LA-SUB--95-62

IGPP PROGRESS REPORT

Project Title:	Renewal: Continental Lithosphere Evolution as a Function of Tectonic Environment
Principal Investigators:	Dr. Nancy J. McMillan, Department of Geological Sciences, New Mexico State University Dr. W. Scott Baldridge, EES-1, Los Alamos National Laboratory
Students:	John Young, M.S. candidate, NMSU
Reporting Period:	Begin: 1 October 1991 End: 31 September 1992
Grant Period:	Begin: 1 October 1992 End: 31 September 1992
Preceding Grant Period:	Begin: 1 October 1991 End: 31 September 1992
Amount:	$14,000 ($7,000 LANL and $7,000 NMSU)

Summary of Objectives, Approach, Results, Conclusions, and Importance

The Cenozoic tectonic environment and stress regime of the southwestern United States have changed dramatically from compression during shallow-angle subduction during the Laramide orogeny in the early Cenozoic to the current mode of Basin and Range extension. Major questions remain unresolved concerning the causes of this transition, despite decades of mapping and structural analysis. For instance, the timing of the initiation of extension is not well documented in most regions; estimates range from 36 to 25 Ma. Is the Basin and Range simply an mega-example of back-arc extension, or is extension related to the subduction of an oceanic spreading center about 30 Ma? Extension appears to have happened in several phases, differing in structural style and volcanic geochemistry. What factors control these phases? Our approach is to examine the patterns of magmagenesis and geochemical composition through Cenozoic time in southern New Mexico, because the magma compositions record the thermal (melting) conditions that existed during the tectonic transitions. We have defined four magma sources that have contributed to Cenozoic magmas. Immediately following the Laramide, magmas contain substantial contributions from the *lower crust* (mantle sources have yet to be determined). Mid-Tertiary extension is related to the eruption of rhyolitic ash-flow tuffs and basalts. The basalts were generated by melting of the *lithospheric mantle*; intercalated rhyolites have a strong *upper crustal* signature. Eruption of basalts and andesites with sources in the lithospheric mantle and *lower crust* continued for several million years after rhyolitic volcanism ceased. The region was nearly void of volcanic activity for 16 million years despite continued extension, but at 10 Ma, basalts derived from the *asthenosphere* began to erupt.

At 10 Ma, the asthenosphere began producing alkalic and mildly alkalic basalts; the lithosphere has made only minor contributions to magmas since then.

Equipment Obtained and Facilities Used

No equipment has been purchased through this grant. We have utilized the X-Ray Fluorescence facility in EES-1 and hope to use the electron microprobe as well. This grant has provided considerable support for the new $^{40}Ar/^{39}Ar$ analytical facility at New Mexico Bureau of Mines, which will prove to be an invaluable resource to geologists in New Mexico and the southwest. Isotopic analyses were performed at McMaster University by Dr. Alan Dickin. The IGPP grant was pivotal in making these analyses possible.

Tangible Results

One manuscript is in preparation, entitled "Magmatic sources involved in the evolution of the Rio Grande rift, southern New Mexico."

Two abstracts have been published and the results presented at international meetings:

McMillan, N.J., Dickin, A.P., and Skuba, C., 1992, Pb-Sr-Nd Isotopic constraints on Cenozoic mantle and crustal magma sources, Southern New Mexico: EOS, 73: 338.
Presented at the Spring American Geophysical Union Meeting, Montreal, May 1992

Cameron, K.C., McMillan, N.J., and Dickin, A.P., 1992, Did the protoliths of the Kilbourne Hole mafic granulite xenoliths crystallize from Tertiary magmas?: EOS, Fall AGU meeting, December 1992.
Presented at the Fall American Geophysical Union Meeting, San Francisco, December 1992.

One MS thesis was completed: "Late Oligocene to Early Pleistocene Basalts of Southwestern New Mexico," by David Haag (NMSU).

Intangible Results

This project has caused a flurry of undergraduate and graduate student theses on these rocks. Two undergraduates are writing senior theses on Cenozoic volcanic rocks: Karlin Danielsen is analyzing a dike swarm dated by K-Ar at 31.5 Ma with asthenospheric major and trace element characteristics but lithospheric isotopic signature. This project will be fundamental in understanding the nature of Oligocene mafic magmatism. Justin Kirby is analyzing a series of Eocene lavas exposed in the Organ Mountains, and trying to locate the volcanic center for this particular volcanic package by mapping the volcanic facies (lahars vs. lavas). Rebecca Ramirez is starting a MS on the Rubio Peak volcanic field, which will be the first detailed geochemical work done on rocks of this age in southern New Mexico. Doug Ware, also a MS candidate, is working with the Bell Top rhyolitic lavas and tuffs to determine vent areas, magmatic processes, and the relationship to coeval basalts.

