THE VOLCANIC AND TECTONIC HISTORY
OF
La PROVIDENCIA ISLAND, COLOMBIA

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ABSTRACT OF THE THESIS

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Thesis director: Professor Martha M. Hamil

Volcanic rocks with some interlayered carbonate rocks constitute La Providencia Island, located at latitude 13 21' N. and longitude 81 22' W. in the southwestern Caribbean Sea. This location is near the boundry between the Nicaragua Rise and the Columbian Basin. La Providencia emerges on a shallow linear submarine ridge trending N25 E. Normal faults bound the ridge, and the normal fault west of the ridge is part of a graben forming system cutting the Nicaragua Rise.

Extensive field work and petrologic analysis reveals a multistage volcanic and tectonic history starting in Miocene-Pliocene time. Stages delineated are: 1) Pillow Basalts, 2) Quiescence, 3) Intermediate and High Silica Flows, 4) Breccia, 5) Uplift, 6) Dikes, and 7) Erosion.

Carbonate rock formation containing fossils

accompanied the pillow basalts and blocky lavas. These flows contain less than 40 weight percent silica and classify as alkali basalts. Continued carbonate rock formation and erosion charactorize the quiescent period during which a magma change took place. Intermediate and high silica flows, now forming the major ridges of the island, renewed the volcanic activity. Silica contents of these flows range from 51 to 72 weight percent and, classify as mugearites, andesites, dacites, and rhyolites. Large amounts of ash and breccia consisting of all earlier rock types ended the eruptive stages. Uplift of over 200 meters preceded dike implacement, the latest magmatic event. The dikes contain 47 to 49 or 64 to 70 weight percent silica. Showing affinities with both the early and late flows. Since the end of tectonism, lahar formation and intense tropical weathering have helped produce the present topography.

Microprobe analysis of the feldspars in these rocks together with the whole rock analysis and field relations establish that both mixing and fractionation took place during the quiescent period. These volcanic rocks show chemical affinities with both island arc and oceanic island volcanism.

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INTRODUCTION

The majority of data on the geology of the southwestern Caribbean Sea has been obtained from seismic records and from studies of several of the corralline islands and cays in the area. Three islands, La Providencia, Big Corn, and Little Corn, in the southwestern Caribbean are reported to have volcanic rocks crop out (Milliman and Supko, 1968). La Providencia Island (Figure 1) occupies a strategic location for gaining a better understanding of the tectonic setting of the region because of its position near the boundry between oceanic and continental crust. Delineation of the volcanic and tectonic history of La Providencia is thus the primary objective of this thesis.

Ten reports mention the geology of La Providencia, they are; Pilbury (1930), Sarmiento, Sandoval and Royo (1947), Mitchell (1955), Hubach (1956), Quintero (1960), Burgl (1961), Pagnacco and Radelli (1962), Milliman and Supko (1968), Kocurko (1974), and Mills and Hugh (1974). Of these, the articles by Pagnacco and Radelli (1962) and Mitchell (1955) are the only ones that provide details

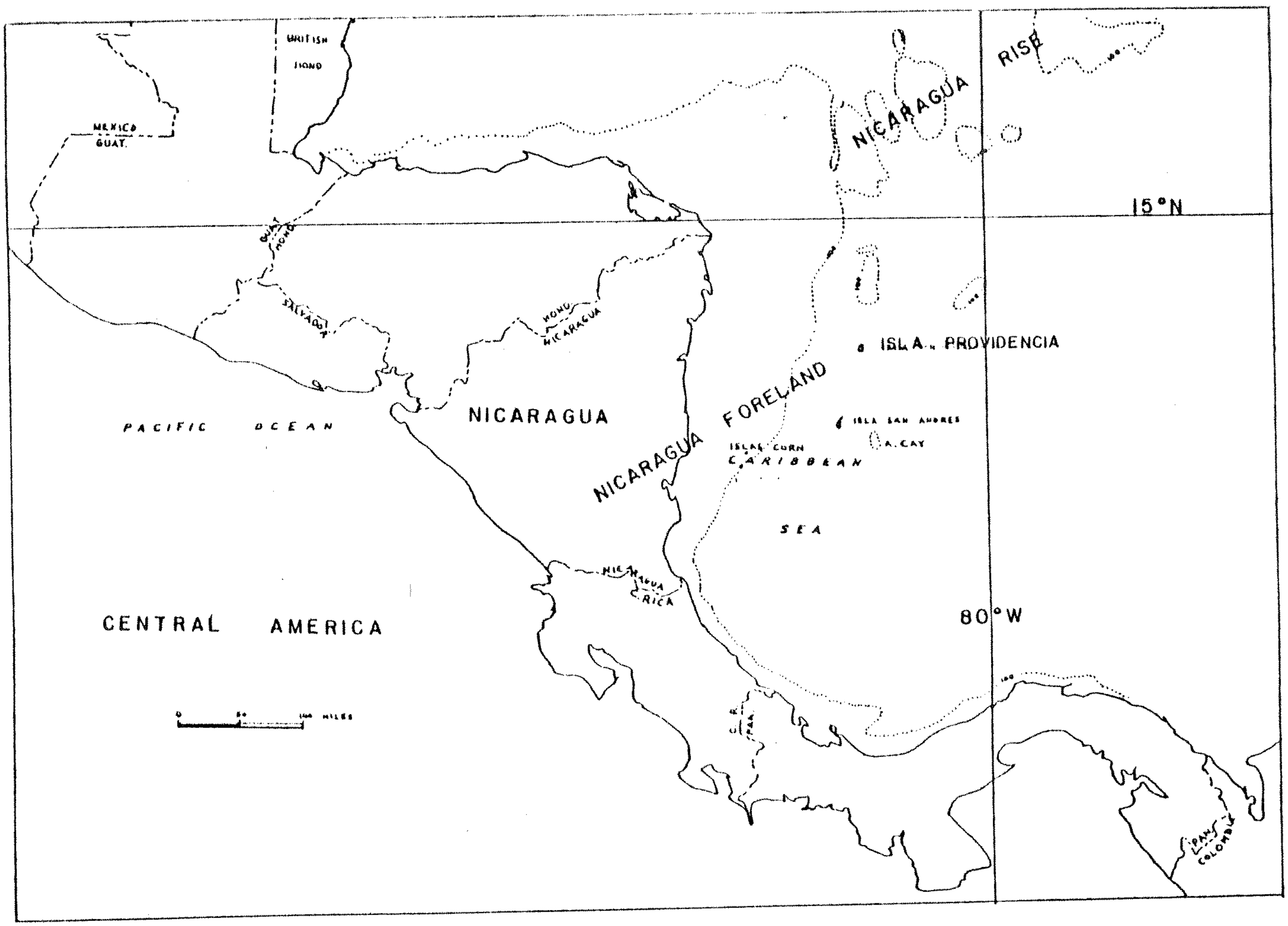


Figure 1: Location map

of La Providencia and both are based on very little field work .

La Providencia is approximately 200 kilometers east of the coast of Nicaragua at lattitude 13 21' N. and longitude 81 22' W., and about 90 kilometers N.N.E. of the island of San Andres. I spent three weeks during January of 1977 collecting rock specimens, mapping all contacts, and taking photographs to aid in the subsequent interpretation of the island's history.

In addition, the three following laboratory techniques were used: 1) petrographic study of rock samples using thin sections, 2) whole rock analysis using atomic emission techniques, 3) and microprobe analysis of feldspars.

GENERAL GEOLOGY

La Providencia is 72 kilometers long by 4.0 kilometers wide, with an approximate area of 13.7 square kilometers. It is the emergent point of a northeast -- striking submarine ridge that elsewhere lies less than 183 meters deep. Most of the ridge is less than 13 meters deep, and is approximately 16 kilometers long. According to Case and Holcombe (1975) the ridge is bounded by large normal faults and may,therefore, be classified as a horst.

The main physiographic feature of the island is a group of peaks, collectively called "High Peak", which rise to an elevation of over 500 meters. High Peak is also surrounded by lower lying hills, some over 300 meters. Among the islands in the southwestern Caribbean Sea, La Providencia is unusual for two reasons. First, with the exception of the carbonate island of San Andres, the other islands and cays are low lying with elevations under several hundred feet. Second, with the exception of the Corn Islands (Mitchell, 1955), La Providencia has the only exposure of volcanic rock in this part of the caribbean.

The structure of the island is interpreted to be that of a volcanoe and/or possibly a caldera which is cut by dikes. The dikes are mainly vertical and strike N35E to N68E. Marine terraces which circle the island show Pleistocene sea level changes (Colombian Geological Survey, 1977). Several exposures of marine carbonates are found in the southwestern portion of the island over 200 meters.

