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Characterization of Mantle/Crust Interactions Using Pb Isotope Analyses of Lavas in the Southern Rio Grande Rift, New Mexico

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NEW MEXICO

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by

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Abstract

The Pb isotope composition of volcanic rocks in the Rio Grande Rift (RGR) can be used to investigate the interaction of mantle melts with continental lithosphere, and has important implications for the composition of the lithosphere. We suggest some compositional signatures may pre-date current tectonic processes. Existing data from several volcanic fields in New Mexico show a converging pattern on a very limited Pb isotope range, corresponding to lower crustal xenolith compositions from Kilbourne Hole. The different volcanic fields show Pb isotope trends diverging from this lower crustal composition, likely depicting mixing with different upper crustal reservoirs. These very common, widespread lower crustal composition that overwhelmed the mantle isotopic signature, subsequently contaminated by variable upper crust. The geographically wide-spread lower crustal, low radiogenic Pb compositions are best explained with time-integrated low U/Pb ratios that imply a Proterozoic, large-scale event.

In this study, we focus on the Pb isotope compositions of the Potrillo, Elephant Butte, Palomas, and the Hillsboro volcanic fields in the southern RGR in New Mexico to test our crust-mantle mixing hypothesis. The studied volcanic fields represent a range in erupted volumes and are spread out over a significant area, therefore likely representing a range in extent of mixing, as well as variation in upper crustal compositions. The data obtained in this study is in agreement with all fields containing a similar lower crustal component that mixed with upper crustal compositions, the extent of which correlates with the erupted volumes. Observations suggest initial mixing of mantle melt with a lower crustal compostition. We also present results for the analysis of a set of USGS rock standards and show the measured compositions are in good agreement with high precision double-spike Pb analyses from the current literature.

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I. Introduction

Widespread volcanism in the Southwest United States and more specifically the Rio Grande Rift (RGR) has long been thought to be related to shallow subduction and foundering of the Farallon Plate, which has affected a wide region of the continental margin (Lipman et al., 1971; Coney and Reynolds, 1977; Elston 1984). During the mid Tertiary, a stage of extension in the RGR resulted in mafic volcanism (Lawton and McMillan, 1999). The many stages of volcanism seen in the RGR exemplify the uniqueness of this wide margin and display the effects of large variations in subduction parameters, such as slab angle and plate age. More importantly, the volcanic fields provide insight into the crust and mantle that generated or were intruded by the melt, and allow for characterization of various geochemical reservoirs. The role of the asthenosphere and the lithospheric mantle, and the upper and lower crust in generating the observed signatures remains under debate (Dungan et., al. 1986).

II. Geologic Background

1. Regional Background

Volcanic history of the southwest United States can be linked to a series of tectonic events since the Jurassic. During the early-mid Jurassic Laramide orogeny, andesitic to dacitic magmatism affected an unusually wide region due to the flat Farallon slab subduction under >1Ga basement (Coney and Reynold, 1977, Dickinson and Snyder, 1978; Busby-Spera, 1988; Mosher, 1998; Lawton and McMillan, 1999). In the mid Tertiary, extensional volcanism due to Farallon slab foundering occurred in two passive rifts resulting in bimodal volcanism in the RGR.

The RGR lies in the southwest United States and runs from the southeastern portion of Colorado into the northern portion of Chihuahua, MX. It was formed as a failed rift extensional margin originating in northern Chihuahua, MX near El Paso, TX. It stretches over 800 km from north to south, and is about 50-80 km wide. The RGR was developed during two stages of rifting. The first stage (mid Tertiary) accounts for 30% to 50% of the overall extension that the rift accommodates. The second phase of rifting occurred around 10 Ma and continues today where the total extension is not constant along the rift (Keller et al. 1990). To the Southwest this change in extension represents a transition to Basin and Range (Roy et al., 2005). This southwest region is an area of greater Cenozoic extension. Based on seismic data, it has been shown that most of the extension is accommodated in the lower crust, which has been extended four times more than the upper crust

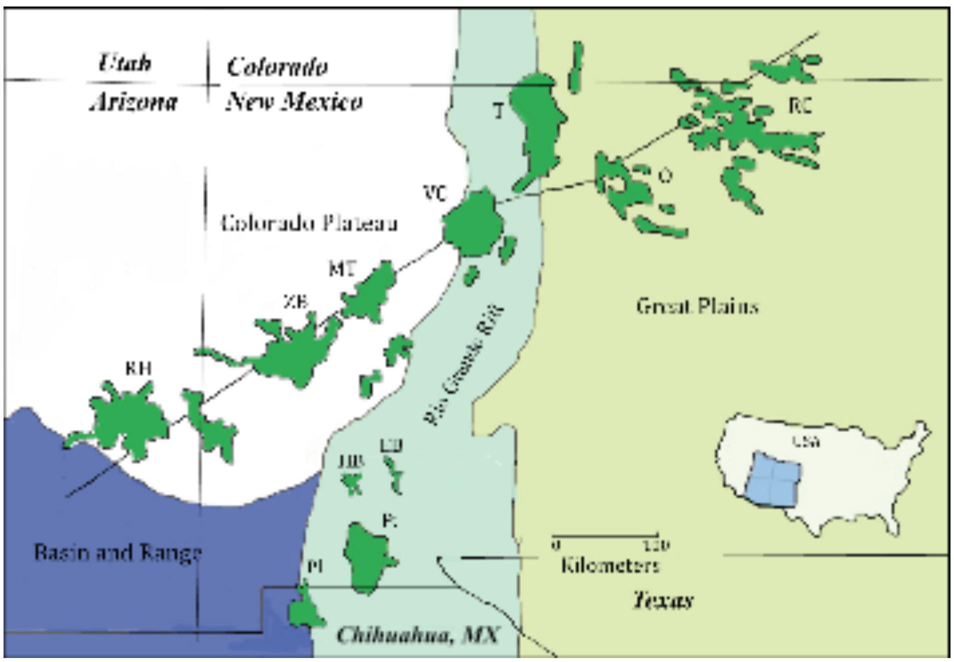

Figure 1: Regional map of the Rio Grande Rift, Basin and Range, and Great Plains. The major volcanic fields in New Mexico are shaded in green and are indicated by initials. RH=Red Hill, ZB=Zuni Bandera, MT=Mt Taylor, VC=Valles Caldera, T=Taos, O=Ocate, RC=Raton Clayton, HB= Hillsboro, EB= Elephant Butte, Pt= Potrillo, and Pl= Palomas volcanic fields.

