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Zircon Geochemical and Isotopic Constraints on the Evolution of the Mount Givens Pluton, Central Sierra Nevada Batholith

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ZIRCON GEOCHEMICAL AND ISOTOPIC CONSTRAINTS ON THE EVOLUTION
OF THE MOUNT GIVENS PLUTON, CENTRAL SIERRA NEVADA BATHOLITH

A Thesis

Presented to

The Faculty of the Department of Geology

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Callie Sendek

December 2016

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The Designated Thesis Committee Approves the Thesis Titled

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by

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December 2016

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ABSTRACT

ZIRCON GEOCHEMICAL AND ISOTOPIC CONSTRAINTS ON THE EVOLUTION OF THE MOUNT GIVENS PLUTON, CENTRAL SIERRA NEVADA BATHOLITH

by Callie Sendek

The Late Cretaceous Mount Givens pluton, located in the central Sierra Nevada batholith, is noteworthy for its large size (~1400 km²) and relative compositional and textural homogeneity. The pluton is characterized by a 30 km wide, ellipse-shaped northern lobe (ca. 98-91 Ma) that connects with a long mass (ca. 95-91 Ma) about 15 km wide and extends 50 km SE. Zircon trace elements and $\delta^{18}\text{O}$ and ϵHf from a sample suite representative of the observable petrologic diversity of the pluton document significant heterogeneities. All zircons have high Ti-in-zircon model temperatures (850-1000 °C), pronounced negative Eu anomalies, and concave down MREE and HREE patterns, indicating initial melts were undersaturated in zircon and that zircon growth occurred during ascent or emplacement of Mount Givens magmas. Zircon trace elements record appreciable variation, and suggest that crystal transfer was ongoing throughout pluton growth. Significant variations in O and Hf isotopes require mixing of multiple, isotopically distinct sources. Longitudinal variation in both systems suggests increasing mantle contributions in the eastern portion of the pluton. A clear decrease in isotopic variability at all scales in post-95 Ma samples indicates that later magmas were more thoroughly mixed prior to emplacement. This increase in zircon isotopic homogeneity paired with the narrow timespan of intrusion hints that the inner portion of the northern lobe may have existed as a large melt reservoir.

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TABLE OF CONTENTS

INTRODUCTION	1
GEOLOGIC SETTING	3
GEOCHEMICAL AND ISOTOPIC ANALYSIS OF ZIRCON	10
Lutetium-Hafnium Isotopes in Zircon	10
Oxygen Isotopes in Zircon.....	12
Trace Elements in Zircon.....	13
Zircon Saturation Thermometer.....	13
Ti in Zircon Thermometry	14
METHODS	16
Zircon Separation and Imaging.....	16
Whole Rock Geochemistry	18
Trace Elements in Zircon.....	18
SIMS Analysis of $\delta^{18}\text{O}$ of Zircon	19
Hf Isotopes in Zircon	20
FIELD OBSERVATIONS.....	26
Northern Lobe.....	26
Equigranular Granodiorite	27
Porphyritic Granodiorite	27
Granodiorite of Cow Meadow	28
Aplite of Jackass Rock.....	29
Enclaves of the Northern Lobe	29
Mixing Zone.....	30
Courtright Reservoir	32
RESULTS	33
Point Counts.....	33
Whole Rock Geochemistry	37
Zircon Thermometry	37
Pluton-Wide Results	37
Intergrain Variations	44
Intragrain Variations	44
Zircon Geochemistry	47

Intercrystalline Variations.....	55
Intracrystalline Variations.....	55
Isotopic Data	56
Longitudinal Variation.....	59
Age Variation.....	61
Intercrystalline Variations.....	61
Intracrystalline Variation	65
DISCUSSION.....	69
CONCLUSIONS.....	77
REFERENCES CITED.....	79
APPENDIX A: Sample Locations and Descriptions	87
APPENDIX B: Cathodoluminescence Images with Indexed Analysis Spots	88
APPENDIX C: Cathodoluminescence Images with $\delta^{18}\text{O}$, ϵHf , and Trace Element Concentrations	100
APPENDIX D: Whole Rock Data	114
APPENDIX E: SHRIMP Trace Element in Zircon Data.....	117
APPENDIX F: O Isotope Data	141
APPENDIX G: Hf Isotope Data	149
APPENDIX H: Mixing Model Parameters.....	153

LIST OF TABLES

Table 1. Point Count Data.....	35
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LIST OF FIGURES

Figure 1. Generalized map of the Sierra Nevada batholith.....	4
Figure 2. Geologic map of Mount Givens pluton and surrounding intrusions	6
Figure 3. Map of U-Pb CA-ID-TIMS ages within the Mount Givens pluton.....	9
Figure 4. Map of O isotopes in Sierran plutons	11
Figure 5. Zircon sample location map	17
Figure 6. External error plot for 91500 zircon standard	20
Figure 7. External error plot for JG1 zircon standard	22
Figure 8. External error plot for R33 zircon standard.....	23
Figure 9. $^{176}\text{Hf}/^{177}\text{Hf}$ vs $^{176}\text{Yb}/^{177}\text{Hf}$ for all R33 analyses	24
Figure 10. R33 Standard measurements for entire Hf analytical session	25
Figure 11. External error plot for Plešovice zircon standard.	26
Figure 12. Representative rock textures in the northern lobe	28
Figure 13. Magmatic interactions in central mixing zone	31
Figure 14. Mafic enclaves and schlieren near Courtright Reservoir	33
Figure 15. QAP diagram showing modal mineralogy of Mount Givens samples	36
Figure 16. Whole rock major element geochemistry	38
Figure 17. Whole rock trace element geochemistry	39
Figure 18. Chondrite normalized whole rock REE plots.	40
Figure 19. Histogram of calculated Ti-in-zircon temperatures for entire sample suite....	41
Figure 20. Ti-in-zircon (T_{iz}) temperature profiles for different rock types.	42
Figure 21. Schematic zircon temperature profile across northern lobe	43
Figure 22. Ti-in-zircon temperature measurements for porphyritic samples.	45

Figure 23. Ti-in-zircon temperature measurements for equigranular samples.	46
Figure 24. Ti-in-zircon temperature measurements for compositional outliers	46
Figure 25. Ti vs. Hf plots.....	48
Figure 26. Eu/Eu* vs Hf plots.....	49
Figure 27. Yb/Gd vs. Hf plots.....	50
Figure 28. Th/U vs. Hf plots	51
Figure 29. REE in zircon plots separated by rock type.....	52
Figure 30. Rank order plot of zircon Hf concentration.....	52
Figure 31. Rank order plot of zircon Th/U	53
Figure 32. Rank order plot of zircon Yb/Gd.....	53
Figure 33. Rank order plot of calculated Ti-in-zircon temperatures	54
Figure 34. Rank order plot of zircon Eu/Eu*	54
Figure 35. Intracrystalline variation in zircon trace elements.....	56
Figure 36. O vs Hf covariation plot	57
Figure 37. Variation of isotopes with bulk rock composition	58
Figure 38. Variation of isotopes along Panthalassan-North American boundary	60
Figure 39. Temporal variation of isotopes.....	62
Figure 40. Covariant $\delta^{18}\text{O}$ and ϵHf plot showing isotopic differences in pre- and post-95 Ma granodiorites	63
Figure 41. Variation of isotopes across Panthalassan-North American boundary, separated by age.....	64
Figure 42. Rank order plot of isotopic variation.....	66
Figure 43. Intracrystalline variation in zircon O and Hf isotopes.....	68
Figure 44. Mixing model for zircon isotopic compositions of Mount Givens samples....	74

INTRODUCTION

Magmatic arcs are important recorders of crustal growth, and large, silicic arc plutons have been extensively studied to understand the complex processes of magma generation, transport, emplacement, and magmatic processing at convergent margins (Bateman and Nokleberg; 1978; Kistler et al., 1986; Sawka, 1988; Hill, 1988; Bateman, 1992; Coleman et al., 1995; Tobisch et al., 1995; Paterson et al., 1996; Barth et al., 1997; Matzel et al., 2006; Paterson et al., 2011; Lackey et al., 2012). Early models of these plutons as large magma chambers and closed system fractional crystallization (e.g. Buddington 1959; Bateman and Chappell, 1979; Petford et al., 2000) have largely been replaced by ones that involve incremental emplacement by injection of multiple batches of magma into the crust (Brown and McClelland, 2000; Miller and Paterson, 2001; Mahan et al., 2003; Glazner et al., 2004; Žák and Paterson, 2005). This shift in understanding was largely brought about by the wide spread of zircon ages (hundreds of ka to tens of Ma) obtained for individual plutons by high precision U-Pb thermal ionization mass spectrometry (TIMS) dating (Coleman et al., 2004; Matzel et al., 2006; Memeti et al., 2010; Davis et al., 2012; Frazer et al., 2014).

Although generally accepted, several aspects of the incremental emplacement model are still unclear. Vigorous debate is ongoing concerning the size of individual magma batches and where they acquire their fundamental chemical and petrologic characteristics. Some workers suggest that plutons grow by sheet-like intrusion of small pulses, which cool rapidly upon emplacement (Mahan et al., 2003; Glazner et al., 2004; Cruden et al., 2005; Bartley et al., 2006; Matzel et al., 2006). In this model, thermal

constraints dictate that each small magma batch acts essentially as a closed system. Any variations in geochemical and isotopic composition in the pluton must therefore be attributed to changes in source material, rather than to interaction with other magmas during transport and/or emplacement, or in mid-shallow crustal arc magma chambers. In contrast, field evidence of magma mixing and uniform ages across volumetrically large units within some of the large intrusive suites have led others to argue that enough heat is present in the system to allow for interaction of disparate magmas at the site of emplacement (Harper et al., 2005; Hirt, 2007; Burgess and Miller, 2008; Economos et al., 2010; Memeti et al., 2010; Lackey et al., 2012). In this model, mid-crustal magma mixing and fractional crystallization can account for observed petrologic, geochemical and isotopic trends.

The accessory mineral zircon provides an excellent tool to investigate fundamental questions about magma genesis and evolution during pluton growth. Zircon is a robust recorder of its magmatic environment during crystallization, including temperature, geochemical, and isotopic information. Furthermore, the mineral's physiochemical resilience (Watson, 1996; Hawkesworth and Kemp, 2006) and the slow diffusion rates of important elements within its crystal lattice (Cherniak, 1995; Watson and Cherniak, 1995) allow zircon to preserve primary magmatic signatures even after being subjected to extreme thermal conditions (Page et al., 2007). Examining variation in zircon trace element and isotopic geochemistry across a pluton, within an individual sample, and within individual crystals (e.g. Claiborne et al., 2010) allows a better understanding of the scale of magma homogeneity, and the nature of magma mixing and

interactions. When paired with age data, this information can produce a detailed record of changing magmatic conditions, and can clarify the extent of interaction between distinct magmas.

The Sierra Nevada batholith provides an excellent record of magmatic arc development in Mesozoic North America (Bateman, 1992; Ducea, 2001). This study aims to use the geochemical and isotopic information recorded in zircon to examine the magmatic history of the Mount Givens granodiorite, in the Central Sierra Nevada batholith. The Mount Givens pluton has been recognized for its relative petrologic homogeneity despite its large size (Bateman and Nokleberg, 1978; Bateman, 1992). By analyzing a sample suite representative of the observable petrologic diversity of the pluton, zircon data will demonstrate if this apparent lack of variability also applies to the geochemical and isotopic signatures of the magma. Measurable variations, paired with age data, will be used to assess how magmatic conditions changed over time, and to evaluate the implications for incremental emplacement of the Mount Givens pluton.

GEOLOGIC SETTING

The Sierra Nevada batholith (Fig. 1) was formed during Mesozoic subduction of the Farallon plate beneath the western margin of the North American continent (e.g. Hamilton, 1969; Kistler and Peterman, 1973; Bateman, 1974; 1992). In the Late Cretaceous, several large-volume intrusions were emplaced in the area now forming the crest of the Sierra Nevada at the peak of a large magmatic ‘flare-up’ (Coleman and Glazner, 1997; Ducea, 2001; DeCelles et al. 2009). Most of the plutons emplaced during this magmatic event exhibit compositional zonation, with inner units becoming

progressively more felsic and porphyritic (Bateman, 1992). Although originally viewed as having formed via fractional crystallization of large magma chambers, more recent zircon U-Pb geochronology has demonstrated evidence for incremental emplacement over periods of up to ten million years (Coleman et al., 2004; Memeti et al., 2011; Davis et al., 2012).

Figure 1. Generalized map of the Sierra Nevada batholith. Green represents metamorphic wall rock, and colors represent ages of granitoid rocks. Rectangle marks the area surrounding the Mount Givens pluton shown in Figure 2. Modified from Lackey et al. (2008).

The Mount Givens pluton lies in the central Sierra Nevada Mountains (Fig. 1), where it intrudes the 106 to 97 Ma Shaver Lake intrusive suite to the west, and is separated from the Cretaceous John Muir intrusive suite to the east by the Goddard Pendant (Fig. 2). It is comparable in size to the zoned intrusive suites of the Sierra Crest, stretching 80 km in a northwest-southeast orientation, with an average width of 15 km. The northern portion of the Mount Givens pluton is a 30-km-wide, bulbous lobe that contains the majority of the pluton's petrologic diversity (Bateman and Nokleberg, 1978). Aluminum-in-hornblende thermobarometric data suggest the pluton cooled at 3.3 ± 0.3 kbar (~11–13 km) (Ague and Brimhall, 1988). Paleomagnetic data indicate a post-cooling tilt of 10° about an axis parallel to regional fabrics ($\sim 320^\circ$; Gilder and McNulty, 1999).

The northern lobe can be divided into four main phases: equigranular, porphyritic, the granodiorite of Cow Meadow, and the aplite of Jackass Rock. As with the zoned intrusive suites of the Sierra Crest, there are broad-scale mafic to felsic and equigranular to porphyritic gradations moving inwards (Bateman and Nokleberg, 1978). This pattern is interrupted by the granodiorite of Cow Meadow, a horseshoe shaped exposure of equigranular, hornblende-biotite granodiorite within the more felsic, porphyritic unit. The external contact of the granodiorite of Cow Meadow has been mapped as intrusive, while the inner one is generally described as gradational (Bateman and Nokleberg 1978; McNulty et al., 2000). The southern portion of the Mount Givens pluton has been mapped as equigranular granodiorite, with the exception of a tongue of porphyritic

material extending from the north, and several small aplite bodies near Courtright Reservoir (Fig. 2) (Bateman and Nokleberg, 1978; Bateman, 1992; McNulty et al., 2000).

Figure 2. Geologic map of Mount Givens pluton and surrounding intrusions. Modified from Frazer et al. (2014).

Early field and petrologic studies of the pluton noted the compositional and textural similarities between the northern lobe of Mount Givens and the zoned intrusive suites of the Sierra Crest. Petrographic and geochemical analysis of a sample transect through the northern lobe documented decreases in abundance and size of mafic minerals moving inwards, complimented by an increase in abundance and size of potassium feldspar and quartz (Bateman and Nokleberg, 1978). The trends all reverse at the contact with the Cow Meadow granodiorite, but continue moving inwards from there. Bateman and Nokleberg (1978) use this pattern as evidence of solidification of the Mount Givens granodiorite from a large magma body by fractional crystallization. The two aplitic units in the northern lobe and to the south were proposed as cooling centers that were the final felsic products of crystallization. Bateman (1992) explained the alternation of textural phases by folding of the pluton during expansion after emplacement of a stratified chamber with the megacrystic phase overlying the equigranular rocks.

Using a combination of magmatic foliation and anisotropy of magnetic susceptibility data from throughout the pluton, McNulty et al. (2000) proposed a multi-stage intrusion model. Their model divided the pluton into three “chambers” (northern, central, and southern), which were fed by north-south feeder dikes. Relatively short estimates of emplacement times were calculated based on floor down-drop as the hypothesized emplacement mechanism (McNulty et al., 2000; Petford et al., 2000). According to McNulty et al. (2000), initial voluminous magmatism produced the equigranular phase, which formed the southern chamber, and part of the central and northern chambers. Subsequent magmatism led to underplating of the megacrystic phase

in the northern lobe, and lateral flow from the lobe into the central chamber. The granodiorite of Cow Meadow was a product of renewed magmatism that caused expansion and doming in the northern lobe. It ascended to its current location during a ring fracturing event that also juxtaposed the equigranular and megacrystic phases at the current level of exposure.

Recent U-Pb chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-ID-TIMS) dates from the Mount Givens pluton span over 7 million years, from 97.92 ± 0.06 to 90.87 ± 0.05 Ma (Fig. 3; Frazer et al., 2014). These dates show little overlap with previous multigrain U-Pb ages that gave a range of 88-93 Ma (Stern et al., 1981; Tobisch et al., 1993). This inconsistency may suggest an even longer period of pluton assembly, or may be due to Pb loss problems in earlier analyses that did not employ chemical abrasion (Frazer et al., 2014). The age spread for individual phases precludes rapid emplacement of each in discrete magmatic pulses, contradicting the emplacement scenario suggested by McNulty et al. (2000). Instead the northern lobe follows a normal younging inward pattern. Frazer et al. (2014) suggest that this may be due to “magmatic cycling”, with exterior equigranular units cooling rapidly after emplacement into low-temperature host rock, and porphyritic textures in the core of the lobe forming during prolonged residence near the solidus.

The vast majority of the Mount Givens pluton lies directly to the east of the Panthalassan-North American boundary, a proposed major lithospheric suture dividing the North American crust to the east and accreted oceanic terranes to the west (Fig. 4). The boundary was originally proposed by Kistler (1990) on the basis of roof pendant

Figure 3. Map of U-Pb CA-ID-TIMS ages within the Mount Givens pluton. Listed ages are based on the interpretations of Frazer et al. (2014). Modified from Frazer et al. (2014).

lithologies and the geochemical and whole rock Sr and O isotopic characteristics of intruded plutons. It has since been shifted eastward by Lackey et al. (2008) with the addition of zircon $\delta^{18}\text{O}$ data (Fig. 4). Consistent isotopic ratios across compositionally variable suites suggest that limited crustal recycling was involved in the magmatism of the Sierra Crest plutons (Coleman and Glazner, 1997; Wenner and Coleman, 2004). Exceptions, including the Johnson Porphyry of the Tuolumne intrusive suite, fall on mixing curves between a mantle endmember and Proterozoic crust. A 1% increase in $\delta^{18}\text{O}$ on the western margin of the Mount Givens pluton may suggest a crustal control on $\delta^{18}\text{O}$, with western magmas showing increasing incorporation of the more highly altered Panthalassan lithosphere (Lackey et al., 2008).

GEOCHEMICAL AND ISOTOPIC ANALYSIS OF ZIRCON

Lutetium-Hafnium Isotopes in Zircon

Radiogenic ^{176}Hf is formed from the beta decay of ^{176}Lu , and has a half-life of approximately 37 billion years. Hf is more incompatible than Lu during partial melting in the mantle, and is concentrated in the crust. Over time, this leads to relatively radiogenic $^{176}\text{Hf}/^{177}\text{Hf}$ ratios in the depleted mantle compared with continental crust, which generally has unradiogenic ratios, owing to low time-integrated Lu/Hf. $^{176}\text{Hf}/^{177}\text{Hf}$ ratios are commonly reported as a deviation from the chondritic uniform reservoir (CHUR) in epsilon units (parts per ten thousand). The Lu-Hf system is particularly useful in zircon because of the high compatibility of Hf relative to Lu in the crystal

Figure 4. Map of O isotopes in Sierran plutons. Also included are the Sr_i 706 line and proposed locations of the Panthalassan-North American lithospheric boundary from Lackey et al. (2008) and Kistler (1990). JMS- John Muir intrusive suite; MG- Mount Givens pluton; NA- North American lithosphere; PA- Panthalassan lithosphere; SIS- Sonora Pass intrusive suite; TIS- Tuolumne intrusive suite; WIS- Whitney intrusive suite. Modified from Lackey et al. (2008).

lattice. Thus, radiogenic Hf accumulation due to *in situ* parental decay is negligible, and $^{176}\text{Hf}/^{177}\text{Hf}$ ratios in zircon reflect those of the parental magma (Kinny and Maas, 2003; Hawkesworth and Kemp, 2006). Because radiogenic isotopes decay with time, there is inherent ambiguity when interpreting epsilon values. For example, a low ϵHf magma could represent either mixing of a mantle melt with unradiogenic crustal material, or melting of mantle derived material that had aged in the crust (Hawkesworth and Kemp, 2006). The extent of the involvement of crustal material can be evaluated independently by O isotope measurements.

Oxygen Isotopes in Zircon

Stable O isotopes undergo mass fractionation, and, like Hf isotopes, can be used to examine possible magmatic source components. The ratio between the two most common isotopes of O is commonly expressed in delta notation, calculated as the deviation from $^{18}\text{O}/^{16}\text{O}$ of Vienna Standard Mean Ocean Water (VSMOW) multiplied by a thousand, and reported in parts per mil (Sharp, 2007). Zircons crystallized from the mantle have spatially and temporally consistent $\delta^{18}\text{O}$ values of $5.3 \pm 0.3\text{‰}$ (Valley, 2003). Near surface, low temperature water-rock interactions generally increase $\delta^{18}\text{O}$ in rocks. More rarely, high temperature interactions with meteoric water decrease rock $\delta^{18}\text{O}$ (Valley et al., 2005). Oxygen diffusion in zircon is sufficiently slow to retain magmatic $\delta^{18}\text{O}$ signatures during subjection to surficial weathering and metamorphism (Watson and Cherniak, 1995; Valley, 2003). Therefore, zircons with $\delta^{18}\text{O}$ values differing from those of the mantle can be assumed to have crystallized from a magma that was derived from, or had assimilated, crustal material. This record of surface alteration is often not present

in the radiogenic record because the timescales are too short for partitioning of parent and daughter (Valley et al., 2005; Hawkesworth and Kemp, 2007).

Trace Elements in Zircon

The trace element concentrations in a melt are strongly affected by the processes of melt formation, mixing, and crystallization. Rare earth element (REE) behavior in silicic systems is primarily controlled by minor phases such as garnet, titanite, hornblende, and apatite. Because ionic radius decreases with increasing atomic number, heavy rare earth elements (HREE) are more compatible than light rare earth elements (LREE). REE are incorporated into zircon by a coupled substitution with yttrium and phosphorous, $(\text{REE} + \text{Y})^{+3} + \text{P}^{+5} = \text{Zr}^{+4} + \text{Si}^{+4}$ (Belousova et al., 2002). The inclusion of certain REE, particularly Eu and Ce, into zircon is also affected by magmatic redox conditions (Trail et al., 2012). The melt source exerts initial control over REE abundances in a magma, with different source compositions producing characteristic REE patterns. Following partial melting, REE abundances can be altered by magmatic processes, often behaving predictively during melt evolution (Barth and Wooden, 2010).

Zircon Saturation Thermometer

The zircon saturation thermometer, initially described by Watson and Harrison (1983) and recently reevaluated by Boehnke et al. (2013), allows calculation of saturation temperature (T_{zm}) based on bulk rock peraluminosity and the partitioning of Zr between zircon and the melt. The peraluminosity parameter, $M = (\text{Na} + \text{K} + 2\text{Ca})/(\text{Al} \cdot \text{Si})$, describes a ratio of network formers to network modifiers, and acts as a proxy for

chemical processes that control zircon dissolution. The relationship is described by the following equation:

$$\ln(D_{Zr}) = \frac{10108}{T(K)} - 1.16(M-1) - 1.48$$

Where D_{Zr} is the distribution coefficient of Zr between zircon and the melt, and T is temperature in Kelvin. Interpretation of T_{zm} is dependent upon zircon saturation conditions within the melt. In initially saturated melts, T_{zm} provides a maximum zircon crystallization temperature, which can be assumed equivalent to the initial magmatic temperature. In initially undersaturated melts, T_{zm} provides a minimum estimate of initial magmatic temperature, as it underestimates the actual zircon crystallization temperature due to the increase in Zr concentration from fractionation of modal minerals (Harrison et al., 2007).

Ti in Zircon Thermometry

Incorporation of Ti into zircon has been experimentally demonstrated to be directly related to crystallization temperature, making it a valuable thermometer for measuring magmatic temperatures (Watson and Harrison, 2005; Watson et al., 2006). Because Ti primarily substitutes for Si in the crystal lattice, the activities of both SiO_2 and TiO_2 in the melt affect this partitioning (Ferry and Watson, 2007). The following equation governs the relationship between Ti concentration in zircon, magma temperature, a_{SiO_2} , and a_{TiO_2} :

$$\log(\text{ppm Ti}) = (5.711 \pm 0.072) - \frac{(4800 \pm 86)}{T(K) - \log(a_{SiO_2}) + \log(a_{TiO_2})}.$$

Estimating thermodynamic activities is complicated by the fact that many zircons did not grow in equilibrium with the final crystallized assemblage. Complex zonation in most crystals records changing magmatic conditions that likely included variations in the activities of both SiO_2 and TiO_2 . Temperature calculations presented here use $a_{\text{SiO}_2}=1$ and $a_{\text{TiO}_2}=0.5$. Several studies have suggested a higher value for a_{TiO_2} (Hayden and Watson, 2007; Claiborne et al., 2010). However, Mount Givens samples show a lack of MREE depletion in whole rock REE patterns and of MREE and HREE enrichment in zircon REE patterns. These trends suggest that titanite was a late crystallizing phase that was not concurrent with zircon crystallization. Calculating temperatures with an $a_{\text{SiO}_2}=1$ is common due to the ubiquitous presence of quartz. If this is an overestimate, it will act to offset error incurred from an underestimate of a_{TiO_2} , as the activities have opposing effects on the calculated temperature.

The Ti in zircon thermometer has a slight pressure dependence, estimated at 5–10 °C/kbar (Ferry and Watson, 2007; Ferriss et al., 2008). The thermometer is calibrated to a pressure of 10 kbar, approximately 6.6 kbar higher than the crystallization pressure of the Mount Givens granodiorite as calculated by Al-in-hornblende thermobarometry. This difference may result in an overestimation of magmatic temperature by approximately 30–60 °C. However, this error has no effect on relative temperature differences within the zircon population, and calculations using this thermometer produce reasonable magmatic temperatures (Claiborne et al., 2010).

METHODS

Zircon Separation and Imaging

In total, thirty-five samples were collected for petrographic, geochemical, and isotopic analysis (See Appendix A for comprehensive list of locations and descriptions). Fourteen samples were prepared for zircon *in-situ* analysis (Fig. 5). Zircons were separated at San José State University using standard separation techniques. Samples were first crushed in a jaw crusher, and then pulverized in a steel disk mill to reduce grain size to less than 1 mm. Zircons were separated from other minerals using a Wilfley table, magnetic separation, and two heavy liquid separations (Bromoform and Methylidodide). Finally, zircons were hand-picked and mounted and polished in 1” epoxy rounds at Stanford University. Mounts were imaged with cathodoluminescence (CL) on the scanning electron microscope at Stanford University in order to image zonation and internal structure to pick spots for analysis targets (see Appendices B and C for zircon CL images). Mounts were also imaged in transmitted light to identify inclusions that might affect analysis.

Figure 5. Zircon sample location map. See Appendix A for full list of sample locations and descriptions.

Whole Rock Geochemistry

Whole rock analysis of major and trace elements was completed at the Washington State University (WSU) GeoAnalytical Lab and the Pomona College XRF Lab. Fractions of coarsely crushed rock were separated prior to pulverization, and weathered chips were removed prior to sample preparation for XRF and ICP-MS. Samples with a “CS” prefix were sent as coarsely crushed rock to WSU for both XRF and ICP-MS characterization. Samples with an “11SN” prefix were first analyzed at the XRF Lab at Pomona College, and then powders were sent to WSU for complementary ICP-MS data. Sample preparation at Pomona College followed an identical procedure to the one used at WSU. Powders were prepared in a shatter box with a tungsten-carbide head, and then diluted with Li-Tetraborate in a 2:1 ratio. Double fusion in graphite crucibles was used to make glass beads. Analytical procedures for both labs follow similar protocols (see Lackey et al., 2012).

