SR, ND AND PB ISOTOPE AND TRACE ELEMENT GEOCHEMISTRY

OF THE NEW ENGLAND SEAMOUNT CHAIN

by

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B. A. (Hons), University of Pennsylvania, Philadelphia
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Samples collected by dredge hauls and submersible dives from the New England Seamount (NES) chain, the most prominent of six seamount groups located in the Northwest Atlantic have been analyzed for Sr, Nd and Pb isotopic compositions and rare earth and other trace element contents. $^{40}Ar-^{39}Ar$ ages determined by Duncan (1983) indicate a progression in seamount age from the southeast (82 m.y., Nashville Seamount) to the northwest (103 m.y., Bear Seamount) suggesting a hotspot origin for the chain.

To obtain useful isotopic data from the old and altered NES samples I analyzed both HCl-leached and unleached whole rock samples and hornblende and clinopyroxene mineral separates. Rare earth element and other trace element contents were measured on unleached whole rock samples. I have demonstrated that primary (unaltered) geochemical data can be obtained from older altered oceanic volcanics.

The NES are shown to have isotopic and trace element characteristics typical of alkaline volcanics from oceanic islands, in particular those characterized by radiogenic Pb isotopic signatures. The seamounts exhibit considerable interseamount isotopic variations, while intraseamount chemical heterogeneity appears to be substantially less. An increase in radiogenic Pb along the chain towards the southeast is suggested. No other simple geographic trends in chemistry are apparent. The isotopic characteristics of the NES necessitate at least three distinct source components and substantial involvement of a "radiogenic Pb" type mantle. The isotopic similarities between the NES, Canaries, Azores and Ahaggar imply some type of systematic geographic distribution of this "radiogenic Pb" component.

Thesis supervisor: Stanley R. Hart, Professor of Geology and Geochemistry

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INTRODUCTION

Batiza (1982) demonstrated that seamounts and oceanic islands compose, by mass, up to 25% of the oceanic crust's volcanic layer. A knowledge of the geochemistry and petrology of oceanic volcanoes is necessary in order to understand the evolution of the ocean crust. While substantial geochemical data exist to show that oceanic island magmas are distinct from those produced at ocean ridges (Hart and Brooks, 1980), seamounts are not as well defined.

Zindler et al. (1980), Batiza (1980) and Batiza (1979) reported substantial geochemical heterogeneity in small seamounts adjacent to the East Pacific Rise (EPR). Some exhibit Mid Ocean Ridge Basalt (MORB) characteristics while others resemble volcanics from oceanic islands. In fact, these authors describe a single seamount which exhibits this entire geochemical variation. Other large seamounts have oceanic island affinities, such as the Discovery Seamount (Sun, 1980), Emperor Seamounts (Lanphere et al., 1980), and Loihi (Staudigel et al., 1984; Moore et al., 1982; Frey and Clague, 1983; Kurz et al., 1983; Lanphere, 1983; Clague et al., 1983).

Oceanic volcanoes are often clustered in groups, sometimes forming lineations. Morgan (1972, 1981) suggested a hotspot origin for most of these lineations. The interplay between tectonics and magma production (and its transport) inferred from the geographic expression and age relationships exhibited by volcanic chains, provides a thought provoking framework from which to anticipate possible geochemical implications. An evolving finite magma supply and variations in the proximity of a "hotspot" source to a spreading ridge or continent may produce geographic trends in chemistry along the hotspot lineations. In contrast, an infinite source or

a regularly reproducible finite source may lead to intrachain chemical homogeneity and, in the latter case, concurrent intravolcano chemical trends. A heterogeneous source may generate seemingly random chemical variations.

Of the many known volcanic chains, only the Hawaiian-Emperor chain and recently, the Cameroon Line (Jacquemin et al., 1982; Fitton and Hughes, 1977; Dunlop and Fitton, 1979) have been subjects of extensive geochemical studies. While a progression in volcano age along the Hawaiian-Emperor chain is well established (McDougall, 1964; 1969; 1971; Ladd et al., 1967; Funkhouser et al., 1968; Dalrymple et al., 1980; Dalrymple and Garcia, 1980), a simple age progression along the Cameroon Line is lacking (Hedberg, 1969; Machens, 1973; Jacquemin et al., 1982; Grant et al., 1972; Dunlop and Fitton, 1979). Isotopic studies of the Hawaiian Islands do not reveal any systematic chemical variations along the trend (Tatsumoto, 1978; Sun, 1980; Chen and Frey, 1983; White and Hofman, 1982; Lanphere, 1983; Stille et al., 1983; Staudigel et al., 1984). Lanphere et al., (1980) proposed that a systematic decrease in $^{87}Sr/^{86}Sr$ along the Emperor Seamount Chain, north from Midway, resulted from an increase in the proportion of a MORB-type component in the seamounts' source and suggested that this was a consequence of the earlier volcanoes proximity to a spreading ridge. Isotopic data on basalts from the Cameroon Line do not demonstrate any systematic geographic variations (Fitton and Dunlop, 1983). This volcanic chain spans both continental and oceanic crusts.

The New England Seamount Chain is the subject of an ongoing geochemical and petrologic study. The project is a collaborative effort involving G. Thompson and W. Bryan at Woods Hole Oceanographic Instutition, R. Duncan of Oregon State University and myself. The purposes of this

paper are to present the isotopic and trace element data I have collected on New England Seamount chain volcanics, to discuss their intrachain and intraseamount variations, to compare the New England Seamounts (NES) to other oceanic floor volcanics and to add to the existing conjecture regarding the petrogenesis of oceanic islands and seamounts. Also, because this study necessitated working on old altered rocks, I will discuss the problems presented by alteration and old age, and procedures invoked to overcome these difficulties.

I will demonstrate the following: 1) the NE Seamounts' isotopic and trace element characteristics are typical of alkaline volcanics from oceanic islands; 2) the seamounts exhibit considerable interseamount isotopic variations, while intraseamount chemical heterogeneity appears to be substantially less; 3) the isotopic characteristics of the seamounts necessitate at least three chemically distinct source components and substantial involvement of a "radiogenic Pb" type mantle. This mantle component underwent an ancient enrichment in U/Pb and Th/Pb ratios and a depletion in Rb/Sr and Nd/Sm ratios relative to those of bulk earth; 4) the only trend in chemistry along the chain is an increase in radiogenic Pb with distance from the craton. The isotopic similarities between the NES, Canaries, Azores and Ahaggar, imply some type of systematic geographic distribution of this "radiogenic Pb" component; 5) the NES exhibit a relatively small contribution from an "enriched" type mantle and lack any chemical trends implicating the involvement of subcontinental mantle (a possible source of the "enriched" component).

An important part of this study is the demonstration that primary geochemical data can be obtained from older altered oceanic volcanics.

GEOLOGIC BACKGROUND

The NES chain is the most prominent of six seamount groups in the Northwest Atlantic (Fig. 1). Consisting of over 35 seamounts, the chain extends 1300 kms from the outer Bermuda Rise to the continental slope south of Georges Bank. The seamounts are underlain by oceanic crust. These large seamounts, rising as much as 4000 m above the ocean floor (approximatly 1/2 the size of the Hawaiian volcanoes) have been sampled by dredging, drilling, and submersible dives.

The NES are divided into a Western group (Bear to Cosnold Seamounts) and an Eastern group, (Gregg to Nashville Seamounts; Fig. 2), based on differences in their geographic orientation and associated geophysical properties. The Western group fits a small circle about a Jurassic pole of rotation for North America (McElhinny, 1973) and is composed of distinct volcanoes, lacking connecting basement ridges (e.g. Heezen et al., 1959; Uchupi et al., 1970; Heirtzler et al., 1977a, b, and references therein). Geophysical properties are continuous across this segment (Vogt et al., 1970; Schouten and Klitgord, 1977). The Eastern group defines a small circle about a Creteceous pole of rotation for North America (McElhinng, 1973). Unlike the Western seamounts, the Eastern group appears to be ridge-connected and exhibits geophysical discontinuities across its trace. These discontinuities include a shallower depth to basement and correspondingly, a higher heat flow, south of the trace than to the north (Hoskins, 1965; Vogt, 1973; Birch, 1965) and a small offset in magnetic anomalies across the trace (Vajk, 1966; Schouten and Klitgord, 1977).

K-Ar and $^{40}Ar-^{39}Ar$ ages determined by Duncan (1983) indicate a progression in seamount age from 82 m.y. in the southeast to 103 m.y. in the northwest, suggesting a hotspot or perhaps a propagating fracture

FIGURE 1

Map of the Northwest Atlantic showing the six major seamount groups, including the New England Seamount chain. The proposed continental precurors of the NES chain, the White Mountain intrusions and the Monteregian Hills, are also indicated.
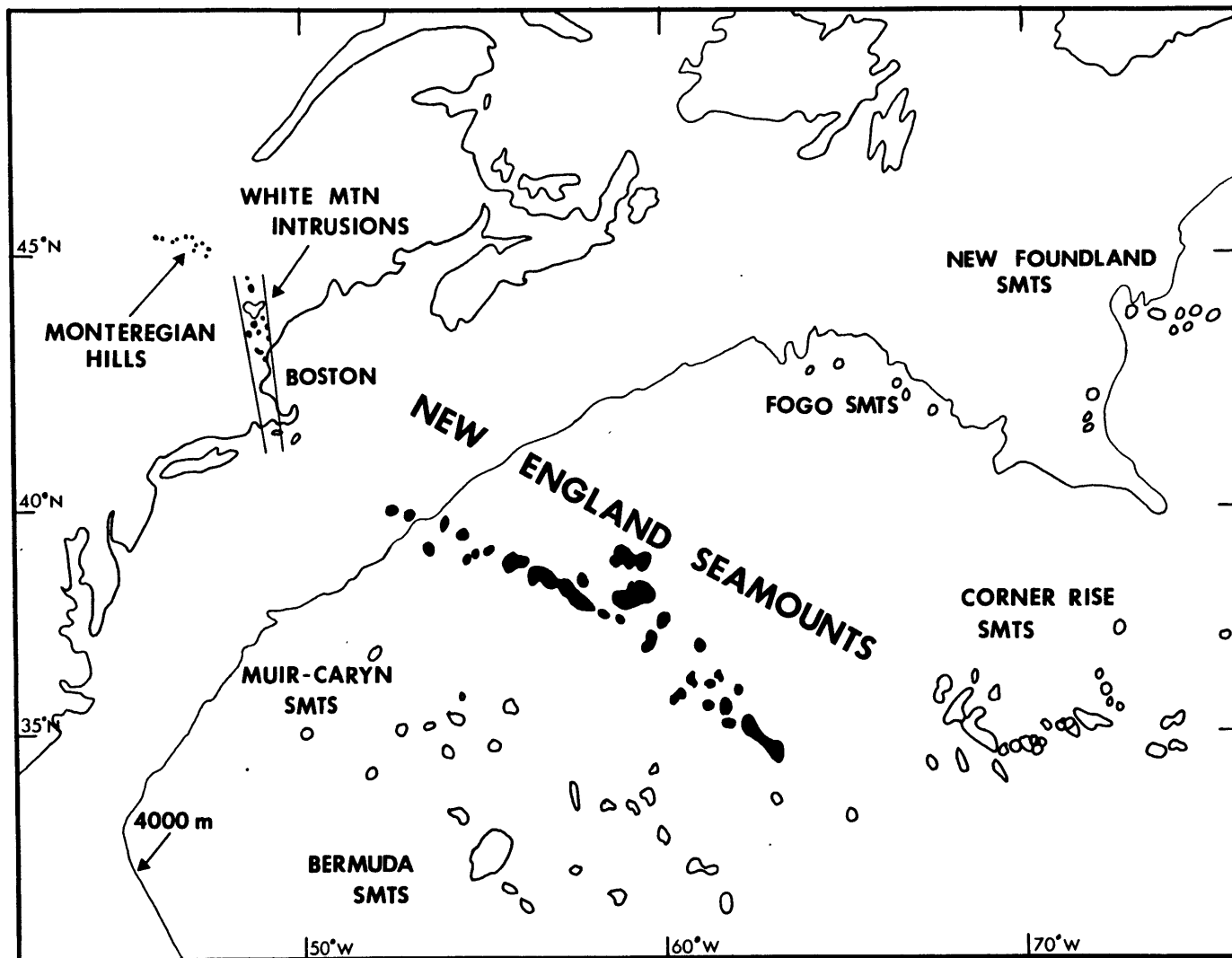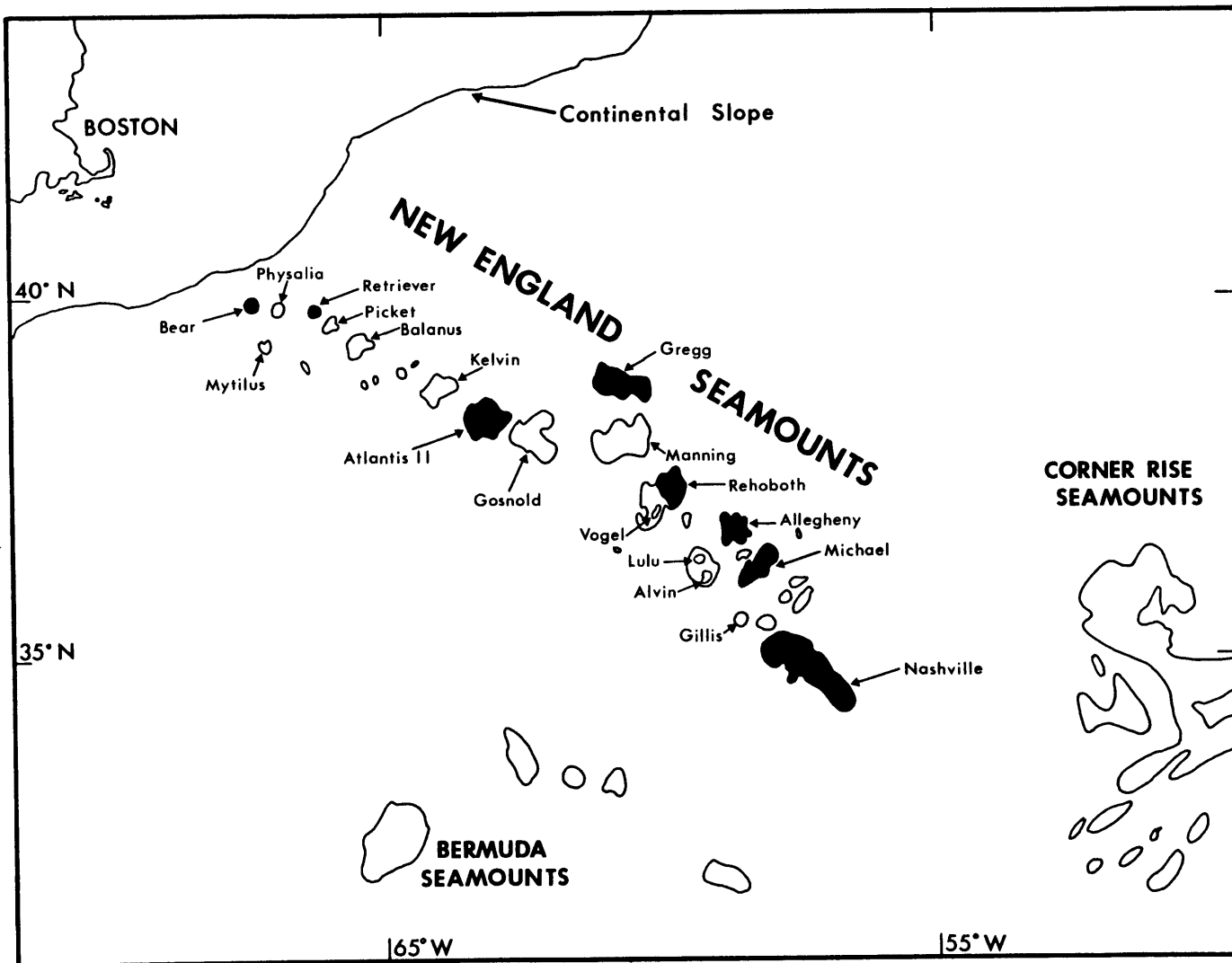
WHITE MTN
INTRUSIONS

NEW FOUNDLAND
SMTS

45°N

MONTEREGIAN
HILLS

BOSTON

FOGO SMTS

NEW

40°N

ENGLAND SEAMOUNTS

CORNER RISE
SMTS

MUIR-CARYN
SMTS

35°N

4000 m

BERMUDA
SMTS

50°W

60°W

70°W

6

FIGURE 2

Map of the NES after Uchupi et al. (1970). Samples from the shaded
seamounts were analyzed in this investigation.

BOSTON

Continental Slope

NEW ENGLAND

SEAMOUNTS

40° N

Physalia

Retriever

Bear

Picket

Balanus

Mytilus

Kelvin

Gregg

Atlantis II

Manning

Gosnold

Rehoboth

Vogel

Allegheny

Lulu

Michael

Alvin

Gillis

35° N

Nashville

CORNER RISE
SEAMOUNTS

BERMUDA
SEAMOUNTS

65° W

55° W

origin for the NES. The seamounts were built on progessively younger seafloor towards the south-east, where Nashville Seamount stands on crust only 15 m.y. older than itself (Vogt and Einwich, 1978; Duncan, 1983). Thus the source of the NES was moving towards a spreading ridge. Many authors have proposed a seaward extension of the trend to the Corner Rise Seamounts (age unknown), suggesting these seamounts formed just prior to the source region's passage beneath the ridge. The "hotspot's" location beyond this point is uncertain (Duncan, 1983). Toulmin (1957), Griscom and Bromery (1968), Coney (1971), Ballard and Uchupi (1972), Morgan (1980), Crough (1981), Sber and Sykes (1973) and Duncan (1983) have proposed models relating the NES to the White Mountain Magma Series. Some of these authors have also suggested that the Monteregian Hills magmatism may be part of this continental precursor (Fig. 1). Though not studied here, this continental igneous activity provides much incentive for subsequent investigations. For example, having characterized some chemical aspects of the NES mantle source, studying the chemistry of the "associated" (the first obstacle) continental rocks may yield some understanding of the subcontinental mantle's chemistry and magma-crust interactions.

