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TWO UPPER CRETACEOUS FLYSCH SEQUENCES IN THE CARIBBEAN MOUNTAINS OF VENEZUELA AND THEIR RELATIONSHIP TO CARIBBEAN TECTONICS

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ABSTRACT

The Caribbean Mountains of Venezuela reach from the Venezuelan Andes to the Northern Ranges of Trinidad. Upper Cretaceous and Paleocene flysch units deposited in a marine euxinic basin are crucial in unraveling the evolution of the mountains. Two formations in the Acarigua region (near the termination in the Venezuelan Andes), the Rio Guache and Nuezalito formations, are the most complete sections of these flysch sequences. A sedimentary petrologic study was undertaken to determine the source areas for these formations, to put age brackets on the timing of uplift and rotation of portions of the Caribbean Mountains.

The mountains are divided into five tectonic divisions: The Cordillera de la Costa Belt, the Tinaco Belt, the Paracotos Belt, the Villa de Cura Belt and the Flysch Basins. The remnants of an island arc system connected with the evolution of the mountains lies off the coastline. Plutonic clasts from the Nuezalito formation indicate that deposition ocurred in a basin bounded on the north by the Tinaco and Villa de Cura belts, a Tinaco Belt correlative which now forms the Guajira Peninsula and possibly the island arc system. The southern margin of the basin was formed by the continental platform. Uplift, plutonism and metamorphism of several belts had already ocurred by the time of deposition of the Nuezalito formation.

The Rio Guache formation was deposited under similar conditions. More abundant metamorphic clasts suggest that uplift of the Cordillera de la Costa Belt ocurred after the Nuezalito and before the Rio Guache formations were deposited. Analysis of graywackes from the two formations shows differences in composition attributable to depositional factors, but no clear variation in maturity which might indicate whether

the Rio Guache formation was derived in part from recycled older sediments such as the Nuezalito formation. Comparison of monocrystalline to polycrystalline quartz ratios in the two formations shows the Rio Guache formation to be more mature, but this may have little statistical validity.

Recent theories for evolution of the Caribbean Mountains speculate that the island arc, rotating to the south as a result of eastward movement of the Caribbean plate, collided with the continental craton, causing orogenesis to occur. Paleomagnetic data suggests that the Tinaco and Villa de Cura as well as the Guajira Peninsula also rotated. The Nuezalito basin rotated with these belts; consequently the timing of rotation cannot be fixed by the provenance of clasts in the Nuezalito formation.

Changes in the style of orogenesis in the Caribbean Mountains are reflected in the clast types present in the Rio Guache and Nuezalito formations. A theory proposed by Crook (1974) states that graywackes reflect three different types of geotectonic terrains. The data collected from graywacke and pebble clast analysis indictes that this model is overly simplistic, and that perhaps the model should be replaced by more exact theories.

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SECTION I

CARIBBEAN TECTONICS AND EVOLUTION

INTRODUCTION

Until the start of this decade, two competing theories detailing evolution of the Caribbean region were debated: fixist versus mobilist. In recent years the fixist theory, that the Caribbean marks the site of a foundered continent has lost credence in the face of mounting evidence from studies such as the D.S.D.P. program.

Newer theories for the evolution of the area envision the Caribbean as a plate pushed into its present position from the Pacific in the Late Cretaceous-Early Tertiary by convergence of the North and South American plates with the East Pacific plate (Freeland and Dietz, 1971; Malfait and Dinkelman, 1972; Maresch, 1974). As this plate migrated eastward, it pushed an island arc consisting of the Netherlands Antilles and Venezuelan Offshore Islands in its path towards the present Venezuelan coastline. A south dipping Benioff zone under the South American craton consumed the oceanic crust on which the island arc was riding.

In this model, the Caribbean Mountains arose from Cordilleran orogenic processes as the island arc was scraped off the subducting, heavier basaltic oceanic crust (Dewey and Bird, 1970).

Recent paleomagnetic data from the island arc suggests that the island arc and portions of the Caribbean Mountains rotated through 90 degrees, from an original north-south orientation to an east-west orientation. This translation delineated the shift from an Atlantic type margin to an active continental margin. A wedge shaped, euxinic marine basin resulted, bounded on the northwest by the island arc complex, on the south by the South American craton and on the east by open ocean.

Late Cretaceous-Paleocene flysch sequences depostied in this basin present a record of the tectonic evolution of the Southern Caribbean boundary. A detailed analysis of the petrography and provenance of these flysch sediments was undertaken to examine several problems concerning the evolution of the area. The abundant clasts of both volcanic and plutonic rocks document the collision of the rotated island arc complex with the Venezuelan continental margin. These clasts reflect uplift and erosion of the Caribbean Mountains and the provenance of the flysch sediments from which they are derived places critical constraints on the timing of orogenic processes along the southern Caribbean boundary.

SECTION II

REGIONAL GEOLOGIC SETTING

Geography

The Caribbean Mountains of Venezuela stand at the junction of the South American and the Caribbean plates. The Mountains trend roughly east-west, extending from the Northern Ranges of Trinidad, 350 kilometers to the west, terminating within the Venezuelan Andes at approximately latitude 60 w. The mountains are 75-100 kilometers wide, stretching from the Caribbean coastline south to the plain of the Orinoco River.

Tectonic Divisions

The Caribbean Mountains are divided into five tectonic divisions. From north to south, they are:

1). Cordillera de la Costa Belt
2). Tinaco Belt
3). Paracotos Belt
4). Villa de Cura Belt
5). Flysch Belt

The different divisions are described below. (see fig. 1)

1). The Cordillera de la Costa belt is composed of the Caracas Group, an Upper Jurassic-Lower Cretaceous sequence of four metasedimentary formations derived from the South American plate (Guyana Shield) and deposited on older, pre-Mesozoic crystalline basement. The Caracas Group is composed of greenschist to epidote-amphibolite facies rocks, (Seiders, 1962) with calc-alkaline intrusives dated at 88 to 71 million years old (Martin-Bellizia et al., 1968). Augen gneisses formerly thought to be pre-Mesozoic have been reinterpreted as contact aureoles associated with these intrusives (Urbani, 1971). The degree of metamorphism increases to the north.

2). The Tinaco Belt is a collection of metamorphic schists and gneisses characterized by two metamorphic events, one in the Triassic (204-210 million years old) and one retrograde event in the Middle Cretaceous (112-117 million years old). The Tinaco Belt also contains a metavolcanic formation, the Tiara Formation. This Belt, the oldest division found in the Caribbean Mountains is commonly defined as basement rock.

3). The Paracotos Belt consists predominantly of Late Cretaceous silty phyllitic shales of the Paracotos Formation. Numerous serpentinites and gabbros intrude the belt.

4). The Villa de Cura Belt is a sequence of metavolcanic and associated fine-grained metasedimentary rocks (Bell, 1967). It is a blueschist assemblage, reflecting high pressure/low temperature metamorphic conditions. Glaucophane and lawsonite typify the assemblage. The Villa de Cura Belt is an allochthonous block moved south to its present position in the Early Cenozoic or Late Cretaceous.

5). The Flysch Belt is a series of Tertiary basins laterally continuous along the southern margin of the Caribbean Mountains. Typical lithologies consist of thin to medium sized beds of fine-grained, quartzitic sandstones and siltstones alternating with finely micaceous, weakly fissile shales and mudstones. Cyclic sequences are common, as well as exotic blocks (Bell, 1967).

An island arc complex consisting of the Netherlands Antilles (Aruba, Curacao, Bonaire), Orchila, Blanquilla and Tobago as well as several smaller islands exists north of the Venezuelan continental margin. Basic volcanic and metavolcanic rocks (andesites, andesitic tuffs and lavas) with indications of deposition in shallow water are common (Schubert and Moticska, 1972; Westermann, 1932). A series of highly sheared quartz diorite and trondhjemite plutons, surrounded by more basic lamprophyres, hornblende diorites and hornblende gabbros crop out in the island arc.

SECTION III

NUEZALITO AND RIO GUACHE FORMATIONS

Areal Extent and Age

The Nuezalito and Rio Guache formations are two flysch sequences deposited in the euxinic marine basin referred to in section I.

The two formations are exposed solely within the westernmost Caribbean Mountains, near the town of Acarigua (Skerlec, 1972). The Nuezalito formation appears over an area 250 square kilometers . The Nuezalito formation has been dated by stratigraphic relationships as Turonian to Coniacian (Skerlec, 1979). The Rio Guache formation, on the basis of foraminifera and correlation with a similar formation to the east, has a date of Maestrichtian to Lower Eocene.

Tectonic Divisions

Of the five tectonic divisions composing the Caribbean Mountains, only three are seen in the Acarigua region: The Cordillera de la Costa Belt, Paracotos Belt correlatives and the Flysch Belt. The Rio Guache formation is a member of the Rio Guache Flysch basin, a correlative of the Flysch Belt. The Nuezalito formation lies in a tectonic division which is associated with the Paracotos Belt, located between the Cordillera de la Costa Belt and the Rio Guache Flysch Basin.

Formation Descriptions

The otherwise similar Rio Guache and Nuezalito formations are distinguished on the basis of metamorphic foliation: The Nuezalito formation has been metamorphosed to very low grade chlorite facies and has well developed metamorphic foliation; the Rio Guache formation is unmetamorphosed. In hand sample, ignoring the metamorphic foliation the two formations are identical.

The two formations consist of three members: a pebble conglomerate member, a graywacke member and a fine-grained siltstone member.

1). The pebble conglomerate is a dark gray to beige which weathers to a light tan color. It is medium-coarse grained with large pebbles and cobbles varying in color from black to cream. The pebbles and cobbles are well rounded, spheroidal to elongate. Sorting is very poor and bedding hard to recognize. Clasts consist of sedimentary, volcanic, plutonic and metamorphic clasts, in that order of abundance. The matrix is variable, from fine grained mudstone to sand sized grains. Two fossils were found in the Nuezalito formation pebble conglomerate: a bryozoan and a shell fragment. There are no large scale structures, though a rough bedding can be distinguished in places due to alignment of the long axes of elongate pebbles.