Trace Elements in Zircon

In situ trace element data in zircon was obtained using the Sensitive High-Resolution Ion Microprobe-Reverse Geometry (SHRIMP-RG) at the joint Stanford-USGS facility. Analytical procedures are analogous to those described in Claiborne et al. (2010) and Barth and Wooden (2010). The secondary beam was produced using a 1.5-2.5 nA O²⁻ primary beam. The beam produced a spot size of approximately 20 μm. Mass resolution on this machine is approximately 11000 at 10% peak height. Each analysis began with a 30 second raster period, followed by sequential analysis of the elements of interest (30 in total). Concentrations were calculated relative to the MADDER standard

(Barth and Wooden, 2010), and corrected for during offline data reduction performed using the SQUID 2 software package (Ludwig, 2009). Counts from each element were ratioed to $^{30}\text{Si}^+$ counts to account for variation in beam intensity. Measurements were screened for inclusions (usually evident by high Fe or Al concentrations), which were removed from the overall dataset.

SIMS Analysis of $\delta^{18}\text{O}$ of Zircon

Values for $\delta^{18}\text{O}$ of zircon was measured at University of Wisconsin—Madison using the CAMECA IMS 1280 with Faraday collection cups. Mounts were polished to remove trace element spots and implanted O from the SHRIMP analyses, then gold coated to mitigate charging. Analyses were located in the same zones as trace element spots to provide correlation between the two data sets. Analyses followed the routine described in Kita et al. (2009). A ~15nm spot size was achieved with a Ce^+ beam of ~2 nA. Secondary ions were accelerated across a 10 keV charge differential, and passed through a 40 eV energy slit to enter the mass spectrometer. Mass resolution of the instrument is approximately 2200. Total analysis time is approximately 3.5 minutes, including 10 seconds of presputtering and 120 seconds of automated secondary ion centering. Integrated measurements of O isotopes occurs in 20 cycles. $^{16}\text{OH}/^{16}\text{O}$ was monitored to ensure no targets were hydrated, which would cause erroneous isotopic composition.

The standard 91500, with an accepted value of 10.07‰ (Valley, 2003), was used to monitor instrumental mass bias and consistency. External precision for the entire run

had a two standard deviation (2SD) value of 0.4‰ (Fig. 6). All O data, including standard measurements, are reported in Appendix D.

Figure 6. External error plot for 91500 zircon standard. Individual analysis errors are two standard error (2SE). The orange line and blue shading indicate the average $\delta^{18}\text{O}$ and 1SD for all 91500 analyses. Accepted value for 91500 is 10.07‰ (Valley, 2003).

Hf Isotopes in Zircon

Following trace element and O isotopic analysis, grains were analyzed for Hf isotopic composition on the Thermo-Finnigan Neptune multi-collector, inductively coupled, plasma mass-spectrometer at the Vrije Universiteit, Amsterdam. Measurements for this study were made on the first two days of a five day analytical session. Material was ionized using a 193 nm Lambda Physik excimer laser ablation system. The laser was operated at an energy of 7 J/cm² with a pulse frequency of 7 Hz to produce a spot size of 49 μm . The laser operated in a He atmosphere, and a mixed He and Ar carrier gas

transported ablated material to the plasma source. Ablation runs lasted between 30 and 90 1-second cycles depending on grain depth, which was monitored by the ^{180}Hf signal. The average ^{176}Hf signal intensity for typical runs was between 250 and 300 mV. Sixty second blank corrections preceded each analysis.

Because laser ablation is an *in-situ* technique, isobaric interferences on ^{176}Hf by ^{176}Yb and ^{176}Lu must be corrected by monitoring interference-free isotopes of the same elements. Both ^{171}Yb and ^{173}Yb were measured to correct the ^{176}Yb interference. The measured $^{171}\text{Yb}/^{173}\text{Yb}$ was compared to the accepted value of 0.882858 (Chu et al., 2002) and used to calculate the Yb mass fractionation factor. This fractionation factor was applied to the interference correction, which utilized the accepted value of $^{176}\text{Yb}/^{173}\text{Yb} = 0.796328$ (Chu et al., 2002) to correct for ^{176}Yb interference on ^{176}Hf .

The interference of ^{176}Lu is smaller than that of ^{176}Yb ; however the correction is carried out in a similar fashion. Mass fractionation effects are accounted for by a Hf mass fractionation factor based on the accepted value $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$ (Vervoort et al., 2004). The interference correction is then made using the accepted $^{176}\text{Lu}/^{175}\text{Lu}$ value of 0.02655 (Vervoort et al., 2004).

All corrections were performed offline on a macro-enabled Excel spreadsheet. Measurements of $^{176}\text{Hf}/^{177}\text{Hf}$, $^{176}\text{Lu}/^{177}\text{Hf}$, and ^{176}Hf mV for all cycles were manually evaluated for each run to screen for isotopic zonation and data quality. Between 25 and 90 cycles, depending on grain size and data scatter, were selected for inclusion into final isotopic calculations for each spot. All unknown ratios were age corrected based on a representative age of 95 Ma. Changing this age by 5 Ma in either direction, which would

encompass the entire age range of the pluton, changes the ϵ_{Hf} by only 0.2 ϵ units, well below the typical internal precision of measurements.

Experimental bias throughout the run was checked with the JG-1 standard, with an accepted $^{176}\text{Hf}/^{177}\text{Hf}$ of 0.282000 ± 0.000005 (Morel et al., 2008). A total of 88 GJ-1 spots were analyzed over the two days of unknown measurements. The first day of measurements had an average of 0.282008 ± 0.000005 , and the second day average was 0.282018 ± 0.000005 . The combined two day average was 0.282014 ± 0.000005 (Fig. 7).

Figure 7. External error plot for JG1 zircon standard. Individual analysis errors are 2SE. Orange line and blue shading indicate the average and 2SD of all analyses. The accepted value for the JG1 standard is 0.282000 ± 0.000005 (Morel et al., 2008).

The standard R33 was also monitored, although less frequently, throughout the session. This standard is useful in assessing the isobaric interference corrections, as it has significantly higher concentrations of ^{176}Lu and ^{176}Yb (by up to a factor of 10). The

accepted $^{176}\text{Hf}/^{177}\text{Hf}$ value for R33 is 0.282764 ± 0.000014 (Fisher et al., 2014). Averages and standard deviations for the two days were variable, with the first day (n=19) producing 0.28276 ± 0.00007 , and the second day (n=7) producing 0.28288 ± 0.00016 . The two day average was 0.28279 ± 0.00015 (Fig. 8). The seven R33 spots run on the second day are more variable and above both the accepted value and the average from the previous day.

Figure 8. External error plot for R33 zircon standard. Individual analysis errors are 2SE. Orange line and blue shading indicate the average and 2SD of all analyses. The accepted value for the R33 standard is 0.282764 ± 0.000014 (Fisher et al., 2014).

Data from the R33 analyses show a correlation between $^{176}\text{Yb}/^{177}\text{Hf}$ and $^{176}\text{Hf}/^{177}\text{Hf}$ for $^{176}\text{Yb}/^{177}\text{Hf}$ greater than 0.1 (Fig. 9). The high $^{176}\text{Hf}/^{177}\text{Hf}$ analyses from day two all have high $^{176}\text{Yb}/^{177}\text{Hf}$ values. This suggests that either the R33 in the mount run on the second day had unusually high concentrations of ^{176}Yb , or that an analytical

issue arose which affected isotopic measurements. As the pattern of sporadic R33 results continued during day three and four of the analytical session (Fig. 10), it is believed there may have been a mechanical problem. However, R33 analyses largely returned to within error of the reported average during the final day of the analytical session, and in a subsequent session of R33 measurements. Evaluation of the R33 standard is ongoing, and further testing may show evidence of isotopic heterogeneity.

Figure 9. $^{176}\text{Hf}/^{177}\text{Hf}$ vs $^{176}\text{Yb}/^{177}\text{Hf}$ for all R33 analyses. Analyses are colored based on the day the measurement was performed. Error bars are 2SE. The errors in $^{176}\text{Yb}/^{177}\text{Hf}$ measurements are approximately the same size as measurement symbols.

Figure 10. R33 Standard measurements for entire Hf analytical session. Data are grouped into individual days of analysis. Error bars are 2SE.

The Plešovice standard, with an accepted $^{176}\text{Hf}/^{177}\text{Hf}$ value of 0.282482 ± 0.000013 (Sláma et al., 2008), was run only on the second day and provided an excellent absolute value and standard deviation (Fig. 11). The consistency of both JG-1 and Plešovice indicates that the issue encountered with R33 during the second day did not affect standards with low interference corrections. Because of possible issues with measurement and correction of high interference measurements, all unknown analyses with $^{176}\text{Yb}/^{177}\text{Hf} \geq 0.1$ have been discarded. External error for all analyses is reported as $2 \text{ } \varepsilon\text{Hf}$, which is conservative. All Hf data are reported in Appendix E.

Figure 11. External error plot for Plešovice zircon standard. Individual analysis errors are 2SE. Orange line and blue shading indicate the average and 2SD of all analyses. The accepted value for the Plešovice standard is 0.282482 ± 0.000013 (Sláma et al., 2008).

FIELD OBSERVATIONS

Northern Lobe

The northern lobe of the Mt. Givens pluton is petrologically and texturally diverse, containing both the equigranular and porphyritic phases of the Mount Givens granodiorite, as well as the granodiorite of Cow Meadow, and the aplite of Jackass Rock (Fig. 12). Due to cover, the contacts between these units are generally inferred. The exterior contact of the granodiorite of Cow Meadow was not observed, but has been mapped as sharp and intrusive by several previous studies (Bateman and Nokleberg, 1978; McNulty et al., 2000).

Equigranular Granodiorite

Equigranular granodiorite composes the majority of the outer “shell” of the northern lobe (Fig. 2). It has an average color index of 10-15, becoming more felsic inwards. The most mafic area observed was in the northern margin, where color index reached 20. The equigranular phase is medium grained, with felsic minerals averaging 2.5 mm. Hornblendes are euhedral in the margins and reach up to 2 cm in length (throughout this section, reported mineral size refers to length). They become smaller and more subhedral moving inwards as biotite becomes the predominant mafic mineral. Mafic minerals define a strong, steeply dipping magmatic foliation that is roughly parallel to concentric unit contacts (McNulty et al., 2000). Titanite, up to 3 mm, is the most common accessory mineral, making up as much as 1% of the rock in places.

Porphyritic Granodiorite

The porphyritic phase makes up the majority of the northern lobe, existing largely in the core, but also along the northwest margin (Fig. 2). The porphyritic phase is less mafic than the equigranular phases, with an average color index of 5-10. Like the equigranular phase, the porphyritic phase is most mafic where it appears on the margins, reaching a color index of up to 15. Grain size is overall coarser in this phase, with felsic minerals commonly reaching 5 mm. Hornblendes are more common in marginal areas, reaching up to 1 cm. Potassium feldspar phenocrysts are an average of 2-3 cm, but reach up to 4 cm, and exhibit zonation defined by mafic minerals. Fabrics in the porphyritic phase are poorly developed.

Figure 12. Representative rock textures in the northern lobe. (a) Equigranular granodiorite. (b) Porphyritic granodiorite. (c) Granodiorite of Cow Meadow. (d) Aplite of Jackass Rock.

Granodiorite of Cow Meadow

The granodiorite of Cow Meadow is horseshoe-shaped in map view, and lies completely within the porphyritic phase (Fig. 2). It is a medium grained, equigranular granodiorite. It is more mafic than the porphyritic material on either side, with average color index of approximately 15. As in other units, hornblende is the dominant mafic mineral; crystals are euhedral and reach 1 cm. Titanite composes 1-2% of the rock. Magmatic foliation defined by mafic minerals is moderately well developed, steeply dipping, and oriented roughly parallel to unit contacts.

Aplite of Jackass Rock

The aplite of Jackass Rock is better described as a homogeneous, fine-grained leucogranite. For consistency with the literature, the term “aplite of Jackass Rock” is used throughout this discussion; however, the sample will be pictured as a leucogranite in compositional diagrams. Felsic minerals are 1-2 mm in size. Occasional potassium feldspar phenocrysts reach up to 5 mm. The color index of the rock is approximately 2, and the primary mafic component is anhedral biotite of approximately 1 mm.

Enclaves of the Northern Lobe

Enclaves are common in the Northern lobe, particularly in the more mafic marginal areas and the granodiorite of Cow Meadow. Enclaves typically have a fine-grained matrix of biotite, hornblende, and plagioclase. Many also contain varying proportions of phenocrysts of these three minerals. The shapes of enclaves range from very elongate (aspect ratios $\geq 10:1$) to spherical, with lens shapes usually elongated in the directions of magmatic foliation. Some enclaves maintain discrete boundaries, while others appear to be in varying stages of disintegration with jagged edges and embayed crystals that are likely incorporated from the host. Enclaves in the porphyritic phase are ≤ 10 cm. Whereas enclaves in the two equigranular phases are up to 60 cm in length, and recorded by other researchers to be up to 1 m. Five enclave swarms have been mapped in the Northern lobe (Tobisch et al., 1997), but were not observed in this study.

Mixing Zone

On the eastern side of the central portion of the pluton, Bateman et al. (1971) mapped an area of equigranular granodiorite with an extraordinary abundance of subangular mafic inclusions. Field observations indicate that this area may be more adequately interpreted as a mixing or hybridization zone. At least four generations of magma were observed: equigranular Mount Givens granodiorite; a felsic endmember; a mafic endmember; and an intermediate hybrid (Fig. 13).

The Mount Givens granodiorite in this zone largely acted as the host rock for later magma injections. Xenoliths of equigranular Mount Givens granodiorite (10s of cm in length) within the intermediate magma showed varying degrees of disaggregation. In places, dikes of the hybrid magma intruded equigranular granodiorite, showing sharp boundaries. In other places, the boundary between the equigranular granodiorite and the hybrid was more wispy and elongated pieces of equigranular granodiorite were entrained within the hybrid. Large hornblendes within the hybrid may have been xenocrysts incorporated from disaggregation of the Mount Givens granodiorite as has been suggested for other locations in the Sierra Nevada batholith (Reid and Hamilton, 1987). Boundaries of large angular blocks of mafic material within the Mount Givens varied between sharp and crenulated, indicating some melting of the Mount Givens granodiorite. The highest degree of remobilization was observed near large mafic bodies in the central region, which were often surrounded by hybrid magmas with hornblendes and crenulated margins. Crenulated margins between mafic and hybrid magmas suggest that they were

largely coeval. However, chilled margins on some mafic enclaves within the hybrid suggest multiple episodes of mafic magma injection.

Figure 13. Magmatic interactions in central mixing zone. Hammer is 28 cm long. (a) Cross-cutting relationships between four generations of magma. Disaggregating xenoliths of equigranular granodiorite within hybrid magma, interactions between hybrid and mafic magmas, cross-cutting felsic dike. (b) Dike of intermediate magma intruding equigranular granodiorite. (c) Angular fragments of mafic material in equigranular granodiorite; some margins are sharp, while others show evidence for magmatic interaction. (d) Large mafic enclaves with crenulated margins and veins of hybrid magma.

A large (~50 m) enclave swarm was observed in the central portion of the Mount Givens pluton. Enclaves vary in size up to 50 cm in length. Several enclaves were composed of the hybrid magma, while some were of a more mafic composition.

Courtright Reservoir

Mount Givens granodiorite in the southern portion of the pluton was observed around Courtright Reservoir (Fig. 2). The granodiorite is largely coarse grained, with an average grain size of 2-4 mm. Color index is fairly consistent, and is ~10. Mafic minerals are generally subhedral, with biotite in greater abundance than hornblende. The size of mafic minerals varies, with hornblendes reaching 8 mm in places, and biotites as large as 4 mm. Titanite is common, euhedral, and up to 3 mm in size. Sparse potassium feldspar phenocrysts are present in most locations, commonly 1-2 cm, but reaching up to 4 cm. Enclaves are common in the southern region, and vary in modes and texture. Several types of enclaves were identified: (1) fine-grained, felsic enclaves with large, subhedral hornblende phenocrysts; (2) fine-grained mafic enclaves with plagioclase phenocrysts, occasionally cored by titanite; and (3) coarser-grained felsic enclaves with plagioclase, hornblende, and biotite phenocrysts (Fig. 13). All three types were observed in an enclave swarm approximately 1.5 m wide and 10 m long. Enclaves in this swarm are tightly packed with high concentrations of mafic mineral aggregates surrounding them. Schlieren range from approximately 5 to 30 m long and are up to 1 m wide.

Bodies mapped as aplite in the southern portion of the pluton can be better described as fine-grained leucogranites, and will be referred to as such in the following discussion. The average grain size is approximately 1 mm, with occasional subhedral quartz up to 0.5 cm and euhedral plagioclase phenocrysts of 1-2 cm. The rock has a color index of approximately 3-5, with biotite making up nearly all of the mafic component.

Figure 14. Mafic enclaves and schlieren near Courtright Reservoir. Hammer is 28 cm long. (a) Rounded enclave containing both mafic and felsic phases. (b) Enclave swarm showing at least three petrologically different mafic magmas. (c) Elongate schlieren approximately 30 m long. (d) Circular schlieren in equigranular Mount Givens.

RESULTS

Point Counts

Point counts were performed on 21 samples, including 11 from the northern lobe, 7 from a central transect, and 3 from the southern portion of the pluton. Results are presented in Table 1. Equigranular granodiorite, porphyritic granodiorite, and the granodiorite of Cow Meadow (abbreviated as eKmg, pKmg, and CM in Table 1) of the northern lobe display variations in modal mineralogy. Samples CS06 and CS05 are on

the margin of the northern contact with host rock, and are largely inconsistent with trends seen in the other samples, and are thus discussed separately.

The overall low percentage of mafic minerals in the porphyritic granodiorite (2-10%) is dominated by biotite (80-100%). This unit also contains samples with the highest proportions of potassium feldspar (up to 35% in the northwest corner), with significant variation in relative proportions of microcline and orthoclase. There are no clear patterns moving inwards in the pluton, but the innermost porphyritic sample (11SN36) has a very low proportion of mafic minerals, all of which are biotite.

The granodiorite of Cow Meadow is slightly more mafic than the porphyritic granodiorite (10-12%), with higher percentages of hornblende (20-23% of mafic minerals). Both samples of the granodiorite of Cow Meadow are located relatively close together in the unit, and thus more variation may be present. This unit has a more plagioclase than porphyritic samples, but less than equigranular ones.

The single equigranular sample is the most mafic (17%) in the northern lobe, and has a significantly higher proportion of hornblende (27.1%). Proportions of normalized plagioclase are higher than elsewhere in the northern lobe. CS05, the marginal equigranular sample, follows similar trends with the felsic minerals, but is significantly more mafic (19%), with very high percentages of hornblende (42%). Both samples lack microcline, with all potassium feldspar existing as orthoclase.

The aplite of Jackass Rock has only very small proportions of biotite (color index = 2). Proportions of modal felsic minerals are approximately equivalent.

Table 1: Point Count Data

Sample		Quartz	Plagioclase	Microcline	Orthoclase	Biotite	Hornblende	Titanite	Opaques	Q	A	P
<i>Northern Lobe</i>												
11SN34	pKmg	187	200	65	3	35	4	4	2	41.1	14.9	44.0
11SN35	pKmg	156	209	57	30	37	9	2	0	34.5	19.2	46.2
11SN36	pKmg	169	207	80	31	10	0	1	2	34.7	22.8	42.5
CS07	pKmg	153	181	9	89	44	8	9	7	35.4	22.7	41.9
11SN40	pKmg	167	194	40	63	33	0	2	1	36.0	22.2	41.8
CS06	pKmg	112	256	52	7	47	19	3	4	26.2	13.8	60.0
11SN38	CM	150	216	29	37	46	14	3	5	34.7	15.3	50.0
11SN39	CM	122	226	64	30	39	10	7	2	27.6	21.3	51.1
11SN41	eKmg	100	215	0	85	62	23	12	3	25.0	21.3	53.8
CS05	eKmg	119	225	0	56	56	40	3	1	29.8	14.0	56.3
11SN37	Leucogranite	176	167	142	11	3	0	0	1	35.5	30.8	33.7
<i>Central Transect</i>												
CS22	eKmg	115	211	36	26	63	45	1	3	29.6	16.0	54.4
CS26	eKmg	91	236	18	43	75	34	1	2	23.5	15.7	60.8
CS23	eKmg	117	221	39	35	42	37	7	2	28.4	18.0	53.6
CS25	eKmg	145	198	37	40	42	30	3	5	34.5	18.3	47.1
CS24	eKmg	150	206	36	43	27	36	0	2	34.5	18.2	47.4
CS21	eKmg	101	217	49	41	56	31	1	4	24.8	22.1	53.2
CS16	eKmg	127	210	53	36	38	29	4	2	29.8	20.9	49.3
<i>Southern Region</i>												
CS12	pKmg	145	237	27	27	45	11	2	6	33.3	12.4	54.4
CS10	eKmg	132	210	54	70	11	14	2	7	28.3	26.6	45.1
CS09	Leucogranite	166	185	70	51	23	0	1	4	35.2	25.6	39.2

Each unit can be distinguished on a QAP diagram (Fig. 15), with decreasing abundance quartz and increasing plagioclase from porphyritic, to the granodiorite of Cow Meadow, to equigranular granodiorite. Samples on the northern margin make up the most mafic, and hornblende rich samples in their respective groups.

Figure 15. QAP diagram showing modal mineralogy of Mount Givens samples. After Streckeisen (1976).

The samples in the central transect differ from the equigranular samples of the north mostly in their mafic content (13-22%), with higher proportions of hornblende (31-47%) relative to biotite. Unlike the northern equigranular samples, K-feldspars are more evenly divided between microcline and orthoclase.

Three representative samples were collected from the southern region for comparison to the north. CS12, the porphyritic sample collected from the western margin is fairly similar to the more mafic-rich porphyritic samples from the north. CS10, the

representative equigranular sample is notably more felsic than northern and central equigranular samples (5% mafic minerals); however it has one of the highest proportions of hornblende (56%) in the pluton. The southern leucogranite is very similar to the aplite of Jackass Rock, although with a slightly lower percentage of K-feldspar.

Whole Rock Geochemistry

Samples, including compositional outliers, from the Mount Givens pluton range in SiO₂ from 50-77%. Major elements show largely linear trends on Harker diagrams (Fig. 16), with increased scatter apparent towards the more mafic end of the spectrum. Alkali elements show the most variation with SiO₂. Trace elements also show largely linear trends on Harker diagrams (Fig. 17), although with increased scatter. A full table of whole rock geochemistry is provided in Appendix B.

All samples except the aplite of Jackass Rock show similar REE patterns, with LREE enrichment and very minor Eu anomalies (Fig. 18). REE concentrations generally decrease with increasing SiO₂. The aplite of Jackass Rock has a strong depletion in MREE, causing a concave up pattern. This is consistent with titanite fractionation and has been observed in fine-grained leucogranites elsewhere in the Sierra Nevada batholith (Burgess and Miller, 2008; Glazner et al., 2008).

Zircon Thermometry

Pluton-Wide Results

Zircon saturation temperatures calculated using the reevaluated thermometer of Boehnke et al. (2013) range from 625 to 735 °C, significantly lower than all Ti-in-zircon temperatures.

Figure 16. Whole rock major element geochemistry.

Figure 17. Whole rock trace element geochemistry.

Figure 18. Chondrite normalized whole rock REE plots. All samples normalized using Sun and McDonough (1989).

Ti-in-zircon temperatures calculated from individual spot measurements (n=186) for all rock types range from 790-1070 °C, with over 75% between 875 and 1000 °C (Fig. 19). Figure 20 shows temperature distributions for each rock type, and slight differences in range are evident. Porphyritic samples have a lower average temperature than equigranular ones, extending down to 800 °C. The granodiorite of Cow Meadow has a noticeably cooler and more restricted temperature profile than the other major rock units. The interior aplite of Jackass Rock ranges to some of the lowest temperatures recorded in the pluton. Both the mafic and felsic units in the central region have relatively restricted, high temperatures.

Figure 19. Histogram of calculated Ti-in-zircon temperatures for entire sample suite. Calculated zircon saturation temperatures are between 625 to 735 °C.

Figure 20. Ti-in-zircon (T_{tiz}) temperature profiles for different rock types.

In the northern lobe, temperatures decrease inwards, with the aplite of Jackass Rock reaching the lowest temperatures (Fig. 21). Sample CS07 is widely variable in temperature and falls off the general trend of the northern samples, with a third of analyses reaching below the lowest temperature measured for the outer equigranular unit. Temperatures on the outer western part of the pluton reach higher temperatures than those in the east. It is uncertain whether this is due to a geographical effect, or is related to textural differences.

Figure 21. Schematic zircon temperature profile across northern lobe (see Fig. 5). Note, sample CS07 falls much farther north than the rest of the samples on the transect. pKmg- porphyritic Mount Givens granodiorite; eKmg- equigranular Mount Givens granodiorite; JM- Jackass Meadow; CM- Cow Meadow.

Intergrain Variations

Temperature variations among zircons in samples ranges from 70 °C, in the central granodiorite, to 200 °C, in the aplite of Jackass Rock (Figs. 22-24). In some cases this dispersion is accounted for mainly by one outlier; for instance the aplite of Jackass Rock has a single temperature analysis at 998 °C, while the rest of the analyses are between 791 and 914 °C. All but one of these high temperature outliers are cores, suggesting that a small portion of zircon growth began at high temperatures (>950 °C), or that high-temperature zircons were entrained in the main melt. However, other samples, such as CS07, with large degrees of variation show a continuous range of temperatures.

Intragrain Variations

Intragrain temperature variations exist in most samples (Figs. 22-24). The greatest amount of intragrain variability is in sample 11SN40, where six of seven zircons analyzed have over a 35 °C difference between core and rim. In the northern lobe, the innermost samples show the least degree of intragrain variation. Among samples with temperature variation, most contain at least one grain with a reversed temperature gradient. Samples 11SN34 and 11SN35, in the northeast corner of the northern lobe are the only two samples that show significant temperature gradients that are all normally zoned.

Figure 22. Ti-in-zircon temperature measurements for porphyritic samples.

Figure 23. Ti-in-zircon temperature measurements for equigranular samples.

Figure 24. Ti-in-zircon temperature measurements for compositional outliers: aplite of Jackass Rock (115N37), felsic sheet (CS13), and mafic samples (CS03 and CS19).

Zircon Geochemistry

Trends in zircon geochemistry are consistent throughout the entire Mount Givens sample suite, despite appreciable scatter in trace element values and ratios. All analyses plot along common trends on trace element diagrams (Figs. 25-28). Hf exhibits a positive correlation with Yb/Gd, and negative correlations with Ti, Eu/Eu* and Th/U. All trends are consistent with zircon crystallization, and do not indicate the onset of any other mineral exerting trace element control during zircon growth. The trace element fields of cores and rims overlap completely for all of these plots (Figs. 25-28). REE patterns for all samples are typical of igneous zircon, showing concave down shapes, strong HREE-enrichment, and pronounced positive Ce and negative Eu anomalies (Fig. 29).

Trace elements concentrations and REE trends in the Mount Givens pluton do not correlate to rock texture. Both porphyritic and equigranular samples span most of the range of trace elements measured for the entire pluton (Figs. 25-28). The granodiorite of Cow Meadow is the most geochemically distinct unit in the pluton. As is shown in Figures 25-28, analyses from these samples are tightly clustered on trace element plots. The unit follows similar fractionation trends, but has restricted low values of Hf, Ti, and Th/U, and high Yb/Gd.

The range of most trace element values and ratios remains consistent throughout the lifespan of the pluton (Figs. 30-34). The clear exception to this is Eu/Eu*, which is consistently higher in samples older than 95 Ma. Post-95 Ma samples also have Th/U ratios that reach significantly higher values than pre-95 Ma samples.

Figure 25. Ti vs. Hf plots. (a) By rock type. (b) By spot location in zircon.

Figure 26. Eu/Eu^* vs Hf plots. (a) By rock type. (b) By spot location in zircon.

Figure 27. Yb/Gd vs. Hf plots. (a) By rock type. (b) By spot location in zircon.

Figure 28. Th/U vs. Hf plots. (a) By rock type. (b) By spot location in zircon.

Figure 29. REE in zircon plots separated by rock type. All samples normalized using Sun and McDonough (1989).

Figure 30. Rank order plot of zircon Hf concentration. Lines connect analysis spots from the same crystal.

