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COMPOSITION OF ISLAND ARC DETRITUS
FROM SOUTHWEST JAPAN:
PROVENANCE AND TECTONIC HISTORY

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Julie Marie Taylor

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Major professor

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# THE COMPOSITION OF ISLAND ARC DETRITUS FROM SOUTHWEST JAPAN: PROVENANCE AND TECTONIC HISTORY

By

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## ABSTRACT

## THE COMPOSITION OF ISLAND ARC DETRITUS FROM SOUTHWEST JAPAN: PROVENANCE AND TECTONIC HISTORY

By

Julie Marie Taylor

The average composition of sediments from site 298 located in the fore-arc region of S.W. Japan is $MQ_{56}$ $PQ_{14}$ $HF_{9}$ $LF_{21}$. The most abundant feldspar is albite and the second most abundant is orthoclase (91-100 Wt % OR). The most abundant type of plagioclase (other than albite) is in the range of 50-70 Wt % AN. This interval reflects the andesitic volcanics associated with island arcs.

Mineralogic comparison of these fore-arc sediments to the back-arc sediments of Japan reflects the different provenance of these sediments. Comparison of several fore-arc regions illustrates the importance of the tectonic history of an island arc. Arcs underlain by a "continental" crust may be associated with fore-arc sediments rich in quartz and sedimentary rock fragments. Island arcs underlain by oceanic crust may be associated with quartz-poor fore-arc sediments rich in volcanic lithic fragments.

## ACKNOWLEDGEMENTS

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# INTRODUCTION

The variation of sediment compositions with tectonic setting has received increased attention in recent years. Particularly important to this paper is the composition of detritus associated with island arcs. Crook (1974) suggested island arc detritus will consist of quartz-poor graywackes reflecting a basic volcanic and ultramafic provenance. Dickinson and Valloni (1980) and Valloni and Maynard (1981) have presented data on island arc sediment compositions from various island arcs showing the sediments to be low in quartz with plagioclase as the predominant feldspar. This paper provides a petrographic analysis of hemipelagic muds from DSDP site 298 located in the fore-arc region of Japan. The composition of these sediments does not fit the models cited above. These sediments are not primarily volcanic in composition yet are derived from an active volcanic arc.

Most studies of clastic sediments have utilized the sand size fraction of a sediment for analysis. However, mudrocks are the most abundant rock type in the sedimentary record (Picard, 1971). The advantages of analyzing sands are the ease of mineral identification and the ability to study rock fragments. The analysis of muds requires special sample preparation and the study of rock fragments in these sediments is very limited, if possible at all. However, analysis of muds may often provide a more complete analysis of provenance than sands. Analysis of only coarse grained material in a sedimentary sequence composed mostly of fine grained sediments may provide biased results. Deep sea samples from site 298 consist predominantly of clayey silt (stone) and silty clay (stone). The coarse silt fraction of sediments from the fore-arc basin of S.W.

Japan are studied here to further the investigation of the provenance of muds and mudrocks and the relation between sediment composition and tectonic setting.

# GEOLOGIC SETTING

Samples from the fore-arc region of S.W. Japan were taken on Leg 31 of the Deep Sea Drilling Project from site 298 (Karig and Ingle, et al., 1975). The samples are Quaternary in age and consist of interbedded hemipelagic muds and turbidites deposited on the lower, inner slope of the Nankai Trough off Shikoku Island (Figures 1 and 2). The term fore-arc region is used in this paper to describe the oceanic side of the arc; between the arc proper and the trench.

Sediment deposition at site 298 is affected by several geomorphological features on the Shikoku slope. Sediment accumulates on benches and in old submarine channels along the slope (Hilde and others, 1969). Active submarine channels off Shikoku transport some sediment to the trough, but much of the sediment is trapped behind the outer edge of the Tosa Terrace (Figure 2). A major input of sediment into the Nankai trough is through the Suruga Submarine Canyon on the northeastern end of the trough. Sediment flows through the Suruga Submarine Canyon down the axis of the trough to the southwestern end of the trough (Hilde and others, 1969).

The Median Tectonic Line provides the major drainage divide on the southwestern islands of Japan (Figure 3). The divide provides the northern limit on the source area supplying detritus to the fore-arc region. Rivers flowing from the divide to the fore-arc region travel through a variety of rock types. The terrain consists of sedimentary, metamorphic and intermediate and basic intrusive and extrusive rock types (Figure 4). However, the metasediments of the Shimanto belt cover the largest area of the source region. It is predominant on the trough side of the divide down the length of the trough (Figures 3 and 4).

The Shimanto belt is a eugeosynclinal belt and is described by Matsuda and Uyeda (1971) as:

> a thick sequence of turbidite graywacke and shale, interbedded irregularly with conglomerate, chert, submarine basaltic lavas and tuffs. Ultramafic intrusions are also found. These rocks...are regionally metamorphosed up to the greenschist facies through the pumpellyite-prehnite metagraywacke facies.

North of the Shimanto belt are the Sambosan, Chichibu, and Sambagawa belts (Figures 3 and 4). These belts also consist of eugeosynclinal sediments. The Sambosan belt is characterized by Middle Permian to early Jurassic limestones, cherts and mafic volcanics. The Chichibu belt consists largely of weakly metamorphosed upper Paleozoic clastic rocks, cherts, limestones and mafic volcanic rocks. The Sambagawa belt is now a high pressure, low temperature metamorphic belt characterized by crystalline schist. Quaternary volcanoes and Miocene volcanics are located on Honshu near the Suruga Submarine Canyon. Quaternary volcanoes are also located on Kyushu (Tanaka and Nozawa, 1977).