SAMPLE DESCRIPTION

G. Thompson, of Woods Hole Oceanographic Institution, provided the samples for this study. He is analysing splits of these samples for their major element, trace element, H_2O and CO_2 contents, while W. Bryan, also of Woods Hole, has undertaken a detailed microprobe and petrographic study. The results of these studies are forthcoming, therefore I have limited myself to a brief sample description.

I selected nine samples from eight seamounts representing the geographic extent of the chain. The samples I gave priority to were the phenocryst-rich, the least altered, those with larger sample volumes and those dated by Duncan. Table 1, in the Appendix, is a dredge and dive summary of these samples.

The sample sizes were small, typically a slab 10x15x2 cm, a large portion of which was usually altered material. Hand sample and petrographic inspection, along with limited major element, H_2O and CO_2 analyses (Table 2 in the appendix) indicates that these samples are moderately to highly altered. They contain secondary phases such as calcite, zeolites and clays. In spite of the degree of alteration, their major phenocryst phases, titaniferous augite ± hornblende (except for sample Knr61 18-34, below) are often unaltered. These phenocrysts are usually a few millimeters in size, though in samples Knr61 14-1 and AII85 13-54 they range up to 10-15 mm in dimensions. When present, olivine and plagioclase phenocysts are completely altered, as is the groundmass. Sample Knr61 18-34 is extremely altered and exceptional because its major phenocryst phase is biotite. The biotite crystals are up to 10 mm in size and contain abundant large apatite crysals (up to 2 mm in size).

The major element analyses, through showing effects of alteration,

indicate that most of the samples are probably undersaturated basalts. Sample Knr61 14-1 appears to be more evolved, perhaps being a trachybasalt. Sample Knr61 18-34 has not yet been analyzed for its major element contents.

METHODS

INTRODUCTION

Pb, Sr and Nd isotope analyses were performed on whole rock samples and mineral separates. The whole rock samples were both acid-leached and unleached. Unleached whole rock samples were also analyzed for their rare earth element (REE) and other trace element contents by instrumental neutron activation analyses (INAA). Judicious use of the sample material was a primary concern, because I planned to analyse both whole rock samples and mineral separates. The H_2O and acid solutions used in sample preparation and leaching were all purified by distillation.

SAMPLE PREPARATION

Whole Rock

After removing saw marks with silicon carbide, the slabs were ultrasonically cleaned in H_2O, wrapped in plastic (to avoid metal contamination) and broken into approximately 1 cm size pieces. Approximately 10 grams of material was selected, avoiding excessively altered portions and attempting to obtain a representative sample. These pieces were ultrasonically cleaned in H_2O, then crushed to a size ê 386 µm using an agate mortar and pestle. Samples for INAA were prepared and provided by G. Thompson.

Splits of the whole rock samples prepared for the isotopic analyses were leached with hot (125° F) 6.2N HCl in a covered teflon beaker for 10-12 hours. The leached material was thoroughly rinsed and ultrasonically cleaned with H_2O. The leachate was discarded.

A preliminary experiment was designed to evaluate the effects of the leaching procedure. A split of sample AII85 13-54 was leached as outlined above, while another portion was subjected to a "mild" leaching. This

"mild" leaching consisted of successive additions of cold 6.2N HCl over approximately a half hour interval, until all the calcite was dissolved (as discerned by the cessation of CO_2 evolution).

Mineral Separates

The approximately 1 cm size pieces of sample (see whole rock prep.) were crushed, as above, and sieved to size fractions permitting the most efficient picking of alteration-free mineral grains, either 220-386 µm or 386-500 µm. The selected size fraction was ultrasonically cleaned in H_2O. The mineral fraction was then concentrated using a Frantz isodynamic magnetic separator.

Pure separates were obtained by hand picking. The grains were immersed in ethanol and picking was done with stainless steel tweezers under a binocular microscope with fiber optic illumination. In order to insure the identification of any unwanted material, it was necessary for the grains to be nearly transparent. Only "pristine looking" grains which were clearly free of alteration products were selected. Thin sections were examined to confirm the purity of the minerals.

The hornblende and cpx mineral separates were cleaned in a three-stage process based on suggestions given by S. Richardson who modified a procedure reported by Shimizu (1975). The separates were successively washed with 2.5N HCl at 125°F for one-half hour, a cold 5% HF solution for ten minutes and again with 2.5N HCl (125°F) for one-half hour. All washing was done in an open teflon beaker. The separates were rinsed with H_2O after the first two stages and ultrasonically cleaned in H_2O after the final stage. They were not crushed prior to dissolution.

Analytical Techniques

Pb isotopic compositions and U and Pb contents were measured on

separate sample dissolutions while $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, and Rb, Sr, and

Nd concentrations were measured on single sample dissolutions. Chemical

and mass spectrometric techniques for the determination of: Pb isotopic

compositions and concentrations were adapted for use in this lab by W.J.

Pegram (personal comm., 1983) from the techniques of Strelow and Toerien

(1966) and Manhes et al. (1978); U contents as adapted from the techniques

of Chen and Wasserburg (1981) by M. Reid (personal comm., 1983); Rb and Sr

concentrations and $^{87}Sr/^{86}Sr$ values followed the procedure of Hart and

Brooks (1977); Sm and Nd contents and $^{143}Nd/^{144}Nd$ values utilized

techniques adapted from the work of Richard et al. (1976) as summarized by

Zindler et al., (1979) and Richardson (1984). Procedural blanks are

insignificant. Standard values used in normalization of isotope ratios for

mass fractionation and systematic machine bias are given in Table 1.

REE and Hf, Th, Ta, Cr, Co, Sc, Na, Rb, Cs and Ba contents were

determined by INAA at MIT using methods described by Ila and Frey (1984)

and the data reduction algorithms of Lindstrom and Korotev (1983).

RESULTS AND DISCUSSION

The isotopic and trace element results are listed in Tables 1 and 2. Before discussing their relevance to the petrogenesis of the NES, I will discuss the difficulties in interpreting these results presented by alteration effects and old age. I will do this for the isotopic data in the following section, and for the REEs, and Th, Ta and Hf data as I begin to apply the results towards understanding the development of the NES. A discussion of the significance of the isotopic data to the NE Seamounts' petrogenesis will follow that for the trace elements.

ALTERATION AND OLD AGE: PROBLEMS AND SOLUTIONS

Introduction

Isotope geochemists often acid-leach samples of young altered rocks to remove secondary effects, enabling the sample's primary (unaltered) Sr, Nd and Pb isotopic compositions to be determined. To be successful, the leaching procedure must completely strip away the secondary isotopic component, while leaving behind a portion of the primary component. Clearly, this assumption holds true for HCl leaching of secondary calcite. However, the usefulness of leaching for samples containing alteration phases such as zeolites and smectite is uncertain. Conventional wisdom presumes that a sample's primary isotopic compostion has been obtained when isotopic values measured subsequent to repeated leachings are constant. However, an alteration product may be as robust to the leaching procedure as the primary phases. As a result, leaching techniques must be used cautiously.

A rock's initial isotopic composition reflects that of its source (the focus of this study). Therefore, on old rocks, the radioactive parent

TABLE 1a. Rb, Sr, Sm, and Nd concentrations and Sr and Nd isotopic compositions of
leached and unleached whole rock samples and mineral separates, NES[1]

Seamount Sample No. age[2]		Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr_i$	$^{87}Sr/^{86}Sr_{prj}$	Sm	Nd	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$^{143}Nd/^{144}Nd_i$	$^{143}Nd/^{144}Nd_{prj}$
Nashville Knr61 14-1 83 m.y.	unleached	–	–	–				16.3	103	.0957	–	.512718	.512821
	leached	–	–	–	.70347±3		.70353	8.53	51.0	.1010	.512770±16	.512715	
	Hornblende	14.0	1659	.0244	.70347±3	.70344	.70350	15.60	75.6	.1247	.512763±14	.512695	.512798
Michael Knr61 18-34 84 m.y.	leached	–	–	–	.70516±3			–	–	–	–		
Allegheny AII85 16-5 84 m.y.	unleached							14.22	81.8	.1052	.512863±15	.512805	
	leached	–	–	–	.70349±3		.70355	–	–	–	.512887±14	.512829	.512933
Gregg Knr61 24-8 87 m.y.	unleached							9.3	45	.1250	–	.512837	.512945
	leached	–	–	–	.70327±3		.70333	4.63	17.57	.1594	.512908±16	.512817	
	Cpx							4.72	16.57	.1721	.512945±13	.512847	.512955
Atlantis II AII85 13-54 89 m.y.	unleached							12.5	67	.1128	–	.512682	.512792
	mildly leached	–	142.8	–	.70366±3								
	leached	–	133.3	–	.70312±2		.70318	7.31	30.53	.1448	.512764±25 .512748±15	.512664	
	Cpx	.1037	185.2	.0016	.70311±3	.70311	.70317	8.21 8.26	32.55 32.84	.1526 .1521	.512750±39 .512774±17	.512685	.512795
Atlantis II AII85 12-2 94 m.y.	leached	–	–	–	.70343±3								
	2nd leaching	–	–	–	.70342±3								
	Cpx	.0899	141.7	.0018	.70323±3	.70323	.70329	7.12 8.20	27.44 32.0	.1569 .1549	.512781±45 .512767±16	.512685 .512672	.512789
Bear AII85 1-47 103 m.y.	unleached							12.6	71	.1073	–	.512709	.512837
	leached	–	–	–	.70345±3		.70352	6.92	34.68	.1206	.512781±21 .512789±39	.512700	

[1] Concentrations in ppm (ug/g). Leached and unleached refer to whole rock samples. Unleached Sm and Nd contents determined by INAA (except for sample AII85 16-5). Errors in Table 2. All other concentrations determined by isotope dilution, with precision for Sr, Nd and Sm ~0.3% and for Rb ~1%. All blanks insignificant. $^{87}Sr/^{86}Sr$ values normalized to 0.70800 for E + A SrCO$_3$ using $^{86}Sr/^{88}Sr$=0.1194. $^{143}Nd/^{144}Nd$ values normalized to .51264 for BCR-1 using $^{146}Nd/^{144}Nd$=0.7219. Errors in isotope ratios, based on in-run statistics, are $2\sigma_{mean}$ corresponding to the least significant digits. Initial ratios calculated using seamount ages (column 1) and $\lambda(^{87}Rb)$=1.42×10^{-11}yr^{-1} and $\lambda(^{147}Sm)$=6.54×10^{-12}yr^{-1}. Isotopic ratios projected (prj) to the present day using the seamounts' ages and $^{87}Rb/^{86}Sr$=0.05 and $^{147}Sm/^{144}Nd$=0.19 for their OIB source.

[2] Seamount ages from Duncan (1983) were determined on the same samples, except for sample knr61 24-8, whose age was interpolated from the other data.

TABLE 1b. Th, U and Pb concentrations and Pb isotopic compositions of
leached and unleached whole rocks and a mineral separate, NES[1]

Seamount Sample No.		Th	U	Pb	$^{232}Th/^{204}Pb$	$^{238}U/^{204}Pb$	$^{235}U/^{204}Pb$	$206/204Pb$	$207/204Pb$	$208/204Pb$	$206/204Pb_i$	$207/204Pb_i$	$208/204Pb_i$	(projected values) $206/204Pb$	$207/204Pb$	$208/204Pb$
Nashville Knr61 14-1	unleached	15.4	3.29	6.00	179	37.1	.269	20.787	15.663	40.796	20.307	15.640	40.058	20.514	15.650	40.264
	leached							20.854	15.645	40.717	20.09					
	Hornblende		.021±.004	.33	–	4.3	–	20.145[2]	–	–						
Michael Knr61 18-34	unleached	11.9	4.94	15.77	51	20.5	.141	19.436	15.668	39.462	19.168	15.655	39.250	19.378	15.665	39.458
								19.453	15.683	39.512						
	leached							20.020	15.672	40.661						
Allegheny AII85 16-5	unleached	–	1.06	7.32	–	9.8	.071	20.171	15.634	40.208	20.043	15.628	–	20.253	15.638	–
			1.07	7.15	–	10.0	.072									
Gregg Knr61 24-8	unleached	3.3	1.19	1.86	122	42.6	.309	20.668	15.649	39.859	20.089	15.621	39.331	20.306	15.631	39.546
	leached							20.87±.01	15.68±.01	40.47±.03						
Atlantis II AII85 13-54	unleached	6.2	1.36	3.81	112	23.7	.172	20.122	15.638	40.283	19.792	15.622	39.789	20.015	15.633	40.010
	leached							20.036	15.643	40.308						
Atlantis II AII85 12-2	unleached	5.7	1.77	3.36	117	35.1	.255	20.401	15.623	40.281	19.885	15.598	39.735	20.121	15.609	39.968
								20.396	15.620	40.271						
Bear AII85 1-47	unleached	7.4	1.82	4.21	120	28.5	.207	19.789	15.614	39.888	19.330	15.592	39.277	19.652	15.604	39.532
	leached							19.876	15.690	40.193						

[1]Concentrations in ppm (µg/g). Leached and unleached refer to whole rocks samples. Th contents determined by INAA, precision in Table 2. U and Pb concentrations determined by isotope dilution, with precision for U and Pb ~1%. Pb isotopic ratios corrected for mass fractionation by that obtained for NBS 981. Reproducibility is 0.05% AMU^{-1}. Initial ratios calculated using seamount ages (Table 1a) and $\lambda(^{238}Th)$=1.55125×10^{-10}yr^{-1}, $\lambda(^{235}U)$=9.8485×10^{-10} and $\lambda(^{232}Th)$=4.9475×10^{-11}. Isotopic ratios projected to the present day using the seamounts' ages and $^{238}U/^{204}Pb$=16 $^{235}U/^{204}Pb$=0.116 and $^{232}Th/^{204}Pb$=50 for their OIB source. Pb blank levels for the hornblende separate of sample Knr61 14-1 were ~1.7% of the total Pb. Corrections were applied. Blank levels were insignificant for all other analyses.

[2]Calculated from isotope dilution measurements.

TABLE 2
Trace Element Contents[1]
Whole rock samples, NES

Seamount	Nashville	Michael	Rehoboth	Gregg	Atlantis II	Atlantis II	Retriever	Bear
Sample No.	Knr61 14-1	Knr61 18-34	Alv540 4-1	Knr61 24-8	AII85 13-54	AII85 12-2	Knr61 31-7	AII85 1-47
La	140±2	122±2	67±1	39.5±.5	65.9±.8	60.0±.8	66.6±.8	78±1
Ce	288±5	281±5	127±2	90±2	143±3	138±3	142±3	166±3
Nd	103±3	132±3	64±2	45±1	67±2	65±2	72±2	71±2
Sm	16.3±.2	21.7±.3	12.5±.2	9.3±.1	12.5±.2	11.7±.2	13.1±.2	12.6±.2
Eu	4.5±1	5.9±.1	3.6±.1	2.92±.07	3.8±.1	3.5±.1	3.8±.1	3.7±.1
Tb	1.4±.1	1.7±1.4	1.3±.1	1.1±.1	1.2±.2	1.1±.1	1.3±.1	1.1±.1
Ho	1.6±.3	2.2±.3	1.2±.2	1.2±.2	1.2±.2	1.3±.2	1.4±.2	1.2±.2
Yb	2.9±.1	3.2±.1	3.1±.2	2.0±.1	2.0±.1	1.8±.1	2.22±.14	2.13±.14
Lu	.43±.02	.48±.03	.46±.02	.27±.02	.28±.02	.29±.02	.34±.02	.32±.02
Na	35100±600	9940±150	11680±120	12110±120	5250±60	14180±150	11820±140	15740±190
Rb	49±9	57±12	35±10	18±7	19±8	55±11	21±7	45±10
Cs	7.2±.5	1.3±.2	----	.4±2	.4±.2	1.2±.2	----	.4±.2
Ba	1530±170	790±100	590±80	270±50	280±50	580±70	520±80	760±100
Hf	11.0±.3	13.6±.3	9.6±.3	6.1±.2	7.5±.2	8.0±.3	8.5±.3	8.4±.2
Th	15.4±.8	11.±9.7	6.6 ±.4	3.3±.2	6.2±.4	5.7±.4	5.2±.3	7.4±.4
U	1.8±.8	3.5±1.5	----	1.9±.6	1.3±.5	1.5±.9	----	1.4±.6
Ta	12.6±.5	10.7±.4	4.3±.2	2.8±.2	4.6±.2	4.4±.2	4.0±.2	5.9±.3
Cr	7.7±.8	148±3	6±1	344±6	287±5	228±4	782±12	55±2
Co	14.6±.2	49.2±.6	33.7±.5	53.9±.7	55.5±.7	51.4±.7	60.9±.8	44.0±.6
Sc	7.8±.1	41.2±.5	18.7±.2	33.6±.4	33.5±.4	36.7±.4	35.3±.4	26.4±.3

[1]Determined by INNA at M.I.T.

(P) and radiogenic daughter (D) concentrations must be measured in order to age-correct their present day isotopic compostions. Obtaining initial ratios from altered old rocks is problematical because of the possibilty that the secondary processes modified the P/D ratios in ways that renders age corrections difficult or impossible. Most geochemists avoid these rocks.

Reliable initial isotopic compositions may be obtained under certain conditions. Obviously, if a P-D pair is robust to the alteration process, there is not a problem. If alteration is complete soon after eruption of the magmas and the daughter's initial isotopic composition is not effected by the secondary process, the present day P/D ratio is the appropriate value to use when calculating the sample's initial ratio. The alteration process may be short-lived for the bulk of the oceanic crust in a spreading ridge environment, but shallow level (ie. dredged) oceanic island volcanics have probably undergone continous low temperature weathering subsequent to the higher temperature alteration occuring upon their eruption. If alteration does continue as the rock ages, as long as the parent's concentation changes monotonically with time and the only change in the daughter's contents and isotopic composition is from decay, the present day P/D ratio is either a minimum or maximum value. If none of these stipulations is met, age corrections remain problematical. Leaching will not alleviate these difficulties, as it would be fortuitous for this techique to yield the P/D ratio corresponding to the radiogenic growth since the rock's eruption.