Figure 31. Rank order plot of zircon Th/U. Lines connect analysis spots from the same crystal.

Figure 32. Rank order plot of zircon Yb/Gd. Lines connect analysis spots from the same crystal.

Figure 33. Rank order plot of calculated Ti-in-zircon temperatures. Lines connect analysis spots from the same crystal.

Figure 34. Rank order plot of zircon Eu/Eu^* . Lines connect analysis spots from the same crystal.

Intercrystalline Variations

As has been found in other studies (e.g. Claiborne et al, 2010), variation in zircon trace element signatures within individual samples often approaches the total variation within the pluton. The amount of intercrystal variation does not correlate with spatial location within the pluton, age, or rock type (Figs. 25-28). Sample CS10 has the greatest variation in Yb/Gd (31) and Eu/Eu* (0.249), as well as a fairly high T_{TiZ} variation (94 °C), although Hf variation is among the lowest of any measured samples (2158 ppm; see Appendix E). Both the central granodiorite (CS25) and the granodiorite of Cow Meadow (11SN38) show little variation, and are tightly clustered on most trace element plots (Figs. 25-28).

Intracrystalline Variations

As with temperature, variations in trace elements within crystals are common in the zircon populations of all samples (Figs. 30-34). Hf is largely anti-correlated with Ti concentration and temperature; however, in some samples zircons that are reversely zoned in temperature are still normally zoned in Hf. In general, Yb/Gd and Eu/Eu* increase from core to rim, while Th/U decreases, consistent with typical fractionation trends (Barth and Wooden, 2010; Claiborne et al., 2010). However, there are many examples of the reverse occurring for each particular element, and nearly all samples contain zircon crystals that show reverse zonation in multiple trace element values and ratios (Fig. 35).

Figure 35. Intracrystalline variation in zircon trace elements. (a) Zircons that show normal, down-temperature fractionation patterns. (b) Zircons that show reverse zonation in trace elements.

Isotopic Data

The O and Hf isotopic systems in the Mount Givens pluton are broadly correlated (Fig. 30). The spread in isotopic data is significantly larger than the 2SD for both systems, indicating that variation is geologically significant. The isotopic composition of the mafic body in the southeast portion of the Mount Givens is constrained to low $\delta^{18}\text{O}$

(5.3–6.0‰, except for one 6.6‰ core) and high ϵ_{Hf} (2.2–8.5). A biotite schist, located on the western margin of the northern lobe, was sampled as a possible crustal endmember. Values of $\delta^{18}\text{O}$ in the schist spans the observed variation in the Mount Givens plutonic samples, but Hf isotopic values are in the upper range of those measured in the pluton.

Figure 36. O vs Hf covariation plot. The data show a broad anticorrelation of ϵ_{Hf} and $\delta^{18}\text{O}$ values.

Both $\delta^{18}\text{O}$ and ϵ_{Hf} show no correlation with bulk rock SiO_2 (Fig. 31). This indicates that isotopic variation in the pluton is not strongly dependent on the compositional evolution of the magma.

Figure 37. Variation of isotopes with bulk rock composition. (a) O values. (b) Hf values. Blue dots and connecting lines show individual analyses for each sample. Yellow triangles show the sample mean.

Longitudinal Variation

Zircons from the Mount Givens pluton exhibits longitudinal variation in both isotopic systems, with a general pattern of increasing $\delta^{18}\text{O}$ and decreasing ϵHf moving westwards towards the proposed Panthalassan-North American lithospheric boundary (Fig. 32). Figure 32 shows the relationship between geographic location and isotopic composition for all analyzed samples. The x-axis displays the shortest distance between each sample's location and the Panthalassan-North American boundary of Lackey et al. (2008). Because of the uncertainty in the location of this boundary, generally the western edge of the Mount Givens pluton, the distance from the boundary measurements should not be viewed as exact. This trend is in agreement with multi-grain laser fluorination O isotope data from a previous study in the pluton (Lackey et al., 2008).

The two samples that most clearly differ from the zircon isotopic pattern are compositional outliers from the central region of the pluton. The sampled mafic body (CS19) has an average zircon $\delta^{18}\text{O}$ of 5.78‰ and zircon ϵHf ranging from 2–8.5, showing its strong affinity with the mantle. The O and Hf isotopic composition of zircon from the felsic sheet (CS13) are noticeably high in $\delta^{18}\text{O}$ and have a wide range of ϵHf (although both analyses with positive ϵHf are from a single zircon crystal). West of the boundary, sample CS07 displays wide variations in zircon O and Hf isotopic ratios, reaching towards more mantle-like values in both isotopic systems.

Figure 38. Variation of isotopes along Panthalassan-North American boundary. (a) O values. (b) Hf values. Bulk laser fluorination O data are included from Lackey et al. (2008). Blue dots and connecting lines show individual analyses for each sample. Yellow triangles show the sample mean.

Age Variation

Isotopic variation is not correlated to age (Fig. 33), indicating that variation cannot be explained simply by changing sources with time. However, the intrusion of the Mount Givens pluton can be broken into two pulses based on zircon isotopic variability. Magmas intruded at or before 95 Ma show a greater range of zircon isotopic variation-compared to those intruded afterwards (Fig. 34). Zircon from samples older than the granodiorite of Cow Meadow range in $\delta^{18}\text{O}$ from 5.31-7.84‰, while zircon $\delta^{18}\text{O}$ in younger samples does not reach above 6.96‰. Similarly, Hf isotopes in the older group vary by 11 ϵHf units, while over 90% of zircon analyses from samples younger than the granodiorite of Cow Meadow are restricted to a 6 ϵHf range (Fig. 35). Of particular interest in the older group are samples 11SN40 and 11SN34, both in the porphyritic unit of the northern lobe, but on opposite sides of the pluton. Zircons from sample 11SN40 shows wide isotopic variation, reaching to some of the most crustal values, while 11SN34 displays restricted, mantle-like values in both isotopic systems. Samples from the younger age group are isotopically intermediate.

Intercrystalline Variations

The total within sample isotopic variability is generally larger in older samples (Figure 36). Analyses in these samples also plot as a more continuous spectrum, rather than having an isotopic range defined by a single outlier analysis. The clear exception to this is the porphyritic sample in the northeast corner (11SN34), which shows minimal

Figure 39. Temporal variation of isotopes. (a) $\delta^{18}\text{O}$ values. (b) ϵHf values. Blue dots and connecting lines show individual analyses for each sample. Yellow triangles show the sample mean. Plot excludes compositional outliers (CS03, CS13, and CS19).

Figure 40. Covariant $\delta^{18}\text{O}$ and ϵ_{Hf} plot showing isotopic differences in pre- and post-95 Ma granodiorites.

Figure 41. Variation of isotopes across Panthalassan-North American boundary, separated by age. (a) Zircon O values. (b) Zircon Hf values. Bulk laser fluorination O data are included from Lackey et al. (2008). Blue dots and connecting lines show individual analyses for each sample. Yellow triangles show the sample mean. The area shaded in red represents the isotopic range of means in samples younger than 95 Ma, and the area shaded in blue represents means in samples older than 95 Ma.

isotopic variability (see Fig. 35). The sample showing the greatest amount of intercrystal dispersion in both isotopes is the oldest porphyritic unit (CS07) (Fig. 35).

Several samples show wide variations in only one of the isotopes, indicating that O and Hf isotopic systems were decoupled in certain areas of the pluton. This is particularly evident in the zircon isotopic signatures of the most felsic samples. The aplite of Jackass Rock (11SN37) has consistent ϵHf , but a 1.2‰ variation in $\delta^{18}\text{O}$. The felsic sheet (CS13) has the widest range of ϵHf , but is restricted to $\delta^{18}\text{O}$ between 6.92 and 7.64‰ (Fig. 35).

Several samples have single zircon crystals that are isotopically dissimilar from the rest of the zircon population. This intercrystal variability suggests that mixing of isotopically distinct sources occurred following zircon crystallization in some areas. These crystals sometimes have crustal isotopic signatures, while others have more mantle-like signatures than the main population.

Intracrystalline Variation

Intracrystalline isotopic variation is also more prevalent in the older samples (Fig. 37A). The most evident variation is in sample 11SN40. Out of five zircon crystals analyzed for O and Hf, four have a $\delta^{18}\text{O}$ variation of at least 0.75‰, and two have Hf variation of at least 3 ϵHf units. Zircons in this sample typically have higher $\delta^{18}\text{O}$ cores, although there is one example where this pattern is reversed. Where zircon is significantly zoned, ϵHf values become more negative from core to rim. Among other older samples, there does not appear to be significant core to rim trends.

Figure 42. Rank order plot of isotopic variation. (a) O isotopes. (b) Hf isotopes. In both isotopic systems, inter- and intragrain variation is more prevalent before 95 Ma. In the post-95 Ma samples, rims have slightly more juvenile values for both isotopes. This plot does not include samples CS13 and CS19, which do not have sufficient age data.

Besides a few outlier analyses, younger samples show little intracrystal variability (Fig. 37B). Among these samples, the average value of rims for both isotopes is slightly more primitive than that of cores.

Decoupling of O and Hf isotopes in zoned crystals is mostly concentrated in the western portion of the northern lobe (Fig. 37C). In about half of these cases, cores have clearly undergone some resorption, while in others, zoning is uninterrupted and lacks any obvious resorption. Six zircons, each from a different sample, exhibit Hf variation of ≥ 4 ϵ Hf. In all but one of these crystals, $\delta^{18}\text{O}$ variation is not statistically significant, with one sample in 11SN41 varying by $\sim 0.5\%$. These zircons indicate that a decoupling of zircon O and Hf systems occurred where large variations in one of the isotopes were introduced without a change in the other.

Four samples have a $\delta^{18}\text{O}$ value that is separated from the sample average by at least two standard deviations. The most dramatic example is a core from CS25 (Fig. 37c) with a value of 5.31‰, 1.2‰ lower than the rim value, and over 1‰ lower than the next lowest value in the sample. Among the low $\delta^{18}\text{O}$ zircon crystals, two have cores that show strong textural evidence for resorption. This indicates incorporation of more mantle-like zircons into a higher $\delta^{18}\text{O}$ magma, although this is not correlated with Hf changes. Both CS03 and CS19 have a single core with a significantly higher $\delta^{18}\text{O}$ than is seen in the rest of the sample. However, the extreme O values do not correlate with any change in Hf, exemplifying the decoupling described earlier.

Two samples contain one spot with significantly lower Hf values than all other analyses. One analysis is in the core of a zircon from the granodiorite of Cow Meadow,

and one is on the rim of a zircon in the inner porphyritic unit. Both crystals show no significant $\delta^{18}\text{O}$ variation and lack evidence for resorption.

Figure 43. Intracrystalline variation in zircon O and Hf isotopes. (a) Zircons from sample 11SN40 shows significant variations in both isotopic systems. (b) Zircons from sample 11SN36 are representative of the general within-crystal homogeneity of younger samples. (c) Zircons from several samples show a decoupling of isotopic systems on the intracrystalline scale.

DISCUSSION

The Mount Givens pluton has been singled out among Sierran plutons as an example of a large ($>1000 \text{ km}^2$) intrusion that exhibits textural and compositional/mineralogical homogeneity. These characteristics, along with rapid flux rates calculated from bulk zircon dates, lead several researchers to propose that the Mount Givens granodiorite may represent a plutonic equivalent to ‘monotonous intermediate’ ignimbrites (Bachman et al., 2007; de Silva and Gosnold, 2007; Lipman et al., 2007; Lipman and Bachman, 2015). Recent ID-TIMS data have demonstrated that the Mount Givens pluton was emplaced over approximately 7 million years (Fig. 3), raising questions about the validity of the ignimbrite correlation (Frazer et al., 2014; Coleman et al., 2016). The long timescale of emplacement makes it challenging to explain the overall homogeneity of the Mount Givens pluton. Age variations and thermal considerations preclude both rapid accumulation of compositionally uniform magma and pluton-scale mixing of several major pulses. Thus, it is important to examine the scale of homogeneity within the pluton in more detail, and to assess the zircon crystal record in order to better evaluate the processes that produced this large, homogeneous (‘monotonous’) intermediate pluton.

Field observations from this study are in agreement with broad compositional and textural trends outlined by earlier work (Bateman and Nokleberg, 1978). However, point counts taken along a northeast-southwest transect show a more limited range of modal mineralogy than previously reported, with nearly all samples plotting within a relatively small area of the granodiorite field of the QAP diagram (Fig. 15). This discrepancy may

be due to my analysis of a different transect than that of previous workers, and may also indicate more compositional variability in the southern portion of the northern lobe, where previous modal studies (Bateman and Nokleberg, 1978) were performed.

Despite the consistency in modal mineralogy throughout much of the pluton, field observations from this study document the involvement of multiple magmatic phases. Observations from the east-central portion of the pluton in areas previously mapped as equigranular granodiorite with a high abundance of subangular mafic inclusions (Bateman et al., 1971) demonstrate that m- to km-scale mixing and hybridization occurred between the host Mount Givens granodiorite, felsic sheets, and mafic bodies in this area (Fig. 12). Unfortunately, no age data are available to more clearly constrain the timing of these compositional outliers with respect to the main granodioritic mass, but the field relationships suggest that the coarse-grained Mount Givens granodiorite host was clearly still mobile, or susceptible to appreciable remobilization, when the felsic sheets and mafic bodies were constructed. The mafic enclave swarms and mafic bodies documented here, and in other work (Tobisch et al., 1997) demonstrate that mafic magmas were important throughout most of pluton growth.

Although field observations in the Mount Givens pluton provide evidence of interaction between multiple batches of compositionally distinct magmas, the finer-scale information recorded in zircon provides a more detailed record of magmatic processes occurring at the onset of crystallization. All analyzed zircons from the Mount Givens suite have high Ti-in-zircon temperatures (Fig. 19) that are consistently higher than zircon saturation temperatures. This indicates that magmas were initially undersaturated

in zircon at anatectic temperatures (cf. Harrison et al., 2007), which would dissolve zircon inherited from melt sources. Therefore, trace element and Hf and O isotopic signatures of zircons reflect those of the magmas from which zircon crystallized after the magmas had cooled sufficiently to saturate in zircon, probably during ascent and/or after emplacement.

The zircon trace element and isotopic data presented in this study, in combination with CA-ID-TIMS dates from Frazer et al. (2014), document changes in the Mount Givens magmatic system over time. Zircon trace element signatures show broad trends that are consistent with down-temperature fractionation for all units; however, the degree of scatter in these data suggest that more complex magmatic processes occurred during zircon crystallization (Figs. 25-29). All samples contain zircons showing normal down-temperature trace element trends. However, because nearly all samples also contain zircon crystals that are reversely zoned in Hf, Ti, Yb/Gd, and Th/U, transfer of zircon crystals between ‘hot’/more juvenile and ‘cold’/more evolved magmas was common throughout pluton growth (Figs. 30-35). The continual interaction of thermally and geochemically distinct magmas documented here is consistent with a mush system where some zircons are incorporated as antecrysts in hotter magmas midway through their growth. Instances where changes in individual trace element values and ratios are inconsistent with general normal or reverse zonation within the crystal (e.g. decoupling of Hf and Ti) may be due to crystallization of minerals that drastically affected local trace element budgets, particularly titanite, which is ubiquitous in the Mount Givens granodiorite. The only clearly distinguishable variation in trace elements with age is the

higher Eu/Eu* values in post-95 Ma samples (Fig. 34), which may indicate early plagioclase fractionation, a transition to a more plagioclase rich source (Hoskin and Schaltegger, 2003), or a systematic change in magmatic oxygen fugacity conditions (Trail et al., 2012).

Isotope analysis of zircon from samples older than 95 Ma, indicates that the isotopic compositions and the degree of mixing of isotopically disparate magmas varied across the pluton during zircon crystallization. Samples 11SN40 and 11SN34, two porphyritic samples of the same age located in the western and eastern portions of the northern lobe respectively (Fig. 5), demonstrate this contrast. The complete lack of overlap between the zircon isotopic compositions of these two samples indicates a lack of unit-wide mixing of magmas. The presence of intracrystal variation in several of the older samples, most notably 11SN40 (Fig. 37), indicates that crystals were transferred between isotopically distinct magmas during the span of their growth. In contrast, the minimal variation in isotopes ratios in sample 11SN34 may indicate that magma feeding the eastern portion of the intrusion was more isotopically homogeneous, or that this portion of the pluton cooled quickly enough that later pulses did not mix appreciably. Finer-scale sampling may resolve if these hypotheses are correct.

Beginning with the intrusion of the granodiorite of Cow Meadow, the isotopic composition of zircon became significantly more homogeneous. This homogeneity is visible at all scales, as the variation between and within samples as well as within individual crystals decreases. Zircon isotopic compositions for these samples largely fall in the middle of the measured range of older samples (Fig. 34). Given that magmas were

not likely saturated at the source, this observation suggests that the decrease in variability is related to mid-crustal level homogenization of magma bodies that produced the Mount Givens pluton. The decrease in inter- and intracrystalline isotopic variation indicates an overall more connected, and thermally mature system that was well mixed at the hand sample scale and remained so throughout zircon growth.

The negative covariation observed for zircon Hf and O data for the Mount Givens sample suite (Fig. 30) is also consistent with mixing and reflects contributions from several isotopically distinct magma sources. Four commonly cited sources for the granitoids of the Sierra Nevada batholith include: depleted mantle, enriched mantle, Proterozoic crust, and Panthalassan crust (Kistler, 1990; Beard and Glazner, 1995; Coleman et al., 1997; Lackey et al., 2008).

Figure 38 shows a mixing model for zircon Hf and O isotope measurements of Mount Givens samples using these end members. The isotopic composition of the mantle end members is based primarily on measurements of Cenozoic basalts in the Sierra Nevada batholith (Beard and Johnson, 1997; Nelson et al., 2013). The depleted and enriched mantle reservoirs differ by up to 15 ϵHf . Isotopic compositions for the two crustal reservoirs, Proterozoic and Panthalassan, are based on values from Lackey et al. (2012). Due to its derivation from oceanic sediments, the Panthalassan crust has significantly more radiogenically derived Hf than the Proterozoic crust (Lackey et al., 2012).

Figure 44. Mixing model for zircon isotopic compositions of Mount Givens samples. Orange diamonds show zircon isotopic compositions of samples from the Mount Givens pluton. Red circles plot zircon isotopic compositions of the mica schist sampled in this study. Colored lines are isotopic mixing curves between the different reservoirs.

Isotopic mixing models involving radiogenic isotopes can be sensitive to elemental concentrations of the isotopes, but O is assumed to be readily available in all silicate reservoirs, and thus mixing is a simple binary linear relationship and a function only of proportion of the end members. The concentration of Hf in the probable end

members is variable, which makes this the largest source of uncertainty in the mixing model shown in Figure 38. Crustal Hf concentrations, both Proterozoic and Panthalassan, for the model were estimated from the global average of Taylor and McLennan (1995). Compositions of Cenozoic basalts in the western U.S. provide a wide range of possible Hf concentrations for both the depleted (2-8 ppm) and enriched (4-9 ppm) mantle (Beard and Johnson, 1997; Nelson et al., 2013). The model displayed here uses a low value of 3 ppm for the Hf concentration of the depleted mantle; increasing this number produces an increasingly poor fit. For a complete explanation of mixing curve parameters see Appendix F.

The spread of data makes it difficult to uniquely identify the melt sources, but the mixing model can be used to outline some general constraints. The decrease of zircon ϵ_{Hf} with increasing zircon $\delta^{18}\text{O}$ requires the involvement of nonradiogenic, probably Proterozoic, crust, which is consistent with other isotopic studies of Sierran plutons (DePaolo, 1987; Kistler, 1990; Lackey et al., 2008; 2012). The high ϵ_{Hf} of the mica schist, plotted as red circles in Figure 38, indicates its potential affinity with Panthalassan lithosphere. The observation that it bounds the high ϵ_{Hf} end of the Mount Givens granodiorite samples also makes it a possible contributor to some of the observed isotopic variation of zircon in the pluton. Several spots with mantle-like $\delta^{18}\text{O}$ fall in the range of enriched mantle ϵ_{Hf} . However, ϵ_{Hf} analyses of zircons from the mafic body in the central portion of the pluton (CS19) reach ϵ_{Hf} values of up to +9 (Fig. 32), indicating contributions from the depleted mantle as well. These data points are not plotted on Figure 31 because they do not have associated $\delta^{18}\text{O}$ values.

Evidence for isotopic mixing between depleted mantle and Proterozoic crust has been suggested for several granitic suites in the Sierra Nevada batholith based on O, Hf, Sr, and Nd isotopic signatures (DePaolo, 1981; Lackey et al., 2012; Nelson et al., 2013). The incorporation of Proterozoic crust, and possibly the depleted mantle, in the formation of Mount Givens magmas distinguishes it from large intrusive suites to the east that have been suggested to have formed almost exclusively by melting and refinement of enriched mantle sources (Coleman et al., 1992; Coleman and Glazner, 1997; Wenner and Coleman, 2004).

The fact that zircon isotopic composition correlates to longitude, and not age, indicates that melts were tapping different sources based on geographic location. This is particularly evident in the older samples, which span a much wider range of $\delta^{18}\text{O}$ and ϵHf . The negligible intracrystalline variation, low $\delta^{18}\text{O}$, and high ϵHf in the easternmost sample of the northern lobe suggest a homogeneous melt with a significant mantle contribution. In contrast, samples in the western portion of the northern lobe show significant variation within individual crystals, higher $\delta^{18}\text{O}$, and lower ϵHf indicating a melt that has a significant crustal component. Scatter and intracrystalline variation in trace element values and ratios also suggest transfer of zircon crystals between geochemically variable melts, although this scatter is present in younger samples as well. The abrupt transition to more homogenous zircon isotopic compositions, intermediate to those seen in early magmatism, beginning with the intrusion of the granodiorite of Cow Meadow, suggests a significant change in the Mount Givens magmatism at this time.

Based on the lack of overlap in zircon ages between units older than and younger than the granodiorite of Cow Meadow (Fig. 3), Frazer et al. (2014) concluded that the outer and inner portions of the northern lobe had little interaction. This suggestion is consistent with the sharp intrusive contact of the Cow Meadow granodiorite and the zircon isotopic data presented here, which suggest a significant difference in isotopic variability between the inner and outer magmas. This late isotopic homogeneity is also reflected in the single granodioritic sample from the southern lobe. The shorter timeframe of intrusion (Frazer et al., 2014), and narrow range of isotopic variability are consistent with a thermally mature and more isotopically homogeneous source, such as a magma assimilation, storage, and homogenization (MASH) zone, and increased intrusive flux into the arc. Appreciable trace element variability suggests efficient mixing and crystal transfer following the onset of zircon crystallization. The considerable overlap in zircon ages of post-95 Ma samples, along with their isotopically homogeneous character, suggest that they record continuous zircon crystallization, within a contiguous magma body of considerable size (10's to 100's of km³) that was present in the late stages of Mount Givens magmatism.

CONCLUSIONS

1. Field observations and point count data from this study are consistent with the mapping and petrologic patterns recorded by previous researchers. A more detailed description of a mixing zone in the east central portion of the pluton documents interactions between at least four generations of magma in an area several km wide.

2. Consistently high Ti-in-zircon temperatures for all zircons suggest that all magmas were produced by melting at high-temperatures under conditions of water undersaturation (e.g. amphibole dehydration). Initial melts were undersaturated in zircon, and zircon growth occurred during magma ascent and/or emplacement.
3. Variation in zircon isotopic composition indicates mixing of magmas that are derived from several distinct isotopic sources. Longitudinal variation in $\delta^{18}\text{O}$ and ϵ_{Hf} suggests increasing mantle contributions in the eastern portion of the pluton.
4. Trace element signatures indicate that normal down-temperature fractionation of magmas was common during zircon crystallization. However, all samples show evidence of reverse zonation in trace elements, indicating that crystal transfer between thermally and chemically distinct environments was also occurring.
5. The characteristics of pre-95 Ma magmatism appear to be spatially controlled, with more homogeneous mantle-like magmas to the east and more heterogeneous magmas to the west that contain a greater crustal contribution.
6. Post-95 Ma magmas were likely derived from the same sources, but magmas were more thoroughly mixed in a mature MASH zone and/or in larger intrusive pulses. The narrow timespan and homogeneity of the zircon isotopic population suggest that the inner portion of the northern lobe may have existed as a large melt or crystal mush reservoir.

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APPENDIX A: Sample Locations and Descriptions

Sample	UTM E	UTM N	Description
CS01	291684	4132107	PJs; Mica-Schist
CS03	290754	4140169	Mafic enclave in Cow Meadow granodiorite
CS05	291684	4153057	Equigranular Mount Givens granodiorite
CS06	291619	4153102	Porphyritic Mount Givens granodiorite
CS07	284392	4150466	Porphyritic Mount Givens granodiorite
CS09	324161	4113867	Courtright Aplite, Leucogranite
CS10	325843	4106077	Equigranular Mount Givens granodiorite
CS12	325204	4105211	Porphyritic Mount Givens granodiorite
CS13	322399	4136210	Felsic sheet in Givens
CS15	321161	4135733	Intermediate mass from mixing zone
CS16	321161	4135733	Equigranular Mount Givens Granodiorite; mixing zone
CS19	317841	4134329	Mafic body
CS20B	317871	4134400	Enclaves in hybrid
CS21	322445	4135412	Equigranular Mount Givens granodiorite
CS22	322450	4134374	Equigranular Mount Givens granodiorite
CS23	321567	4132948	Equigranular Mount Givens granodiorite
CS24	320422	4131241	Equigranular Mount Givens granodiorite
CS25	317179	4132285	Equigranular Mount Givens granodiorite
CS26	312474	4127476	Equigranular Mount Givens granodiorite
11SN34	299156	4157996	Equigranular Mount Givens granodiorite
11SN35	297831	4153335	Equigranular Mount Givens granodiorite
11SN36	296809	4145484	Equigranular Mount Givens granodiorite
11SN37	295467	4145248	Aplite of Jackass Rock
11SN38	291268	4140381	Cow Meadow granodiorite
11SN39	290815	4140069	Cow Meadow granodiorite
11SN40	289492	4139770	Porphyritic Mount Givens granodiorite
11SN41	288203	4137702	Equigranular Mount Givens granodiorite

APPENDIX B: Cathodoluminescence Images with Indexed Analysis Spots

CS01

CS03

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.

CS07

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.
CS10

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.
CS13

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.
CS19

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.
CS25

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.
11SN34

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.
11SN36

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.

11SN37

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.
11SN38

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.

11SN40

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.

11SN41

* SHRIMP trace element spots in red, SIMS oxygen spots in green, LA-ICPMS Hf spots in blue.