2). The graywacke member is a dark gray, fine-grained, indurated, homogeneous rock. Grains are sub-rounded to sub-angular, with no clasts or pebbles. Sorting is fair to good. The matrix is hard to discern, though it imparts the gray color by which graywackes are classified. Small rock fragments are discernible with a hand lens; these include chert, feldspar, quartz and intraformational clasts.

3). The third member is a fine-grained, well sorted siltstone. Different beds are distinguished on the basis of color rather than grain size. Bedding is well developed, with irregular color variations. There are occasional clasts of intraformational pebbles. No sedimentary structures other than some possible rip-up clasts appear.

Contacts and Thickness

The Nuezalito formation is a member of the Villanueva Group, which consists of four formations, from oldest to youngest, the Volcancito, Nuezalito, Yacumbu and Palo Gacho formations.

The base of the Nuezalito formation is in fault contact with a Lower Cretaceous formation in the northern outcrop area and in transitional contact with the Volcancito formation in the central area. In the south, the Nuezalito formation overlies the younger Yacumbu and Rio Guache formations (Skerlec, 1979). Upper contacts are not exposed.

Average thicknesses for the Nuezalito formation are 1.5 to 2.0 kilometers.

The Rio Guache does not have exposed contacts except for the unconformably overlying Nuezalito formation. The Rio Guache is estimated to be 1.5 kilometers thick (Skerlec, 1979).

Environment of Deposition

The three members of the formation are the result of submarine fan deposition. The coarse pebble conglomerate is the near-shore member of the fan; the graywacke is the intermediate member and the fine-grained siltstone is the distal turbidite member. Unfortunately, many of the criteria for determining environments of deposition depend on large scale structures such as bedding variations, Bouma sequences, morphology and physiography (Nilsen and Neilson, in Shaver and Dott, eds., 1973; Winn and Dott, 1978). Since only hand samples were available, large scale structures could not be used. Nonetheless, some information could be gained from the hand samples.

The near-shore member, the pebble conglomerate, greatly resembles published descriptions of Late Mesozoic flysch sequences from Tierra del Fuego (Winn and Dott, 1978). There the coarse clastic conglomerates and diamictite members of the sequence were deposited from traction, probably at the base of turbulent flows. In addition, lenses of pebbly sandstone and conglomerate were present in the flysch, products of " inner fan channel deposition " (Winn and Dott, 1978). What is seen in the Nuezalito supports a similar theory. There is very little graded bedding, sorting or imbrication; cross-beds are totally absent. All the pebbles are well rounded, indication that some form of transport ocurred prior to deposition. The above evidence rules out fluvial deposits. Fossils found in the other members (a bryozoan, an echinoid fragment and an oölitic limestone fragment) rule out lacustrine deposits. This leaves a deltaic marine environment as the only viable possibility.

The graywacke member was deposited farther offshore. When the turbidite or current lost sufficient tractive velocity to support the larger cobbles and pebbles these dropped out. The finer portion continued until it too was deposited, thus forming the graywacke .

Finally, the finest portion came out of suspension, forming the third member of the formation. At this point, well developed bedding becomes evident, due to the small volume of flows and settling effects. Very small rip-up clasts seen in some of the thicker beds presumably resulted from traction currents.

Analysis of modern and ancient fans has shown that the three facies result not only from transport distance but also from channeling effects within the fan (Nilsen and Neilson, in Dott and Shaver, eds., 1973). Like a river delta, a fan maintains a series of shifting channels. The three members of the Rio Guache and Nuezalito formations could be channel and interchannel facies, the coarse pebble conglomerates deposited by channel gravity flows, graywackes farther down the channel and silts deposited as inter-channel flows.

SECTION IV

PREVIOUS WORK

There are several published works and unpublished Ph.D theses on Upper Cretaceous flysch sequences in Venezuela.

Seiders (1962), studied the Paracotos and Urape formations, Upper Cretaceous flysch sequences similar to the Nuezalito and Rio Guache formations. He found identical sources for clastic fragments in both formations, terrains where mechanical erosion exceeded chemical weathering. While not assigning a specific source, he decided that maturity differences indicated variations in distance from source or variations in volcanic detritus supply.

Konigsmark (1958), investigated the Garrapata and Paracotos formations. He interpreted the Garrapata formation as a deltaic deposit with clasts brought by swift, south flowing rivers from Turonian-Coniacian age highlands. On the evidence accumulated from clasts, he decided that the Paracotos formation was a shallow sea deposit in a fault bounded basin.

Menendez (1962), felt that the Paracotos formation was deposited in deep water near its source, islands of the unstable, rugged " northern provenance " , probably the Tinaco and Villa de Cura Belts. Palinspastic restoration based on Villa de Cura Belt detrital fragments in the Guarico formation indicated that the Guarico flysch trough was oriented east-west, and was bounded on the north by the exposed Villa de Cura block.

Bell (1967), also looked at the provenance of the Guarico and Garrapata formations. He concluded that the volcanic clasts were Tiara formation fragments; that the Garrapata formation accumulated along the margin of a basement high formed by the Tinaco Belt, the Villa de Cura

Belt and the Tiara formation. Additionally, the Guarico formation was found to be more mature than the Garrapata formation, attributable to recycling of older sediments. Therefore, these two formations showed changes in basinal environments which reflected the southward sliding of the Villa de Cura Belt and Late Cretaceous uplift.

SECTION V

METHODS

Ten thin sections from each formation (pebble conglomerate member) were point counted to determine the relative percentage of clast types present in each formation. Twelve hand samples from the Nuezalito formation and six from the Rio Guache formation were point counted with a transparent grid overlay, after having sectioned, polished and sprayed plastic enamel on the rock.

Fifteen graywacke thin sections from each formation were point counted to determine modal composition.

37 slides from both formations were analyzed to ascertain the ratio of mono-crystalline to poly-crystalline quartz.

Petrographic descriptions were made of plutonic clasts found in thin sections from both formations.

Photomicrographs were taken with a Zeiss non-polarizing microscope, substituting sheets of Polaroid for the nicol prisms.

SECTION VI

CLAST PROVENANCE

Clast Types

Four types of clasts are present in the Nuezalito formation: sedimentary, volcanic, metamorphic and plutonic. The sedimentary clasts (chert and intraformational clasts) are common; volcanic fragments are ubiquitous and metamorphic clasts are rare. Lack of knowledge concerning volcanic stratigraphy, similarity of sedimentary sources and paucity of metamorphic fragments makes these clasts unsuitable for provenance studies in the Caribbean Mountains.

Plutonic Clasts

A total of fifteen plutonic clasts large enough to give modal estimates or other analyses were found. Of these, thirteen were silicic or alkalic and two were mafic.

Figure 3 is an albite-anorthite-orthoclase ternary composition diagram. Plotted on it are the compositions of clasts from the Nuezalito formation assignable to the diagram. Except for three points, all the points fall above the An_{10} line, in the trondhjemite and granite divisions of the ternary diagram (O'Connor, 1965).

The two mafic clasts were both small rounded pebbles, 1 to $\frac{1}{2}$ cm. in diameter. Slide 149-B, from the conglomerate pebble member of the Nuezalito formation contained a hornblende diorite. It consisted of 80 % twinned plagioclase (An_{12} avg.; Michel-Levy method) and a hornblende phenocryst completely surrounded by the plagioclase groundmass. Some alteration to sericite and uralite was evident.

Slide 571, also from the pebble conglomerate member contained a clast of saussuritized gabbro. The groundmass was altered sodic plagioclase (An_{15} , though one grain was An_{40}). Chloritized hornblende and epidote made up the remaining 30-40 % of the clast. One epidote grain enclosed a small plagioclase phenocryst. Calcite replacement was common. Some green hornblende was present as an accesory mineral.

Slide 218-C contained two highly distinctive clasts similar to sample 765-A, a float cobble derived from the Nuezalito formation. All three are silicic, leucocratic clasts composed of 70 to 75 % highly regular perthitic feldspar with accessory microcline and albite. The remaining 25 to 30 % is quartz. Average grain size is 2-3 mm.

Figure 4 is a quartz-k-feldspar-orthoclase ternary composition diagram. Plotted on it (triangles) are the compositions of the three clasts from slide 218-C and 765-A.

Slide 395 contains a plutonic fragment with several sericitized zoned plagioclase crystals with up to seven rings.

Possible Sources

Table 1 is a list of possible sources for these plutonic clasts and their tectonic divisions, compiled from published sources.

TABLE I

ROCK TYPE	TECTONIC DIVISION
Trondhjemite	Tinaco Belt
Aplite dikes in trondhjemites	"
Gabbroic sills, hornblendite	"
Hornblende basalt	"
Hornblende diorite	Villa de Cura Belt
Altered gabbros	Villa de Cura and Tinaco
Hornblende gabbro	"
Guaremal Granite	Cordillera de la Costa Belt
Siapana granodiorite	Guajira peninsula
Amparo granodiorite	"
Jojoncito leucogranite	Macuira fm. *

Table 1 (cont'd)

Gabbroics in serpentinites	Macuira fm *
El Salado granite	Cordillera de la Costa
Guayacan gneiss	"
Diabase schist	Island arc
Quartz diorite batholith	"

* The Macuira formation is a sequence of metasediemnts on the Guajira peninsula possibly correlated with the Tinaco Belt.