In order to obtain useful isotopic data from the old and altered NES samples, I analyzed both leached and unleached whole rock samples and mineral separates for their isotopic compositions. By comparing these

results below, I will evaluate the assumptions inherent in the leaching technique, investigate the effects of seawater alteration on the elements analyzed and select the data which are most useful in investigating the petrogenesis of the NES.

The alteration studies, cited below, have been performed on MORB which has experienced a hydrothermal alteration process unique to a spreading ridge environment. However, to my knowledge, there are not any studies of similar quality and comprehensive nature which have examined seawater alteration of ocean island volcanics; it seems reasonable to assume that at least the direction of elemental partitioning between seawater and basalt observed at ridge is applicable to the oceanic island environment.

The isotopic systems

1. Rb-Sr system

Of the isotopic systems I am examining, the Rb-Sr system is the most susceptible to alteration effects, and is the most problematical. Rb, like the other alkali elements, is added to oceanic floor volcanics during alteration, occupying sites in palagonite and clays (Hart, 1969; Hart et al., 1974; Frey et al., 1974, Richardson et al., 1980; Staudigel et al., 1981; Hart and Staudigel, 1978, 1982). Alteration also increases the Sr content of the seafloor volcanics as seawater Sr, with it high $^{87}Sr/^{86}Sr$ value, is partitioned strongly into secondary calcite and to a lesser extent, into secondary clays and zeolites (Hart et al., 1974; Hart and Staudigel, 1978; Richardson et al., 1980; Staudigel et al., 1981; Taras, unpublished). As a result, the Rb and Sr concentrations and Sr isotopic compositions of seafloor basalts are likely to be modified during alteration. Even if alteration was complete soon after eruption (unlikely for shallow level seamount volcanics) the whole rock Rb/Sr value will be

useless for age correcting because the initial isotopic composition of Sr has also been altered.

I proceeded to leach whole rock samples in hot 6.2N HCl, pessimistically hoping that it would remove all secondary Sr effects, thus permitting the measurement of a primary isotopic value. Comparing the $^{87}Sr/^{86}Sr$ values of two splits of sample AII85 13-54, which underwent different degrees of leaching (Table 1, see methods), indicates a substantial reduction in $^{87}Sr/^{86}Sr$ during the leaching process. For samples AII85 13-54 and Knr61 14-1 (Table 1, Fig. 3) the $^{87}Sr/^{86}Sr$ values measured on minerals (equal to the initial ratios) agree with those measured on their acid-leached host, whole rocks. This agreement indicates that leaching "cleansed" the rocks of secondary effects, and that the whole rock $^{87}Rb/^{86}Sr$ ratios, corresponding to the measured $^{87}Sr/^{86}Sr$ values, were too small to contribute a significant amount of radiogenic Sr.

The $^{87}Sr/^{86}Sr$ value for leached whole rock AII85 12-2 is significantly higher than its mineral value, and repeated leaching did not reduce the discrepancy (Table 1, Fig. 3). If, as suggested by samples Knr61 14-1 and AII85 13-54, the leaching process successfully removed all of the secondary Sr effects, then this whole rock sample must have an $^{87}Rb/^{86}Sr$ ratio that contributed a significant amount of radiogenic Sr to the measured $^{87}Sr/^{86}Sr$ value. An $^{87}Rb/^{86}Sr$ = 0.14, typical of oceanic island basalts (Hart and Brooks, 1981) is sufficient to age correct the whole rock's $^{87}Sr/^{86}Sr$ to the minerals initial ratio, supporting the idea that the high $^{87}Sr/^{86}Sr$ value need not be due to alteration. Also, the whole rock $^{87}Sr/^{86}Sr$ value for Knr61 18-34 shows the effect of the high $^{87}Rb/^{86}Sr$ in the biotite phenocrysts (Table 1).

The leaching process appears to yield primary Sr isotopic

FIGURE 3

Nd-Sr isotope correlation diagram showing NES leached whole rock and mineral separate data. Encircled symbols represent mineral separate analyses. Arrows indicate unmeasured values.

Legend (within figure):

+ Nashville   Knr61 14-1

★ Allegheny   AII85 16-5

● Gregg   Knr61 24-8

■ Atlantis II   AII85 13-54

□ Atlantis II   AII85 12-2

▲ Bear   AII85 1-47

○ Mineral

↔ Unmeasured value

Uncertainty

Y-axis: $^{143}Nd/^{144}Nd$

X-axis: $^{87}Sr/^{86}Sr$
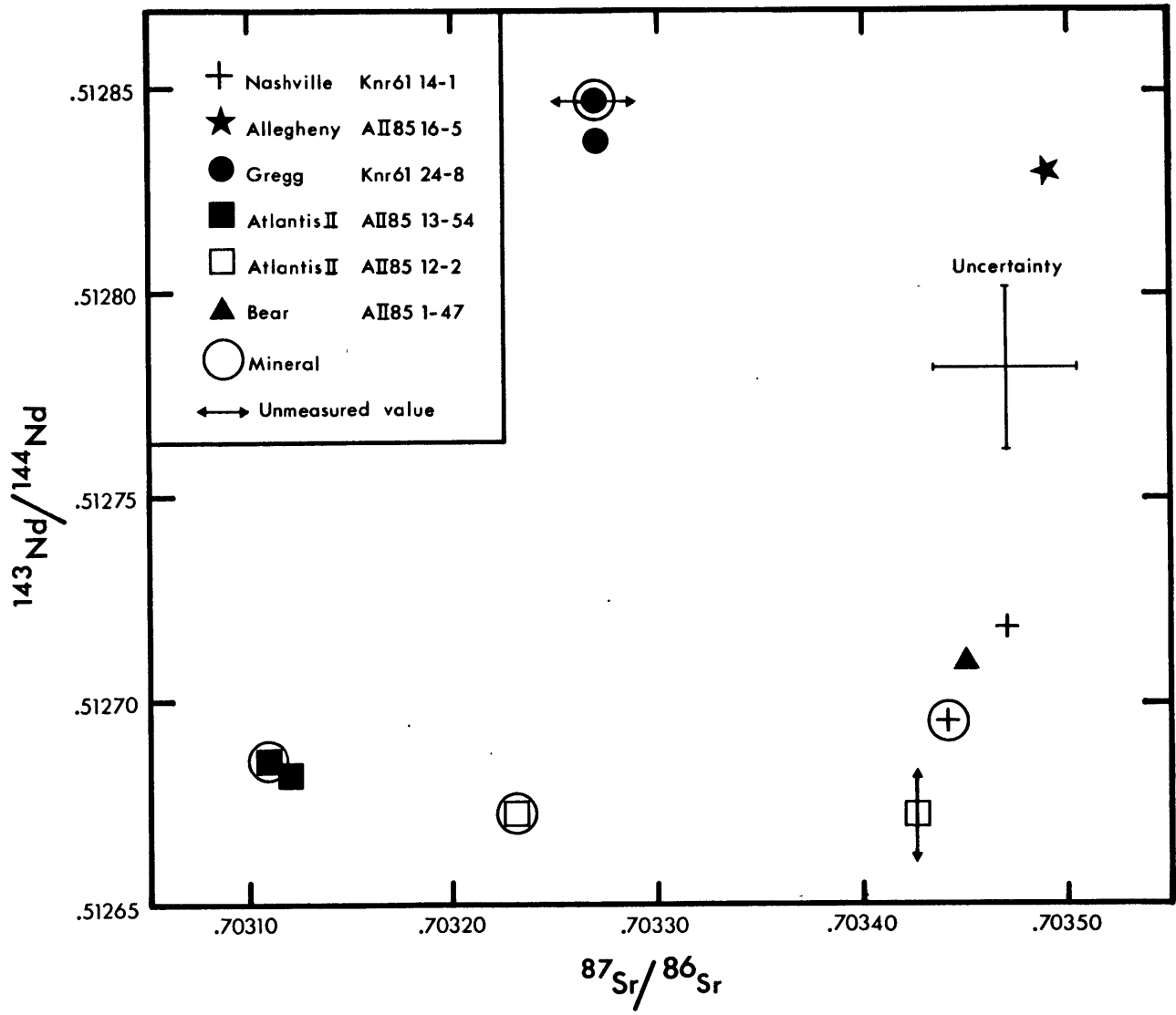
compositions. However, age corrections, when necessary, can not be accurately calculated because of the inability to measure the appropriate $^{87}Rb/^{86}Sr$ ratio. Therefore, the measured whole rock $^{87}Sr/^{86}Sr$ values are maximum values and somewhat limited in interpretive power, as a reasonable range of $^{87}Rb/^{86}Sr$ ratios must be considered when calculating age corrections. So, although the leaching procedure may provide useful information, its limitations must be recognized.

2. The Sm-Nd system

Conventional wisdom presumes that the low REE contents of seawater (less than 10^{-6} x MORB, Elderfield and Greaves, 1982) make seafloor weathering and hydrothermal alteration unlikely means for affecting the REE features of an oceanic basalt. However, an element's low concentration in seawater, in itself, does not indicate that this element's contents in seafloor basalt is robust to seawater alteration. In fact, Cs has a low concentration in seawater because it is strongly partitioned into the oceanic crust during alteration (Staudgel and Hart, 1982, 1983). Therefore, studies examining both altered oceanic crust and the seafloor alteration processes are necessary to understand the behavior of an element during these secondary processes.

By comparing altered and fresh oceanic floor basalts Frey et al. (1974), Ludden and Thompson (1979), and Juteau et al. (1979) showed that seawater alteration can mobilize the REE and, in particular, selectively enrich the light REE. On the other hand, studies of altered glass, Staudigel and Hart (1983), and hydrothermal vent waters, Michard et al. (1984), have demonstrated the immobility of the REE in the ocean crust during hydrothermal alteration. Staudigel and Hart attributed the conflicting results to differences in water/rock ratios, indicating that

while most of the ocean crust does not experience REE mobilization, rocks in those areas with exceptionally high permeability, such as highly fractured crust or the sea floor surface, may have their REE characteristics modified.

By comparing the $^{147}Sm/^{144}Nd$ and the $^{143}Nd/^{144}Nd$ values measured on acid-leached and unleached whole rocks and mineral separates I will demonstrate that seawater alteration has not significantly affected the Sm-Nd isotopic systematics, even though the NES samples are dredged (high water/rock ratio) basalts. Also, I will show that it is appropriate to use either leached or unleached whole rock $^{143}Nd/^{144}Nd$ values and unleached whole rock $^{147}Sm/^{144}Nd$ values when contemplating the petrogenesis of the NES. I will argue for the primary nature of the NE Seamounts' overall REE characteristics when I present and discuss the REE contents of the unleached whole rock samples, determined by INAA.

$^{143}Nd/^{144}Nd$ values measured on leached and unleached splits of sample AII85 16-5, are identical within error (Table 1), affirming the stability of the Sm-Nd system. To be efficient, I chose to analyse only leached whole rock splits of the other samples, thus permitting the measurement of Sr and Nd isotopic compostions and Sm and Nd concentrations on the same sample dissolution.

Comparing the isotopic dilution data on the leached whole rocks with the INAA data on unleached whole rocks indicates that leaching reduced the Sm and Nd contents by up to 65%. Leaching also fractionated these elements causing a 20% increase in the $^{147}Sm/^{144}Nd$ ratios of the leached whole rocks (Table 1). These differences in $^{147}Sm/^{144}Nd$ ratios produce only small, approximately analytical error in size, variations in the whole rock's calculated initial $^{143}Nd/^{144}Nd$ values. The initial ratios determined using

the $^{147}Sm/^{144}Nd$ ratio of the unleached samples are nearer the corresponding

mineral's initial $^{143}Nd/^{144}Nd$ value than those determined using the

$^{147}Sm/^{144}Nd$ ratios of the leached samples (Table 1). This indicates that

the unleached whole rock $^{147}Sm/^{144}Nd$ ratios are more representative of the

sample's primary value.

These whole rock initial $^{143}Nd/^{144}Nd$ values are identical, within

error, to those of their corresponding minerals (Table 1; Fig. 3)

confirming the stabiltiy of the Sm-Nd isotopic system for the NES samples

and verifying the combined use of leached whole rock $^{143}Nd/^{144}Nd$ (=

unleached values) and unleached whole rock $^{147}Sm/^{144}Nd$ ratios when

discussing the petrogenesis of NES.

3. The Th-U-Pb systems

The low concentrations of Pb and Th in seawater, about $5x10^{-6}$ x MORB

(Schaule and Patterson, 1981) and about $1x10^{-6}$ x MORB (Kaufman, 1969),

respectively, are often invoked to suggest that seawater alteration

processes do not effect the contents of these elements in oceanic basalts.

Again, this is not a conclusive arguement. The U contents of seawater is

substantially higher (about $1x10^{-2}$ x MORB, Turekian and Chan, 1971).

Studies of altered MORB, Tatsumoto (1978), and hydrothermal vent

waters, Michard et al. (1984), suggest that alteration depletes oceanic

basalts in Pb, causes slight or no depletions in Th and enriches basalts in

U, resulting in increased U/Pb, Th/Pb and U/Th ratios. By comparing

altered and unaltered MORB, Hart and Staudigel (1982) have also argued that

the upper crust acts as a sink for U.

As the alteration of NE Seamounts' shallow level volcanics most likely

continued long after their eruption, the measured P/D ratios will be larger

than the P/D ratios corresponding to the time-intergrated radiogenic growth

of Pb. Therefore, the initial Pb isotopic compostions calculated using these P/D ratios will be minimum values. The Th, U and Pb contents and the Th/U (except for Knr61 18-34) and U/Pb ratios (Table 1) of the NES samples are typical of alkalic oceanic island volcanics (Sun, 1980). This implies limited alteration effects and therefore accurate age corrections. The somewhat low Th/U value (= 2.4) of sample Knr61 18-34 is probably due to secondary processes, as this sample is extremely altered. Its U/Pb ratio is not correspondingly high (Pb gain?).

Variations between the Pb isotopic compositions measured on leached and unleached splits of 4 samples ($\approx 1\%$ in $^{206}Pb/^{204}Pb$, < 0.5% in $^{207}Pb/^{204}Pb$ and < 1.5% in $^{208}Pb/^{204}Pb$) are small compared to the total variation exhibited by the NES. A fifth sample, Knr61 18-34, shows larger variations in $^{208}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ (about 3%) without any substantial variation in $^{207}Pb/^{204}Pb$ (Fig. 4).

If leaching had preferentially removed seawater or pelagic sediment Pb ($^{206}Pb/^{204}Pb=19.04$, $^{207}Pb/^{204}Pb=15.64$, $^{208}Pb/^{204}Pb=39.06$ for Northwest Atlantic manganese nodules; Reynolds and Dasch, 1971) isotopic variations in the proportions indicated in figure 4 would result. The relative magnitude and sense of the isotopic variations exhibited by the NES samples do not reflect those expected from preferential leaching of seawater or pelagic sediment Pb.

Most apparent is that the $^{208}Pb/^{204}Pb$ variations are equal to or slightly larger that those for $^{206}Pb/^{204}Pb$ for samples Knr61 18-34, Knr61 24-8 and AII85 1-47. This implies that seawater alteration is not the cause of these variations.

The large $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ variations and nearly constant $^{207}Pb/^{204}Pb$ in sample Knr61 18-34 could have been caused by the leaching

FIGURE 4

Comparison of Pb isotopic compositions measured on leached (L) and unleached (UL) whole rock (WR) samples.

$$\% \text{ variation} = \frac{\text{L WR value} - \text{UL WR value}}{\text{UL WR value}} \times 100\ \%$$

The column entitled seawater Pb addition illustrates the relative change in Pb isotope ratios expected if the leaching process removed a seawater Pb component. The last column indicates the relative change in Pb isotope ratios expected if the Pb isotopic composition of the leached whole rock was fractionated while being measured.