Appendix C: Cathodoluminescence Images with $\delta^{18}\text{O}$, ϵHf , and Trace Element Concentrations

APPENDIX D: Whole Rock Data

Normalized Major Elements

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO*	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
CS01	59.98	1.068	16.77	6.71	0.317	3.47	5.72	2.59	3.11	0.264	100
CS03	50.83	1.399	18.96	10.33	0.22	5.16	5.87	4.16	2.75	0.324	100
CS05	61.98	0.736	17.49	5.57	0.107	2.32	5.22	4	2.39	0.186	100
CS06	66.49	0.517	16.67	3.69	0.08	1.25	3.39	3.99	3.77	0.154	100
CS07	69.76	0.383	15.66	2.76	0.074	0.94	3.04	4.15	3.13	0.109	100
CS09	71.87	0.32	14.94	2.1	0.054	0.58	1.94	3.69	4.39	0.101	100
CS10	68.07	0.443	15.99	3.13	0.061	1.21	3.29	3.84	3.82	0.15	100
CS12	63.69	0.638	17.39	4.28	0.069	1.79	4.03	4.07	3.81	0.229	100
CS13	67.99	0.508	16.21	3.2	0.056	1.03	3.66	3.59	3.61	0.148	100
CS15	59.36	0.956	17.92	6.66	0.138	2.86	6.09	3.73	2.09	0.194	100
CS16	66.87	0.474	16.3	3.61	0.07	1.5	3.76	3.38	3.93	0.105	100
CS19	54.79	1.064	18.03	8.44	0.125	4.45	6.77	3.38	2.66	0.296	100
CS20b	56.83	0.9	19.59	6.73	0.127	2.56	5.58	4.46	2.82	0.411	100
CS21	65.67	0.557	16.3	4.16	0.081	1.76	4.13	3.42	3.79	0.123	100
CS22	65.23	0.622	16.22	4.56	0.085	1.95	4.37	3.31	3.51	0.139	100
CS23	64.6	0.584	16.69	4.55	0.084	1.92	4.81	3.61	3.02	0.137	100
CS24	65.49	0.573	16.19	4.44	0.085	1.89	4.09	3.26	3.85	0.132	100
CS25	65.74	0.634	15.87	4.61	0.084	1.95	3.96	3.39	3.58	0.189	100
CS26	64.49	0.716	16.34	5.1	0.093	2.09	4.63	3.53	2.83	0.175	100
11SN-41	62.3	0.86	16.19	6.31	0.1	2.58	4.53	3.22	3.41	0.22	100
11SN-40	70.48	0.38	15.87	2.3	0.04	0.78	2.24	3.21	4.36	0.09	100
11SN-39	66.9	0.61	15.7	4.2	0.07	1.51	3.75	3.55	3.3	0.17	100

Normalized Major Elements Continued

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO*	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
11SN-38	66.48	0.57	16.34	4.16	0.07	1.56	3.69	3.52	3.21	0.17	100
11SN-37	76.64	0.09	13.29	0.74	0.02	0.13	0.87	3.2	4.91	0.01	100
11SN-36	75.18	0.17	13.7	1.12	0.05	0.31	1.37	3.49	4.42	0.04	100
11SN-35	69.24	0.46	15.23	3.02	0.05	1.07	2.8	3.13	4.63	0.12	100
11SN-34	70.26	0.43	15.04	3	0.08	0.95	2.77	4.09	3.06	0.12	100

Trace Elements

	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th	Nd	U
CS01	21	55	20	143	640	139	331	162	24	10.2	18	5	287	51	34	47	6	28	3
CS03	27	42	19	196	351	219	405	148	11	13.4	29	44	189	13	30	51	7	21	6
CS05	6	9	13	112	919	92	459	172	21	8.4	19	19	80	13	24	50	7	21	2
CS06	3	6	7	59	1595	118	409	195	17	7.5	17	2	70	16	25	44	7	18	2
CS07	3	5	6	45	786	124	321	147	17	8	17	4	49	18	20	37	12	18	4
CS09	3	4	4	29	1215	194	391	184	10	11.7	19	4	60	25	42	72	24	26	4
CS10	3	7	6	63	1002	138	535	127	9	7.5	18	7	58	22	20	37	12	15	6
CS12	6	9	7	86	1025	135	674	157	9	8	20	13	81	19	30	49	11	19	3
CS13	2	4	5	51	1072	122	547	146	11	8.7	19	1	68	18	26	47	11	19	3
CS15	4	2	15	158	719	79	659	101	17	9.2	20	10	97	10	19	37	5	20	3
CS16	5	9	9	72	605	140	361	119	17	7.4	16	4	50	20	22	35	23	16	7
CS19	25	3	16	188	815	99	748	118	16	6	21	44	98	9	22	39	6	17	4
CS20b	4	3	10	106	1039	105	792	248	26	12.4	22	9	104	11	34	69	10	33	4
CS21	5	10	10	85	751	155	374	122	16	7.9	17	27	59	21	15	33	26	14	9
CS22	5	10	11	97	830	135	396	133	18	8.3	16	12	61	17	19	36	16	15	6

Trace Elements Continued

	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th	Nd	U
CS23	5	11	11	96	691	119	427	128	19	8	17	10	61	18	16	34	15	16	6
CS24	4	10	10	89	835	152	376	136	18	7.4	17	9	63	21	15	30	26	17	5
CS25	8	12	8	85	837	150	463	160	15	9.6	18	9	76	18	22	45	22	22	7
CS26	5	11	9	101	721	150	464	160	17	9.9	19	10	75	16	19	37	20	20	8
11SN-41	13.7	17.3	14.4	119.8	960.1	128.5	475.2	202.9	21	13.3	19.4	12.5	100.3	12.1	32.2	76.7	15.9	23.4	4.6
11SN-40	3.5	7.2	2.8	35.6	939.9	151.1	386.6	140.1	13	11.6	18.6	-1.9	50.2	16.2	34.7	68.1	21.2	13.1	5.1
11SN-39	5.4	6.6	9.4	73.1	892.9	118.8	478.9	149.4	14.2	12.8	18.1	6.4	71.8	13.8	33.4	69.1	21.8	18.1	5.7
11SN-38	10.2	13	10.1	75.9	855.2	105.5	494.9	138.4	10.8	9.5	18.3	11.3	71.5	11.9	27.9	54.1	14.1	12.2	3.4
11SN-37	4.8	7.2	6.8	14.4	185.9	207.6	105.1	70.8	4.8	5.9	15.7	0.7	14.2	32.2	28	40.4	29.6	0.5	8.8
11SN-36	-0.5	7.9	1.7	16.7	646.5	192.2	215.5	82.4	9.1	9.1	16.1	-1.9	32.2	23.5	23.8	46.3	17.8	14.1	3.2
11SN-35	9.4	4.7	6.7	50.5	106	177.6	402.9	134	15.2	12.6	16.8	3.5	65.3	22.6	29.4	56.2	24.6	20	4.9
11SN-34	7.8	6.5	5.2	39	772.8	117.4	286.2	159.8	24	12	17.5	-0.6	55.1	12.4	41.2	76.7	16.8	19.7	4.9

APPENDIX E: SHRIMP Trace Element in Zircon Data

Highlighted analyses were not included in results because they are likely inclusions.

	Li	Be	B	F	Na	Al	P	K	Ca	Sc	⁴⁸ Ti
CS01-1.1	1.75	0.27	1.71	154.22	8.00	74.82	629.73	13.76	27.66	284.05	45.14
CS01-1.2	0.44	0.30	2.37	83.08	3.33	28.34	338.99	1.22	5.35	154.85	55.18
CS01-2.1	0.76	0.06	0.52	66.07	6.20	22.79	402.28	1.70	7.45	140.87	19.22
CS01-2.2	2.90	0.14	5.32	71.07	9.13	53.24	519.06	126.84	19.33	139.93	121.93
CS01-3.1	0.50	0.17	1.23	37.09	2.19	17.34	567.33	0.92	3.76	108.89	24.40
CS01-3.2	3.46	0.62	3.85	79.87	4.06	30.47	1476.93	1.15	7.64	225.80	31.26
CS01-4.1	1.85	0.12	2.08	49.85	5.76	23.33	1066.63	1.31	5.50	281.11	38.27
CS01-4.2	1.83	0.15	0.78	50.15	4.89	23.93	850.15	1.31	4.46	200.90	38.40
CS01-5.1	0.86	0.23	2.26	49.92	5.32	21.38	515.86	1.37	4.85	78.16	26.60
CS01-5.2	0.58	0.12	2.64	159.29	6.19	37.13	557.81	1.40	11.41	75.74	31.79
CS01-6.1	0.19	0.03	2.64	98.55	5.50	21.45	374.40	1.09	5.07	153.15	40.66
CS01-7.1	2.79	0.89	44.32	956.37	23.20	2295.48	700.94	62.57	111.67	99.83	219.14
CS01-8.1	0.67	0.33	1.83	60.94	3.81	21.29	786.22	1.32	5.51	229.03	33.12
CS01-8.2	1.14	0.09	3.52	65.73	3.80	25.58	610.31	1.57	5.94	145.98	43.33
CS01-9.1	3.09	0.26	3.13	143.33	2.39	52.36	76.90	1.07	8.20	116.24	50.76
CS01-10.1	1.15	0.06	10.21	55.63	4.68	698.13	469.49	1.02	3.28	134.92	22.52
CS01-10.2	0.51	0.09	12.29	85.42	10.45	29.88	649.47	3.07	10.69	325.87	59.28
CS01-11.1	0.73	0.16	7.50	77.88	6.73	26.29	562.97	1.41	6.05	139.37	53.53
CS03-1.1	1.70	0.03	3.83	13163.65	10.58	26.52	8711.81	1.74	8558.10	34.61	22.76
CS03-1.2	0.08	0.00	2.24	31.04	2.47	21.82	202.57	1.02	4.48	44.88	19.27
CS03-2.1	0.50	0.03	3.24	77.18	2.74	21.64	171.52	1.22	5.33	50.31	20.11
CS03-2.2	1.25	0.25	5.16	65.25	2.86	173.64	166.04	1.43	8.70	93.30	37.65
CS03-3.1	0.65	0.09	1.68	51.05	5.67	23.24	349.82	2.13	5.01	87.18	30.82
CS03-4.1	1.48	0.00	4.58	36.32	3.06	22.11	82.82	1.87	6.35	34.34	25.78
CS03-4.2	0.25	0.16	1.84	29.13	2.79	20.29	313.00	1.16	5.94	102.71	32.79
CS03-6.1	0.13	0.03	1.48	43.87	3.38	22.65	326.56	1.73	7.91	75.07	45.50
CS03-6.2	0.33	0.00	2.98	47.77	3.84	23.23	255.97	1.82	9.79	57.72	43.08

	Li	Be	B	F	Na	Al	P	K	Ca	Sc	48Ti
CS03-8.1	0.46	0.03	1.84	53.02	2.75	19.54	152.92	1.30	13.26	34.52	22.78
CS03-8.2	1.63	0.03	2.12	77.15	3.36	21.75	218.57	1.40	11.46	52.37	25.93
CS03-8.3	0.33	0.08	8.94	64.99	2.67	370.93	203.65	2.01	11.92	59.17	32.94
CS03-9.1	2.93	0.58	179.77	54.52	1460.81	23701.18	21.31	9207.60	250.62	4.08	8.25
CS03-9.2	1.08	0.03	13.64	40.01	11.13	24.69	136.93	3.58	16.10	42.22	22.39
CS03-10.1	1.06	0.10	3.64	43.68	2.77	82.94	335.98	1.23	11.79	68.74	37.97
CS03-10.2	0.83	0.10	3.04	46.08	2.80	22.17	171.61	1.23	12.28	47.54	32.07
CS03-11.1	1.25	0.03	8.40	63.62	5.05	1113.77	318.23	6.22	8.50	46.44	44.03
CS03-11.2	2.25	0.05	2.31	41.29	3.26	19.49	343.27	1.01	6.66	61.73	24.63
CS07-1.1	0.53	0.01	1.90	8.11	1.30	10.76	587.30	0.80	2.25	167.61	31.76
CS07-1.2	0.24	0.02	0.33	7.95	1.22	17.42	353.78	0.69	2.26	52.40	21.83
CS07-1.3	0.73	0.08	1.55	22.25	1.60	13.27	409.10	1.07	2.71	69.68	23.76
CS07-2.1	0.58	0.08	0.67	3.49	1.36	11.79	676.93	0.68	2.01	126.94	15.82
CS07-2.2	5.05	0.14	1.13	9.41	1.46	14.06	592.91	0.81	2.12	100.73	9.98
CS07-3.1	1.27	0.04	1.32	9.53	1.31	19.50	590.63	0.74	2.30	104.34	29.86
CS07-3.2	0.61	0.01	1.87	11.08	1.28	20.68	584.26	0.68	2.12	136.08	43.24
CS07-4.1	2.60	0.04	0.76	5.63	2.10	11.29	161.13	0.80	2.47	16.31	9.02
CS07-4.2	0.19	0.00	1.00	21.84	1.41	12.79	344.57	0.79	2.35	76.93	33.79
CS07-4.3	3.63	0.08	1.49	13.92	1.43	13.01	284.73	1.02	3.39	36.70	16.98
CS07-5.1	0.28	0.00	0.82	15.86	1.20	9.92	332.60	0.48	1.67	89.25	30.13
CS07-5.2	0.33	0.00	0.74	12.26	1.37	11.49	341.45	0.67	2.45	99.90	34.34
CS07-6.1	0.39	0.12	1.22	6.83	1.38	11.88	573.69	0.63	4.15	109.81	14.02
CS07-6.2	0.57	0.01	0.74	4.41	1.13	40.73	1112.30	0.50	1.76	381.42	33.87
CS07-6.3	0.23	0.07	0.76	14.67	1.09	9.07	483.42	0.58	1.88	113.34	31.77
CS07-7.1	1.24	0.06	1.08	9.51	1.41	10.65	445.74	0.68	2.18	53.13	20.29
CS07-7.2	0.77	0.25	11.12	18.43	17.22	158.41	667.15	66.43	3.65	184.86	43.08
CS10-1.1	1.64	0.00	1.99	37.37	2.70	19.68	251.97	1.31	4.67	90.68	19.07
CS10-1.2	1.14	0.05	1.98	25.46	2.81	22.25	270.61	1.28	4.41	97.52	26.63
CS10-2.1	0.82	0.05	2.68	66.94	2.34	19.65	285.09	1.21	5.60	87.11	33.84
CS10-2.2	0.80	0.00	1.83	20.23	2.09	20.04	237.59	1.06	4.81	77.23	28.78

	Li	Be	B	F	Na	Al	P	K	Ca	Sc	48Ti
CS10-3.1	2.76	0.22	2.43	51.64	2.13	20.22	147.01	1.20	15.00	120.33	17.74
CS10-3.2	0.67	0.05	3.30	68.53	2.44	18.85	121.19	1.28	4.05	75.99	18.75
CS10-3.3	0.93	0.02	1.49	49.09	2.60	17.00	152.55	1.32	5.39	70.26	16.07
CS10-4.1	1.46	0.17	2.53	40.78	2.37	237.47	2043.74	1.77	7.29	539.34	44.82
CS10-4.2	2.89	0.09	1.65	36.81	2.67	45.46	54.99	1.09	4.69	96.78	17.80
CS10-5.1	1.12	0.13	3.43	54.71	2.87	22.95	91.07	1.66	4.45	106.58	18.95
CS10-5.2	1.47	0.07	1.78	20.85	1.53	17.20	173.22	1.03	2.94	60.70	21.57
CS10-7.1	1.87	0.07	1.21	32.68	7.36	16.35	141.22	1.25	8.67	79.21	22.30
CS10-7.2	0.73	0.17	2.53	29.50	3.61	17.89	175.45	1.05	4.48	107.50	27.68
CS10-8.1	0.77	0.10	2.96	45.06	3.62	20.28	577.90	1.55	4.59	205.70	62.83
CS10-8.2	1.94	0.07	4.74	41.00	4.71	590.48	148.74	5.32	26.49	24.59	34.86
CS10-10.1	0.49	0.06	1.24	40.58	2.66	18.07	217.86	1.45	5.64	80.10	23.32
CS10-10.2	2.32	0.13	3.34	46.97	2.81	19.64	215.23	1.53	6.16	55.11	23.58
CS13-1.1	0.22	0.00	3.19	29.80	2.40	19.88	394.27	1.13	4.51	52.20	21.16
CS13-1.2	1.52	0.07	4.09	70.78	2.75	22.35	335.95	1.69	8.36	78.32	26.55
CS13-2.1	0.71	0.02	1.26	27.12	2.12	15.37	515.71	1.36	4.35	138.69	29.38
CS13-2.2	0.70	0.04	1.77	67.54	2.91	14.03	477.69	1.37	4.88	159.90	35.64
CS13-3.1	1.31	0.17	2.30	32.52	14.14	25.61	444.13	3.91	14.97	104.92	34.96
CS13-4.1	0.30	0.00	17.41	42.60	4.75	25.56	302.71	1.42	6.61	108.40	35.07
CS13-4.2	0.26	0.00	1.79	50.59	4.62	15.85	283.89	1.46	4.36	92.27	26.96
CS13-5.1	1.15	0.04	2.86	66.35	3.24	23.67	239.67	1.88	5.53	75.71	25.67
CS13-5.2	0.70	0.09	3.76	274.28	2.59	18.17	343.47	0.99	27.95	89.51	23.23
CS13-5.3	0.90	0.07	3.12	65.76	2.76	17.03	234.58	0.88	5.32	57.20	24.33
CS13-6.1	1.20	0.06	8.60	32.37	18.65	154.77	216.44	47.79	10.36	31.76	22.62
CS13-6.2	2.85	0.04	3.19	33.54	2.72	18.66	690.69	1.23	4.02	43.67	25.24
CS13-7.1	0.23	0.04	3.22	34.45	3.83	17.31	248.21	2.13	6.07	66.37	30.76
CS13-7.2	1.94	0.12	2.33	40.80	3.07	22.35	170.02	1.63	5.59	36.67	23.26
CS13-9.1	0.44	0.00	1.36	20.88	2.04	19.74	192.53	0.96	4.62	44.04	20.69
CS13-9.2	1.75	0.04	3.98	50.11	1.88	24.49	134.77	0.71	5.52	54.67	33.69
CS19-1.1	0.47	0.08	1.59	33.39	1.79	118.37	197.09	1.39	3.81	62.61	19.56

	Li	Be	B	F	Na	Al	P	K	Ca	Sc	48Ti
CS19-2.1	0.24	0.02	2.85	13.06	2.50	16.78	238.76	0.90	6.36	63.30	20.52
CS19-2.2	1.10	0.14	4.60	52.39	3.19	20.91	260.25	1.70	7.02	85.16	28.82
CS19-3.1	0.30	0.00	2.17	51.56	1.80	78.89	120.44	6.23	10.17	36.70	24.23
CS19-3.2	0.40	0.04	1.16	34.44	1.71	15.40	223.18	0.81	3.66	40.65	14.01
CS19-4.1	0.64	0.06	2.09	29.63	1.82	20.66	117.78	0.74	4.08	27.07	16.32
CS19-4.2	1.51	0.20	1.95	73.97	2.22	24.40	1241.37	1.11	6.43	262.29	46.76
CS19-5.1	2.27	0.55	101.27	49.76	2478.11	10989.48	361.18	571.11	522.20	67.05	40.77
CS19-5.2	3.21	2.28	289.79	1368.72	79.04	7376.17	3331.47	218.30	1001.19	183.04	1139.21
CS19-6.1	0.78	0.07	3.77	22.13	2.55	18.11	529.63	0.95	4.50	190.28	27.63
CS19-6.2	10.94	0.40	36.24	145.95	6.97	976.60	777.84	12.73	12.44	236.88	46.65
CS19-7.1	1.32	0.13	6.38	35.91	2.79	41.68	185.59	2.19	14.23	45.89	25.91
CS19-7.2	3.34	0.26	15.36	163.51	17.37	1246.63	184.71	28.91	103.97	57.43	74.15
CS25-1.1	0.81	0.02	4.57	95.82	2.21	19.35	292.71	1.14	10.18	63.28	22.95
CS25-1.2	1.94	0.06	1.65	48.62	2.32	18.08	254.92	1.07	6.26	53.26	23.99
CS25-2.1	1.02	0.13	3.20	21.60	3.38	23.81	376.24	1.34	3.82	97.44	21.07
CS25-2.2	0.44	0.02	24.73	87.50	2.42	17.91	314.61	1.08	7.08	78.95	28.99
CS25-3.1	0.20	0.07	6.20	108.60	3.32	46.56	386.93	1.15	13.01	92.13	33.75
CS25-3.2	0.96	0.02	6.03	28.38	5.61	25.73	223.03	1.78	16.20	41.21	35.88
CS25-4.1	0.44	0.02	1.75	29.99	1.93	16.44	212.15	0.89	4.10	60.91	26.96
CS25-4.2	2.42	0.09	2.45	25.59	1.67	17.98	619.69	0.84	3.43	112.08	28.61
CS25-4.3	1.66	0.04	2.10	28.81	1.53	50.39	176.81	1.20	3.60	61.26	28.47
CS25-6.1	3.47	0.09	3.21	52.43	2.56	17.48	363.13	1.97	5.78	70.66	33.02
CS25-6.2	4.20	0.35	19.24	146621.15	15.83	539.42	94769.77	15.87	54274.41	65.88	85.61
CS25-7.1	0.42	0.05	4.63	39.12	3.27	172.57	354.29	2.83	6.37	75.52	35.60
CS25-7.2	6.98	0.65	15.37	167.23	15.86	1313.12	429.15	14.98	12.39	83.42	133.50
CS25-8.1	1.66	0.22	1.42	38.22	1.94	16.61	259.74	1.00	4.57	53.10	27.42
CS25-8.2	3.40	0.07	5.41	49.59	2.43	23.78	650.26	1.25	5.54	81.24	34.23
CS25-8.3	2.04	0.15	6.39	45.15	2.31	162.14	266.82	2.70	7.18	59.65	34.63
11SN34-1.1	0.34	0.12	1.53	97.00	6.91	19.17	381.74	5.27	2.50	84.45	26.06
11SN34-1.2	0.61	0.16	1.42	87.55	6.64	12.76	434.89	4.83	2.63	114.11	15.51

	Li	Be	B	F	Na	Al	P	K	Ca	Sc	48Ti
11SN34-2.1	0.07	0.04	2.08	69.30	1.76	17.10	208.73	2.01	3.15	57.11	31.18
11SN34-2.2	0.42	0.13	0.74	39.93	1.85	15.16	403.96	1.56	3.33	95.51	12.86
11SN34-3.1	6.03	4.39	101.52	1766.81	6.38	490.68	1458.63	11.71	350.47	164.61	183.75
11SN34-3.2	3.54	0.13	1.48	53.00	1.45	15.60	104.30	1.35	3.85	23.10	10.69
11SN34-4.1	0.19	0.14	1.89	94.72	1.84	16.81	631.73	1.45	3.74	172.09	21.73
11SN34-4.2	0.33	0.14	2.18	44.37	1.79	133.32	525.43	2.11	5.28	197.60	38.41
11SN34-5.1	0.53	0.10	1.36	69.89	1.89	18.51	350.81	1.48	5.31	84.76	29.52
11SN34-5.2	0.78	0.15	2.31	36.69	1.94	17.53	467.74	1.48	3.70	133.72	18.92
11SN34-6.1	1.87	0.12	9.05	18.21	262.67	25494.69	85.53	16980.83	5.26	13.31	20.41
11SN34-6.2	2.62	0.07	2.10	413.85	1.83	30.50	1150.90	1.35	427.79	90.10	24.57
11SN34-6.3	5.70	2.56	38.77	250.11	3.04	238.07	992.53	2.44	92.71	128.84	118.46
11SN34-7.1	0.76	0.27	2.16	77.94	3.03	48.10	425.61	5.64	5.97	99.89	18.06
11SN34-7.2	1.74	0.15	2.14	17.73	1.69	23.90	694.50	1.15	3.32	122.50	23.53
11SN34-8.1	0.45	0.10	1.90	53.09	6.42	15.75	197.34	5.00	3.96	43.54	17.38
11SN34-8.2	2.15	0.20	2.17	43.51	5.37	13.37	816.53	5.31	3.90	106.17	19.57
11SN35-1.1	2.59	0.28	1.58	34.12	1.43	13.12	187.74	1.16	2.85	40.95	8.46
11SN35-1.2	1.19	0.09	3.99	47.52	2.16	230.80	281.86	19.19	7.38	57.08	58.51
11SN35-2.1	1.59	0.01	1.29	9.66	1.15	13.10	196.82	0.97	2.80	45.01	19.98
11SN35-2.2	0.45	0.05	1.21	35.33	1.29	14.08	351.60	1.14	2.76	86.70	26.16
11SN35-3.1	2.93	0.12	0.98	8.94	1.34	12.90	227.44	1.13	3.00	48.77	14.85
11SN35-3.2	1.02	0.29	3.83	31.64	15.92	75.53	2731.89	14.76	2646.41	101.42	26.40
11SN35-4.1	3.73	0.11	0.75	11.07	4.03	12.15	255.50	3.23	2.79	48.08	14.98
11SN35-4.2	0.18	0.03	0.49	25.68	5.54	12.44	645.33	3.40	2.55	111.01	43.32
11SN35-5.1	0.59	0.06	1.00	10.13	2.99	14.94	428.14	2.49	2.78	138.70	20.83
11SN35-5.2	1.27	0.19	2.17	36.02	3.10	14.89	232.05	2.64	5.62	152.59	15.15
11SN35-6.1	1.90	0.08	1.24	8.60	1.21	10.91	313.31	0.66	2.48	54.72	21.39
11SN35-6.2	1.52	0.14	2.76	517.61	7.37	78.08	954.73	27.43	511.83	69.57	23.84
11SN35-7.1	3.59	0.04	2.86	13.99	1.36	14.74	329.92	0.81	3.13	60.24	24.71
11SN35-7.2	1.48	0.08	4.35	266.27	2.32	14.97	409.95	0.73	6.88	84.33	19.99
11SN35-8.1	1.70	0.04	1.14	6.58	1.41	13.38	317.37	0.75	2.47	57.64	20.16
11SN35-8.2	1.87	0.07	1.85	3.71	1.50	12.71	224.29	0.67	2.61	60.64	19.75

	Li	Be	B	F	Na	Al	P	K	Ca	Sc	48Ti
11SN35-8.3	1.05	0.11	1.06	3.11	1.62	12.96	354.76	0.79	2.85	76.76	28.10
11SN36-1.1	1.30	0.05	0.92	1.79	1.02	10.66	155.28	0.76	2.16	85.67	13.21
11SN36-1.2	7.28	0.29	1.23	4.95	1.53	12.96	151.68	0.93	2.40	122.85	17.43
11SN36-2.1	3.63	0.11	1.31	11.75	1.24	12.59	288.58	0.86	2.22	58.98	20.92
11SN36-2.2	1.94	0.03	1.60	13.87	1.19	13.66	288.42	0.86	2.20	89.68	17.05
11SN36-3.1	1.43	0.11	0.95	6.83	1.32	13.60	102.77	0.89	2.30	60.40	11.77
11SN36-3.2	5.17	0.50	2.70	18.28	1.65	14.16	170.48	1.00	2.92	169.38	16.20
11SN36-4.1	0.29	0.07	0.91	9.42	1.36	19.30	456.38	0.86	2.67	158.45	17.92
11SN36-4.2	0.42	0.83	7.08	111.61	7.08	153.73	545.74	15.64	110.71	227.37	27.86
11SN36-5.1	1.96	0.09	2.48	13.00	2.60	13.62	274.39	2.41	4.52	59.89	18.98
11SN36-5.2	1.62	0.18	2.08	17.52	1.63	13.79	362.29	1.01	3.98	93.77	21.04
11SN36-6.1	1.57	0.36	4.72	16.75	2.10	14.38	182.87	1.78	5.30	108.40	49.53
11SN36-6.2	0.28	0.43	10.01	25.66	2.85	541.63	271.66	2.29	11.12	78.75	45.15
11SN36-7.1	0.16	0.04	0.83	20.86	1.52	12.78	268.92	0.64	2.42	58.32	19.19
11SN36-7.2	3.57	12.64	484.07	1139.96	58.81	2713.84	743.96	19.93	79.46	203.13	382.31
11SN36-8.1	0.97	0.08	2.60	20.59	1.34	20.48	203.85	0.56	4.10	52.60	25.61
11SN36-8.2	2.16	0.34	1.37	21.57	1.49	11.99	110.81	0.61	2.79	90.18	16.40
11SN37-1.1	5.94	0.26	1.30	3.75	2.96	15.21	177.54	1.22	2.86	76.60	17.62
11SN37-1.2	2.09	0.53	8.22	17.32	12.05	260.80	132.52	5.85	5.62	105.80	94.63
11SN37-2.1	2.78	0.23	1.82	3.72	1.97	46.94	161.68	1.90	3.44	292.82	43.12
11SN37-2.2	1.64	1.87	35.39	449.02	6.73	896.69	817.12	2.95	25.62	184.79	441.42
11SN37-3.1	3.60	0.14	0.87	12.90	0.76	6.14	100.69	0.44	0.88	118.15	9.54
11SN37-3.2	1.06	0.11	2.09	36.32	0.96	21.71	212.43	0.40	1.40	68.01	14.36
11SN37-4.1	1.35	0.06	0.86	19.96	0.17	10.48	143.93	0.09	0.33	57.73	16.17
11SN37-4.2	2.08	0.74	75.49	371.22	6.45	692.56	164.95	2.51	13.61	41.80	279.55
11SN37-5.1	3.57	0.11	1.81	64.31	2.49	15.35	247.34	1.10	2.50	34.42	23.26
11SN37-5.2	0.98	0.08	2.46	51.70	1.77	13.06	450.23	0.78	2.72	101.49	20.09
11SN37-6.1	1.31	0.09	1.06	35.47	1.82	12.41	74.59	0.63	2.09	45.19	7.91
11SN37-6.2	4.98	0.11	1.11	30.34	1.49	12.12	83.94	0.71	2.21	48.14	7.86

