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MAJOR, TRACE ELEMENT AND ISOTOPE GEOCHEMISTRY OF MAFIC-ULTRAMAFIC MASSIFS EMPLACED WITHIN THE GNEISSIC BASEMENT OF NORTHERN VENEZUELA: MANTLE-CRUST INTERACTIONS.

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ABSTRACT

Trace element and isotopic (Sr, Nd) studies carried-out on two mafic-ultramafic bodies (Apa, Todasana massifs) situated within the Caribbean chain of northern Venezuela had the following main objectives: 1) to contribute to the understanding of the development of an alpine type collision zone i.e. oceanic crust/continental crust; and 2) to attempt to understand the processes of fusion of the mantle and the interaction with the crust in the actual geodynamic environment.

The mafic-ultramafic Apa massif units constitute different levels of the same magma chamber. Geochemical data obtained from this massif display characteristics of island arc magmas. The evolution of Sr and Nd isotope compositions (through differentiation) is indicative of progressive contamination of the initial magma by crustal materials.

The basic Todasana massif corresponds to different stages of differentiation by fractional crystallization of an alkaline-type parent magma. Nd isotope compositions indicate a probable contamination trend between the basic and the continental materials.

These two mafic bodies are emplaced in the continental crust and as a result must have interacted at different levels with crustal materials.

KEYWORDS: **Mafic, Ultramafic, Caribbean chain, Mantle, Crust.**

INTRODUCTION.

This study was carried-out on two mafic-ultramafic massifs in the Tertiary Caribbean mountain system of northern Venezuela viz: the basic/ultrabasic Apa massif emplaced within the Villa de Cura tectonic belt, in the central part of the Caribbean belt and the basic Todasana massif situated within the Coast Range Tectonic belt (Fig. 1).

The Tertiary Caribbean mountain system of Venezuela represents a typical example of a collision zone mountain belt. It is composed of a succession of layers thrust southwards and structurally superimposed as follows.(Fig.2):- i) the Coast Range Tectonic belt. ii) the eclogites and peridotite bearing "Coastal Fringe-Margarita" Unit. iii) the Caucagua-El Tinaco tectonic belt. iv) the Ophiolite belt. e) the Villa de Cura Unit and, v) the foothills tectonic belt.

Contrary to intercontinental collision mountain systems, the Caribbean mountain system displays the presence of oceanic type materials (e.g. Ophiolite complexes) and extensive development of "external zones" with flysch and molasse facies and with the general occurrence of thrusting. This mountain system was formed as a result of the impingement of the Caribbean plate against that of South America and several models have been proposed for its development.
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Several authors favour an interpretation suggesting that the entire Caribbean mountain system formed as an E-W trending collision boundary between the Caribbean and the South American plates
(Piburn, 1967; Santamaria and Schubert, 1974), in disagreement with the palaeomagnetic model proposed by Skerlec and Hargraves, 1980; Stearns et al.,1982 suggesting that this belt resulted from a megatectonic rotation, during the lower Cretaceous times, of a once N-S trending arc/trench complex situated NW of South America.

It is well established that mountain systems result either from processes involving the interaction of ocean/continent, or continent/continent domains. These interaction processes are dynamos for crustal formation, as well as the consequent modification of its composition (DePaolo. 1980, 1985). The conditions underwhich these processes take place are essential to the understanding of crustal growth and mantle evolution.