This project has also initiated collaboration between Nancy McMillan and Ken Cameron (UC Santa Cruz). Ken has worked on similar problems in southern Chihuahua, Mexico, and is starting to work on Uvas age lavas in Arizona. Currently, McMillan and Cameron are examining mafic granulite xenoliths from the Kilbourne Hole maar to determine whether they represent mafic underplating from Uvas magmatism or other events.

Future of the Project

A major goal for the IGPP phase of this work was to produce an initial data set to support a NSF proposal. The proposal was funded in June 1992 for two years. The initial funding was $70,000, and an additional $20,000 was funded for undergraduate participation in the project. Because of this success, we will not be applying to IGPP for additional funding on this project.

Funds Received as Result of IGPP-Sponsored Research

A NSF grant to Nancy McMillan (NMSU) began in June 1992, and will run for 2 years. Total funding is $90,000, which includes $20,000 for undergraduate participation.

Los Alamos Facilities Used for this Project

The X-Ray Fluorescence facilities at EES-1 were used for some of the major element analyses. Graduate student John Young helped to develop a new, more efficient, method for sample preparation. He worked closely with Gary Ludemann and Scott Baldridge in EES-1.

Introduction

The tectonic evolution of southwestern North America is unique in geologic history and provides a valuable experiment to evaluate the response of lithosphere to a major change in stress regime and tectonic environment. A region in southern New Mexico, where the Rio Grande rift and Basin and Range merge, was selected because Cenozoic rocks have been thoroughly mapped, preliminary age determinations have been made, and data sets exist in both the Rio Grande rift and Basin and Range provinces for comparison. This project involves major element, trace element, isotopic, mineralogic analysis, and $^{40}Ar/^{39}Ar$ age determinations of Cenozoic igneous rocks (mainly volcanic) with the hope of defining the dominant source regions as a function of time and tectonic regime. Our results are compatible with similar studies near Socorro, NM and throughout the Basin and Range, although somewhat better constrained because of the excellent map base.

Progress During the Reporting Period

Major Findings

Continuing isotopic and trace element analysis allows us to define four magma source regions that were involved at various times during the Cenozoic (Figure 1). Immediately following the Laramide orogeny, arc-like magmas of intermediate composition (Rubio Peak Formation) have fairly non-radiogenic $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, and $^{87}Sr/^{86}Sr$, and ϵ_{Nd} values between -2 and -5, suggesting that the dominant source region during this time was the lower crust. Mantle source regions cannot be evaluated at this time because we have yet to sample mafic lavas of this age. However, a strong lower crustal influence is consistent with magmagenesis models in the Andes arc. Lavas of the Rubio Peak Formation are overlain by mid-Tertiary rhyolitic tuffs and basalts of the Bell Top Formation, which range from 36 to 28.5 Ma. Three source regions were tapped during this time (Figure 1). Rhyolites have low ϵ_{Nd} but relatively radiogenic $^{87}Sr/^{86}Sr$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ and represent an upper crustal source. In contrast, the coeval basalts were derived from the lithospheric mantle and contaminated in the lower crust (non-radiogenic Pb and Sr isotopic ratios). Calc-alkaline basaltic and andesitic lavas of the Uvas volcanic field overlie the Bell Top Formation. Previous workers envisioned the Uvas-type volcanism as separate from the Bell Top episodes because of the lack of rhyolitic tuffs in the

Uvas field. However, our work indicates that the Bell Top basalts are identical to Uvas basalts for every element and isotopic ratio determined. Thus, we interpret the field and geochemical data as indicating that mafic and silicic volcanism started at about the same time, but that the upper crustal source for the rhyolites was exhausted before the basaltic magmatism ceased. A period of roughly 16 million years (26 Ma - 10 Ma) passed without volcanism. During this time, extension continued, and several basins of this age contain significant thicknesses of conglomerates and sandstones. At approximately 10 Ma, basaltic volcanism began again, with alkalic magmas similar to ocean island basalts from upwelling asthenosphere. These Late Cenozoic basalts are characterized by high ϵ_{Nd}, low $^{87}Sr/^{86}Sr$, and radiogenic $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$ (Figure 1).