	Li	Be	B	F	Na	Al	P	K	Ca	Sc	48Ti
11SN37-7.1	1.80	0.18	4.28	49.28	2.29	121.78	134.78	1.19	3.14	85.20	19.39
11SN37-7.2	2.42	0.34	18.39	102.19	6.93	525.49	98.88	9.12	12.45	62.77	22.87
11SN37-8.1	1.97	0.20	1.20	42.88	1.81	11.23	229.54	0.76	1.81	67.66	12.95
11SN37-8.2	1.54	0.14	2.93	58.65	2.58	72.04	272.14	1.21	1.92	136.84	12.82
11SN38-1.1	1.17	0.03	7.69	57.16	2.45	234.72	428.24	1.16	4.09	109.97	28.64
11SN38-1.2	2.69	0.03	6.51	67.58	4.96	20.80	236.87	4.35	6.76	47.11	28.57
11SN38-1.3	0.95	0.04	1.52	32.08	1.47	11.49	252.09	0.62	2.08	56.25	15.86
11SN38-2.1	1.90	0.01	1.16	38.26	1.54	11.63	335.88	0.62	2.16	52.85	12.52
11SN38-2.2	0.75	0.04	4.19	35.62	1.32	10.33	212.99	0.59	2.11	61.67	13.91
11SN38-3.1	0.65	0.03	4.24	270.97	1.91	12.65	161.49	2.55	7.71	21.56	12.89
11SN38-3.2	1.33	0.04	6.91	73.00	1.99	11.94	291.83	1.06	5.71	60.33	17.31
11SN38-4.1	2.22	0.03	1.71	23.09	2.03	16.53	128.16	0.93	2.21	36.67	14.68
11SN38-4.2	0.80	0.06	2.04	33.20	1.57	10.96	230.38	0.75	2.82	52.12	16.56
11SN38-5.1	1.29	0.03	2.58	168.25	2.04	13.86	307.42	1.11	25.42	64.70	18.85
11SN38-5.2	0.70	0.09	154.37	212.59	269.65	3925.60	797.72	1527.46	134.36	132.45	64.32
11SN38-6.1	0.69	0.10	44.22	123.52	6.90	1134.18	688.09	2.94	8.21	140.15	57.27
11SN38-6.2	2.05	0.00	0.75	20.86	1.94	10.28	214.64	0.59	2.31	49.77	14.57
11SN38-7.1	4.22	0.03	2.76	50.22	3.30	589.05	131.45	6.26	7.81	37.60	21.96
11SN38-7.2	0.36	0.00	1.74	21.52	1.60	18.74	234.72	0.55	2.73	48.38	22.91
11SN38-8.1	1.65	0.00	1.00	20.81	1.27	9.78	227.93	0.61	2.35	34.61	19.83
11SN38-8.2	0.39	0.00	1.49	219.59	2.13	10.90	1169.88	0.52	566.36	88.22	17.45
11SN38-8.3	1.39	0.03	1.48	20.03	1.24	11.87	139.58	0.44	1.93	23.38	10.69
11SN40-1.1	0.34	0.00	3.05	25.94	2.71	18.75	256.08	1.31	5.90	72.68	25.18
11SN40-1.2	1.18	0.12	2.09	23.72	2.17	21.28	115.32	1.08	6.24	161.74	16.42
11SN40-2.1	0.96	0.36	2.56	185.23	3.46	25.71	345.50	1.87	11.90	66.15	28.63
11SN40-2.2	2.33	0.20	2.13	219.37	2.17	16.34	332.67	0.77	31.65	86.02	21.68
11SN40-3.1	14.21	0.27	19.15	222.55	5.71	838.33	2078.62	2.72	15.36	53.17	49.39
11SN40-3.2	0.69	0.09	6.12	55.85	4.83	30.79	174.20	2.04	9.02	61.46	19.30
11SN40-4.1	0.89	0.54	1.45	43.73	4.14	49.18	169.14	1.74	8.03	70.94	31.64
11SN40-4.2	1.79	0.12	2.17	46.39	4.53	25.87	139.42	1.86	6.27	135.33	20.26

	Li	Be	B	F	Na	Al	P	K	Ca	Sc	48Ti
11SN40-5.1	0.26	0.00	2.67	106.71	3.01	24.17	145.09	1.66	9.05	28.83	28.80
11SN40-5.2	2.02	0.09	1.60	32.33	2.85	26.42	193.63	1.33	22.52	95.77	28.39
11SN40-6.1	0.07	0.00	2.57	53.44	2.74	23.22	753.92	1.36	6.73	218.17	47.96
11SN40-6.2	2.51	0.18	2.15	54.21	2.65	28.88	249.66	0.96	6.46	163.66	22.31
11SN40-7.1	4.67	0.69	3.40	34.72	2.80	30.45	1126.53	1.16	4.33	142.22	35.66
11SN40-7.2	1.47	0.12	1.59	38.41	2.41	21.46	249.90	1.14	4.23	52.57	25.39
11SN40-9.1	0.33	0.00	1.36	53.19	1.34	18.11	601.72	0.73	3.22	99.63	31.20
11SN40-9.2	3.28	0.00	2.45	34.56	1.88	20.83	117.28	1.09	3.81	52.62	20.79
11SN40-10.1	5.41	0.16	2.86	32.96	2.01	141.55	217.31	1.07	5.85	87.70	37.08
11SN40-10.2	0.37	0.06	2.41	43.09	2.00	20.43	364.58	1.01	5.26	145.65	39.33
11SN41-1.1	1.79	0.00	2.99	160.78	6.59	46.08	357.08	2.87	19.59	94.55	51.87
11SN41-1.2	1.29	0.00	4.56	30.94	2.37	25.01	374.01	1.16	8.51	66.88	35.20
11SN41-2.1	0.24	0.06	2.72	114.65	2.96	28.00	437.60	1.87	11.01	105.74	39.88
11SN41-2.2	1.14	0.00	2.32	69.25	3.04	26.52	292.08	1.70	9.16	65.37	37.88
11SN41-3.1	2.71	0.61	5.34	90.82	3.07	28.57	247.89	1.52	9.84	166.53	19.14
11SN41-3.2	1.39	0.13	42.08	101.91	4.90	2031.11	319.63	17.08	37.90	47.50	130.41
11SN41-4.2	0.38	0.06	3.07	46.70	2.72	30.16	209.28	1.57	10.76	61.62	68.00
11SN41-5.1	0.65	0.03	1.81	32.72	1.98	19.29	168.96	1.07	6.43	38.44	20.40
11SN41-5.2	1.22	0.06	1.74	51.08	2.74	22.67	510.48	1.12	9.09	110.51	32.82
11SN41-7.1	1.56	0.12	3.92	106.94	2.50	26.22	291.09	1.14	9.41	52.07	35.25
11SN41-7.2	2.28	0.15	3.27	475.14	2.43	27.37	936.14	1.64	9.60	143.41	37.98
11SN41-8.1	0.96	0.06	3.02	4324.65	27.89	922.19	2619.85	578.27	1881.40	48.68	29.64
11SN41-8.2	0.54	0.00	1.81	51.80	2.63	33.82	509.62	1.50	8.36	154.30	38.91
11SN41-9.1	0.28	0.03	2.88	43.48	1.90	22.22	268.65	0.93	4.62	60.92	34.82
11SN41-9.2	0.80	0.06	1.29	46.90	3.66	21.40	232.80	0.90	5.97	56.03	24.07
11SN41-10.1	2.11	0.00	2.29	54.33	2.05	27.19	592.93	1.13	6.71	83.72	27.53
11SN41-10.2	0.55	0.12	3.55	63.00	1.99	20.85	339.30	0.89	6.94	60.07	22.86
11SN41-11.1	0.67	0.09	2.63	42.55	1.66	22.63	251.69	1.11	4.54	54.92	20.92
11SN41-11.2	1.05	0.00	1.09	45.53	1.88	24.44	243.95	0.96	6.17	51.02	21.80
11SN41-11.3	0.22	0.06	1.73	59.90	1.86	20.70	251.35	1.31	4.34	38.63	18.41

	49Ti	Fe	Y	Nb	La	Ce	Nd	Sm	Eu	Gd	Ho
CS01-1.1	43.26	15.96	4935.27	285.17	0.492	481.67	3.90	9.41	0.78	75.05	192.72
CS01-1.2	54.70	8.12	3458.06	48.88	2.287	246.75	5.62	10.76	1.12	63.72	126.89
CS01-2.1	19.56	7.28	2538.68	115.18	0.080	206.41	1.67	3.10	0.45	37.57	102.28
CS01-2.2	96.24	160.03	1515.55	68.80	0.356	219.30	8.55	9.63	1.32	43.11	62.74
CS01-3.1	22.26	3.40	2281.40	129.57	0.051	451.56	1.23	3.93	0.33	37.17	83.02
CS01-3.2	30.92	2.70	3387.05	95.42	0.106	456.02	1.88	5.60	0.99	54.68	134.03
CS01-4.1	35.93	7.28	6548.73	247.68	0.099	412.58	11.17	21.52	2.25	150.06	265.63
CS01-4.2	36.30	7.99	4437.73	178.16	0.099	312.79	9.28	15.56	1.83	122.78	187.96
CS01-5.1	21.81	5.37	2518.38	132.12	0.113	496.58	1.41	3.85	0.37	34.09	90.60
CS01-5.2	30.76	11.32	3576.46	160.59	1.673	879.95	18.18	9.56	0.85	61.71	132.17
CS01-6.1	37.65	2.47	1531.32	40.57	0.072	114.67	0.83	1.87	0.26	22.56	56.93
CS01-7.1	177.49	764.68	3156.21	144.47	4.939	1376.11	16.25	11.04	2.59	65.09	105.43
CS01-8.1	30.25	5.21	6087.04	82.11	0.080	328.81	24.89	29.42	4.11	167.65	257.38
CS01-8.2	46.57	4.87	2593.17	77.49	0.036	237.66	4.17	7.69	1.09	49.73	94.77
CS01-9.1	48.02	36.64	682.87	29.86	0.536	141.43	3.04	1.25	0.23	4.38	19.37
CS01-10.1	23.40	10.18	2280.36	92.59	2.216	332.88	9.05	2.07	1.03	52.42	101.99
CS01-10.2	57.85	5.68	3755.66	156.23	0.093	394.41	5.61	3.81	1.07	67.09	137.61
CS01-11.1	54.26	5.51	3395.01	70.36	0.142	191.33	6.74	11.30	1.07	73.02	130.92
CS03-1.1	18.48	9.16	773.22	30.25	106.347	1762.74	112.76	11.56	0.96	22.36	24.86
CS03-1.2	18.50	1.64	874.76	21.26	0.077	42.38	1.12	2.23	0.40	21.16	32.36
CS03-2.1	19.99	4.15	2857.06	37.55	0.082	283.13	4.74	9.32	1.54	72.97	106.88
CS03-2.2	36.75	13.91	1304.72	61.16	0.825	453.33	2.59	1.70	0.62	19.00	43.98
CS03-3.1	27.35	2.24	2133.55	26.65	0.078	340.56	7.04	8.69	2.24	59.31	87.18
CS03-4.1	25.89	3.45	626.66	15.38	0.092	135.57	2.12	2.68	0.72	11.88	21.64
CS03-4.2	32.31	4.16	3136.56	56.74	0.110	729.52	11.07	15.21	2.70	98.13	135.91
CS03-6.1	41.57	1.54	883.88	18.98	0.053	123.49	1.43	3.36	0.59	20.41	33.45
CS03-6.2	41.49	2.13	918.19	23.47	0.046	145.92	2.25	3.19	0.63	17.81	31.89
CS03-7.1	33.89	12.34	2973.13	43.06	0.924	638.44	10.54	12.70	2.23	73.15	116.97
CS03-7.2	25.62	2.61	1797.21	74.69	0.058	385.76	1.92	3.17	0.77	26.42	58.18

	49Ti	Fe	Y	Nb	La	Ce	Nd	Sm	Eu	Gd	Ho
CS03-8.1	20.15	2.57	811.72	13.93	0.061	180.89	0.87	1.67	0.22	14.15	36.50
CS03-8.2	23.19	3.13	1098.27	47.15	0.074	210.32	1.12	2.77	0.35	14.60	37.18
CS03-8.3	30.45	27.25	1077.24	48.25	0.142	271.69	1.48	3.05	0.40	12.88	34.21
CS03-9.1	7.44	58.14	117.87	5.63	0.118	46.38	0.88	1.27	0.08	3.62	7.62
CS03-9.2	18.85	3.35	432.68	15.65	0.038	106.95	0.46	1.09	0.16	3.34	12.54
CS03-10.1	38.44	11.19	2716.91	51.97	0.281	565.16	7.91	11.81	1.78	68.88	108.65
CS03-10.2	30.55	3.33	1001.30	27.78	0.117	246.91	1.40	1.79	0.51	16.19	39.72
CS03-11.1	38.23	163.93	1129.25	21.59	0.163	201.16	3.19	5.17	1.04	30.48	38.14
CS03-11.2	22.78	2.92	1381.16	43.93	0.048	299.20	1.40	3.54	0.71	23.49	50.18
CS07-1.1	32.00	2.36	2839.77	67.30	0.073	223.36	3.20	5.74	1.10	37.20	104.08
CS07-1.2	19.60	1.42	894.19	16.53	0.050	79.65	0.64	1.62	0.37	13.39	33.04
CS07-1.3	22.60	4.03	3830.02	40.34	0.041	353.53	10.35	13.59	2.00	87.02	148.93
CS07-2.1	15.45	2.94	2874.13	140.88	0.077	667.36	2.86	5.96	0.49	50.02	109.73
CS07-2.2	9.42	5.02	1239.05	45.63	0.035	142.59	0.48	1.89	0.17	15.10	42.99
CS07-3.1	33.72	2.40	1494.11	24.85	0.015	187.73	1.93	4.43	0.44	30.04	57.94
CS07-3.2	40.40	1.25	2109.26	26.35	0.039	185.74	6.45	9.58	1.11	53.65	80.85
CS07-4.1	7.32	3.82	554.75	26.40	0.022	150.97	0.54	0.65	0.09	6.30	19.44
CS07-4.2	29.89	1.49	1173.50	31.49	0.038	216.09	1.17	3.12	0.41	22.31	44.69
CS07-4.3	17.24	5.35	1577.75	48.23	0.016	320.45	2.06	3.41	0.32	22.15	54.80
CS07-5.1	31.67	1.21	1713.91	16.11	0.029	175.43	2.15	4.52	0.52	31.37	48.74
CS07-5.2	34.89	1.48	1240.85	23.13	0.040	169.28	1.96	2.89	0.45	25.73	48.13
CS07-6.1	14.35	3.10	2454.73	126.29	0.038	438.85	1.89	3.75	0.33	37.31	94.44
CS07-6.2	33.07	2.25	1885.16	37.27	0.062	82.17	1.06	2.39	0.31	21.41	74.10
CS07-6.3	32.85	1.95	1666.35	38.35	0.026	244.12	1.69	3.55	0.92	27.84	65.88
CS07-7.1	20.57	6.73	2080.97	103.63	0.033	472.55	2.24	3.60	0.35	30.36	78.96
CS07-7.2	44.52	17.06	6290.74	161.76	0.097	1673.55	26.68	30.55	4.60	176.33	251.76
CS10-1.1	17.53	2.52	988.44	23.13	0.102	253.92	1.82	2.04	0.59	12.74	29.32
CS10-1.2	26.28	3.89	2533.58	106.34	0.061	732.01	2.28	5.62	1.35	46.47	89.86
CS10-2.1	33.99	2.44	1363.51	40.27	0.102	255.46	2.35	3.68	0.74	24.99	48.16
CS10-2.2	32.26	2.18	1239.35	40.98	0.079	268.73	1.68	3.01	0.54	20.68	44.07

	49Ti	Fe	Y	Nb	La	Ce	Nd	Sm	Eu	Gd	Ho
CS10-3.1	15.76	4.40	1629.77	80.44	0.308	562.26	1.90	4.45	0.80	31.13	61.48
CS10-3.2	19.04	2.39	856.22	30.78	0.053	262.75	0.99	1.15	0.32	11.86	27.08
CS10-3.3	15.84	2.88	1619.40	37.21	0.051	339.45	3.92	5.40	1.08	34.65	60.76
CS10-4.1	37.50	78.82	10274.29	241.40	1.425	2689.05	21.89	33.35	6.38	235.35	390.91
CS10-4.2	16.98	9.06	426.23	19.29	0.247	143.03	0.78	0.46	0.30	3.75	12.58
CS10-5.1	19.34	4.01	1377.70	35.31	0.092	353.10	1.48	2.22	0.62	21.39	36.57
CS10-5.2	22.31	2.87	1133.78	42.70	0.048	418.82	2.23	3.48	0.68	21.36	42.61
CS10-7.1	17.16	3.77	1429.17	15.41	0.069	308.88	3.79	5.31	1.23	29.65	45.92
CS10-7.2	28.96	3.32	1416.12	45.64	0.123	406.35	1.36	2.00	0.62	20.43	46.90
CS10-8.1	58.26	4.20	6118.51	143.79	0.065	1653.98	11.15	19.46	5.46	167.66	238.27
CS10-8.2	34.24	17.88	636.20	27.07	1.997	440.73	11.96	4.31	1.92	15.97	26.23
CS10-10.1	27.15	2.56	1695.14	66.13	0.078	597.88	1.96	3.65	0.87	28.37	58.54
CS10-10.2	21.22	4.06	1134.63	35.22	0.067	452.04	1.96	2.83	0.82	23.15	42.24
CS13-1.1	19.28	2.73	2008.87	78.70	0.046	286.19	1.18	2.54	0.31	23.42	66.17
CS13-1.2	25.28	3.01	973.04	67.21	0.045	280.22	0.91	1.64	0.23	16.06	35.14
CS13-2.1	24.60	5.16	4090.69	47.88	0.037	578.92	11.91	17.49	2.95	96.38	139.88
CS13-2.2	34.57	3.46	2209.11	66.73	0.060	377.30	2.48	4.60	1.10	45.44	89.94
CS13-3.1	36.49	13.30	1893.62	59.15	0.136	241.08	1.83	3.22	0.63	23.33	59.35
CS13-4.1	34.04	2.28	629.76	18.40	0.055	38.63	1.33	1.61	0.35	16.16	23.48
CS13-4.2	24.37	2.83	1798.63	32.27	0.089	113.69	4.43	7.10	0.62	53.09	81.39
CS13-5.1	23.47	10.08	2065.58	83.26	2.958	367.01	6.73	5.38	0.62	36.20	73.40
CS13-5.2	22.43	8.76	3774.03	57.90	0.319	298.44	12.16	16.65	2.49	105.80	141.49
CS13-5.3	23.88	7.02	1342.85	45.80	0.087	222.20	2.51	3.80	0.51	28.01	50.30
CS13-6.1	26.12	10.18	1296.12	50.77	0.083	147.70	1.86	3.14	0.29	24.35	50.60
CS13-6.2	21.33	5.25	1935.36	48.39	0.050	136.10	1.48	3.63	0.19	28.78	64.61
CS13-7.1	27.57	6.40	1607.79	16.46	0.497	176.44	4.72	6.56	0.97	29.84	57.48
CS13-7.2	20.32	16.66	1028.00	38.85	1.092	119.03	1.18	2.11	0.37	15.32	34.50
CS13-9.1	17.07	4.10	1199.98	16.58	0.120	133.25	2.66	4.82	0.65	33.95	49.92
CS13-9.2	27.04	11.37	1039.19	36.85	0.200	170.43	1.57	3.13	0.46	18.95	36.58
CS19-1.1	19.95	56.06	1205.24	21.24	0.068	296.19	1.93	2.64	0.94	24.18	42.69

	49Ti	Fe	Y	Nb	La	Ce	Nd	Sm	Eu	Gd	Ho
CS19-2.1	20.56	7.32	1807.51	49.99	0.081	740.42	5.50	8.87	3.16	72.96	88.12
CS19-2.2	26.57	10.46	2293.14	95.80	0.124	1159.31	8.54	12.78	4.44	97.93	108.92
CS19-3.1	20.16	12.58	446.99	12.65	20.745	1875.90	57.19	5.93	1.05	10.84	17.66
CS19-3.2	13.26	2.15	1348.82	57.55	0.032	248.48	0.70	3.21	0.26	23.91	66.52
CS19-4.1	12.74	7.05	630.55	14.37	0.137	180.54	0.81	1.41	0.39	9.99	20.71
CS19-4.2	47.09	26.94	11205.19	253.54	0.217	3440.78	32.62	42.40	11.80	281.66	364.38
CS19-5.1	41.24	732.57	1547.96	72.40	0.340	338.42	3.31	4.08	1.05	25.82	49.98
CS19-5.2	1162.49	1449.56	5867.71	185.57	118.937	8007.03	650.74	193.94	58.03	366.23	178.68
CS19-6.1	27.43	9.54	4210.86	80.29	0.069	1033.18	12.57	17.58	4.81	103.17	138.06
CS19-6.2	44.80	25.36	6887.85	131.59	0.297	2010.50	22.96	29.56	8.27	201.32	219.97
CS19-7.1	25.33	21.76	1059.98	21.89	1.144	365.81	5.37	4.17	1.05	18.71	29.86
CS19-7.2	83.32	104.69	1269.52	103.17	15.412	1337.56	21.36	5.17	3.00	48.99	55.34
CS25-1.1	23.75	5.31	2663.65	29.71	0.118	257.41	6.28	7.36	1.41	64.03	99.06
CS25-1.2	24.89	8.37	1319.46	44.19	0.074	318.14	1.57	3.61	0.35	23.83	47.54
CS25-2.1	21.51	12.62	2601.61	149.23	0.762	443.93	8.48	5.84	0.59	36.59	89.32
CS25-2.2	28.85	3.21	2054.26	24.22	0.126	274.33	2.90	4.82	0.59	35.78	67.64
CS25-3.1	31.46	3.99	2264.94	64.79	0.083	282.73	3.47	6.20	0.33	42.37	80.50
CS25-3.2	32.79	3.26	456.82	19.94	0.065	112.70	0.45	0.88	0.11	6.60	16.36
CS25-4.1	26.67	4.00	1266.34	31.30	0.048	212.27	1.54	2.97	0.39	26.40	54.51
CS25-4.2	30.03	5.13	1397.06	35.96	0.037	149.76	0.81	2.06	0.25	21.35	49.69
CS25-4.3	23.65	11.56	1284.98	53.73	1.353	391.65	2.77	2.73	0.60	23.75	61.34
CS25-6.1	31.38	8.40	1022.65	37.87	0.061	132.23	0.80	2.04	0.22	14.96	37.52
CS25-6.2	86.80	174.02	1191.78	28.53	255.683	2338.89	61.52	1.65	2.52	32.86	45.84
CS25-7.1	33.30	13.34	2286.98	26.42	0.550	344.62	3.47	7.79	0.97	46.88	89.50
CS25-7.2	124.32	466.28	624.93	43.02	5.926	486.93	5.55	2.01	0.87	8.30	22.09
CS25-8.1	27.85	6.80	1119.32	33.60	0.054	206.90	1.41	2.59	0.33	18.98	38.30
CS25-8.2	31.96	7.18	1661.37	45.66	0.093	204.95	1.63	3.32	0.36	25.04	58.81
CS25-8.3	32.81	19.02	1248.74	42.96	0.773	305.05	3.37	3.20	0.55	20.54	45.45
11SN34-1.1	24.53	2.05	2103.71	20.74	0.016	168.39	4.79	6.34	1.44	50.97	78.19
11SN34-1.2	13.26	4.60	2414.33	103.78	0.034	391.00	1.38	3.43	0.77	33.32	91.54

	49Ti	Fe	Y	Nb	La	Ce	Nd	Sm	Eu	Gd	Ho
11SN34-2.1	29.44	0.97	614.39	9.70	0.054	72.18	0.74	1.08	0.30	8.74	23.77
11SN34-2.2	15.22	2.65	2152.26	90.66	0.020	351.17	1.28	3.42	0.55	31.34	77.47
11SN34-3.1	177.13	466.23	10493.47	1114.07	119.912	3680.94	412.51	92.90	14.00	208.67	391.77
11SN34-3.2	9.58	10.17	660.80	49.52	0.056	72.79	0.27	0.36	0.06	3.30	19.74
11SN34-4.1	21.72	3.14	5396.52	78.67	0.048	804.87	6.85	16.55	2.51	137.38	257.73
11SN34-4.2	39.41	24.07	1991.92	55.91	0.891	261.40	4.90	6.34	1.37	41.59	81.02
11SN34-5.1	28.67	2.48	1232.05	31.32	0.037	144.54	0.94	2.46	0.46	18.25	42.79
11SN34-5.2	19.14	6.35	2946.79	123.37	0.050	417.44	2.16	5.51	0.82	41.00	114.57
11SN34-6.1	18.75	45.88	284.31	18.28	0.169	54.63	0.82	0.50	0.07	2.74	10.59
11SN34-6.2	22.52	30.75	1496.51	35.46	1.642	176.22	3.32	2.64	0.54	19.05	50.49
11SN34-6.3	114.68	87.06	8161.40	1138.60	43.635	2193.75	165.78	43.17	4.72	113.75	298.76
11SN34-7.1	19.25	291.08	2617.05	142.83	0.101	379.54	1.90	4.00	0.61	34.84	92.64
11SN34-7.2	25.30	2.64	1655.92	29.30	0.025	151.51	1.78	2.64	0.64	25.09	60.85
11SN34-8.1	17.60	3.93	1504.49	46.39	0.030	249.82	0.38	2.19	0.28	23.72	56.85
11SN34-8.2	19.21	8.03	4269.69	83.09	0.064	559.13	9.59	14.74	2.62	99.44	180.34
11SN35-1.1	7.99	5.11	2545.58	27.79	0.027	353.60	2.58	6.67	0.79	41.44	82.96
11SN35-1.2	59.64	12.15	1303.53	45.35	1.107	255.95	3.34	3.80	0.40	21.43	47.14
11SN35-2.1	21.56	1.84	488.71	16.63	0.027	94.65	0.30	0.84	0.13	7.22	18.20
11SN35-2.2	27.01	2.59	3423.99	26.44	0.084	188.27	15.99	18.61	2.44	120.33	166.72
11SN35-3.1	14.31	5.00	1313.12	56.61	0.025	308.59	1.26	3.45	0.31	22.64	47.36
11SN35-3.2	19.74	5.31	2885.66	43.90	3.058	391.39	7.16	7.48	0.85	48.28	79.10
11SN35-4.1	12.31	4.19	1254.23	60.26	0.017	311.07	1.35	2.62	0.30	22.01	47.34
11SN35-4.2	45.80	1.75	2679.63	45.15	0.034	175.68	4.52	7.09	0.39	51.53	91.53
11SN35-5.1	20.85	1.41	1645.36	21.45	0.039	209.28	1.91	3.30	1.05	25.35	59.27
11SN35-5.2	13.37	6.83	2755.21	145.49	0.131	471.58	3.26	6.00	1.10	49.25	100.56
11SN35-6.1	20.90	6.55	1435.82	48.49	0.017	320.64	1.49	3.29	0.39	26.09	51.81
11SN35-6.2	27.41	12.00	1054.45	27.60	5.412	280.78	13.72	3.87	0.40	19.35	36.21
11SN35-7.1	22.47	7.53	1387.79	35.40	0.112	288.32	2.81	3.45	0.57	26.98	46.82
11SN35-7.2	19.39	6.80	2109.47	90.44	0.033	413.10	1.97	4.36	0.55	31.55	67.23
11SN35-8.1	19.02	3.03	1388.62	48.47	0.017	294.14	1.56	2.91	0.36	22.28	49.48
11SN35-8.2	19.60	4.28	1124.72	24.02	0.073	140.36	0.91	3.76	0.47	22.32	42.79

