

TIME-SPACE VARIATIONS IN MESOZOIC AND CENOZOIC
METEORIC WATERS, SOUTHWESTERN
NORTH AMERICA

By

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STATEMENT BY THE AUTHOR

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APPROVAL BY RESEARCH COMMITTEE

As members of the research committee, we recommend that this prepublication manuscript be accepted as fulfilling the research requirement for the degree of Master of Science.

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DISCLAIMER

This manuscript represents a rudimentary pass at interpreting the distribution of meteoric water compositions for the last 200 Ma in southwestern North America. The results present here reflect several new data and a compilation and interpretation of data from the literature, which may be expanded before final submission. Although this stage reflects considerable effort on the part of the authors, much remains to be done before publication. Readers are urged to contact the authors or refer to a future published version for more complete, accurate, and fully interpreted versions of the data set. In particular, we will be addressing completeness, interpretation of fluid sources and compositions in light of deposit geology, and a fuller synthesis of possible links between meteoric water compositions and their topographic and climatic controls.

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ABSTRACT

Mesozoic and Cenozoic hydrothermal systems of the southwestern North American Cordillera contain a complex record from which meteoric water stable isotope compositions ($\delta^{18}\text{O}$ and δD) can be inferred. This record is therefore of interest as a proxy for climate. New analytical results combined with systematic review of isotopic values from more than 200 locations in the southwestern North American Cordillera show regular isotopic patterns in time and space. Jurassic isotopic ratios are high, and Late Cretaceous values are more negative. During the Oligocene, there is a transition to more negative values. The ancient dD values are higher from most locations when compared to younger and present day values. This enrichment is compatible with warmer climates in the past and with changes in tectonic environments and paleoelevation and paleolatitude estimates over the same time interval. Complications in the application of the data include uncertainties in the estimated temperatures, alteration ages, isotopic disequilibrium, and incorporation of multiple fluids.

INTRODUCTION

The deuterium and oxygen isotopic compositions of meteoric waters vary systematically with latitude, temperature, elevation and distance from water source. Minerals formed in hydrothermal systems can incorporate fluids from various sources and commonly retain a record of these fluids. Thus, the isotopic compositions of hydrothermal and weathering-related minerals potentially contain an interpretable, yet complicated, record of climate. Modern hydrothermal systems have been shown to incorporate a meteoric water isotopic signature (Giggenbach and Corrales, 1992). Therefore, our intent is to explore the isotopic compositions of ancient hydrothermal systems as a means of studying larger scale isotopic trends in paleometeoric trends. These would be expected to have varied significantly, reflecting differences in tectonism (elevation) and climate.

Southwestern North America provides an excellent setting for this type of study, as it has been an active plate boundary zone since the late Paleozoic, with Mesozoic initiation of an Andean-type margin, followed by mid-Tertiary collapse (Dickinson, 1989; Lawton, 1994). As a result of this tectonism, there has been increased heat flow out of the crust, which provides the driving force for large convection cells that have the potential to incorporate large amounts of meteoric water. The isotopic composition of meteoric water is widely used to reconstruct paleoclimate (Savin, 1980; Seal and Rye, 1993; Sorensen et al., 1998). Previous work by Sheppard and Taylor (1969) on Cenozoic hydrothermal ore deposits in North America shows isotopic distributions that are broadly similar to those in modern meteoric water.

The isotopic record preserved in altered rocks depends on initial isotopic compositions of minerals and fluids, temperature of equilibration, and the water-rock ratio.

The possible fluids involved in hydrothermal events can be of meteoric, magmatic, metamorphic, and connate origin (Fig 1). The isotopic compositions of water within the hydrologic cycle are dependent on isotope fractionations that accompany evaporation and rain formation (Gat, 1996). These processes result in the depletion of meteoric waters relative to ocean waters and the enrichment of evaporative systems. Meteoric isotopic variation closely follows the equation $\delta D \approx 8 * \delta^{18}O + 10$ (Craig, 1961), where δ is defined as $\delta = ((R_{\text{sample}}/R_{\text{standard}}) - 1) * 1000$ [‰] and R stands for the isotope ratios of $^2\text{H}/^1\text{H}$ or $^{18}\text{O}/^{16}\text{O}$. Magmatic, metamorphic, and "connate" saline formation waters fall within coherent, although partially overlapping, isotopic fields. Notably, connate waters vary from place to place, especially with latitude.

The path followed during alteration of primary igneous rocks by meteoric water, for example (Fig 1), will initially be most evident in the hydrogen isotopic values (assuming $\delta D_{\text{initial}} \neq \delta D_{\text{fluid}}$), as the hydrogen concentration of natural rocks is relatively low. With continued exchange, changes in oxygen isotopic composition become more evident, and the bulk fluid-rock isotopic composition migrates toward the meteoric line (Taylor and Silver, 1978). Given a high water-to-rock ratio, minerals formed will approach isotopic equilibrium with waters. Fluid isotopic composition can be calculated from the mineral isotopic value and the temperature of formation using published fractionation-factors for mineral-H₂O exchange¹ (Appendix 2).

Interpretations of terrestrial pre-Quaternary paleoclimates are generally based on climate-dependent indicators that may reflect short-term anomalies such as seasonality or

¹ Data Repository item 9998. Appendix 2, References and details regarding applied $\delta^{18}\text{O}$ and δD isotopic fractionation factors, is available upon request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

biological activity. In contrast, meteoric water isotopic compositions preserved in hydrous mineral phases of supergene, hypogene and other hydrothermal mineralization events from water-dominated systems can provide evidence of regional and temporal patterns in the isotopic composition of precipitation. These systems can be active for hundreds of thousands to millions of years, thereby smoothing any short-term effects. Calculated meteoric water values only provide a proxy for climate, as the isotopic record is dependent on paleotemperature, paleolatitude and paleoelevation. Unfortunately, the means of determining these factors are limited. The most quantitative estimates rely on indicators solely constrained by climatic data, which can result in circular reasoning when both temperature and elevation estimates are derived from these data. However, in the context of regional paleogeography and tectonics, meteoric water isotope data can still provide insight into temperature and elevation changes.

Our database includes published $\delta^{18}\text{O}$ and δD values, plus twenty new analyses³ from over two hundred spatially or temporally distinct locations³ (Appendix 1). Samples range in

² Isotopic data are reported as δH and $\delta^{18}\text{O}$, where $\delta = 1000((R_{\text{sample}}/R_{\text{standard}}) - 1)$, where R_{sample} is D/H or $^{18}\text{O}/^{16}\text{O}$ in the sample and R_{standard} is D/H or $^{18}\text{O}/^{16}\text{O}$ in an appropriate standard, SMOW (assigned 0 ‰ for both δD and $\delta^{18}\text{O}$). Oxygen isotopic analysis was done following the method of Sharp (1980-add to EN). All samples were loaded into wells on a solid nickel plug, and placed under vacuum in the laser extraction line. Samples were heated by a Melles Griot CO_2 laser in the presence of BrF_5 , in order to liberate oxygen gas. The sample gas was cryogenically cleaned, then converted to CO_2 via a heated graphite finger. CO_2 gas was frozen into stopcock vessels for analysis on a Finnigan Mat Delta S mass spectrometer. Data for quartz were corrected by adding 0.75‰ to the analytical results, based on data for a variety of in-house and published standards that were run along with the samples. The analyses are reproducible within ± 0.5 ‰ $\delta^{18}\text{O}$. Hydrogen analytical procedures were modeled after Brown (1983). Clay samples were first dried for 24hrs at 50°C to remove any adsorbed water. Hydrous minerals were loaded into quartz tubes and placed under vacuum for eight hours. H_2O was cyclically liberated by exposure to a heated 140v platinum wire furnace for 15-20 minute intervals, increasing the percent voltage by 2% until all water was liberated. H_2O was passed through a U-235 furnace at 800°C to obtain H_2 gas, which was cryogenically cleaned and contained in sealed glass tubes. Tubes were placed on the

age from the Jurassic to the Quaternary and are from several types of igneous-related hydrothermal systems, extension-related hydrothermal systems, and supergene alteration zones of porphyry copper deposits. The results are interpreted in terms of independent data on North American tectonics, paleolatitudes, and paleoelevations, as well as global paleoclimate data.

STABLE ISOTOPE SYSTEMATICS OF HYDROTHERMAL SYSTEMS

Data that had the potential for reconstructing the isotopic composition of meteoric fluids were selected from the published literature on hydrothermal deposits in the southwestern Cordillera. Data displaying convincing evidence of non-meteoric fluid dominance were eliminated from consideration. Sites selected for the database³ include those that showed isotopic shifts away from primary magmatic values and that contained hydrothermal or weathering mineral assemblages, including quartz (veins and other), sericite, clays, epidote, and others. Where salinity was reported, data corresponding to high salinity were avoided in order to minimize complexities associated with brine fluid sources.