VOLCANIC STRATIGRAPHY OF LA PROVIDENCIA

Stage One - Pillow Basalts

Blocky lavas and pillow basalts characterize the oldest observable flows of La Providencia (Plate 1). Outcrops of these early lavas are presently exposed at low elevations between 0 and 20 meters (map). The elevation is important because flows were depositted in stratigraphic succession. These flows form the present base of La Providencia and the youngest flows constitute its peaks (Figure 2). This would concur with the work of Milliman and Supko (1968), Burgl (1961), and others, who believe that the carbonates of San Andres, Albuquerque cay, and other cays, are underlain by basaltic volcanics. Milliman and Supko (1968) obtained a basaltic cobble while dredging off Albuquerque cay which supports the hypothosis of an underlying basaltic base.

In addition to the pillow basalts associated with these early flows, another possible indication of their subaqueous deposition is cross-bedding and channeling in the ash accompanying the flows.

During this period of volcanism, water depths became sufficiently shallow to support the growth

Plate 1: Pillow basalts exposed on the southern end of La Providencia - sample 43.

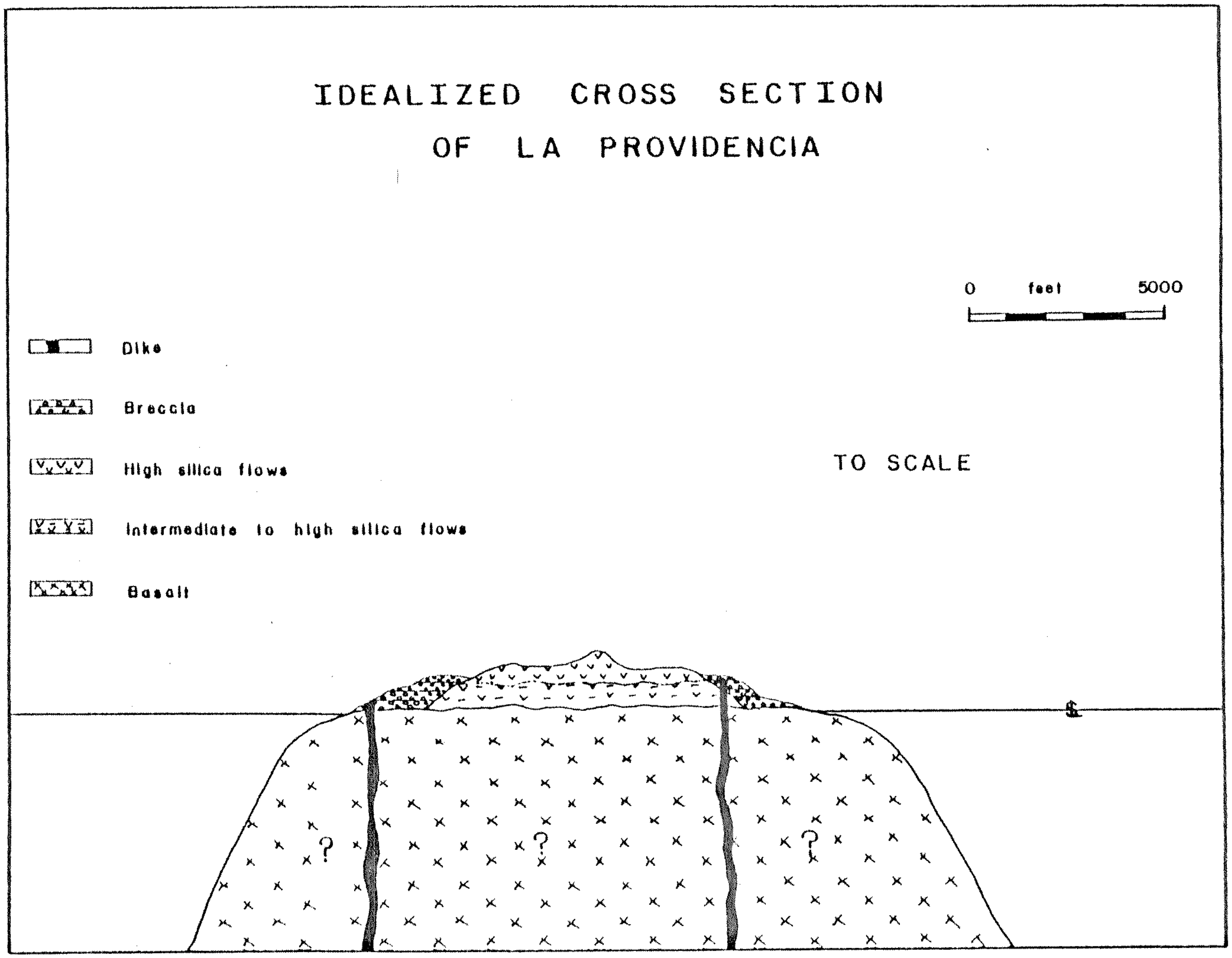


Figure 2: Idealized cross section of La Providencia Island.

of shallow water marine organisms and carbonates. These examples of early carbonate growth also show that this phase of volcanism must have occurred as several events rather than a single event. Plate 2 shows a basalt flow over a suite of fossils which lived in shallow water. Thus, volcanics had to build sufficiently close to the surface for these organisms to grow, followed by a later flow of this stage one type which caused the death assemblage. This death assemblage of pectins, echinoderms, and corals has been dated as Miocene-Pliocene on the basis of the fossil collection (Blake Blackwelder, personal communication, 1977). Therefore, La Providencia's early volcanics are consistent with other reported tectonic events in the south-western Caribbean during that time (Kocurko 1974, Milliman and Supko 1968, Dengo 1969).

Stage Two - Quiescence

A period of quiescence followed the first eruptive stage. At this time, carbonate growth and depostiion continued, and possible erosion occurred. Water-worn basaltic cobbles form a distinct horizon in reef material showing the continuing growth of the reef. This is taken as a post stage one but pre-stage three horizon

Plate 2: Low silica flow (dark), over fossil suite and ash (light)-samples 117 and 116.

because of the lack of cobbles other than basalt. Approximately 200 meters of shallow water carbonate material overly the basalt flow plate 2 and show the continuation of carbonate deposition. All of these exposures crop out on the southern end of the island.

Erosion or gravity sliding may have taken place during the second stage as indicated at the southern end of the island by an angular unconformity (Plate 3). However, the small exposure of the unconformity does not allow it to be conclusively placed in stage two. Thus, volcanic activity ceased for a period of time after stage one.

Stage Three - Intermediate and High Silica Flows

Higher silica content and a different type of flow characterize the second phase of eruption which followed the quiescent period. Three major and one minor type comprise the flows of this second volcanic phase. The three major types are: a reddish fine-grained banded flow which seems to make up the underlying rock of the most prominent ridges (Plate 4), a variously colored coarser grained porphorytic type of flow which is more

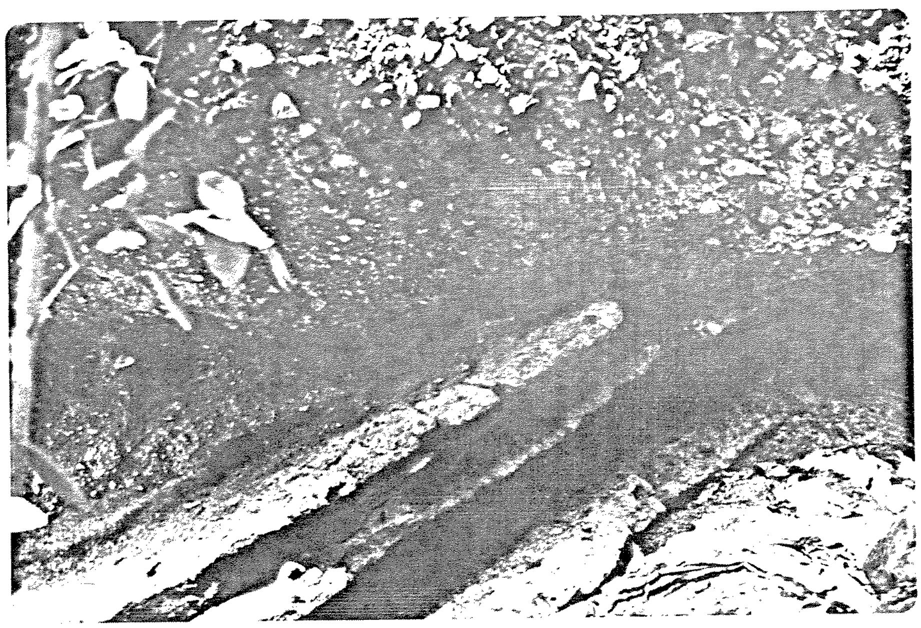


Plate 3: Angular unconformity exposed on the southern end of the island near sample 114.

Plate 4: Banded Rhyolite flow which forms the ridge above San Felipe - sample 4.

susceptible to weathering (Plate 5), and a very light to whitish colored fine grained flow that is chemically very similar to the banded flows. Two glassy flows, 1.5 kilometers apart, are exemplary of the minor flow type.

