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Helium, Argon and Methane Studies: The Sunda-Banda Arc, Indonesia

Office of Naval Research Grant #N00014-89-J-1424

Final Technical Report

Expedition Dates: 23rd May - 26th June, 1989.

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Expedition Members:

Dr. J.C. Varekamp (Wesleyan University, Connecticut)
Dr. R. Kreulen (University of Utrecht, Holland)
Mr. T. Sriwana (Volcanological Survey, Indonesia)
Dr. D.R. Hilton (Scripps Institution of Oceanography)

Introduction

→ The expedition to Indonesia, led by Dr. Varekamp, consisted of the collection of high temperature volcanic gases and phenocryst-bearing lavas from 3 islands of the archipelago. The aim of the expedition was to provide helium, argon and methane isotope and abundance analysis along the strike of the eastern Sunda Arc, and to compare these results with analysis made by Dr. Varekamp on Snellius Expedition in 1984 when he collected volcanic gases from the adjacent Banda volcanic arc. In this way, it was planned to obtain a unique suite of geothermal gases contrasting the effects of oceanic crust subduction along the Sunda Arc with continental subduction along the Banda Arc.

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Sampling Localities

In a west to east direction, the islands visited and collections made were:

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- (1) Java - Collections of volcanic gases were made at Tangkuban Parahu, near Bandung in west Java, and Merapi near Yogyakarta in central Java. Tangkuban Parahu was sampled by Dr. Hilton during a 5-day stay at the headquarters of the Geological Survey in Bandung prior to travelling to the eastern islands. Merapi was sampled by Dr. Varekamp at the end of the expedition. A visit was made by Dr. Hilton to Bromo volcano in east Java, but the locality was considered too dangerous to sample without major logistic support involving the accompaniment of a climbing expert and associated safety equipment.
- (2) Flores - Three volcanoes were sampled for volcanic gases and thermal waters: Iya and Keli Mutu in central Flores, and Egon in eastern Flores.
- (3) Lombok - Volcanic gases were only collected (successfully) at Lewotolo volcano by Dr. Varekamp. Two steam localities on Werung volcano toward the south of the island were attempted by Dr. Hilton but subsequent laboratory analysis revealed atmospheric contamination at both sites.

Field Logistics - Recommendations

Field work in Indonesia is extremely hard work but can be immensely rewarding. Conditions, at the best of times, are difficult and the following are only general recommendations:

- (1) Delays - Although the expedition was in Indonesia for over 1 month it proved impossible to visit all the localities on our itinerary. The principal problem relates to travelling through and between the islands. Travel overland is extremely slow due to the appalling (by western standards) condition of the roads, and the air-network is invariably operating at full capacity (overbooked) and is, at times, unreliable. At



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che end of the expedition it took 5 days to move from one island to an adjacent island in order to get a plane back to Jarkarta. Also, although individual volcanoes can be sampled in a single day, our average of one volcano every five days seemed good considering the travelling between localities, recuperation period after sampling and inevitable travel delays or cancellations involved with transfer to the next sampling locality. Finally, it took 5 days to leave the Geological Survey at Bandung due to administrative matters - this again should be anticipated. I recommend at least 6 weeks, as a minimum, to achieve a reasonable sampling campaign of more than three islands in the eastern archipelago.

(2) Health Precautions - It is essential to come prepared with prophylactics and be vaccinated - malaria and hepatitis were endemic in the eastern islands. It is also important to be physically fit: reaching volcano summits involved walking up to 8 hours per day often at quite steep gradients and in 30°C+ heat. Food, at times, was basic or non-existent, and one has to be extremely wary at all times that the food and drink had been prepared properly. An essential item of field equipment for these islands is a mosquito net. It is also important to take advantage of villagers for guidance to the best routes up the volcanoes, and for carrying all supplies - by western standards the cost is very low.

Scientific Results

The attached abstract summarises the scientific results of the expedition to date. Although we didn't get to all our planned localities, we collected enough samples at crucial localities (and were able to supplement our sample list with generous donations of samples from other workers) to reveal the general picture of isotopic variations between the two arcs. The most important results are:

- (a) High helium isotope ratios (similar to mid-ocean spreading ridges) in the west of Java, as predicted by earlier work in circum-Pacific arcs (see Poreda & Craig, Nature 1989).