Because natural variations in D/H are much greater than $^{18}\text{O}/^{16}\text{O}$, all the results are interpreted in terms of δD fluid values. If hydrogen isotopic data were available, the fluid δD values were calculated based on the temperature of formation and the appropriate published fractionation factor for the mineral and temperature. When only $\delta^{18}\text{O}$ data were available,

Finnigan Mat Delta S mass spectrometer, then cracked to introduce gas for H/D isotopic analysis. Hydrogen isotopic data were corrected by adding 1.3‰ to the analytical results, based on data for a variety of in-house and published standards that were run along with the samples. The δD analyses are reproducible within $\pm 1.3\%$.

³ Data Repository item 9999. Appendix 1, Details regarding selected meteoric-influenced $\delta^{18}\text{O}$ and δD isotopic values, is available upon request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

fluid $\delta^{18}\text{O}$ was calculated based on the appropriate $\delta^{18}\text{O}$ fractionation-factor. Then, δD was calculated assuming that the original fluid composition fell on the meteoric water line (Craig, 1961), All $\delta\text{D}_{\text{fluid}}$ values were calculated and will be referred to as paleo-meteoric water δD , or $\delta\text{D}_{\text{pmw}}$.

There are several uncertainties with this approach. They include incomplete spatial coverage, analytical and theoretical uncertainties, age uncertainties, multiple fluid sources, and isotopic disequilibrium. The spatial and temporal coverage are limited by the presence of hydrothermal or weathering events. Analytical uncertainties contribute $<1\text{ ‰}$ and $<10\text{ ‰}$ variations in $\delta^{18}\text{O}$ and δD values, respectively, and thus are subordinate to the $>100\text{ ‰}$ per mil variations in the data set. There are also uncertainties in extrapolating fractionation curves constructed from high-temperature experimental data to lower temperatures. In many cases, available data lack constrained temperatures of mineral formation or equilibration. In order to use these data, a minimum and maximum temperature of formation were estimated given the alteration style, mineral assemblage (if reported), and the geologic setting. In rare situations, the δ values were calculated, and the midpoint was assigned as the δ value.

The ages of alteration events are often poorly constrained, despite extensive geochronological studies. In addition, in geologically complex areas it is often impossible to ascertain which alteration event is being sampled. This is particularly a problem in areas with multiple periods of emplacement and/or alteration, such as the San Juan Mountains, Colorado (Balsley, 1994; Hayba, 1997). Many hydrothermal systems are dated within $\pm 5\text{ m.y.}$ With others, only a qualitative age estimate for an alteration/mineralization event is available, and an age with suitable error brackets is assigned. This method of assigning large error brackets to data from locations with only general age information could unfairly weight these data

points on the time slice maps, as they will possibly plot on several maps. Given that most data have better defined age constraints, these points were left in the plots in order to provide the most comprehensive regional coverage.

Sources of hydrothermal fluids can be difficult to resolve. Fluids types include ocean water, "connate" formation waters, metamorphic waters, magmatic waters, fluids modified by exchange along the flow path, or mixtures of the above types (see Fig. 1). This is particularly relevant to lower-latitude, warmer regions, where meteoric δD values overlap with the values of many other types of fluids. In certain cases, detailed sampling and hydrogen and oxygen isotopic analyses have been used to determine the local mixing trends and time-space variations in the fluid sources (Giggenbach and Corrales, 1992). Isotopic data from systems with mixed fluids will record the isotopic composition of the mix, based on mass-balance calculations. Hydrothermal systems rarely interact with only one kind of aqueous fluid, although circulating meteoric fluids have been inferred to be the dominant fluid in many non-submarine hydrothermal systems (Hoefs, 1987).

Incomplete meteoric exchange, whether due to short temporal duration of the hydrothermal event or low water-rock ratio, will most affect δD values ($\delta D_{\text{initial}} \neq \delta D_{\text{fluid}}$) with little to moderate change of the $\delta^{18}\text{O}$ values (Fig. 1). Both δD and $\delta^{18}\text{O}$ values are essential to confidently ascertain the nature of the fluid. Otherwise, it may be impossible to know if there has been complete meteoric exchange. When oxygen is not fully exchanged during a hydrothermal alteration event, a calculated δD value would be unconstrainably higher than the actual value. Therefore, δD values in our data set that were calculated from $\delta^{18}\text{O}$ values constitute maximum estimates of the δD value.

In spite of these complications, the patterns presented below are remarkable when compared with current interpretations of paleoclimate and paleoelevation from the Jurassic to the present.

RESULTS

Figure 2 shows six time slice maps with δD_{pmw} values across southwestern North America. Jurassic - Early Cretaceous δD_{pmw} values tend to be high, with only 1 locations more negative than -80‰ (Fig. 2a). Spatial coverage is better in the Paleocene-Late Cretaceous (Fig. 2b), with numerous values around -100‰ . A belt of low values extends from inland California to Montana. Values of less than -100‰ are present throughout Nevada, Utah, and Colorado. Values on the order of -100‰ are present throughout Colorado and Montana.

Paleo-meteoric water δD values under -120‰ are more numerous in Eocene (Fig. 2c), with more negative values present in central Nevada, and farther inland and northward. There are no Eocene data from California and Oregon, likely reflecting the lack of arc magmatism and associated hydrothermal activity. There is dense spatial coverage during the Oligocene (Fig. 2d), encompassing much of southwestern Cordillera. Coastal areas are dominated by high values, transitioning to values less than -120‰ northeast of northeastern Nevada. During the Miocene (Figs. 2e), the lowest values occur in a belt through Utah, Nevada, and Idaho, parallel to the continental margin. The Pliocene - Pleistocene plot (Fig. 2f) contains few data points, especially in southern Arizona and Nevada. Despite this, it is still clear that the most negative values are inland from northwestern Nevada and Utah.

An alternate depiction of the data illustrates the change in values over time (Fig. 3). Only data from locations between 37° and 43° latitude are plotted. Less negative Jurassic

values tended to be restricted to more easterly locations. Two Early Cretaceous data points are in the -30‰ to -80‰ range. From 90 to 60 Ma, considerable hydrothermal activity appears to have shifted eastward in time, and values less than -100‰ became common. At 40 Ma, hydrothermal activity increased throughout the Cordillera, with average δD_{pmw} values less than those of earlier time periods. Between 20 and 30 Ma, there are fewer of the more negative δD_{pmw} values. By 20 Ma, low values constitute the bulk of the data, and the most negative values appear to have shifted westward in time, although this could be due to lack of spatial constraints. Little data is available for the last 10 Ma, probably due to the lack of exhumation of many recently active hydrothermal systems.

INTERPRETATION

Our high isotopic values during the Jurassic indicate a low, equatorial continent, which is consistent with plate reconstructions (e.g. Ross, 1992) that place the North American craton near the equator during the Jurassic. Best-fit wind directions for the Late Jurassic indicate a westerly flow, similar to present conditions (Parrish and Peterson, 1998), and evident in the isotopic values paralleling the West Coast. Our Cretaceous lower δD_{pmw} values correlate with a change in elevation, as suggested by Chase et al. (1998), who provided quantitative estimates of paleoelevations based on a reinterpretation of fossil flora physiognomy using an MAT-based paleoaltimeter. This evidence suggests that the Western Cordillera has been elevated since the Cretaceous. Our data is consistent with this and shows a marked depletion in δD_{pmw} values from the Jurassic to the Cretaceous. The δD_{pmw} values from the Laramide become significantly lower and range from -40‰ to less than -160‰. These results are similar to Dettman's (1994) Late Cretaceous through Eocene stable isotope variability, based on aragonitic bivalves from primarily fluvial deposits. Paleogeographic

interpretations place the western margin of North America near its current location by Late Paleocene (Ross, 1992), and our data maintain low isotopic values. The presence of numerous negative values from the inland regions of our Tertiary data set concur with Chase et al. (1998), who determined that elevations of 3 to 4 km were not uncommon throughout the Western Interior during the Tertiary. We see fewer extreme low values in the middle Eocene, in comparison to the more abundant low values in the Latest Cretaceous-Paleocene and late Oligocene data. During the Miocene, there is wider variability in the data, with limited isotopically heavier values present in the Western Interior.