The plutonic rocks intruding the Tinaco Belt vary from Triassic to Late Cretaceous in age (MacDonald, 1966). The trondhjemite contains large microcline crystals, quartz, biotite and a small amount of hornblende. Some sericitized zoned plagioclase grians are present (Menendez, 1962). Aplite dikes are common. The hornblendite and hornblende diorite are similar to other intrusives seen throughout the Tinaco complex, a group of Upper Cretaceous alpine type peridotites (Seiders, 1962), and zoned ultramafic intrusives (Murray, 1972). These have central bodies of olivine pyroxenite grading out through olivine-magnetite pyroxenite, hornblende-magnetite pyroxenite to hornblendite at the margins in roughly circular fashion. They are thought to be the mafic fractionates of basaltic magma, the high alumina portion of which might have formed the Tiara Volcanic Andesites (Murray, 1972). The average composition is 95 % hornblende, 5 % clinopyroxene in the hornblendite, and 30 % hornblende, 70 % saussuritized plagioclase and 1-2 % leucoxenized magnetite in the gabbroic portions.

Cordillera de la Costa intrusives are mostly granites with associated gneissic contact aureoles. There is a biotite-microcline-albite granite , the Guaremal Granite, as well as other leucocratic granites.

The Villa de Cura intrusives appear to be genetically related to some of the Tinaco belt intrusives. Several serpentinites, altered gabbros and hornblende diorites intrude both the Villa de Cura and Tinaco belts (Seiders, 1962; Jarvis, 1964; Konigsmark, 1958).

Descriptions of Late Cretaceous intrusives on the islands of Aruba, Tobago, Los Roques, Los Testigos and La Blanquilla have been published. They are the only descriptions available for the island arc complex.

The intrusives are divided into two groups on the basis of silica content. There is a gabbro/uralite diabase with associated hornblende schist contact aureoles (Westermann, 1932). Tuffs, conglomerates and breccias are believed to be the extrusive equivalents of this group. The second group is a diorite batholith with several differentaites. Zoned plagioclase is the dominant constituent, typically oligoclase to andesine with some amounts of orthoclase; hornblende is present (up to the amount of plagioclase), along with small amounts of quártz. Hooibergites, melanocratic rocks with large hornblende crystals, quartz and plagioclase (albite-oligoclase), with some graphic quartz-plagioclase intergrowths are described on Aruba (Westermann, 1932). There are also gabbros, granodiorites and aplite dikes.

Three modal analyses are listed below for the island arc hornblende diorites and meladiorites:

	Tb 94	Tb 100	Tb 149
Plagioclase	42.5	44.5	63.3
Quartz	-	-	26.9
Magnetite/ilmenite	4.6	1.3	.6
Augite	10.8	-	-

	Tb 94	Tb 100	Tb 149
Uralite	39.5	-	-
Biotite	2.1	1.0	9.0
Epidote	-	5.8	.2
Apatite	.5	-	-
Hornblende	- +	47.4 +	- +
	100.0	100.0	100.0

(Data from Maxwell, 1957)

Interpretation

Figure 5 is an albite-anorthite -orthoclase ternary feldspar diagram identical to figure 4. Plotted on it are the compositions of forty samples from possible source areas, obtained from published data (Menendez 1962; Seiders, 1962; Maresch, 1972; Jarvis, 1964). All of the Tinaco Belt samples except one lie above the An_{10} line, while all the others except three lie below the An_{10} line. This indicates that the Nuezalito formation was receiving plutonic clasts predominantly from the Tinaco Belt. The three points below the An_{10} line imply, however, that there might be other sources for a small fraction of the clasts.

Alteration due to weathering during transport is of prime importance in detailing possible shifts in bulk composition of the clasts which might affect the diagram. The ternary diagram gives no indication of the percentages of alteration products in the clasts. Changes caused by weathering during transport might explain the shift in clast compositon away from the Tinaco Belt samples and towards the orthoclase corner.

During weathering, the order of stability is (from most to least stable): potassic feldspar, albite, and anorthite (Pettijohn, Potter and Seiver, 1971). This is mitigated to some extent by p.H., E.h. and other salient chemical and environmental factors. Both field and laboratory studies however, confirm this ordering.

One would expect therefore to see a shift in the clast diagram towards the K-spar and albite corner caused by weathering and selective destruction of plagioclase rich clasts.

Figure 5 reflects this. The composition of the lithic clasts has been shifted to the right relative to the unweathered source materials. Sampling error caused by weathering and alteration is largely responsible.

Of the possible sources in Table 1, only $\frac{1}{4}$ could be plotted on figures 4 and 5, either because there was no modal analysis or because the rocks did not plot on the diagram. Consequently, comparison of clast thin-sections with published sources was attempted.

There are several descriptions of leucocratic rocks in the Caribbean Mountains (Maresch, 1972; Menendez, 1962; Lockwood, 1967). Only two of the described rocks however, contain perthitic feldspar as the dominant constituent and have highly regular exsolution lamellae in the feldspar, similar to slides 765-A and 218-C. These are the Siapana granodiorite and the Jojoncito leucogranite, both found on the Guajira Peninsula. The Guajira Peninsula juts out into the Caribbean on the west flank of Lake Maracaibo. It contains outcrops of both the Tinaco Belt and the Cordillera de la Costa, as well as the Macuira formation, mentioned above. These intrusives are postulated to be co-genetic, Upper Paleozoic or Lower Triassic rocks (Lockwood, 1965).

The CIRCLES on figure 4 are the compositions of five samples from the Jojoncito leucogranite (Alvarez, 1967). The clasts fall within the same area as the samples, suggesting that they are from the same area. The plutons intrude the Macuira formation. If the inferred relationship between the Macuira formation and the Tinaco Belt is correct, and there is no reason to believe that it is not, then this is a second line of evidence that the Tinaco Belt was a source area.

Saussuritized gabbros greatly resembling the gabbroic clast in slide 571 have been described in the Caribbean Mountains (Murray, 1971; Skerlec, 1979). Both the El Chacao ultramafic complex and the Cerro Pelon complex are zoned mafic intrusives located in the Villa de Cura Belt. Both complexes contain saussuritized gabbros; no other sources of these rocks are known in the Caribbean Mountains excluding other smaller, cogenetic zon ed intrusives in the Villa de Cura Belt.

Hornblende diorites similar to the clast in slide 149-B are described in three tectonic divisions: The Villa de Cura, the Tinaco Belt and theisland arc complex (Menendez, 1962; Westermann, 1932). Table 2 demonstrates the possibility that the island arc was a source for the hornblende diorites.

Conclusion

Clearly, there are several possible sources for the plutonic rock fragments in the Nuezalito formation. These include the Tinaco Belt, the Villa de Cura belt, the Guajira peninsula (Tinaco Belt), and the island arc. On the basis of data from the feldspar ternary diagram, it is proposed that one of the sources was the Tinaco Belt. The altered gabbros are solid evidence that a second source was the Villa de Cura Belt. The Guajiran arch was a third source, on the basis of the perthitic clasts from Permo-Triassic intrusives in the Macuira formation. Whether the island arc was contributing detritus is unclear.

The existence of clasts derived from the Guajira Peninsula in the Nuezalito formation is of interest in constructing palinspastic models of the area at the end of the Cretaceous. The Guajiran Arch has been linked structurally with the continental craton rather than the ocean basin structures such as the island arc, Tinaco Belt and Villa de Cura Belt (Menendez, 1962). Paleomagnetic data however, suggests that the Guajira through 90 degrees in the same fashion as the island arc, Villa de Cura and Tinaco Belts (Skerlec and Hargraves, in prep.), and was therefore associated with these offshore structures rather than the continental structures. Guajiran clasts in the Nuezalito formation, which rotated with the arc, supports this theory.

SECTION V

ANALYSIS OF GRAYWACKES

Purpose

The modal composition, maturity and clast abundance of the Rio Guache and Nuezalito formations were compared to determine:

1). If the Rio Guache and Nuezalito formations had dissimilar sources, which might indicate whether uplift of the Cordillera de la Costa Belt had ocurred after deposition of the Nuezalito formation,

2). If the Rio Guache formation is more mature than the Nuezalito, hence whether the Rio Guache formation might contain recycled Nuezalito formation detritus,

3). Whether the Nuezalito formation was derived from an island arc regime, continental regime or a mixture of the two.

Data

A total of thirty six graywackes from both formations were studied. Modal analyses were obtained to determine the relative percentages of quartz, feldspar, chert and sediment, metamorphic and igneous fragments, mica, matrix and calcite. Percentages of monocrystalline versus polycrystalline quartz and plutonic versus volcanic fragments were also recorded. The results are summarized in figure 6, a standard graywacke composition diagram (Folk, 1954).

Point counts of clast type were also executed for the graywacke and pebble conglomerate members of both formations to ascertain the relative proportions of volcanic, plutonic, metamorphic and sedimentary clasts. Figure 6 is a plot of this data.

Interpretation

Similar Upper Cretaceous flysch sequences situated to the east of the

Acarigua region, the Guarico and Garrapata formations have been similarly analyzed and significant compositional differences found by plotting the data on a ternary graywacke diagram (Bell, 1967) (see fig. 6). The Guarico formation, a correlative of the Rio Guache formation, is a more mature graywacke than the Garrapata formation, itself similar to the Nuezalito formation.

The Nuezalito formation has a wide spread in maturity, parallel to the Q pole from Q_4 to Q_{65}. Clearly the formation is both more mature and less mature than the Rio Guache formation. The Rio Guache formation has a variation of its own, parallel to the M pole from M_{12} to M_{65}.

The cause of the variation in the Rio Guache formation can be traced to mica content. The 33 slides analyzed from this formation clearly show two facies, differentiated on the basis of mica content. The mica rich slides all plot above the M_{55} line while the mica poor ones all plot below the M_{40} line. This variation is readily apparent under the microscope. The muscovite and biotite all have preferential alignment parallel to their long axes in the mica rich facies, while the mica from the other facies have no preferential alignment. Additionally, calcite is an important constituent in 3 of the 13 mica poor samples and in none of the mica rich samples.

The cause of the mica variation is undetermined; the most plausible explanation is transport and settling effects. The mica rich facies resulted from low energy environment deposition while the mica poor facies was a result of a higher energy environment where settling could not occur.

The cause of the Nuezalito formation variation is undetermined.