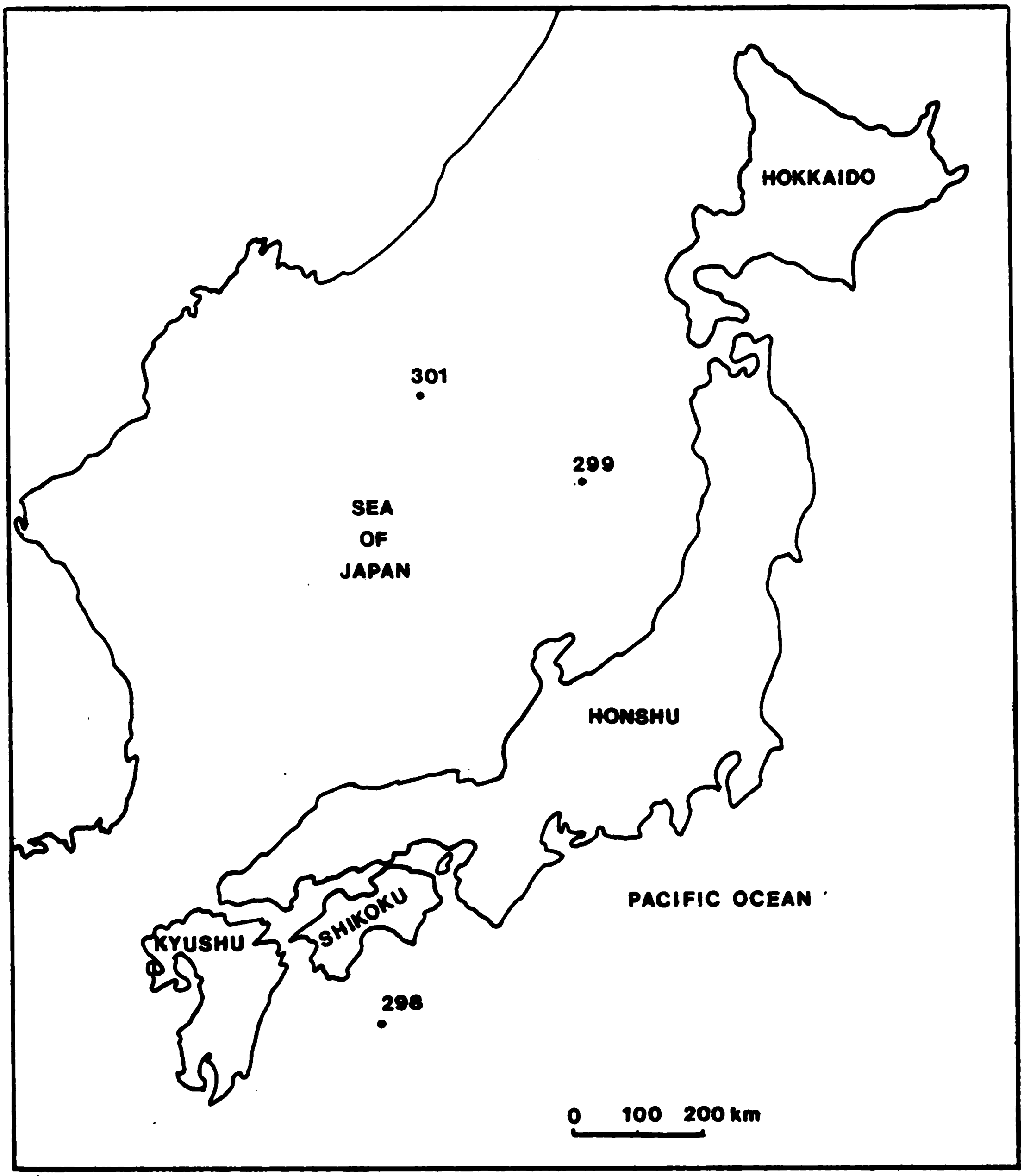


Figure 1. Locations of D.S.D.P. sites 298, 299 and 301.

Figure 2. Bathymetric surface of the Shikoku slope. Locations of the Tosa Terrace, Suruga Submarine Canyon and Nankai Trough included (after Hilde and others, 1969).

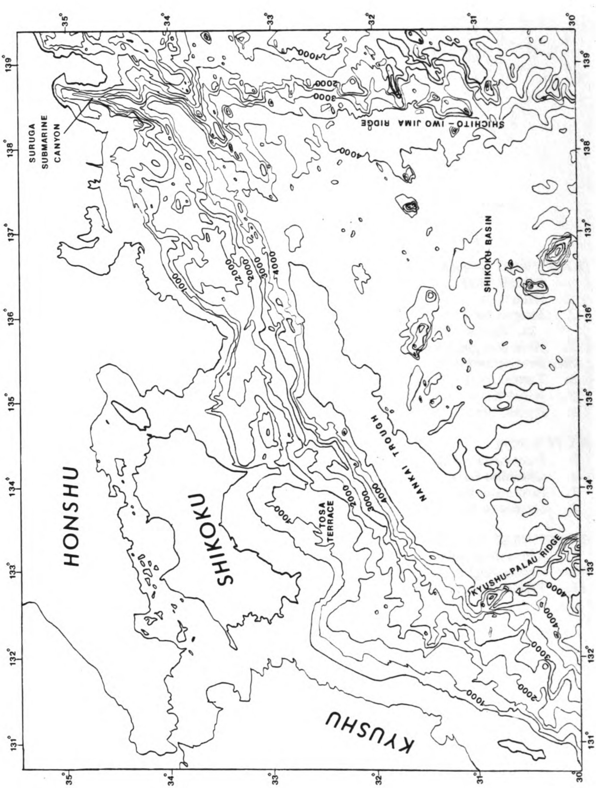
HONSHU
SHIKOKU
KYUSHU
SURUGA SUBMARINE CANYON
NANKAI TROUGH
TOSA TERRACE
SHIKOKU BASIN
KYUSHU-PALAU RIDGE
SHICHITO - IWO JIMA RIDGE
1000
2000
3000
4000
131°
132°
133°
134°
135°
136°
137°
138°
139°
30°
31°
32°
33°
34°
35°

Figure 2.

Figure 3. Geotectonic division of Japan (Pre-Neogene) (after Tanaka and Nozawa, 1977).

SOUTHWEST JAPAN

INNER SIDE

1. Hida Belt
2. Sangun Belt
   2s. Maizuru Structural Belt

2'. Hida Marginal Belt

2". Joetsu Belt

3. Tamba Belt

3'. Ashio Belt

4. Ryoke Belt

OUTER SIDE

5. Sambagawa Belt
6. Chichibu Belt
7. Sambosan Belt
8. Shimanto Belt

NORTHWEST KYUSHU

9. Ainoshima Belt
10. Nishisonogi Belt
11. Tsushima Belt

NORTHEAST JAPAN

12. Abukuma Belt
13. South Kitakami Belt
    13h. Hayachine Structural Belt
14. North Kitakami Belt
15. Iwaizumi Belt
16. Taro Belt

CENTRAL HOKKAIDO

17. Ishikari Belt
18. Kamuikotan Belt
19. Hidaka Belt
20. Tokoro Belt

EAST HOKKAIDO

21. Nemuro Belt

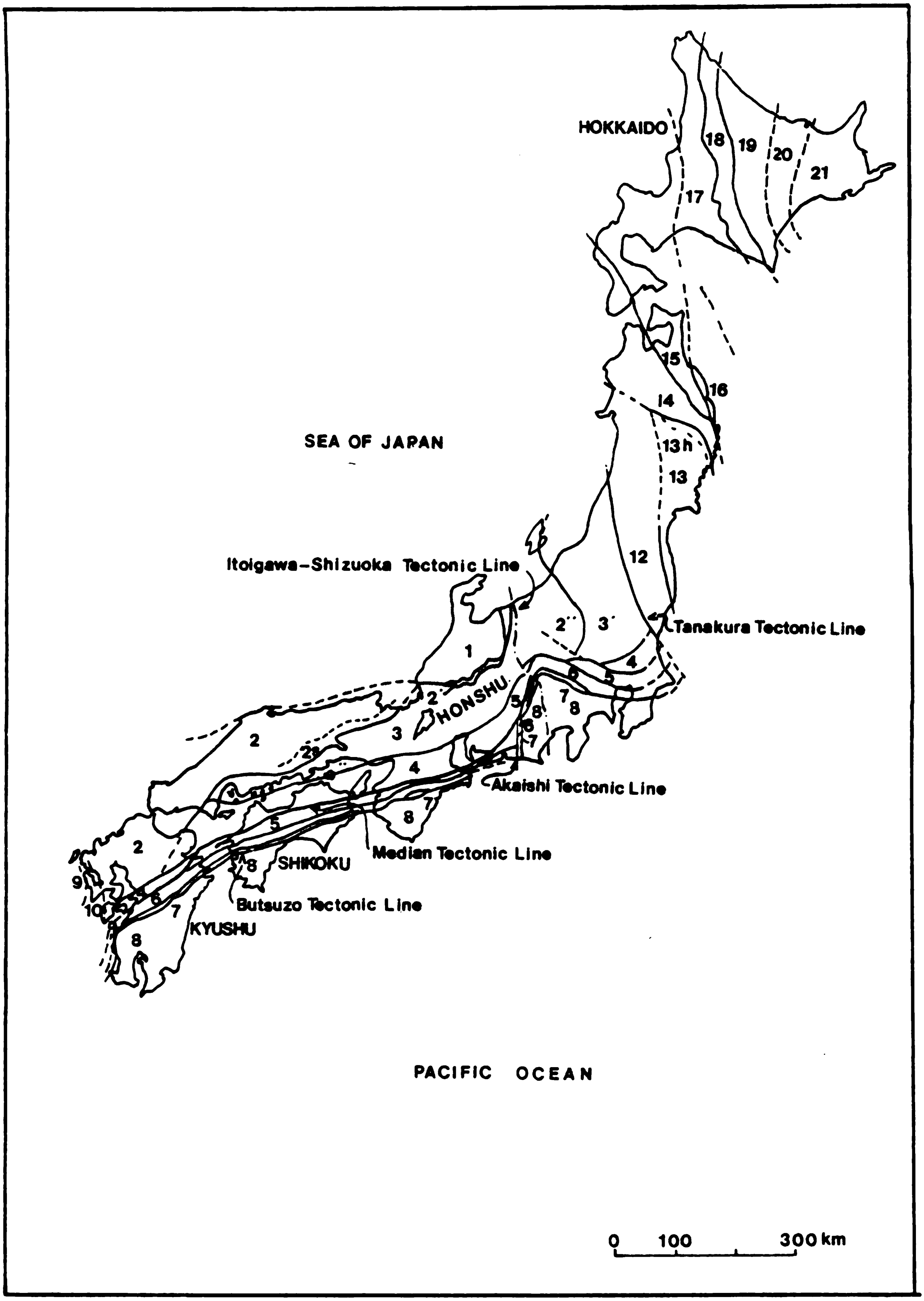
HOKKAIDO
18
19
20
21
17
15
16
14
13h
13
12
SEA OF JAPAN
Itoigawa-Shizuoka Tectonic Line
2''
3'
Tanakura Tectonic Line
1
4
6
5
2'
HONSHU
7
8
3
2
2a
Akaishi Tectonic Line
5
SHIKOKU
Median Tectonic Line
Butsuzo Tectonic Line
9
10
6
7
8
KYUSHU
PACIFIC OCEAN
0 100 300 km

Figure 3.