These variations could be due to a number of factors, including changes in seawater composition, climate, latitude, or elevation. Exclusive of recent perturbations due to glacial events, the $\delta^{18}\text{O}$ value of seawater has been relatively constant through the Cenozoic and Mesozoic. Since the Jurassic, $\delta^{18}\text{O}$ seawater has changed by $\sim 1\text{‰}$ $\delta^{18}\text{O}$ (Gregory, 1991; Zachos et al., 1994). Ice core studies (Anklin et al., 1993) have shown that δD shifts correspond with shifts in $\delta^{18}\text{O}$, following the GMWL (Craig, 1961) $\pm 4\text{‰}$, and is subordinate to the $>100\text{‰}$ δD variations observed in the data set. The climate has cooled on the order of 10°C since the Jurassic (Drummond et al., 1993; Wolfe, 1990; Wolfe, 1994). Given the temperature- δD relationships of $\delta^{18}\text{O}$ 0.69‰C^{-1} (Rozanski et al., 1993) and δD 5.6‰C^{-1} (Dansgaard, 1964), this amount of cooling would represent on the order of 60‰ δD variation, close to half of what we observe in the data set. Changes due to the continental effect (depletion of heavy isotopes with distance) are shown to correlate to changes of $\sim 3.8\text{‰}$ $\delta^{18}\text{O}$ per 1000 km ($\sim 40\text{‰}$ δD) (Rozanski et al., 1993). Although the Western Interior has not maintained a constant width, the variation seen in the data plots is greater than 40 per 1000 km. Changes in elevation have been shown to dramatically effect the δD of meteoric

water (Ingraham and Taylor, 1986; Yonge et al., 1989). Although the temperature decrease and the continental effect contribute to the isotopic trends, they cannot sufficiently explain the observed ranges or variations in time and space that are evident in our data set. Therefore, it is likely that elevation effects are overprinting the other trends.

Given that elevation is a controlling factor, we interpret the lowering of isotopic values in the Cretaceous to be indicative of marked uplift of the southwestern Cordillera. Despite studies showing that the mid-Tertiary was the warmest time since the Jurassic, our data remain isotopically light, showing that the Western Interior remained at a high elevation. The collapse of the Basin and Range province is evident in the extreme variability and higher isotopic values in our Miocene and younger data.

CONCLUSIONS

Paleoclimatic indicators differ in the amount of spatial coverage, the period to which they pertain, and their usefulness in resolving events. In addition, only a small number of climate proxies can be applied to time periods older than the Quaternary. Plotted isotopic data from the Jurassic to the Paleocene clearly show depletion of isotope ratios with distance from coastal regions and thus indicate the involvement of a meteoric fluid. In addition, the distribution of values corresponds to current interpretations of paleoclimate and paleoelevation. The effects of many first-order climate factors, such as seasonal variations or glaciation, are not obvious in the plots. Continental effects and climate factors cannot account for the observed variations in δD . We interpret onset of more negative δD values in the Late Cretaceous to indicate the uplift of the Cordillera, with elevations staying high into the Oligocene. Miocene collapse is evident in the presence of less positive and spatially variable δD values. Given the likelihood that some data points are representative of areas

which may not have undergone complete exchange or were not entirely meteoric water dominated, the trends observed in this study are indeed remarkable.