Exposures of the fine grained banded flows are found all over the island, always stratigraphically above the pillow basalts and blocky lavas of stage one and below the breccias of stage four. These flow banded rocks make up the majority of the highest ridges in the interior of the island. A most spectacular example of this is in the northcentral interior of the island where a seasonal waterfall has cut a small gorge approximately 30-35 meters deep into a ridge of flowbanded rock.

The coarser grained flows comprise most of the intermediate and some of the higher elevation rocks. These coarser grained rocks are more susceptible to weathering than the finer grained flows. Iron Hill on the east side of the island appears to be a parasitic fissure eruption which consisted of the coarser grained flow material. It forms a distinct point jutting out into the Caribbean from the main body of the island.

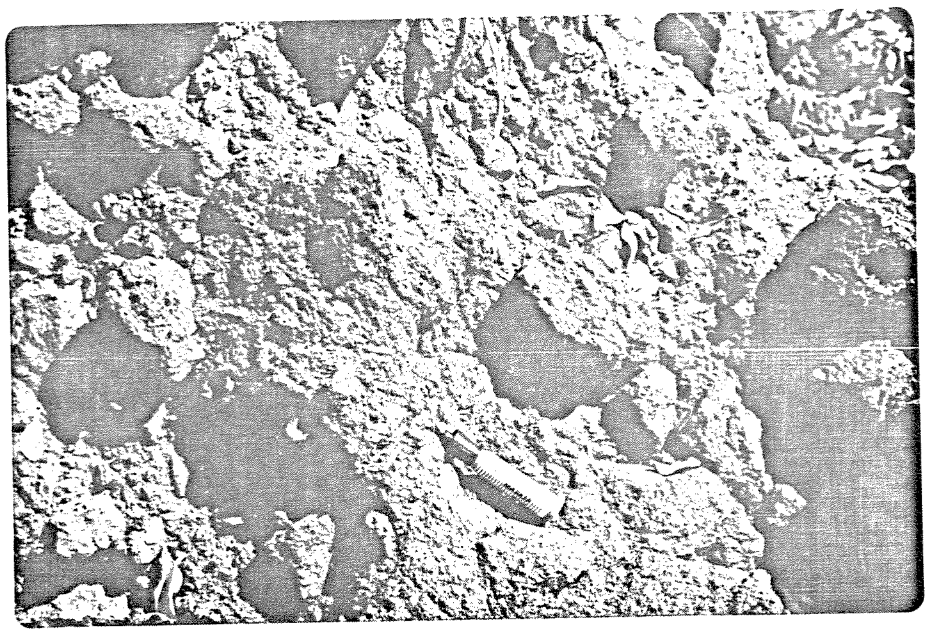


Plate 5: Porphyrytic flow exposed on northeastern side of the island at approximately 75 meters near sample 30.

The light colored flows are analagous to the banded flows, but appear to be slightly younger stratigraphically. They form several of the highest peaks on the island and compose several of the lower hills on the southeastern side of the island.

Two small glassy flows are interesting because their appearance is one of almost pure obsidian with devitrification. And, at least in one outcrop, they seem to be associated with the light colored flows.

Thus, during the period of quiescence, a magna composition change must have taken place. This leads to the speculation that La Providencia and the Corn Islands (Mitchell, 1955) are emergent because of their second volcanic phase, whereas the basaltic-based carbonate islands of San Andres, Albuquerque Cay and Courtown Cay had no such additional volcanic phase.

Stage Four - Braccia

The final eruptive phase on La Providencia was the rythmic spewing out of tremendous quantities of ash and breccia in an explosive type of eruption. The breccia is made up of clasts varying in size from 1 mm to more than a meter and is interbedded with the finer grained ash. The clasts are a conglomeration of all the previous rock types, which supports the idea of the breccia as the final eruptive phase.

This ash and breccia layer blankets every other rock type below 300 meters except where it has been eroded. The majority of ash and breccia layers show characteristics of subaqueous deposition such as cross bedding, channels, and extensive parallel bedding. Thus, La Providencia was probably not uplifted until after this final eruptive phase. Exposures of in situ shallow marine carbonates at 200-250 meters elevation on the southern end of the island also support the idea of large scale uplift.

Kocurko (1974) found windblown volcanic fragments in the late miocene carbonates of San Andres which he believes was uplifted during that time. The ash layers exposed on the southern and western sides of La Providencia are much thicker than those on the northern and eastern sides indicating a northeast paleo trade wind that could have blown volcanic ash towards San Andres (Plate 6 & 7). Hence, wind-blown ash from La Providencia may be the sole source of the volcanic fragments on San Andres. And, the uplift of San Andres at that

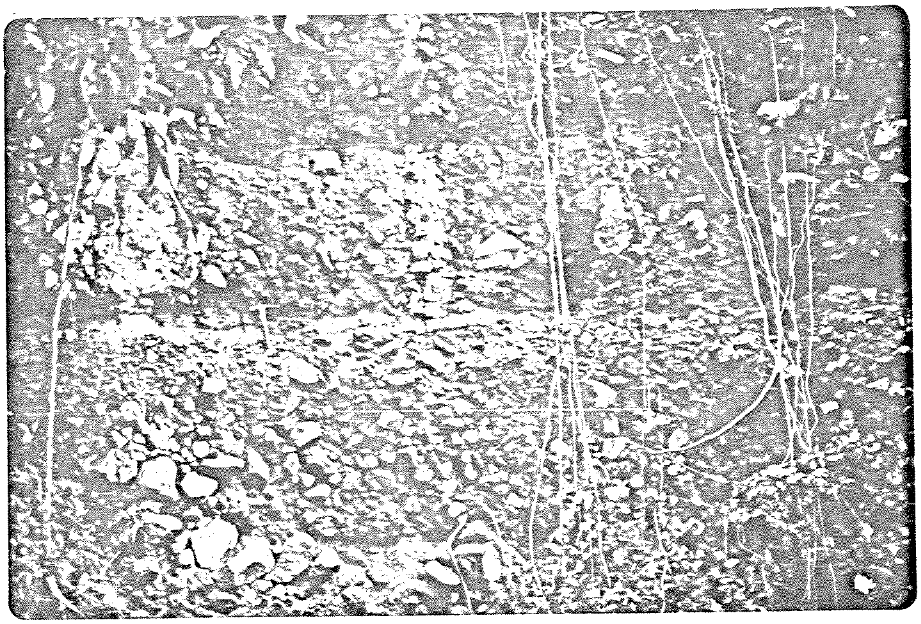


Plate 6: Breccia, exposed above Santa Isabel, showing thin beds of ash.

Plate 7: Breccia exposed at the southern end of the island, near sample 114, showing thick ash layers.

time correlates with the postulated uplift of La Providencia.

Two possible locations for the source of this final eruption are: 1) off-shore to the northeast, and 2) the high peak area. Off-shore to the northeast water depths are shallow for 5-6 kilometers, and the ash and breccia could have once been part of a larger La Providencia island that also occupied this northern area. The high peak area is the second possible source area for the ash and breccia. With appropriate allowance for tropical weathering and vegetation High Peak may be the remnant of a collapsed caldera.

Stage Five - Uplift

The uplift of La Providencia after this final phase of eruption is probably linked with the maximal uplift suggested for this part of the Caribbean during Miocene and Pliocene time (Kocurko 1974). And, La Providencia having a second stage of volcanics may be related to the graben structure located due west of the island. However, further work needs to be done before a definite relationship can be established between the volcanics of La Providencia and the graben structure off its west coast.

The hypothesized uplift of La Providencia during Miocene-Pliocene time is not consistent with the conclusions of Mills and Hugh (1974). These authors propose that La Providencia is the top of a previously subaerial volcanoe on a presently lowered foreland of Central America. But, if, as suggested here, La Providencia was uplifted after forming subaqueously, it could not have formed before the foreland subsided.

Stage Six - Dikes

The final phase of tectonism following the emergence of La Providencia, appears to have been renewed volcanism. This took the form of the implacement of vertical to near vertical dikes (Plate 8). These dikes cut all previously mentioned rock types and have a northeasterly strike.

Stage Seven - Erosion

Since the cessation of volcanism and tectonism on La Providencia several events have brought about changes which helped form the present topography. Large blocks of volcanic rocks are found in a mud matrix at several localities

Plate 8: Thick verticle dike which cuts both banded flow material and overlying breccia.

showing that lahars occurred shortly after emergence. Also, many of the less resistant rock units were partially removed by intense tropical rains. This is shown by many of the present-day valleys.
The vegetation now on the island has more or less stabilized the slopes and brought about a selva type of topography.