Magma types are a reflection of the geodynamic environment under which they

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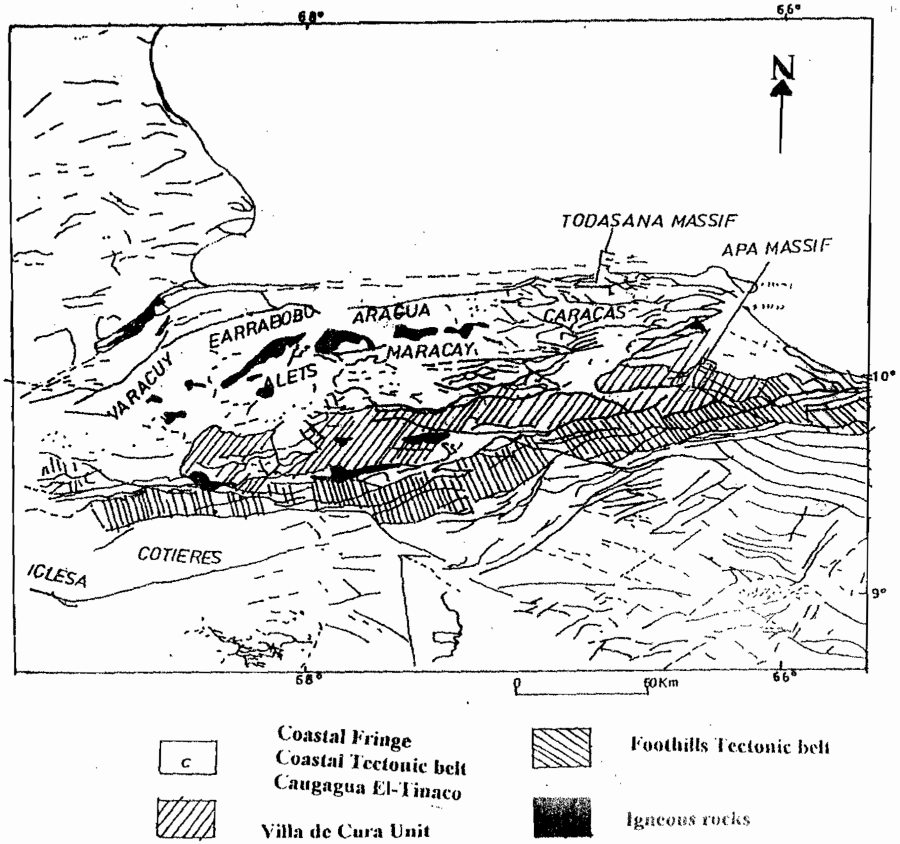

Fig.1 Geological and structural map of northern Venezuela showing the different lithostructural units and the locations of Apa and Todasana massifs studied. (Source: Mapa base tomado del mapa fisico. Republica de Venezuela sexta edicion 1957).

develope. The main aims of this study are: (1) to put constraints, on the geodynamical development of the Caribbean chain of Venezuela based on geochemical characteristics. It is known that magmatism associated, for example, with mid-oceanic ridges, hot spots, subduction and intracontinental zones, each display distinct characteristics. (2) to study the evolution of mantle magmas and their interactions with the continental crust, in the geodynamic environment of the formation of a mountain system resulting from ocean/continent collision processes. From field and structural studies the general geology of this mountain chain is already well established, but its development with time remains a major problem to tackle. However, one Sm-Nd date on garnet separates realised in one of our previous works (Lar et al., 1998) suggests an age of formation of about 100Ma.

GENERAL GEOLOGICAL SETTING.

(i) The Apa Massif.

The Apa massif is an ultramafic intrusive within the Villa de Cura unit which is one of the main tectonic units of the Caribbean chain of Venezuela (fig.1). The Villa de Cura unit has been subject to several studies by many authors (e.g. Shagam, 1960. Piburn, 1967). It outcrops in the central part of the Caribbean chain and is composed of 4 to 5 km of an allochthonous sequence of metavolcanics interlayered with metasedimentary rocks. The sequence has been metamorphosed mainly under low temperature conditions but also at high temperature (Piburn 1967). Schists bearing glaucophane indicating metamorphism of blueschist facies are also present. The latter series being intruded by number of ultramafic complexes (Chacaco, Ap etc) which are not completely metamorphosed.

Volcanic rocks are represented b keratophyres and spilites (Shagam, 1960 Piburn 1967). Murray (1972, a,b) noted the similarities between this series with those o tholeiitic arcs reported by Jakes and Gill, (1970 and the andesitic affinity of rocks of south Tiar which conformably overlie the Villa de Cur group. Murray (op.cit) suggested that volcani rocks of Tiara may well represent an extrusiv suite genetically linked to ultrabasic complexe