% VARIATION
LEACHED:
UNLEACHED

Bear All85 1-47 Atlantis II All85 13-54 Gregg Knr6l 24-8 Michael Knr6l 18-34 Nashville Knr6l 14-1 Sea Water Pb Addition Mass Fractionation of Leached WR Measurements

$\frac{206}{204}$ Pb

$\frac{207}{204}$ Pb

$\frac{208}{204}$ Pb

Uncertainty
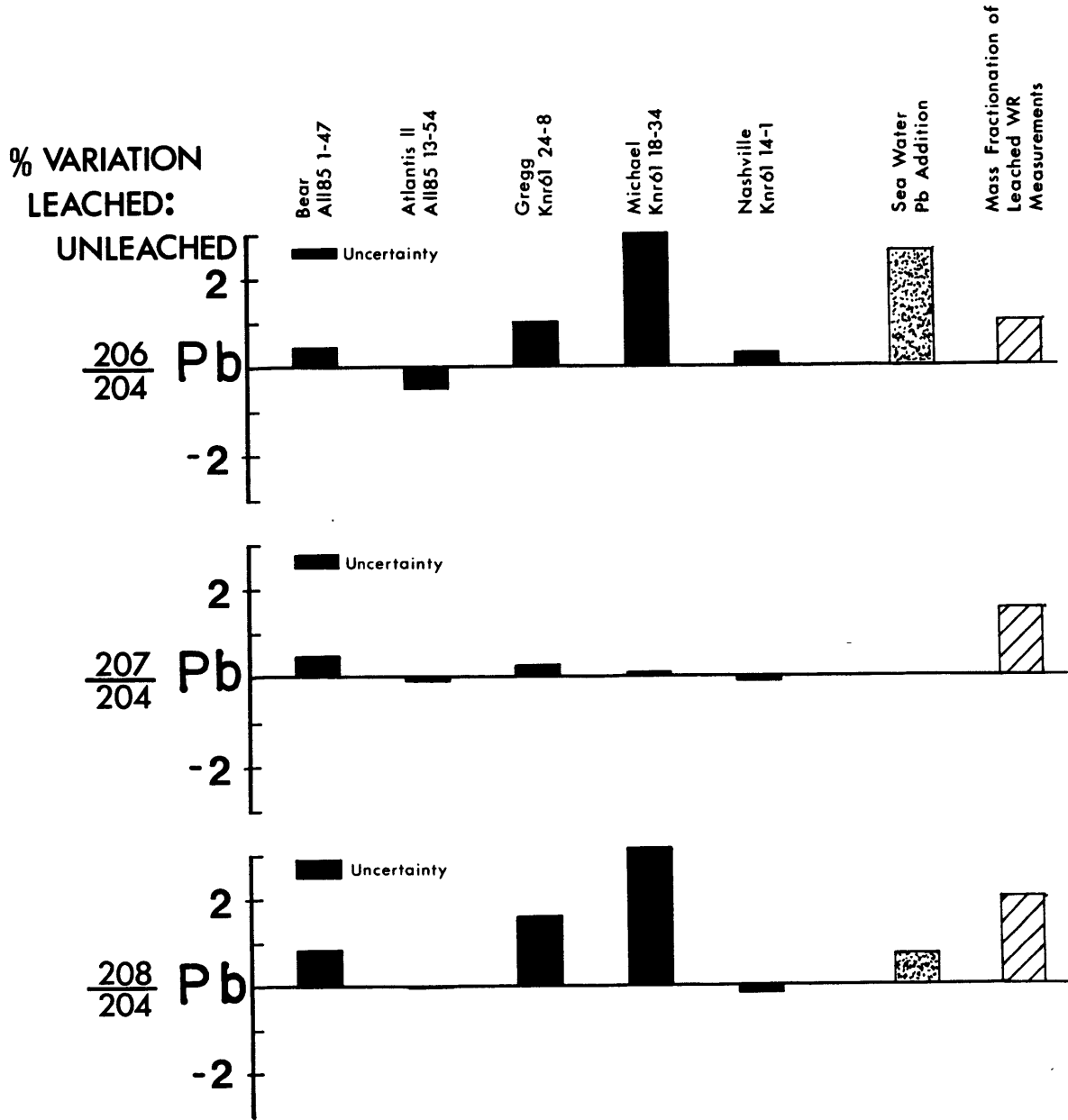
process if it preferentially left behind radiogenic Pb in a high U/Pb, Th/Pb phase. In this case, the lack of increase in ^{207}Pb would be a consequence of the relative abundance of uranium's isotopes (^{235}U << ^{238}U). Biotite, the dominant phenocryst phase in Knr61 18-34, contains numerous and large (up to 2 mm in size) apatites. Apatite typically has high U/Pb and Th/Pb ratios, and would be capable of causing the observed variations.

Samples Knr61 14-1 and AII85 13-54 demonstrate good agreement between leached and unleached Pb isotopic compositions while the variation in sample AII85 1-47 is easily explained by mass fractionation during the measurement of the leached whole rock's isotopic composition (Fig. 4). Some of the variation in sample Knr61 24-8 is also a result of mass fractionation effects during the measurement of the leached whole rock's Pb isotopic composition. A small remaining variation is not so easily explained and is possibly the result of the leaching process preferentially leaving behind radiogenic Pb.

The variations between the leached and unleached whole rock Pb isotopic compositions thus appear to be caused by preferential leaching of Pb and mass fractionation effects, not by alteration processes. As a result, I will use the isotopic compositions measured on the unleached whole rock samples along with the U, Pb and Th (INAA) data, also measured on unleached whole rock samples, when discussing the NE Seamounts' Pb isotopic characteristics. A note of concern: the leaching process may change the isotopic compostion of an element in an old rock by selectively removing or leaving behind radiogenic Pb.

I calculated an initial ^{206}Pb/^{204}Pb value for a hornblende separate using isotope dilution results (Table 1). It is within 1% of its whole rock host's value, a good agreement considering the former's large

uncertainty. These results support the general reliability of the whole rock values. In order to make a more definitve comparison I am currently picking a hornblende separate that I will directly analyse for its Pb isotopic composition. The $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values were not calculated from the isotope dilution measurements because of poor peak resolution, lack of Th data and the high ^{207}Pb and ^{208}Pb abundances in the spike.

Summary

I have shown that primary isotopic data can be obtained from older altered oceanic volcanics. In subsequent sections I will present these results and discuss their relevance to the petrogenesis of the NES. The following section is a presentation of the trace element data, including further arguements for the primary nature of the REE contents of the NES samples.

RESULTS AND THE PETROGENESIS OF THE NEW ENGLAND SEAMOUNTS

Trace element characteristics

1. Alkaline Affinities of the NES

Trace element data determined by INAA on eight unleached whole rock samples are presented in Table 2 and Figures 5, 6 and 7. Their high REE contents (La_N = 125-450 and Yb_N = 9-15) and light REE enriched REE patterns (La/Yb =20-48; Table 2; Fig. 5) suggest that these NES samples are typical oceanic island alkaline volcanics (Kay and Gast, 1973; Sun and Hanson, 1975a, b; Clague and Frey, 1982). Unlike some of the small EPR seamounts described by Zindler et al. (1983), the NES do not bear any resemblance to MORB.

Had seawater alteration significantly modified these REE features, I would expect to see both selective light REE enrichment (Ludden and

FIGURE 5

Chondrite-normalized rare earth element plot for NES unleached whole rocks.
The measured values were normalized to the chondrite abundances 1.27 times
those determined by Evenson (1978). Symbols as in figure 3, except
X = ALV540 4-1, Rehoboth Seamount and Δ = Knr61 31-7, Retriever Seamount.

FIELD OF
HONOLULU
    ALKALINE
    VOLCANICS
(Clague and Frey, 1982)

MORB
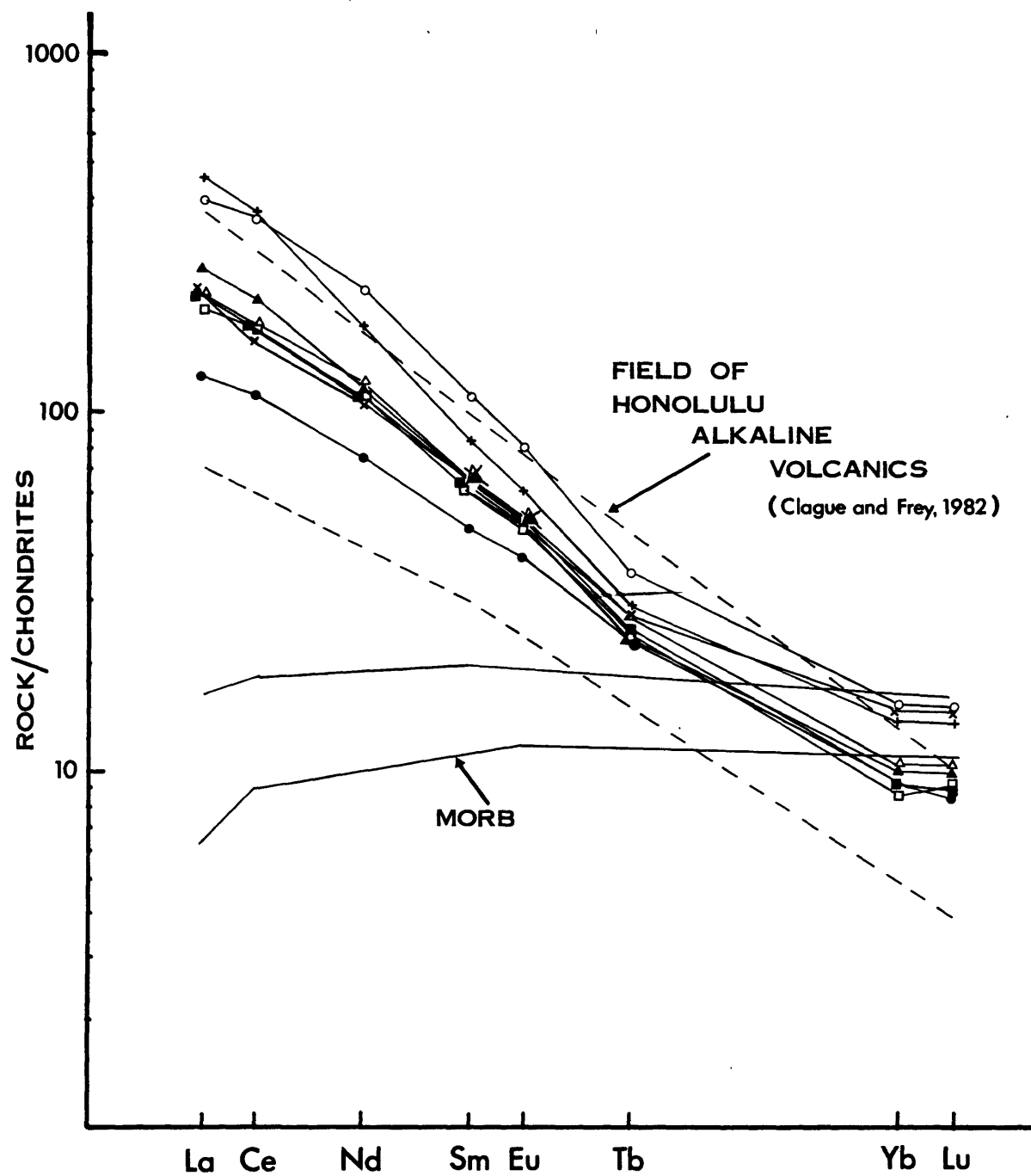
Thompson, 1979) and a correlation between light REE enrichment and extent

of alteration. The nearly constant slope of the REE patterns and the lack

of a correlation between either La/Ce or La/Nd and $\%H_2O$ (Fig. 6)

demonstrate that the REE contents of these samples have not been

significantly altered and confirm the alkaline nature of the NES. The

slightly shallower slope defined by the heaviest REE, Tb-Yb, is a common

feature of oceanic island alkaline volcanics (Sun and Hanson, 1975a, b;

Basaltic Volcanism Study Project, 1981; Clague and Frey, 1982).

Furthermore, these samples lie in the alkaline within-plate magma

region on a Th-Hf-Ta ternary diagram (Fig. 7), that is useful in

discriminating between alkaline and tholeitic within plate volcanics. (Wood

et al., 1979). These high field strength elements are especially useful

when studying altered rocks since they are insensitive to secondary

processes (Pearce and Cann, 1973; Floyd and Winchester, 1975). Also, as

they are incompatible in the silicate phenocryst phases of

intermediate-mafic magmas, their relative abundances will not be affected

by either accumulation or fractionation of these minerals. Greater than

2-3% cumulate Fe-Ti oxides, into which Ta is more strongly partitioned than

Hf and Th, can limit the usefulness of this diagram (Wood, 1980). However,

petrographic evidence does not reveal cumulate Fe-Ti oxides in these

samples.

The extent of alkaline volcanism at a particular seamount cannot be

ascertained from one or two analyzed samples, especially when the samples

have been dredged. However, considering that all the analyzed samples are

alkalic and that their collection localities range relatively far from the

seamounts' summits (Table 1 in the Appendix) suggests the presence of at

least a substantial cap of alkaline volcanics at each seamount. Subsequent

FIGURE 6

% H_2O vs. La/Ce and La/Nd for NES unleached whole rocks. Symbols as in figures 3 and 5.
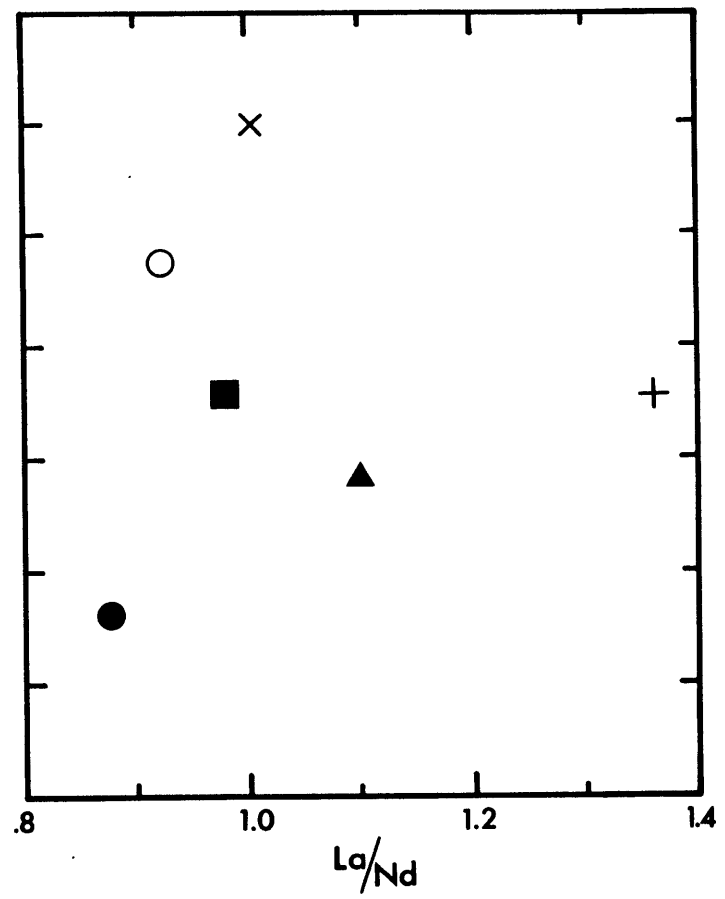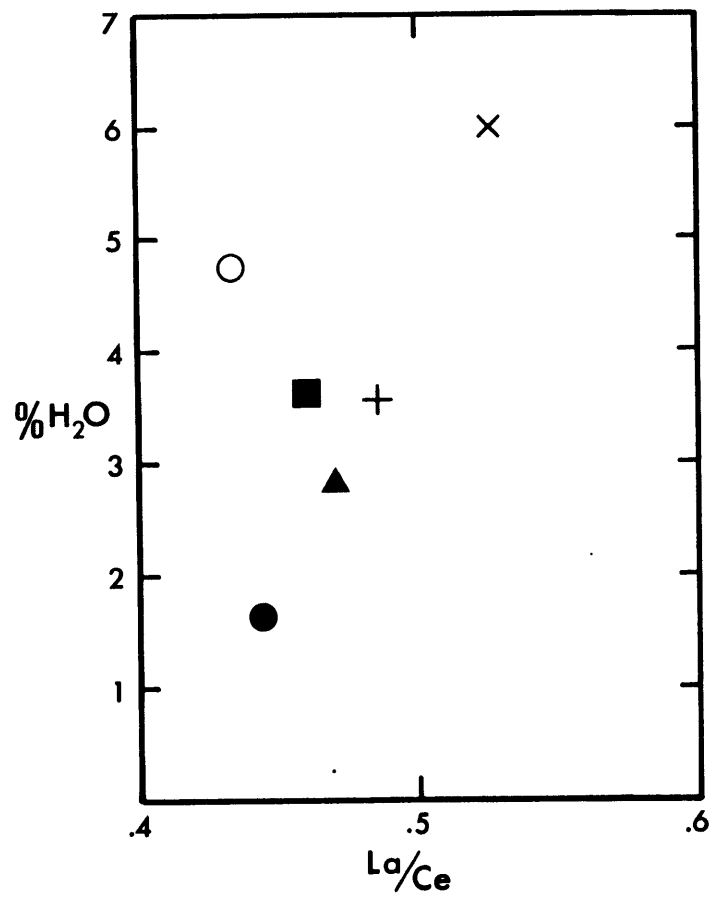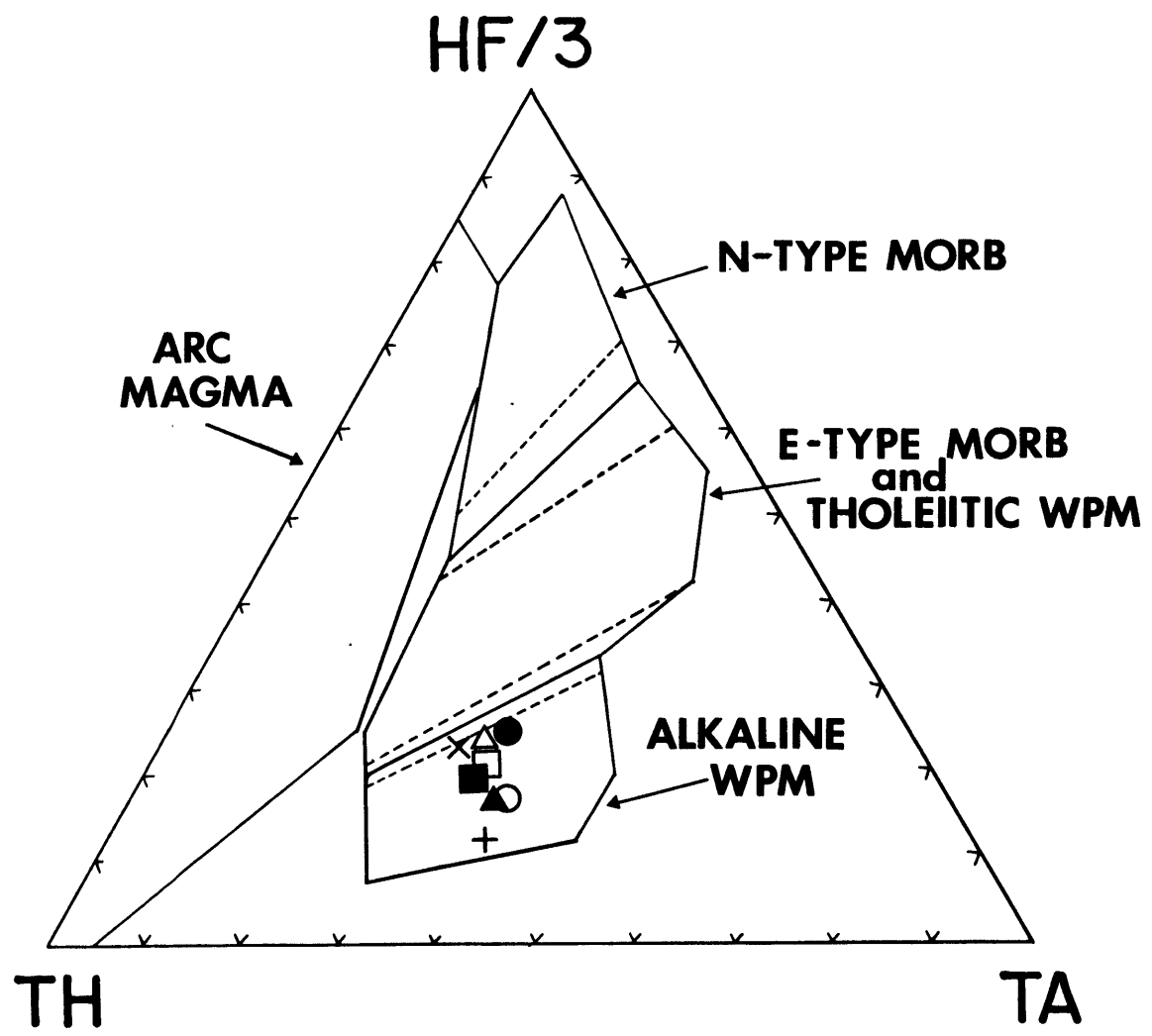
FIGURE 7

Th-Hf-Ta ternary diagram after Wood et al. (1979), depicting fields of

magma compositions corresponding to different tectonic environments.