(Wilson et al., 2005). The extension in the RGR led to high heat flow, crustal doming, and a thinning of the crust, which all contributed to volcanic activity.

2. Volcanic Fields

The Rio Grande rift volcanic fields are located in an area characterized by a linear series of faulted sedimentary basins. In the southern portion of the RGR, the rift represents the eastern boundary of the Basin and Range Province (Figure 1; Baldridge, 2004). Most of the volcanism in the rift is located along a northeast trending zone that is referred to as the Jemez lineament. This zone is described as a linear crustal feature in the southwest that could represent a suture zone from the Proterozoic accretion in North America (Magnani et al., 2005). This zone lies perpendicular to the greatest areas of extension in the rift zone. It is also characterized as having unusually hot mantle underneath it, which was brought up in response to extension, leading to melting and volcanism (Gao, 2004). Studies have shown that below 35 km in depth beneath the rift the geotherm is non-conductive and appears to be controlled by convection of mantle material beneath the lower crust. This convection seems to be occurring at depths between 50 km to 70 km up into the lower crust (Keller et al. 1990, Thompson, 2005). The greatest volume of melt has erupted both in the Jemez lineament as well as outside the area, forming volcanic fields across the rift and the state of New Mexico. Below follows a brief description of the New Mexican volcanic fields of interest to this study.

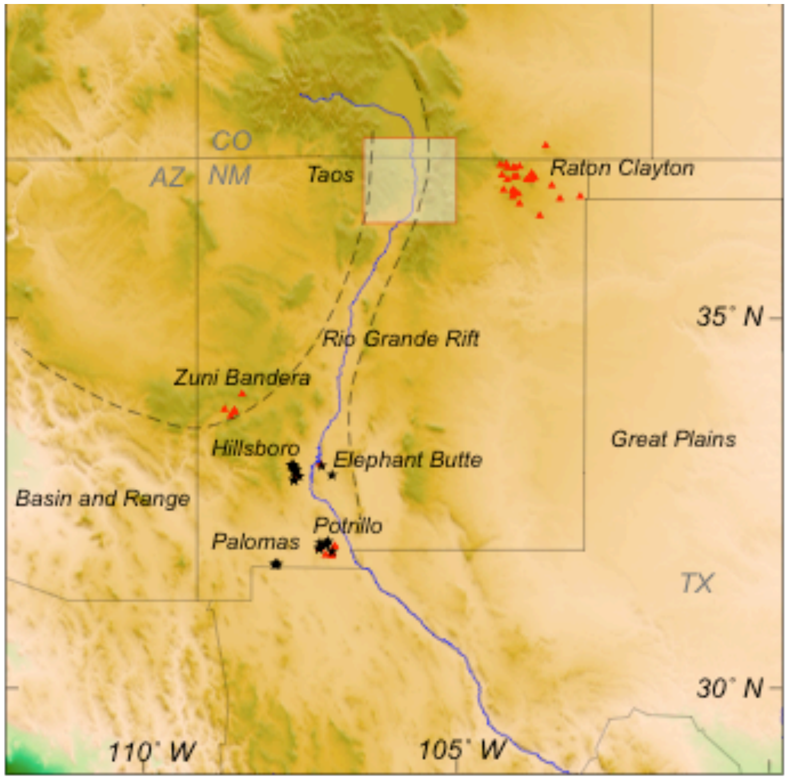

Figure 2: Figure showing the volcanic fields in New Mexico and the locations from where Pb data was collected. The Taos volcanic field is represented as an area. Data collected for this study is shown in black and all other previously collected data is shown in red. (NAVDAT; Everson, 1979; Williams, 1999)

Taos Volcanic Field

The Taos volcanic field is located near the northern border of New Mexico, and it is the largest volcanic field in the RGR covering an area of 7000 km^2 (Baldridge, 2004). The Taos field has been K-Ar dated to be between 2.5-4.0 Ma (Lipman, P.W. and Mehnert, H.H., 1978) and has a larger range in composition than the Potrillo volcanic field. It contains centrally located basalts, with andesitic volcanoes surrounding the basalts, and dacitic domes on the outskirts of the field (Baldridge, 2004). The time-evolution of the field indicates that the eruption of the andesite and the dacite occurred after the eruption of the basalt. It has been proposed that the mafic melts in the Taos field were contaminated by lower and upper crustal rocks in an assimilation- fractionation crystallization process. There was probably a long period

of upper mantle melting, which supplied the heat necessary for crustal assimilation, resulting in the hybrid compositions of the volcanic rocks. (McMillan and Dungan, 1988, Baldridge, 2004).