Several causes are possible:

1). Variations in composition and clast content within the graywacke member. This is doubtful however, since the same variation would be expected in the Rio Guache formation graywacke member.

2). Statistical effects due to tallying conventions with regard to volcanic and sedimentary clasts. Variations in source terrains might have led to variations in proportions of volcanic and sedimentary clasts which would affect the diagram.

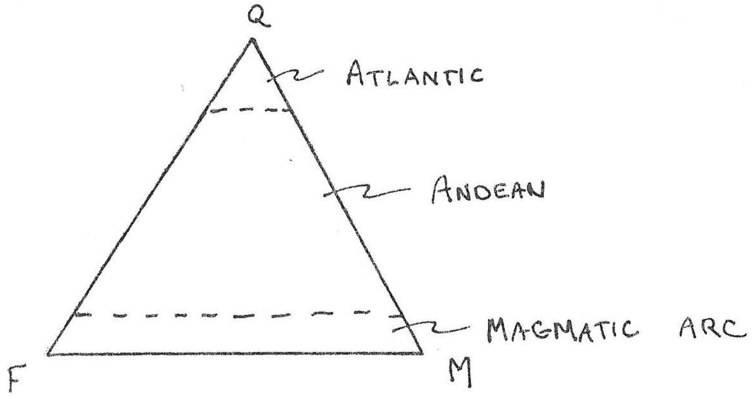
3). Operator error. This is discussed in Section 7 , Procedures and Error.

4). There is a real variation in maturity . Possible causes for a variation in maturity include transport distance and source terrain differences.

The greater percentage of metamorphic clasts in the Rio Guache formation (fig. 7) relative to the Nuezalito formation is clear evidence that the Cordillera de la Costa Belt was uplifted prior to deposition of the Rio Guache formation. Both formations were deposited as submarine fans, an environment which implies rapid deposition of large amounts of detrital material. Weathering and other pre-depositional effects can be disregarded, therefore. The cause of the variation must rest in effects governed by source terrain.

Uplift of the Cordillera de la Costa and exposure of the Caracas Group metasediments to erosion is the explanation for the source terrain shift. This new influx of detrital material replaced that lost by erosion of the Villa de Cura Belt and Tinaco Belt.

The ternary graywacke diagram can be used to assign a general source for a formation, depending on where it plots relative to a Q pole (Crook, in : Dott and Shaver, eds., 1973). Quartz poor graywackes come from magmatic island arcs, quartz intermediate graywackes from Andean type continental margins and quartz rich graywackes from Atlantic type margins:



According to Crooks theory, the Nejuzalito and Rio Gauche formations were both deposited in an Andean type, geotectonically active continental margin. This raises questions which are discussed in the final section.

Conclusion

Graywacke analysis produced some ambiguous results which are unresolved. Rather than showing the Rio Guache formation to be a more mature rock than the Nejuzalito formation, it highlighted variation in the depositional environment, leaving source terrain questions unresolved.

An upper limit on timing of uplift of the Cordillera de la Costa was obtained from the metamorphic clast data. Uplift occured in the Coniacian to Maastrichtian.

SECTION VI

ANALYSIS OF QUARTZ

Purpose

The ratios of chert to quartz, volcanic rock fragments to lithic rock fragments and monocrystalline to polycrystalline quartz were studied in both formations, to shed more light on the question of source terrains and relative maturity.

Results

The ratio of chert to quartz in both formations came out well over .5 :

Nuezalito fm. = .64
Rio Guache fm. = .59

V/L ratios for the two formations are over .75 :

Nuezalito fm. = .85
Rio Guache fm. = .90

The ratio of polycrystalline to monocrystalline quartz in the two formations is summarized below :

	RIO GUACHE	NUEZALITO
MONOCRYSTALLINE	.81	.72
POLYCRYSTALLINE	.19	.28

Uses

Detrital quartz and chert are potentially useful source indicators. One can distinguish between polycrystalline and monocrystalline quartz, between sutured and polygonized quartz, and between plutonic and volcanic quartz. This knowledge can be used not only to identify sources but to infer conclusions about sediment maturity, source area and tectonic regime.

Early attempts to use detrital quartz revolved around assigning the quartz to igneous, metamorphic or sedimentary sources on the basis of inclusions, grain shape and extinction pattern

(Krynine, 1949). Unfortunately, this approach was found to be unsatisfactory, due to difficulties in applying the criteria and lack of knowledge about quartz in source rocks (Pettijohn, Potter and Seiver, 1971).

During the 1960's several people looked at previously uninvestigated aspects of detrital quartz. Voll observed the relationship of polygonized quartz to metamorphic regime (Voll, 1960). He concluded that polygonized quartz came from regions where static annealing prevailed and sutured quartz where cold rollingpredominated (polygonized quartz grain boundaries are straight, forming polygons).

Undulatory extinction was investigated and found to be of limited use (Blatt, 1963; Blatt and Christie, 1967). 91 % of volcanic quartz is unstrained while only 14 % of plutonic igneous rocks, schists and gneisses are unstrained. Therefoe, there is a 10 % chance that unstrained quartz is not volcanic and a 15 % chamce that strained quartz is volcanic. The percentage of strained quartz is a better indicator of sediment maturity, strained quartz being less stable than non-strained quartz and more prone to disintegration in repeated weathering cycles.

Data can be deduced by a more careful analysis of the ternary graywacke diagram. Subdividing the Q pole into a ratio of chert to quartz allows one to assign the sample to one of three source terrains:

1). C/Q is low; Q 0 Volcanic sandstone
2). C/Q is low, Q 25 Plutonic sandstone
3). C/Q is high, Q 25-50 Tectonic Highlands.

(Dickinson, 1970)

" The parameter C/Q reveals how far a plotted point in the Q. F. L. diagram would move parallel to the Q-L side if the stable lithic fragments (C) were counted with the unstable lithic fragments (L) to emphasize supracrustal source rather than stability, the factor that parameter Q was designed to reveal (Dickinson, 1970).

Subdividing the L corner into a ratio of V/L gives a second set of ratios:

1). V/L = 1 Volcanic source
2). V/L =.75-.25 Plutonic source
3). V/L approaching 0 Tectonic Highlands

In sum, monocrystalline to polycrystalline quartz ratios serve best as indicators of maturity rather than source. C/Q and V/L ratios are better source indicators for graywackes.

Interpretation

C/Q ratios for the Rio Guache and Nuezalito formations show that tectonic highlands were contributing detrital fragments to the flysch basins. These highlands are postulated to have been the Villa de Cura and Tinaco Belts. V/L ratios imply that there was a plutonic source for both formations. This source was probably plutonic intrusives in the Villa de Cura and Tinaco Belts. Together with the graywacke data from the ternary graywacke plots, this leaves little doubt that there were exposed highs constituting several different tectonic belts in the Late Cretaceous, including the Villa de Cura and Tinaco Belt, the Guajira Peninsula and possibly the island arc complex.

Whether the Nuezalito formation acted as a source for the Rio Guache formation remains unresolved. The ratio of polycrystalline to monocrystalline quartz shows that the Rio Guache formation is more mature than the Nuezalito. However, the difference does not appear large enough to draw any conclusions concerning the source of the Rio Guache formation.

SECTION VII

PROCEDURES AND ERROR

Procedures

A portion of the data in this study was accumulated by point counting, a statistical technique for estimating modal composition.

A Leitz point counter attached to a standard petrographic microscope was used to estimate thin section modal composition. At least 250 points were tallied on each slide. The inherent error depends not only on the number of points counted but also on the percentage present of any given mineral. Figure 8 shows estimates of probable error at the 95 % and 50 % confidence level (Galehouse, in Carver, ed., 1971). 250 points were counted, because it offered maximization of confidence level versus time required to reach a figure for composition. Average error is estimated at 4 %.

For hand samples, a transparent photostat of standard 10 x 10 graph paper was produced. Placed over the slab, the clasts and grid intersections were clearly visible. Identification was made either with the naked eye or with a non-petrographic microscope. Size limitations restricted the number of points counted to 175 - 200.

For the ternary graywacke diagrams, chert, quartz and sedimentary fragments were tabulated on the Q pole; feldspars, plutonic and volcanic fragments on the F pole and mica (biotite and muscovite) and metamorphic fragments on the M pole. Care was taken to distinguish detrital from authigenic mica in both formations. Relationships between the mica and the surrounding grains and matrix were the primary criteria: mica growing at the expense of matrix, clay or weathered clastic fragments was considered authigenic. Chlorite, illite and sericite were considered matrix. Size was also a criteria: very few detrital grains were less than 4 mm. long; anything smaller was considered authigenic.

In point counting the graywackes, ratios of monocrystalline to polycrystalline quartz were tabulated as well as chert to quartz ratios.

Ten slides were point counted from each formation specifically to obtain the monocrystalline to polycrystalline quartz ratios; at least 200 points were counted on each slide.

Error

There are two types of error inherent in any type of point counting; one stems from operator error: misidentification of grains or incorrect tallying. The other stems from statistical causes: grain size effects , volumetric effects, etc.

The Chayes point counting method, used in this study, is designed to reduce grain size and volumetric effects to a minimum. When estimating composition of a graywacke, these effects are miniscule compared with the possible errors attributable to alteration, grain overgrowths and matrix over-estimation. Regardless of cause, these types of error are within the ± 4 % figure.

Any discussion of operator or statistical error is predicated on the assumption that the petrographer is fully able to distinguish between grain types (Chayes, 1956). The best determination of error is reproducubility of results. Having the same operator count a slide several times over is a bettr test of error than having several people count the slide once: personal vagaries are eliminated.

Several graywackes from both formations were point counted three times: in November, in March and again in April. The results are summarized in TABLE 1. Clearly, some of the slides show great similarity in all the counts and a few show moderate variation. The cause of the variation is problems inherent in graywacke petrology:

1). Variations in matrix estimation
2). Twinned and altered feldspar
3). Distinuishing detrital from authigenic mica
4). Distinguishing clast types

All of the above could lead to wide variations in modal estimates of graywackes and clast abundance in the pebble conglomerates.