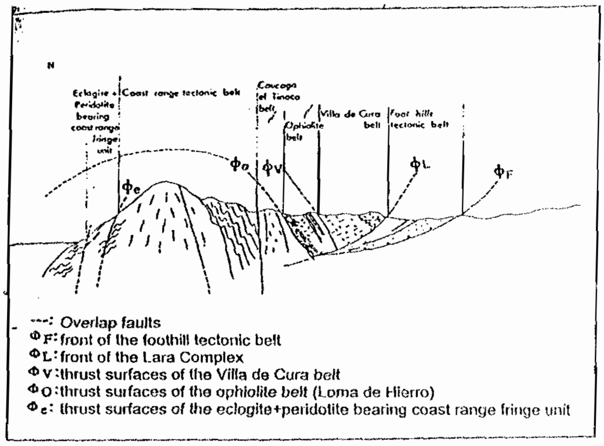

Fig.2 Cross-section N-S of the Caribbean chain of Venezuela showing the different geological units (After Stephan et al, 1980).

within the Villa de Cura belt. From the geochemical data (Ti, Cr, Zr) (Loubet et al., 1985), the rocks of Villa de Cura exhibit characteristics typical of calc-alkaline series. Certain authors (Oxburgh, 1966, Harvey, 1971 and Murray, 1972a&b) are of the view that the Villa de Cura unit is a pre-Cretaceous Basement. Others (Menendez, (1962) (1967), Piburn, 1967, Maresch, (1974), Bellizzia (1972) (1977) and Skerlec, (1974), (1979), (1980) consider this unit as an allochthonous mass (a fragment of oceanic crust (or an arc) derived from the northern end of the present continental margin during the upper Cretaceous to Palaeocene and itself overlies the metasedimentary series of the Coast Range Tectonic belt. The latter hypothesis is largely accepted today, although, the exact position of the Villa de Cura unit within the Mesozoic reconstruction is still debatable. The Apa massif, like several of the ultramafic massifs intrusive into the Villa de Cura unit, is zoned, and outcrops over 48 km^2 separated into two portions by a narrow band of the host metamorphic rocks. In each portion, there is a variation of mineralogic compositions (from the interior of the massif towards the exterior from olivine pyroxenite, to hornblendites) accompanied by a progressive increase in Fe/Mg ratios.

The ultrabasic rocks are cross-cut by intrusions and gabbroic dykes (with hornblende and 2-pyroxenes), that are either within or at the extremity of the ultrabasic intrusion (Murray, 1973).

(ii) *The Todasana massif.*

The basic massif of Todasana is situated in the Coast Range Tectonic belt. It is a complex structure consisting of an association of structurally concordant rocks:- (1) metasedimentary (2) metamorphosed volcanoclastics (3) metaigneous of different sources formed in various environments. (4) gneissic granitic rocks (Talukalar and Louriero, 1982). The metasedimentary rocks include, pelitic A K-Ar age obtained from an amphibole extracted from the amphibolite Tod26 (Sagna, 1990 unpublished), indicates a Cretaceous age of metamorphism (110 ± 32Ma). Recent ages of 20 to 25 Ma (Sagna, 1990 unpublished) have also been obtained from mica separates from samples Tod24, Tod26 and

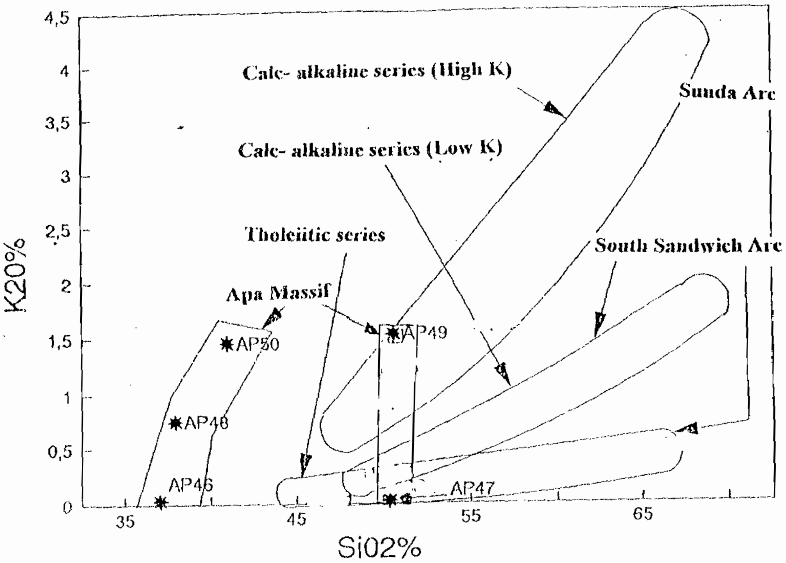

Fig.3 Evolution diagram (K_2O% Versus SiO_2%) of Island arc volcanic suites. (Source of data: Luff, 1982, Foden, 1983) AP=Samples from the Apa massif.