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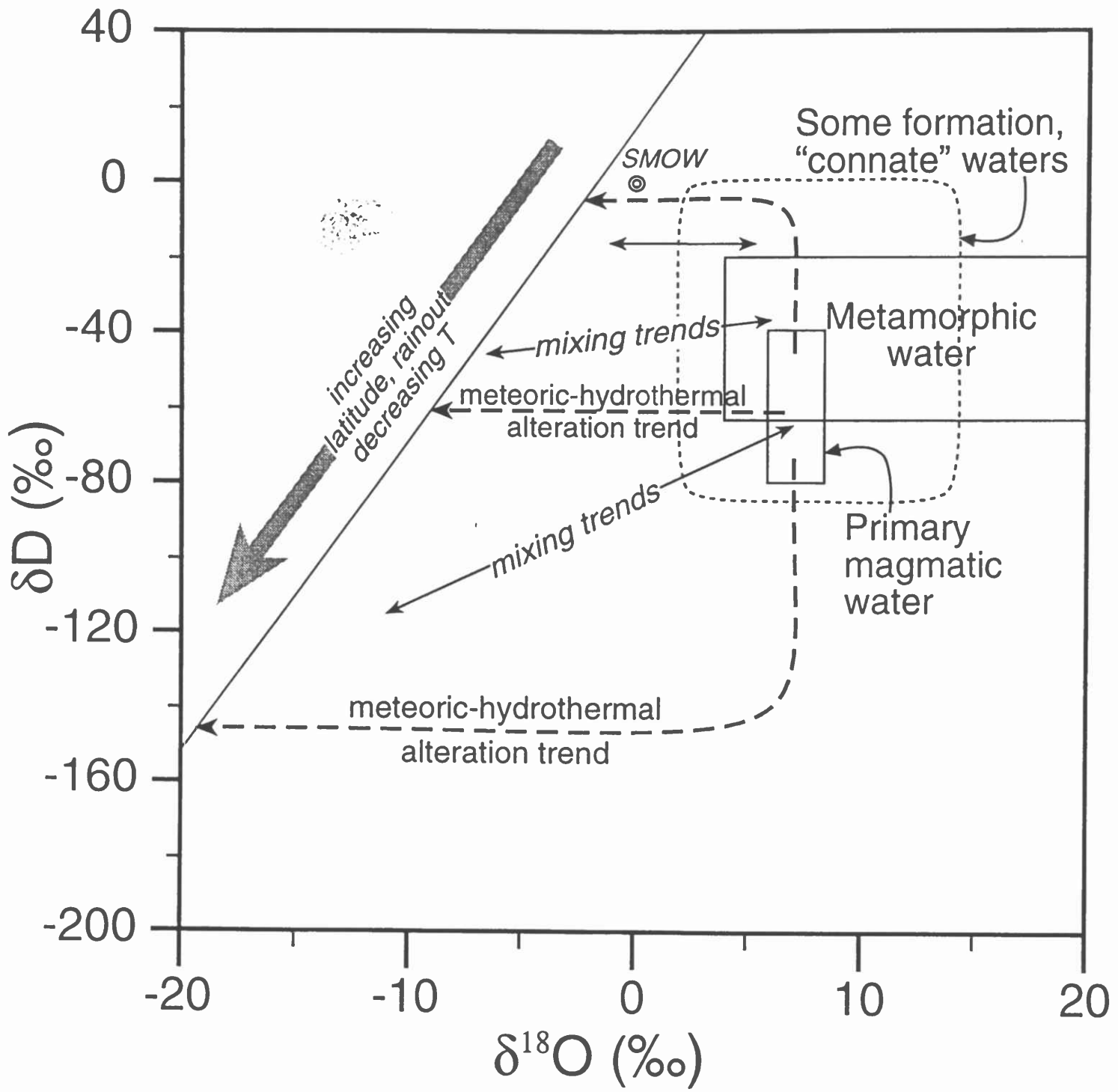
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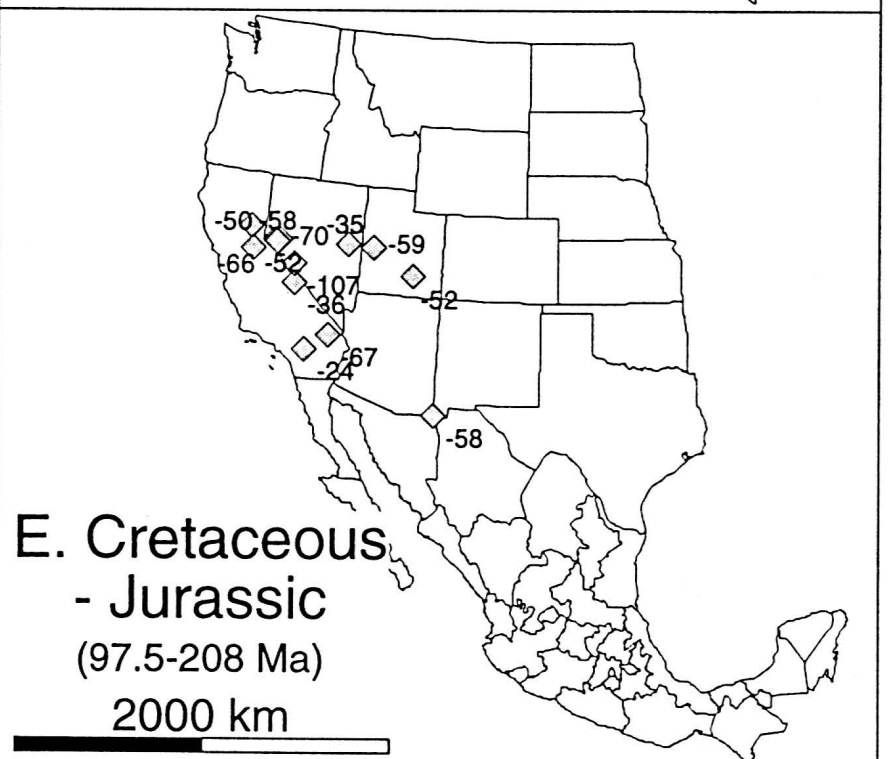
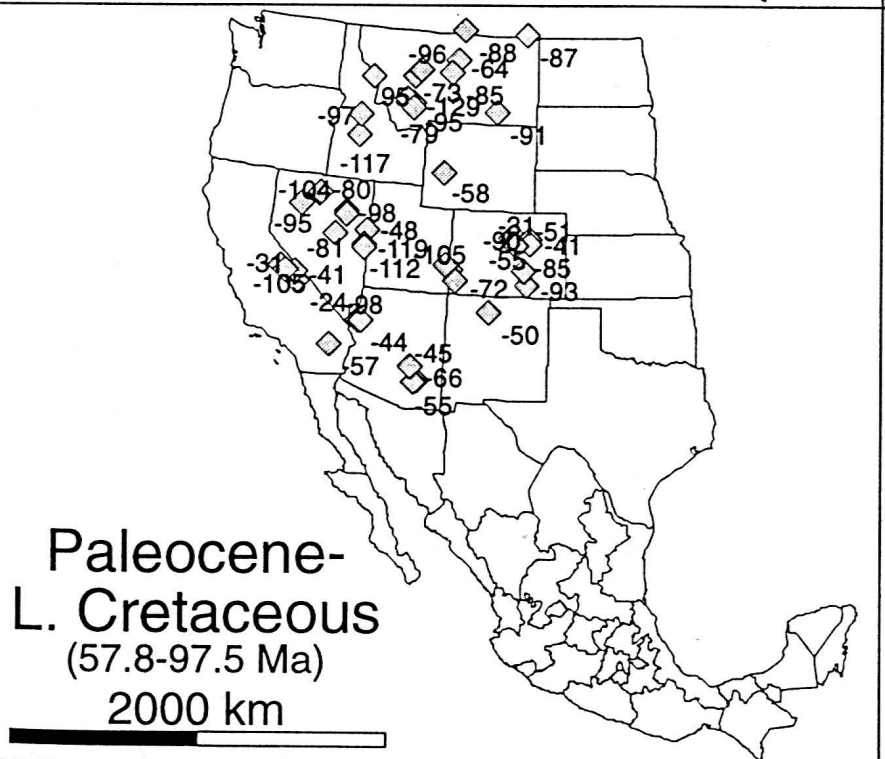
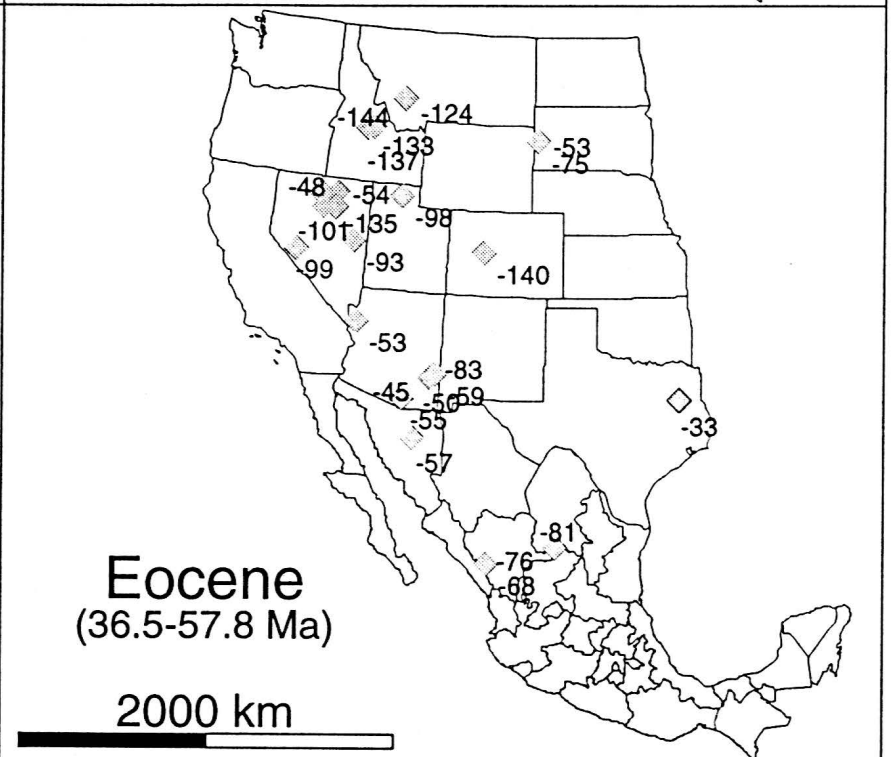
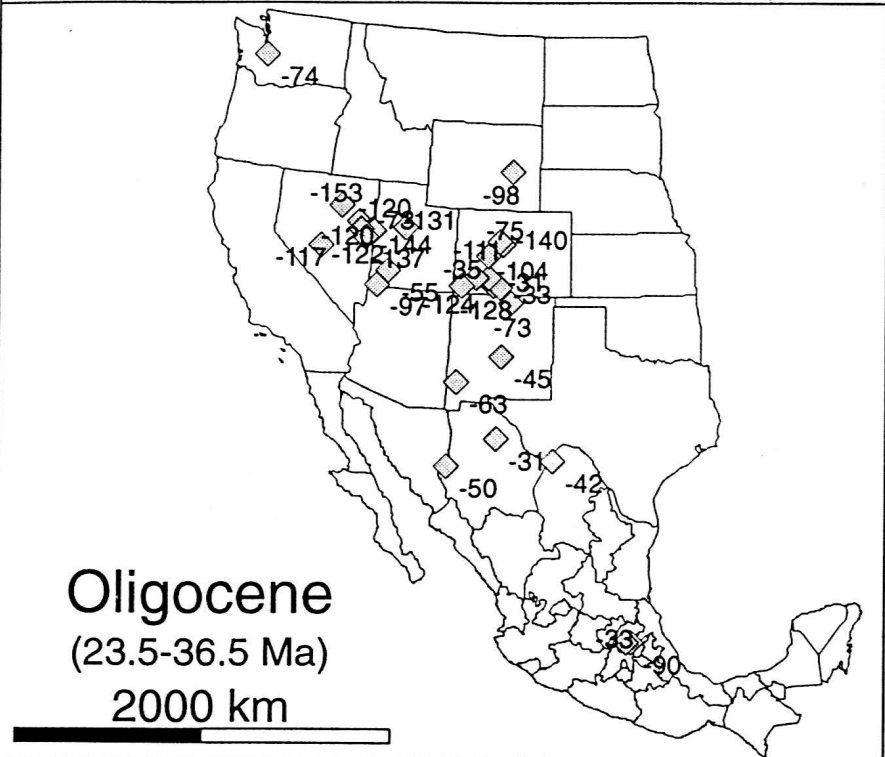
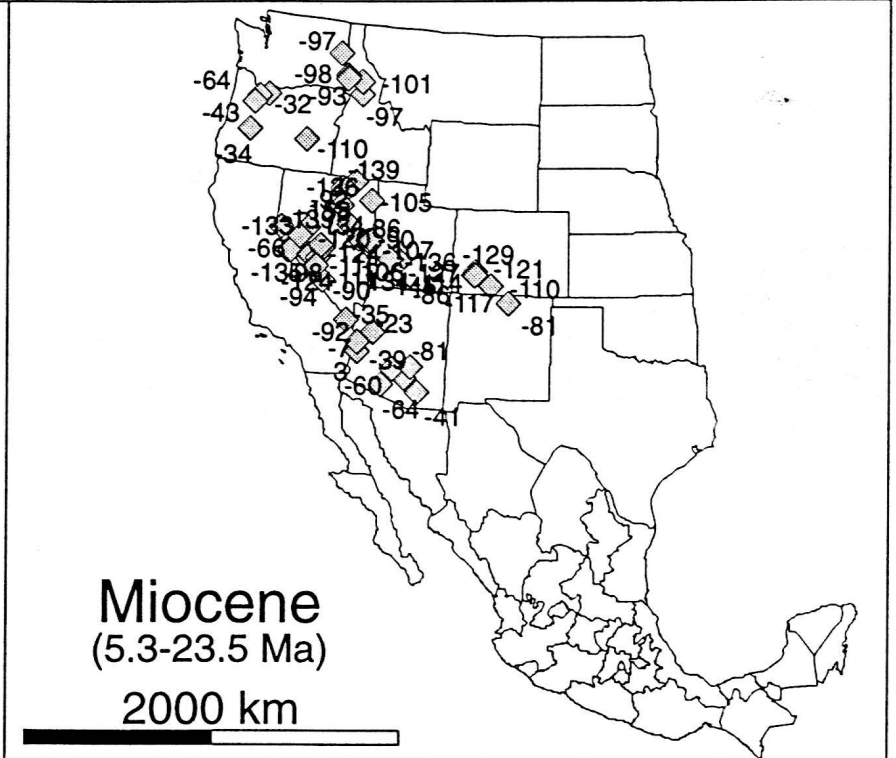
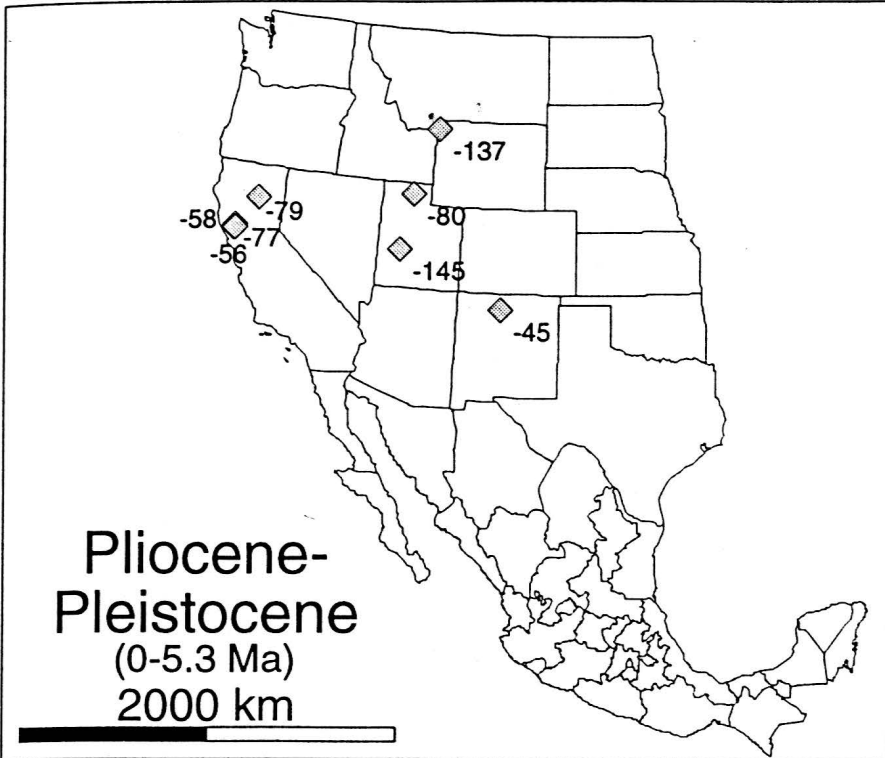
FIGURE CAPTIONS