Staining with sodium cobaltinitrite was attempted to accentuate the feldspars. The matrix and mica tends to absorb the stain however. This made it harder to identify most grains; consequently, the method was not used.

Perthitic feldspars were a source of error. Estimates of the K-spar/plagioclase ratios were made by counting the numer of bands in the grain and by the albedo of the extincted sections. Needless to say, there was great possibility for error.

There was great possibility for error, considering the nature of the subject. All of the error is believed to fall, however, within a ± 4 % figure.

SECTION VIII

DISCUSSION

The Nuezalito and Rio Guache formations are part of a series of Upper Cretaceous flysch sequences on the southern flank of the Caribbean Mountains, shed from uplifted highlands into marine basins. Thrusting has deformed, truncated and shortened all these formations, making basin reconstruction difficult. Though both the Nuezalito and Rio Guache formations have been similarly affected, they are the most complete of all the flysch sequences and are of great importance in detailing the tectonic history of the area. The sources of plutonic clasts in the flysches are the first step in unravelling the history.

Plutonic clasts in the Nuezalito formation are derived from a source area which lay to the north of the Nuezalito basin, consisting of the Tinaco and Villa de Cura Belt, the Guajira Peninsula and possibly the island arc. Unfortunately, the petrology of distinctive plutonic rocks in the island arc is too similar to other intrusives from different belts to state absolutely whether clasts are derived from the island arc. The southern margin of the basin was formed by a topographic high constituting the northern edge of the South American Craton. The site of deposition of the Nuezalito formation was separated from the southern margin by a deep water basin. The types of clasts inthe Nuezalito formation imply that uplift, plutonism and metamorphism of the northern highlands ocurred prior to deposition of the Nuezalito formation. The Nuezalito is dated from stratigraphic evidence as Cenomanian-Campanian (Skerlec, 1979)..

Less is known about the Rio Guache formation source areas. Greater percentages of metamorphic clasts in the Rio Guache formation compared to the Nuezalito formation suggest that uplift of the Cordillera de la Costa Belt ocurred in the period between deposition of the two formations, Maestrichtian-Paleocene. The Rio Guache and Nuezalito formations were deposited in similar conditions however, which implies that similar depositional processes must have been operating.

The deposition of the Nuezalito formation marked the start of rotation of the island arc complex, as it collided with the continental craron. The influx of metamorphic clasts from the Cordillera de la Costa marked the cessation of rotation, as thrusting, pushed allochthonous blocks such as the Villa de Cura Belt southwards and uplifted the The Cordillera de la Costa, changing the style of sedimentation. The lack of non-rotated sources means that the Nuezalito basin was always associated with the island arc and that it rotated with the arc into its present orientation.

Thrusting and deformation has confused the stratigraphy on Margarita, an island south of the island arc complex and unrelated genetically. Outcrops of greenstones, eclogites and amphibole gneisses are common (Maresch, 1971).

It has been proposed that the island arc complex formed on ocean floor basalt (Silver et al., 1971). Oriented north-south at its creation, the wedge of ocean floor with its attached island arc and flysch basins rotated clockwise and partial subduction of portions of it ocurred. The Nuezalito and other Upper Cretaceous flysch sequences accumulated on this wedge.

The absence of both a high T/p assemblage and a Franciscan type melange on Margarita suggests that subduction was not complete (Maresch, 1974). Impedance, caused by collision of the rotating arc with the South American Craton, produced another subduction zone north of the island arc. This caused active orogenesis to cease in the Caribbean Mountains as the new subduction zone bypassed the earlier focus of activity. Uplift of the Cordillera de la Costa marked the last activity, except for thrusting, which continued into the Miocene. (see figure 9)

The interpretation of data from graywacke analysis according to Crooks hypothesis indicates that both formations were deposited in an Andean type regime (Crook, 1974). The evidence concerning the rotation and partial subduction as it relates to orogenesis suggests that the idea of assigning geotectonic settings based on position in a graywacke diagram may be overly simplified.

The Nuezalito and Rio Guache formations record a shift in sedimentation style. The Nuezalito formation was deposited as the island arc collided with the continent and silicic and andesitic debris was shed into the flysch basin. The Rio Guache formation was deposited as compressive stress inaugurated thrusting which uplifted and exposed previously deposited metasediments such as the Cordillera de la Costa

Belt. These are very different tectonic styles, yet Crooks model describes them both as Andean type, tectonically mobile.

Crooks hypothesis has some valid basis, but data collected in this study suggests that perhaps a more detailed system of assigning geotectonic sources and style should be developed.

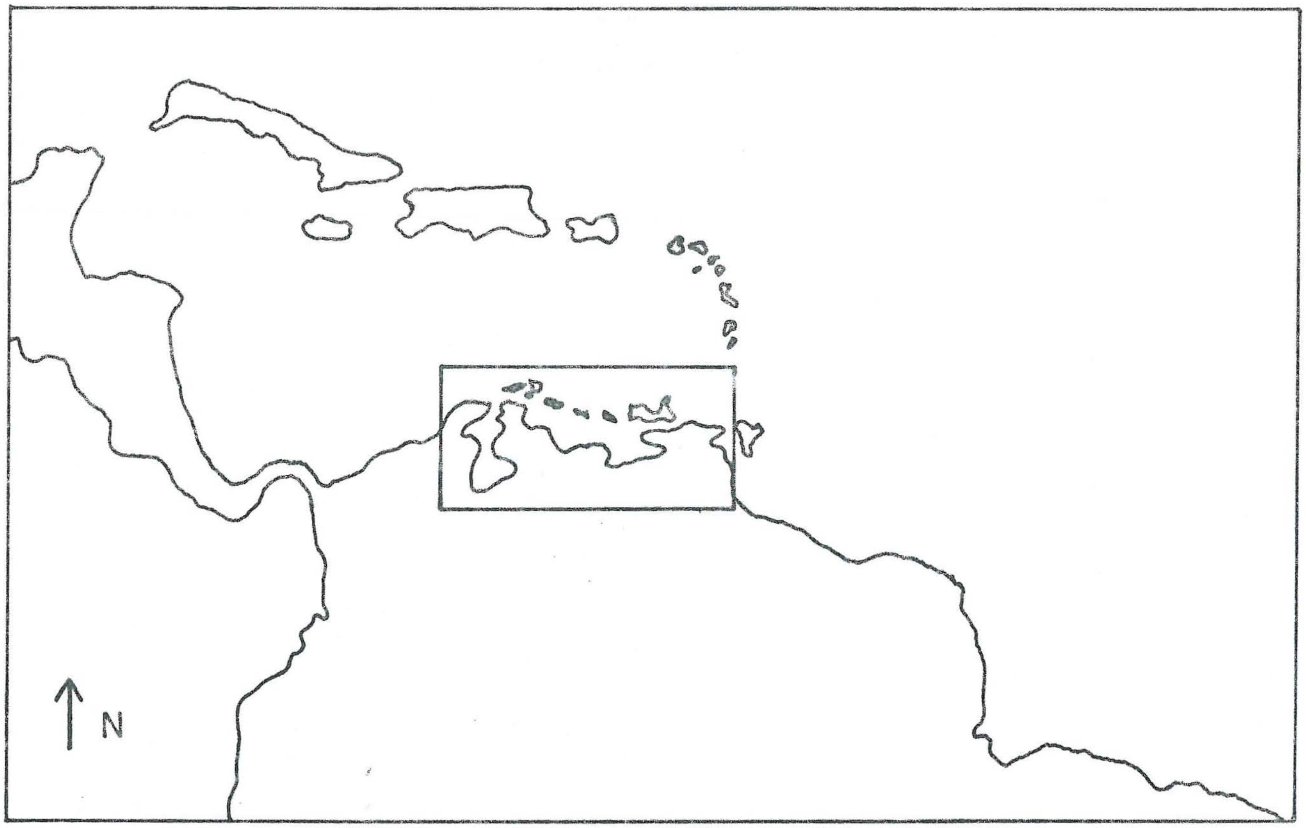


Figure 1. Map of Northern South America and the Caribbean Ocean.