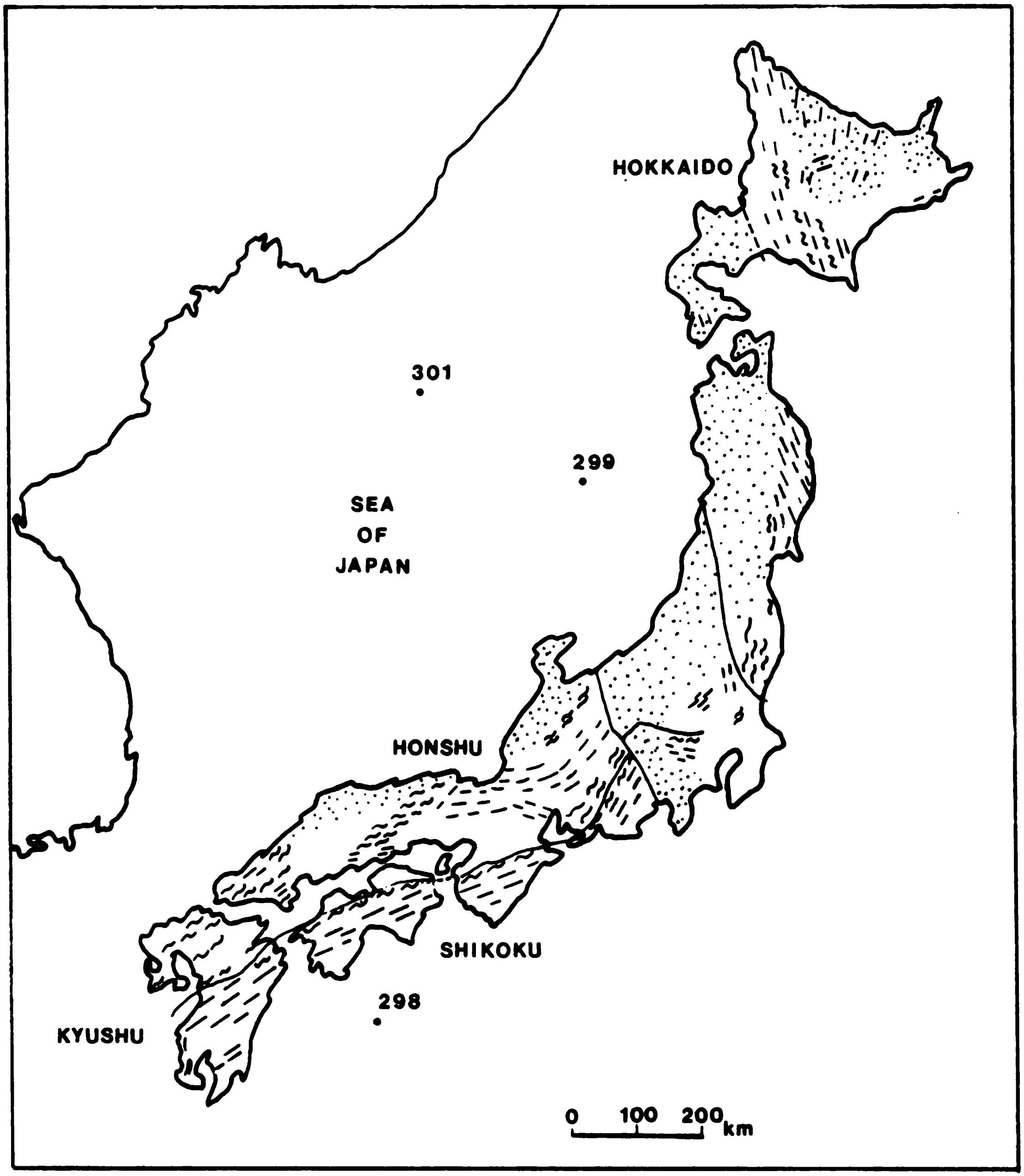


Figure 4. Geologic sketch map of Japan
(after Tanaka and Nozawa, 1977).

Early Neogene volcanic terranes ("Green Tuff" region).

Main Paleozoic and Mesozoic sedimentary terranes.

Main metamorphic terranes.

# METHODS

Thirty-two samples were examined from site 298. These samples were taken from all levels of the core and range from clayey silt (stone) to silty clay (stone) with < 5% sand. The samples were processed in order to allow identification of quartz and feldspar grains. The sample preparation techniques are applicable to well-indurated mudrocks to allow comparative studies with ancient rocks. The samples were first broken up by hand and ultrasonically cleaned. Each sample was then heated in alternating solutions of .5 m NaOH and 10% HCl until warm. This served to remove organics, iron oxides and carbonates. After the sample was dried, it was boiled in potassium hydrogen sulfate for 20 minutes to remove phyllosilicates (Blatt and Schultz, 1976). Upon cooling, each sample was boiled for 5-10 minutes in 10% HCl to remove remaining potassium hydrogen sulfate and iron oxides liberated by the pyrosulfate fusion. Finally, the sample was brought to a boil in .5 m NaOH to remove any silica wreckage resulting from the breakdown of the clays. The residual grains were quartz and feldspar plus a few surviving rock fragments.

The samples were wet sieved through 270 mesh and 325 mesh screens. Measurement of the long axis of grains with the microscope revealed the size range to vary from .031 mm to .125 mm (coarse silt to very fine sand) although most grains were in the .044 mm to .053 mm (coarse silt) range.

A test of this process was made on an artificial sample consisting of coarse silt to very fine sand sized grains of quartz, plagioclase and alkali feldspar. The composition of this sample before processing was determined by point counting. Three hundred grains were counted resulting in 26% monocrystalline quartz (MQ), 16% high feldspar (HF, $n > 1.54$) and 58% low feldspar (LF, $n < 1.54$). The composition of the sample after processing was found to be $MQ_{30}\,HF_{14}\,LF_{56}$. A chi-square test was performed on the data resulting in a $\chi^2$ value of 1.58. The critical value of $\chi^2$ is 5.99, $\alpha = .05$. Therefore, a significant difference between the processed and unprocessed sample cannot be shown at the 95% level of confidence.

Jones (1979) determined the effects of pyrosulfate fusion on quartz and feldspar in the coarse silt fraction. The results of his work are listed in Table 1. The largest loss is found in the bytownite samples, which in this study amounts to a maximum loss of 1% of the total feldspar.

Table 1. Mineral Loss During Fusion.

| Mineral | Weight% Lost During Fusion |
|---|---|
| Quartz | .8 |
| Microcline | 2.5 |
| Albite | 3.5 |
| Oligoclase | 4.7 |
| Andesine | 11.7 |
| Bytownite | 23.6 |

Grain mounts of the 32 samples were examined by the ribbon method (Galehouse, 1969) on the petrographic microscope. Approximately 300 grains were identified on each slide in order to determine the percentage of MQ, PQ (polycrystalline quartz, including chert), HF and LF in each sample.