Raton-Clayton Volcanic Field

The Raton Volcanic Field lies in the northeastern corner of New Mexico, just east of the Taos volcanic field. Volcanism in the Raton-Clayton field began about 7.5 Ma with the eruption of alkali basalts and intermittently continued until about 10 ka (Phelps et al. 1983). Rock types in the Raton-Clayton field are similar to the surrounding fields in that it is composed of a variety of andesitic and dacitic compositions. Interestingly, late in the volcanic field history, a group of mafic rocks (basanite to olivine nephelinite) were generated (Baldridge, 2004). These rocks are silica undersaturated, and contain phenocrysts of olivine, clinopyronxene, and by feldspathoids in their groundmass (Bultitude and Green, 1967; Brey and Green, 1975). These are the most alkaline and undersaturated of any of the RGR volcanic fields which indicate that they were probably formed under higher pressures than the more common alkali olivine basalts (Phelps et., al., 1983; Baldridge, 2004). Therefore, melt generation may have taken place at a variety of depths in the volcanic field, with potential of sampling different source compositions.

Elephant Butte Volcanic Field

The Elephant Butte Volcanic Field is located in central New Mexico and consists of numerous basalt flows, cinder cones, spatter cones, and maars. It is approximately 350 km^2 and is located on a transfer fault zone (Baldridge, 2004). K-Ar whole-rock age determinations on the lavas were performed by Bachman and Mehnert (1978) and yielded ages of 2.9-2.1 Ma. The Elephant Butte Volcanic field, together with the Potrillo volcanic field (Kilbourne Hole) is well

known for the occurrence of xenoliths. These xenoliths represent samples brought to the surface by the recent melts, and therefore represent unique samples from the upper mantle and crust that provide information of conditions within the Earth. For example, lherzolite, clinopyroxenite, and granulite samples were used to determine the thermal structure of the crust underlying the Elephant Butte volcanic field and they show exceptionally high temperatures near 1000ºC at 50 km in depth (Warren et al. 1979). This suggested that the geothermal gradient of the crust must be elevated from thermal pulses of shallow intrusions (Baldridge, 1979b; 2004), and/or thin crust with shallow upper mantle (Gao et., al., 2004).

Hillsboro volcanic field

The Hillsboro volcanic field is probably the least studied field in the RGR. It consists of 20 isolated mafic flow fields and vents scattered over an area of 1000 km^2 (Anthony et al., 1992) Baldridge, 2004). It has been dated by with whole rock K-Ar dating by Seager et al. (1984), yielding 4.8, 4.5, and 4.2 Ma. During sampling for this study, crustal xenoliths were observed in some of the lava flows.

Potrillo Volcanic field

The Potrillo volcanic field that lies just west of El Paso, is different in composition from the northern fields in that it is dominantly silica undersaturated basanite (Anthony et., al., 1992; Williams, 1999; Thompson, 2005). The ages of the youngest volcanic products in the Potrillo volcanic field range from 80-17 ka based on ^3He surface exposure dating (Anthony and Poths, 1992). It is associated with the second stage of rifting in the Rio Grande rift. Anthony et al. (1992) shows that in the last 5 Ma, mafic volcanism has surfaced in two compositional groups in the Potrillo volcanic field. Patterns between geochemistry, age, and location are difficult to

discern between these two groups. The two different groups vary predominantly in alkalinity. Morphologically, the field consists mainly of cinder cones in the west, a shield volcano and related flows in the east, and a number of maar-type volcanoes, including the well-known Kilbourne Hole. Kilbourne Hole is the source of a range of xenoliths from both upper mantle and crust. These xenoliths yield important information about potential mantle source compositions, since their presence indicates limited residence (and thus interaction) during magma ascent. Residence times have to be limited, since prolonged residence of high-density xenoliths in lower density melts would result in the xenoliths settling out of the melt. Combined with the range in sizes of the volcanic fields, a range of crustal contributions to the melt can be sampled, allowing for the characterization of mantle (melts) and crust.

Palomas Volcanic Field

The Palomas volcanic field lies in southwestern New Mexico and northern Chihuahua and consists of more than 30 cinder cones. The majority of the field lies in northern Chihuahua. Many N-S trending dikes occur in the field with a number of volcanoes originating at their originations (Aranda-Gomez et al, 2007). It consists mostly of alkaline olivine basalts that erupted both subaerially and subaqueously with some pillow basalts found in northern Chihuahua. These pillow basalts likely originated from extrusion in Lake Palomas, the largest of several pluvial lakes that formed in the RGR as termination of river systems that head in the Sierra Madre Occidental, as well New Mexico. The ancestral upper Rio Grande River drained into Lake Palomas in Pliocene to early Pleistocene times (Hawley, 1993). Many of the basalts contain xenocrysts of feldspar, quartz, and orthopyroxene. More evolved compositions including trachytes exist in the field, and combined with the xenocrysts, suggest that crustal contamination is significant in this field. The basaltic rocks in the Palomas field are inferred to post-date the

more evolved rock types. K-Ar whole-rock dating for the basaltic rocks dates this field from 3.0-5.1 Ma which is older than the fields that lie directly within the RGR (Hawley, 1981: Seager et al, 1984).

3. Volcanic Fields and Crust-Mantle Interaction

The interaction of crust and mantle is studied here using Pb isotope compositions from the volcanic fields described above. The Taos and Raton-Clayton volcanic fields have been studied in detail (Zhu, 1995; Johnson et., al., 1996), and we compare published data from these fields with new data for the Hillsboro, Elephant Butte, Potrillo and Palomas fields.