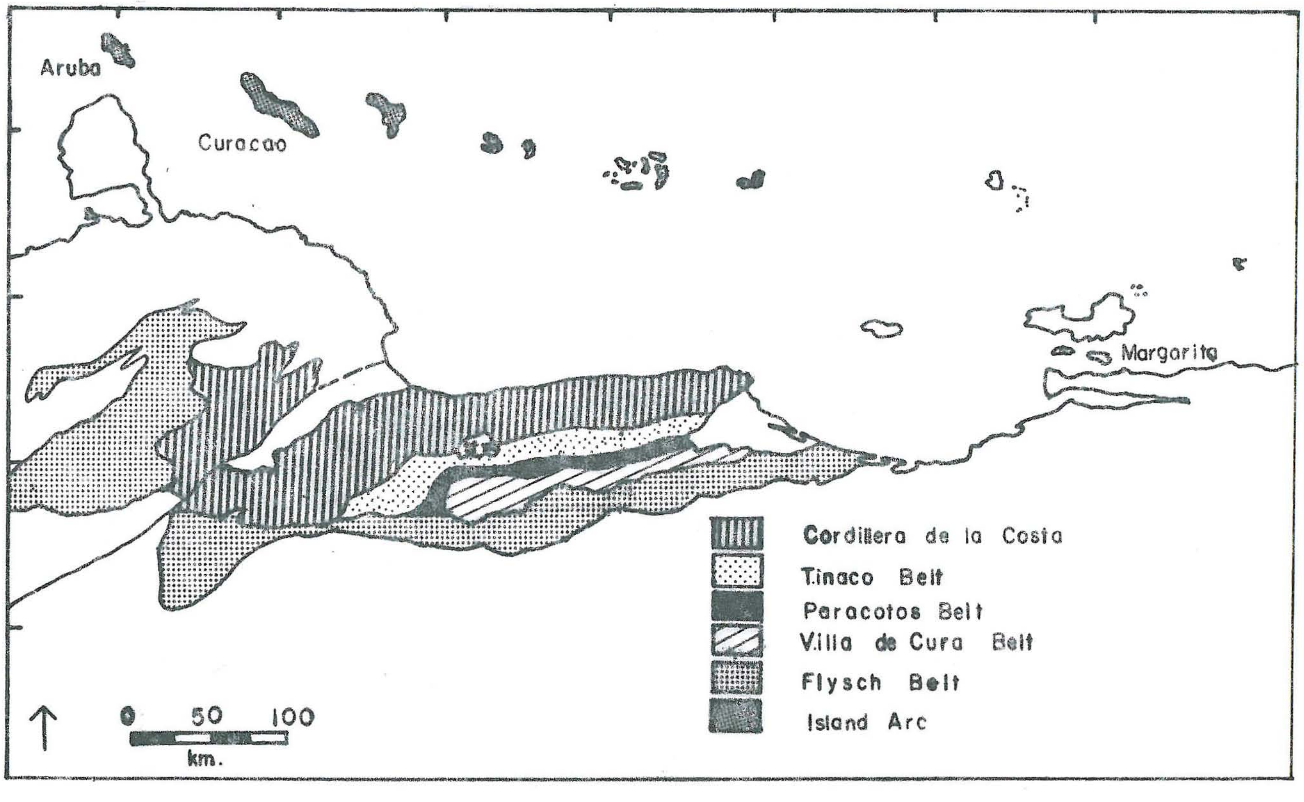


Figure 2. Map of the Caribbean Mountains. The Acarigua region is in the lower left corner of the map.

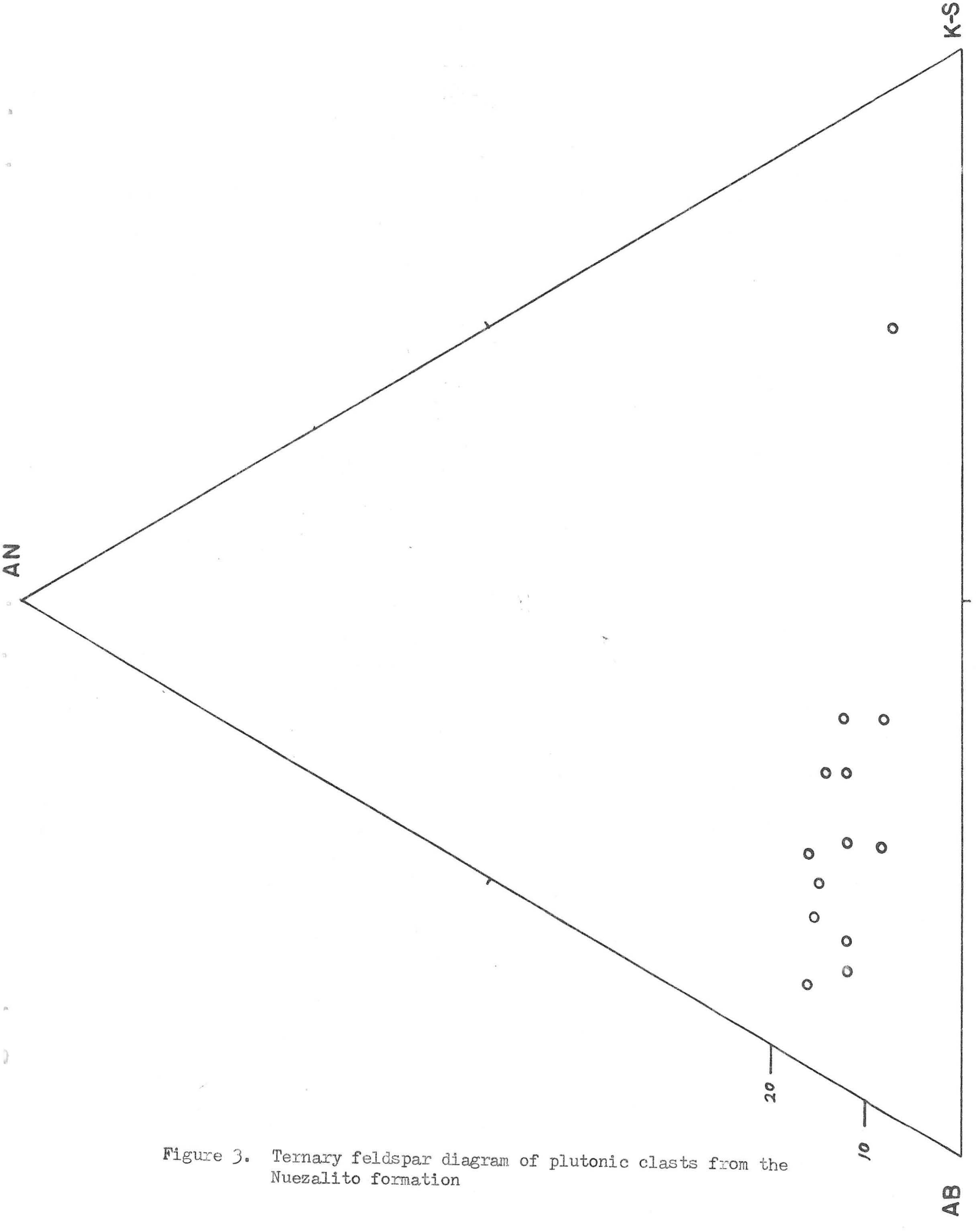


Figure 3. Ternary feldspar diagram of plutonic clasts from the Nuezalito formation

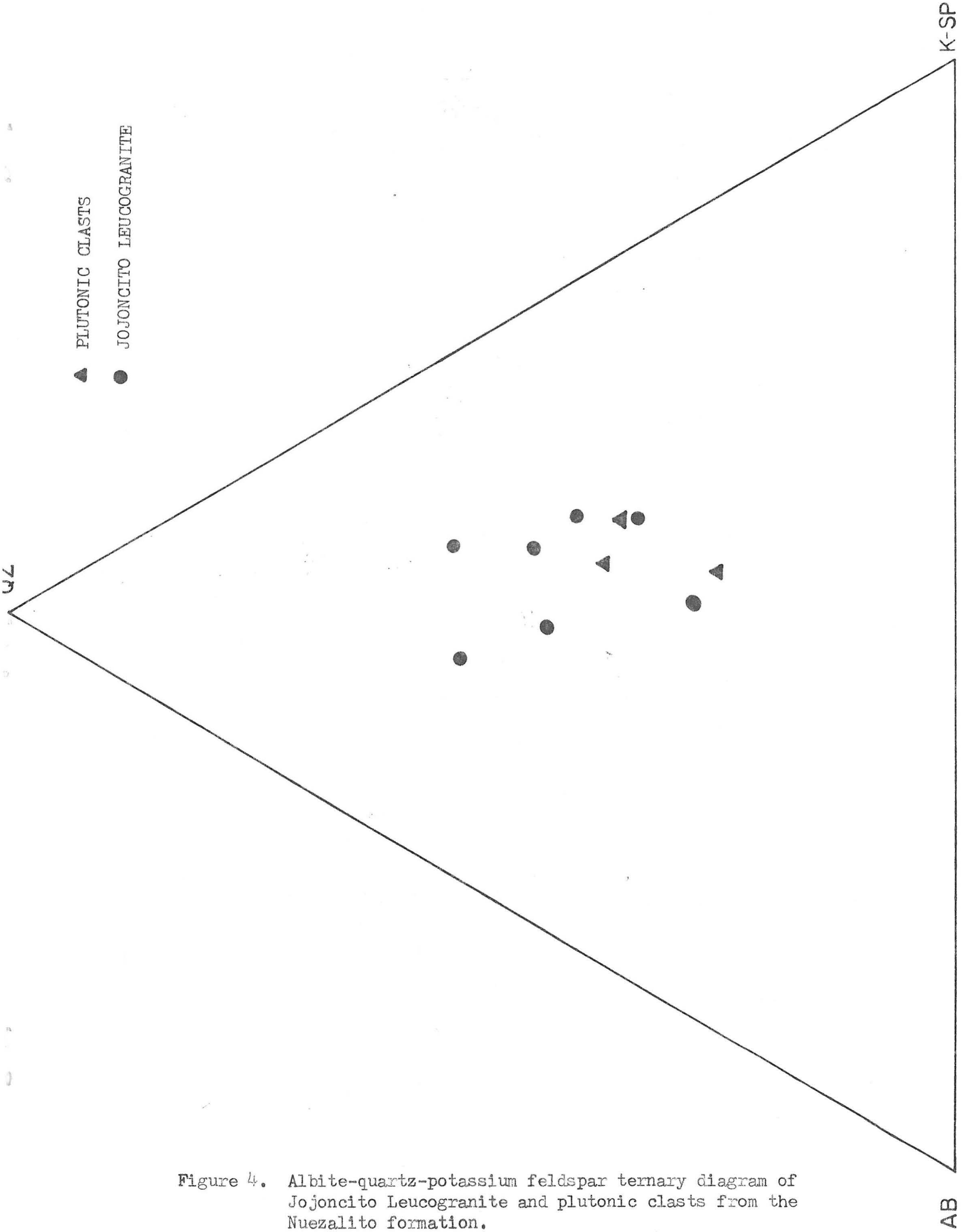


Figure 4. Albite-quartz-potassium feldspar ternary diagram of Jojoncito Leucogranite and plutonic clasts from the Nuezalito formation.