PETROLOGY OF THE LA PROVIDENCIA VOLCANICS

Whole rock analysis, microprobe analysis, and normative mineral compositions of the analized La Providencia volcanics (Table 1 and 2, Figures 3 and 4, and Appendix A and B) show that four groups of rocks can be distinguished, namely: 1) undersaturated basaltic rocks with silica less than 50 weight percent and consistently high An content, 2) slightly undersaturated to saturated rocks with silica ranging from 50 to 63 weight percent and variable An content, 3) saturated rocks with silica greater than 65 weight percent and consistently low An content, 4) dike rocks with silica ranging from 47 to 69 weight percent and variable An content. The whole series can also be divided into an alkaline and a subalkaline group using the method of Irvine and Baragar (1971) (Figure 5). These groups all correlate with specific volcanic and tectonic stages.

The early flows of La Providencia all have a silica content of less than 50 weight percent and have been classified as alkali basalts based on their chemical composition (Table 2). These lavas have phenocrysts of olivine, plagioclase, and pyroxene with a fine-grained ground mass of

	89B Flow	4 Flow	92 Flow	44A Dike	118 Dike	109 Flow	94 Flow	37 Dike	62 Flow	77 Flow
SiO_2	71.52	70.24	69.74	68.97	68.81	68.09	65.31	64.77	62.40	59.03
Al_2O_3	13.81	14.81	14.94	15.51	16.30	15.38	14.98	16.76	16.5	18.97
Total Fe as FeO	0.97	1.86	1.67	1.83	1.92	2.28	3.93	2.49	4.73	3.69
MnO	.01	.04	.03	.04	.04	.04	.03	.04	.04	.04
MgO	.47	.27	.30	.46	.36	.23	.81	.68	1.65	.89
CaO	.81	1.22	1.03	1.73	1.68	1.29	3.03	2.05	5.03	6.06
Na_2O	4.18	4.67	4.41	4.80	4.89	4.36	4.06	4.95	4.19	4.11
K_2O	3.58	3.77	3.83	3.75	3.78	3.75	2.77	4.16	1.41	1.58
TiO_2	.22	.24	.21	.33	.34	.34	.69	.44	.97	1.40
P_2O_5	.21	.15	.18	.19	.23	.20	.18	.22	.17	.25
H_2O	2.72	.88	1.55	2.89	1.02	1.45	2.46	2.07	2.61	3.42
Total	98.5	98.2	97.9	100.5	99.4	97.4	98.3	98.6	99.7	99.4

TABLE #1

	30 Flow	53 Flow	13A Flow	42 Flow	114 Dike	115 Dike	66 Flow	22 Flow	25 Flow	23 Flow
SiO_2	53.6	53.56	51.73	49.80	49.54	47.92	47.61	47.11	47.14	46.92
Al_2O_3	17.88	18.11	18.89	18.04	17.36	17.91	17.07	16.70	16,53	16.73
Total Fe as FeO	7.22	4.95	7.29	8.54	6.90	7.80	8.75	9.27	9.00	9.35
MnO	.14	.06	.07	.09	.08	.11	.16	.15	.15	.15
MgO	1.28	1.64	1.48	3.25	3.58	2.89	5.38	5.77	6.55	5.85
CaO	4.71	8.36	5.32	8.37	9.91	9.63	9.45	9.54	9.37	9.41
Na_2O	4.36	4.41	4.12	3.94	3.14	3.16	3.73	2.98	2.67	2.96
K_2O	3.39	2.85	2.09	1.45	1.68	1.97	2.14	1.46	1.75	1.41
TiO_2	1.46	1.79	1.48	1.65	2.07	2.36	1.78	1.98	1.75	1.99
P_2O_5	.23	.32	.20	.23	.20	.37	.29	.30	.17	.25
H_2O	3.50	2.26	4.58	3.19	3.78	1.17	2.64	2.79	2.36	3.04
Total	97.8	98.3	97.3	98.6	98.2	95.4	99.0	98.1	97.4	98.1

TABLE #2

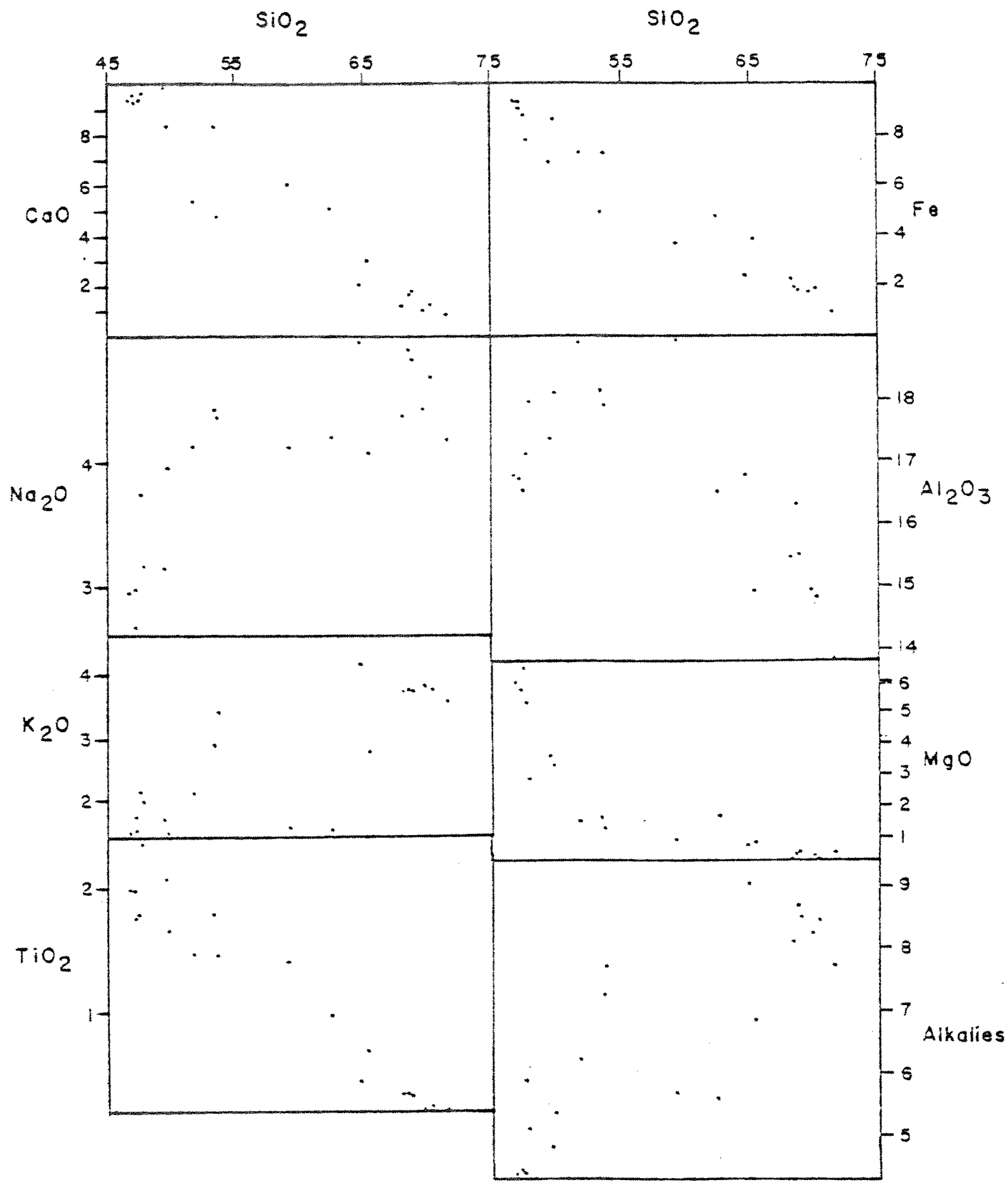


Figure 3: Harker plots for La Providencia Island rocks.