Samples from the NES plot in the Alkaline Within-Plate Magma (WPM) field.

Symbols as in figures 3 and 5.

HF/3

N-TYPE MORB

ARC
MAGMA

E-TYPE MORB
and
THOLEIITIC WPM

ALKALINE
WPM

TH   TA

chemical analyses of samples collected by submersible and drilling will permit a more complete determination of the seamounts' general chemical structure.

2. Inter-seamount Variations

Neither the relative abundances of the NE seamounts' rare earth and high field strength elements nor their absolute concentrations, after considering crystal fractionation effects, demonstrate trends along the chain or distinguish between the East and West seamount groups (Figs. 2, 5 and 7).

Isotopic characteristics

1. Introduction

The results that most accurately reflect the primary isotopic characteristics of the NES chain are presented in Tables 1 and 2 and in Figures 8-13. After examining the significance of the present day values on isochron and $^{207}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ diagrams, I will describe the inter-and intraseamount variations as represented by the initial isotopic compositions of these samples. Then, following a description of my method for projecting the NE Seamounts' initial isotopic ratios to the present day, I will compare the NE seamounts' isotopic characteristics to those of other young oceanic volcanics. This projection does not result in any significant change in either the sense or magnitude of the variations exhibited by the initial ratios. This permits me to refer to the diagrams bearing these data when I discuss the inter- and intraseamount variations in initial isotopic composition.

2. Isochron diagrams

The Sm-Nd and $^{238}U-Pb$ "isochron" dates given by the whole rock-mineral pairs are consistent with the $^{40}Ar-^{39}Ar$ ages of Duncan (1983; Figs. 8 and

FIGURE 8

Sm-Nd isochron diagram for NES whole rocks and mineral separates.
Encircled symbols represent mineral separate analyses. Arrows point from
unleached to the leached whole rock $^{147}Sm/^{144}Nd$ ratios. Whole rock-mineral
pair ages are indicated for both leached and unleached whole rock
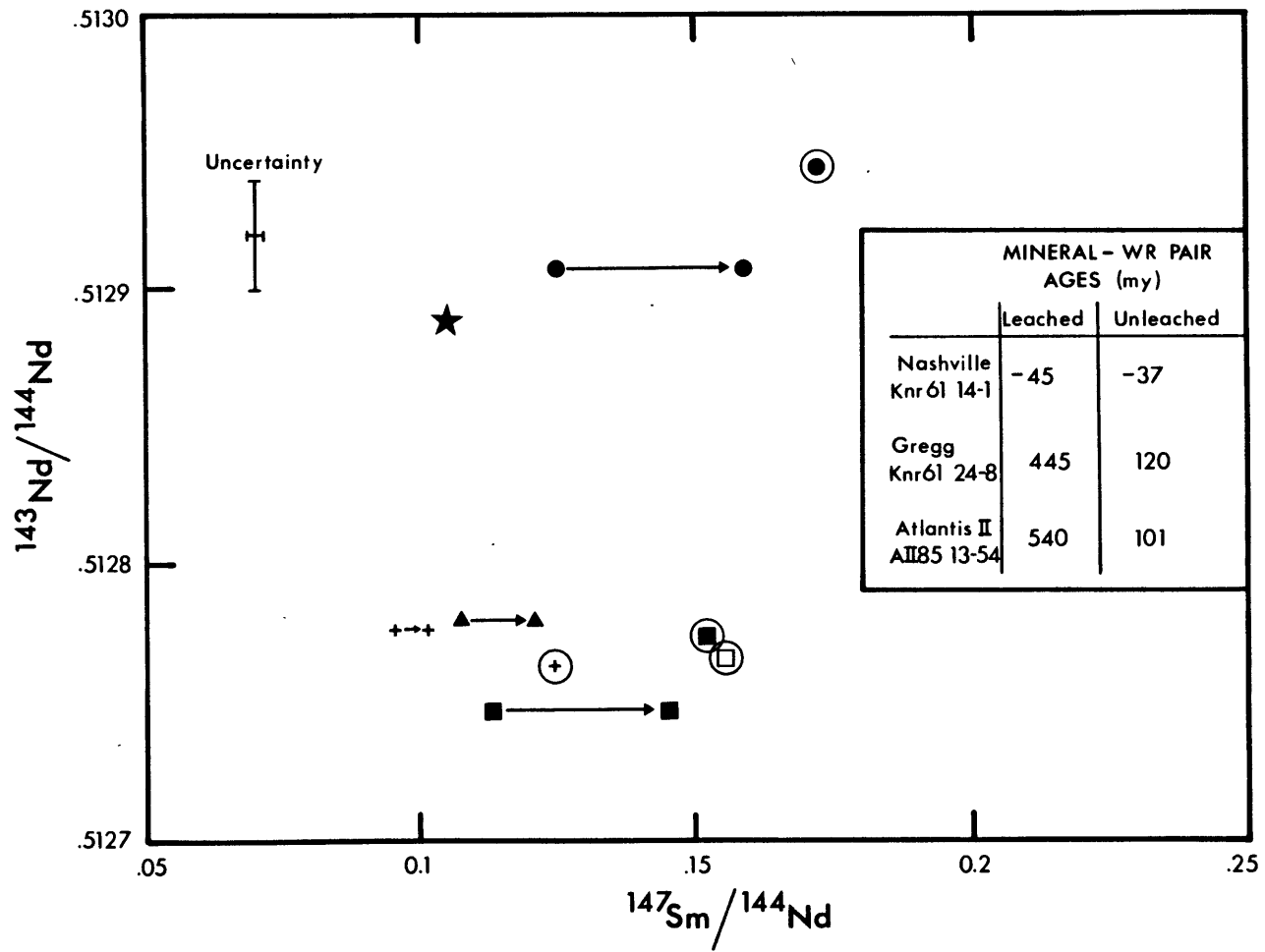$^{147}Sm/^{144}Nd$ ratios. Symbols as in figures 3 and 5.

	MINERAL – WR PAIR AGES (my)	
	Leached	Unleached
Nashville Knr61 14-1	−45	−37
Gregg Knr61 24-8	445	120
Atlantis II AII85 13-54	540	101

Uncertainty

$^{143}Nd/^{144}Nd$

$^{147}Sm/^{144}Nd$

44

FIGURE 9

^{238}U-Pb isochron diagram for NES unleached whole rocks and a mineral separate (represented by the encircled symbol). A 125 m.y. age is indicated by the whole rock-mineral pair. Symbols as in figures 3 and 5.
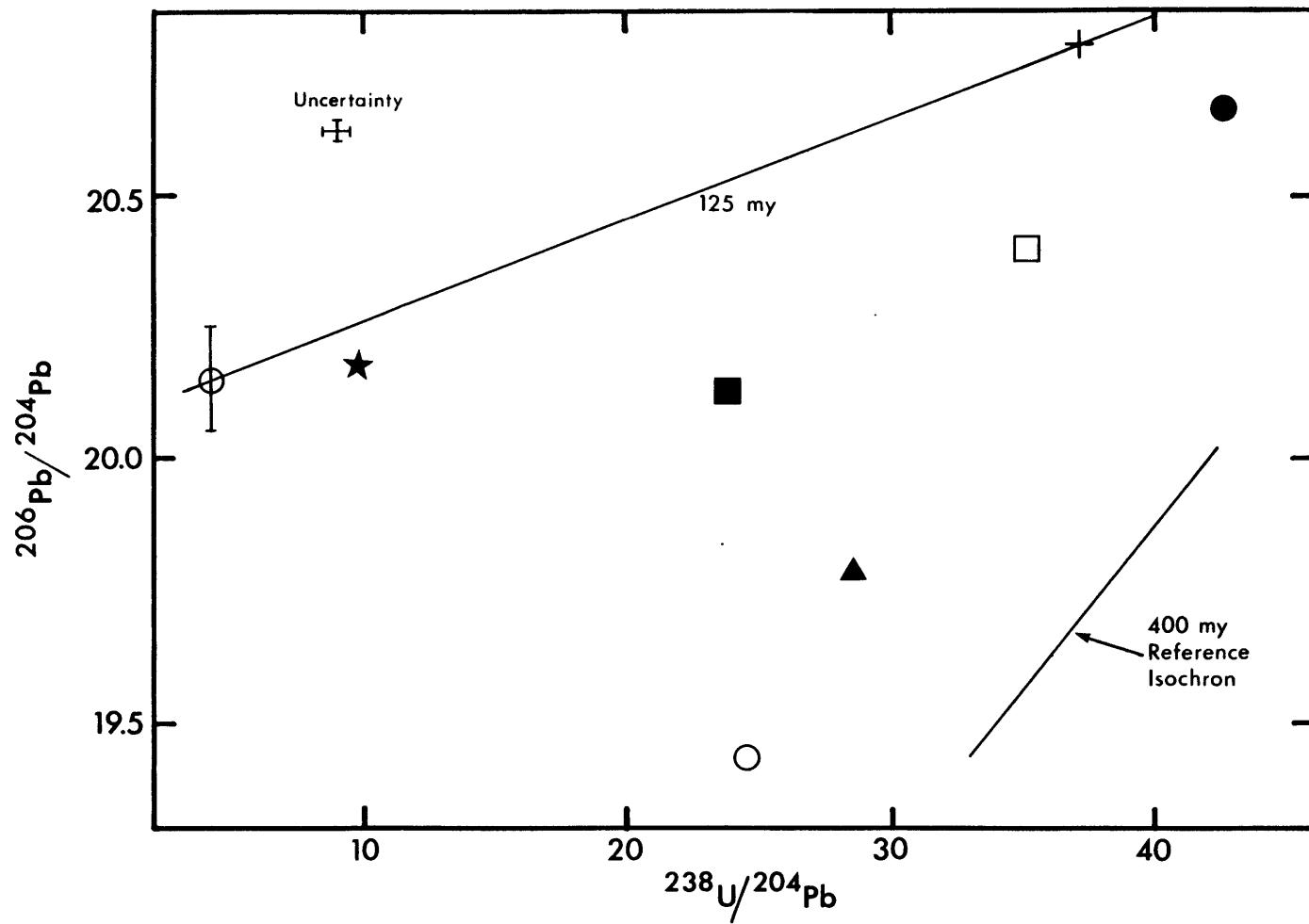
9). They do not provide any further age constraints because of their large uncertainties resulting from the small range in Sm/Nd ratio and the large error associated with the hornblende's calculated $^{206}Pb/^{204}Pb$ value. Taken together, the whole rock and mineral Sm-Nd results do not define a simple trend.

The whole rock data do not demonstrate any significant correlation on either the Sm-Nd and U-Pb isochron diagrams or the $^{207}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ diagram (Figs. 8-11). Omitting sample Knr61 18-34 from consideration on the $^{207}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ diagram (Fig. 11) results in a trend with a slope defining an age less than zero. My interpretation of these results, which includes a consideration of the consequences of reasonable seawater alteration, is that the isotopic variations reflect source heterogeneities.

The data on a Th-Pb isochron diagram define a pseudo-isochron indicating an age of 225 ± 50 m.y. (Fig. 12). A Th-Pb "isochron" defined by samples having been effected by continuous Pb loss (seawater alteration) would indicate an age less than the true age. Therefore, 225 ± 50 m.y. is the minimum age this "isochron" can represent. This age is essentially equal to or greater than the age of the oldest oceanic crust in the area (= 185 ± 10 m.y., Vogt and Einwich, 1978), therefore it cannot bear any relationship to the seamounts' ages.

The lack of similar age relationships in the other isochron diagrams and in the $^{207}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ diagram, and the recognition that this Th-Pb "isochron" is essentially just a three point correlation, argue against this correlation having any age significance (such as the recording of a pre-rifting mantle event). I believe this "isochron" is a fortuitous result of sampling a heterogenous mantle.

FIGURE 10

^{235}U-Pb isochron diagram for NES unleached whole rocks. Symbols as in figures 3 and 5.
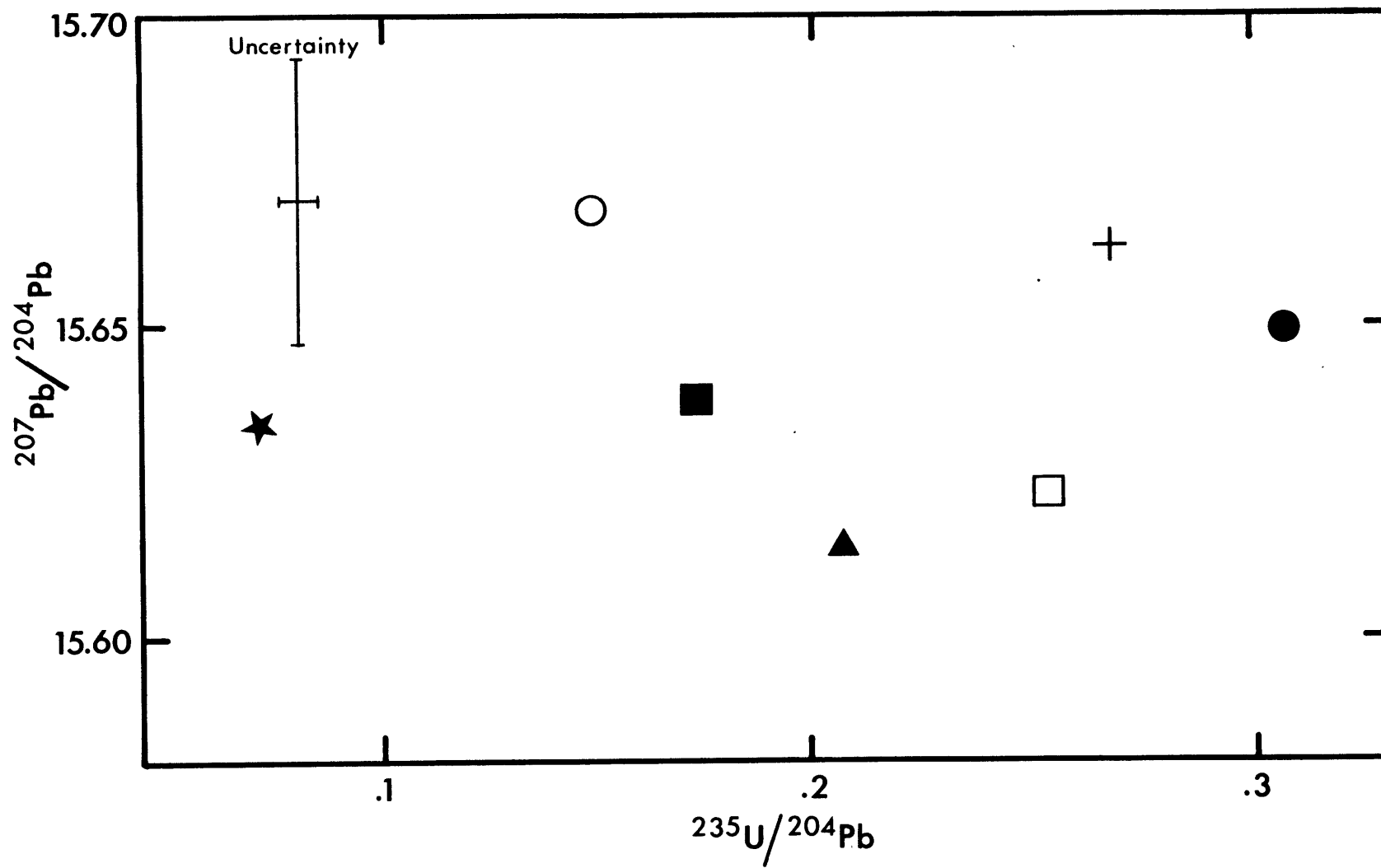
FIGURE 11

$^{207}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ correlation diagram for NES unleached whole