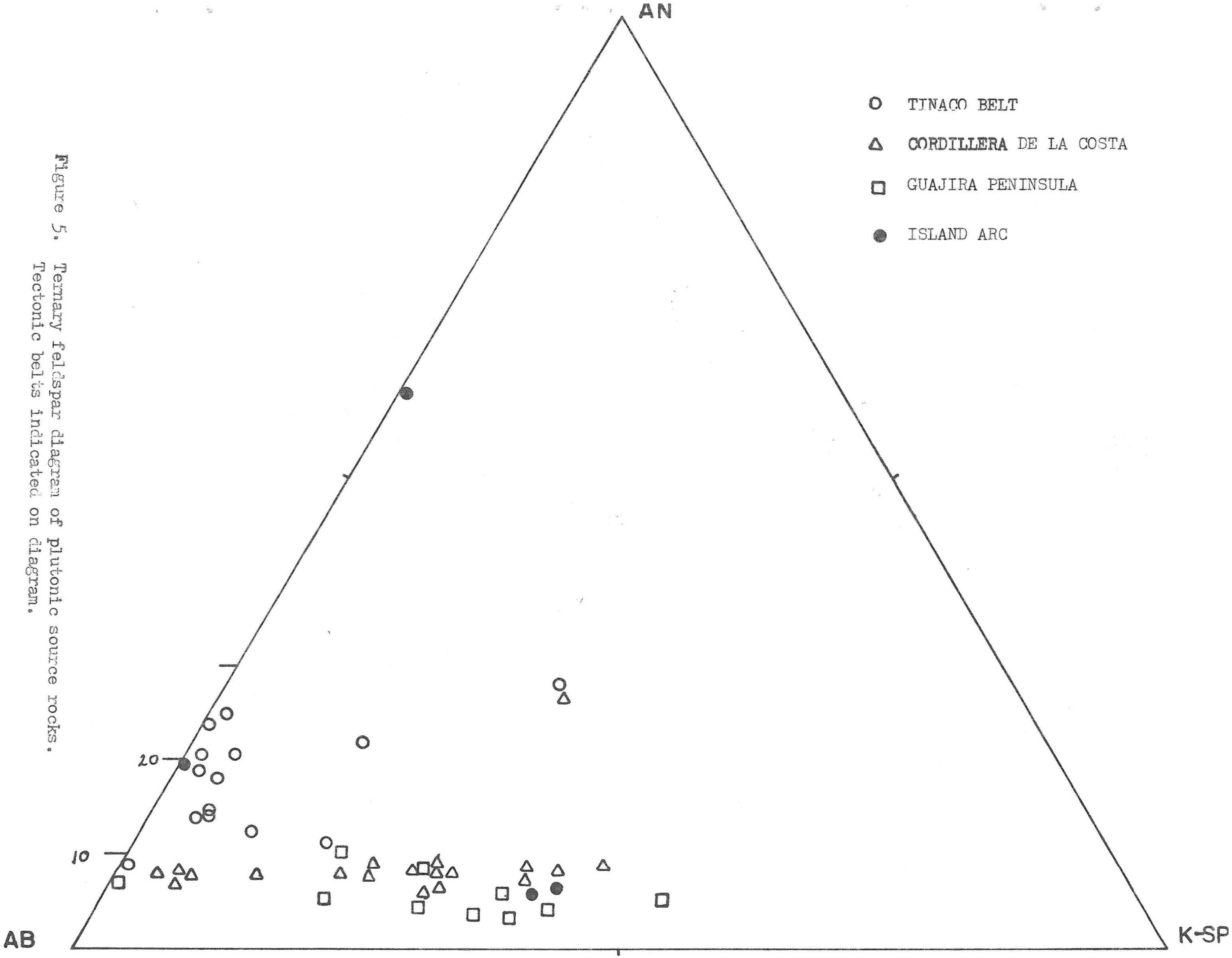


Figure 5. Ternary feldspar diagram of plutonic source rocks. Tectonic belts indicated on diagram.

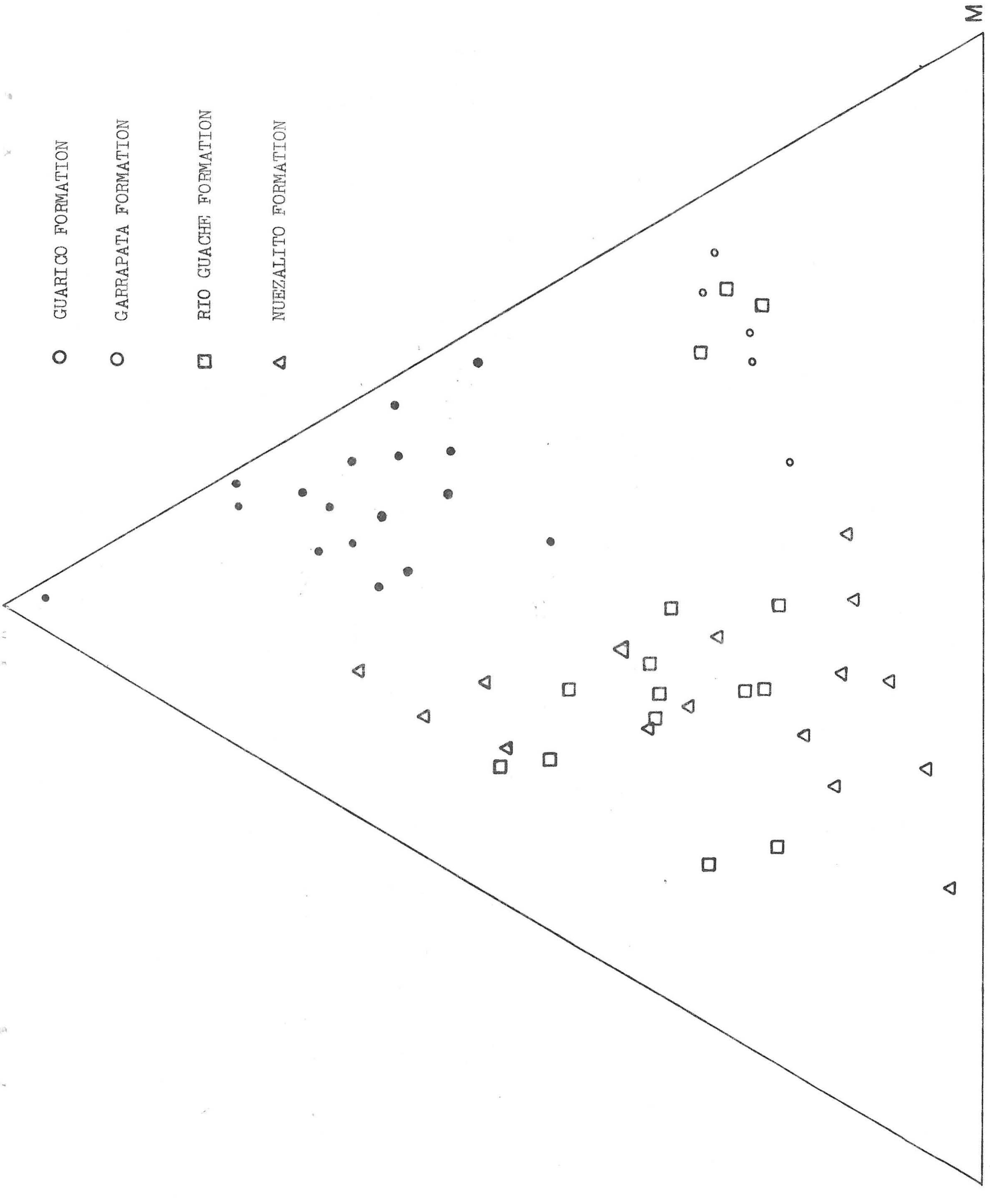


Figure 6. Ternary graywacke diagram for the Guarico, Garrapata Nuezalito and Rio Guache formations.

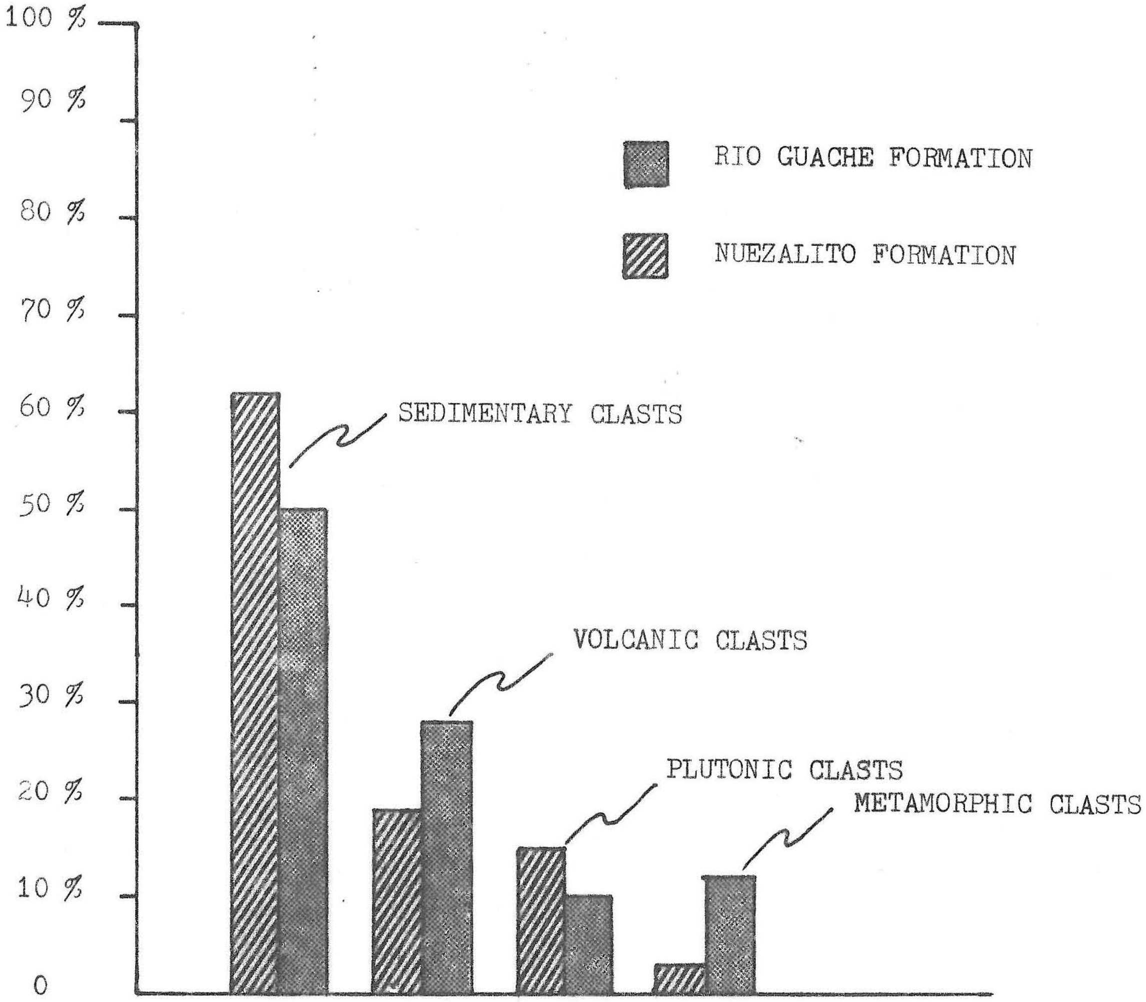


Figure 7. Histogram comparing relative percentages of sedimentary, volcanic, plutonic and metamorphic clasts in the Rio Guache and Nuezalito formations