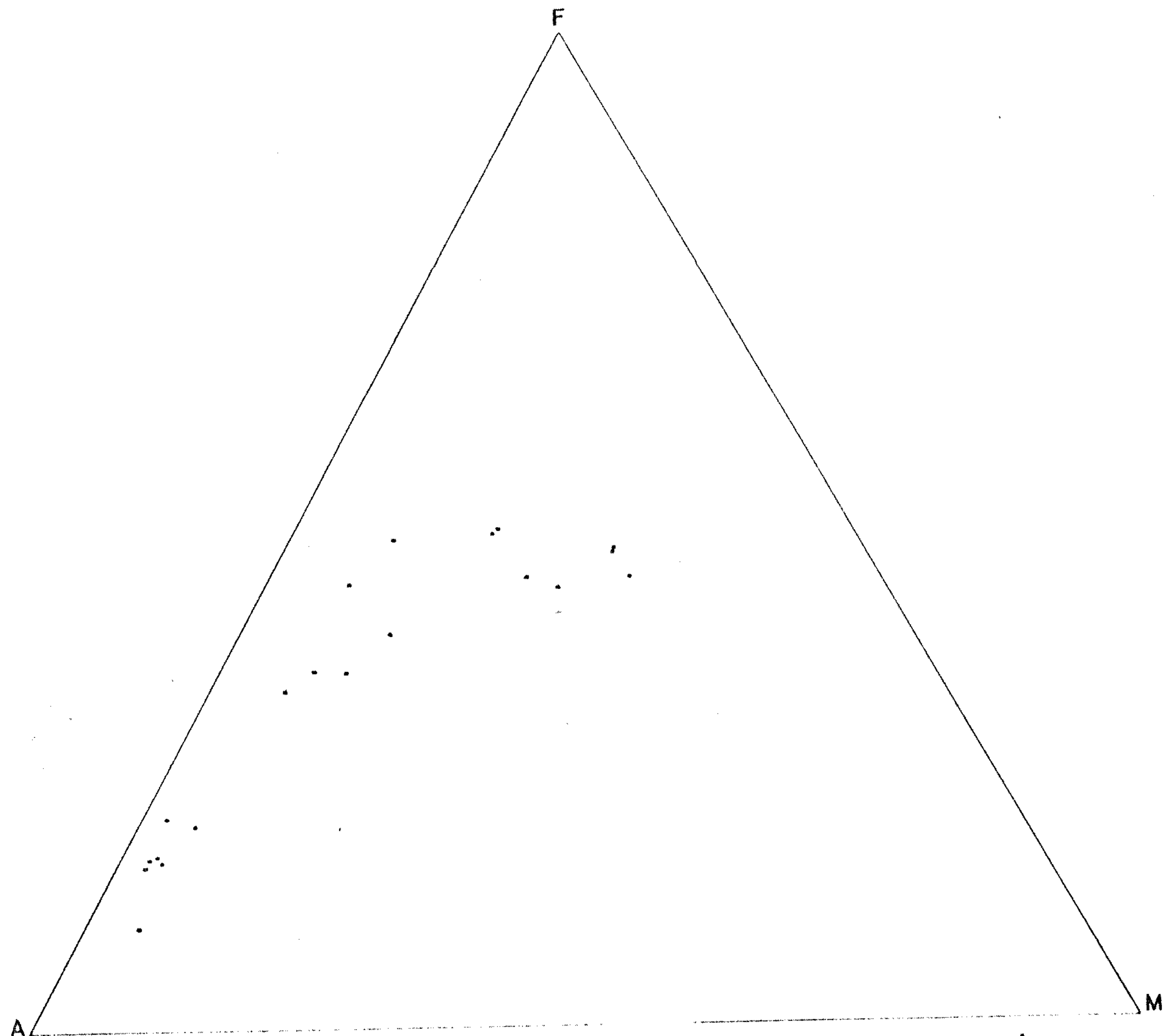


Figure 4: AMF diagram of La Providencia Island rocks.

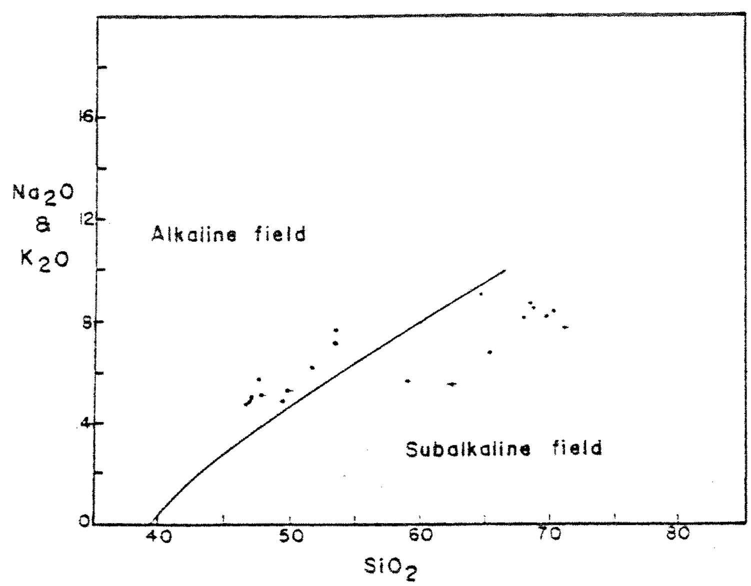


Figure 5: Plot of Na_2O and K_2O versus SiO_2 for La Providencia Island rocks.

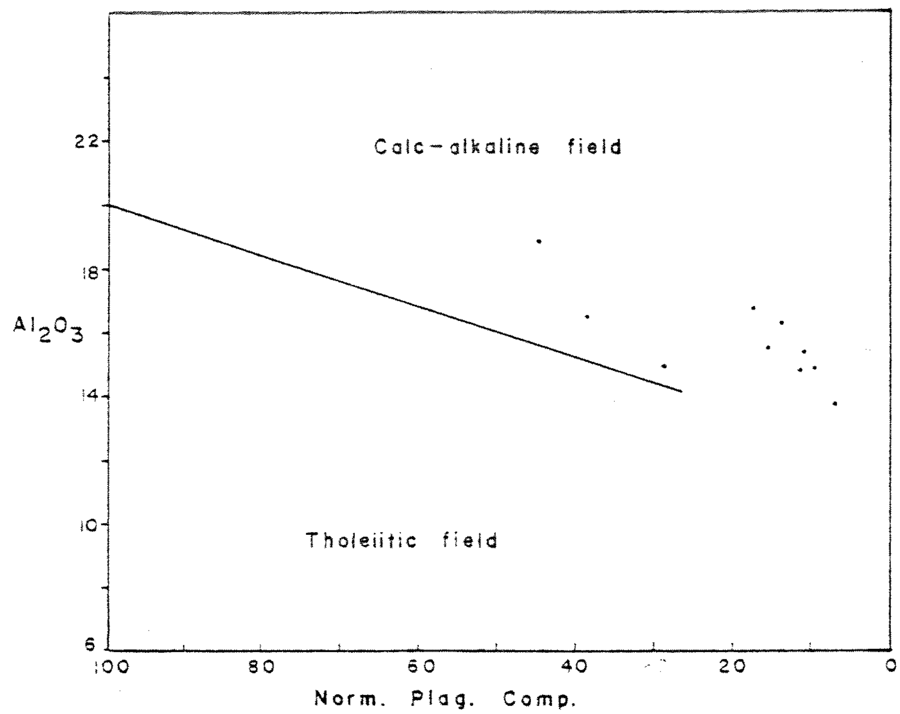


Figure 6: Plot of Al_2O_3 versus Normative Plagioclase Composition for La Providencia Island rocks.

plagioclase, glass and opaques. Microprobe analysis shows a fairly consistent plagioclase composition around An 65, with some evidence for fractionation in the later rocks (Figure A-1). Thus, the basal rocks cropping out on La Providencia were probably derived from an alkali basalt magma.

The second period of exposed flows, as mentioned earlier, comprise two groups of lavas, an intermediate silica group (50 to 63 weight percent) and a high silica group (greater than 65 weight percent) (Table 1 and 2).

The intermediate silica group has rocks which plot in both the alkaline and subalkaline fields and are classified as Mugearites and Andesites respectively (Figure 5). Microprobe analysis of these rocks shows a wide range of plagioclase composition (An 20 to An 80) (Figure A-2). This and large scale reverse zoning in the plagioclase supports magma mixing.

The high silica group all plot in the subalkaline or calc-alkaline field and classify as Dacites and Rhyolites (Figure 6). Microprobe analysis of these rocks show an average plagioclase composition around An 30 (Figure A-3). Thus, during the second stage of volcanism a magma change from alkaline to subalkaline occurred.

The dike rocks which formed during the final stage of volcanism are interesting because of their bimodal variation of silica and major elements (Figure 3). Microprobe analysis of the feldspars in these rocks show a wide range of plagioclase composition (An 8 to An 68), but no reversed zoning (Figure A-4). The plagioclases around An 8 are similar to the rhyolitic rocks, while the plagioclases around An 68 are similar to the alkali basalt rocks. This seems to indicate two distinct magmas -- one which plots in the subalkaline field and one which plots in the alkaline field. This is similar to the intermediate silica flows of stage two which also plot in two fields but which exhibited reversed zoning in the plagioclases. A difference in cooling history and/or the absence of mixing could have caused the lack of reversed zoning in these dike rocks.

A COMPARISON WITH OTHER VOLCANIC SETTINGS

A comparison of La Providencia's volcanics to those of 1) oceanic ridges, 2) oceanic islands, 3) subduction zones, and 4) Central America demonstrates the complex petrology of the island.

Irvine and Baragar (1971) use a plot of Al_2O_3 versus normative plagioclase composition to distinguish between Calc-alkaline rocks and Tholeitic rocks when dealing with subalkaline rock types. Using this diagram (Figure 6), the subalkaline rocks of La Providencia all plot within the Calc-alkaline field. Thus, La Providencia was not formed under conditions similar to those in which tholeitic lavas of mid-ocean ridges are formed.

Oceanic islands are characterized by alkaline rock types which are the lowest exposed rocks found on La Providencia. But, true oceanic islands (those in mid-ocean away from subduction zones) do not have a Calc-alkaline association. This does not hold for La Providencia. Hence this leads to the probable conclusion that the conditions that formed La Providencia are different from those which form most oceanic islands.