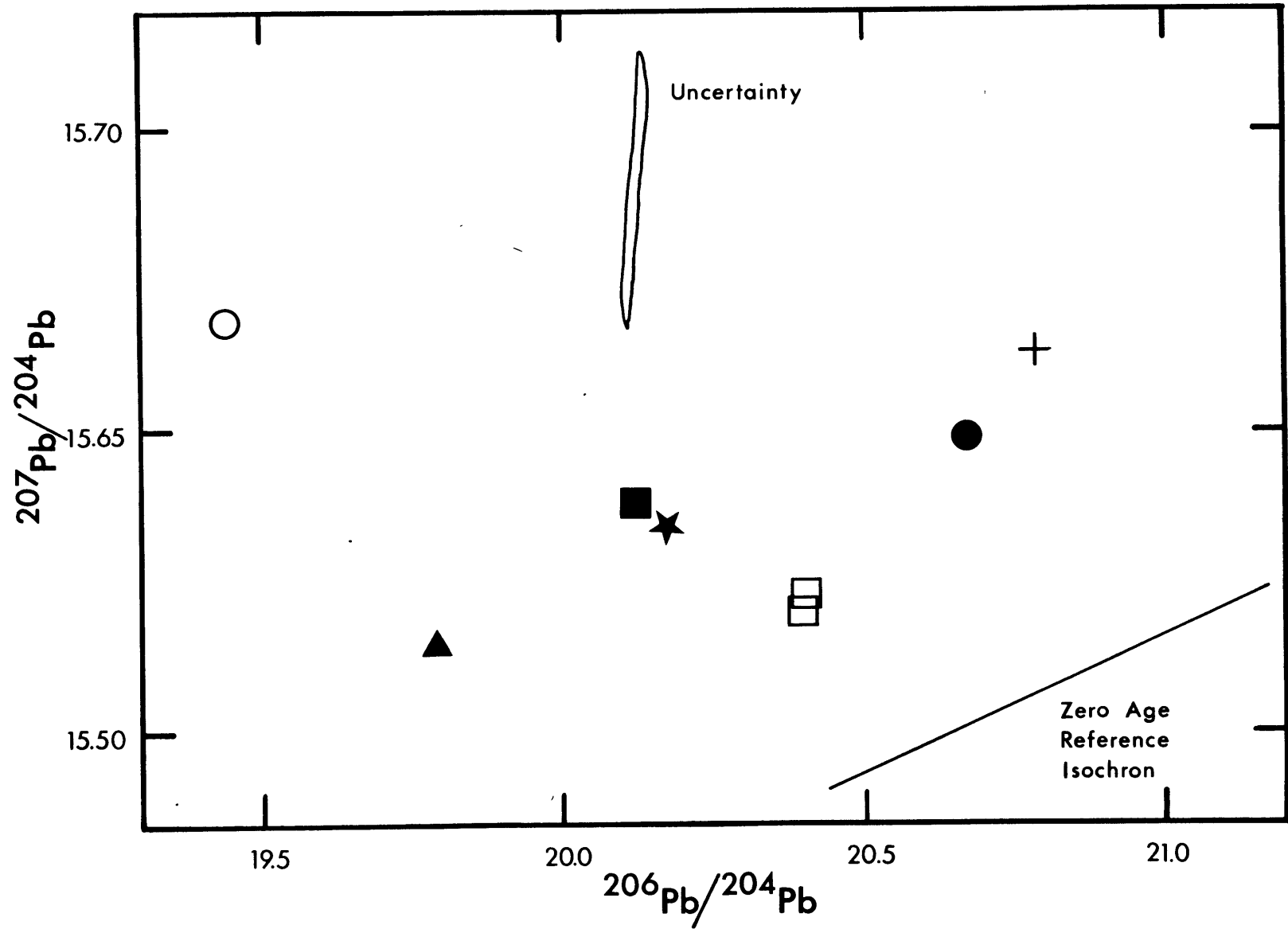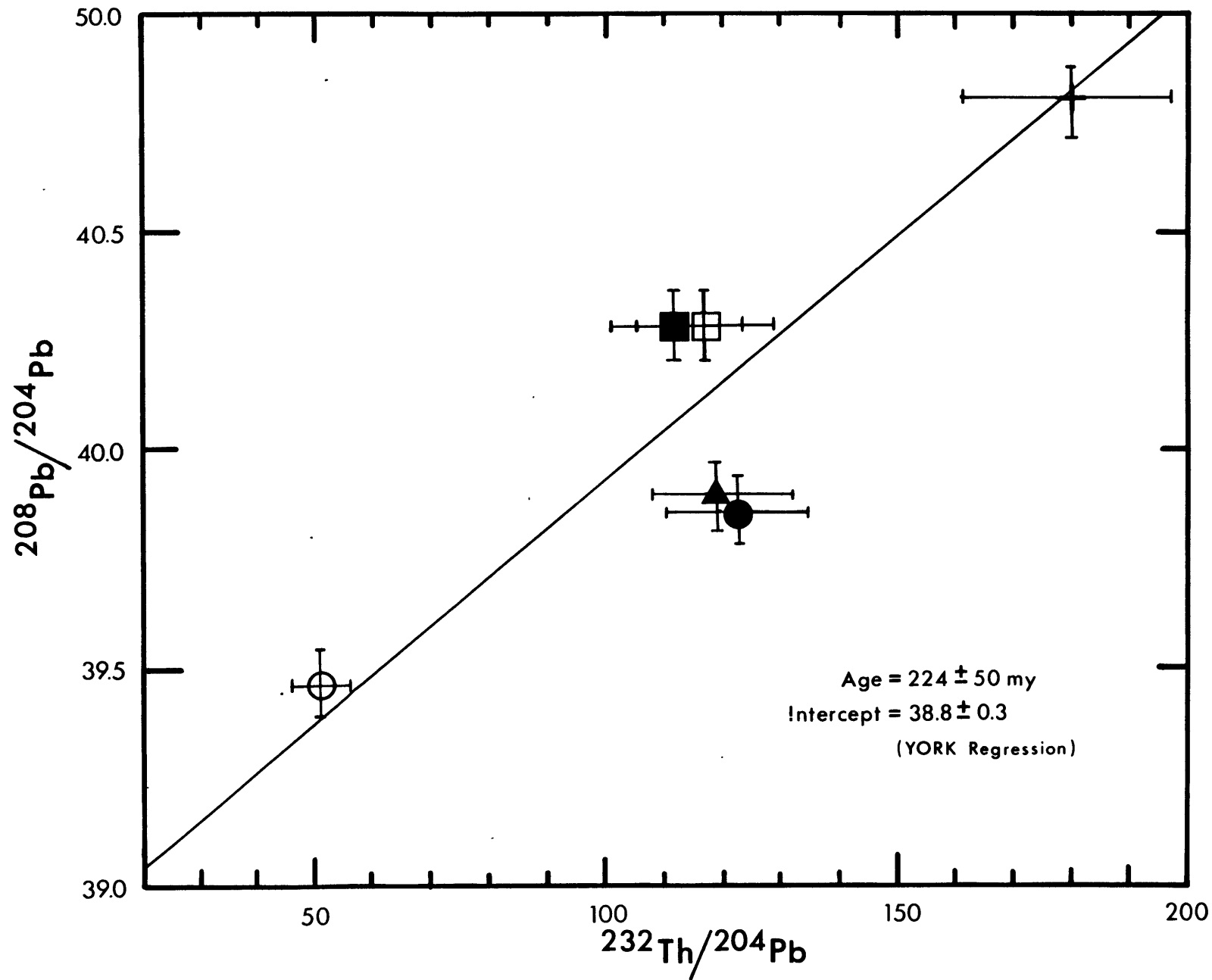rocks. Symbols as in figures 3 and 5.

FIGURE 12

^{232}Th-Pb isochron diagram for NES unleached whole rocks. These data define

a pseudo-isochron indicating a 224 ± 50 m.y. age and an initial

^{208}Pb/^{204}Pb ratio = 38.8 ± 0.3 . Symbols as in figures 3 and 5.

Age = 224 ± 50 my

Intercept = 38.8 ± 0.3

(YORK Regression)

3. Initial ratios

a. Introduction

A rock's initial isotopic composition reflects that of its source. In order to investigate the NE Seamounts' source region, I have age corrected the present day Sr (except the whole rock values), Nd and Pb isotopic compositions using the ^{40}Ar–^{39}Ar seamount ages determined by Duncan (1983). Duncan dated all but one of these samples (Table 1a).

The whole rock ^{87}Sr/^{86}Sr value of sample AII85 12-2 requires a minor age correction that could not be calculated because the appropriate ^{87}Rb/^{86}Sr ratio could not be measured due to alteration effects. This uncertainty is inherent in each whole rock ^{87}Sr/^{86}Sr analysis. It is fair to presume that the low ^{87}Sr/^{86}Sr whole rock values do not need substantial age corrections. The higher values are more questonable, even though the high whole rock ^{87}Sr/^{86}Sr value (= .70347) for sample Knr61 14-1 is confirmed by its hornblende separate.

Again, I have reasonable control on this uncertainty, since the sense of the correction is known and its magnitude can be estimated from the ^{87}Rb/^{86}Sr ratios of other oceanic island alkaline volcanics. Although this uncertainty may affect the fine interpretation of the data it does not affect the major conclusions of this paper.

b. Inter- and intraseamount variations

While the NE Seamounts' isotopic heterogeneity is not extreme (inspite of their large geographic extent) it is comparable to that described for the Hawaiian islands, Canaries, Iceland and EPR small seamounts (Figs. 14-18). The two samples from Atlantis II Seamount (sample localities in appendix) have nearly identical Sr, Nd and Pb isotopic compositions corresponding to their trace element similarities. This suggests that the

chemical variation within a single seamount may be substantially less than the total range exhibited by the seamount chain. Subsequent analyses will test this notion. Similarly, the isotopic heterogeneity of each volcano making up the Hawaiian islands, (less so for Loihi) is much less than the total variation displayed by the island group (Tatsumoto, 1978; Sun, 1980; Chen and Frey, 1983; White and Hofmann, 1982; Lanphere, 1983; Stille et al., 1983; Staudigel et al., 1984). The homogeneity exhibited by Atlantis II Seamount, together with the considerable isotopic heterogeneity demonstrated by the entire NES chain justify the examination of this limited data set for possible geographic trends.

When considering all of the seamounts, the isotopic variations appear to be random (Fig. 13). However, excluding sample Knr61 18-34 (Michael Seamount) from the data set leads to some interesting trends. The rationale for excluding sample Knr61 18-34 is as follows. The chemical composition of this sample is much different than that of the others as an extreme enrichment in incompatible elements is indicated by its large biotite phenocrysts, abundant apatite and problems encountered during the separation of Sr and Nd that are typically caused by high alkali element concentrations. Its high H_2O content (= 4.5 %) and low Th/U values indicate that it is very altered. Also, this sample's Pb isotopic composition showed the largest variation between leached and unleached whole rock splits. Although these facts may not warrant ostracism of this sample, they are reason enough to propose its exclusion and then examine the consequences.

As can be seen in figure 13, the $^{206}Pb/^{204}Pb$ values now increase from Bear to Nashville Seamounts. Although the $^{207}Pb/^{204}Pb$ values are nearly identical within error, their measured values show a similar variation. A

FIGURE 13

Variations of initial Sr, Nd and Pb isotope ratios with distance from

Nashville Seamount along the NES chain. Pb isotopic compositions are for

unleached whole rocks. $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ values are those of

leached whole rock samples when there is no corresponding mineral value.

When the whole rock and mineral values agree within their uncertainties a

single value (that of the mineral) is plotted. Otherwise, an arrow points

from the whole rock isotope ratio to that of its mineral pair. An arrow

accompanied by a question mark represents the uncertainty in the $^{87}Sr/^{86}Sr$

values of the leached whole rocks without a mineral pair. Isotope values

of Sample AII85 13-54 from Atlantis II Seamount are plotted to the left of

those of Sample AII85 12 from the same seamount.
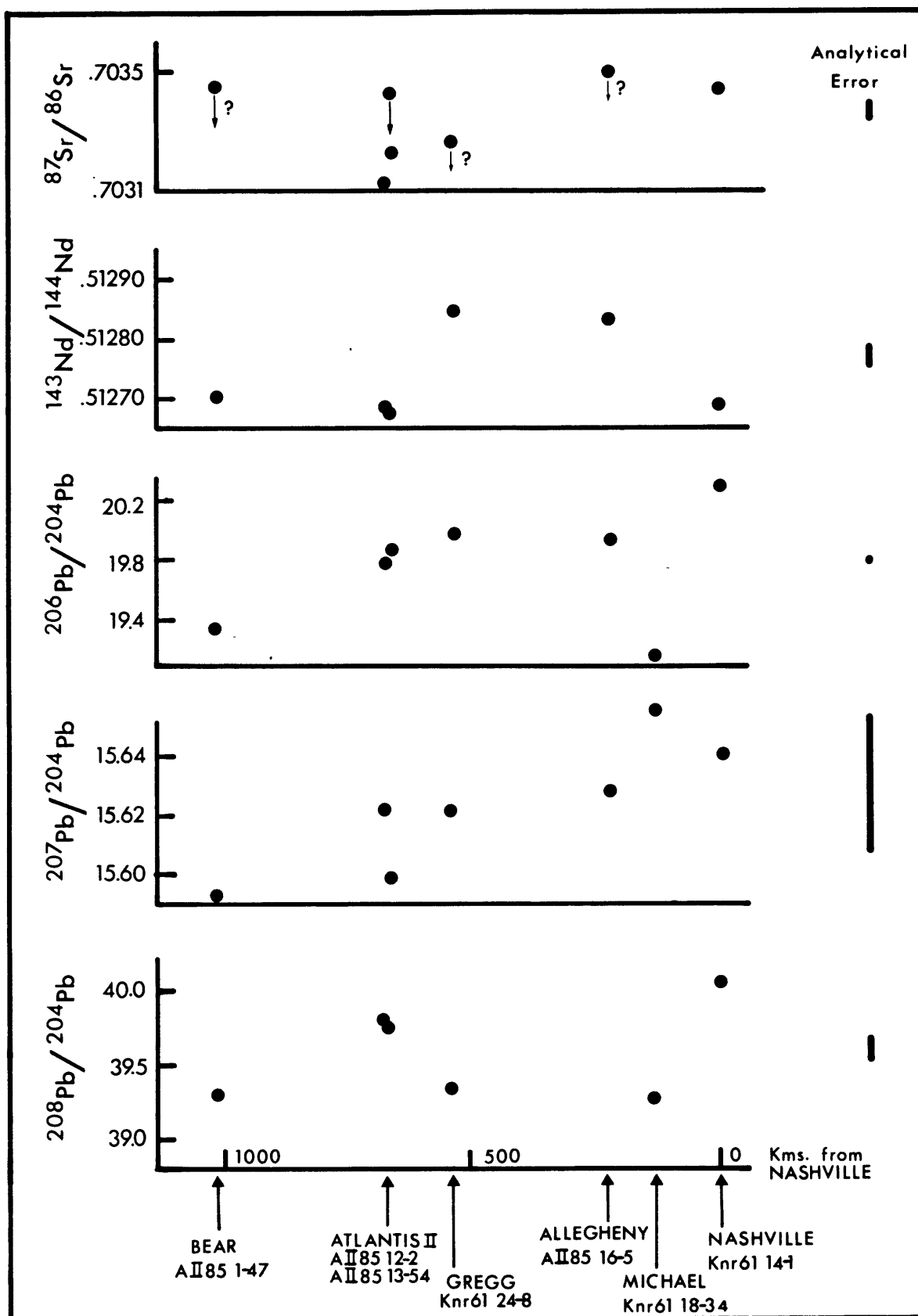
trend along the chain is less clear for $^{208}Pb/^{204}Pb$ and non-existant for $^{143}Nd/^{144}Nd$. An increase in $^{87}Sr/^{86}Sr$ along the chain is possible only if sample AII85 1-47 has a whole rock $^{87}Rb/^{86}Sr$ value > 0.23, a value which is near the upper limit of the range exhibited by oceanic island alkaline basalts (Hart and Brooks, 1981). If the isotopic variations of Sr are correlated with those of Pb, it is expected that the isotopic composition of Nd would also show corresponding variations, as the Sr and Nd systems tend to be correlated. This is not so, therefore it is more likely that the U-Pb systems (with or without the Th-Pb system) are independent of the Rb-Sr and Sm-Nd systems which are, in turn, uncorrelated. This would imply a modest, and perhaps more reasonable, whole rock $^{87}Rb/^{86}Sr$ value for sample AII85 1-47.

Analyzing the chain as two seamount groups indicates that the Western seamounts have constant $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ values which are either relatively constant or which decrease to the east. The Eastern seamounts exhibit a crude increase in $^{87}Sr/^{86}Sr$ values to the east with a corresponding decrease in $^{143}Nd/^{144}Nd$ values. These trends approximate the correlated behavior expected of the Rb-Sr and Sm-Nd systems. The $^{208}Pb/^{204}Pb$ values increase to the east in both groups, though not continuously, as Gregg and Bear Seamounts have the same value. This may suggest two somewhat chemically distinct sources for the East and West seamount groups. At this point, such a suggestion is too speculative to warrant further discussion. However, it does encourage further analyses. I will examine possible implications of only the proposed Pb isotopic trends when I discuss the petrogenesis of the NES.

Comparing the New England Seamounts with other ocean volcanics

1. Introduction

In order to compare the NES to other young oceanic volcanics, I have
adjusted the samples' initial isotopic compositions to account for the
radiogenic growth they would have experienced had they remained in their
oceanic island mantle reservoir until recently. To do so necessitated
choosing P/D ratios corresponding to those of the NE Seamounts' mantle
source.

Allegre et al. (1983) presented the $^{87}Rb/^{86}Sr$ and $^{147}Sm/^{144}Nd$ values
that they felt best estimated those of an oceanic island basalt (OIB)
source. These values, $^{87}Rb/^{86}Sr = 0.05$ and $^{147}Sm/^{144}Nd = 0.19$, are the
average P/D ratios of ocean island tholeiites (alkaline basalts were
omitted to avoid residual garnet effects during partial melting), adjusted
to compensate for interactions between the MORB and OIB sources and
chemical fractionation during basalt formation. I will use these values.

Chase (1981) proposed a two-stage Pb evolution model to explain the
linear $^{207}Pb/^{204}Pb-^{206}PB/^{204}Pb$ arrays defined by oceanic islands. These
arrays, he argued, are secondary isochrons defining the age of the
secondary reservoir's (=OIB source's) formation. He then calculated the
range in the secondary reservoir's P/D ratio necessary to produce the
observed variation in isotopic composition.

Based on this two-stage Pb evolution model and the isotopic
compositions of the NES, I chose $^{238}U/^{204}Pb = 16$ and $^{232}Th/^{204}Pb = 50$ to be
the average P/D values of the NES source. Because the NE Seamounts'
proposed array on the $^{207}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ correlation diagram has no
age significance, I had to assume their source was formed approximately 1.8
b.y. ago. This is the average secondary isochron age given by the other

oceanic island arrays (Chase, 1981). Also, whether these arrays are true secondary isochrons or mixing lines is not important for my purposes, as their radiogenic character had to be developed regardless.

It is important to recognize that even extreme P/D ratios chosen for the OIB source will not change the projected values by more than twice the analytical error. These variations do not effect my conclusions.

2. The comparision

The projected values are listed in Table 1 and the NES are compared with other oceanic volcanics in figures 14-18.