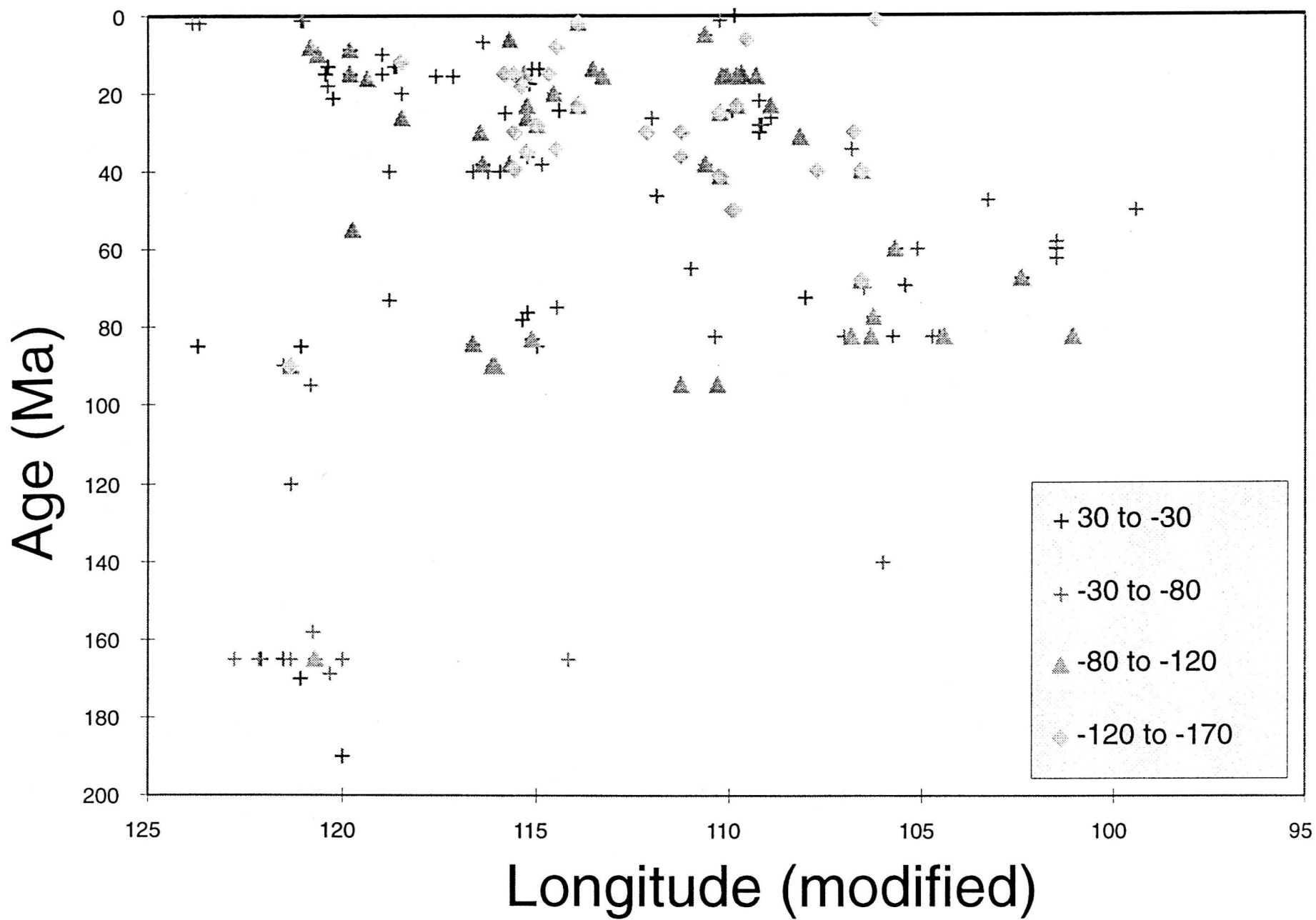
Fig. 1 Fluid isotopic variations in natural waters showing fields of magmatic, metamorphic, and "connate" waters (Hoefs, 1987; Taylor, 1978) and the meteoric water line (Craig, 1961). Dashed arrows show possible isotope evolution paths of minerals during meteoric-hydrothermal alteration of magmatic parent with increasing water/rock ratio after Taylor (Taylor, 1978). Straight solid arrows show bulk fluid isotopic values undergoing progressive mixing, or dilution, of magmatic with various meteoric waters.

Fig. 2 Plotted δD -paleo-meteoric-water values from hydrothermally altered locations in southwestern North America for selected time periods. (a) Jurassic to Early Cretaceous (208-97.5 Ma); (b) Latest Cretaceous-Paleocene "Laramide" (97.5-57.8 Ma); (c) Eocene (57.8-36.5 Ma); (d) Oligocene (36.5-23.5 Ma); (e) Miocene (23.5-5.3 Ma); (f) Pliocene-Pleistocene (5.3-0 Ma)

Fig. 3 δD -paleo-meteoric-water values verses time from 200 Ma to 1 , between 37° and 43° latitude.







APPENDIX 1

Details Regarding Selected Meteoric-Influenced $\delta^{18}\text{O}$ and δD Isotopic Values

To be submitted to Geology Data Repository, Documents Secretary,

GSA, P.O. Box 9140, Boulder, CO 80301

Database footnotes:

(1) If existing hydrogen isotopic data was available, the δD fluid was calculated directly.

When only $\delta^{18}\text{O}$ data were available, $\delta\text{D}_{\text{fluid}}$ was calculated based on the appropriate $\delta^{18}\text{O}$ fractionation-factor and the meteoric water equation. When possible, fluid-inclusion δD measurements were used directly.

(2) For locations that experienced alteration for known duration published age and error is used. If the alteration mineralization is not dated, but interpreted to coincide with the later stages of a dated event, the younger of any published ages were used, with appropriate errors.

When no qualitative age data exists for the alteration/ mineralization event, an age with appropriate error is assigned (i.e. "late Oligocene" equals 27 ± 4 Ma). Data was not discarded when an age estimate exists; therefore, the data set includes numerous points which will plot within a large window. For example, there are data from 11 regions that plot over 30 Ma of the Tertiary, due to lack of better age constraints than "mid Tertiary". This method of assigning large error brackets to data from locations with only general age information unfairly weights these data points. Given that most data has better defined age constraints, these points were left in the plots in order to provide the most comprehensive regional coverage