The same argument which was used for oceanic islands can also be used in a comparison of La Providencia's volcanic suite with that of a typical subduction zone. That is, that most subduction zones are not typically characterized by contemperaneous Calc-alkaline and alkaline suites. Thus, La Providencia shares common rock types with both oceanic islands and subduction zones, but is not totally comparable with either one.

The tertiary volcanic history of Central America as discussed by McBirney and Williams (1965) and Reynolds (1977) state that Miocene-Pliocene time had large scale eruptions of basalt, andesite, rhyolite and breccia. However, no mention is made of alkaline rocks during Tertiary time. Pichler and Weyl (1976) do discuss the recent finding of Quaternary alkaline volcanics in Central America. That association is marked by tholeiite and alkaline rocks and not the calc-alkalic and alkaline association of La Providencia. Pichler and Weyl hypothosize that the areas they studied were formed by two distinct magmas-Tholeiite and Alkali basalt -- which are a result of the present day configuration of the Central

America subduction zone. It is possible that the calc-alkaline - alkaline association of La Providencia was also formed by two distinct magmas -- Calc-alkaline and Alkaline. These magmas were the result of the Tertiary configuration of the Central American subduction zone, and were erupted along one of the northeast trending fractures formed at that time (McBirney, 1965).

A MODEL TO EXPLAIN THE STRATIGRAPHIC AND PETROGRAPHIC TRENDS OF LA PROVIDENCIA

The volcanic sequence and chemical trends exhibited on La Providencia can best be explained by a combination of fractional crystalization and the mixing of two different magmas.

The early flows of stage one were probably derived from an alkali basalt magma sometime during late miocene time. This date for eruption correlates with the previously discussed fossil ages whereas the chemical composition of the magma would have to match the oldest exposed alkali basalt flows. Evidence for fractional crystalization of this early magma and a possible reinjection comes from by microprobe analysis of sample 66 (Figure A-1). This first period of eruption was then followed by a period of quiescence. Both stratigraphic evidence and the fact that a magma composition change took place during this time support this hypothosis.

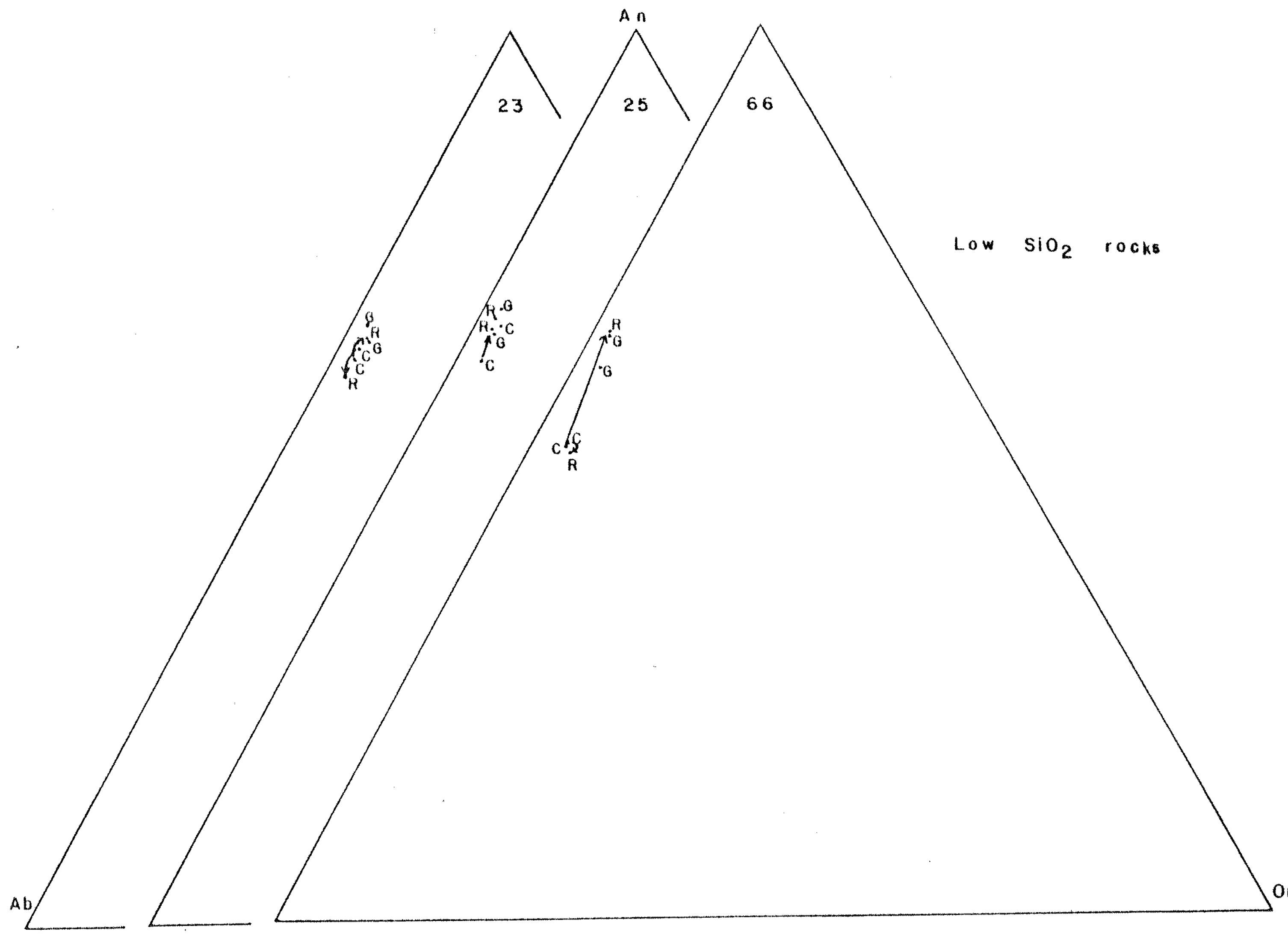
Two groups comprise the second period of flows. These are: an intermediate silica group, and a high silica group. The intermediate group seems to have been formed by the mixing of a alkali basalt magma (of stage one type) and a calc-alkaline magma. The microprobe analyses which show large scale reverse zoning and the over-lapping of two distinct trends in the harker plots support this hypothosis. This overlapping of the trends is probably the result of the more alkaline, calc-alkaline magma mixing with the less alkaline and fractionated alkali-basalt magma (Michael J. Carr, personal communication, 1977). The high silica group was then formed solely by the fractionation of the calc-alkaline magma. The series dacite to rhyolite to silica glass, which is exposed on the island, and, microprobe analysis which shows normal zoning in this series strongly supports this idea.

The breccia phase probably indicates another change within the crust or mantle which resulted in a violent explosion and ejection of rocks of all previously discussed types and the subsequent uplift of the island.

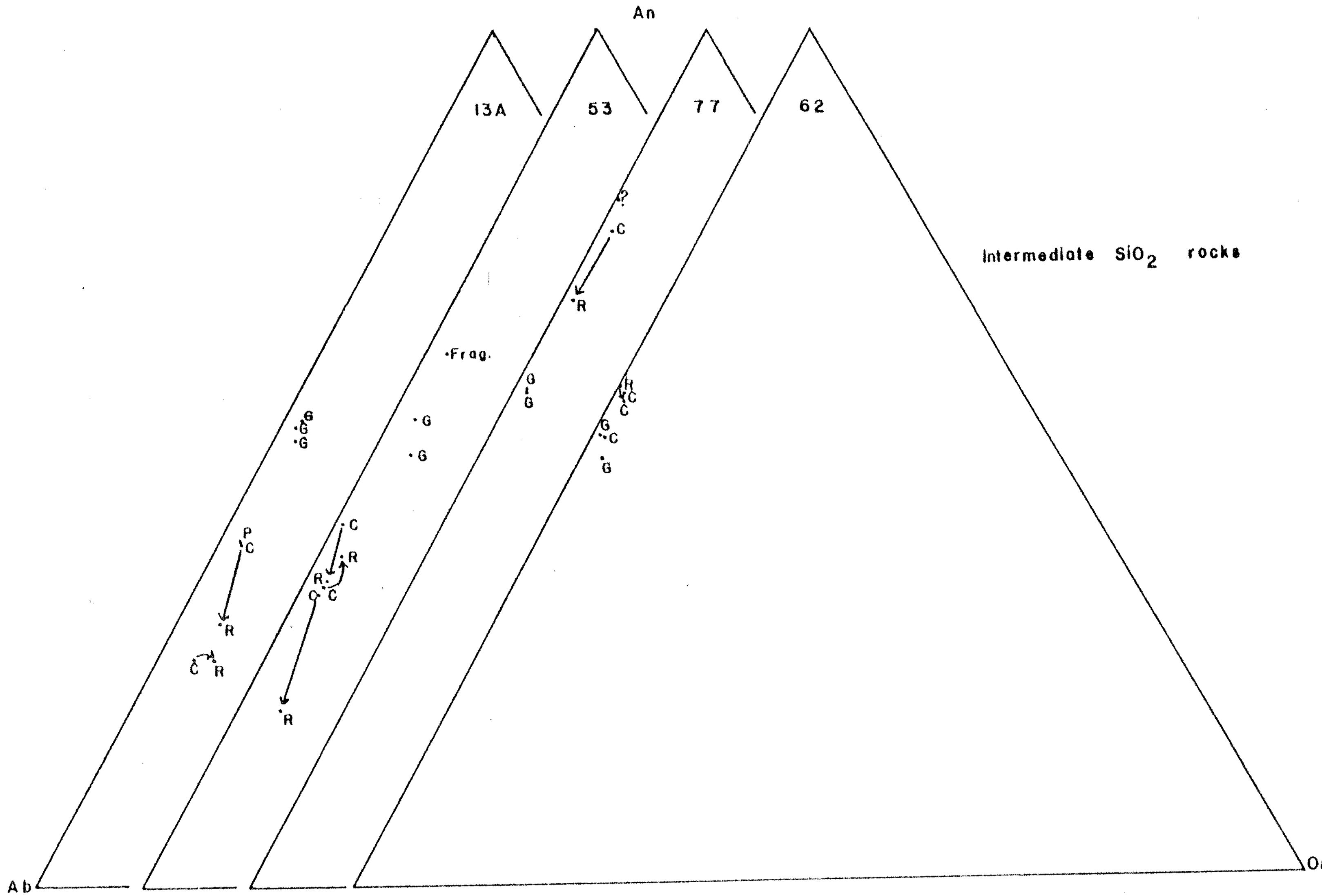
The dikes, which make up the final phase of volcanism, were then made up of the remainder of the two magma types. The wide range of feldspar composition in probe analyses and the fact that the dikes plot at the two extremes of the Harker plots points to this conclusion.