On a $^{143}Nd/^{144}Nd-^{87}Sr/^{86}Sr$ correlation diagram depicting fields of young oceanic volcanics (Fig. 14) the NES plot between St. Helena and Bouvet, occupying an area largely below the original mantle array (Richard et al., 1976; DePaolo and Wasserberg, 1976; O'Nions et al., 1977). This region, nearly a square, has a slight vertical orientation. The Sr and Nd isotopic variations are not correlated.

Other North Atlantic volcanoes, in particular the Canaries and some of the Azores have similar Sr and Nd isotopic characteristics. The small EPR seamounts are distinct from the NES but trend towards them.

The NES Pb isotopic characteristics are displayed in $^{207}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ correlation diagrams (Figs. 15 and 16). The NE Seamounts' Pb isotopic characteristics also closely resemble those of the Canaries, Azores, Bouvet and St. Helena, though St. Helena's $^{207}Pb/^{204}Pb$ value is more radiogenic. Seawater alteration acts to over age correct these Pb isotope ratios. Therefore, the NES values are the minimum values.

The proposed geographic trend in $^{207}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ space approaches $^{206}Pb/^{204}Pb$ values as high as those of St. Helena. As indicated

FIGURE 14

Nd-Sr isotope correlation diagram comparing the NES with other oceanic

volcanics, adapted from that of Zindler et al. (1984). Leached whole rock

isotope values are plotted when there is no corresponding mineral value,

otherwise the mineral values are plotted. The isotope values are initial

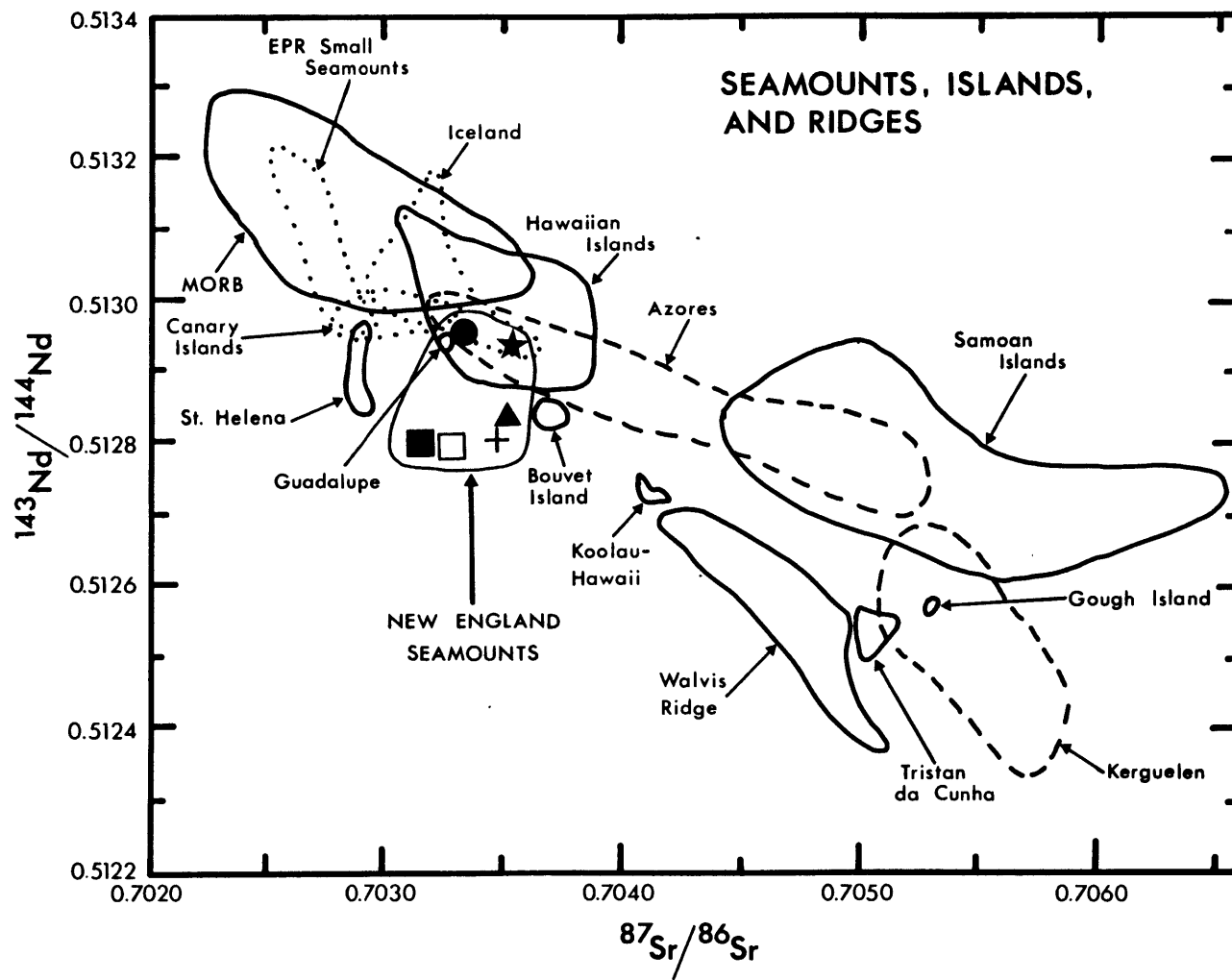values projected to the present as discussed in text. Symbols as in

figures 3 and 5.

SEAMOUNTS, ISLANDS, AND RIDGES

$^{143}Nd/^{144}Nd$ (vertical axis)

$^{87}Sr/^{86}Sr$ (horizontal axis)

EPR Small Seamounts

Iceland

Hawaiian Islands

Azores

MORB

Canary Islands

St. Helena

Guadalupe

Bouvet Island

NEW ENGLAND SEAMOUNTS

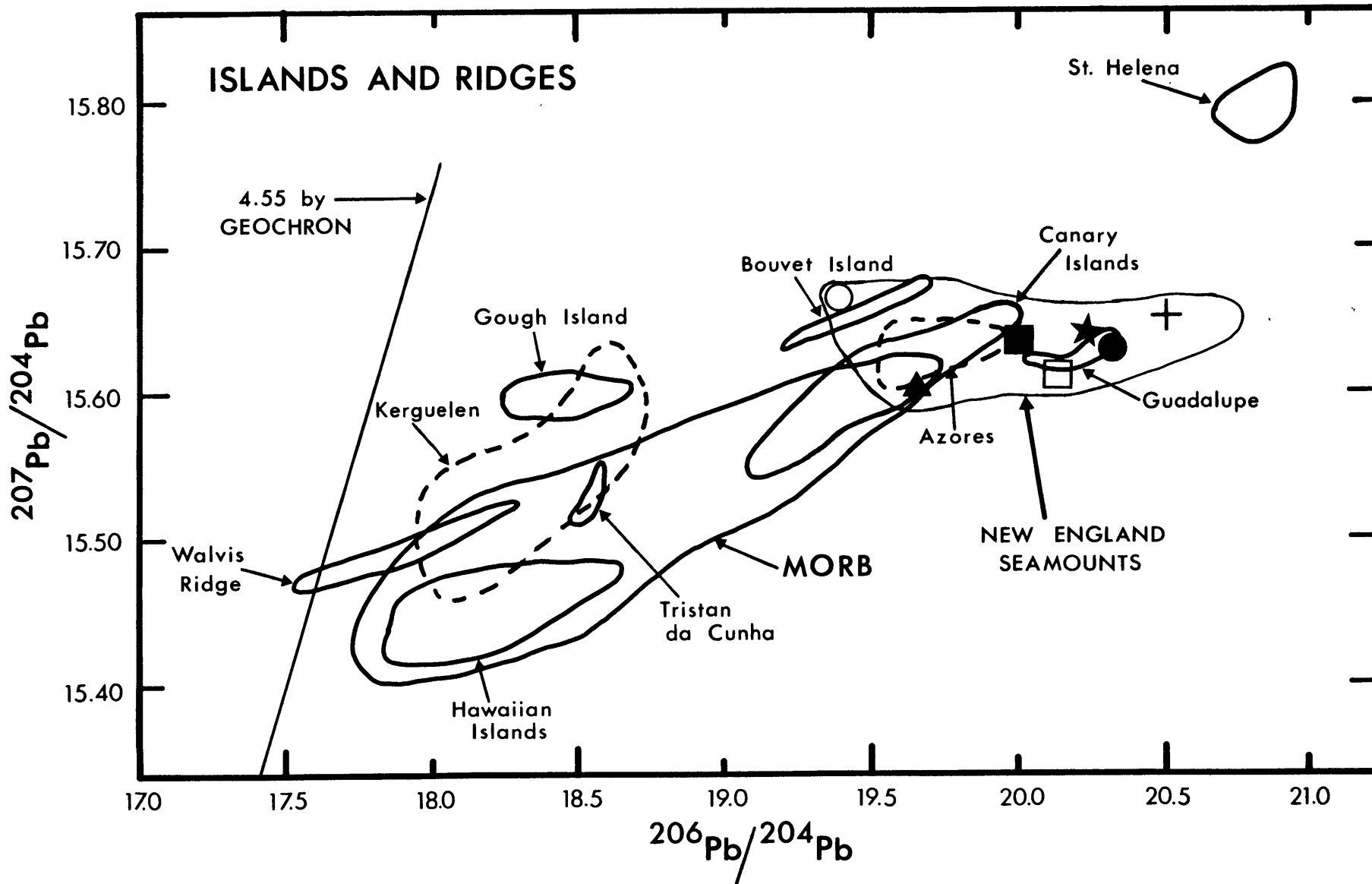Koolau-Hawaii

Samoan Islands

Gough Island

Walvis Ridge

Tristan da Cunha

Kerguelen

FIGURE 15

$^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ correlation diagram comparing the NES with

other oceanic volcanics, adapted from that of Staudigel et al. (1983).

Plotted are unleached whole rock initial Pb isotope ratios projected to the

present as discussed in text. Symbols as in figures 3 and 5.

ISLANDS AND RIDGES

St. Helena

4.55 by GEOCHRON

Bouvet Island

Canary Islands

Gough Island

Kerguelen

Azores

Walvis Ridge

Guadalupe

MORB

NEW ENGLAND SEAMOUNTS

Tristan da Cunha

Hawaiian Islands

$^{207}Pb/^{204}Pb$

$^{206}Pb/^{204}Pb$

FIGURE 16

$^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ correlation diagram comparing the NES with other oceanic volcanics, adapted from that of Sun (1980) using data reported in Hart (1984) and references therein. Symbols as in figures 3 and 5.
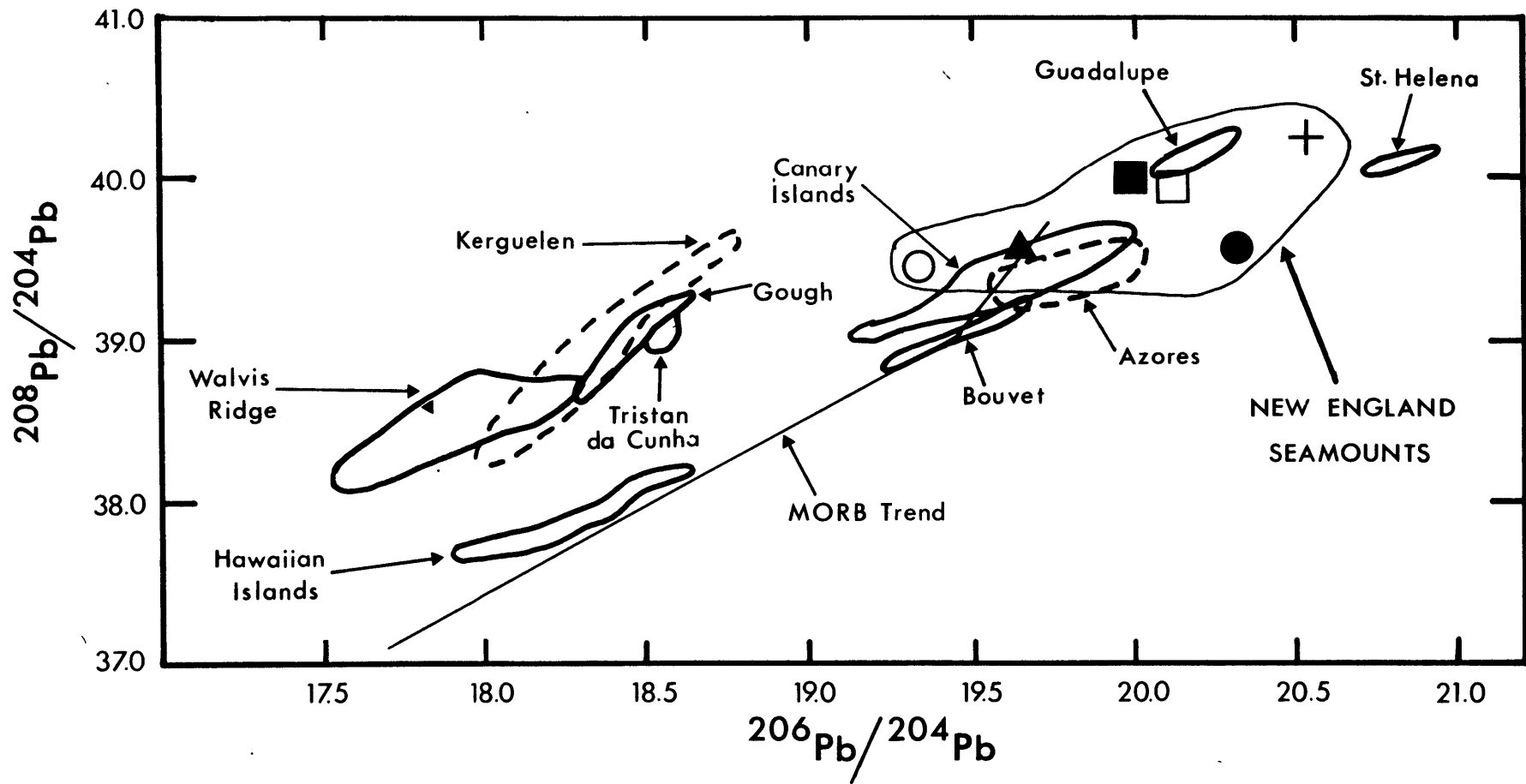
earlier, a similar trend is exhibited in $^{208}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ space

(Fig. 17). In this diagram Knr61 24-8 (Gregg Seamount) lies off this trend

to low $^{208}Pb/^{204}Pb$ values, while Knr61 18-34 lies on this trend but not in

a position corresponding to its geographic location. Figures 17 and 18

offer different perspectives of the same relationships.

Using average values of $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ (.703390 and 20.144,

respectively) for NES in the equation for the mantle plane (Zindler et al.,

1982) gives an average $^{143}Nd/^{144}Nd$ value of .512892. This value is only

0.008% greater than the average of the NES (=.512851), indicating that NES

is on the mantle plane.

The source of the New England Seamounts

1. Introduction

The trace element and isotopic characteristics of the NES indicate

that their petrogenesis was similar to that of oceanic islands. A time

intergrated source depletion in incompatible elements, relative to bulk

earth, followed by a recent enrichment in these elements, has led to the

combined depleted Nd and Sr isotopic signatures and enriched incompatible

element characteristics of most oceanic islands. Kerguelen, Gough, Tristan

da Cunha and Walvis Ridge exhibit slightly enriched Sr and Nd isotopic

signatures but still require a recent incompatible element enrichment.

Both small degrees of partial melting of the mantle source with garnet in

the residue (Gast, 1968; Kay and Gast, 1973; Sun and Hanson, 1975b; Frey et

al., 1978) and mantle metasomatism by an incompatible element enriched

component (Frey and Green, 1974; Menzies and Murthy, 1980; Clague and Frey,

1982; Menzies and Wass, 1983) are proposed processes for accomplishing this

recent enrichment. The Pb isotopic signatures of almost all oceanic

volcanics are more radiogenic than that of bulk earth, indicating long term

FIGURE 17

$^{87}Sr/^{86}Sr$ vs. $^{206}Pb/^{204}Pb$ correlation diagram comparing the NES with other

oceanic volcanics, adapted from that of Staudigel et al. (1983). Data

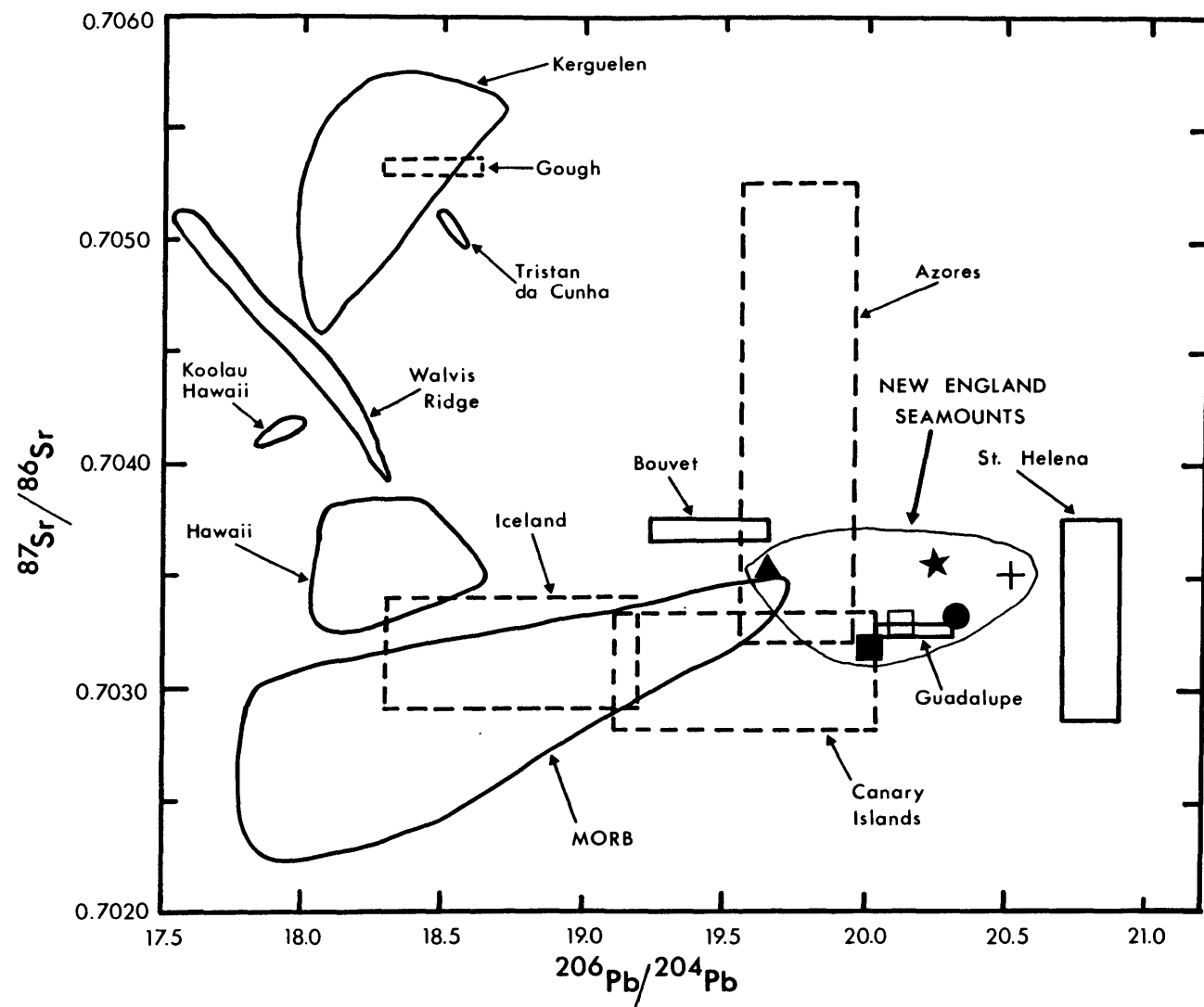plotted as in figures 14 and 15. Symbols as in figures 3 and 5.