III. Methods

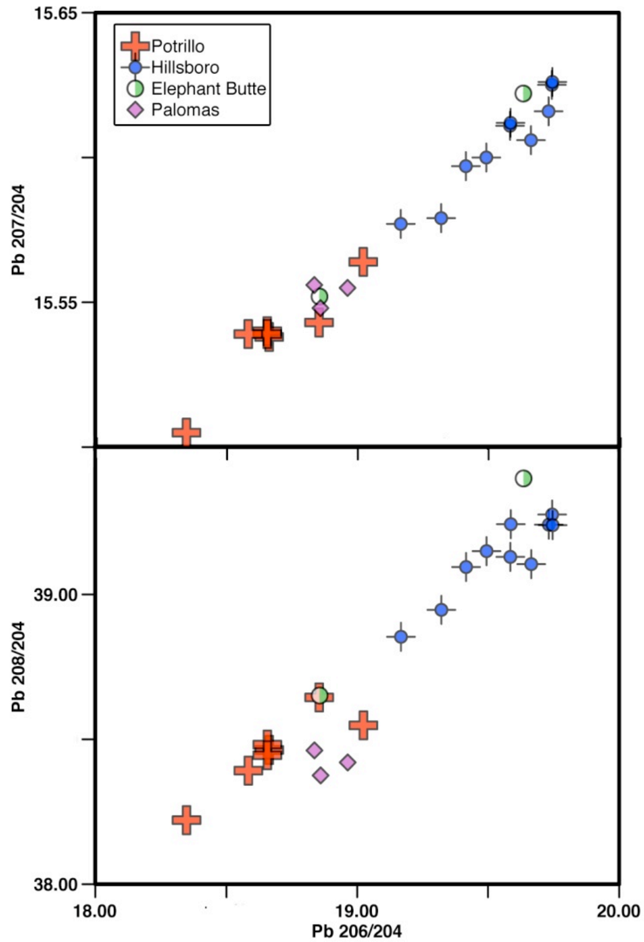

Figure 3: Pb data from the studied fields

The samples in this study were analyzed for Pb isotope compositions and include samples from Hillsboro, Elephant Butte, Potrillo and Palomas volcanic fields (Table 1), to which published data from the NAVDAT database has been added. Some samples were duplicates of previously analyzed basalts from the Potrillo and Elephant Butte fields. In addition, seven USGS rock standards were analyzed to assess accuracy of the Pb isotope technique. Results of the rock standard analyses and comparison to previous data can be found in Appendix A, together with a more detailed description of the analytical methods. Briefly, Pb was separated after dissolving samples in $HF-HNO_3$ mixtures. The Pb separation was performed with standard HBr-HCl column chemistry (Hanan and Schilling, 1989). After the Pb separation from the lavas, the isotopic signatures were measured using a Nu Plasma MC-ICP-MS in the department of Geological Sciences at the University of Texas at El Paso. The Pb isotopic analyses were carried out by Tl doping (SRM 997 Tl and 205Tl/203Tl=2.3889), using bracketing SRM 981 to correct for instrumental mass-based fractionation (White et al., 2000; Hanan et al., 2004, 2008). Bracketing SRM 981 values were adjusted to accepted values (Todt

et al., 1996). The standard SRM 981 averaged 206Pb/204Pb=16.934±4, 207Pb/204Pb=15.489±5, and 208Pb/ 204Pb=36.689±15 (2σ/√n) over an extended period, whereas averages of individual sessions have 2σ/√n of b0.001 for 206Pb/204Pb and 207Pb/204Pb, and b0.002 for 208Pb/204Pb. A total blank was run, resulting in < 40 pg, affirming that no corrections needed to be made for any background levels of Pb. A duplicate (BHVO-1) was analyzed and is identical within our reproducibility (see Appendix A).

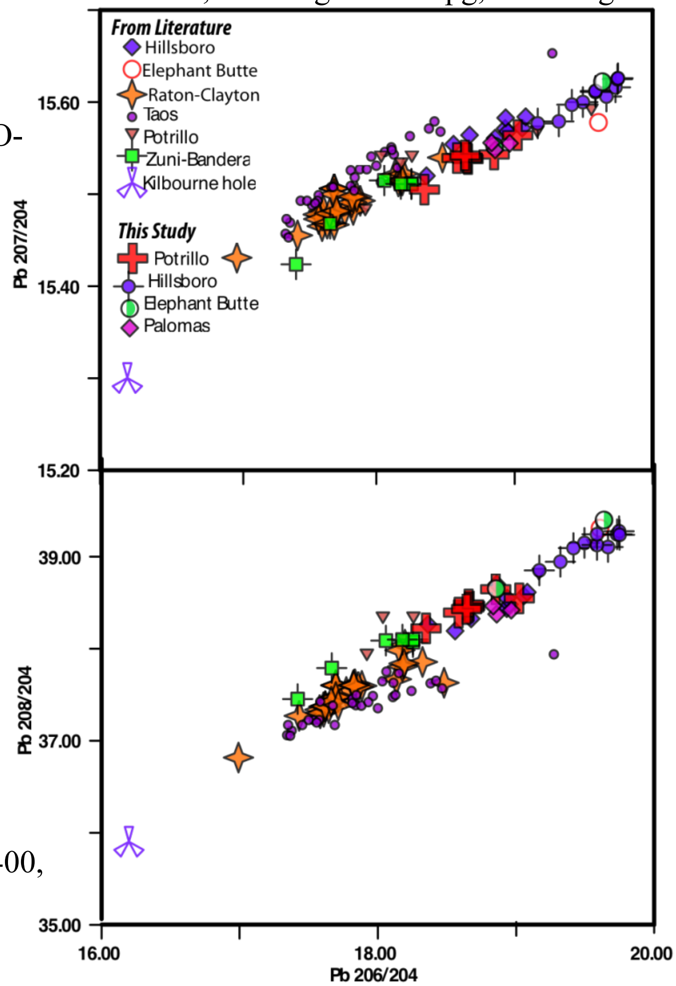

Figure 4: RGR Pb data taken from the NAVDAT, Williams, and Everson data. Also included is the new data collected from the Potrillo, Hillsboro, Elephant Butte, and Palomas fields. The Kilbourne hole point represents a lower crustal composition.

