, 280 ka) formed since the deposition of the Bishop Ash (F?). P3: Only three generations of the epigenetic calcites are evident at or near the topographic surface (F). P4: The emplacement of the fourth generation (mean U/Th age of 170 ka) appears to have been restricted to the lower region of the vadose zone (F).

8.18.2 Arguments

A1: If P1, P2, P3, and P4, then both direct field observations and U/Th ages yield the same number of depositional episodes of local calcretes (V and F).

8.18.3 Analysis

Argument A1 is valid, however, available evidence does not support acceptance of its conclusion. Uranium series measurements (Szabo et al., 1981; Szabo and Kyser, 1985; Szabo and O'Malley, 1985; Rosholt et al., 1985, 1988; Luo and Ku, 1991; U.S. Department of Energy, 1993; Muhs, et al., 1990; Kaufman, 1993; Zielinski et al., 1986; Vaniman, 1993) indicate that P1 is probably true, P2 is false, P3 is false, and P4 is false.

8.19 CALCRETE FORMATION CORRELATIVE TO MAGMATIC HISTORY

8.19.1 Premises

P1: The chronology of local magmatic activity can be derived from K/Ar and $^{40}Ar/^{39}Ar$ dating and geomorphic analyses (?). P2: S8.18P2 (U/Th ages of the late epigenetic calcites indicate that there have been four generations of calcites (30, 75, 170, 280 ka) formed since the deposition of the Bishop Ash) (F?).

8.19.2 Arguments

A1: If P1 and P2, then the K/Ar and $^{40}Ar/^{39}Ar$ ages for samples of local basaltic flows and cinders are in fairly satisfactory agreement with average U/Th ages of late epigenetic calcites (IV and F). A2: If A1, then the presumed igneous origin of carbon and hypogene origin of these calcites is correct (IV and F).

8.19.3 Analysis

Reviews of the K/Ar dating of volcanic features (Wells et al., 1990; Turrin and Champion, 1991; Crowe et al., 1983, 1986, 1992; Hill et al., 1993) indicate P1 is likely to be false. Szymanski (1992) did not provide a logical connection between the premises and the conclusion of this argument, and A1 is invalid. Since both premises P1 and P2 are false, this suggests the K/Ar and $^{40}Ar/^{39}Ar$ ages for samples of local basaltic flows and cinders are not in fairly satisfactory agreement with average U/Th ages of late epigenetic calcites.

Argument A2 is invalid and the sole premise of this argument is false. Szymanski (1992) did not provide any justification to connect the premise of this argument to its conclusion. The uranium series isotopes presented no substantial evidence to infer a presumed igneous origin of carbon and hypogene origin for the vadose zone and near surface calcites.