An average of 25 feldspar grains were analyzed from each grain mount on the electron microprobe. Feldspars were chosen by the ribbon method to insure randomization (Galehouse, 1969). Counts for K, Ca, and Na were simultaneously recorded at 20 nanoamps for 10 seconds. Readings were taken at least three times on each feldspar grain. Weight percent anorthite, albite and orthoclase were determined in the following manner (after Bence and Albee, 1968):

Wt% AN =

$$\frac{\dfrac{CPS_{U}^{Ca}}{CPS_{AN\ Std}^{Ca} \cdot \beta_{AN\ Std}^{Ca}}}{\dfrac{CPS_{U}^{Ca}}{CPS_{AN\ Std}^{Ca} \cdot \beta_{AN\ Std}^{Ca}} + \dfrac{CPS_{U}^{Na}}{CPS_{AB\ Std}^{Na} \cdot \beta_{AB\ Std}^{Na}} + \dfrac{CPS_{U}^{K}}{CPS_{OR\ Std}^{K} \cdot \beta_{OR\ Std}^{K}}} \times 100$$

Wt% OR =

$$\frac{\dfrac{CPS_{U}^{K}}{CPS_{OR\ Std}^{K} \cdot \beta_{OR\ Std}^{K}}}{\dfrac{CPS_{U}^{K}}{CPS_{OR\ Std}^{K} \cdot \beta_{OR\ Std}^{K}} + \dfrac{CPS_{U}^{Ca}}{CPS_{AN\ Std}^{Ca} \cdot \beta_{AN\ Std}^{Ca}} + \dfrac{CPS_{U}^{Na}}{CPS_{AB\ Std}^{Na} \cdot \beta_{AB\ Std}^{Na}}} \times 100$$

Wt% AB =

$$\frac{\dfrac{CPS_{U}^{Na}}{CPS_{AB\ Std}^{Na} \cdot \beta_{AB\ Std}^{Na}}}{\dfrac{CPS_{U}^{Na}}{CPS_{AN\ Std}^{Na} \cdot \beta_{AB\ Std}^{Na}} + \dfrac{CPS_{U}^{Ca}}{CPS_{AN\ Std}^{Ca} \cdot \beta_{AN\ Std}^{Ca}} + \dfrac{CPS_{U}^{K}}{CPS_{OR\ Std}^{K} \cdot \beta_{OR\ Std}^{K}}} \times 100$$

CPS = Counts per second

U = Unknown

$\beta$ = Correction factors (Sweatmen and Long, 1969)

## PETROGRAPHIC ANALYSIS OF THE FORE-ARC SEDIMENTS

The average composition of the samples examined from site 298 is $MQ_{56}$ (s = 9.33) $PQ_{14}$ (s = 7.64) $HF_9$ (s = 3.06) $LF_{21}$ (s = 5.59). A complete list of this data is included in Table 2. Most of the polycrystalline quartz is chert (microcrystalline and cryptocrystalline quartz, shown in Figure 5). Trace amounts of felsite were noted in some samples and it is possible that some felsite may have been recorded as chert (Pettijohn, et al., 1973; Wolf, 1971; Dickinson, 1970; Blatt, 1967). Felsite and chert were distinguished by the presence of feldspars or glass shards in felsite when visible. The feldspars were rarely twinned or zoned in this size fraction (Figure 5). Therefore, these characteristics were not often utilized in determining composition or provenance. Feldspar grains of every composition often contain numerous inclusions. Thus, the presence of cloudy albite grains does not unequivocally indicate albitization has occurred. Rock fragments were not analyzed because they are too difficult to identify in the silt size fraction and many rock fragments may be destroyed during pyrosulfate fusion.

Harrold and Moore (1975) examined seven samples from sand units at site 298. They found a Q (total quartz)/F (total feldspar) ratio of .94 for the > .0625 mm size fraction. These sands range in size from very fine sands to coarse sands. The Q/F ratio determined in this study for the coarse silt fraction of the silty clay and the clayey silt units is 2.30. The > .0625 mm size fraction was examined in three samples from silty clay and clayey silt units (Table 3). These sands range in size from very fine to fine sand. The Q/F ratio of these sands is 2.05. The difference in the quartz to feldspar ratios of the sand and silt units may be due to the abundance of sedimentary rock fragments in the sand size fraction. Sedimentary rock fragments composed of quartz and feldspar in an argillaceous matrix comprise 41% of the sand units. Natural disaggregation of these sedimentary rock fragments will provide an increase of quartz and feldspar grains in a finer grain size. It appears that the additional quartz found in the silty units may be bound in sedimentary rock fragments in the sand units. Disaggregation of sand sized sedimentary rock fragments in the silty units by pyrosulfate fusion may provide some additional silt sized quartz and feldspar. However, the sand fraction of the silty units is < 5%. It does not appear that the disaggregation of sand sized sedimentary rock fragments by pyrosulfate fusion techniques would provide the volume of silt sized quartz needed to account for the difference in the Q/F ratios of the sand and silt units.

Table 2. Petrographic Analyses.

| Age | Core | Sample Section | Interval | Number of Grains Counted MQ | PQ | HF | LF |
|---|---|---|---|---|---|---|---|
| Pleistocene-Holocene | 2 | 2 | 48-52 | 196 | 10 | 40 | 54 |
| | 2 | 2 | 92-94 | 191 | 20 | 33 | 56 |
| | 2 | 2 | 100-101 | 158 | 55 | 31 | 56 |
| Late Pleistocene | 4 | 1 | 68-70 | 169 | 35 | 27 | 63 |
| | 4 | 2 | 99-101 | 167 | 19 | 44 | 71 |
| | 4 | 2 | 100-101 | 156 | 37 | 23 | 84 |
| | 5 | 1 | 75-76 | 209 | 28 | 19 | 44 |
| | 5 | 1 | 103-105 | 189 | 43 | 22 | 45 |
| | 7 | 1 | 52-54 | 125 | 103 | 30 | 42 |
| | 7 | 1 | 100-101 | 193 | 16 | 45 | 46 |
| | 7 | 2 | 100-102 | 144 | 39 | 40 | 77 |
| Early Pleistocene | 8 | 2 | 50-52 | 123 | 49 | 33 | 88 |
| | 8 | 2 | 96-98 | 125 | 73 | 38 | 64 |
| | 8 | 2 | 100-101 | 132 | 69 | 26 | 73 |
| | 10 | 1 | 48-50 | 144 | 64 | 20 | 69 |
| | 10 | 2 | 30-31 | 172 | 45 | 25 | 58 |
| | 10 | 2 | 52-54 | 231 | 6 | 20 | 43 |
| | 10 | 3 | 100-102 | 184 | 10 | 43 | 64 |
| | 11 | 2 | 100-101 | 131 | 83 | 14 | 72 |
| | 11 | 3 | 100-101 | 140 | 56 | 19 | 85 |
| | 11 | 4 | 100-101 | 171 | 27 | 41 | 61 |
| | 12 | 2 | 100-101 | 135 | 74 | 20 | 71 |
| | 12 | 3 | 100-101 | 173 | 38 | 14 | 75 |
| | 12 | 4 | 100-101 | 137 | 33 | 26 | 104 |
| | 13 | 2 | 100-101 | 167 | 24 | 17 | 92 |
| | 13 | 3 | 100-101 | 199 | 20 | 16 | 65 |
| | 13 | 5 | 100-101 | 168 | 54 | 36 | 42 |
| | 14 | 2 | 100-101 | 207 | 35 | 24 | 34 |
| | 14 | 4 | 100-101 | 159 | 59 | 27 | 55 |
| | 15 | 3 | 100-101 | 169 | 37 | 26 | 68 |
| | 16 | 2 | 40-41 | 166 | 58 | 23 | 53 |
| | 16 | 5 | 100-101 | 201 | 33 | 22 | 44 |

MQ = monocrystalline quartz
PQ = polycrystalline quartz and chert
HF = high feldspar, $n > 1.54$
LF = low feldspar, $n < 1.54$

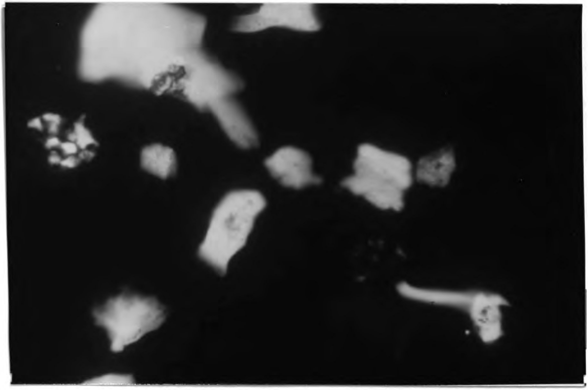

Figure 5. Grain mount from site 298
(width of field is .17 mm).