This model synthesizes all the observed chemical trends and the interpretted volcanic-tectonic history. Thus, even though further work is needed to link the volcanism with the paleotectonic configuration of Central America, this preliminary work supports tectonic events causing the formation, fractionation, mixing, and eruption of two different magmas. Subsequently these two magmas combined to form La Providencia island during Miocene-Pliocene time.

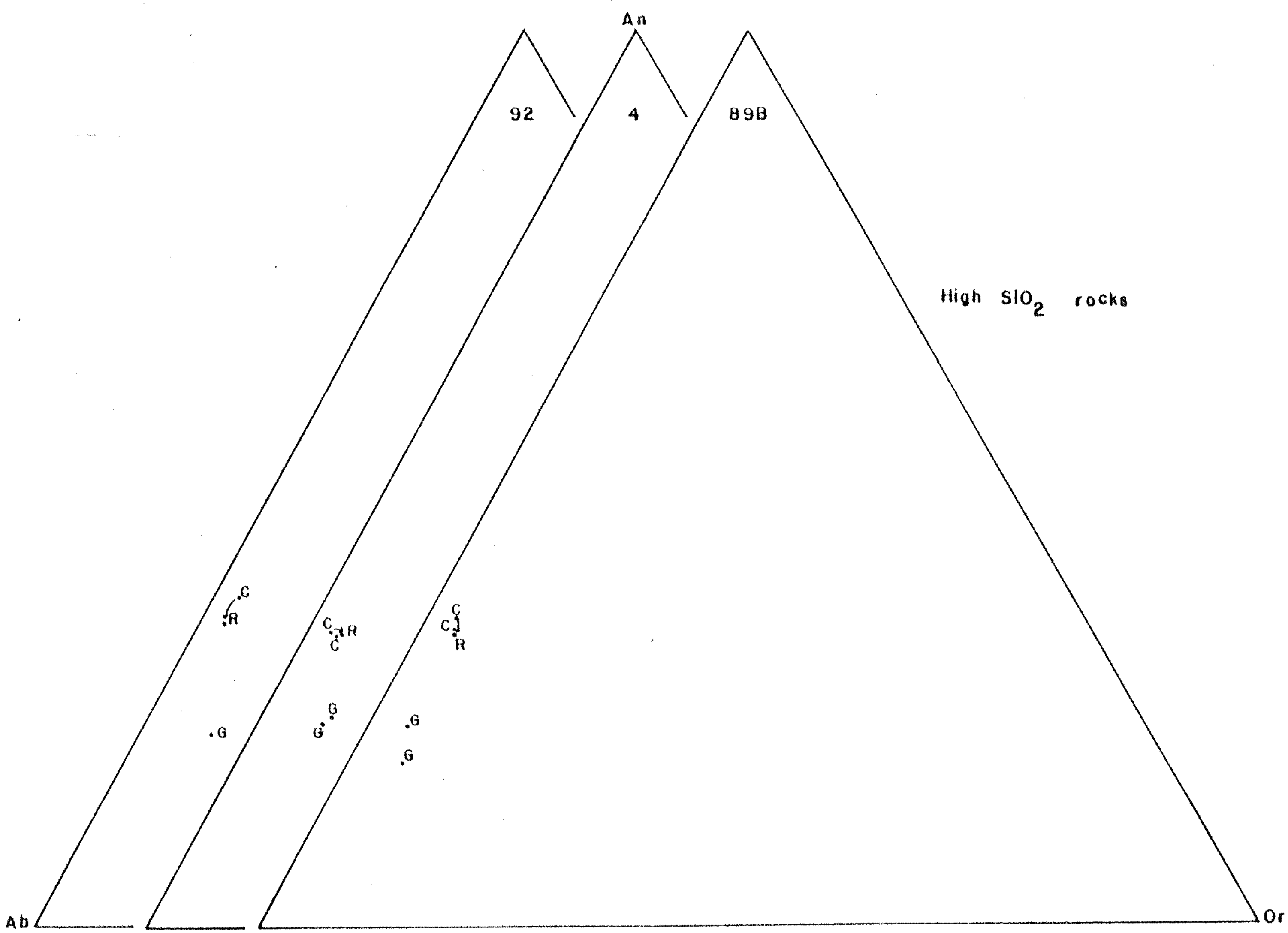
APPENDIX A



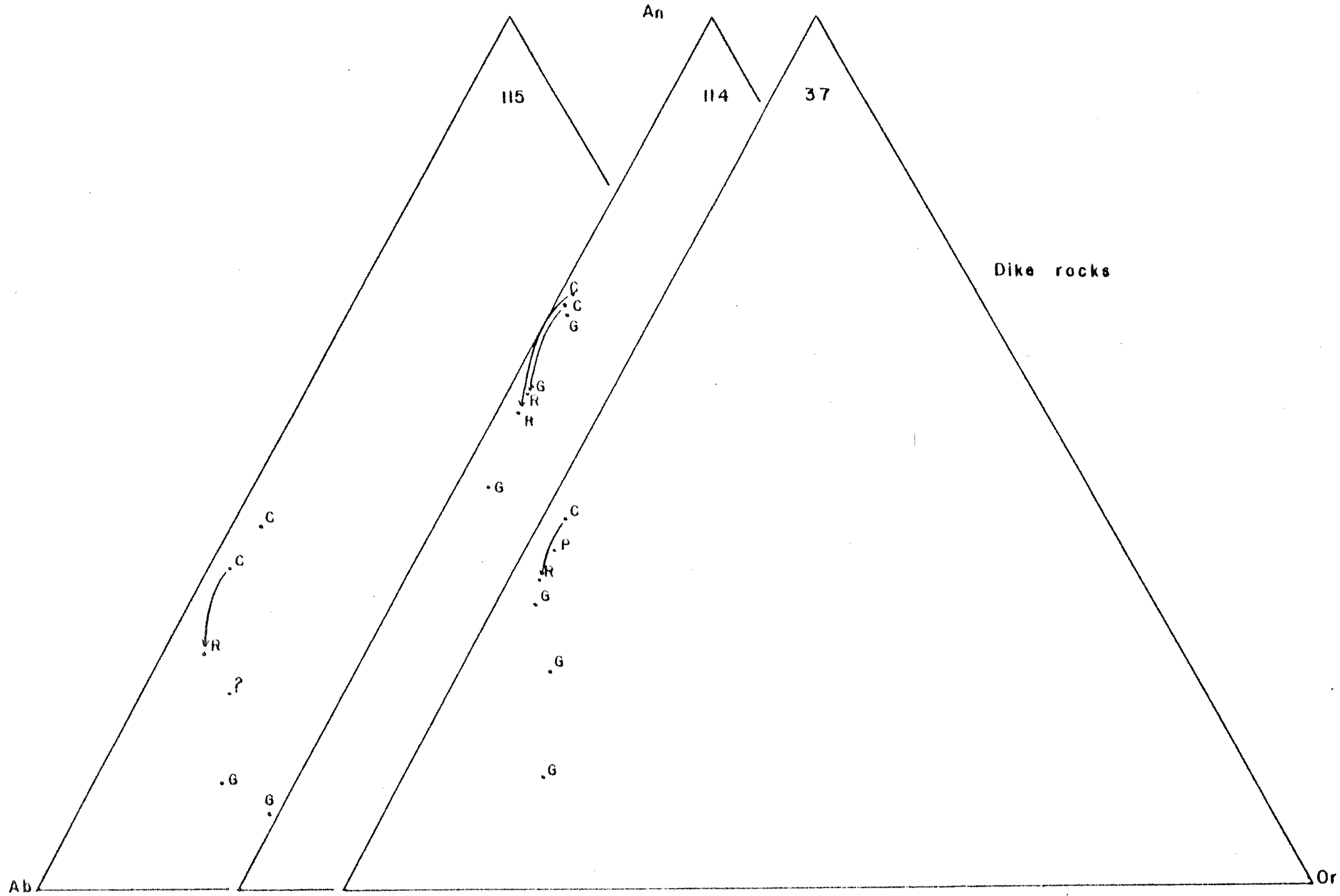
A-1: Low SiO_2 rocks



A-2: Intermediate SiO_2 rocks



A-3: High SiO_2 rocks



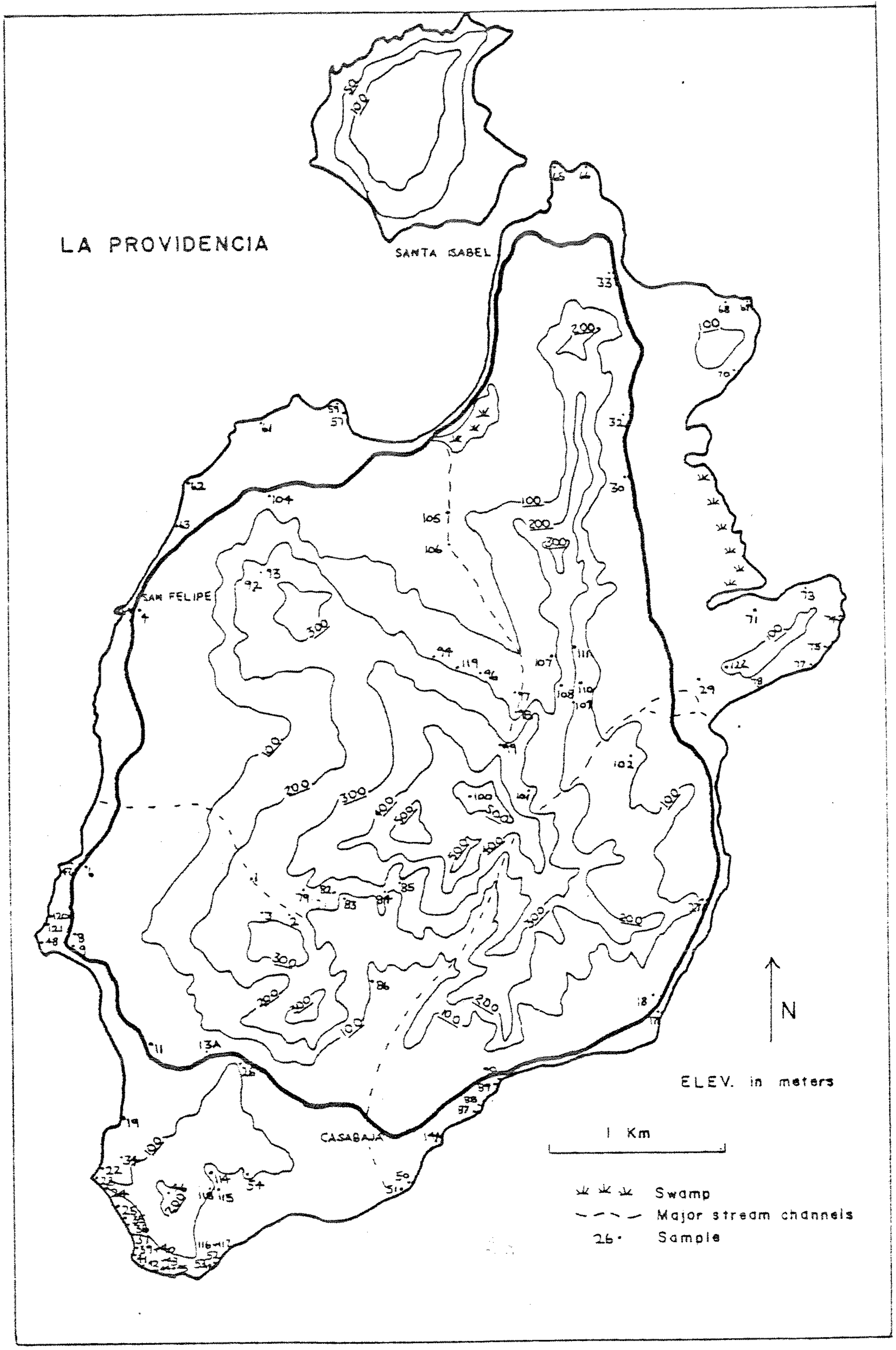
A-4: Dike rocks

APPENDIX B

	89B	4	92	44A	118	109	94	37	62	77
Q	31.4	25.4	26.7	22.3	21.8	25.1	22.7	14.5	18.9	14.9
Or	21.2	22.3	22.6	22.2	22.3	22.2	16.4	24.6	8.3	9.3
Ab	35.4	39.5	37.3	40.6	41.4	36.9	34.4	41.9	35.5	34.8
An	2.6	5.1	3.9	7.3	6.8	5.1	13.9	8.7	22.1	28.4
Ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	2.1	1.2	2.1	0.9	1.7	2.3	0.2	1.0	0.0	0.1
Di	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0
Hy	1.8	2.1	2.0	2.4	2.2	2.2	4.7	3.4	6.3	3.5
Wo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mt	0.5	0.9	0.8	0.9	0.9	1.1	1.9	1.2	2.3	1.8
Il	0.4	0.5	0.4	0.6	0.6	0.6	1.3	0.8	1.8	2.7
Hm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ap	0.5	0.3	0.4	0.4	0.5	0.5	0.4	0.5	0.4	0.6
H_2O	2.7	0.9	1.5	2.9	1.0	1.4	2.5	2.1	2.6	3.4

	30	53	13A	42	114	115	66	22	25	23
Q	2.3	0.7	4.6	0.0	1.5	0.0	0.0	0.0	0.0	0.0