	49Ti	Fe	Y	Nb	La	Ce	Nd	Sm	Eu	Gd	Ho
11SN35-8.3	28.30	5.52	1509.22	53.43	0.025	268.05	1.65	3.10	0.40	23.81	52.00
11SN36-1.1	14.91	1.76	938.12	21.77	0.057	241.26	1.18	2.43	0.63	18.99	36.66
11SN36-1.2	18.67	10.91	1965.92	98.62	0.028	975.06	4.07	6.11	1.20	41.82	65.08
11SN36-2.1	21.58	4.86	2618.79	77.76	0.036	348.72	2.64	6.34	0.29	62.47	122.07
11SN36-2.2	14.09	4.41	1965.07	29.35	0.029	258.79	4.47	5.48	0.96	29.91	55.42
11SN36-3.1	11.86	1.96	996.40	23.17	0.049	235.98	1.00	1.53	0.44	11.10	30.62
11SN36-3.2	13.88	6.80	2344.77	136.84	0.031	877.42	2.75	5.35	1.01	39.98	75.92
11SN36-4.1	18.37	0.96	1083.83	25.56	0.020	167.61	1.81	3.61	0.86	24.16	39.04
11SN36-4.2	26.77	3.23	2982.63	122.63	1.560	828.04	6.78	7.45	1.94	63.47	106.33
11SN36-5.1	19.25	2.93	1000.41	52.01	0.070	190.59	1.01	1.86	0.11	12.09	37.32
11SN36-5.2	20.62	3.58	2616.11	61.61	0.040	287.02	2.46	5.26	0.55	37.56	88.07
11SN36-6.1	50.07	6.77	3242.52	43.40	0.315	822.28	10.79	10.74	1.70	64.39	104.60
11SN36-6.2	50.41	372.36	778.26	156.37	4.343	415.56	40.90	14.51	2.19	29.65	27.13
11SN36-7.1	20.61	1.53	1790.03	45.46	0.050	440.75	4.63	6.29	1.07	37.16	63.72
11SN36-7.2	344.78	1102.24	4238.47	2290.55	89.170	4966.79	526.73	137.37	15.25	203.52	139.58
11SN36-8.1	25.71	7.78	1178.75	39.63	0.952	316.33	10.02	5.96	1.18	30.71	42.79
11SN36-8.2	16.39	4.58	1081.16	42.27	0.027	343.08	1.08	1.59	0.41	13.16	33.83
11SN37-1.1	14.75	7.00	1253.36	41.84	0.041	619.97	2.77	4.04	1.03	29.18	44.19
11SN37-1.2	93.52	621.69	1319.32	69.31	3.911	730.02	21.56	5.53	1.12	23.19	41.21
11SN37-2.1	40.64	21.41	3223.96	190.92	3.558	986.14	15.21	4.28	0.82	28.65	91.44
11SN37-2.2	432.47	194.30	6628.25	333.79	56.230	5695.93	205.48	47.45	9.63	166.52	254.04
11SN37-3.1	10.32	4.69	1142.28	45.55	0.158	441.42	2.59	2.53	0.54	17.51	34.52
11SN37-3.2	14.23	3.55	931.09	21.75	0.678	292.08	5.50	2.06	0.53	10.71	25.86
11SN37-4.1	15.90	4.33	1647.63	35.09	0.231	402.00	4.69	6.92	1.18	34.63	59.94
11SN37-4.2	269.65	60.75	495.93	122.24	30.537	2362.65	132.88	18.22	3.32	19.36	19.04
11SN37-5.1	21.14	2.61	672.39	27.26	0.069	247.35	1.36	1.99	0.51	14.73	23.07
11SN37-5.2	20.79	2.85	3513.20	71.56	0.033	772.10	12.28	16.40	2.74	102.71	135.56
11SN37-6.1	7.07	1.50	583.15	14.65	0.027	150.96	0.79	1.17	0.38	8.63	17.73
11SN37-6.2	7.66	2.74	511.17	19.80	0.026	201.62	0.33	1.22	0.29	6.60	15.87

	49Ti	Fe	Y	Nb	La	Ce	Nd	Sm	Eu	Gd	Ho
11SN37-7.1	20.20	72.98	1273.58	44.86	1.729	510.54	10.44	2.77	0.87	17.89	41.40
11SN37-7.2	23.25	379.40	601.62	38.55	13.979	980.52	70.26	8.17	1.36	15.08	21.07
11SN37-8.1	14.36	2.86	2265.76	26.46	0.036	431.22	7.57	9.42	2.07	55.47	79.02
11SN37-8.2	15.06	43.74	2195.61	51.98	0.081	678.62	2.68	4.78	0.89	37.36	75.11
11SN38-1.1	26.01	205.44	3301.18	89.67	0.993	500.03	13.59	14.27	2.05	82.66	127.78
11SN38-1.2	27.70	2.93	1149.76	49.59	0.076	350.95	1.71	2.44	0.42	20.35	39.88
11SN38-1.3	16.77	2.11	1552.39	63.12	0.012	365.71	1.30	2.55	0.59	26.33	52.91
11SN38-2.1	11.60	3.53	1101.17	35.81	0.056	248.48	0.77	1.76	0.42	17.01	36.03
11SN38-2.2	14.12	2.14	1426.53	77.69	0.024	408.48	1.36	2.65	0.53	21.51	49.77
11SN38-3.1	12.98	1.63	420.20	23.56	0.103	164.92	0.64	0.65	0.15	5.35	14.27
11SN38-3.2	19.01	3.91	1578.07	64.44	0.087	375.25	1.53	3.55	0.67	26.27	53.69
11SN38-4.1	15.64	3.33	616.65	25.69	0.048	238.83	0.81	1.65	0.28	11.23	20.35
11SN38-4.2	15.20	2.19	2010.64	32.21	0.038	375.05	5.16	7.32	1.25	49.95	76.26
11SN38-5.1	17.99	7.55	1591.96	58.96	0.253	429.07	2.26	3.42	0.67	25.38	56.04
11SN38-5.2	59.25	51.22	6365.03	121.69	1.099	1471.16	26.37	33.37	5.52	189.33	262.65
11SN38-6.1	55.34	30.73	5714.00	122.87	1.494	1421.19	27.94	27.10	5.05	146.24	206.20
11SN38-6.2	14.54	2.36	1039.70	35.57	0.039	291.81	1.52	2.47	0.46	20.45	36.01
11SN38-7.1	26.00	20.61	497.34	24.99	2.665	298.75	4.41	1.98	0.35	8.74	17.29
11SN38-7.2	22.62	0.98	556.31	11.78	0.021	88.50	0.60	1.62	0.33	9.05	19.10
11SN38-8.1	19.45	2.11	951.58	35.01	0.026	297.20	1.19	2.69	0.42	17.41	34.55
11SN38-8.2	16.55	4.06	2717.10	138.19	5.904	495.82	10.12	7.18	0.59	45.35	106.42
11SN38-8.3	11.48	1.60	614.19	28.24	0.032	206.65	0.31	1.15	0.21	8.59	20.56
11SN40-1.1	25.51	3.14	1943.81	27.26	0.046	208.80	2.19	7.00	0.79	44.25	74.49
11SN40-1.2	15.07	6.87	1726.42	81.05	0.074	199.10	0.71	2.48	0.58	22.37	56.76
11SN40-2.1	29.13	7.69	2770.94	76.03	0.110	522.48	4.29	8.87	0.78	60.87	118.12
11SN40-2.2	23.15	6.16	2913.94	134.58	0.510	735.52	6.02	10.19	0.97	61.32	134.94
11SN40-3.1	47.25	58.18	5396.17	1027.25	3.924	373.94	29.23	11.94	1.18	58.08	179.03
11SN40-3.2	17.30	5.62	1593.43	68.65	0.036	173.55	0.84	3.00	0.44	24.90	55.72
11SN40-4.1	34.34	16.62	2282.17	45.35	0.090	261.59	2.60	6.50	1.00	46.72	86.57
11SN40-4.2	18.14	5.94	2157.67	110.99	0.111	227.09	1.36	3.55	0.56	30.75	70.62

	49Ti	Fe	Y	Nb	La	Ce	Nd	Sm	Eu	Gd	Ho
11SN40-5.1	29.38	2.56	480.28	16.06	0.046	118.33	0.55	0.65	0.24	6.09	16.76
11SN40-5.2	25.56	7.58	2333.93	161.82	0.046	497.76	2.81	5.70	0.88	44.70	85.83
11SN40-6.1	44.90	2.52	2288.11	23.20	0.078	157.57	5.15	9.95	2.21	57.29	86.68
11SN40-6.2	22.59	8.50	3644.55	288.50	0.074	393.65	0.79	3.52	0.57	35.84	114.59
11SN40-7.1	38.60	2.65	2801.59	51.26	0.100	299.69	4.37	5.96	0.77	49.34	98.38
11SN40-7.2	22.26	3.46	1310.22	43.54	0.045	278.94	2.01	2.62	0.42	20.34	45.91
11SN40-9.1	28.87	3.42	3723.94	57.29	0.114	527.15	9.37	15.27	1.60	83.53	140.59
11SN40-9.2	18.95	5.90	1039.40	38.94	0.056	204.36	0.64	1.63	0.24	9.28	31.99
11SN40-10.1	36.05	17.84	2578.49	242.58	0.218	397.80	1.09	3.04	0.36	24.00	82.03
11SN40-10.2	40.32	3.88	2934.35	41.95	0.110	329.39	13.47	15.26	3.03	88.08	111.10
11SN41-1.1	45.84	5.53	1774.64	51.68	0.130	325.31	2.86	5.94	0.68	25.92	63.30
11SN41-1.2	36.35	3.76	1335.05	25.01	0.072	149.09	1.34	2.80	0.48	18.15	43.00
11SN41-2.1	39.73	4.54	2630.02	35.13	0.104	408.34	3.98	9.36	1.22	72.00	113.64
11SN41-2.2	40.52	3.29	1044.25	27.18	0.107	197.27	0.84	2.72	0.34	19.49	37.88
11SN41-3.1	18.82	12.73	7561.10	142.78	0.086	501.51	6.96	11.82	2.54	112.84	296.92
11SN41-3.2	121.07	1941.13	984.25	44.87	13.654	473.81	26.95	5.67	1.16	17.63	36.53
11SN41-4.2	62.33	2.95	849.43	20.83	0.163	175.26	1.40	1.97	0.27	12.59	32.63
11SN41-5.1	21.68	2.86	729.68	27.51	0.047	122.88	0.53	1.65	0.31	11.22	26.59
11SN41-5.2	35.97	2.07	1685.06	24.70	0.089	188.17	2.97	4.33	0.57	30.11	67.50
11SN41-7.1	37.69	4.37	1126.46	33.61	0.119	246.08	1.45	2.90	0.31	22.42	42.44
11SN41-7.2	32.53	3.35	5003.42	61.39	0.332	562.94	15.63	17.40	2.07	122.02	193.66
11SN41-8.1	27.27	261.89	1042.81	41.42	25.578	983.49	50.56	10.04	2.16	26.24	35.99
11SN41-8.2	40.19	2.87	2610.92	21.70	0.149	142.47	9.17	12.81	2.85	81.52	102.05
11SN41-9.1	30.95	2.32	823.44	22.78	0.054	176.37	0.34	1.32	0.21	14.65	33.83
11SN41-9.2	26.81	2.59	1137.48	26.88	0.053	193.60	1.97	2.02	0.39	19.00	41.28
11SN41-10.1	27.23	3.69	1471.41	34.90	0.087	153.18	1.49	3.17	0.33	25.42	54.01
11SN41-10.2	25.59	4.06	1630.98	50.93	0.082	296.01	1.12	2.42	0.39	24.49	57.65
11SN41-11.1	19.91	3.89	1419.16	59.38	0.063	253.98	0.85	2.88	0.30	17.89	51.10
11SN41-11.2	20.42	2.75	758.23	21.32	0.104	140.56	1.08	1.51	0.27	9.60	27.95
11SN41-11.3	19.81	2.51	1166.69	30.51	0.099	222.26	0.91	1.99	0.26	16.60	43.98

	Tb	Dy	Er	Tm	Yb	Lu	Hf	Pb	Th	U
CS01-1.1	30.33	387.84	937.46	222.98	1962.33	363.10	14070	35	1115	1495
CS01-1.2	24.82	288.43	653.23	140.37	1260.29	231.51	12181	10	610	521
CS01-2.1	16.47	221.32	512.38	115.09	1030.00	193.17	12289	22	884	985
CS01-2.2	14.54	159.87	295.29	61.44	568.14	106.78	12140	56	428	808
CS01-3.1	14.19	186.77	451.26	109.74	980.07	179.33	10654	9	523	557
CS01-3.2	21.84	274.18	666.92	156.03	1358.66	251.14	10445	7	542	570
CS01-4.1	55.51	638.24	1183.82	257.59	2133.12	361.10	9521	30	4187	1751
CS01-4.2	44.96	502.47	920.08	198.91	1704.34	286.44	9153	27	4078	1582
CS01-5.1	14.34	188.34	469.13	114.26	1094.37	209.65	13240	11	724	767
CS01-5.2	21.99	290.98	686.41	172.12	1633.55	304.06	13129	27	2447	2015
CS01-6.1	8.99	116.25	288.79	68.29	614.79	108.50	12144	4	148	174
CS01-7.1	22.69	252.34	503.04	118.04	1045.31	202.36	12162	22	3947	1984
CS01-8.1	56.92	624.14	1189.13	259.07	2302.13	405.11	8949	19	1525	925
CS01-8.2	18.22	221.12	465.60	104.18	941.29	168.62	9754	14	1235	699
CS01-9.1	1.95	31.14	138.35	43.68	606.61	180.31	18257	23	518	1645
CS01-10.1	17.17	218.80	452.30	98.51	883.64	149.82	11978	14	1455	897
CS01-10.2	23.42	294.67	703.20	178.54	1499.18	291.54	9971	13	1031	819
CS01-11.1	26.69	292.00	616.92	133.53	1136.99	199.85	10102	7	406	416
CS03-1.1	5.09	54.33	121.78	27.12	300.82	55.28	9047	5	282	375
CS03-1.2	6.85	81.35	142.24	31.45	309.02	53.77	11093	1	83	126
CS03-2.1	24.67	273.26	541.08	128.18	1130.70	208.53	13132	23	1673	1496
CS03-2.2	5.56	89.98	233.01	70.29	759.11	162.79	12265	20	944	1224
CS03-3.1	18.62	197.71	402.59	94.66	890.99	183.18	8996	7	982	612
CS03-4.1	3.77	42.44	88.24	25.31	247.98	62.36	14108	7	383	591
CS03-4.2	31.22	320.33	641.28	137.38	1308.00	235.85	9809	25	2579	1579
CS03-6.1	6.50	75.31	164.50	39.12	335.27	67.94	8663	2	144	134
CS03-6.2	7.03	73.38	160.71	43.86	426.78	89.07	9650	2	184	187
CS03-7.1	28.17	315.96	621.32	146.09	1452.45	272.21	13089	24	2752	1929
CS03-7.2	9.79	127.01	314.63	84.58	863.68	180.34	12485	10	879	1031

	Tb	Dy	Er	Tm	Yb	Lu	Hf	Pb	Th	U
CS03-8.1	7.32	86.66	194.42	52.80	498.31	86.21	12546	4	357	397
CS03-8.2	5.60	80.62	203.58	52.42	556.18	107.33	12825	7	561	666
CS03-8.3	5.69	75.34	184.87	46.93	490.06	105.80	12053	11	545	768
CS03-9.1	1.31	15.86	44.63	11.52	107.00	20.33	2850	2	107	111
CS03-9.2	1.77	23.10	73.14	21.05	241.23	63.31	12703	7	218	551
CS03-10.1	23.23	273.69	516.94	116.57	1107.83	197.97	11864	19	1792	1393
CS03-10.2	7.10	91.09	231.65	59.02	607.11	119.33	11700	7	572	643
CS03-11.1	8.60	96.70	186.38	46.25	453.29	86.27	11092	5	433	440
CS03-11.2	10.03	103.10	262.23	58.17	633.89	135.66	12392	12	824	971
CS07-1.1	15.88	218.33	569.06	139.62	1332.70	252.62	10023	7	520	430
CS07-1.2	5.26	71.03	191.25	45.82	481.89	92.47	10198	4	169	202
CS07-1.3	30.50	345.23	724.07	166.55	1542.89	276.93	12237	12	1160	757
CS07-2.1	18.95	247.27	550.93	130.90	1161.90	206.91	13331	11	807	744
CS07-2.2	7.60	101.58	247.57	66.08	660.58	146.74	17377	17	227	1271
CS07-3.1	11.60	129.90	283.99	65.34	577.38	108.00	11552	5	359	333
CS07-3.2	16.60	190.14	348.88	73.86	656.26	110.90	10922	4	332	247
CS07-4.1	2.74	35.04	111.32	31.03	339.24	70.00	15950	8	309	549
CS07-4.2	8.70	103.64	219.96	51.74	441.32	77.83	12338	3	282	242
CS07-4.3	8.30	112.36	284.35	77.11	788.70	151.39	14658	18	1018	1170
CS07-5.1	10.19	114.78	213.59	49.21	418.84	68.87	11193	3	200	170
CS07-5.2	8.92	112.95	225.54	53.10	476.19	81.68	11007	3	232	217
CS07-6.1	14.88	199.89	470.95	122.83	1055.39	202.89	13292	10	504	617
CS07-6.2	10.41	151.71	399.11	101.99	971.87	194.01	12532	4	146	243
CS07-6.3	12.07	146.23	326.44	74.36	681.58	123.45	10440	3	252	219
CS07-7.1	12.31	167.78	403.78	101.71	932.68	171.14	13302	14	1039	941
CS07-7.2	54.98	601.52	1150.39	244.42	2192.35	381.97	10153	39	4713	1260
CS10-1.1	4.77	55.67	149.56	38.50	361.52	81.72	11942	5	459	442
CS10-1.2	15.53	195.07	434.44	99.71	959.16	181.54	11180	12	1143	982
CS10-2.1	7.31	104.55	253.17	65.01	614.83	125.84	11647	8	516	551
CS10-2.2	7.47	100.58	231.62	58.89	599.16	124.38	13143	8	599	642

	Tb	Dy	Er	Tm	Yb	Lu	Hf	Pb	Th	U
CS10-3.1	9.52	119.80	277.45	66.55	685.49	131.27	14032	18	1941	1571
CS10-3.2	4.37	54.56	153.98	38.60	436.77	94.60	12460	8	488	535
CS10-3.3	11.90	151.14	293.31	68.29	667.03	130.76	11278	9	1106	733
CS10-4.1	86.05	971.73	1800.24	382.51	3177.86	531.39	10302	38	7138	3002
CS10-4.2	1.75	20.24	65.75	24.50	284.08	80.77	13259	9	503	702
CS10-5.1	6.58	79.49	189.34	48.29	500.22	101.58	13008	7	649	645
CS10-5.2	7.58	93.70	198.29	48.92	465.30	97.40	11976	12	1281	868
CS10-7.1	9.97	125.61	245.56	58.18	582.78	121.13	13043	13	912	923
CS10-7.2	7.68	91.88	245.98	62.35	645.96	131.95	12864	8	693	672
CS10-8.1	56.35	590.00	1025.73	223.97	1897.47	311.30	9717	23	4994	1748
CS10-8.2	4.34	62.84	124.27	26.24	255.46	46.15	12801	5	644	468
CS10-10.1	11.65	139.33	291.13	66.32	651.33	121.78	10404	9	1074	762
CS10-10.2	7.02	95.02	197.65	47.10	433.33	89.67	12836	9	961	702
CS13-1.1	10.18	137.00	396.71	96.36	928.67	174.00	11563	8	471	606
CS13-1.2	6.23	77.52	184.05	45.16	494.50	96.30	11912	10	515	607
CS13-2.1	33.51	341.15	649.36	151.30	1275.89	219.84	10051	8	908	559
CS13-2.2	16.69	207.66	486.80	122.94	1176.77	214.36	10316	8	590	560
CS13-3.1	9.31	121.03	303.69	83.39	810.67	165.27	11122	21	931	1544
CS13-4.1	5.38	66.35	118.21	23.74	219.22	36.72	9393	1	55	57
CS13-4.2	17.69	196.76	370.62	75.48	639.83	104.35	10240	5	344	318
CS13-5.1	13.18	172.18	367.96	85.96	799.96	147.68	12857	21	954	1242
CS13-5.2	33.14	352.14	627.03	137.25	1163.58	200.64	12295	17	1176	1373
CS13-5.3	10.28	105.83	234.30	58.36	509.38	103.35	12895	8	569	814
CS13-6.1	9.24	109.68	269.98	63.70	638.01	126.98	13333	13	633	885
CS13-6.2	10.82	130.20	327.06	81.81	699.06	133.32	12616	7	385	575
CS13-7.1	10.80	136.41	299.34	68.74	703.07	126.05	11822	10	696	628
CS13-7.2	6.64	84.39	190.06	48.27	463.58	93.48	14646	26	506	1611
CS13-9.1	11.36	131.25	267.99	56.98	567.72	107.98	11742	12	802	855
CS13-9.2	6.83	85.66	181.20	50.49	474.76	103.55	14413	13	555	1064
CS19-1.1	7.70	92.00	195.97	47.21	427.52	83.96	12478	4	433	308

	Tb	Dy	Er	Tm	Yb	Lu	Hf	Pb	Th	U
CS19-2.1	26.78	277.79	441.19	91.78	826.22	139.48	9562	16	5295	1093
CS19-2.2	32.39	313.68	432.23	92.16	732.25	123.34	11821	17	6315	1136
CS19-3.1	2.79	37.48	86.44	24.23	243.12	47.94	11667	1	69	120
CS19-3.2	11.04	137.36	361.53	92.58	891.40	170.48	13476	8	595	689
CS19-4.1	3.89	43.96	105.36	28.51	282.90	59.71	13428	6	234	417
CS19-4.2	85.71	879.85	1456.37	318.23	2663.68	466.21	8507	26	8513	1860
CS19-5.1	8.60	102.47	248.31	67.18	605.54	124.89	8162	5	840	523
CS19-5.2	60.05	495.49	563.49	117.42	911.74	164.02	9455	12	7872	1091
CS19-6.1	34.14	340.78	559.30	114.60	882.94	144.23	10160	9	1618	555
CS19-6.2	59.26	605.11	892.59	182.37	1549.47	259.13	9565	19	4575	1378
CS19-7.1	7.18	68.98	147.13	34.86	335.83	71.96	12141	10	766	802
CS19-7.2	13.63	122.94	187.49	45.62	375.98	73.03	8324	10	3057	690
CS25-1.1	19.66	227.08	457.87	108.56	1045.90	195.64	11810	14	1333	1111
CS25-1.2	8.26	100.09	255.53	64.16	606.10	120.27	14133	15	863	960
CS25-2.1	15.89	196.61	477.27	126.27	1214.79	233.15	13172	32	1531	2101
CS25-2.2	13.71	145.13	314.18	70.82	668.78	117.18	12057	6	515	390
CS25-3.1	15.20	172.00	355.00	75.95	679.27	114.82	11233	6	429	469
CS25-3.2	3.03	34.70	84.72	24.06	216.04	40.28	13208	3	149	220
CS25-4.1	8.92	128.72	303.39	74.17	751.38	145.77	12799	13	770	930
CS25-4.2	8.79	109.15	241.89	61.05	564.70	110.39	11671	6	390	527
CS25-4.3	9.04	120.40	321.86	75.93	797.67	152.84	15286	11	759	941
CS25-6.1	5.87	83.62	200.85	49.23	518.67	97.86	13399	8	391	659
CS25-6.2	9.42	95.40	203.04	57.89	551.97	103.93	15122	8	547	633
CS25-7.1	19.25	215.42	416.24	97.43	877.42	151.33	11789	8	847	584
CS25-7.2	2.63	34.41	105.05	33.79	411.05	119.17	20842	22	816	1912
CS25-8.1	7.21	83.08	201.11	52.16	519.34	102.83	13317	7	466	516
CS25-8.2	10.65	134.43	297.50	76.53	741.36	140.29	13020	10	650	770
CS25-8.3	6.81	96.42	231.76	61.27	603.81	116.07	12740	9	628	691
11SN34-1.1	15.64	176.15	384.02	85.87	850.01	151.23	10214	5	402	281
11SN34-1.2	15.52	191.44	493.40	122.19	1214.53	232.20	11118	9	738	739

	Tb	Dy	Er	Tm	Yb	Lu	Hf	Pb	Th	U
11SN34-2.1	4.72	70.24	182.93	46.14	466.17	91.09	10714	2	279	238
11SN34-2.2	11.41	166.30	423.16	104.75	1001.67	188.18	12447	7	537	588
11SN34-3.1	65.90	831.90	2000.03	484.63	4494.80	815.04	18456	101	8739	7239
11SN34-3.2	2.02	31.85	126.90	43.94	554.15	133.68	15743	14	189	1201
11SN34-4.1	51.84	655.56	1267.71	271.65	2236.09	378.16	13259	15	1499	970
11SN34-4.2	13.56	182.80	378.67	87.70	761.04	132.88	11241	4	263	238
11SN34-5.1	6.49	81.78	220.00	56.26	562.48	108.56	11702	4	225	232
11SN34-5.2	18.54	239.94	633.16	147.68	1355.70	254.31	11502	15	934	913
11SN34-6.1	1.39	19.09	74.47	19.18	210.01	45.48	7509	4	98	219
11SN34-6.2	8.50	107.96	272.25	71.51	712.75	134.48	11915	5	307	364
11SN34-6.3	42.34	562.64	1508.79	368.90	3601.78	631.58	20335	75	3940	5476
11SN34-7.1	14.28	188.84	527.83	136.68	1307.34	248.52	12785	17	802	1133
11SN34-7.2	9.48	120.64	302.39	77.69	757.04	143.43	11041	4	266	279
11SN34-8.1	9.31	117.74	311.67	74.14	724.96	139.91	13990	6	410	517
11SN34-8.2	34.75	425.33	918.18	211.66	1993.12	356.94	9639	19	2120	1298
11SN35-1.1	15.81	181.48	459.32	117.68	1226.69	242.37	14979	34	1468	2292
11SN35-1.2	8.83	107.32	262.47	69.34	701.06	139.54	11918	13	871	963
11SN35-2.1	2.95	40.95	96.63	23.32	225.28	42.95	12626	5	182	282
11SN35-2.2	39.68	428.87	771.32	169.37	1406.28	245.54	10295	13	1225	956
11SN35-3.1	8.55	99.04	243.55	64.41	624.14	115.48	13230	15	1074	1214
11SN35-3.2	15.88	181.55	355.86	87.37	737.42	133.67	11806	9	756	688
11SN35-4.1	8.81	102.19	241.43	60.04	558.89	106.61	14080	14	813	1021
11SN35-4.2	18.67	211.13	434.63	100.63	790.79	139.02	10395	5	390	341
11SN35-5.1	10.05	123.10	335.26	87.39	899.72	176.44	9964	10	622	677
11SN35-5.2	20.07	235.99	522.93	125.06	1186.92	212.34	12187	26	1382	1884
11SN35-6.1	9.23	116.44	269.08	65.81	650.63	119.46	13082	13	1001	1016
11SN35-6.2	6.81	80.83	181.19	44.94	420.14	80.81	11420	5	316	412
11SN35-7.1	8.92	111.20	235.95	61.93	559.81	114.15	11956	14	1136	970
11SN35-7.2	12.92	141.74	334.09	82.52	785.45	145.92	13199	20	1489	1353
11SN35-8.1	8.67	108.89	244.59	62.60	620.39	118.16	13778	9	746	823
11SN35-8.2	8.31	95.62	209.26	54.04	521.04	95.39	12312	9	565	695