IV. Results

Compositionally, the four fields analyzed varied in overall Pb isotopic compositions with ^{206}Pb/^{204}Pb ratios of 18.389-19.747, ^{207}Pb/^{204}Pb ratios of 15.505-15.645, and ^{208}Pb/^{204}Pb ratios of 38.222-39.400, which fall in the range of crust and common upper mantle assemblages. Individually, the fields ranged as follows: The ^{206}Pb/^{204}Pb ratios of the Potrillo field ranged from 18.349-19.024, the ^{207}Pb/^{204}Pb ranged from 15.505-15.564, and the ^{208}Pb/^{204}Pb ranged from 38.222-38.644. The Hillsboro field had the highest overall

ratios of the four fields analyzed with $^{206}Pb/^{204}Pb$ ratio of 19.167-19.747, the $^{207}Pb/^{204}Pb$ ranged from 15.577-15.626, and the $^{208}Pb/^{204}Pb$ ratio ranged from 38.853-39.276. The Palomas field was closest to the Potrillo field isotopically and very limited in its isotopic range, where $^{206}Pb/^{204}Pb$ ranged from 18.836-18.964, $^{207}Pb/^{204}Pb$ ranged from 15.548-15.556, and $^{208}Pb/^{204}Pb$ ranged from 38.376-38.462. Finally, the Elephant Butte field had a $^{206}Pb/^{204}Pb$ of 18.857-19.636, the $^{207}Pb/^{204}Pb$ ratio ranged from 15.552-15.622, and the $^{208}Pb/^{204}Pb$ ranged from 38.652-39.4.

The volcanic ranges of the four fields of study overlap with previous isotope studies (Figure 4). The Potrillo, Hillsboro, Elephant Butte, and Palomas fields of this current study overlap with the Raton-Clayton and (partially) the Taos ranges. A striking feature, particularly in the $^{208}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ diagram is the widening of the data trends at more radiogenic compositions. The various volcanic fields seem to fan out from unradiogenic compositions to more radiogenic compositions. Notably, a Kilbourne Hole granulite xenolith from the Potrillo volcanic field plots where the other isotopic ranges seem to focus. This sample is the least radiogenic lower crustal (LC) sample in a suite of lower crustal samples generally unradiogenic in $^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$ (Scherer, 1997; Reid, 1989).

On the radiogenic end of the volcanic field trends, a range of potential upper crustal (UC) compositions is possible as mixing components.

V. Discussion

Radiogenic isotope compositions of lavas are helpful in investigating mixing processes between two or more end-member compositions. Pb isotopes are good indicators of mixing trends in lavas between crustal and mantle geochemical reservoirs, allowing for an evaluation of crustal contamination and characterization of various reservoirs. The low concentration of Pb in mantle melts compared to the crust allow the crustal Pb isotope composition to overwhelm the original melt Pb isotope composition, whereas Sr and Nd isotopes are less affected (Johnson and Thompson, 1991). Pb isotope data from the RGR show trends for each volcanic field that could be explained by mixing of a lower crustal component such as has been reported for Kilbourne Hole (Reid, 1989; Scherer et., al., 1997) with various upper crustal components. Thus, Pb isotope compositions in the RGR recent volcanic rocks seem to be controlled by crustal Pb.

Early Pb isotope research suggested that many Pb isotope ratios in the RGR and Basin and Range basalts have signatures similar to volcanic arc and oceanic settings (Everson, 1979). However, more recent investigations have shown some heterogeneity and possible crustal input in the RGR lavas. For example, McMillan and Dungan, (1988) and Zhu (1995) suggested that the presence of mantle melt mixing with lower crust, followed by contamination by two different types of upper crust. These studies demonstrated the potential of Pb isotopic compositions to investigate crustal interactions. Our data overlaps with the existing data, and extends the Pb isotopic compositions to much more radiogenic compositions, particularly for the small eruptions in the Hillsboro and Elephant Butte fields.

Explanations for the radiogenic values for Hillsboro and Elephant Butte consist of either a large amount of upper crustal component mixed in, or very little influence from both lower and upper crust on a mantle melt. The maximum value of ~19.7 in $^{206}Pb/^{204}Pb$ for the Hillsboro samples precludes upper mantle found in the ocean basins as possible mixing end-members. Furthermore, this value falls within the range of the common mantle component (C) (Hanan and Graham, 1996), requiring effectively no contribution from crustal Pb were the upper mantle to be the cause of the observed signature. However, the lavas from Hillsboro were found to contain crustal xenoliths, suggesting it is likely that the crust did affect the melt compositions. In addition, the small scale of the Hillsboro field, combined with the small erupted volumes, agrees well with the suggestion of increased upper crustal interaction. Based on this hypothesis, the crustal components can be further investigated.