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA AZ	Buckskin Range	Picacho Metamorphic Complex	13	2	fsp	O	225	275	-64	32.75	111.37	(Kerrich et al., 1984)
USA AZ	Catalina Core Complex	Colossal Cave	20	3	qtz	O	240	260	-41	32.13	110.58	(Rudders, 1996)
USA AZ	Childs Ardwinkle	Copper Creek	65.8	2	phlog	D	400	500	-55	32.76	110.49	(Becker, this study)
USA AZ	Harcuvar Mountains		13	3	cc	O	100	130	-23	34.83	113.50	(Roddy et al., 1988)
USA AZ	Harcuvar Mountains		13	3	qtz	O	100	130	-35	34.83	113.50	(Roddy et al., 1988)
USA AZ	Ithaca Peak	Mineral Park	73	3	clay	D	80	150	-98	35.38	114.00	(Becker, this study)
USA AZ	Little Ajo Mtns.	Ajo	18.5	3	feld	O	100	200	-60	32.36	112.75	(Becker, this study)
USA AZ	Miami	Miami Mine	60	6	ser	D	100	250	-45	33.42	110.88	(Becker, this study)
USA AZ	Mineral Park		40	15	kaol	D	40	80	-53	35.41	114.18	(Sheppard et al., 1969)
USA AZ	Morenci		40	15	kaol>mont	D	40	80	-59	33.09	109.37	(Sheppard et al., 1969)
USA AZ	Morenci	Morenci	40	15	ser	D	100	250	-83	33.10	109.37	(Becker, this study)
USA AZ	Mule Mtns., Warren District	Bisbee	175	6	qtz	O	100	200	-58	31.40	109.05	(Becker, this study)
USA AZ	Safford		40	15	mont	D	60	150	-50	32.94	109.61	(Sheppard et al., 1969)
USA AZ	San Manuel region	Kalamazoo	65	3	ser	D	300	400	-65	32.68	110.69	(Becker, this study)
USA AZ	Silverbell	Esperanza	48.2	3	ser	D	200	300	-55	31.87	111.12	(Becker, this study)
USA AZ	Silverbell		48.2	3	ser	D	100	250	-50	31.87	111.12	(Becker, this study)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T (°C) min	T (°C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA AZ	South Mountains	Moon Mt. detachment	15	3	qtz	O	110	110	-69	33.17	112.17	(Smith and Reynolds, 1985)
USA AZ	Superior		22	2	dkt	D	200	350	-81	33.32	111.07	(Becker, this study)
USA AZ	Wallapai District	Mineral Park	73	3	anhydrite	O	120	200	-44	35.41	114.18	(Lang et al., 1989)
USA AZ	Copperstone	Copper-stone Gold	15	3	cc	O	80	120	-7	33.87	114.29	(Salem, 1993)
USA CA	Alabama Hills		85	20	Afs	O	230	250	-24	36.92	118.00	(Sorensen et al., 1998)
USA CA	Birch Creek		95	20	musc	D	345	355	-41	37.33	118.13	(Battles, 1990)
USA CA	Bishop District	Pine Creek	90	10	epid	AU	300	300	-105	37.36	118.70	(Brown et al., 1985)
USA CA	Clear Lake Volcanic field, Mine Coast Range	Mc Laughlin	2	1	qtz	D (FI)	150	200	-56	38.83	122.67	(Sherlock et al., 1995)
USA CA	Darwin	Defiance	165	25	sphal	FI	325	325	-66	38.43	120.57	(Rye et al., 1974b)
USA CA	Geysers-Clear Lake Area	Geysers	1	1	water	W			-57.9	38.84	122.73	(Donnelly et al., 1993)
USA CA	Hart mining district	Jumbo South	15	2	illite/smect	D	30	160	-91	35.27	115.08	(Mitchell and Crowe, 1993)
USA CA	Iron Age	Iron Age	58	5	qtz	O	200	225	-57	34.07	115.64	(Becker, this study)
USA CA	Lassen Nat. Park	Bumpus Hill	1	1	kaol	D	40	80	-79	40.47	121.50	(Sheppard et al., 1969)
USA CA	Marble Mtns.	Iron Hat	165	10	albite	O	195	205	-67	34.83	115.50	(Hall et al., 1988)
USA CA	Mono County	Bodie District	8	2	adularia (qtz)	FI	245	255	-98	38.22	119.02	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA CA	Ritter Range		90	5	WR	O	230	240	-31	37.57	119.07	(Hanson et al., 1993)
USA CA	Rodman-Ord Mts.	Stoddard Wells Pluton	165	25	WR	O	300	400	-23	34.00	116.76	(Solomon and Taylor, 1991)
USA CA	S. Inyo Mountains		158	15	Afs	O	170	230	-36	37.05	117.83	(Sorensen et al., 1998)
USA CA	Sierra Nevada Foothills	Allegghany Grass Valley, Washington	125	18	qtz, cc, mica	AU	300	350	-50	39.50	120.83	(Boehlke and Kistler, 1986)
USA CA	Sulphur Bank	Sulphur Bank	2	1	kaol	D	40	60	-77	39.00	122.66	(Sheppard et al., 1969)
USA CA	Whipple Mtns.		21	3	qtz	O	320	360	3	34.27	114.33	(Morrison, 1994)
USA CO	Adams County		82	15	kaol	D	30	40	-41	39.75	104.30	(Lawrence and Meaux, 1993; Rashkes, 1988)
USA CO	Arapahoe County		82	15	kaol	D	30	40	-51	39.53	104.30	(Lawrence and Meaux, 1993; Rashkes, 1988)
USA CO	Aspen		40	20		AU	260	260	-140	39.10	106.85	(Beaty et al., 1989)
USA CO	Boulder		82	15	kaol	D	30	40	-58	42.68	109.73	(Lawrence and Meaux, 1993; Rashkes, 1988)
USA CO	Bullfrog District		9	2	adularia (qtz)	FI	245	255	-94	37.01	116.79	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)
USA CO	Central City		60	2	py	FI			-90	39.78	105.48	(Rice et al., 1985)
USA CO	Climax		30	7	ser	D	270	280	-140	39.37	106.17	(Hall et al., 1974)
USA CO	Eureka Mining District	Sunnyside Mine, San Juan County	15	2	qtz	AU	295	300	-121	37.90	107.60	(Casadevall and Ohmoto, 1977)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA OO	Gilman District		34	3		AU			-75	39.53	106.38	(Beaty et al., 1988)
USA OO	Gunnison Co.	White Rock Stock	31	3	WR	D	250	350	-111	38.83	107.00	(Weidemann, 1986)
USA OO	Huerfano		82	15	kaol	D	30	40	-93	37.57	104.42	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA OO	Jefferson County		82	15	kaol	D	30	40	-55	39.42	105.17	(Lawrence and Meaux, 1993; Rashkes, 1988)
USA OO	Park County		82	15	kaol	D	30	40	-91	45.58	106.65	(Lawrence and Meaux, 1993; Rashkes, 1988)
USA OO	Pueblo		82	15	kaol	D	30	40	-85	38.25	104.58	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA OO	San Juan Mtns.	Lake City, Red Mtn.	23	1	ser	D	150	200	-117	37.87	107.70	(Bove et al., 1990)
USA OO	San Juan Mts.	South Mountain Dome Summit-ville	17	6	kaol	AU			-110	37.42	106.67	(Rye, 1993)
USA OO	San Juan Mts.	Creede	25	10	qtz	AU	245	255	-104	37.75	107.00	(Foley et al., 1989)
USA OO	San Juan Mts.	Alamosa River Stock Region	26	4	WR	O	250	300	-33	37.41	106.63	(Williams, 1980)
USA OO	San Juan Mts.	Mammoth Venue Vein, Platoro Caldera	26	4	qtz	O	230	230	-31	37.33	106.25	(Brooks, 1986)
USA OO	San Juan Mts.	Ouray	6	4	dickite	D	80	120	-129	38.08	107.67	(Sheppard et al., 1969)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T (°C) min	T (°C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA	CO	Schwartzwald	69	1	cc	O	100	190	-31	39.85	105.28	(Wallace and Whelan, 1986)
USA	CO	Slick Rock	63	5	cc	O	70	90		38.17	108.98	(Breit and Meunier, 1990)
USA	CO	W of San Juans	65	5	WR	O	100	300	-72	37.67	108.67	(Larson and Zimmerman, 1991)
USA	CO	West San Juan Mtns.	24	4	qtz	O	190	200	-35	37.78	107.70	(Musgrave and Thompson, 1991)
USA	ID	Bayhorse mining district	50	2	fluor	FI			-137	44.49	114.33	(Seal and Rye, 1993)
USA	ID	Clearwater	15.5	8.5	kaol	D	30	40	-102	46.45	115.78	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA	ID	Idaho Batholith	95	20	biot	D	450	450	-116	44.08	115.33	(Criss and Taylor, 1986)
USA	ID	Idaho Batholith	95	20	biot	D	450	450	-96	45.00	115.33	(Criss and Taylor, 1986)
USA	ID	Letah	15.5	8.5	kaol	D	30	40	-99	46.67	116.72	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA	ID	Nez Perce	15.5	8.5	kaol	D	30	40	-98	46.52	116.68	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA	ID	Owyhee County	15	2	adularia (qtz)	FI	245	255	-136	41.50	116.17	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)
USA	ID	S. Idaho Batholith	41	4	qtz	O	200	260	-132	44.45	114.72	(Criss and Taylor, 1983)
USA	ID	Yankee Fork	40	20	qtz (vein)	O	50	150	-144	44.45	114.71	(Criss et al., 1985)
USA	MT	Boulder Batholith	70	10	biot	D	490	510	-79	45.50	112.00	(Sheppard and Taylor, 1974)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T (°C) min	T (°C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA MT	Butte	Badger	40	15	kaol	D	30	80	-124	45.92	112.50	(Sheppard et al., 1969)
USA MT	Butte	Orphan Girl	68	5	ser	D	295	305	-129	45.92	112.50	(Sheppard and Taylor, 1974)
USA MT	Cascade		82	15	kaol	D	30	40	-96	47.25	111.68	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA MT	Judith Mtns.	Gies Mine District	67	2	kaol	D	220	230	-85	47.25	109.67	(Zhang and Spry, 1994)
USA MT	Little Rocky Mtns.	Zortman-Landusky Mine areas	58	3	illite	D	30	160	-64	47.83	109.33	(Wilson and Kyser, 1988)
USA MT	Mineral County	Snowbird Deposit	72	2	qtz	O	400	500	95	46.80	114.83	(Metz et al., 1985)
USA MT	Whitehall	Golden Sunlight	77	4	ser	D	165	170	-95	45.75	112.03	(Spry et al., 1996)
USA MT	Wolf Creek		60	10	WR glass	D	220	300	-73	46.95	112.05	(Taylor, 1968)
USA NA	Yerington	Standard Slag	169	1	mt	O	200	250	-58	38.95	119.15	(Becker, this study)
USA NM	Mesa Alta	Rio Arriba County	82	15	kaol	D	30	40	-50	36.20	106.58	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA NM	Nogal Mining District	Maud; Lincoln County	26	2	qtz	O	235	245	-45	34.00	106.00	(Douglass and Campbell, 1994)
USA NM	Questa	Sulfur gulch	23	3	WR	D	480	520	-81	36.65	105.58	(Hagstrum and Johnson, 1986)
USA NM	Questa	Rio Hondo	25	3	biot	D	490	510	-73	36.65	105.58	(Hagstrum and Johnson, 1986)
USA NM	Santa Rita		30	15	mont > kaol	D	30	40	-63	32.67	108.50	(Sheppard et al., 1969)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T (°C) min	T (°C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA NM	Valles Caldera	Valles Caldera	1	1	qtz	O	200	350	-45	36.25	106.50	(Goff and Gardner, 1994)
USA NV	Alligator Ridge		15	7	kaol	O	190	205	-134	39.77	115.58	(Ilchik, 1990; Ilchik, 1991; Ilchik and Barton, 1997)
USA NV	Ann-Mason Porphyry Copper Deposit	Yerington	169	2	ser	D	175	225	-52	38.99	119.28	(Dilles et al., 1992)
USA NV	Aurora District		10	1	adularia (qtz)	FI	245	255	-124	38.29	118.90	(Field and Fifarek, 1985; O'Neil and Silberman, 1974; Taylor, 1973)
USA NV	Battle Mtn mining district	Copper Canyon-East ore body	38	2	biot	D	500	500	-101	40.58	116.95	(Theodore et al., 1982)
USA NV	Candelaria		190	15	WR (sericitized)	D	245	255	-107	38.00	118.00	(Thomson et al., 1994)
USA NV	Carlin		30	15		FI			-153	40.62	116.18	(Field and Fifarek, 1985)
USA NV	Carlin		15	7	kaol	D	175	200	-158	40.62	116.18	(Bendrick, 1989; Ilchik, 1990; Kuehn and Rose, 1995)
USA NV	Comstock Lode		13	1	adularia (qtz)	FI	245	255	-133	39.30	119.67	(Field and Fifarek, 1985; O'Neil and Silberman, 1974; Taylor, 1973)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T (°C) min	T (°C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA NV	Comstock Lode, Virginia City	Mt. Davidson	18	10	WR	O	250	300	-66	39.30	119.67	(Criss and Champion, 1991)
USA NV	Cortez		30	15	qtz	FI			-128	37.33	108.58	(Field and Fifarek, 1985; Rye et al., 1974a)
USA NV	Cortez	Horse Canyon	36	2	kaol	D	175	245	-124	37.33	108.58	(Rye et al., 1974a)
USA NV	Dawley Canyon		83	1	musc	D	300	360	-98	40.37	115.50	(Battles, 1990)
USA NV	Egan Range	Ward	38	5	cc	O	240	260	-93	39.17	114.83	(Barton, 1998)
USA NV	Ely	Liberty Pit	6	4	halloy-site	D	30	50	-86	39.17	114.83	(Sheppard et al., 1969)
USA NV	Ely	Ruth	111	5	ser	O	150	250	-35	39.17	114.83	(Becker, this study)
USA NV	Fish Creek Range	McCullough Butte	84	5	musc (vein)	D	300	360	-81	39.37	116.03	(Barton, 1998)
USA NV	Gilbert District		8	1	adularia (qtz)	FI	245	255	-111	38.17	117.74	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)
USA NV	Humboldt District		73	1	adularia (qtz)	FI	245	255	-95	40.57	118.33	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)
USA NV	Jarbidge District		14	1	adularia (qtz)	FI	245	255	-139	41.85	115.42	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)
USA NV	Jerritt Canyon		20	10	qtz	AU	220	230	-92	41.40	115.97	(Daly et al., 1991; Hofstra et al., 1991; Hofstra et al., 1988; Ilchik, 1990)
USA NV	Kern Mtns		24	2	WR	O			-72	39.63	114.06	(Lee et al., 1984)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA NV	Kern Mtns.	Tungstonia	75	2	biot	D	425	425	-48	39.67	114.17	(Trim, 1990)
USA NV	Kern Mtns.	Tungstonia	34	2	musc	D	250	260	-137	39.67	114.17	(Trim, 1990)
USA NV	Kern Mtns.	Skinner	34	2	musc (fine vein)	D	255	305	-144	39.67	114.17	(Trim, 1990)
USA NV	Manhattan District		16	1	adularia (qtz)	FI	245	255	-116	38.55	117.03	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)
USA NV	N. Egan Range	Warm springs area	26	7	musc	D	220	260	-120	39.63	114.88	(Lee et al., 1984)
USA NV	New Boston		55	15	mont > kaol	D	180	250	-99	38.47	118.20	(Sheppard et al., 1969)
USA NV	Osgood Mts.	Granite Creek Mine	90	1	amph.	AU	535	545	-104	41.13	117.28	(Taylor and O'Neil, 1977)
USA NV	Osgood Mts.	Moly Mine	90	1	FI	FI			-80	41.20	117.26	(Taylor and O'Neil, 1977)
USA NV	Post/Betze	Goldstrike	39	20	kaol	D	30	80	-135	40.62	116.18	(Arehart, 1993; Ilchik, 1990)
USA NV	Regent District	Rawhide (Denton)	16	1	adularia (qtz)	FI	245	255	-120	39.01	118.39	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)
USA NV	Round Mountain		12	4	alunite	D	25	50	-124	38.68	117.13	(Gerike, 1991)
USA NV	Round Mountain		26	1	qtz	O	286	286	-117	38.68	117.13	(Gerike, 1991)
USA NV	Ruby Range	Dawley Canyon	85	5			450	450		40.48	115.50	(Battles, 1990)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA NV	Ruby-East Humbolt Range	Secret Creek and Northern Ruby Range	28	5	biot	D	480	620	-120	40.00	115.00	(Fricke et al., 1992)
USA NV	S.Snake Range Detachment	Williams Canyon	18	2	biot	D	480	620	-134	38.92	114.30	(Lee et al., 1984)
USA NV	S.Snake Range Detachment	Osceola	76	2	biot	D	480	580	-112	39.03	114.30	(Lee et al., 1984)
USA NV	S.Snake Range Detachment	Lexington Creek	78	2	musc	D			-119	38.87	114.22	(Lee et al., 1984)
USA NV	S.Snake Range Detachment	Pole Canyon-Young Canyon	23	1	biot	D	480	580	-106	38.95	114.22	(Lee et al., 1984)
USA NV	Sandstone-Kendell		21	1	qtz, Fl	Fl	233	248	-135	37.67	117.25	(Vikre, 1989)
USA NV	Schell Creek Range		35	2	biot	D	480	580	-122	39.26	114.51	(Lee et al., 1984)
USA NV	Shamrock batholith		165	5	amph	D	440	455	-70	39.00	119.00	(Battles, 1990)
USA NV	Snake Range Detachment	Black Horse Creek District	14	3	cc	O	75	77	-107	39.14	114.27	(Losh, 1997)
USA NV	Snake Range Detachment	Rock Canyon	14	3	cc	O	94	96	-89	39.17	114.14	(Losh, 1997)
USA NV	Tenmile District		16	1	adularia (qtz)	Fl	245	255	-97	45.83	115.67	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA NV	Toana Mtns.		15.4	2	biot	D	350	450	-105	41.01	114.30	(Lee et al., 1984)
USA NV	Tonopah District		19	1	adularia (qtz)	FI	245	255	-90	38.07	117.22	(Field and Fifarek, 1985; O'Neil and Silberman, 1974; Taylor, 1973)
USA NV	Tuscarora		38	1	adularia (qtz)	O	245	255	-53	41.30	116.20	(O'Neil and Silberman, 1974)
USA NV	Twin Creeks	Chimney Creek & Rabbit Creek	40	10	ser & kaol	D	250	300	-48	41.25	117.18	(Ilchik, 1990; Osterberg and Guilbert, 1990)
USA NV	Wonder		22	1	adularia (qtz)	FI	245	255	-139	39.43	118.05	(Field and Fifarek, 1985; O'Neil and Silberman, 1974)
USA OR	Clackamas County		15.5	8.5	kaol	D	30	40	-65	45.17	122.33	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA OR	Marion County		15.5	8.5	kaol	D	30	40	-44	44.90	122.50	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA OR	Red Butte		15	1	qtz	O	120	120	-110	43.50	118.83	(Zimmerman and Larson, 1994)
USA OR	W.Cascade Range	Mt. Hood	7	2	fsp	O	250	350	-32	45.33	121.75	(Taylor, 1971)
USA OR	W.Cascade Range	Bohemia	10	4	WR	O	250	350	-32	43.58	122.58	(Taylor, 1971)
USA SD	N. Black Hills	Homestake	50	10	qtz	FI			-75	44.33	103.75	(Rye and Rye, 1974)
USA SD	N. Black Hills	Double Rainbow Mine	50	10	sphal	FI			-53	44.33	103.75	(Rye and Rye, 1974)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA TX	Cherokee County		47.2	10	kaol	D	30	40	-33	32.00	95.30	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA TX	Eastland County		300	20	kaol	O	30	40	-31	32.40	98.90	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA TX	Young County		300	20	kaol	D	30	40	-24	35.10	98.60	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA UT	Alunite Ridge	Marysvale, L&N Mine	23	5	alunite(O H)	D	40	40	-86	38.33	112.25	(Cunningham et al., 1984; Rye, 1993; Rye et al., 1992)
USA UT	Bingham		5	2	kaol>mont	D	275	305	-80	41.52	112.15	(Sheppard et al., 1969)
USA UT	Bingham		38	1	smect/sericite	D	300	300	-98	41.52	112.15	(Bowman et al., 1987)
USA UT	Central Mining District	Marysvale, Winkleman Mine	23	5	alunite(O H)	D	170	170	-114	38.33	112.25	(Cunningham et al., 1984; Rye, 1993; Rye et al., 1992)
USA UT	Henry Basin		140	5	cc	O	25	30	-52	38.00	110.80	(Northrop et al., 1990a; Northrop et al., 1990b)
USA UT	Iron Springs		25	3	mt	O	200	250	-55	37.80	113.00	(Becker, this study)
USA UT	Lisbon Valley area		62	7	cc	O	45	55	-105	38.33	109.33	(Breit and Meunier, 1990)
USA UT	Marysvale	Dear Trail Mine	23	5	qtz (late)	AU	220	220	-127	38.33	112.25	(Beaty et al., 1986)
USA UT	Marysvale	Ohio & Mt Baldy Mining districts	23	5	alunite (vein)	D	140	140	-146	38.33	112.25	(Nuelle, 1988)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
USA UT	Mineral Mountains	Corral Canyon, Cave Canyon Detachment	8	1	WR	D	150	240	-136	38.38	112.88	(Barnett et al., 1996)
USA UT	Notch Peak		165	2	WR	AU	290	310	-59	39.17	113.33	(Nabelek et al., 1984)
USA UT	St. George		30	15	dickite	D	80	120	-97	37.08	113.53	(Sheppard et al., 1969)
USA UT	Tintic Mining District		30	15	qtz	AU	210	210	-131	39.95	112.12	(Batchelder et al., 1979)
USA UT	Twin Peaks, Millard Co.	Cudahy Mine, Coyote Hills, Mid Dome	2	1	WR	D	250	300	-145	38.79	112.74	(Nuelle, 1988)
USA WA	Pierce County		36	15	kaol	D	30	40	-75	47.00	122.25	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA WA	Spokane		15.5	8.5	kaol	D	30	40	-94	47.57	117.35	(Lawrence and Meaux, 1993; Lawrence, 1970)
USA WY	Yellowstone Nat. Park	Fountain Paint Pot	1	1	kaol	D	250	250	-137	44.60	110.83	(Sheppard et al., 1969)
MEX CHI	La Perla	La Perla	30	6	mt/mrt	O	200	250	-98	42.82	105.80	(Becker, this study)
MEX DUR	Tayoltita	Culabra Area	42	2	chl	D	240	245	-68	24.11	105.93	(Conrad et al., 1995)
MEX DUR	Tayoltita		42	2	qtz	O	240	245	-76	24.11	105.93	(Churchill, 1980)
MEX HID	Providencia	Pachuca	30	10	adularia (qtz)	FI	240	260	-90	20.25	98.75	(O'Neil and Silberman, 1974)
MEX HID	Providencia	Pachuca	30	10	qtz	O	240	260	-33	20.30	99.00	(O'Neil and Silberman, 1974)