87Sr/86Sr vs 206Pb/204Pb diagram showing fields for Kerguelen, Gough, Tristan da Cunha, Azores, Koolau Hawaii, Walvis Ridge, NEW ENGLAND SEAMOUNTS, St. Helena, Hawaii, Iceland, Bouvet, Guadalupe, Canary Islands, and MORB.

FIGURE 18

$^{143}Nd/^{144}Nd$ vs. $^{206}Pb/^{204}Pb$ correlation diagram comparing the NES with other oceanic volcanics, adapted from that of Staudigel et al. (1983). Data plotted as in figures 14 and 15. Symbols as in figures 3 and 5.
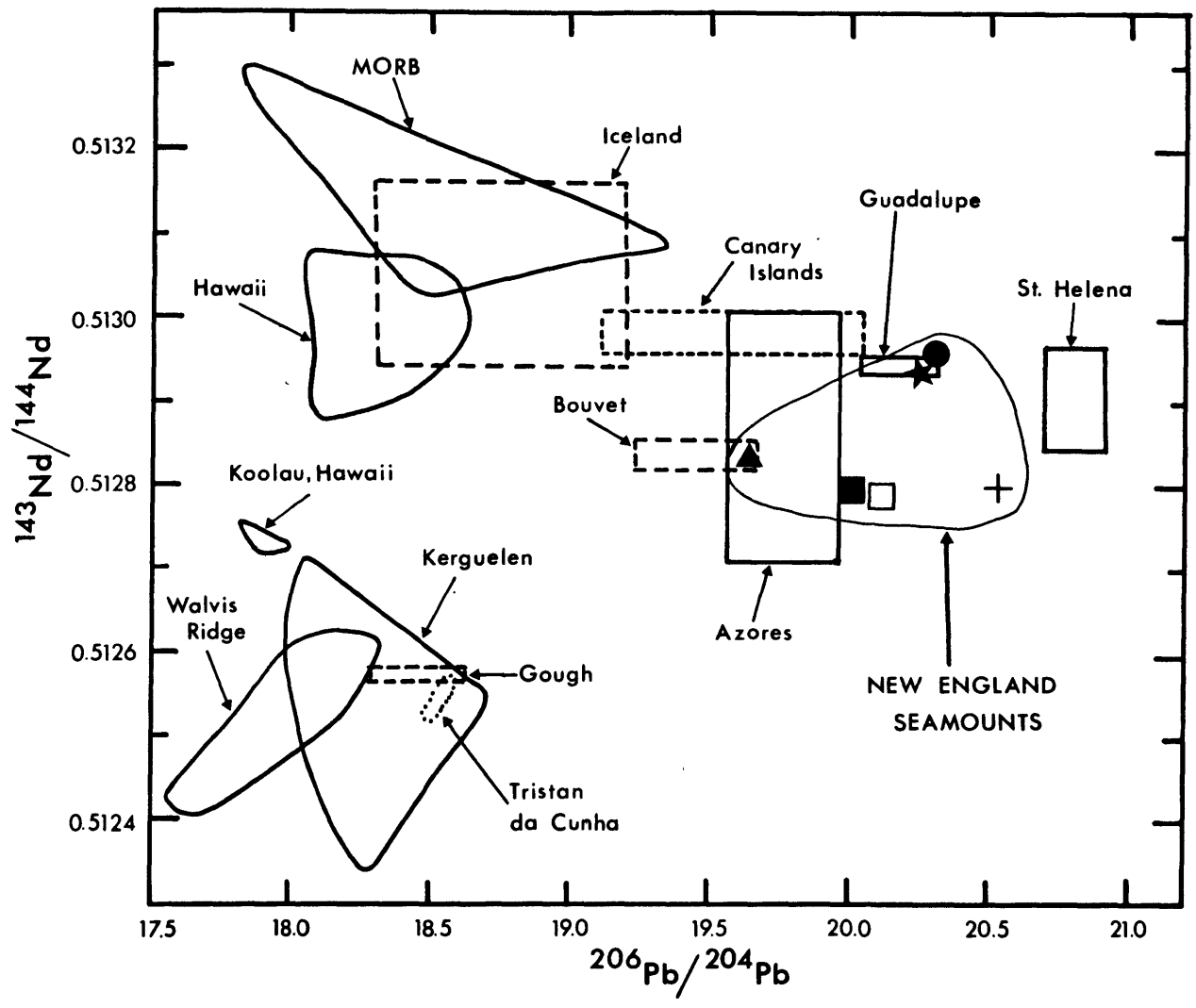
U/Pb and Th/Pb ratio enrichments for these sources. The generation of these radiogenic Pb ratios require this enrichment to be ancient, perhaps 1.8 b.y. old (Chase, 1981).

At least three chemically distinct source components are required to generate the isotopic characteristics of oceanic island volcanics. The most commonly proposed chemical components are: a depleted MORB type; an "undifferentiated" or "enriched" type, most closely represented by Gough, Tristan du Cunha and Kerguelen; and a "radiogenic Pb" type, having had long term U/Pb and Th/Pb ratio enrichments relative to its Rb/Sr and Nd/Sm ratios, most closely represented by St. Helena (Chase, 1981; Zindler et al., 1982; Hofmann and White, 1982). The physical significance and distribution of these components in the mantle are widely debated topics.

2. The New England Seamounts

The proposed hotspot origin for the NES chain warrents contemplating an isotopically homogeneous source for this chain. Any heterogeneity produced by this source would be limited to that of radiogenic growth. Although the proposed increase in radiogenic Pb with decreasing seamount age is suggestive of this type of source region, an isotopically homogeneous source, with P/D ratios as suggested above, can produce only a small portion of the observed isotopic heterogeneity given the 20 m.y. necessary to construct the seamount chain (Table 3). Also, this petrogenetic scheme cannot account for the lack of correlated Sr, Nd and Pb isotopic variations exhibited by the NES (Figs. 13-18). An isotopically heterogeneous source is required to explain both the sense and magnitude of the NE Seamounts' isotopic variations.

The lack of correlated isotopic variations (Figs. 13-18) demonstrates the involvement of at least three chemically distinct components in the

TABLE 3. Isotopically Homogeneous, Closed System, Source Evolution

Isotopic System	P/D Source[1]	$\Delta(D^*/D)=P/D(e^{\lambda t}-1)$ $t=20$ m.y.	Range in D^*/D NES	$\dfrac{\Delta(D^*/D)}{\text{NES Range in } D^*/D} \times 100\%$
$^{87}Rb-^{87}Sr$	0.05	1.42×10^{-5}	3.6×10^{-4}	4%
$^{147}Sm-^{143}Nd$	0.19	2.5×10^{-5}	1.75×10^{-4}	14.3%
$^{238}U-^{206}Pb$	16	.05	.98	5%
$^{235}U-^{207}Pb$	0.116	2.3×10^{-3}	.063	3.7%
$^{232}Th-^{208}Pb$	50	.05	.81	6%

[1]Discussed P/D choices in text

development of the NE Seamounts' source. MORB type mantle is one likely

end member. Below, I will discuss the role of the "enriched" type and the

"radiogenic Pb" type components in the petrogenesis of the NES.

. The NES are modestly displaced towards Gough, Kerguelen, Tristan da

Cunha and Walvis Ridge, the "enriched" oceanic volcanics, on the

$^{143}Nd/^{144}Nd-^{87}Sr/^{86}Sr$ correlation diagram (Fig. 14). Richardson (1984) has

convincingly demonstrated the existance of an enriched mantle residing

below the continents. Also, volcanics of continental rifts, possibly

tapping the subcontinental mantle, have the enriched Sr and Nd

characteristics required to generate these oceanic islands (Jacobsen and

Wasserburg, 1978; Williams and Murthy, 1979; Zindler, 1980; Mckenzie and

O'Nions, 1983). Perhaps continental rifting events preceeding ocean

formation are a means of introducing this subcontinental mantle into the

proto-oceanic mantle, enabling it to contribute to the source of oceanic

islands.

Such an enriched component does not dominate the NES source or cause

any apparent geographic trends in the chemistry of the NES (Fig. 13) This

is inspite of the seamount chain's orientation and proximity to the

continental margin, its possible generation by a hotspot previously

overlain by subcontinental mantle, and its developement soon after a

rifting event. Perhaps these tectonic relationships are not important in

sampling this component.

The isotopic similarities between the NES and St. Helena (Figs. 14-18)

focus attention onto the "radiogenic Pb" component. The coupling of

radiogenic Pb isotopic compositions with relatively nonradiogenic

$^{87}Sr/^{86}Sr$ values and radiogenic $^{143}Nd/^{144}Nd$ values in this

component is problematical. It requires an enrichment of U/Pb and Th/Pb

ratios independent of a similar enrichment in Rb/Sr and Nd/Sm ratios. Chase (1981), Zindler et al. (1982) and Hofmann and White (1982) have proposed that ancient subducted altered oceanic crust satisfies these geochemical requirements and that this subducted crust maintains its chemical identity to later resurface as a component in some oceanic volcanics.

The proposed trend in Pb isotopic composition may result from an increasing contribution of this "radiogenic Pb" component to the NES source as a function of time or geographic location. The shallow trajectory of the NES trend in $^{207}Pb/^{204}Pb-^{206}Pb/^{204}Pb$ space is not directed at the high $^{207}Pb/^{204}Pb$ values of St. Helena. This may result from variations in the age of the "radiogenic Pb" component. Incorporation of crust subducted when ^{235}U was abundant would result in greater ^{207}Pb contributions than incorperation of more recently subducted crust. In this context, the recycled component sampled by the NES would be younger than that sampled by St. Helena.

The seamounts were built on progressively younger sea floor towards the southeast, where Nashville Seamount stands on crust only 15 m.y. older than itself. Perhaps the thermal and convection features of the spreading ridge enviroment resulted in an increased contribution of this recycled crust, which may have been residing on the core-mantle boundary (Hofmann and White, 1982). The field of MORB itself extends to Pb isotopic compositions equivalent to those of the less radiogenic Canary, NES and Azores values (Figs. 15 and 16). Is this a result of additions of this same "radiogenic Pb" component?

The NE Seamounts' source region demonstrates considerable isotopic heterogeneity. The development of some of this heterogeneity is suggested

to have taken place during the construction of the seamount chain by both
the homogeneity of a single seamount and the proposed trend in Pb isotopic
composition. These observations are based on a limited data set.
Therefore, it is still reasonable for the NE Seamounts' source
heterogeneity to have been essentially constant during the time of seamount
construction.

The isotopic similarities amoung the NES, Canaries, Azores and Ahaggar
(Allegre et al., 1981) implicate similar source chemistry for all of these
volcanoes. Hart (1984) proposed that ancient, world wide heterogeneities
still exist in the mantle and cause such regional consistencies in isotopic
signatures.

CONCLUSIONS

The following have been demonstrated:

The isotopic and trace element characteristics of the NES are typical of alkaline volcanics from oceanic islands, in particular those characterized by radiogenic Pb signatures. Unlike many of the small EPR seamounts, the NES do not resemble MORB.

While the NE Seamounts' isotopic heterogeneity is not extreme, they do exhibit considerable interseamount isotopic variations. The chemical heterogeneity of a single seamount is suggested to be substantially less.

An increase in radiogenic Pb with decreasing age is suggested. No other simple geographic trends are apparent. The east and west seamount groups do not appear to be chemically distinguishable.

The non-correlated variations of the NE Seamounts' Sr, Nd and Pb isotopic compositions necessitate at least three distinct source components. The MORB source is likely to be one. Two mantle components commonly invoked for the generation of oceanic islands, the "enriched" type and the "radiogenic" type, are also applicable to the NE Seamounts' petrogenesis.

The NES exhibit a relatively small contribution from the "enriched" component and lack any chemical trends implicating a significant involvement of subcontinental mantle (a possible source of the "enriched" component).

The NES chemistry is characterized by the "radiogenic Pb" type component. The suggested increase in radiogenic Pb with distance from the craton implies some type of systematic distribution of this component.

Importantly, this study has shown that primary geochemical data can be obtained from older altered oceanic volcanics.

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APPENDIX

Contents

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TABLE A-1
AII-85 Leg I
26 August - 12 September, 1974
DREDGE SUMMARY

Dredge No.	Date	Latitude N	Longitude W	Depth Corr. M.	Area	Result
1	28 Aug.	39°47.3' to 39°51.1'	67°28' 67°24.9'	3100-2400	South slope Bear Smt	95 kg rocks: 28 kg erratics, 8 kg breccias, 1 kg lithified carbonates, 6 kg mud, 50 kg basalts with amphibole pheno- crysts & plagioclase - fair to badly weathered.
12	2 Sept.	38°24.6' to 38°26.3'	63°14.7' 63°14.8'	3300-3100	S slope Atlantis II Smt	95 kg rocks: 87 kg lithified carbonate with Fe/Mn crusts, 1 erratic, 8 kg weathered basalt. Sponge specimens.
13	3 Sept.	38°25.3' to 38°27.3	63°13.9' 63°15.0'	2500-2200	Upper S slope Atlantis II Smt	175 kg rocks: 3 kg erratics, 10 kg lithified carbonates, 155 kg Fe/Mn crusts & nodules, 7 kg weathered basalts.
16	6 Sept.	36°49.3' to 36°51.6'	58°49.4' 58°48.3'	3900-3300	Lower S slope Allegheny Smt	41 kg rocks: 5 kg Fe/Mn crust, 36 kg weathered basalts.

KNR-61
3 - 22 November, 1976
DREDGE SUMMARY

Dredge No.	Station No.	Latitude N	Longitude W	Depth Corr. M.	Area	Result
14	24	35°18.2' to 35°18.6'	57°32.3' (s) 57°34.9' (L-C)	2725-2125	Nashville Smt, E flank of Western- most peak (1193 fm)	100 kg rocks: 35 kg alt. basalt; 55 kg Fe/Mn oxide crusts; 10.5 kg calc. sed.; 0.1 kg coral

Dredge No.	Station No.	Latitude N	Longitude W		Depth Corr. M.	Area	Result
18	31	36°18.8' to 36°20.7'	58°18.0' 58°18.7'	(s) (s)	3125-1900	Michael Smt, mid Peak, SSE flank	110 kg rocks: 55 kg alt. basalt; 0.1 kg volc. breccia; 0.6 kg Fe/Mn oxide crusts; 1.7 kg erratics; 24 kg calc. sed.; 27 kg claystone; 0.5 kg coral
24	38	38°54.6' to 38°54.9'	60°59.2' 60°58.3'	(s) (s)	1575-1100	Gregg Smt, SE flank	40 kg rocks: 6.4 kg alt. basalt; 5 kg volc. breccia; 14 kg Fe/Mn oxide crusts; 0.7 kg erratics; 12 kg calc. sed.; 0.7 kg coral
31	47	39°47.2' to 39°47.9'	66°16.8' 66°16.8'	(s) (s)	2725-3000	Retriever Smt, SE flank	7.4 kg ROCKS: 0.1 kg alt. basalt; 6.4 kg Fe/Mn oxide crusts; 0.9 kg erratics

ALVIN DIVE £540
26 August, 1974
SUMMARY

Pilot	Observers	Latitude	Longitude	Area	No. Sta.	Duration	Result
Donnolly	Heirtzler Houghton	38°07.2'N	61°00.4'N	Rehoboth	3	4h 13m	130 kg Rocks

TABLE A-2

Seamount...	Nashville	Michael	Rehoboth	Gregg	Atlantis II	Bear
Sample No....	Knr61 14-1	Knr61 18-34	Alv540 4-1	Knr61 24-8	AII85 13-45	AII85 1-47
H_2O+	3.53	4.82	6.05	1.65	3.62	2.86
CO_2	0.01	0.46	4.25	0.44	3.53	0.04
SiO_2	50.90			42.62	39.04	43.02
TiO_2	3.09			3.84	4.22	4.46
Al_2O_3	18.61			12.02	13.91	15.09
FeO	7.95			14.03	14.80	13.91
MnO	0.22			0.20	0.25	0.19
MgO	2.71			8.58	7.58	6.44
CaO	6.67			16.18	18.02	12.52
Na_2O	4.37			1.15	0.11	1.65
K_2O	4.01			0.66	.067	1.78
P_2O_5	0.99			0.17	0.40	0.37
Total	99.52			99.45	99.00	99.43

Data courtesy of G. Thompson, Woods Hole Oceanographic Institution

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