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Introduction

The past two years of research conducted under the auspices of DOE grant DE-FG02-87ER13722.A002 have been fruitful and exciting. Using Microcline Thermochronology (MTC), we have investigated the hydrothermal maturity of the Salton Sea Geothermal Field, potential for hydrocarbon maturation associated with heating due to ridge subduction beneath accretionary prism sediments, developed a single crystal dating system which has proven to greatly enhance interpretations regarding MTC, and also have begun to develop sound theoretical and experimental techniques which truly revolutionize our understanding of argon systematics in K-feldspars. The following is a brief synopsis of these projects in accordance with "Monitoring and Reporting of Program Performance."

Micro-analysis

Because our geologic results and interpretations arise from the instrumentation, it is appropriate to begin our report with a discussion of the development of our argon analysis system that has been supported by DOE.

With a renewed commitment from VG Isotopes, our VG 1200S mass spectrometer has been performing to specifications since September 1988. The argon extraction system connected to the mass spectrometer has the capabilities of either heating samples with an argon laser or a double-vacuum tantalum furnace which has precise ($\pm 1^\circ\text{C}$) temperature control. The laser system has a ^{40}Ar blank of $\sim 1.5 \times 10^{-16}$ moles for typical heating plus gas cleanup times. The double vacuum furnace has a higher blank and increases with temperature, but still is only $\sim 5 \times 10^{-16}$ mol ^{40}Ar at 900°C and $\sim 2 \times 10^{-15}$ mol at 1200°C (Figure 1). The lower blank for laser heating is a definite advantage over the resistance furnace, but at the same time sacrifices accurate temperature monitoring. Depending on specific requirements, we have the flexibility of using either system and exploiting the benefits particular to the laser or resistance furnace. For instance, total fusion experiments are best carried out with the laser, as would be step heating samples where incrementing the gas without temperature control is acceptable. On the other hand, analysis of a K-feldspar for which kinetic data is desired along with the age spectrum, use of the furnace is necessary as accurate temperature control is required for generation of the Arrhenius diagram.

We have put both systems to use successfully on single crystals of K-feldspars and muscovite. First, the laser system has been used to analyze detrital muscovite and K-feldspar from sediments from the Bengal fan, which has lent unprecedented insight towards the onshore tectonics of the Himalayas and Tibetan plateau (Copeland et al., 1989).

Laser argon extraction of Pliocene sanidines from the Valles Caldera volcanic rocks located in New Mexico has met with great success. We are readily able to obtain high resolution results for volcanic stratigraphy from 1 mg single crystal sanidines which range in age from 100,000 to 500,000 years (Spell et al., 1989). These results reveal volcanic stratigraphy and eruption periodicity, and the technique alleviates problems associated with contamination of a mineral aggregate by older xenocrystic material which often is incorporated from wall rocks during eruption.

Single K-feldspar crystals from the Old Woman pluton in southeastern California have been fused with the laser. Analysis of K-feldspar aggregates have revealed excess argon in this sample, thus individual crystals were interigated to access the variability in degree of excess argon from crystal to crystal (Foster et al., 1989).

Though the laser single crystal results are extremely interesting, the true beauty of the system as far as MTC work is concerned, is coupling the low argon blank furnace with accurate temperature control, with the sensitive mass spectrometer. Through this the Arrhenius diagram, which is a plot of diffusion coefficient (calculated from the fraction of ^{39}Ar lost during a heating increment) versus the

reciprocal, absolute temperature for a given heating step, can be generated. These data are needed to constrain the kinetic parameters which govern the argon retentivity of a given K-feldspar. Only from the routine measurement of these data can we confidently ascribe geologic meaning to our analytic results. As will be discussed in some detail in the next section, unprecedented thermal maturation estimates for the Salton Sea geothermal system have been made through single crystal $^{40}\text{Ar}/^{39}\text{Ar}$ results.