Country /State	District	Specific Location	MY	±	Mineral	Origin	T ('C) min	T ('C) max	D/H fluid	Latitude	Longitude	REFERENCES
MEX SON	Cananea	E. Colorado	57	1	kaol	D	300	400	-57	30.00	110.33	(Wodzicki, 1995)
MEX SON/ CHI	Mulatos Region	El Nopal	30	5	kaol	D	30	60	-31	30.05	106.07	(Staupe, 1995)
MEX SON/ CHI	Mulatos Region	Cerro Estrella	30	5	pyroph	D	290	310	-50	28.65	108.73	(Staupe, 1995)
MEX SON/ CHI	Mulatos Region	Buenvista 2 (Cerro Estrella)	30	5	pyroph + dick	D	240	260	-42	29.03	102.89	(Staupe, 1995)
MEX ZAC	Providencia Concepcion Del Oro	Animas ore body	40	10	qtz	FI	355	360	-81	24.98	102.27	(Rye, 1966)
CAN Skwn	Big Muddy Vally		82	15	kaol	D	30	40	-87	49.10	104.83	(Dean, 1975; Lawrence and Meaux, 1993)
CAN Skn	Cactus Hill		82	15	kaol	D	30	40	-88	49.17	109.08	(Dean, 1975; Lawrence and Meaux, 1993)