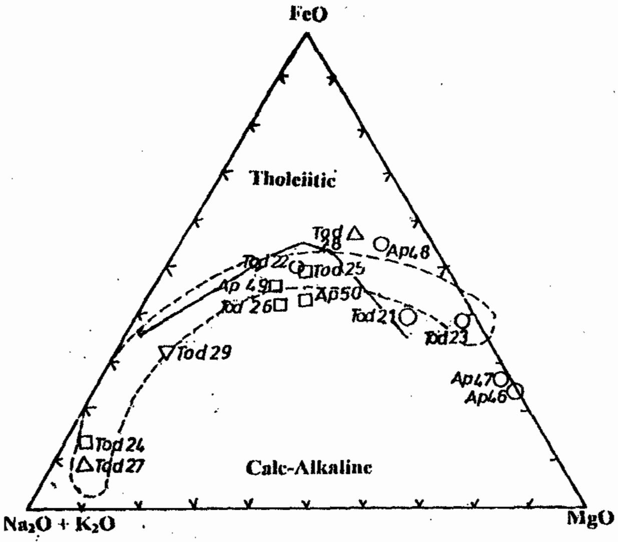

Fig.4 AFM diagram of rock samples from the Apa and Todasana massifs.

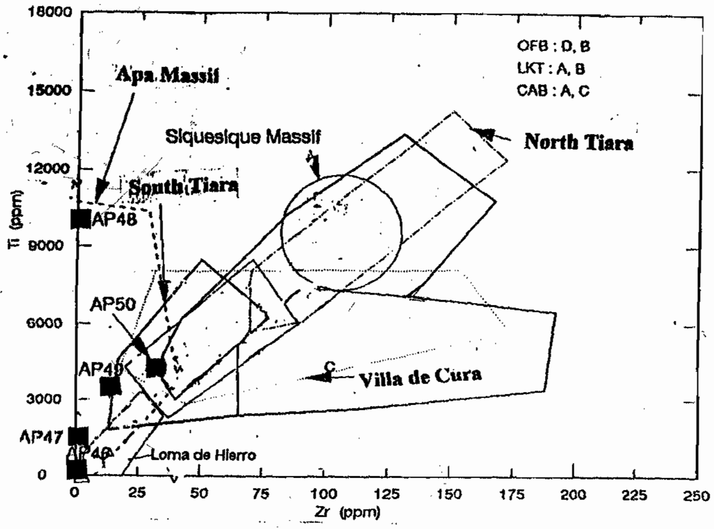

Fig.5 Ti, Zr compositions of rocks from the Apa massif compared with those of other massifs within the Caribbean chain. (Source of data:- Loubet et al, 1985) AP: Rock samples from Apa massif.

Tod27 indicating more recent tectonic and thermal phases.

The gnessic-granitic rocks are granitic intrusions of a remobilised basement. These intrusions are relatively ancient (the Sebastopol complex 420Ma; Hurley and Hess, 1972 and the granite of Guaremal 403Ma (Urbani, 1983)).

Talukdar and Louriero, (1982) proposed a genetic model attributing the origin of all the basic formations to a period prior to the Cretaceous orogenesis.

PETROGRAPHIC DESCRIPTION OF SAMPLES STUDIED.

(i) Apa Massif.

The various rocks sampled present the following characteristics:-

Ap46: **Peridotites** (lherzolite to harzburgite) are equigranular in texture, composed of olivine, orthopyroxene and clinopyroxene, spinel, amphiboles are abundant.

Ap47: **Wehrlite**. It is of a granular texture composed essentially of clinopyroxene, orthopyroxene and interstitial olivine.

Ap48: **Hornblendite.** It occurs with green hornblende, interstitial orthopyroxene and rare opaque and sphene.

Ap49: **Altered/Amphibolised Gabbro**. It is of doleritic texture, composed of plagioclase, clinopyroxene, green hornblende, opaques and apatite.