Recently, our theoretical and analytical results on K-feldspar aggregates have provided a major break-through in the interpretation of K-feldspar age spectra and Arrhenius data (Lovera et al., 1989). Detailed discussion will follow, but briefly, Lovera et al. (1989) have documented the existence of discrete multiple diffusion domains in K-feldspar and have provided a strong preliminary discussion as to the consequences of this phenomenon. The micro-analyses on single crystals from the aggregates have shown that the multiple diffusion domains are not an artifact of the bulk analysis, but rather occur on the single grain scale.

The VG 1200S system (mass spectrometer and extraction lines) was shipped to Los Angeles in June 1989, assembled, tested, and has been performing to specification since August 1989. We shall commission a new VG 3600 mass spectrometer in December 1989 enabling us to increase our sample throughput.

Salton Sea Geothermal Field

$^{40}\text{Ar}/^{39}\text{Ar}$ analyses on detrital K-feldspars from sandstones collected from various depths from a number of wells within the Salton Sea geothermal field provide quantitative estimates for the heating duration and ages of provenance. A summary of the samples collected and analyzed is given in Table 1.

Fine-grained (~120 micron) K-feldspar aggregates were analyzed from depths of 473, 609, 906, 1170, and 1305 meters (148, 186, 253, 278, 286°C, respectively) from the State 2-14 well. The age spectra (Fig. 2a) are characterized by broad minima between 40 and 130 Ma for the first 40-65% gas released and rise sharply to apparent ages between 400-700 Ma. The deepest sample, S1305, displays zero apparent ages for most of its age spectrum and is indicative of high degrees of recent argon loss. Sample S906 also indicates recent argon loss as defined by the zero ages for the first 3-5% of gas released. It is difficult to assess whether the other samples have experienced recent argon loss as excess argon in the initial gas releases may be precluding this observation. The old ages in the age spectra are suggestive of old source material and are not thought to be related to excess ^{40}Ar . The Arrhenius data (Fig. 2b) reveal similar diffusion coefficients and indicate an E of 37 kcal/mol and D_0/a^2 of 4000/sec for all samples except S609. Sample S609 is albite and displays a slightly higher D_0/a^2 .

With the exception of S609, there appears to be increased argon loss with depth and temperature. We would expect this to be the case if all the aggregates had a similar background argon distribution and argon retentivity. Elaboration on multiple provenances for these samples will be presented later.

A K-feldspar aggregate has been separated from 2199 and 1756 meters from the Landers #1 and Dearborn Farms #1 wells, respectively (Table 1). Their age spectra (Fig. 2a) display age gradients with minima at 150 and 350 Ma and rise to ages greater than 800 Ma. These samples are contaminated by excess argon in the initial steps, thus hindering the likelihood of observing zero ages indicative of recent loss. It is tempting to extrapolate through the excess argon (especially for L2199) to zero and attribute the age gradient to result from recent argon loss of an originally very old sample. As will be shown from the single crystal results, this is an erroneous interpretation. However, we can confidently discern that there is a significant Proterozoic component to the bulk separate.

Several K-feldspars separated from cuttings taken from the Magmamax #2, Elmore #3, and Sinclair #3 wells have been analyzed as single crystals (Table 1). Furthermore, populations of crystals defined on physical properties were also separated for intra-sample comparison. Most of the samples were heated in the double-vacuum furnace, but a few small samples (~0.1 mg) were degassed in the laser apparatus.

Six crystals have been analyzed from the 418 meter interval of the Magmamax #2 well. Crystals MM418a, b and c yield similar age spectra and Arrhenius data (Figs. 3a,b). The spectra are characterized by age gradients ranging from 60 to 75 Ma, and display no evidence of recent argon loss. Crystals a and b are characterized as euhedral-white, while crystal c is rounded-pink; the different physical populations do not relate to different provenance ages in this case. Crystals MM418d, f, and g were heated by the laser and have quite variable apparent ages which range from Cretaceous to Cambrian.

Single crystals MM582a, b, and c yield three substantially different ages ranging from Tertiary to Proterozoic (Fig. 4a). Crystal MM582a (white-euhedral) is very similar to the late Cretaceous MM418a, b, and c presented above. The pink-rounded MM582b is Proterozoic, while another pink-rounded crystal (MM582c) yields a complex age spectrum, but overall has an age gradient from about 25-50 Ma (Fig. 4a). Notably, these crystals do not yield age spectra consistent with recent argon loss even though they are presently at 240°C. The Arrhenius data are given in Figure 4b.