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APPENDIX 2

References and Temperatures Regarding Applied $\delta^{18}\text{O}$ and δD Isotopic Fractionation

Factors

To be submitted to Geology Data Repository, Documents Secretary,

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OXYGEN FRACTIONATION FACTORS		
Mineral	Temp °C	Reference
Alunite (all O)	250-450	Stoffregen et al., 1994
Alunite (OH)	250-450	Stoffregen et al., 1994
Anhydrite	300-500?	Chiba et al., 1981
BaCO ₃	0-500	O'Neil et al., 1969
Barite	100-350	Friedman et al., 1977
Calcite	0-500	O'Neil et al., 1969
Chlorite	0-1200	Zheng, 1995
Alk-Feldspar	350-800	O'Neil and Taylor, 1967
Alk-Feldspar	500-800	Bottinga and Javoy, 1987
Plag-Feldspar	350-800	O'Neil and Taylor, 1969
Plag-Feldspar	500-800	Bottinga and Javoy, 1987
Illite	0-170	Lee, 1984; Savin and Lee, 1988
Illite/Smectite	29-120	Savin and Lee, 1988
Kaolinite	0-330	Savin and Lee, 1988
Magnetite	500-800	Fortier et al., 1995
Montmorillonite	20	Lawrence and Taylor, 1972
Musc paragonite	450-650	O'Neil and Taylor, 1969
Musc paragonite	500-800	Bottinga and Javoy, 1987
Pyrophyllite	0-330	Savin and Lee, 1988
Quartz	200-500	Clayton et al., 1989
Quartz	500-800	Bottinga and Javoy, 1987
Quartz	195-573	Shiro and Sakai, 1972
Smectite	0-330	Matsuhisa et al., 1979
SrCO ₃	0-500	O'Neil et al., 1969

HYDROGEN FRACTIONATION FACTORS		
Mineral	Temp °C	
Actinolite	400	Graham et al., 1984b
Alunite	25-400	Stoffregen et al., 1994
Biotite	400-800	Suzuoki and Epstein, 1976
Chlorite	200-700	Graham et al., 1984a
Hornblende	400-800	Suzuoki and Epstein, 1976
Illite/Smectite	29-120	Savin and Lee, 1988; Yeh, 1980
Illite/Smectiteser	140-350	Marumo et al., 1980
Kaolinite	200-480	Gilg and Sheppard, 1996
Kaolinite	250-352	Liu and Epstein, 1980
Kaolinite	17	Savin and Epstein, 1970
Kaolinite	25-200	Savin and Epstein, 1970; Vennemann and O'Neil 1996
Montmorillonite	20	Lawrence and Taylor, 1972
Musc paragonite	450-650	Suzuoki and Epstein, 1976
Smectite	22	Lawrence and Taylor, 1972
Tremolite	>650	Graham et al., 1984b

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