Ap50: **Pegmatitic gabbro** of granular to coarse grained. Though altered, it is composed of plagioclase, green hornblende and opaques

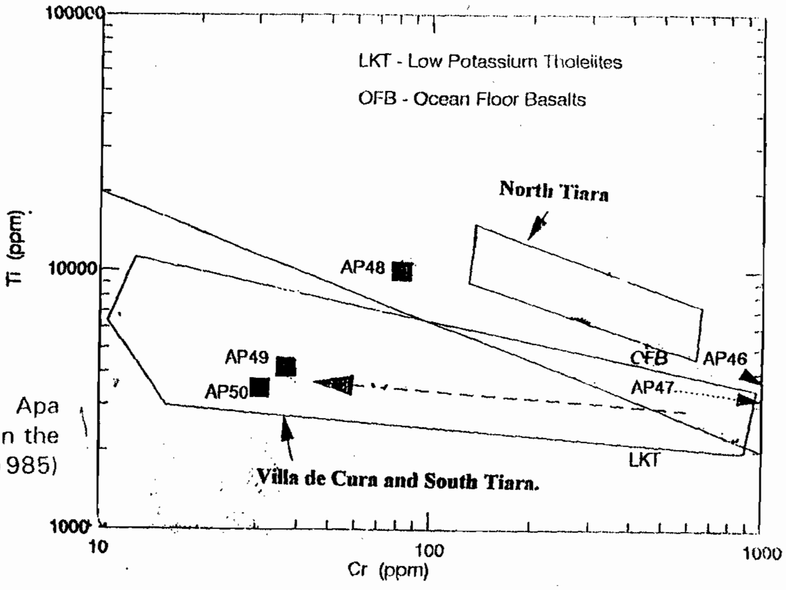

Fig. 6 Ti, Cr compositions of rocks from the Apa massif compared with those of other series within the Caribbean chain. (Source of data:-Loubet et al, 1985) AP: Rock samples from Apa massif.

(ii) Basic Todasana Massif

A series of rocks representative of the diverse lithologic units in the Coast Range Tectonic belt were studied. The samples were collected at the southern extremity of the Todasana massif . These rocks include: A metasedimentary rock composed essentially of green hornblende, few interstitial plagioclase and opaques. (Tod24); five rocks from the basic complex composed of hornblendite (Tod21, Tod23); two Gabbros (Tod26, Tod29), and two amphibolites (Tod26,Tod28); an augen gneiss (Tod27) and a volcanic rock representing a post-tectonic dyke cross-cutting the previous series (Tod25).

Tod21 : **Garnet bearing hornblendite** essentially composed of brown hornblende, pyroxene, plagioclase and accessory minerals such as spinel; biotite, zircon, opaques.
Tod22 : **Amphibole gabbro** characterised by the presence of hornblende, biotite and plagioclase. The accessory minerals are opaques and fine calcite veins.
Tod23 : **Hornblendite** composed principally of chloritised hornblende and some plagioclases and biotite.
Tod24 : Fine grained **metasedimentatry rock**, essentially composed of muscovite, orthoclase, quartz, epidote and rare biotite.
Tod25: **Volcanic rock** essentially composed of plagioclase (Oligoclase-Andesine)
Tod26: **Amphibolite** with a low quantity of garnet. It is composed principally of hornblende, biotite and sodic plagioclase with accessory opaques.
Tod27: **Augen gneiss** composed of quartz, plagioclase, microcline, biotite muscovite, hornblende, epidote, opaque and zircon.
Tod 28: **Hornblendite** without garnet. It is
Tod 29: **Gabbro** composed of orthoclase, biotite, clinopyroxene, abundant apatite, sphene and opaques

ANALYTICAL TECHNIQUES

The major elements, (except for Na and K), were measured by X-Ray Fluorescence (XRF) on a Siemens X-ray Spectrometer in the Toulouse University Petrological laboratory using fused pellets with the classical heavy absorber method. Na and K were analysed by flame spectrometry at the Geochemical Laboratory of Toulouse University (GLTU). Volatile elements were determined by loss on ignition at 1000°C. Analytical accuracy (and precision) is considered to be better than 2% XRF spectrometry using pressed powder pellets (with a 10% weight binder) was used to analyze certain trace elements (Ti, V, Cr, Co, Ni, Nb, Zr). Matrix, instrumentation as well as interference and enhancement effects were corrected by methods developed by Bougault, et al., (1977). Selected international rock standards (Nancy CRPG standards) were used for calibration. Analytical accuracy for trace elements other than Nb was within 5% to 10% for concentrations higher than 20 ppm. This accuracy was (2 ppm at lower concentrations.