The depth representing the hottest temperature analyzed in the Magmamax #2 well is at 829 meters. This level is presently at 280°C and many of the K-feldspar crystals have a recrystallized or frosted appearance. Crystal MM829a displays a noisy age spectrum ranging from late to middle Cretaceous (Fig. 5a). Again, despite the high present temperature, no zero ages are recorded in the age spectrum for these samples. The Arrhenius data are plotted in Figure 5b.

Two K-feldspar crystals from 552 meters have been analyzed from the Elmore #3 well. The age spectra for E552a and b as shown in Figure 6a are essentially flat at 25 Ma, and do not show recent argon loss. The Arrhenius data for these crystals are significantly different with the rounded-pink E552b having a greater slope than the white-euhedral E552a, thus indicating a higher activation energy (Fig. 6b).

Sinclair #3 age spectra for crystals SN1444a and b are very similar to the Elmore #3 samples as they have flat age spectra at 25 Ma and reveal no recent argon loss (Fig. 7a). These crystals have virtually identical Arrhenius results (Fig. 7b) even though they represent two physically different populations.

Discussion: Provenance ages

The Salton Trough is thought to have been receiving sediments from the Colorado River from Miocene until mid-Pleistocene. The sedimentary thickness is 6000 meters and is inferred to be constructed from Colorado River detritus with only minor contributions from the Chocolate Mountains and Peninsular ranges which border the trough.

The Colorado River drains a vast portion of the western U.S. and also cross-cuts a variety of geologic terranes of distinct ages. If the Salton Trough is mainly filled with Colorado River detritus, a signature of age populations common to its drainage should be observed. Three dominant age groupings are apparent from the argon results. The age spectra for K-feldspars from the State 2-14, Landers #1 and Dearborn Farms #1 wells reveal a significant component of late Paleozoic to Precambrian detritus (Fig. 2a). Muscovites have also been separated from two levels in the State 2-14 well (Table 1). S473 and S1170 muscovite age spectra are shown in Figure 8, and indicate a dominance of Proterozoic detritus. The irregularity of the age spectra most likely reflects incorporation of some younger material, but for S473, the majority of muscovite is at least 1250 Ma.

Additional provenance ages are revealed from the single crystal K-feldspar analyses. The Proterozoic source is further established by MM582b, which records a greater than 1 Ga cooling history (Fig. 3a). The other dominant provenance ages are Oligocene and late Cretaceous. The flat 25 Ma age spectra for samples from the Elmore #3 and Sinclair #3 wells indicate a source which underwent rapid unroofing at 25 Ma or that these K-feldspars are from high-level intrusives which would have cooled quickly. The K-feldspars are not sanidine, and most likely are derived from the Tertiary detachment terranes documented throughout the southwest. These core complexes are also the likely source area for the late Cretaceous K-feldspars (i.e., MM418a, b, c; Fig. 3a:) as regional metamorphism, plutonism, and cooling at 75 Ma in southeastern California has been demonstrated to produce K-feldspars very similar to these.

The provenance ages delineated here support the inference that the Salton Trough sands have been derived through deposition by the Colorado River as Oligocene, late Cretaceous and Proterozoic are common mineral ages for rocks drained by this river. Furthermore, these samples suggest that the southeastern California mountain ranges have been exposed since the onset of deposition in the Salton Trough.

Discussion: Thermal maturity

As brought to light by the single crystal analyses, there is a strong likelihood that the K-feldspar aggregates analyzed from the State 2-14, Landers #1 and Dearborn Farms #1 sites have a mixture of provenances. This ambiguity precludes detailed discussion of the results, thus for this report, we will concentrate on the single crystal results.

Generally, the amount of argon loss is used to calculate time scales or thermal intensity. In this case, none of the single crystals analyzed display significant recent argon loss, but use of this "negative" data also allows estimation of maximum heating duration for a given temperature. The well-behaved nature of the Elmore #3 and Sinclair #3 data (Figs. 6 and 7) make them ideal candidates for the thermal calculations.