Table 3. Analysis of the > .0625 mm
size fraction in silty clays and clayey silts.

| Sample | MQ | PQ | HF | LF |
|---|---|---|---|---|
| 2-2-100-101 | 131* | 63 | 46 | 60 |
| 5-1-103-105 | 144 | 53 | 32 | 71 |
| 14-2-100-101 | 151 | 61 | 32 | 56 |

*Number of grains counted out of 300.

## MICROPROBE ANALYSIS OF THE FORE-ARC SEDIMENTS

Microprobe analysis of 860 feldspars from site 298 revealed the following proportions of feldspar types: 35% plagioclase (minus albite), 27% albite, 35% alkali feldspar and 3% ternary feldspar. Ternary feldspars are defined as feldspars with > 50 Wt% AB > 10 Wt% AN and > 10 Wt% OR. Albite is defined as feldspars with < 10 Wt% AN and < 10 Wt% OR. A complete list of this data is provided in Table 4. A histogram of the frequency of feldspar types occurring in the sediments from site 298 is shown in Figure 6. Compositional groups in the histogram were chosen according to the plagioclase series and this was extended to the alkali feldspars for convenience and clarity. The histogram shows highest frequencies for albite and feldspars with 91-100 Wt% OR and lowest frequencies for feldspars with 91-100 Wt% AN and 31-50 Wt% OR. The most abundant type of plagioclase (other than albite) is in the range of $AN_{50-70}$. This interval reflects the calc-alkaline volcanic series associated with island arcs.

In order to compare microprobe and microscope feldspar determinations, all alkali feldspars and plagioclase with < 22 Wt% AN were grouped as low feldspar grains. All plagioclase grains with > 22 Wt% AN were grouped as high feldspar grains. A chi-square test was performed on the data for each sample. Yate's correction was applied for the 2 x 2 probabilities. For samples which contained cells with expected numbers < 5 an approximation of the chi-square test was used (Mainland, et al., 1965).

Significant difference between microprobe and microscope feldspar analyses were found in only two samples; 11-2 (100-101) and 14-4 (100-101). The amount of HF identified with the microprobe is higher than expected in both samples. The data obtained by use of the microscope is consistent with data for other samples from the site. Therefore, the microprobe data for these samples have been left out of all analyses in this study.

Table 4. Microprobe Analyses.

| Sample | | | Number of Grains Counted | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Wt% AN | | | | | | Wt% OR | | | | | | |
| Core | Sample | Interval | 0-10 | 11-30 | 31-50 | 51-70 | 71-90 | 91-100 | 0-10 | 11-30 | 31-50 | 51-70 | 71-90 | 91-100 | T |
| 2 | 2 | 48-52 | 7 | 5 | 5 | 7 | 6 | 0 | 4 | 4 | 0 | 2 | 1 | 5 | 0 |
| 2 | 2 | 92-94 | 7 | 5 | 2 | 3 | 2 | 1 | 2 | 1 | 1 | 1 | 3 | 2 | 0 |
| 2 | 2 | 100-101 | 1 | 2 | 1 | 5 | 2 | 1 | 1 | 2 | 0 | 2 | 0 | 4 | 1 |
| 4 | 1 | 68-70 | 4 | 3 | 1 | 4 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 2 | 1 |
| 4 | 2 | 99-101 | 2 | 4 | 1 | 4 | 0 | 1 | 1 | 3 | 1 | 1 | 2 | 3 | 1 |
| 4 | 2 | 100-101 | 7 | 4 | 2 | 3 | 2 | 0 | 2 | 3 | 3 | 2 | 5 | 5 | 1 |
| 5 | 1 | 75-76 | 5 | 1 | 2 | 6 | 0 | 0 | 2 | 5 | 0 | 2 | 2 | 3 | 0 |
| 5 | 1 | 103-105 | 3 | 2 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 2 | 2 |
| 7 | 1 | 52-54 | 5 | 0 | 1 | 2 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 1 |
| 7 | 1 | 100-101 | 3 | 5 | 2 | 3 | 3 | 1 | 1 | 4 | 1 | 0 | 0 | 7 | 0 |
| 7 | 2 | 100-102 | 4 | 3 | 3 | 5 | 1 | 3 | 5 | 1 | 1 | 2 | 1 | 4 | 1 |
| 8 | 2 | 50-52 | 3 | 4 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 3 | 0 |
| 8 | 2 | 96-98 | 3 | 3 | 4 | 5 | 3 | 0 | 2 | 4 | 0 | 0 | 0 | 1 | 1 |
| 8 | 2 | 100-101 | 9 | 1 | 4 | 0 | 1 | 0 | 4 | 2 | 1 | 0 | 1 | 6 | 0 |

Table 4. Microprobe Analyses (Continued).

| Sample | | | Number of Grains Counted | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Wt% AN | | | | | | Wt% OR | | | | | | |
| Core | Sample | Interval | 0-10 | 11-30 | 31-50 | 51-70 | 71-90 | 91-100 | 0-10 | 11-30 | 31-50 | 51-70 | 71-90 | 91-100 | T |
| 10 | 1 | 48-50 | 7 | 4 | 5 | 1 | 0 | 0 | 1 | 7 | 0 | 0 | 1 | 2 | 1 |
| 10 | 2 | 30-31 | 3 | 1 | 1 | 4 | 3 | 0 | 7 | 3 | 1 | 0 | 2 | 4 | 1 |
| 10 | 2 | 52-54 | 3 | 1 | 1 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 1 |
| 10 | 3 | 100-102 | 1 | 1 | 0 | 1 | 0 | 1 | 2 | 0 | 0 | 2 | 2 | 2 | 1 |
| 11 | 3 | 100-101 | 5 | 2 | 2 | 2 | 0 | 3 | 2 | 2 | 1 | 0 | 3 | 8 | 1 |
| 11 | 4 | 100-101 | 6 | 1 | 3 | 3 | 3 | 0 | 2 | 3 | 0 | 1 | 1 | 8 | 1 |
| 12 | 2 | 100-101 | 3 | 1 | 1 | 2 | 0 | 0 | 5 | 5 | 0 | 2 | 1 | 4 | 0 |
| 12 | 3 | 100-101 | 7 | 2 | 5 | 4 | 1 | 0 | 2 | 4 | 1 | 0 | 1 | 3 | 0 |
| 12 | 4 | 100-101 | 8 | 3 | 2 | 6 | 1 | 0 | 0 | 4 | 1 | 3 | 5 | 3 | 0 |
| 13 | 2 | 100-101 | 7 | 2 | 3 | 0 | 1 | 1 | 2 | 3 | 0 | 0 | 2 | 3 | 1 |
| 13 | 3 | 100-101 | 16 | 1 | 4 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 2 |
| 13 | 5 | 100-101 | 2 | 2 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 1 | 2 | 4 | 0 |
| 14 | 2 | 100-101 | 11 | 5 | 1 | 4 | 1 | 0 | 0 | 6 | 0 | 1 | 0 | 4 | 0 |
| 15 | 3 | 100-101 | 2 | 3 | 1 | 1 | 2 | 1 | 1 | 2 | 0 | 1 | 2 | 5 | 1 |
| 16 | 2 | 40-41 | 5 | 1 | 1 | 0 | 0 | 0 | 2 | 4 | 0 | 0 | 1 | 3 | 2 |
| 16 | 5 | 100-101 | 8 | 1 | 3 | 1 | 1 | 0 | 3 | 4 | 0 | 1 | 1 | 6 | 0 |

*Grains with less than 5 Wt% OR and less than 5 Wt% AN were arbitrarily recorded in terms of Wt% OR or Wt% AN.