REE, Rb, Sr, and Ba concentrations were measured by isotope dilution at the GLTU on a modified CAMECA THN 206 MASS SPECTROMETER. Accuracy for these analyses was estimated at approximately 2%. Chemical separation of the elements was carried out on a AG 50 W (200-400 mesh) cationic ion exchange column. Sr was separated from Ca using ammonium citrate as a complexing agent (Birck and Allegre, 1978). REE were separated for mass spectrometry in three fractions on a HDEHP (Di(2ethylhexyl) orthophosphoric acid) column (Richard et al, 1976).

Sr isotopic composition measurements were performed on a Finnigan 261 automatic multicollector mass spectrometer at the GLTU. NES 987 Standard was measured with a $^{87}Sr/^{86}Sr$ ratio of 0.71020 (0.00002 (2σ N). Mass discrimination effect was corrected by normalizing the $^{88}Sr/^{86}Sr$ ratio to a value of 8.375209.

RESULTS/DISCUSSION

(i) Apa Massif.

Major and Trace element compositions are presented in Table 1.

(a) Major elements

It is usual to distinguish within Island Arc chains volcanic suites varying from tholeitic to calc-alkaline character. The AFM and K_20% versus $Si0_2$% diagrams are here utilised to distinguish these characters. In the diagram K_20% versus $Si0_2$% (fig.3), four of the samples plotted out of the domain of the different magma series: Ap46 Ap48 and Ap 50. In addition to these samples is Ap47 as observed in the AFM diagram (fig.4). This suggests that, these samples (Ap46, Ap47, Ap48 and Ap50) represent cumulates. Only sample Ap49 falls within the domain of magmas characteristic of calc-alkaline magma in both diagrams.

(b) Trace elements

It is usual to use the concentrations of incompatible elements and elements of immobile character (Ti, Cr) (Ti, Zr), to differentiate

Table.1 Major (%) and Trace (in ppm) composition of rock samples studied from Apa and Todasana massifs. (Major and trace elements:- Analysis by XRF; Ba and REE:- Analysis by mass spectrometer by isotope dilution).

Samples	AP46	AP47	AP48	AP49	AP50	Tod21	Tod22	Tod23	Tod24	Tod25	Tod26	Tod27	Tod28	Tod29
Si02	37.12	50.48	37.95	50.52	40.94	43,66	49,37	51,18	75,84	46,03	48,79	78,89	49,80	56,50
Al203	0.46	2.93	12.43	17.93	24.53	12,47	18,61	4,69	12,74	16,33	16,17	10,88	12,70	18,10
Fe203	10.01	6.85	18.89	8.54	6.17	13,07	9,48	12,87	1,34	11,63	10,93	0,97	14,40	6,10
Mn0	0.21	0.13	0.16	0.17	0.13	0,18	0,12	0,25	0,03	0,18	0,18	0,04	0,26	0,10
Mg0	41.56	17.88	11.18	3.53	3.63	14,43	4,14	17,64	0,32	5,43	5,65	0,67	6,80	1,40
Ca0	1.28	20.43	11.85	9.31	14.8	8,51	9,13	8,39	1,17	10,32	6,09	0,80	9,90	3,70
Na20	0.09	0.26	1.86	4.06	2.34	3,02	3,71	0,79	3,56	4,49	5,44	3,31	2,90	7,20
K20	0.03	0.02	0.75	1.53	1.45	0,74	0,88	0,14	3,70	1,17	2,13	4,55	0,09	3,10
Ti02	0.05	0.24	1.67	0.7	0.58	1,60	1,00	0,40	0,18	1,70	1,69	0,11	1,80	1,24
P205	0.02	0.02	0.05	0.17	0.05	0,17	0,20	0,02	0,03	0,24	0,24	0,04	0,16	0,39
H20	3.34	1.2	1.4	2.1	3.8	0,28	0,94	1,94	0.9	0,56	0,96	0,50	0,75	1,00
Total	98.17	100.4	98.19	98.65	9840	98,13	97,58	98,31	99,80	98,07	98,27	100,76	99,70	98,83
Rb	<1	<1	72	19	<1	38	25	1	99	9	25	145	<1	18
Nb	2	1	2	1	1	17	12	4	7	25	34	17	7	32
Sr	9	45	277	570	1076	434	442	30	379	640	737	90	84	908
Zr	1	1	1	33	14	144	132	24	143	173	225	87	98	137
Y	4	8	1	29	20	12	42	23	17	34	32	35	38	22
V	35	133	921	317	196	214	222	204	16	415	252	22	471	10
Co	171	48	89	19	14	73	23	86	3	31	31	4	57	4
Ni	967	151	43	3	11	354	14	242	1	37	71	3	51	1
Cr	1444	1212	82	37	31	684	47	810	10	100	186	11	162	3
Cu	1	1	238	54	1	93	80	102	1	51	4	1		
Zn	70	31	64	87	53	76	71	103	32	86	79	33	38	17
Ba	1.66	12.63	118.9	498	194.2									
La	0.09	0.65	1.3	12.12	3.56									
Ce	0.21	1.66	6.12	22.25	8.85									
Nd	0.21	2.28	6.76	17.59	7.37									
Sm	0.07	0.88	2.5	4.05	2.05									
Eu	0.02	0.3	0.89	1.47	0.91									
Gd	0.09	1.06	3.49	4.8	2.3									
Dy	0.09	0.84	2.18	3.75	1.77									
Er	0.05	0.43	1.46	1.98	1.09									
Yb	0.05	0.33	1.13	2.07	0.92									
Lu		0.04												