The small diffusion domain for the Sinclair #3 samples SN1444a, b has an $E = 49.5$ kcal/mol and a $D_0/a^2 = 1.6 \times 10^6$ /sec. These data, along with the present temperature of 225°C, allows generation of Figure 9. Figure 9 is a plot of the predicted argon loss for a given time using the information for SN1444. The calculated curve predicts 3.5% argon loss in 100,000 years (Fig. 9), thus, if previous work suggesting heating durations of ~3 to 20 ka is correct, we would expect exactly what we see; no significant argon would be lost from these samples in less than 10,000 years.

E552b from the Elmore #3 well also provides the necessary information to generate an argon loss versus heating duration curve (Fig. 10). The combination of the higher temperature (250°C) and lower E (45.9 kcal/mol) for this sample, relative to SN1444, results in a much more sensitive indicator of degassing. The age spectrum technique for these samples will allow identification of 5% argon loss quite readily, but, as shown in Figure 10, this much loss would occur in 1000 years. Thus, only by analysis of single crystals in a furnace which allows accurate temperature control can we confidently suggest that the present temperature of 250°C in the Elmore #3 well has not been maintained for greater than 1000 years.

Conclusions

⁴⁰Ar/³⁹Ar results on K-feldspar and muscovite aggregates and K-feldspar single crystals yield quantitative estimates on heating duration and provenance ages for sands from the Salton Sea geothermal field.

Provenance ages span the Tertiary through Proterozoic, but cluster at Oligocene, late Cretaceous and Proterozoic. These ages are consistent with detritus being transported by the Colorado River from mountain ranges in southeastern California and southwestern Arizona.

Single crystals analyzed in a low argon blank furnace equipped with accurate temperature monitoring capabilities provides the necessary kinetic data to constrain argon retentivity. This, along with argon loss estimates, indicates that the present temperatures measured in several wells have not been maintained for greater than 1000 years.

Ridge Subduction

Accretionary prisms are thick sedimentary piles which occur along many convergent margins. Sediments accumulate near the trench axis from both the subducting oceanic plate and from the convergent margin. There are several areas where the sediments (which are deposited in a cold environment) have experienced post-depositional heating. The heat source for this is thought to be the subduction of a hot oceanic ridge in areas such as southwest Japan, southwest Alaska and the California coastline. We have analyzed detrital K-feldspar from a number of accretionary prism environments to assess the heating intensity and duration that was related to the ridge subduction event. The results yield important constraints as to whether these environments are strong candidates for hydrocarbon maturation. All the samples related to ridge subduction studies are listed in Table 2.

K-feldspars from accretionary prism sediments along the convergent margins in southwest Alaska and southwest Japan have been dated (Table 2). The sediments from which the K-feldspars have been separated have inferred paleo-temperatures of $\sim 200^{\circ}\text{C}$, based mainly on vitrinite reflectance data. These anomalously high temperatures for an accretionary complex environment are believed to be related to heating by subduction of active spreading centers (Byrne and Hibbard, 1987; Hibbard and Karig, 1987).

The age of the igneous rocks thought to be generated from ridge subduction are Early to Middle Miocene (12-18 Ma) in southwest Japan and ~ 59 Ma in southwest Alaska and the heating of the accretionary sediments inferred to be consanguous.

Sample V-3-87 is from the Valdez Formation located on the Kenai Peninsula, Alaska. The formation is Late Cretaceous (75-80 Ma) based on Maestrichtian fossils. The K-feldspars from this unit yield a release spectrum which exhibits an age gradient from ~ 63 -90 Ma (Fig. 11a). The fact that the age spectrum reveals ages younger than the stratigraphic age indicates heating of this unit above $\sim 100^{\circ}\text{C}$ (closure temperature 110°C , Fig. 11b). The youngest apparent age of 63.0 ± 3.5 Ma is in good agreement with the proposed 59 Ma timing of ridge subduction.