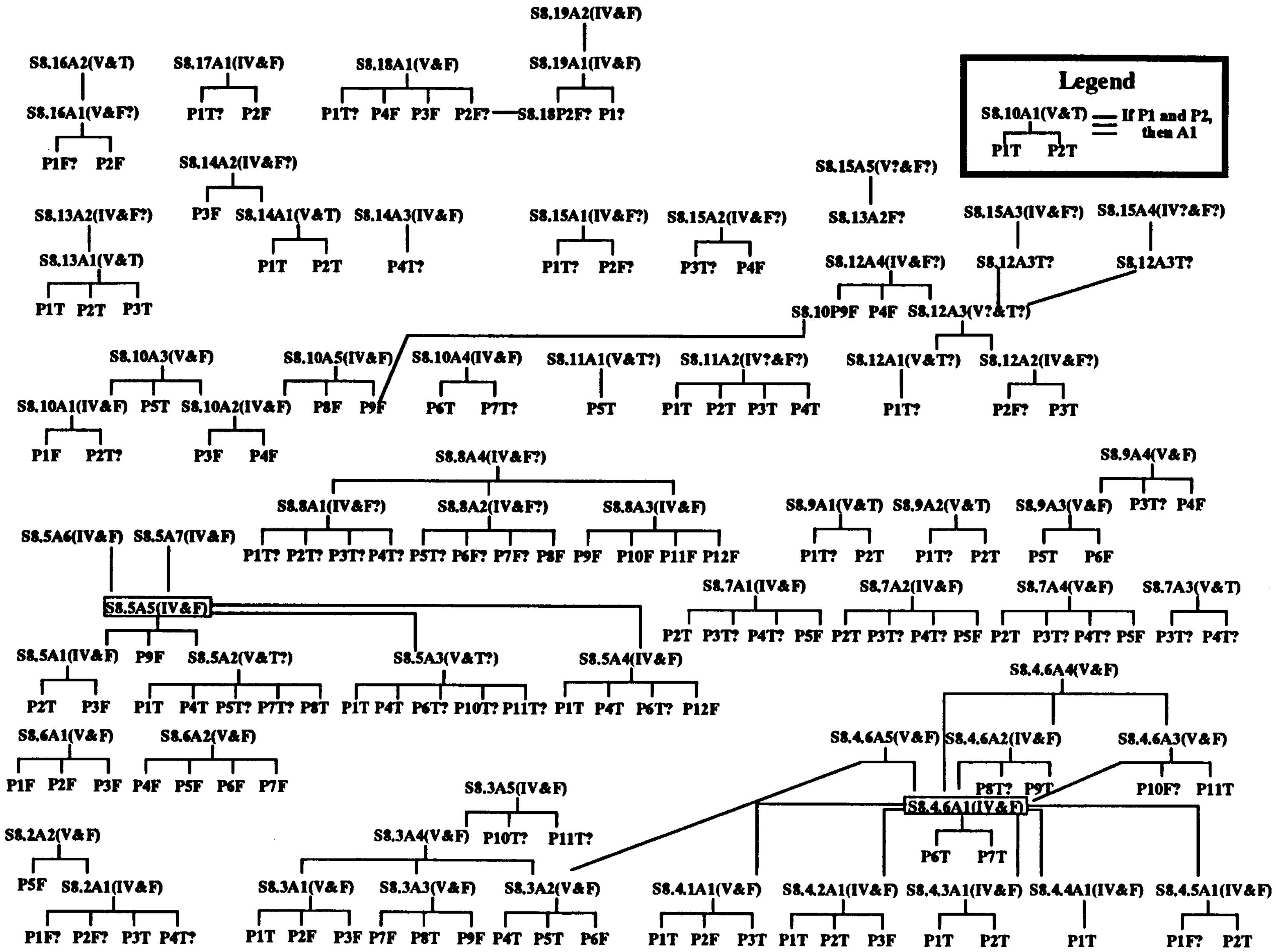
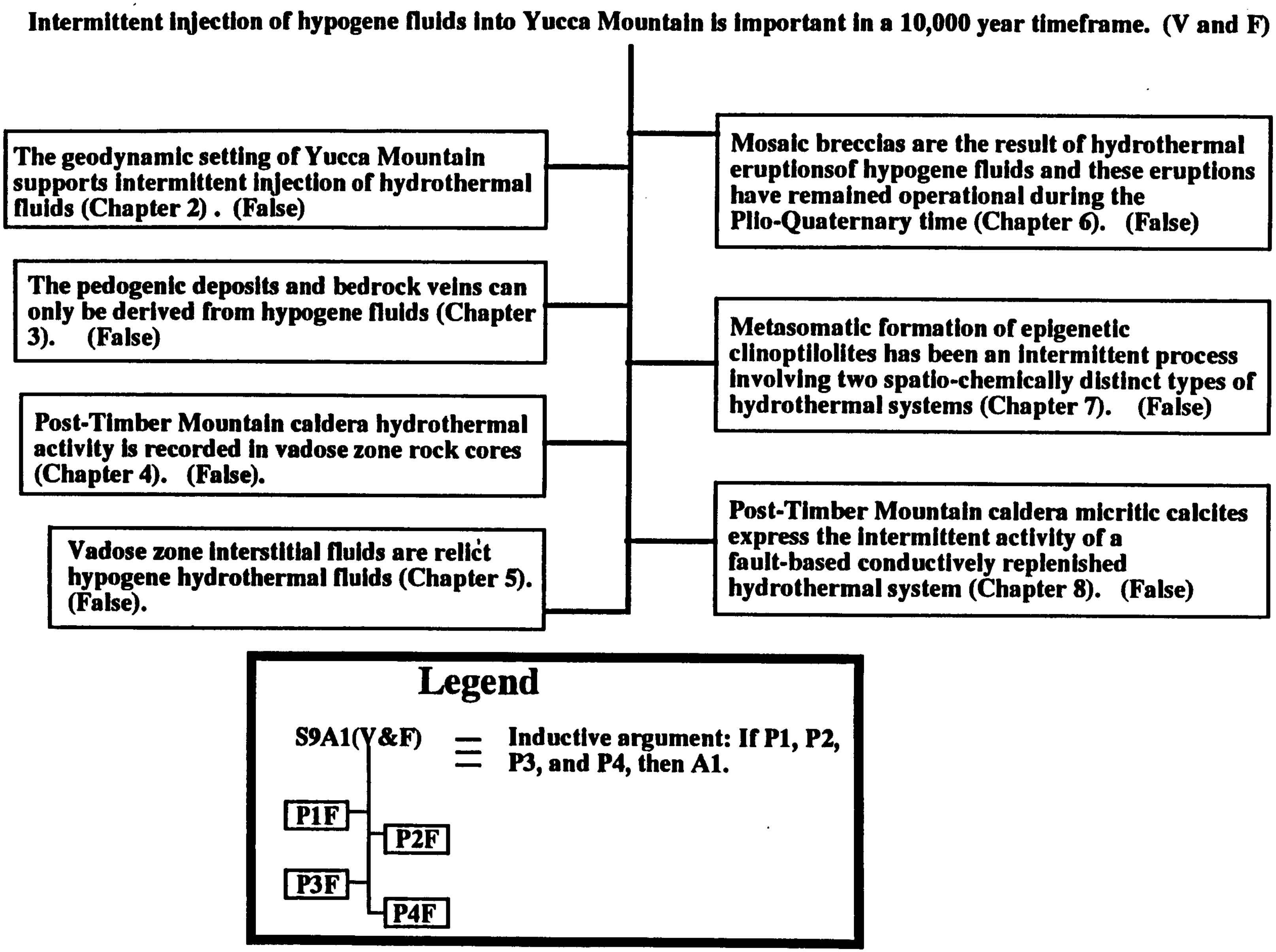