Or	20.0	16.8	12.4	8.6	9.9	11.6	12.6	8.6	10.3	8.3
Ab	36.9	37.3	34.9	33.3	26.6	26.7	21.3	25.2	22.6	25.0
An	19.3	21.2	25.1	27.1	28.4	28.8	23.6	27.9	27.9	28.1
Ne	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0
C	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Di	2.2	12.3	0.0	10.5	15.6	13.4	17.2	14.1	14.1	13.6
Hy	6.8	0.0	8.3	6.5	4.7	4.3	0.0	3.0	3.3	3.4
Wo	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ol	0.0	0.0	0.0	1.5	0.0	0.1	7.8	7.5	8.8	7.5
Mt	3.5	2.4	3.5	4.1	3.3	3.8	4.2	4.5	4.3	4.5
Il	2.8	3.4	2.8	3.1	3.9	4.5	3.4	3.8	3.3	3.8
Hm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ap	0.5	0.7	0.5	0.5	0.5	0.9	0.7	0.7	0.4	0.6
H_2O	3.5	2.3	1.6	3.2	3.8	1.2	2.6	2.8	2.4	3.0

MAP AND SAMPLE KEY


LA PROVIDENCIA
SANTA ISABEL
SAN FELIPE
CASABAJA
N
ELEV. in meters
1 Km
Swamp
Major stream channels
26 · Sample

SAMPLE KEY

Low SiO_2 rocks -- 19, 22,23, 23A, & B, 25, 36, 40,
41, 42, 43, 57, 59, 66, 68, 117

Intermediate SiO_2 rocks -- 13A, 14B, 26x, 26, 29B,
30,32, 33, 39, 53, (61, 62), 63,
65, 70, 73, 74, 75, 77, 78, 82,
83, 86, 96, 97, (104, 105, 106), 122

High SiO_2 rocks -- 1, 3, 4, 11, 14A, 17A, 18, 26, 50,
64, 79, 83B, 85, 87, 88, 89A & B,
92, 93, 94, 98, 99, 100, 101, 107,
108, 109, 110

Breccia clasts -- 8, 51, 54, 69, 90

Dike rocks -- 34, 37, 44A, 114, 114b, 115, 118

Ash -- 2, 29, 44B, 84, 116, 120,121

Carbonate rocks -- 6, 9, 35, 45B, 46, 47, 48, 48B, 52

Carbonate and Ash -- 24

Laker material -- 17B

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