Sample 87-JS-1 is from the Late Oligocene-Early Miocene Shijuiyama Formation of the Hioki complex, southwest Japan (Hibbard and Karig, 1987). This K-feldspar release spectrum has an age gradient from ~ 70 -120 Ma (Fig. 12a). There is no clear evidence for a Miocene thermal disturbance causing temperatures greater than $\sim 100^{\circ}\text{C}$ in this area (125°C is the apparent closure temperature of 87-JS-1, Fig. 12b). The argon data does not support the vitrinite reflectance data, at least in the sense that the paleotemperatures were reached in the Miocene.

K-feldspars from accretionary prism sediments located on the central California coast have been analyzed to assess the heating related to Tertiary ridge subduction. Sediments from the Cambria, Pfeiffer Beach and Pt. San Luis Slabs (Table 2) have been sampled and reveal generally flat age spectra indicating provenance cooling ages ranging from ~ 75 to 92 Ma. These ages are expected as the provenance is likely the adjacent Salinian Block. The deepest sample in the section (M88-72 K-feldspar) records apparent ages much younger than the stratigraphic age and, therefore, is interpreted to have experienced significant argon loss during ridge subduction (Fig. 13a). For a convergence rate of 50 mm/yr, the thermal perturbation due to subducting the hot ridge would be ~ 3 Ma. As this sample has an $E = 53.1$ kcal/mol and $D_0/a^2 = 2.63 \times 10^7$ /sec it would suggest a heating intensity of $\sim 250^{\circ}\text{C}$ for the observed argon loss. These data certainly suggest that portions of the sedimentary pile higher up have experienced

paleotemperatures between ~150-200°C and thus ridge subduction environments can be considered as appropriate candidates for hydrocarbon maturation.

Multiple diffusion domains

The DOE supported research projects have certainly been dominated with analysis of K-feldspar. If only through consideration of sheer numbers, we have gained the experience and expertise for proper interpretation of K-feldspar argon systematics for thermochronology. Our need to better describe argon loss profiles and understand Arrhenius data for MTC has lead to a revolutionary discovery that K-feldspars invariably possess multiple (typically three) diffusion domains. The implication of this is that each domain, being of different size, will have a particular argon retentivity. This means that it is possible for a given thermal perturbation that one domain is completely outgassed, one is partially outgassed, and one may not lose argon at all.

Lovera et al.(1989) has developed the mathematical expressions for argon transport considering multiple domain diffusion. This, coupled with several argon extraction experiments (e.g., Fig. 14 and 15) using non-conventional heating schedules (i.e., isothermal, long and short duration and cycled heating/cooling), have lead to a fascinating data set with far reaching implications for understanding the thermal consequences of a variety of geologic processes.

Table 1: Sample listing with respect to location, mineral type (Ksp = K-feldspar, Musc = muscovite), present temperature ($^{\circ}\text{C}$), separate type (SC = single crystal, Agg = Aggregate) and extraction system (Fur = Furnace, Las = Laser). Number in sample name equals depth in meters.

Well	Sample	Mineral	Present Temp.	SC	AGG	FUR	LAS
State 2-14	S473	Ksp	148		X	X	
State 2-14	S473	Musc	148		X	X	
State 2-14	S609	Albite	186		X	X	
State 2-14	S906	Ksp	253		X	X	
State 2-14	S1170	Ksp	278		X	X	
State 2-14	S1170	Musc	278		X	X	
State 2-14	S1305	Ksp	286		X	X	
Landers #1	L2199	Ksp	250		X	X	
Dearborn Farms #1	DF1756	Ksp	172		X	X	
Magmamax #2	MM418a	Ksp	185	X		X	
Magmamax #2	MM418b	Ksp	185	X		X	
Magmamax #2	MM418c	Ksp	185	X		X	
Magmamax #2	MM418d	Ksp	185	X			X
Magmamax #2	MM418f	Ksp	185	X			X
Magmamax #2	MM418g	Ksp	185	X			X
Magmamax #2	MM418h	Ksp	185		X	X	
Magmamax #2	MM582a	Ksp	240	X		X	
Magmamax #2	MM582b	Ksp	240	X		X	
Magmamax #2	MM582c	Ksp	240	X		X	
Magmamax #2	MM829a	Ksp	280	X		X	
Magmamax #2	MM829c	Ksp	280	X			X
Magmamax #2	MM829d	Ksp	280	X			X
Elmore #3	E552a	Ksp	250	X		X	
Elmore #3	E552b	Ksp	250	X		X	
Sinclair #3	SN1444a	Ksp	225	X		X	
Sinclair #3	SN1444b	Ksp	225	X		X	