	Tb	Dy	Er	Tm	Yb	Lu	Hf	Pb	Th	U
11SN35-8.3	9.06	121.44	278.30	70.59	677.00	130.82	11738	9	699	672
11SN36-1.1	6.73	77.77	201.51	50.84	563.79	121.37	11502	21	1363	1350
11SN36-1.2	12.80	152.99	334.61	87.00	937.54	185.94	14513	93	9118	5829
11SN36-2.1	23.05	287.22	594.31	134.45	1211.13	218.85	16320	19	758	1302
11SN36-2.2	11.15	125.09	264.81	68.01	638.27	121.04	12252	15	1065	1071
11SN36-3.1	4.71	60.37	152.28	40.04	444.86	94.56	12862	12	596	837
11SN36-3.2	14.21	170.00	398.02	98.29	1029.43	209.54	14252	74	5102	4440
11SN36-4.1	7.53	91.40	193.30	45.05	448.72	87.03	10821	1	134	146
11SN36-4.2	19.56	243.05	511.30	117.13	1056.90	204.60	11215	8	771	596
11SN36-5.1	5.80	71.50	198.93	52.26	518.90	99.63	13015	7	323	638
11SN36-5.2	14.11	190.54	512.71	141.76	1462.80	308.36	14770	36	1189	2155
11SN36-6.1	19.75	235.04	551.11	143.91	1488.66	308.07	13279	40	3174	2359
11SN36-6.2	7.42	64.91	112.71	26.74	267.99	50.87	10732	2	601	272
11SN36-7.1	11.88	152.49	324.06	80.77	792.94	150.47	12325	13	1436	943
11SN36-7.2	46.18	377.19	613.88	150.02	1477.51	282.66	14996	90	9140	6192
11SN36-8.1	9.21	109.45	204.14	49.86	490.84	93.40	11636	8	830	554
11SN36-8.2	5.28	65.13	174.89	44.87	474.66	105.42	12208	13	933	1032
11SN37-1.1	8.74	108.24	219.81	50.96	526.71	110.11	12273	41	4839	2946
11SN37-1.2	8.32	95.07	229.32	58.77	625.19	127.60	12740	26	2434	1917
11SN37-2.1	11.77	176.16	568.05	166.27	1902.46	418.75	15382	85	3250	5194
11SN37-2.2	51.74	624.31	1155.19	251.96	2189.26	376.41	9391	68	12383	4870
11SN37-3.1	5.91	79.59	204.29	55.18	635.48	147.97	14021	43	1391	2248
11SN37-3.2	4.86	59.45	146.24	39.12	424.25	97.40	11523	13	631	819
11SN37-4.1	13.18	144.16	316.20	77.64	746.23	149.88	12611	11	1101	1013
11SN37-4.2	5.07	46.97	107.52	26.09	268.18	56.35	11572	7	2386	804
11SN37-5.1	4.35	55.32	119.89	30.28	293.57	58.42	10781	8	657	565
11SN37-5.2	32.20	366.77	663.82	153.91	1386.11	243.51	10443	25	2843	1527
11SN37-6.1	2.78	37.64	92.43	27.06	272.22	61.86	12019	8	471	563
11SN37-6.2	2.24	32.05	95.65	26.18	302.12	73.27	13877	22	772	1158

	Tb	Dy	Er	Tm	Yb	Lu	Hf	Pb	Th	U
11SN37-7.1	7.31	93.54	229.57	59.83	633.63	130.81	10694	22	1393	1333
11SN37-7.2	4.11	46.28	118.95	34.46	384.69	83.45	11629	14	675	857
11SN37-8.1	18.45	202.83	405.70	96.70	927.56	170.94	10820	21	2007	1300
11SN37-8.2	13.77	176.38	408.14	97.31	1026.98	191.61	10752	32	2338	1846
11SN38-1.1	28.91	355.76	664.75	154.98	1433.22	268.62	10866	43	2625	2367
11SN38-1.2	7.85	95.18	222.83	56.65	574.66	108.57	10446	19	1249	1148
11SN38-1.3	8.85	123.87	296.68	73.54	739.30	139.81	10999	16	830	959
11SN38-2.1	6.44	78.19	202.78	50.32	544.43	109.80	10836	12	637	827
11SN38-2.2	7.97	107.12	274.51	70.41	688.84	136.12	10981	16	807	905
11SN38-3.1	2.43	30.34	80.23	23.51	220.90	46.98	11734	5	221	336
11SN38-3.2	9.54	114.55	302.71	75.84	777.66	149.34	11294	15	859	951
11SN38-4.1	4.22	45.15	110.02	25.43	298.49	61.97	12171	14	637	893
11SN38-4.2	16.59	188.30	380.61	89.13	864.22	159.50	11176	17	1428	1079
11SN38-5.1	9.85	126.45	298.71	78.77	767.34	152.13	10991	15	930	922
11SN38-5.2	59.72	707.09	1289.30	291.86	2653.09	454.92	7912	33	4783	2046
11SN38-6.1	48.59	551.24	1025.28	225.91	2028.77	354.93	10667	49	5481	2991
11SN38-6.2	7.50	84.62	204.38	49.43	540.57	103.84	11598	16	752	782
11SN38-7.1	3.23	39.21	89.22	23.22	246.04	56.29	11749	9	494	895
11SN38-7.2	3.64	41.31	101.34	25.11	271.81	55.75	9688	2	113	128
11SN38-8.1	6.34	78.56	180.30	42.64	443.10	80.52	10928	11	687	646
11SN38-8.2	17.94	233.37	544.59	124.52	1112.95	204.43	10762	10	549	597
11SN38-8.3	3.10	46.49	117.76	30.56	319.06	63.72	12653	7	344	450
11SN40-1.1	15.18	172.06	353.00	87.84	769.89	140.93	12670	12	845	772
11SN40-1.2	9.75	123.94	334.14	88.35	943.42	187.16	14313	29	798	1887
11SN40-2.1	25.60	308.16	652.70	156.01	1522.82	277.18	11973	39	3597	2932
11SN40-2.2	26.69	316.63	687.51	158.35	1465.09	272.11	12511	27	3835	2846
11SN40-3.1	25.37	364.61	1024.35	258.54	2469.28	460.33	22355	87	1250	5438
11SN40-3.2	10.36	129.11	269.44	61.60	660.08	113.68	12959	12	733	971
11SN40-4.1	16.10	200.89	461.11	115.93	1157.42	230.40	13882	28	1865	2031
11SN40-4.2	11.16	137.69	410.70	110.28	1174.38	244.77	14687	32	1246	2275

	Tb	Dy	Er	Tm	Yb	Lu	Hf	Pb	Th	U
11SN40-5.1	2.78	33.43	97.54	29.79	262.29	53.16	11854	3	193	226
11SN40-5.2	16.86	202.69	424.61	103.60	1027.54	197.72	14078	43	3044	2906
11SN40-6.1	19.23	202.68	413.32	95.47	842.41	161.42	8509	2	195	121
11SN40-6.2	15.47	207.18	553.03	144.81	1434.68	281.27	14349	36	1698	2872
11SN40-7.1	17.15	235.37	481.86	111.15	1011.05	176.76	11820	9	800	700
11SN40-7.2	7.52	102.33	248.91	63.79	610.33	122.32	12330	11	805	889
11SN40-9.1	28.02	323.38	640.86	137.44	1205.66	202.23	12678	15	1286	838
11SN40-9.2	4.99	60.03	199.15	57.95	649.82	156.59	16858	18	735	1815
11SN40-10.1	10.13	135.41	524.73	153.50	1770.16	373.36	19117	62	1159	4354
11SN40-10.2	26.79	285.68	481.77	105.18	949.54	158.44	10742	7	925	651
11SN41-1.1	10.82	121.63	336.08	81.72	772.76	149.02	11472	14	1227	1127
11SN41-1.2	7.30	90.59	230.83	62.81	609.72	117.91	12686	10	493	625
11SN41-2.1	26.50	284.71	536.29	121.51	997.29	176.15	11603	8	1022	644
11SN41-2.2	6.85	90.24	186.07	49.97	436.56	80.27	11874	5	386	422
11SN41-3.1	47.88	572.06	1591.35	436.61	4648.67	951.17	16460	155	3960	9223
11SN41-3.2	6.87	82.99	211.65	52.02	501.05	98.89	13765	7	1286	597
11SN41-4.2	5.62	72.30	159.77	39.12	380.21	78.21	13037	4	322	373
11SN41-5.1	4.60	52.39	132.43	34.19	358.25	75.46	10372	6	316	402
11SN41-5.2	12.04	145.34	315.22	71.16	586.62	113.72	11462	5	396	423
11SN41-7.1	7.47	102.35	197.41	47.90	491.48	90.87	12745	8	587	606
11SN41-7.2	46.62	491.18	934.81	199.90	1735.45	298.49	10983	17	2167	1176
11SN41-8.1	6.11	72.34	189.35	49.41	429.98	85.76	14215	7	1903	722
11SN41-8.2	24.61	250.95	458.95	98.63	929.40	155.48	9574	5	520	351
11SN41-9.1	4.61	67.33	156.11	36.96	332.14	60.49	12549	3	189	227
11SN41-9.2	7.58	89.12	212.46	57.30	535.53	106.12	12618	8	477	558
11SN41-10.1	9.19	108.54	290.60	71.98	646.99	130.11	11328	8	480	591
11SN41-10.2	9.58	132.25	316.23	75.45	707.72	128.27	14187	7	646	733
11SN41-11.1	8.82	108.92	273.07	64.58	652.62	121.07	14574	7	565	698
11SN41-11.2	4.95	63.60	159.44	41.32	433.66	88.42	12994	6	397	492
11SN41-11.3	8.36	93.62	219.74	57.41	507.38	99.00	12579	7	476	553

APPENDIX F: O Isotope Data

Spot Number	$\delta^{18}\text{O}$ ‰ VSMOW	2SD (ext.)	Mass Bias (‰)	$\delta^{18}\text{O}$ ‰ measured	2SE (int.)	^{16}O (Gcps)	IP (nA)	Yield (Gcps/nA)	$^{16}\text{OH}/^{16}\text{O}$
MC44 91500 g2				10.283	0.23	2.6367	1.8611	1.4167	1.2991E-03
MC44 91500 g3				10.177	0.28	2.6417	1.8637	1.4175	1.3077E-03
MC44 91500 g4				10.121	0.21	2.6438	1.8639	1.4184	1.3042E-03
MC44 91500 g5				10.343	0.26	2.6335	1.8615	1.4147	1.3152E-03
average and 2SD	10.07		0.15939	10.231	0.20				
MC44 11SN34_1.1	5.83	0.16		5.965	0.22	2.6042	1.8528	1.4055	1.3635E-03
MC44 11SN34_1.2	5.83	0.16		5.968	0.19	2.5887	1.8437	1.4041	1.4695E-03
MC44 11SN34_2.1	5.73	0.16		5.865	0.17	2.5697	1.8307	1.4037	1.3896E-03
MC44 11SN34_2.2	5.79	0.16		5.932	0.22	2.5434	1.8201	1.3974	1.4748E-03
MC44 11SN34_3.1	5.70	0.16		5.836	0.22	2.5343	1.8082	1.4015	1.4918E-03
MC44 11SN34_3.2	5.46	0.16		5.596	0.17	2.5079	1.7987	1.3943	1.5035E-03
MC44 11SN34_4.1	5.79	0.16		5.924	0.18	2.4723	1.7817	1.3876	1.4876E-03
MC44 11SN34_4.2	6.00	0.16		6.133	0.18	2.4602	1.7680	1.3915	1.5807E-03
MC44 11SN34_5.1	5.54	0.16		5.674	0.21	2.6238	1.8609	1.4100	1.4670E-03
MC44 11SN34_5.2	5.68	0.16		5.822	0.24	2.6348	1.8687	1.4100	1.4633E-03
MC44 91500 g2.1				10.235	0.26	2.6319	1.8675	1.4094	1.4987E-03
MC44 91500 g3.1				10.124	0.28	2.6358	1.8661	1.4125	1.5071E-03
MC44 91500 g4.1				10.153	0.17	2.6285	1.8607	1.4127	1.4985E-03
MC44 91500 g5.1				10.228	0.19	2.6137	1.8579	1.4068	1.5186E-03
average and 2SD				10.185	0.11				
bracket average and 2SD	10.07		0.13662	10.208	0.16				
MC44 11SN36_8.1	6.15	0.18		6.189	0.24	2.5957	1.8454	1.4066	1.6188E-03
MC44 11SN36_8.2	6.25	0.18		6.292	0.24	2.5846	1.8393	1.4053	1.5796E-03
MC44 11SN36_6.1	6.59	0.18		6.625	0.22	2.5548	1.8273	1.3981	1.5972E-03
MC44 11SN36_6.2	6.22	0.18		6.264	0.25	2.5518	1.8191	1.4028	1.6143E-03
MC44 11SN36_4.1	6.96	0.18		6.998	0.19	2.5370	1.8106	1.4012	1.6638E-03

Spot Number	$\delta^{18}\text{O}$ VSMOW	‰	2SD (ext.)	Mass Bias (‰)	$\delta^{18}\text{O}$ measured	‰	2SE (int.)	^{16}O (Gcps)	IP (nA)	Yield (Gcps/nA)	$^{16}\text{OH}/^{16}\text{O}$
MC44 11SN36_4.2	6.83		0.18		6.872		0.22	2.5150	1.8010	1.3965	1.6451E-03
MC44 11SN36_3.1	6.31		0.18		6.347		0.24	2.5031	1.7898	1.3985	1.6183E-03
MC44 11SN36_3.2	6.18		0.18		6.220		0.25	2.4879	1.7816	1.3964	1.7404E-03
MC44 11SN36_2.1	5.87		0.18		5.905		0.22	2.4609	1.7687	1.3913	1.7346E-03
MC44 11SN36_2.2	5.77		0.18		5.810		0.27	2.6153	1.8640	1.4031	1.6125E-03
MC44 91500 g2.2					10.073		0.26	2.6403	1.8737	1.4091	1.5670E-03
MC44 91500 g3.2					10.001		0.19	2.6490	1.8751	1.4127	1.5662E-03
MC44 91500 g4.2					10.046		0.22	2.6390	1.8739	1.4083	1.5872E-03
MC44 91500 g5.2					10.017		0.20	2.6430	1.8723	1.4116	1.5547E-03
average and 2SD					10.034		0.06				
bracket average and 2SD	10.07			0.03923	10.110		0.18				
MC44 CS07_7.1	5.90		0.40		6.042		0.22	2.6247	1.8667	1.4061	1.6358E-03
MC44 CS07_7.2	5.87		0.40		6.014		0.17	2.6269	1.8642	1.4091	1.7278E-03
MC44 CS07_6.1	5.64		0.40		5.787		0.18	2.6217	1.8600	1.4095	1.6639E-03
MC44 CS07_6.2	6.74		0.40		6.882		0.20	2.6087	1.8562	1.4054	1.6665E-03
MC44 CS07_6.3	6.38		0.40		6.526		0.22	2.6023	1.8516	1.4054	1.7753E-03
MC44 CS07_5.1	7.03		0.40		7.169		0.26	2.5874	1.8440	1.4032	1.6808E-03
MC44 CS07_5.2	7.32		0.40		7.460		0.24	2.5742	1.8370	1.4013	1.6691E-03
MC44 CS07_2.1	5.80		0.40		5.946		0.18	2.5490	1.8258	1.3961	1.7236E-03
MC44 CS07_2.2	6.18		0.40		6.327		0.18	2.5483	1.8176	1.4020	1.7413E-03
MC44 11SN37_3.1	6.38		0.40		6.520		0.22	2.5209	1.8034	1.3979	1.7437E-03
MC44 11SN37_3.2	6.05		0.40		6.191		0.19	2.5226	1.7939	1.4062	1.9359E-03
MC44 11SN37_4.1	6.56		0.40		6.705		0.16	2.4920	1.7829	1.3977	1.7356E-03
MC44 11SN37_4.2	6.40		0.40		6.544		0.21	2.4662	1.7727	1.3912	1.7448E-03
MC44 91500 g2.3					10.516		0.29	2.6144	1.8701	1.3980	1.6781E-03
MC44 91500 g3.3					10.240		0.29	2.6488	1.8785	1.4101	1.6353E-03
MC44 91500 g4.3					10.240		0.22	2.6583	1.8801	1.4139	1.6130E-03

Spot Number	$\delta^{18}\text{O}$ ‰ VSMOW	2SD (ext.)	Mass Bias (‰)	$\delta^{18}\text{O}$ ‰ measured	2SE (int.)	^{16}O (Gcps)	IP (nA)	Yield (Gcps/nA)	$^{16}\text{OH}/^{16}\text{O}$
MC44 91500 g4.4				10.518	0.24	2.6547	1.8778	1.4137	1.6098E-03
MC44 91500 g5.3				10.274	0.23	2.6564	1.8767	1.4155	1.5963E-03
average and 2SD				10.358	0.29				
bracket average and 2SD	10.07		0.14245	10.214	0.40				
MC44 11SN37_5.1	6.34	0.26		6.584	0.21	2.6241	1.8711	1.4024	1.7057E-03
MC44 11SN37_5.2	6.14	0.26		6.387	0.22	2.6281	1.8669	1.4078	1.6969E-03
MC44 11SN37_6.1	5.96	0.26		6.210	0.21	2.6390	1.8638	1.4159	1.6506E-03
MC44 11SN37_6.2	5.34	0.26		5.590	0.23	2.6528	1.8604	1.4259	1.8973E-03
MC44 11SN38_8.1	6.40	0.26		6.644	0.16	2.6071	1.8506	1.4088	1.6303E-03
MC44 11SN38_8.2	5.97	0.26		6.217	0.25	2.5868	1.8435	1.4032	1.6239E-03
MC44 11SN38_7.1	6.62	0.26		6.867	0.28	2.5712	1.8350	1.4012	1.6451E-03
MC44 11SN38_7.2	6.24	0.26		6.484	0.24	2.5762	1.8271	1.4100	1.7158E-03
MC44 11SN38_2.1	6.35	0.26		6.595	0.19	2.5682	1.8156	1.4145	1.7791E-03
MC44 11SN38_2.2	6.30	0.26		6.544	0.19	2.5307	1.8104	1.3979	1.6677E-03
MC44 11SN38_1.1	6.48	0.26		6.728	0.26	2.5051	1.8012	1.3908	1.7217E-03
MC44 11SN38_1.2	6.31	0.26		6.559	0.24	2.4839	1.7936	1.3848	1.6640E-03
MC44 91500 g2.4				10.369	0.20	2.4737	1.7801	1.3897	1.6984E-03
MC44 91500 g3.4				10.233	0.19	2.4521	1.7679	1.3870	1.6860E-03
MC44 91500 g4.5				10.318	0.21	2.6104	1.8683	1.3972	1.6271E-03
MC44 91500 g5.4				10.143	0.23	2.6536	1.8812	1.4106	1.5994E-03
average and 2SD				10.266	0.20				
bracket average and 2SD	10.07		0.24432	10.317	0.26				
MC45 91500 g2.1				10.278	0.22	2.6499	1.8814	1.4085	1.4593E-03
MC45 91500 g3.1				10.299	0.24	2.6600	1.8802	1.4147	1.4635E-03
MC45 91500 g4.1				10.148	0.20	2.6604	1.8768	1.4175	1.4688E-03
MC45 91500 g5.1				10.152	0.19	2.6551	1.8750	1.4161	1.4865E-03
average and 2SD	10.07		0.14776	10.219	0.16				

Spot Number	$\delta^{18}\text{O}$ ‰ VSMOW	2SD (ext.)	Mass Bias (‰)	$\delta^{18}\text{O}$ ‰ measured	2SE (int.)	^{16}O (Gcps)	IP (nA)	Yield (Gcps/nA)	$^{16}\text{OH}/^{16}\text{O}$
MC45 11SN40_9.1	6.20	0.21		6.399	0.14	2.6215	1.8687	1.4029	1.4889E-03
MC45 11SN40_9.2	7.10	0.21		7.300	0.20	2.6196	1.8654	1.4043	1.5144E-03
MC45 11SN40_6.2	7.31	0.21		7.513	0.23	2.6224	1.8587	1.4108	1.6042E-03
MC45 11SN40_6.1	6.21	0.21		6.416	0.25	2.6375	1.8536	1.4229	1.8100E-03
MC45 11SN40_3.1	6.57	0.21		6.773	0.19	2.6213	1.8464	1.4197	1.6849E-03
MC45 11SN40_3.2	7.36	0.21		7.563	0.23	2.5939	1.8389	1.4106	1.5259E-03
MC45 11SN40_1.1	7.85	0.21		8.049	0.21	2.5751	1.8308	1.4066	1.5111E-03
MC45 11SN40_1.2	6.68	0.21		6.881	0.22	2.5646	1.8243	1.4058	1.5673E-03
MC45 11SN40_4.1	6.70	0.21		6.900	0.28	2.5382	1.8122	1.4007	1.7070E-03
MC45 11SN40_4.2	6.61	0.21		6.814	0.19	2.5206	1.8027	1.3982	1.6038E-03
MC45 11SN41_3.1	6.69	0.21		6.895	0.27	2.5082	1.7898	1.4014	1.5959E-03
MC45 11SN41_3.2	6.08	0.21		6.283	0.26	2.5258	1.7785	1.4202	1.9173E-03
MC45 91500 g2.2				10.429	0.25	2.6214	1.8747	1.3983	1.5861E-03
MC45 91500 g3.2				10.243	0.20	2.6670	1.8834	1.4161	1.5532E-03
MC45 91500 g4.2				10.416	0.28	2.6668	1.8845	1.4151	1.5354E-03
MC45 91500 g5.2				10.229	0.26	2.6606	1.8840	1.4122	1.5401E-03
average and 2SD				10.329	0.22				
bracket average and 2SD	10.07		0.20221	10.274	0.21				
MC45 11SN41_5.2	7.14	0.25		7.462	0.20	2.6697	1.8824	1.4183	1.5950E-03
MC45 11SN41_5.1	6.66	0.25		6.984	0.28	2.6598	1.8800	1.4148	1.5583E-03
MC45 11SN41_10.1	6.81	0.25		7.134	0.26	2.6384	1.8751	1.4070	1.6416E-03
MC45 11SN41_10.2	6.42	0.25		6.742	0.22	2.6457	1.8724	1.4130	1.5445E-03
MC45 11SN41_11.1	6.51	0.25		6.836	0.18	2.6250	1.8666	1.4063	1.5813E-03
MC45 11SN41_11.2	6.31	0.25		6.630	0.22	2.6194	1.8638	1.4054	1.5466E-03
MC45 CS03_6.1	6.29	0.25		6.613	0.21	2.6099	1.8644	1.3998	1.6316E-03
MC45 CS03_6.2	6.10	0.25		6.425	0.24	2.6243	1.8615	1.4098	1.2939E-03

Spot Number	$\delta^{18}\text{O}$ ‰ VSMOW	2SD (ext.)	Mass Bias (‰)	$\delta^{18}\text{O}$ ‰ measured	2SE (int.)	^{16}O (Gcps)	IP (nA)	Yield (Gcps/nA)	$^{16}\text{OH}/^{16}\text{O}$
MC45 CS03_9.1	6.52	0.25		6.846	0.23	2.6249	1.8523	1.4171	1.4534E-03
MC45 CS03_5.1	6.57	0.25		6.890	0.20	2.5970	1.8441	1.4083	3.0884E-03
MC45 CS03_5.2	6.33	0.25		6.654	0.28	2.5891	1.8388	1.4080	1.3258E-03
MC45 CS03_3.1	6.68	0.25		7.001	0.23	2.5658	1.8292	1.4027	1.3220E-03
MC45 91500 g2.3				10.495	0.23	2.5394	1.8169	1.3976	1.3072E-03
MC45 91500 g3.3				10.489	0.19	2.5344	1.8063	1.4030	1.2974E-03
MC45 91500 g4.3				10.284	0.29	2.5411	1.8347	1.3850	1.3367E-03
MC45 91500 g5.3				10.624	0.25	2.4931	1.7900	1.3928	1.3464E-03
MC45 91500 g5.4				10.408	0.23	2.4816	1.7765	1.3969	1.3780E-03
average and 2SD				10.460	0.25				
bracket average and 2SD	10.07		0.32139	10.395	0.25				
MC45 CS03_2.1	6.70	0.37		6.943	0.22	2.4705	1.7598	1.4039	1.5964E-03
MC45 CS03_2.2	7.33	0.37		7.574	0.18	2.4417	1.7471	1.3976	1.4575E-03
MC45 CS01_8.1	5.89	0.37		6.131	0.32	2.7133	1.8646	1.4551	1.4601E-03
MC45 CS01_8.2	6.98	0.37		7.228	0.33	2.6589	1.8757	1.4175	1.4558E-03
MC45 CS01_5.1	5.51	0.37		5.753	0.24	2.6687	1.8778	1.4212	1.4056E-03
MC45 CS01_5.2	5.92	0.37		6.165	0.23	2.6671	1.8783	1.4200	1.3971E-03
MC45 CS01_3.2	5.69	0.37		5.932	0.21	2.6683	1.8758	1.4225	1.4686E-03
MC45 CS01_3.1	5.85	0.37		6.089	0.36	2.6528	1.8750	1.4148	1.4202E-03
MC45 CS01_1.2	7.78	0.37		8.024	0.23	2.6532	1.8692	1.4195	1.5338E-03
MC45 CS01_1.1	7.72	0.37		7.965	0.21	2.6439	1.8666	1.4164	1.4651E-03
MC45 CS10_1.1	6.26	0.37		6.501	0.23	2.6180	1.8594	1.4080	4.0528E-03
MC45 CS10_1.2	6.74	0.37		6.983	0.25	2.6135	1.8549	1.4090	1.4645E-03
MC45 91500 g2.4				10.121	0.22	2.5975	1.8477	1.4058	1.4525E-03
MC45 91500 g3.4				10.132	0.17	2.5869	1.8404	1.4056	1.4627E-03
MC45 91500 g4.4				10.160	0.26	2.5594	1.8315	1.3975	1.4843E-03

Spot Number	$\delta^{18}\text{O}$ ‰ VSMOW	2SD (ext.)	Mass Bias (‰)	$\delta^{18}\text{O}$ ‰ measured	2SE (int.)	^{16}O (Gcps)	IP (nA)	Yield (Gcps/nA)	$^{16}\text{OH}/^{16}\text{O}$
MC45 91500 g5.5				10.150	0.20	2.5525	1.8226	1.4005	1.5005E-03
average and 2SD				10.141	0.04				
bracket average and 2SD	10.07		0.24179	10.314	0.37				
MC45 CS10_3.3	6.57	0.44		6.833	0.23	2.5192	1.8051	1.3956	1.5427E-03
MC45 CS10_3.2	6.57	0.44		6.826	0.23	2.5064	1.7941	1.3971	1.5681E-03
MC45 CS10_3.1	6.42	0.44		6.681	0.23	2.4847	1.7816	1.3946	1.5624E-03
MC45 CS10_6.2	6.88	0.44		7.135	0.20	2.4552	1.7661	1.3902	1.5701E-03
MC45 CS10_6.1	6.55	0.44		6.804	0.26	2.4428	1.7564	1.3908	1.6206E-03
MC45 CS10_10.1	6.70	0.44		6.957	0.26	2.6508	1.8733	1.4150	1.5090E-03
MC45 CS10_10.2	6.64	0.44		6.897	0.25	2.6640	1.8822	1.4154	1.5455E-03
MC45 CS13_7.1	6.92	0.44		7.181	0.23	2.6641	1.8815	1.4159	1.5133E-03
MC45 CS13_7.2	7.47	0.44		7.732	0.20	2.6596	1.8811	1.4138	1.5061E-03
MC45 CS13_6.1	7.64	0.44		7.902	0.28	2.6588	1.8780	1.4158	1.5612E-03
MC45 CS13_6.2	7.08	0.44		7.344	0.21	2.6571	1.8762	1.4162	1.4911E-03
MC45 CS13_5.1	7.65	0.44		7.912	0.27	2.6463	1.8704	1.4148	1.5892E-03
MC45 91500 g2.5				10.307	0.22	2.6442	1.8644	1.4183	1.5081E-03
MC45 91500 g3.5				10.564	0.23	2.6160	1.8568	1.4089	1.5210E-03
MC45 91500 g4.5				10.506	0.28	2.6104	1.8483	1.4124	1.5123E-03
MC45 91500 g5.6				10.663	0.25	2.5900	1.8405	1.4072	1.5300E-03
MC45 91500 g6.1				10.555	0.22	2.5750	1.8326	1.4051	1.5441E-03
average and 2SD				10.519	0.26				
bracket average and 2SD	10.07		0.25728	10.330	0.44				
MC45 CS13_5.2	7.34	0.50		7.583	0.27	2.5591	1.8232	1.4036	1.5874E-03
MC45 CS13_1.1	7.45	0.50		7.696	0.28	2.5258	1.8078	1.3971	1.6558E-03
MC45 CS13_1.2	7.11	0.50		7.351	0.22	2.5177	1.7987	1.3997	1.5460E-03
MC45 CS19_3.1	6.60	0.50		6.842	0.24	2.4965	1.7842	1.3992	1.5784E-03