- (b) Continuation of these high helium ratios through the eastern Sunda Arc until eastern Flores, revealing the contribution of Indian Ocean crustal subduction to magma genesis over this wide area.
- (c) Discontinuities in helium isotope results through the transition zone between the Sunda and Banda Arcs, consistent with a complex history of magma mixing involving both oceanic and continental material.
- (d) Mantle $\text{CH}_4/{}^3\text{He}$ ratios in Java and Lombok indicating the surprising result of the presence of methane in these volcanic gases and its likely derivation from the mantle.

Results of analysis of the samples collected will appear in an article to be submitted to the journal Nature shortly and should appear before the end of the year.

Abstract of Paper to be Presented at Fall Meeting
American Geophysical Union

**Helium Isotopes and Gas Chemistry of Volcanic Arcs:
A Transect Along the Sunda Arc of Indonesia**

D R Hilton* and H Craig (Isotope Laboratory, SIO/UCSD,
La Jolla, CA 92093). *(Now at: FR Geochemie, Freie
Universitat Berlin, 1000 Berlin 33 FRG).

The Indonesian archipelago is a unique juxtaposition of two volcanic arcs of contrasting tectonic style. To the west lies the Sunda Arc, related to subduction of Indian Ocean crust along the Java Trench. The eastern archipelago includes the Banda Arc, the only collision zone involving loss of continental crust. Poreda & Craig (*Nature* 338, 473, 1989) identified the Banda Arc as the only circum-Pacific arc with helium isotope ratios significantly lower than those found at MOR spreading centers. In this report we contrast those results with $^3\text{He}/^4\text{He}$ ratios and chemistry of volcanic gases and lavas along a 1500 km section of the Sunda arc, from Java on the west to the eastern island of Lombok in the transitional region between the arcs.

Helium isotope ratios (reported as R/R_A , the air normalized $^3\text{He}/^4\text{He}$ ratio) for Tangkuban Parahu in west Java ($R/R_A = 8.2$) and Merapi in central Java ($R/R_A = 5.7$) are consistent with the range of arc segments around the Pacific margins ($R/R_A = 6 - 8$), and show the dominance of magmatic helium along this part of the Sunda arc. Significantly, Tangkuban Parahu is also characterized by a MORB $\text{CH}_4/^3\text{He}$ ratio ($= 12 \times 10^6$), and a non-atmospheric nitrogen component ($\text{N}_2/\text{Ar} = 856$). Magmatic helium isotope ratios continue through the central region of the arc at Sangean Api on the island of Sumbawa ($R/R_A = 6.5$), and as far east as the volcanoes Iya ($R/R_A = 4.6$) and Keli Mutu ($R/R_A = 6.0$) in central Flores. These ratios contrast markedly with the predominantly radiogenic R/R_A ratios, of 1.1 - 1.7, in the Banda arc (*op. cit.*), and indicate a very small contribution of subducted oceanic crust to magma genesis over this wide region. The transition to radiogenic helium isotope ratios is first seen at Egon in east Flores ($R/R_A = 1.3$) and marks a sharp transition from Keli Mutu which lies <100 km to the west. This large decrease in R/R_A signifies a distinct change in the helium characteristics of the source magmas, and probably marks the westernmost limit of the influence of continental subduction. There is no systematic variation across this transition zone: R/R_A for Lewotolo volcano on Lombok (3.7), and Batu Tara (3.4), show a reduced radiogenic He input more than 100 km closer to the Banda arc. Thus the eastern Sunda arc probably has a complex mixing history for source magmas at this juncture of the two arc domains.

These results are in striking agreement with the prediction (*op.cit.* above) that "Sunda lavas should have $R/R_A = 7 \pm 0.5$ with a well-defined transition to the much lower Banda arc ratios near Lewotolo", based on tectonics and $^3\text{He} - ^{87}\text{Sr}$ correlations in circum-Pacific arcs. We thank J.C. Varekamp for logistics and field assistance and NSF and ONR for support.