Table 2: Samples related to ridge subduction work

<u>Sample</u>	<u>Location</u>	<u>Rock Type</u>	<u>Mineral</u>
V-3-87	SW Alaska	sandstone	K-feldspar
TS-4-87	Kodiak Island	sandstone	K-feldspar
M2-17	Kodiak Island	pluton	K-feldspar
S-70	Alaska Peninsular	pluton	K-feldspar, biotite
88ACY-9	Alaska Peninsula	pluton	K-feldspar, biotite
M88-2	Cambria Slab	sandstone	K-feldspar
M88-66	Cambria Slab	sandstone	K-feldspar
M88-72	Cambria Slab	sandstone	K-feldspar
M88-90	Cambria Slab	sandstone	K-feldspar
M88-98	Cambria Slab	sandstone	K-feldspar
OPCG-77	Cambria Slab	dike	Hornblende
C-6-88	Cambria Slab	sandstone	K-feldspar
C-7-88	Cambria Slab	sandstone	K-feldspar
C-8-88	Cambria Slab	sandstone	K-feldspar
C-3-87	Cambria Slab	sandstone	K-feldspar
F-13-87	Cambria Slab	sandstone	K-feldspar
87-JS-1	SW Japan	sandstone	K-feldspar

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Figure Captions

- Figure 1: Argon extraction line blanks for the VG 1200S double vacuum furnace and laser heating system. The plot of ^{40}Ar concentration versus temperature shows the effective blank for a standard heating increment. Total heating and gas cleanup for the furnace is typically 20 minutes. Laser extraction entails less than 1 minute of heating and 10 minutes of gettering. There is no blank-temperature dependence for the laser as only the crystal warms during argon extraction. Though the blank increases with temperature for the furnace, the percentage of blank to sample gas generally remains low (5%) as K-feldspars typically undergo enhanced degassing between 1100 to 1300°C.
- Figure 2a: Age spectra for K-feldspars and one albite (S609) from the State 2-14, Landers #1 and Dearborn Farms #1 wells. The samples are aggregates and the K-feldspars from the State 2-14 well reveal an apparent increase in argon loss with temperature. The Landers #1 and Dearborn Farms #1 samples do not show recent argon loss and the apparent age gradients may reflect a mixture of young and old material with differing degassing characteristics. The age spectra do, however, indicate that a portion of the sample contains crystals of Precambrian age.
- Figure 2b: Arrhenius plot for the K-feldspars and one albite (S609) from the State 2-14. The K-feldspars have remarkably similar Arrhenius plots considering the probability of a mixture of crystals sizes. The low temperature array suggests an E of 37 kcal/mol and D_0/a^2 of 4000/sec.
- Figure 3a: Age spectra for K-feldspars from the 418 m interval from Magmamax #2 well. MM428a, b, c single crystals indicate a late Cretaceous provenance.
- Figure 3b: Arrhenius plot for single crystals MM418a, b, c from the Magmamax #2 well. These data do not show a pronounced break in slope for points below 1200°C, but define a single array with a relatively low E of 24.3 kcal/mol and D_0/a^2 of 1.8/sec.
- Figure 4a: Three significantly different ages are revealed by single crystals MM582a, b, c of Tertiary, late Cretaceous and Proterozoic. No recent loss of argon is noted even though the present temperature is 240°C.
- Figure 4b: Diffusion data for Magmamax #2 single crystals MM582a, b, c. Departure from linearity occurs after the first two or three steps, thus making assignment of kinetic parameters ambiguous. There does, however, appear to be definition of more than one diffusion domain, especially for crystal b.
- Figure 5a: Age spectra for single crystal MM829a from the 280°C level in Magmamax #2 well. Despite high present temperature, the sample does not indicate recent argon loss.
- Figure 5b: Arrhenius data for MM829a reveals a linear array for data below ~1150°C, but corresponding to an unrealistically low E of 13 kcal/mol. The apparent lack of discrete diffusion domains (as would be defined by a knee in the data) is thought to represent degassing from a continuum of diffusion domain sizes.
- Figure 6a: Age spectra for two K-feldspars from the Elmore #3 well. Both crystals E552a and b yield essentially identical Oligocene provenance ages and also have remarkably flat age profiles. The samples are not sanidine, but must have