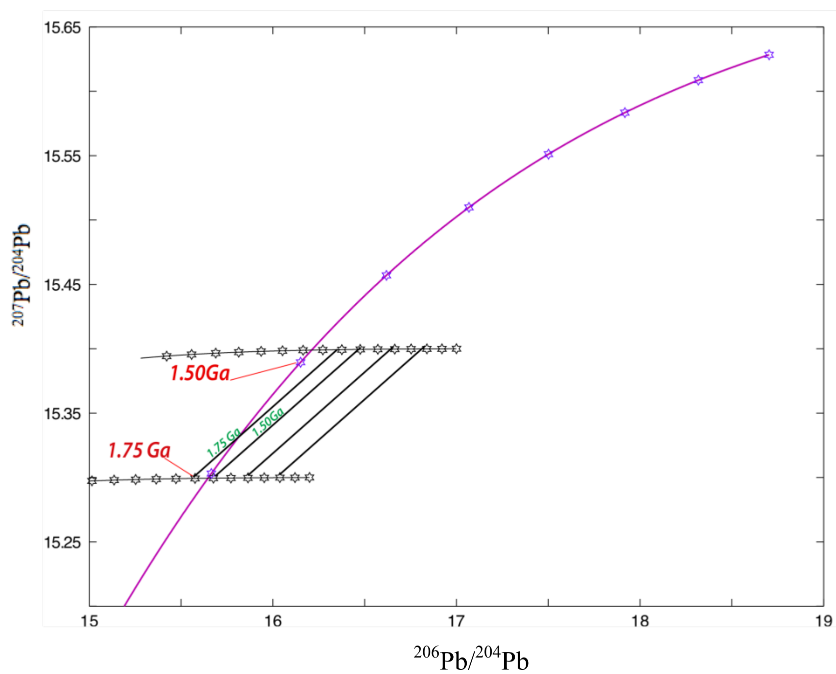

Figure 5: Using the Stacey and Kramers 2 stage Pb evolution model, I estimated a lower crustal age of 1.5-2.0 Ga. My age estimates are shown in green and the Stacey and Kramer age estimates are shown in red. The ages are overestimated based on the Stacey and Kramer model which models crust extraction at 3.7 Ga.

1. Lower Crust

Combining data from several fields suggest Pb isotope data can help constrain the composition of the lower and upper crust. Figure 4 shows $^{206}Pb/^{204}Pb$-$^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$-$^{208}Pb/^{204}Pb$ data that have been collected for New

Mexico and the four volcanic fields we studied. Kilbourne hole xenoliths provide direct samples of the LC, however the UC is seems more variable from the fan shape of the Pb isotope data.

The LC paragneisses and the silicic orthogneisses from Kilbourne Hole exhibit low Pb isotope ratios, suggesting a depletion of U in the past (Reid, 1989; Scherer et.al., 1997). Such an unradiogenic Pb isotope composition is seen throughout the central United States throughout the RGR and even as far north as the Leucite Hills, Wyoming indicating a very common and wide-spread isotopic LC composition (Mirnejad and Bell, 2006). The question then arises as to why the LC has such a limited compositional range throughout the United States.

Even though the various volcanic fields splay from each other, the volcanic fields seem to all point in the same direction in Pb isotope composition, even on a regional scale, with the unradiogenic compositions implying an old age. The LC samples from Kilbourne Hole have been estimated to be early-middle Proterozoic in origin (Reid, 1989). This data is consistent with other regions like Leucite Hills (Mirnejad and Bell, 2006) showing these Pb ratios of the lower crust to be Proterozoic in origin. Using two extreme data points from Scherer et al. (1997), an estimate of the age of the lower crust can be made, illustrated in Figure 5. Using the Stacy and Kramers (1975) two-stage Pb isotope model, an approximate age between 1.5-2.0 Ga is obtained. However, the Stacey and Kramer (1975) model estimates global crust extraction to take place at 3.7 Ga (Stacey and Kramers, 1975) while the RGR crust was formed between 1.8-1.6 Ga (Karlstrom, and Humphreys, 1998). Therefore, the 1.5-2.0 Ga estimate likely overestimates the true timing of the U depletion event that generated the unradiogenic LC compositions.

Interestingly, a major granitic event occurred throughout Laurentia around 1.4 Ga while also spanning roughly the same N-S geographical area as the LC mixing component. Nd-Sr isotopic studies reveal that most of these granites compositionally are 1.9-1.7 Ga Paleoproterozoic crust with little to no Archean contributions (Anderson and Morrison, 2005). These granites are thought to be anorogenic and stretch from present day California to Wisconsin (Anderson and Morrison, 2005; Barnes et. al., 2002). Such A type granites are believed to be formed during a period of tectonic quiescence. The granites in the southwestern United States are categorized as magnetite-series granites by Anderson and Morrison (2005) characterized by low potassium, small enrichment in LILE, and high $\delta^{18}O$ values. These granites appear to be derived from lower crustal sections that consisted of oxidized and more hydrous plutons (Frost and Frost, 1997; Anderson and Morrison, 2005). They appear to be metasedimentary in origin because they are hosted in country rock terrains that were dominated by metasedimentary gneisses. The metasedimentary component of the crustal source could lead to a small abundance of incompatible elements and lead to large scale melting (Anderson and Morrison, 2005; Barnes et. al., 2002). Several alternatives have been proposed as the cause of this widespread event.

Although there is much debate over the exact formation of this massive granitic suite, a recent interpretation argues that melting was due to an unusually hot underlying mantle (Frost et. al., 1999; Frost et. al., 2001, Anderson et. al., 2003; Goodge and Vervoort, 2006). Other models have proposed that an extensional event or flat slab subduction caused the emplacement of the granites (Graubard, 1990; Hildreth et. al. 1991; Kirby et.al. 1995; Scoates and Chamberlain, 1997; Frost and Frost, 2010), but the argument against these models is the sheer volume of the granitic suite. This volume is too large to be extensionally driven given the lack of juvenile calcalkaline magmas which are common in modern or ancient subduction zones, and the lack of

abundance of dike swarms (Anderson and Bender, 1989; Anderson and Morrison, 2005; Goodge and Vervoort, 2006). Based on the modeling of the emplacement of this granitic suite being due to a large lower crust melting event, it is reasonable to assume that this large generation of melt could have greatly reduced the U/Pb ratio in the lower crust resulting in the unradiogenic Pb isotope ratios seen across this area.