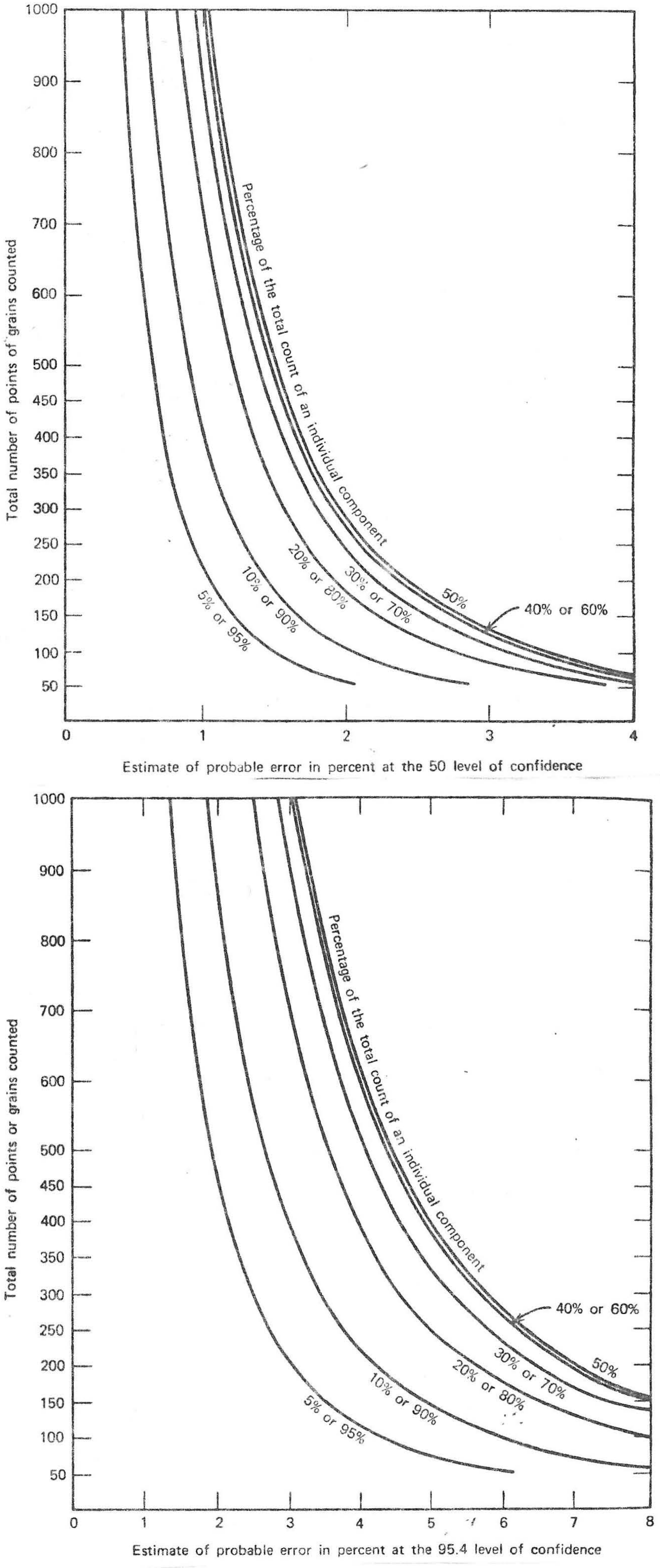

Total number of points of grains counted
1000
900
800
700
600
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
Estimate of probable error in percent at the 50 level of confidence
Percentage of the total count of an individual component
5% or 95%
10% or 90%
20% or 80%
30% or 70%
50%
40% or 60%
Total number of points or grains counted
1000
900
800
700
600
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Estimate of probable error in percent at the 95.4 level of confidence
Percentage of the total count of an individual component
40% or 60%
50%
30% or 70%
20% or 80%
10% or 90%
5% or 95%

Figure 8.

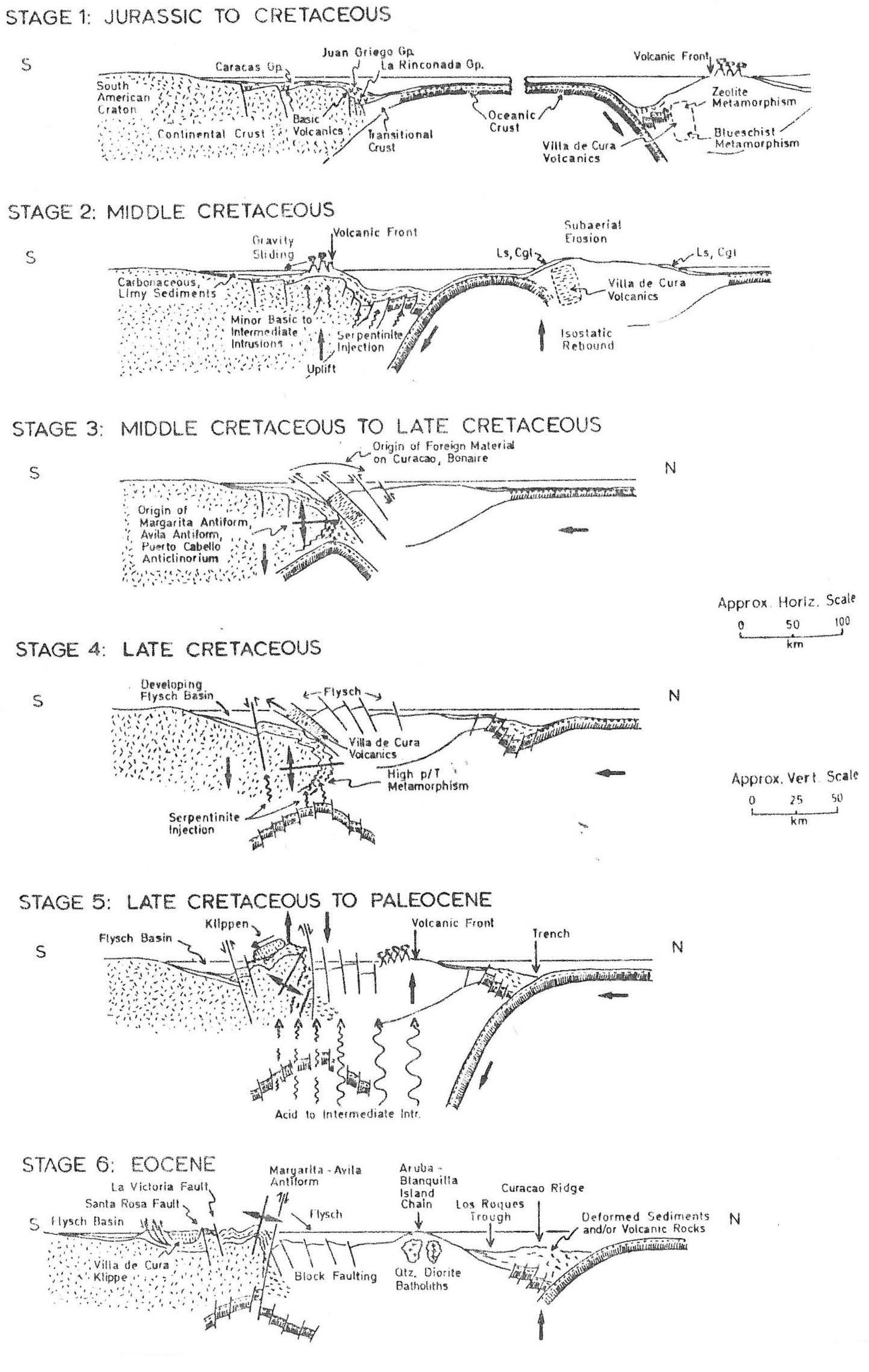


Figure 9. Cross sections illustrating development of subduction zones in the southern Caribbean. (from Maresch, 1974)

FORMATION	SL. NO.	Q	F	M
Nuezalito	831-B	30	43	26.5
Nuezalito	831-B	64	24	11
Nuezalito	831-B	57	37	6
Nuezalito	441	27.6	38	34
Nuezalito	441	37	35	27
Nuezalito	441	34	35	30
Rio Guache	587-A	34	56	9
Rio Guache	587-A	32	34	45
Rio Guache	587-A	47	49	6
Rio Guache	1513	35	47	16
Rio Guache	1513	36	31	32
Rio Guache	1579	46	50	5
Rio Guache	1579	49	39	11
Rio Guache	1579	46	37	17

Table I. Comparison of slides point counted in November, 1978 and March and April, 1979

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