experienced rapid cooling at ~25 Ma. There also is no evidence of recent argon loss.

Figure 6b: Contrasting Arrhenius data for E552a, b single crystals. Crystal b yields strong definition of at least two diffusion domains, whereas crystal a apparently reflects simultaneous degassing of multiple domains.

Figure 7a: Age spectra from Sinclair #3 SN1444a and b single crystals displaying flat age patterns indicating Oligocene provenance ages. As with the Elmore #3 single crystals, these samples have experienced rapid cooling at 25 Ma and have not been heated sufficiently to cause later argon loss.

Figure 7b: Essentially identical diffusion coefficients for SN1444a and b yield an E of 49.5 kcal/mol and D_0/a^2 of 1.6×10^6 and 2.0×10^4 /sec for the small and large domains, respectively.

Figure 8: Age spectra for detrital muscovite separates from the State 2-14 well. Both S473 and S1170 indicate a significant Proterozoic signature though some of the age spectra irregularity probably arises from mixture with younger material. These results confirm the old source ages suggested by the old apparent ages in the K-feldspar age spectrum from the State 2-14 well.

Figure 9: Predicted argon loss versus time as modelled for a plane sheet geometry assuming: Temperature = 225°C, E = 49.5 kcal/mol and $D_0/a^2 = 1.6 \times 10^6$ /sec. These parameters indicated that the SN1444a and b single crystals would undergo ~3.5% argon loss in 100,000 years. The high argon retentivity of the sample does not make for a sensitive heating duration indicator at this temperature, but the zero percent argon loss evidenced by the age spectrum does indicate a heating duration of less than 50,000 years.

Figure 10: Kinetic parameters of E = 45.9 kcal/mol, $D_0/a^2 = 7.0 \times 10^5$ /sec, temperature = 250°C and a plane sheet geometry yield this heating duration versus fraction loss curve. Five percent argon loss would be easily resolved for E552b, but it is not observed. These data predict 5% less in ~1000 years, thus it appears the present temperature has not been experienced for longer than the past several hundred years.

Figure 11a: Age spectrum and K/Ca plot for an aggregate of K-feldspar from accretionary prism sediments from SW Alaska.

Figure 11b: Arrhenius plot for V-3-87 K-feldspar from SW Alaska indicating an apparent closure temperature of ~110°C.

Figure 12a,b: Age spectrum and Arrhenius plot for detrital K-feldspars from SW Japan. The lack of Tertiary argon loss coupled with the 125°C closure temperature indicates paleo-temperatures of less than ~100°C.

Figure 13a,b: Age spectrum and Arrhenius plot for a K-feldspar aggregate (M88-72) from the Cambria Slab, California. The apparent ages less than 75 Ma (the stratigraphic age) reflect degassing associated with ridge subduction in the Tertiary. The kinetic data suggest a thermal history of a 3 Ma heating at 250°C to produce the degree of outgassing observed.

Figure 14: Theoretical Arrhenius plot for a sample with a distribution of diffusion domains and kinetic parameters as defined by MH-8 K-feldspar (Fig. 15). The departure from linearity reflects exhaustion of argon held in small diffusion domains and outgassing of larger domains at higher temperatures. Note the very good agreement with the experimental run shown in Figure 15.

Figure 15: Arrhenius plot generated with a non-conventional heating schedule to elucidate the diffusion domains of MH-8 K-feldspar. These experimental results are in very good agreement with the predicted Arrhenius plot calculated in Figure 14.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

Figure 11

FIGURE 12.

FIGURE 13

FIGURE 14