The unradiogenic LC Pb isotope ratios require low U/Pb and Th/Pb ratios over a significant amount of time. Fractionation, producing low U/Pb and Th/Pb ratios, may have accompanied the melting event. Th and particularly U are less compatible than Pb during melting, such that U/Pb values can be reduced due to high grade metamorphism and anatexis, controlled by the break-down of accessory phases like apatite, allanite, zircon, and monzanite (e.g. Moorbath et.al., 1969; Whitehouse, 1988; Bolhar et. al. 2007). Therefore, the low Pb ratios seen in the lower crust could be explained by fractionation of U and Th due to some melting event where U and Th are removed from a system and Pb is left behind resulting in the unradiogenic ratios seen in the lower crust.

2. Upper Crust

However, crustal contamination has recently been proven to be relatively widespread in the western U.S. and even in areas that contain mantle xenoliths (Baldridge et. al., 1996). These authors modeled the effect of only 4% of Proterozoic crust interacting with a lherzolite flow from the RGR rift and found that even a small amount had a significant impact on Pb isotope ratios (1996). By looking at $\delta^{18}O$ values for quartz within these flows, that small amount of Proterozoic crust significantly increased the $^{206}Pb/^{204}Pb$ values. He argues that even though the

Sr and Nd signatures may not indicate crustal contamination and that the flows lack xenoliths or xenocrysts, Pb ratios could still be affected. This evidence suggests that the rinds on the mantle xenoliths from the Portillo field are crustally contaminated due to the small interaction with partial melt. This explains how the Kilbourne hole KHSyn samples (xenoliths) plot near to the Aden and Afton flow volcanics that are known to have a much longer time residing in the crust which leads to crustal contamination. Also, the Potrillo and Palomas field plot near each other further indicating crustal contamination in the Potrillo field as Palomas field does contain xenocrysts of feldspar and quartz. The variances within the fields now lie with the amount of crustal contamination each field has experienced.

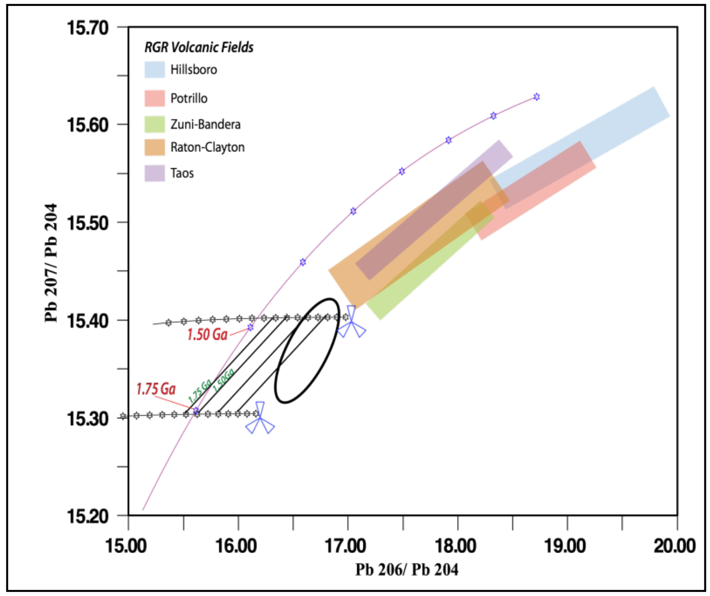

Figure 6: Plot illustrating volcanic field Pb ranges, and the above age plot. The oval and symbol represent Kilbourne hole lower crustal compositions. Each star represents 250 Ma age steps.

The Pb data from the various volcanic fields in the RGR all seem to "fan" from a central LC signature into various UC components (Fig 6). The major variances seen are within the amount of UC contamination each field has encountered. For example, when looking at the Pb data from the Hillsboro field, a large amount of UC contamination with the melt is seen as compared to the Elephant Butte or Potrillo fields. This high Pb signature could be contributed to the amount of initial melt volume as compared to the larger fields like the Potrillos. This smaller melt volume

seen in the Hillsboro field allowed great UC contamination and mixing with the original melt. The larger fields had less interaction with UC components and therefore remain truer to their original compositions.

The occurrence of mantle xenoliths at Kilbourne Hole and the relatively radiogenic Pb isotope composition for the Potrillo volcanic field in general seems to argue against this interpretation. This argument stems from the idea that in order for a lava to contain mantle xenoliths, the residence time of the melt in the crust must have been limited. However, prolonged exposure of wall-rock to melts with short residence times might still lead to interaction. Baldridge et. al. (1996) described lavas containing mantle xenoliths as well as crustal xenocrysts. These authors modeled the effect of only 4% of Proterozoic crust interacting with a mafic melt from the RGR rift and found that even a small amount had a significant impact on Pb isotope ratios. By looking at $\delta^{18}O$ values for quartz within these flows, that small amount of Proterozoic crust significantly increased the $^{206}Pb/^{204}Pb$ values. Baldridge et al. (1996) argue that even though the Sr and Nd signatures may not indicate crustal contamination and that even if the flows lack xenoliths or xenocrysts, Pb ratios could still be affected. This observation suggests that radiogenic Pb isotope compositions of the Potrillo field can simply reflect crustally contaminated partial melts. This explains how the Kilbourne Hole basalt rinds on mantle xenoliths plot near to the Aden shield volcano compositions, despite the expected longer residence time under the Aden volcano compared to the maar eruption at Kilbourne Hole. Also, the Potrillo and Palomas field plot near each other further indicating crustal contamination in the Potrillo field as Palomas field does contain xenocrysts of feldspar and quartz (Frantes, 1981). Therefore, variances within the fields are likely the result of the amount of crustal contamination each field has experienced.