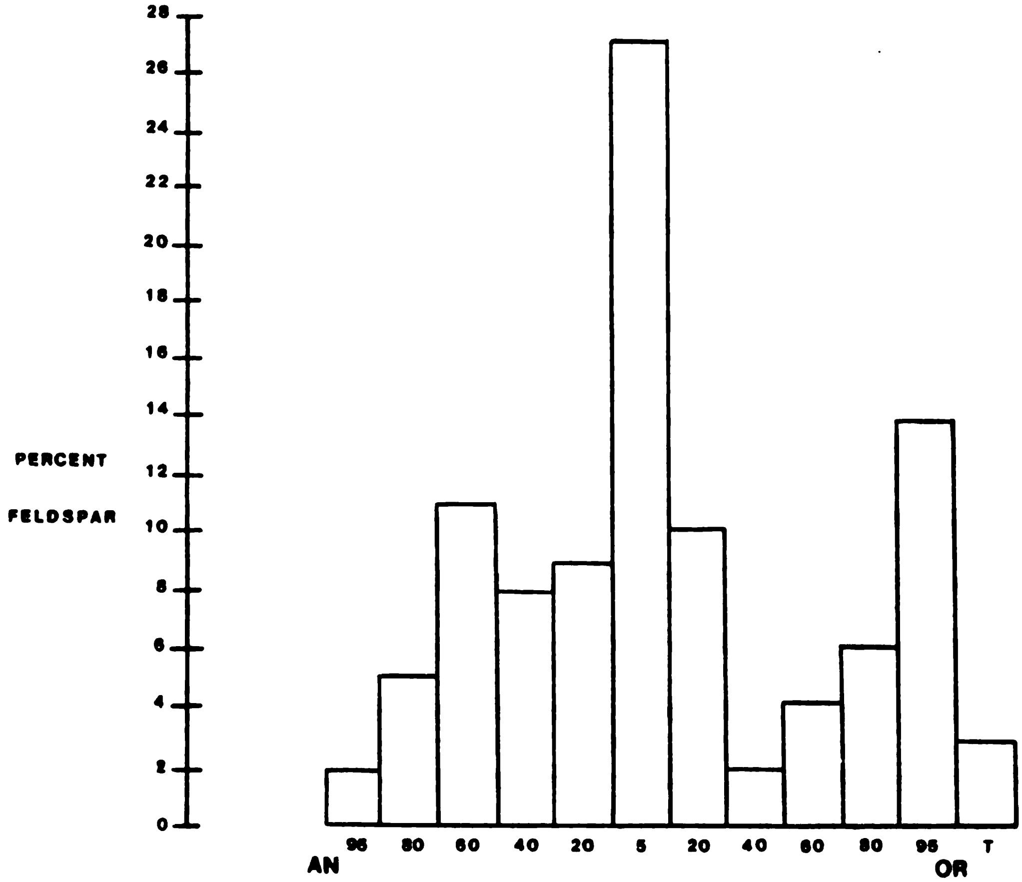


Figure 6. Histogram of feldspar compositions in the fore-arc sediments. The median values of the class intervals are listed on the X-axis. Class interval T represents Ternary feldspars.

## PROVENANCE OF THE FORE-ARC SEDIMENTS

The provenance of site 298 sediments can be inferred from the feldspar composition, Q/F, HF/F and PQ/Q ratios of the sediment. The range of feldspar compositions indicates a diverse source region of acid and basic rocks (Table 5). Approximately 15% of the feldspars are ternary feldspars or have a composition between $OR_{11}$-$OR_{50}$ which indicates a volcanic source (Trevena and Nash, 1981). Nineteen percent of the feldspars have a composition between $AN_{31-70}$ which reflects the calc-alkaline nature of the volcanic arc. The fourteen percent of the sample having a composition of $OR_{91-100}$ indicates the presence of plutonic or metamorphic rocks in the source region.

Examination of Figure 4 shows a variety of probable sources for the fore-arc sediments. The Shimanto belt and Quaternary volcanoes within it (Figure 7) may provide volcanic input, the Shimanto belt and Sambagawa belts may provide a metamorphic source, and ultramafic intrusions and granitic plutons occurring in the Shimanto and Chichibu belts may provide a plutonic source.

The predominance of the metasediments of the Shimanto belt in the source areas for the detritus in the fore-arc region may explain the relative abundance of quartz to feldspar and low feldspar to high feldspar in the sediments at site 298 (Table 6). Detritus enriched in monocrystalline quartz relative to feldspar and low feldspar relative to high feldspar would be expected from a sedimentary source because quartz is more stable than feldspar and alkali feldspars are more stable than Ca-plagioclase.

Table 5. Distribution of feldspar compositions in the fore-arc.

| Composition | Percentage of Feldspar Grains |
|---|---|
| AN 91-100 | 2 |
| AN 71-90 | 5 |
| AN 51-70 | 11 |
| AN 31-50 | 8 |
| AN 11-30 | 9 |
| AN 0-10 and OR 0-10 | 27 |
| OR 11-30 | 10.5 |
| OR 31-50 | 1.5 |
| OR 51-70 | 3.5 |
| OR 71-90 | 5.5 |
| OR 91-100 | 14 |
| TERNARY | 3 |

Figure 7. Location of Quaternary volcanoes in Japan.

- ◊ Tholeiitic basalt
- • Pyroxene andesite
- ✱ Pyroxene andesite and associated hornblende andesite
- ✱ Hornblende andesite with or without biotite phenocryst
- ● Dacite or rhyolite
- + Alkali basalt and/or other alkali rocks
- ⥱ Pyroclastic flow deposit
- o Caldera whose diameter is larger than 10 km

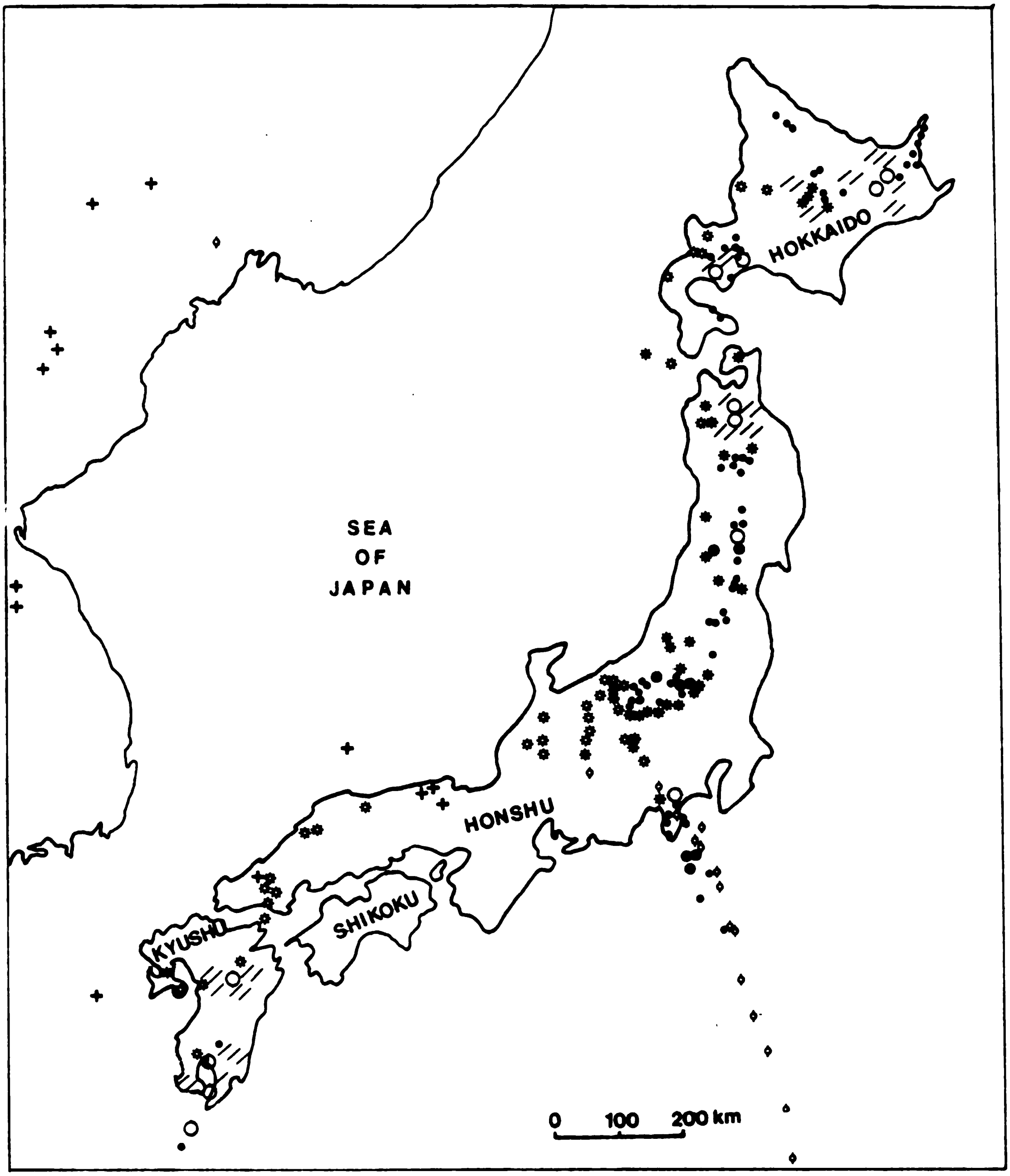


Figure 7.