Conclusions

The temporal succession of source regions allows us to suggest a model for changes in thermal conditions and melting mechanisms in the southern Rio Grande rift. The Rubio Peak arc-like lavas probably represent compressional tectonics similar to the Andes, developed as the dip of the Farallon plate increased at the end of the Laramide orogeny. Melting was caused by the addition of hydrous solutions to the mantle wedge above the Benioff zone. The increase in subduction angle permitted (or required) the influx of asthenospheric mantle behind the arc. The inflow of hot asthenosphere may have been responsible for the initiation of extension at about 36 Ma and for an increase in lithospheric temperature, causing melting of the lithospheric mantle and lower crust to form the Bell Top basalts. Intrusion of these mafic magmas into an already warm upper crust caused local crustal melting to produce the Bell Top rhyolitic tuffs. This upper crustal heat source, however, could not be maintained for a long period of time, because it was not sustained by an arc or active rift, but rather by an unusual case of continental back-arc extension. Thus, rhyolitic volcanism shut off and mafic volcanism persisted in the Uvas volcanic field for another 2 Ma. This thermal regime, produced by the influx of asthenosphere, and the melting, caused by mild extension-produced decompression, decayed as the lithosphere cooled during the early Miocene. There is sedimentological evidence for significant extension during this time. Volcanism did not accompany extension because there was no trigger for melting: the asthenosphere could not yet rise to shallow depths and experience decompression melting, and the lithospheric mantle had cooled below its solidus.

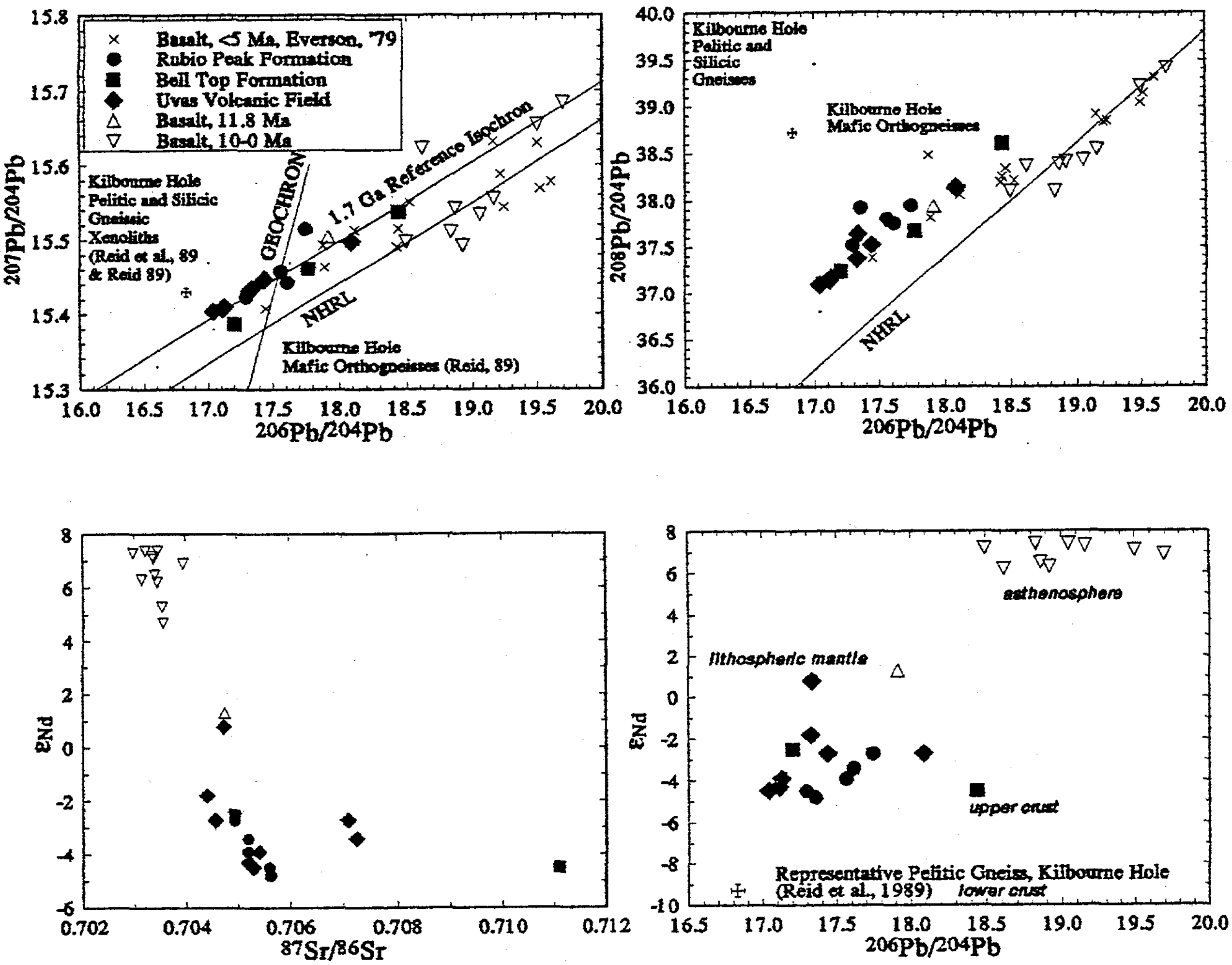

Figure 1.
Final report, Grant #62R
McMillan, NMSU