Spot Number	$\delta^{18}\text{O}$ ‰ VSMOW	2SD (ext.)	Mass Bias (‰)	$\delta^{18}\text{O}$ ‰ measured	2SE (int.)	^{16}O (Gcps)	IP (nA)	Yield (Gcps/nA)	$^{16}\text{OH}/^{16}\text{O}$
MC45 CS19_3.2	5.91	0.50		6.154	0.22	2.4802	1.7721	1.3996	1.5793E-03
MC45 CS19_6.2	6.03	0.50		6.268	0.20	2.6362	1.8825	1.4004	1.5566E-03
MC45 CS19_6.1	5.39	0.50		5.633	0.23	2.6822	1.8901	1.4190	1.6311E-03
MC45 CS19_7.1	5.80	0.50		6.044	0.25	2.6795	1.8913	1.4168	1.5386E-03
MC45 CS19_7.2	5.32	0.50		5.563	0.21	2.6788	1.8920	1.4158	1.6624E-03
MC45 CS19_2.1	5.39	0.50		5.630	0.22	2.6668	1.8881	1.4125	1.5849E-03
MC45 91500 g2.6				9.982	0.18	2.6778	1.8854	1.4203	1.5027E-03
MC45 91500 g2.7				10.051	0.19	2.6658	1.8830	1.4158	1.5138E-03
MC45 91500 g3.6				10.216	0.22	2.6508	1.8771	1.4121	1.5183E-03
MC45 91500 g3.7				10.263	0.18	2.6509	1.8717	1.4163	1.5225E-03
MC45 91500 g4.6				10.015	0.28	2.6346	1.8645	1.4130	1.5313E-03
average and 2SD				10.105	0.25				
bracket average and 2SD	10.07		0.23979	10.312	0.50				
MC45 CS10_9.1	6.84	0.30		6.926	0.25	2.6114	1.8551	1.4077	1.5456E-03
MC45 CS10_9.2	6.25	0.30		6.338	0.23	2.6018	1.8500	1.4063	1.5250E-03
MC45 91500 g2.8				10.164	0.16	2.5776	1.8416	1.3996	1.5211E-03
MC45 91500 g5.7				10.015	0.20	2.5686	1.8337	1.4008	1.5425E-03
MC45 91500 g4.7				10.385	0.22	2.5542	1.8260	1.3988	1.5564E-03
MC45 91500 g6.2				10.338	0.23	2.5316	1.8153	1.3946	1.5554E-03
average and 2SD				10.226	0.34				
bracket average and 2SD	10.07		0.08789	10.159	0.30				
MC45 91500 g2.9				10.279	0.20	2.5751	1.8296	1.4075	9.6910E-04
MC45 91500 g3.7				10.422	0.22	2.5772	1.8298	1.4084	9.3527E-04
MC45 91500 g4.8				10.420	0.26	2.5677	1.8307	1.4026	1.0059E-03
MC45 91500 g5.8				10.407	0.21	2.5706	1.8300	1.4046	1.0334E-03
average and 2SD				10.382	0.14				

Spot Number	$\delta^{18}\text{O}$ ‰ VSMOW	2SD (ext.)	Mass Bias (‰)	$\delta^{18}\text{O}$ ‰ measured	2SE (int.)	^{16}O (Gcps)	IP (nA)	Yield (Gcps/nA)	$^{16}\text{OH}/^{16}\text{O}$
MC45 CS25_1.1	6.54	0.35		6.735	0.24	2.5645	1.8289	1.4023	1.0941E-03
MC45 CS25_1.2	6.41	0.35		6.610	0.21	2.5661	1.8289	1.4031	1.0710E-03
MC45 CS25_2.1	6.58	0.35		6.776	0.24	2.5595	1.8263	1.4015	1.2039E-03
MC45 CS25_2.2	6.88	0.35		7.081	0.21	2.5514	1.8235	1.3992	1.1013E-03
MC45 CS25_3.1	5.31	0.35		5.504	0.17	2.5435	1.8171	1.3998	1.2568E-03
MC45 CS25_3.2	6.78	0.35		6.980	0.19	2.5271	1.8110	1.3954	1.1419E-03
MC45 CS25_3.3	6.59	0.35		6.787	0.23	2.5042	1.8040	1.3881	1.1972E-03
MC45 CS25_6.1	7.26	0.35		7.455	0.22	2.4882	1.7926	1.3880	1.2187E-03
MC45 CS25_6.2	7.33	0.35		7.524	0.24	2.4717	1.7846	1.3850	1.1685E-03
MC45 CS25_8.2	6.35	0.35		6.551	0.24	2.4589	1.7722	1.3875	1.4351E-03
MC45 CS25_8.1	6.78	0.35		6.975	0.21	2.4430	1.7641	1.3848	1.2033E-03
MC45 91500 g2.10				10.419	0.19	2.5521	1.8300	1.3946	1.1757E-03
MC45 91500 g3.8				10.280	0.28	2.5759	1.8338	1.4047	1.1631E-03
MC45 91500 g4.9				10.033	0.19	2.5759	1.8345	1.4041	1.1639E-03
MC45 91500 g4.10				9.961	0.24	2.5645	1.8351	1.3975	1.1984E-03
MC45 91500 g5.9				10.201	0.22	2.5853	1.8325	1.4108	1.1468E-03
average and 2SD				10.179	0.37				
bracket average and 2SD	10.07		0.19713	10.269	0.35				

APPENDIX G: Hf Isotope Data

	$^{176}\text{Lu}/^{177}\text{Hf}$	2 SE	$^{176}\text{Yb}/^{177}\text{Hf}$	2 SE	$^{176}\text{Hf}/^{177}\text{Hf}$	2 SE	$^{178}\text{Hf}/^{177}\text{Hf}$	2 SE	$^{180}\text{Hf}/^{177}\text{Hf}$	2 SE	ϵHf	$\pm 2 \text{ S.D.}$
11SN34_1	0.00209054	0.00014	0.06619485	0.0040	0.282791	0.000039	1.466567	0.00046	1.8864807	0.00014	2.2	1.4
11SN34_2	0.00235868	0.00013	0.07090462	0.0059	0.282749	0.000049	1.466506	0.00043	1.8865361	0.00017	0.7	1.7
11SN34_3	0.00104525	0.00008	0.03484118	0.0031	0.282737	0.000031	1.466679	0.00046	1.8866489	0.00011	0.3	1.1
11SN34_4	0.00094388	0.00002	0.02877181	0.0003	0.282765	0.000037	1.466664	0.00043	1.8863605	0.00015	1.3	1.3
11SN34_5	0.00129433	0.00007	0.04232991	0.0027	0.282761	0.000035	1.466680	0.00040	1.8867724	0.00012	1.2	1.2
11SN34_6	0.00091806	0.00008	0.03028810	0.0028	0.282743	0.000042	1.466802	0.00053	1.8865915	0.00014	0.6	1.5
11SN34_7	0.00119012	0.00010	0.03360653	0.0015	0.282694	0.000030	1.467449	0.00059	1.8866625	0.00012	-1.2	1.1
11SN34_8	0.00145805	0.00007	0.04738186	0.0029	0.282762	0.000037	1.466869	0.00045	1.8866256	0.00012	1.2	1.3
11SN34_9	0.00176210	0.00016	0.05770327	0.0062	0.282785	0.000044	1.466872	0.00058	1.8866296	0.00014	2.0	1.6
11SN36_1	0.00101038	0.00006	0.03501574	0.0025	0.282613	0.000032	1.466955	0.00042	1.8866259	0.00008	-4.0	1.1
11SN36_2	Signal too low											
11SN36_3	0.00155962	0.00026	0.05112317	0.0103	0.282660	0.000039	1.467177	0.00067	1.8866234	0.00009	-2.4	1.4
11SN36_4	0.00105356	0.00006	0.03104408	0.0010	0.282686	0.000031	1.466927	0.00042	1.8866667	0.00008	-1.4	1.1
11SN36_5	0.00077660	0.00007	0.02449917	0.0020	0.282617	0.000029	1.466964	0.00045	1.8866056	0.00009	-3.9	1.0
11SN36_6	0.00056485	0.00005	0.01836948	0.0020	0.282536	0.000031	1.466986	0.00039	1.8866101	0.00008	-6.7	1.1
11SN36_7	0.00085110	0.00011	0.02714719	0.0036	0.282683	0.000024	1.466632	0.00046	1.8867378	0.00011	-1.6	0.9
11SN36_8	0.00063642	0.00005	0.01980438	0.0019	0.282637	0.000023	1.466914	0.00031	1.8866267	0.00008	-3.2	0.8
11SN36_9	0.00051902	0.00002	0.01530229	0.0006	0.282662	0.000026	1.466800	0.00039	1.8866367	0.00010	-2.3	0.9
11SN36_10	0.00048207	0.00002	0.01358899	0.0008	0.282682	0.000022	1.466965	0.00041	1.8867172	0.00007	-1.5	0.8
11SN37_1	0.00057706	0.00002	0.01634530	0.0008	0.282639	0.000029	1.466721	0.00040	1.8866689	0.00010	-3.1	1.0
11SN37_2	0.00071518	0.00002	0.02065061	0.0007	0.282654	0.000031	1.466884	0.00049	1.8866878	0.00010	-2.6	1.1
11SN37_3	0.00073965	0.00004	0.02014443	0.0005	0.282694	0.000032	1.466527	0.00042	1.8866530	0.00009	-1.1	1.1
11SN37_4	0.00094012	0.00003	0.02874178	0.0005	0.282675	0.000036	1.466856	0.00045	1.8867326	0.00009	-1.8	1.3
11SN37_5	0.00087085	0.00004	0.02685200	0.0019	0.282671	0.000028	1.466317	0.00051	1.8866551	0.00011	-2.0	1.0
11SN37_6	0.00046376	0.00004	0.01235644	0.0008	0.282639	0.000023	1.466769	0.00044	1.8866983	0.00007	-3.1	0.8
11SN37_7	0.00061654	0.00004	0.01738659	0.0011	0.282672	0.000025	1.466643	0.00039	1.8866706	0.00009	-1.9	0.9
11SN38_1	0.00098689	0.00004	0.03129659	0.0020	0.282596	0.000027	1.466732	0.00055	1.8866082	0.00011	-4.6	1.0
11SN38_2	0.00100295	0.00008	0.03206429	0.0030	0.282482	0.000032	1.466915	0.00039	1.8866244	0.00011	-8.7	1.1

	$^{176}\text{Lu}/^{177}\text{Hf}$	2 SE	$^{176}\text{Yb}/^{177}\text{Hf}$	2 SE	$^{176}\text{Hf}/^{177}\text{Hf}$	2 SE	$^{178}\text{Hf}/^{177}\text{Hf}$	2 SE	$^{180}\text{Hf}/^{177}\text{Hf}$	2 SE	ϵ_{Hf}	$\pm 2 \text{ S.D.}$
11SN38_3	0.00058350	0.00001	0.01816974	0.0008	0.282685	0.000032	1.466677	0.00043	1.8866449	0.00011	-1.5	1.1
11SN38_4	0.00061984	0.00008	0.01780851	0.0023	0.282672	0.000036	1.466979	0.00064	1.8867211	0.00010	-1.9	1.3
11SN38_5	0.00106513	0.00012	0.03610033	0.0053	0.282617	0.000041	1.467025	0.00048	1.8866649	0.00012	-3.9	1.5
11SN38_6	0.00130712	0.00008	0.04404528	0.0027	0.282684	0.000034	1.466727	0.00063	1.8866785	0.00008	-1.5	1.2
11SN38_7	0.00050607	0.00000	0.01533556	0.0004	0.282636	0.000032	1.466888	0.00050	1.8867310	0.00011	-3.2	1.1
11SN38_8	0.00131495	0.00018	0.04072089	0.0064	0.282670	0.000039	1.466794	0.00051	1.8866483	0.00010	-2.1	1.4
11SN40_1	0.00072438	0.00005	0.02900454	0.0016	0.282632	0.000025	1.466990	0.00057	1.8866720	0.00012	-3.4	0.9
11SN40_2	0.00084780	0.00002	0.03540700	0.0011	0.282589	0.000035	1.467145	0.00044	1.8866539	0.00015	-4.9	1.2
11SN40_3	0.00128059	0.00015	0.05670152	0.0082	0.282636	0.000038	1.466429	0.00090	1.8865505	0.00019	-3.2	1.3
11SN40_4	0.00114325	0.00004	0.04797225	0.0025	0.282569	0.000034	1.466807	0.00095	1.8866193	0.00019	-5.6	1.2
11SN40_5	0.00123476	0.00009	0.05332453	0.0033	0.282650	0.000044	1.466989	0.00062	1.8866028	0.00017	-2.7	1.6
11SN40_6	0.00072540	0.00002	0.02883700	0.0007	0.282514	0.000033	1.466803	0.00070	1.8865435	0.00018	-7.5	1.2
11SN40_7*	0.00349019	0.00013	0.14810154	0.0083	0.282585	0.000038	1.466905	0.00064	1.8868284	0.00015	-5.2	1.3
11SN40_8	0.00061332	0.00001	0.02573489	0.0010	0.282490	0.000030	1.466833	0.00075	1.8866247	0.00017	-8.4	1.1
11SN40_9	0.00057164	0.00004	0.02413598	0.0008	0.282522	0.000026	1.466946	0.00062	1.8866772	0.00014	-7.2	0.9
11SN40_10	0.00071716	0.00004	0.02767787	0.0011	0.282533	0.000031	1.466789	0.00043	1.8866557	0.00009	-6.8	1.1
11SN41_1	0.00068167	0.00008	0.03463110	0.0040	0.282521	0.000032	1.466652	0.00059	1.8866106	0.00014	-7.3	1.1
11SN41_2	0.00061023	0.00003	0.02836695	0.0020	0.282609	0.000029	1.466933	0.00043	1.8867267	0.00013	-4.2	1.0
11SN41_3	0.00115724	0.00014	0.06446100	0.0070	0.282670	0.000053	1.466911	0.00062	1.8866830	0.00019	-2.0	1.9
11SN41_4	0.00081866	0.00004	0.04503055	0.0018	0.282501	0.000034	1.466902	0.00055	1.8866311	0.00017	-8.0	1.2
11SN41_5	0.00086514	0.00005	0.04317502	0.0019	0.282601	0.000021	1.466929	0.00043	1.8867183	0.00013	-4.5	0.7
11SN41_6	0.00054994	0.00001	0.02804554	0.0004	0.282600	0.000027	1.466962	0.00050	1.8867914	0.00012	-4.5	1.0
11SN41_7	0.00137556	0.00003	0.06913091	0.0025	0.282595	0.000028	1.467120	0.00041	1.8868143	0.00011	-4.7	1.0
11SN41_8	0.00137138	0.00003	0.06885116	0.0025	0.282601	0.000030	1.467100	0.00040	1.8868010	0.00011	-4.5	1.1
CS01_1*	0.00214023	0.00019	0.11841764	0.0106	0.282747	0.000027	1.466895	0.00065	1.8866070	0.00015	0.6	0.9
CS01_2*	0.00213178	0.00008	0.11560884	0.0037	0.282755	0.000044	1.466999	0.00070	1.8866991	0.00019	0.9	1.6
CS01_3	0.00174095	0.00007	0.08203896	0.0058	0.282777	0.000044	1.466501	0.00066	1.8866836	0.00017	1.7	1.6
CS01_4	0.00146322	0.00006	0.07633048	0.0051	0.282781	0.000026	1.466665	0.00058	1.8867039	0.00013	1.9	0.9
CS01_5*	0.00282409	0.00048	0.12529583	0.0139	0.282541	0.000086	1.465739	0.00098	1.8865286	0.00022	-6.7	3.0
CS01_6	0.00142326	0.00009	0.07250614	0.0034	0.282654	0.000032	1.466851	0.00055	1.8865927	0.00014	-2.6	1.1
CS01_7*	0.00203452	0.00005	0.11541118	0.0038	0.282722	0.000037	1.467623	0.00231	1.8870029	0.00038	-0.2	1.3

	$^{176}\text{Lu}/^{177}\text{Hf}$	2 SE	$^{176}\text{Yb}/^{177}\text{Hf}$	2 SE	$^{176}\text{Hf}/^{177}\text{Hf}$	2 SE	$^{178}\text{Hf}/^{177}\text{Hf}$	2 SE	$^{180}\text{Hf}/^{177}\text{Hf}$	2 SE	ϵHf	$\pm 2 \text{ S.D.}$
CS03_1	0.00096897	0.00010	0.05464807	0.0086	0.282619	0.000059	1.467198	0.00118	1.8868504	0.00030	-3.8	2.1
CS03_2	0.00097640	0.00003	0.05072849	0.0011	0.282562	0.000044	1.467116	0.00076	1.8869583	0.00021	-5.8	1.6
CS03_3	0.00059109	0.00001	0.02965206	0.0009	0.282686	0.000032	1.466822	0.00041	1.8867834	0.00012	-1.4	1.1
CS03_4	0.00093239	0.00005	0.05138531	0.0025	0.282667	0.000044	1.466974	0.00055	1.8867619	0.00014	-2.1	1.5
CS03_5	0.00076667	0.00004	0.04025235	0.0035	0.282609	0.000039	1.466990	0.00085	1.8867066	0.00019	-4.2	1.4
CS03_6	0.00059251	0.00005	0.03051345	0.0033	0.282760	0.000039	1.466456	0.00099	1.8867198	0.00022	1.2	1.4
CS03_7	0.00096855	0.00011	0.05276175	0.0058	0.282581	0.000036	1.466741	0.00048	1.8867340	0.00016	-5.2	1.3
CS03_8	0.00075148	0.00002	0.03614928	0.0023	0.282564	0.000028	1.466965	0.00064	1.8867347	0.00014	-5.8	1.0
CS03_9	0.00101116	0.00014	0.05561938	0.0103	0.282705	0.000041	1.466288	0.00075	1.8863941	0.00021	-0.8	1.5
CS07_1	0.00178977	0.00006	0.06306065	0.0027	0.282536	0.000035	1.467074	0.00049	1.8865393	0.00013	-6.8	1.2
CS07_2	0.00097985	0.00001	0.03213915	0.0011	0.282710	0.000030	1.466949	0.00045	1.8865901	0.00009	-0.6	1.0
CS07_3	0.00096926	0.00003	0.03243939	0.0004	0.282682	0.000039	1.466817	0.00050	1.8865897	0.00014	-1.6	1.4
CS07_4	0.00077705	0.00001	0.02636454	0.0008	0.282700	0.000027	1.466890	0.00036	1.8866309	0.00010	-1.0	0.9
CS07_5	0.00051719	0.00002	0.01850386	0.0011	0.282572	0.000027	1.466893	0.00048	1.8864709	0.00010	-5.5	1.0
CS07_6	0.00034658	0.00001	0.01161454	0.0005	0.282581	0.000025	1.466739	0.00050	1.8864760	0.00013	-5.1	0.9
CS07_7	0.00121954	0.00023	0.04205869	0.0080	0.282752	0.000031	1.466653	0.00056	1.8865430	0.00013	0.9	1.1
CS07_8	0.00098132	0.00001	0.03454277	0.0011	0.282724	0.000028	1.466907	0.00044	1.8865896	0.00010	-0.1	1.0
CS10_1	0.00079118	0.00003	0.03689723	0.0020	0.282699	0.000049	1.466745	0.00074	1.8865795	0.00013	-1.0	1.7
CS10_2	0.00042503	0.00001	0.02012635	0.0004	0.282688	0.000037	1.466752	0.00071	1.8867584	0.00017	-1.3	1.3
CS10_3	0.00072884	0.00004	0.03263044	0.0020	0.282686	0.000034	1.466927	0.00051	1.8866208	0.00014	-1.4	1.2
CS10_4	0.00070070	0.00005	0.03076914	0.0014	0.282614	0.000039	1.467226	0.00064	1.8868566	0.00014	-4.0	1.4
CS10_5	0.00049570	0.00004	0.02559826	0.0017	0.282617	0.000044	1.466599	0.00074	1.8866180	0.00012	-3.8	1.6
CS10_6	0.00072806	0.00002	0.03702864	0.0017	0.282670	0.000048	1.466918	0.00065	1.8867846	0.00012	-2.0	1.7
CS10_7	0.00050587	0.00002	0.02421964	0.0009	0.282686	0.000038	1.466871	0.00058	1.8866480	0.00015	-1.4	1.4
CS10_8	0.00062824	0.00002	0.02767219	0.0014	0.282655	0.000040	1.467240	0.00053	1.8867411	0.00012	-2.5	1.4
CS10_9	0.00085777	0.00009	0.03632042	0.0023	0.282651	0.000046	1.466134	0.00068	1.8865322	0.00019	-2.7	1.6
CS10_10	0.00078440	0.00005	0.03453287	0.0018	0.282603	0.000043	1.466605	0.00057	1.8867483	0.00015	-4.4	1.5
CS13_1	0.00076284	0.00005	0.03580041	0.0016	0.282643	0.000031	1.466985	0.00060	1.8867321	0.00013	-3.0	1.1
CS13_2	0.00105495	0.00018	0.05646955	0.0095	0.282580	0.000044	1.467084	0.00049	1.8867955	0.00014	-5.2	1.6
CS13_3	0.00079296	0.00002	0.03990526	0.0008	0.282518	0.000027	1.467095	0.00039	1.8867930	0.00012	-7.4	1.0
CS13_4	0.00080337	0.00006	0.04109339	0.0048	0.282564	0.000037	1.466403	0.00055	1.8864855	0.00014	-5.8	1.3

	$^{176}\text{Lu}/^{177}\text{Hf}$	2 SE	$^{176}\text{Yb}/^{177}\text{Hf}$	2 SE	$^{176}\text{Hf}/^{177}\text{Hf}$	2 SE	$^{178}\text{Hf}/^{177}\text{Hf}$	2 SE	$^{180}\text{Hf}/^{177}\text{Hf}$	2 SE	ϵHf	$\pm 2 \text{ S.D.}$
CS13_5	0.00063200	0.00005	0.03213649	0.0017	0.282497	0.000039	1.466823	0.00047	1.8865685	0.00014	-8.1	1.4
CS13_6	0.00108422	0.00015	0.06143983	0.0096	0.282851	0.000046	1.467115	0.00065	1.8866441	0.00015	4.4	1.6
CS13_7	0.00174686	0.00011	0.09496655	0.0059	0.282813	0.000050	1.467086	0.00048	1.8867504	0.00013	3.0	1.8
CS13_8	0.00090273	0.00007	0.05012273	0.0065	0.282665	0.000032	1.467007	0.00048	1.8866587	0.00014	-2.2	1.1
CS13_9	0.00078210	0.00001	0.04055734	0.0008	0.282711	0.000032	1.466995	0.00044	1.8866923	0.00013	-0.6	1.1
CS19_1*	0.00350874	0.00031	0.16758988	0.0175	0.282819	0.000044	1.467096	0.00041	1.8869147	0.00018	3.1	1.6
CS19_2	0.00176716	0.00035	0.08040453	0.0151	0.282829	0.000051	1.467068	0.00042	1.8868904	0.00015	3.6	1.8
CS19_3	Signal too low											
CS19_4	0.00089056	0.00007	0.04592467	0.0056	0.282788	0.000061	1.466410	0.00078	1.8864496	0.00019	2.2	2.1
CS19_5	0.00083918	0.00008	0.03845303	0.0039	0.282829	0.000069	1.466090	0.00086	1.8867424	0.00014	3.6	2.5
CS19_6*	0.00262568	0.00036	0.12685881	0.0099	0.282930	0.000074	1.465873	0.00077	1.8865257	0.00020	7.1	2.6
CS19_7	0.00155409	0.00019	0.06781250	0.0076	0.282865	0.000053	1.465885	0.00072	1.8865482	0.00021	4.9	1.9
CS19_8	0.00078413	0.00008	0.03679749	0.0047	0.282967	0.000073	1.465533	0.00132	1.8863884	0.00027	8.5	2.6
CS19_9	0.00120137	0.00014	0.05572465	0.0062	0.282827	0.000067	1.465590	0.00096	1.8862665	0.00027	3.5	2.4
CS19_10	0.00589984	0.00070	0.30442071	0.0377	0.282895	0.000075	1.466978	0.00046	1.8866825	0.00017	5.6	2.7
CS25_1	0.00078535	0.00002	0.04041696	0.0011	0.282795	0.000029	1.466847	0.00080	1.8866205	0.00020	2.4	1.0
CS25_2	0.00123916	0.00007	0.06765347	0.0054	0.282682	0.000041	1.466891	0.00044	1.8867313	0.00014	-1.6	1.4
CS25_3	0.00093830	0.00005	0.05123919	0.0041	0.282544	0.000029	1.467081	0.00043	1.8867462	0.00011	-6.5	1.0
CS25_4	0.00083706	0.00004	0.04481190	0.0028	0.282673	0.000030	1.466665	0.00041	1.8867013	0.00014	-1.9	1.1
CS25_5	0.00070641	0.00003	0.03103071	0.0008	0.282667	0.000036	1.466694	0.00055	1.8864709	0.00018	-2.1	1.3
CS25_6	0.00105738	0.00008	0.05909455	0.0049	0.282733	0.000039	1.466862	0.00053	1.8866863	0.00013	0.2	1.4
CS25_7	0.00105277	0.00012	0.05592242	0.0059	0.282680	0.000039	1.466982	0.00052	1.8867014	0.00017	-1.7	1.4
CS25_8	0.00105581	0.00004	0.05480857	0.0014	0.282596	0.000032	1.466752	0.00044	1.8866141	0.00013	-4.6	1.1
CS25_9	0.00061966	0.00001	0.03046001	0.0009	0.282708	0.000026	1.466820	0.00052	1.8867270	0.00013	-0.7	0.9

* $^{176}\text{Yb}/^{177}\text{Hf} > 0.1$, analysis not included in results

APPENDIX H: Mixing Model Parameters

Mantle Melt Fraction	DM*-Ptz ⁺ I		DM*-Ptz ⁺ II		DM*-Pln**		EM [#] -Ptz ⁺		EM [#] -Pln**	
	εHf	δ ¹⁸ O	εHf	δ ¹⁸ O	εHf	δ ¹⁸ O	εHf	δ ¹⁸ O	εHf	δ ¹⁸ O
0	-22.0	11.5	-30.0	11.5	10.0	11.5	10.0	11.5	-30.0	8.5
0.2	-16.9	10.3	-26.7	10.3	10.6	10.3	8.9	10.3	-23.7	7.9
0.4	-10.9	9.0	-22.5	9.0	11.2	9.0	7.5	9.0	-16.5	7.2
0.6	-4.0	7.8	-17.1	7.8	12.0	7.8	5.7	7.8	-8.0	6.6
0.8	4.2	6.5	-10.0	6.5	12.9	6.5	3.3	6.5	2.0	5.9
1	14.0	5.3	0.0	5.3	14.0	5.3	0.0	5.3	14.0	5.3

* Depleted Mantle was calculated with the following parameters: δ¹⁸O = 5.3‰ (Valley et al., 2003), εHf = +14 (Lackey et al., 2012; Nelson et al., 2013), Hf = 4 ppm (Beard & Johnson, 1997)

Enriched Mantle was calculated with the following parameters: δ¹⁸O = 5.3‰ (Valley et al., 2003), εHf = 0.0 (Beard & Johnson, 1997), Hf = 3 ppm (Beard & Johnson, 1997; Omerod et al., 1991).

⁺ Proterozoic Crust was calculated using the following parameters: δ¹⁸O = 8.5 to 11.5‰ (Lackey et al., 2012), εHf = -22 to -30 (Goodge & Vervoort, 2006; Lackey et al., 2012), Hf = 6 ppm (Taylor & McLennan, 1995).

** Panthalassan crust was calculated using the following parameters: δ¹⁸O = 10 to 12‰ (Lackey et al., 2012), εHf = +9 to +12 (Lackey et al., 2012), Hf = 6 ppm (Taylor & McLennan, 1995).