Table 6. Fore-arc mineral proportions.

| | | | |
|---|---|---|---|
| Q/F | = 2.30 | HF/F = | .30 |
| MQ/F | = 1.84 | PQ/Q= | .20 |

The Q/F and PQ/Q ratios found for the fore-arc sediments fit the "tectonic" provenance model for subquartzose sandstones suggested by Dickinson (1970). Sands indicative of a "tectonic", mixed provenance, as described by Dickinson (1970) will have a Q/F ratio of up to 2, including a significant amount of chert. Dickinson (1970) writes:

> The source rock are mainly chert and sedimentary or metasedimentary strata of argillite, slate, phyllite, etc., with variable amounts of intercalated volcanic and metavolcanic strata...derived from the erosional destruction of volcano-plutonic orogens or magmatic arcs and deposited in adjacent oceanic trenches and associated troughs (Ojakangas, 1968; Dickinson, 1970).

Thus, the tectonic provenance model suggested by Dickinson (1970) seems to well fit the fore-arc sediment composition and its most likely source, the Shimanto belt.

Sugimura and Uyeda (1973) provide a summary of papers on the source area of the eugeosynclinal sediments of the Shimanto belt. It is suggested on the basis of sedimentary structures and conglomerates within the sediment that there was once a land source with a continental crust to the south of the Shimanto belt. The fore-arc sediments at site 298 appear to be multicycle with a source consisting, in part, of eroded sialic continental crust.

## COMPARISON OF THE FORE-ARC AND BACK-ARC BASINS

Sibley and Pentony (1978) examined back-arc sediments from DSDP sites 299 and 301 in the Sea of Japan (Figure 1). The difference between the composition of Quaternary sediments from sites 299 and 301 are very small compared to the differences between these sites and site 298 from the fore-arc area. Therefore, the data from sites 299 and 301 have been combined to make comparisons between the fore-arc and back-arc basins. The average composition of Quaternary back-arc basin samples of the very fine sand to coarse silt size fraction was determined as $MQ_{41}\ HF_{24}\ LF_{35}$ (Sibley and Pentony, 1978). Only trace amounts of polycrystalline quartz or chert were found in these samples.

Comparison of the back-arc mineralogy to the fore-arc sediment composition of $MQ_{56}\ PQ_{14}\ HF_{9}\ LF_{21}$ shows striking contrast. Statistical comparison of the occurrence of MQ, HF, and LF in the two basins by $\chi^2$ showed a significant difference between the mineralogy of the two basins ($\chi^2 = 1114.33$, $\alpha = .05$). The percentages of MQ and Q are significantly higher in the fore-arc sediments than the back-arc sediments by t tests ($\alpha = .05$). The percentages of HF and LF are significantly lower in the fore-arc sediments than in the back-arc sediments by t tests ($\alpha = .05$).

Table 7 lists the percentage of feldspar types found in the samples from the fore-arc and back-arc basins. All of the data is restricted to Quaternary samples only, as sites 299 and 301 penetrated Tertiary sediments and site 298 did not. Sibley and Pentony (1978) did not analyze "dirty" feldspars with the microprobe. These feldspars have an albite composition. Thus the number of albite grains analyzed with the microprobe does not indicate the total percentage of albite grains in the back-arc basin. Therefore, samples with the composition $AN_{0-10}$ or $OR_{0-10}$ are not included in the data listed in Table 6.

Significant differences were found by t tests in every category between the two basins except in the $OR_{91-100}$ and $AN_{71-100}$ categories (Table 7). The most outstanding contrast between the basins is the relative enrichment of plagioclase in the back-arc basin. The most abundant type of feldspar in the back-arc basin listed in Table 7 is in the compositional range of $AN_{31-70}$. This composition reflects the calc-alkaline volcanic series associated with the island arc.

Sibley and Pentony (1978) showed the islands of Japan to be a common source area for the back-arc sites within the Asian continent supplying additional detritus to site 301. The most likely source area for the bulk of detritus in the region of sites 299 and 301 is N.E. Honshu and S.W. Hokkiado. This area is known as the "Green Tuff' region (Figure 4) and is characterized by volcanic effusives of Miocene age (Tanaka and Nozawa, 1977). Quaternary volcanics have continued to be distributed in this region and also in S.W. Hokkaido (Figure 7).

Plutonic, metamorphic, and volcanic rocks are present in the source areas for both basins. However, the relative abundance of metasediments in the fore-arc source region and the extensive volcanics in the back-arc source region appear to explain the major differences in the mineralogy of the fore-arc and back-arc basin sediments. As shown in Table 8, the fore-arc sediments have larger Q/F and MQ/F ratios than the back-arc basin sediments. The fore-arc detritus also has a much lower HF/LF ratio than the back-arc basin sediments. This corresponds to electron microprobe analyses indicating a relative enrichment of plagioclase feldspars in the back-arc basin and of K-spars in the fore-arc. The abundance of plagioclase feldspars in the range of $AN_{30-70}$ in the back-arc basin reflects the predominantly volcanic nature of the source for these sediments. The abundance of feldspars of varying compositions in the fore-arc sediments reflects the mixed provenance of these sediments. The mineralogical differences between the fore-arc and back-arc basin sediments may be largely attributed to the metasediments occurring in the Shimanto belt in the fore-arc source region and the Green Tuff and Quaternary volcanics occurring in the back-arc source region. Both source regions have, from time to time, been partially overlain by marine sediments, but it appears that the lower strata account for the major mineralogical differences between the fore-arc and back-arc detritus.

Table 7. Occurrence of feldspar compositions in the fore-arc and back-arc basins.

| Feldspar Composition | Percent of Total Feldspar (Minus Albite) | | T Test Results |
|---|---|---|---|
| | Fore-arc | Back-arc[1] | |
| $OR_{91-100}$ | 20 | 21 | N.S. |
| $OR_{51-90}$ | 12 | 4 | S.D. |
| $OR_{11-50}$ | 17 | 1 | S.D. |
| $AN_{11-30}$ | 12 | 18 | S.D. |
| $AN_{31-70}$ | 26 | 49 | S.D. |
| $AN_{71-100}$ | 9 | 6 | N.S. |
| TERNARY | 4 | 1 | S.D. |

[1]Data from Sibley and Pentony, 1978

Table 8. Mineral proportions in the fore-arc and back-arc basins.

| Mineral Proportions | Fore-arc | Back-arc[1] | T Test Results |
|---|---|---|---|
| Q/F | 2.30 | .70 | S.D. |
| MQ/F | 1.84 | .70 | S.D. |
| PQ/Q | .20 | - | S.D. |
| HF/LF | .44 | .70 | S.D. |
| HF/F | .30 | .42 | S.D. |

[1]Data from Sibley and Pentony, 1978

## THE IMPORTANCE OF ISLAND ARC CRUSTAL TYPES

Comparison of fore-arc detritus from island arcs underlain by "continental" and oceanic crust types are made with the limited amount of data presently available. The following comparisons are based on samples of varying grain sizes. Some petrographic data is available from the silt and sand size fractions from all sites, except the fore-arc region of Sumatra. Due to the varying amounts of petrographic data available on the silt to coarse sand fractions direct comparison of petrographic data values may not provide exacting compositional limits on fore-arc detritus. However, based on the limited amount of data available, the provenance of sediments at each site does not appear to vary with grain size.