Figure 8-1. Logic diagram of arguments presented in Chapter 8

9 SUMMARY AND CONCLUSIONS

A systematic logical analysis of J.S. Szymanski's 1992 report, "The Origin and History of Alteration and Carbonatization of the Yucca Mountain Ignimbrites," was completed. In this analysis, validity of both deductive and inductive arguments posed by Szymanski (1992) was determined, together with evaluating the accuracy of both premises and conclusions of the arguments contained within that report. Szymanski's (1992) detailed use of a variety of field evidence and laboratory measurements of samples collected from the Yucca Mountain region in developing his arguments required a comprehensive and interdisciplinary evaluation of current knowledge of the hydrologic, petrologic, sedimentologic, and geochemical properties of the proposed candidate repository site at Yucca Mountain, Nevada. Szymanski (1992) asserted there was evidence that hydrothermal and auxiliary gas-assisted processes have been active at Yucca Mountain. Critical evaluation of the site data and the analysis of the logic (Figure 9-1) used by Szymanski indicates there is presently inadequate documentation to support his assertions.

The systematic and comprehensive approach used in this report identified several areas of current scientific uncertainty which directly influence the strength of arguments posed by Szymanski (1992) and which, if resolved, could provide the necessary information to unambiguously conclude between competing premises/models. Technical uncertainties were derived from incomplete characterization of the proposed flux of dust to the topographic surface in the Yucca Mountain area (necessary to support the supergene model), inadequate characterization of the history and mechanisms of recharge to the Alkali Flat/Furnace Creek groundwater system, an incomplete assessment of the degree to which non steadystate processes (climate) may control the formation of pedogenic deposits and other geochemical features of the subsurface, and an insufficient degree of integration of scientific measurements (multiple types of characterization of individual mineral specimens). The critical assumption (Szymanski, 1992) of an asthenospheric mantle as the framework from which geodynamic processes in Yucca Mountain are derived adversely affected many of Szymanski's arguments concerning the geodynamic possibilities for conductive and convective hydrothermal systems in the Yucca Mountain region. Analyses of his geodynamic arguments indicate a clear understanding of the thermal structure of the mantle in the Yucca Mountain area is not available. This seriously impacts the ability to adequately resolve the paleo-geothermal regime. In the future, in order to quickly and accurately examine possible alternative scenarios which could seriously impact the safety of the proposed repository, it would be wise to have the availability of integrated databases.



Intermittent injection of hypogene fluids into Yucca Mountain is important in a 10,000 year timeframe. (V and F)

The geodynamic setting of Yucca Mountain supports intermittent injection of hydrothermal fluids (Chapter 2) . (False)

The pedogenic deposits and bedrock veins can only be derived from hypogene fluids (Chapter 3). (False)

Post-Timber Mountain caldera hydrothermal activity is recorded in vadose zone rock cores (Chapter 4). (False).

Vadose zone interstitial fluids are relict hypogene hydrothermal fluids (Chapter 5). (False).

Mosaic breccias are the result of hydrothermal eruptionsof hypogene fluids and these eruptions have remained operational during the Plio-Quaternary time (Chapter 6). (False)

Metasomatic formation of epigenetic clinoptilolites has been an intermittent process involving two spatio-chemically distinct types of hydrothermal systems (Chapter 7). (False)

Post-Timber Mountain caldera micritic calcites express the intermittent activity of a fault-based conductively replenished hydrothermal system (Chapter 8). (False)

Legend

S9A1(V&F) ≡ Inductive argument: If P1, P2, P3, and P4, then A1.

Figure 9-1. Logic diagram of arguments presented in Chapter 9

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