VI. Conclusions

The Pb isotope compositions of four Southern New Mexican volcanic fields fall between lower and upper continental crustal Pb isotope compositions. The origin of the signatures observed in the lavas likely involved interplay between asthenospheric and lithospheric components. The exact role of the upper and lower crust in compositionally influencing these reservoirs has been under debate, but it is likely that the crustal components overwhelmed any mantle signature. From the Pb isotope data, it appears that a particular lower crustal composition is very common across the region and anchors the unradiogenic end of mixing trends with various upper crustal compositions. It is proposed that more radiogenic Pb isotope signatures may be explained by a larger fraction of crust assimilated into the melt. Since the volume of original melt throughout these volcanic fields seems to decrease with increasing radiogenic Pb isotope signatures, the amount of upper crustal contamination is probably directly related to melt volumes.

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Appendix A

The samples analyzed in this study include primarily alkali basalts and their differentiates. These include samples from the UTEP archive and 16 samples collected on site. All samples were leached prior to isotopic analysis to counter the effect of caliche. Background data in diagrams were taken from the online NAVDAT and data collected by Wendi Williams dissertation work on the Potrillo volcanic field (Williams, 1999).

Appendix A

USGS Rock Standards	Sample ID	Pb 208/Pb 204	Std Err	Pb 207/Pb 204	Std Err	Pb 206/Pb 204	Std Err
	STM-1	39.187	1.00E-03	15.628	5.00E-04	19.519	6.00E-04
	G-2	38.860	9.00E-04	15.626	4.00E-04	18.402	4.00E-04
	AGV-1	38.533	1.00E-03	15.645	5.00E-04	18.932	5.00E-04
	BHVO-1	38.331	2.00E-03	15.562	8.00E-04	18.688	9.00E-04
	Duplicate	38.332	1.84E-03	15.564	7.10E-04	18.682	8.22E-04
	BIR-1	38.431	2.00E-03	15.637	5.00E-04	18.834	6.00E-04
	RGM-1	38.645	2.00E-03	15.615	8.00E-04	18.988	9.00E-04

TABLE 1

Volcanic Field	Sample ID	Latitude	Longitude	Pb 208/Pb 204	Std Err	Pb 207/Pb 204	Std Err	Pb 206/Pb 204	Std Err
Potrillo	NM1169	32.025	-107.162	38.644	9.97E-04	15.543	3.73E-04	18.854	4.24E-04
	NM879	32.025	-107.162	38.548	1.57E-03	15.564	5.85E-04	19.024	4.97E-04
	AD-4	31.980	-106.960	38.464	2.64E-03	15.538	9.32E-04	18.664	9.09E-04
	AD-6	32.087	-106.151	38.482	1.15E-03	15.540	4.58E-04	18.656	5.71E-04
	AD-2	32.073	-107.058	38.445	1.59E-03	15.539	5.02E-04	18.656	5.33E-04
	AF-4	31.985	-106.956	38.222	1.14E-03	15.505	4.35E-04	18.349	4.83E-04
	AD-5	32.065	-107.065	38.393	9.97E-03	15.539	3.85E-03	18.585	4.86E-03
	AD-3	32.077	-107.053	38.429	1.04E-03	15.542	4.94E-04	18.643	3.80E-04
Hillsboro	Jmesa_Upper	33.112	-107.559	39.241	1.22E-03	15.616	4.33E-04	19.731	5.09E-04
	09_HB_2_2	32.923	-107.553	39.104	2.37E-03	15.606	8.71E-04	19.665	7.83E-04
	HB_Myers	33.034	-107.531	39.150	7.43E-04	15.600	2.84E-04	19.494	3.55E-04
	HB-VF-Salado	33.114	-107.595	38.947	1.69E-03	15.579	4.94E-04	19.322	5.08E-04
	HB_LF_2	32.923	-107.553	39.129	8.160E-04	15.611	3.000E-04	19.584	3.370E-04
	HB-LF-1	32.965	-107.467	39.242	1.340E-03	15.612	4.110E-04	19.586	4.900E-04
	HB-MillerMesa	33.078	-107.547	38.853	1.170E-03	15.577	4.170E-04	19.167	4.850E-04
	HB-LF-BellMtn	33.030	-107.551	39.094	9.270E-04	15.597	3.760E-04	19.416	4.530E-04
	HB-Jmesa-lwr	33.112	-107.559	39.276	8.090E-04	15.625	3.260E-04	19.744	3.930E-04
	HB-LF-Artesia	33.052	-107.513	39.239	8.170E-04	15.626	3.660E-04	19.747	5.240E-04
Elephant Butte	EBAS-1	33.100	-107.116	39.400	1.050E-03	15.622	3.780E-04	19.636	5.060E-04
	EB-4			38.652	1.72E-03	15.552	5.19E-04	18.857	5.12E-04
Palomas	PAL-VF-01	31.811	-107.802	38.376	8.000E-04	15.548	3.140E-04	18.861	3.710E-04
	PAL-VF-02-Midd	31.806	-107.835	38.462	1.20E-03	15.556	3.97E-04	18.836	4.31E-04
	PAL-VF-02-Bott	31.806	-107.835	38.421	2.60E-03	15.555	8.26E-04	18.964	7.50E-04

VIII. Curriculum Vitae

Lynnette Crocker was born in Tulsa, Oklahoma as the first daughter of Bob and Kay Crocker. She graduated from Broken Arrow High School in Broken Arrow, OK in the spring of 1999. She then moved to Lawrence, KS to pursue an art degree from The University of Kansas. In 2001, Lynnette moved to El Paso, TX to enter into the geology department at the University of Texas at El Paso. She graduated with a Bachelor of Science in Geology in 2005 and then moved to Los Angeles, CA to work as an environmental consultant for 3 years. She returned to the University of Texas at El Paso in 2008 to pursue a Master's of Science in Geology. She plans to work for Chevron beginning in the fall of 2010.

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