Petrographic data from the fore-arc regions of Puerto Rico (Breyer and Ehlmann, 1981) and the central Aleutians (Stewart, 1978; Scholl, et al., 1971) reflects the volcanic provenance for the sediments in both of these regions. Petrographic data from the fore-arc regions of S.W. Japan and Sumatra (Moore, 1979) do not reflect a primarily volcanic source. Comparison of the provenance of these fore-arc sediments provides insight as to the nature of the mineralogic differences seen in the fore-arc detritus derived from magmatic arcs.

The volcanics of S.W. Japan, Sumatra, Puerto Rico, and the central Aleutians (Andreanof Islands) are predominantly calc-alkaline (Windley, 1977; Katili, 1975; Mattson, 1977; Coats, 1952). Windley (1977) utilizes the predominant volcanic series on an island arc as a measure of the relative maturity of an arc. The maturity of an arc increases from the tholeitic series to the calc-alkaline to the alkaline series. By this definition, all four arcs are at a similar stage of evolution.

Petrographic data from the fore-arc sediments of S.W. Japan, Sumatra, Puerto Rico and the central Aleutians is shown in Table 9. Considerable variation occurs between all four sites. Variability in P/F ratios may be due to the alteration of feldspars. Moore (1979) suggests original K-spar in melange sediments off of Sumatra may have been altered by reaction with seawater. Altered feldspars were noted at most sities. In general, the fore-arc sediments of S.W. Japan and Sumatra are enriched in quartz and sedimentary-metasedimentary rock fragments compared to the fore-arc sediments of Puerto Rico and the central Aleutians.

A correlation between fore-arc detritus mineralogy and the nature of the crust underlying the adjacent island arc is found for these island arcs. Sumatra (Hamilton, 1977; Katili, 1975) and S.W. Japan (Sugimura, 1968) are underlain by sialic crust of continental thicknesses > 20 km. Puerto Rico (Donnelly, 1964) and the central Aleutians (Coats, 1962) are underlain by nonsialic oceanic type crust of < 20 km. Thus, there is a correlation between the occurrence of relatively quartz rich detritus with abundant sedimentary rock fragments in fore-arc regions and the presence of sialic crust underlying the adjacent island arc.

The source areas for sediments from the fore-arc regions of Sumatra (Moore, 1979) and S.W. Japan are characterized by the presence of metasediments and the exposure of metamorphic, plutonic, and volcanic rocks on the magmatic and frontal arcs of these arc systems. The source areas of the fore-arc sediments off Puerto Rico and the central Aleutians are primarily volcanic and from the adjacent arc (Stewart, 1978; Breyer and Ehlmann, 1981). Puerto Rico and the central Aleutians, although having the same volcanic maturity as S.W. Japan and Sumatra, do not have such exposures of metasediments and metamorphic rocks (Coats, 1962; Breyer and Ehlmann, 1981).

It is possible that the uplift, exposure, and erosion of a sialic "continental" type crust accounts for the mineralogy of the fore-arc detritus in S.W. Japan and Sumatra. Sugimura and Uyeda (1973) provide a summary of papers on the source area of the eugeosynclinal sediments of the Shimanto belt. It is suggested on the basis of sedimentary structures and conglomerates within the sediment that there was once a land source with a continental crust to the south of the Shimanto belt. The sedimentary/metasedimentary source rocks on Sumatra are part of a Tertiary arc complex. Moore (personal communication, 1982) suggests that the metasediments exposed on Sumatra were derived from the exposed plutonic roots of an earlier arc system and from the erosion of the Malaysian continent. The fore-arc basin sediments of Japan and Sumatra appear to be multicycle with an original source consisting, in part, of an uplifted, exposed and eroded "continental" crust. The lack of such a crust under Puerto Rico and the central Aleutians may account for the differences seen in fore-arc sediments.

Table 9. Mineral proportions of various fore-arc sediments.

| Location | Size Fraction | Number of Samples | Q/F | PQ/Q | MQ/F | P/F | V/L | S/L |
|---|---|---|---|---|---|---|---|---|
| S.W. Japan | coarse silt | 32 | 2.30 | .20 | 1.86 | (A) | N.A. | N.A. |
| | very fine - coarse sand[1] | 6 | .94 | .25 | N.A. | .82 | .27 | .68 |
| Sumatra | medium sand[2] (slope basin) | 12 | 4.53 | .06 | 4.28 | .41 | .37 | .46 |
| | medium sand[2] (melange) | 12 | 9.7 | .04 | 9.00 | .99 | .21 | .27 |
| Puerto Rico | silt to sand[3] | 18 | .61 | .35 | .40 | .81 | .52 | .31[(B)] |
| Central Aleutians | sand[4] | 27 | .17 | .68 | .05 | .97 | .96 | .02 |
| | silty clay[5] | 2 | .23 | N.A. | N.A. | N.A. | N.A. | N.A. |
| | silty sand[5] | 1 | .25 | N.A. | N.A. | N.A. | N.A. | N.A. |
| | sand[5] | 1 | .20 | N.A. | N.A. | N.A. | N.A. | N.A. |

Data from 1) Harrold and Moore, 1975, 2) Moore, 1979, 3) Breyer and Ehlmann, 1981, 4) Stewart, 1978, 5) Scholl and Creager, et al., 1973.

(A) The P/F ratio of silts from the fore-arc region of S.W. Japan may not be directly comparable to the other P/F ratios listed in this table because of differences in analytical techniques. The P/F ratio of the fore-arc sediments of S.W. Japan was determined with the electron microprobe. All other P/F ratios listed in the table were determined by staining techniques. It is unclear if albite grains with small amounts of potassium will stain yellow. Therefore, feldspar compositions determined with the electron microprobe have been used to provide maximum and minimum P/F ratios. If plagioclase grains are defined as feldspars with < 10 Wt% OR, then the P/F ratio will equal a maximum value of .62. If plagioclase grains are defined as feldspars with > 10 Wt% AN, the P/F ratio will represent a minimum of .35. The HF/F ratio for these sediments is .30.

(B) Most of these sedimentary rock fragments are mud rip-up clasts and do not indicate a sedimentary source on the island arc (Breyer and Ehlmann, 1981).

## SUMMARY

Comparison of the fore-arc basin detritus of S.W. Japan to back-arc basin detritus from the Sea of Japan and other fore-arc sediments exemplifies the importance of provenance and tectonic history in the analysis of island arc detritus. Provenance proved to be particularly important in the comparison of the fore-arc and back-arc detritus of Japan. Here, the source area for back-arc detritus is a volcanically active area overlying an unexposed sialic crust. The source area for the fore-arc detritus is an area of relatively little volcanic activity with large exposures of eugeosynclinal sediments. These different source areas are directly reflected in the fore-arc and back-arc basin petrology.

Comparison of several fore-arc basins illustrates the importance of the tectonic history of an island arc. Arcs underlain by a "continental" crust may be associated with fore-arc sediments rich in quartz and sedimentary rock fragments. Likewise, island arcs underlain by "oceanic" crust may be associated with quartz-poor detritus rich in volcanic lithic fragments. However, it should be noted that island arcs underlain by oceanic crust with large exposures of plutonic bodies may shed local pockets of detritus rich in quartz. It is also possible that extreme tropical weathering may provide detritus enriched in quartz (Breyer and Ehlmann, 1981).

It is questionable whether back-arc basin detritus, like that from Japan (Q/F = .70, predominant feldspar is plagioclase) may be distinguished from fore-arc regions such as that of Puerto Rico (Q/F = .68, predominant feldspar is plagioclase) on the basis of sediment compositions. Clearly, more petrographic data is needed to define the compositional limits of tectonic basins.

The main compositional control of island arc detritus appears to be provenance. The provenance of the sediments appears to be largely affected by the tectonic history of the arc, i.e., development of an arc on continental or oceanic crust; the occurrence and location of magmatic activity. Thus, the composition of arc detritus may provide insight as to the composition and tectonic history of ancient arcs.

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