Table.2 Nd-Sr isotopic compositions and Ba, Sr contents of rock samples from Apa massif. (Analysis by Isotope dilution).

Sample	Rb(ppm)	Sr(ppm)	87Rb/86Sr	87Sr/86Sr	2Sigma	ƐSr(0)	Sm(ppm)	Nd(ppm)	147Sm/144Nd	143Nd/144Nd	2SIGMA	ƐNd(0)
AP46-Dunite	0,14	5,65	0,07422	0,703358	0,000013	-17.03	0.07	0.21	0.1939	0.513012	0.000015	7.3
AP47-Werhlite	0,15	43,99	0,00994	0,704350	0,000030	-2.13	0.88	2.28	0.2316	0.512978	0.000013	6.63
AP48-Hornblendite	72,00	285,25	0,72987	0,703553	0,000025	-13.44	2.50	6.79	0.2226	0.513030	0.000013	7.65
AP49-Hornblende Gabbro	19,00	590,52	0,09309	0.703794	0,000030	-10.02	4.05	17.58	0.1391	0.512894	0.000009	4.99
AP50-Pegmatitic Gabbro	0,73	1167,00	0,00180	0,703524	0,000033	-13.85	2.05	7.37	0.1681	0.512985	0.000010	6.73

Table.3 $^{143}Nd/^{144}Nd$, $^{87}Sr/^{86}Sr$ isotopic compositions and Rb-Sr concentrations of rocks from the Todasana basic massif. (Analysis by Isotopic dilution).

Sample	143Nd/144Nd	2Sigma	Nd(0)	Rb(ppm)	Sr(ppm)	87Rb/86Sr	87Sr/86Sr	2Sigma	ƐSr(0)
Tod21(Hornblendite)	0,512708	0,000027	1,37	38	492.18	0.223	0,702947	0,000028	-2204
Tod22(Gabbro)	0,512035	0,000021	-11.76	21.89	371.17	0.171	0.713743	2.2E-05	131.19
Tod23(Hornblendite)	0,511767	0,000019	-16.99	1.57	26.45	0.172	0.712974	1.7E-05	120.28
Tod24(Sedimentary rock)	0,511701	0,000036	-18.27	99	443.39	0.647	0.724881	2.7E-05	289.29
Tod25(Andesite)	0,512775	0,000008	1,62	9	640	0.041	0.702988	1.6E-05	-21.46
Tod26(Amphibolite)	0,512668	0,000030	0.59	25	747	0.097	0.70477	1.5E-05	3.8325
Tod27(Augen gneiss)	0,512642	0,000011	0.08	145	124	3.396	0.746193	0.00001	5918
Tod28(Amphibolite)	0,513062	0,000010	8,27	0.62	80.66	0.022	0.706134	0.000008	23.193
Tod29(Gabbro)	0,512634	0,000009	-0.08	16.57	928.48	0.052	0.702993	0.000008	-2139

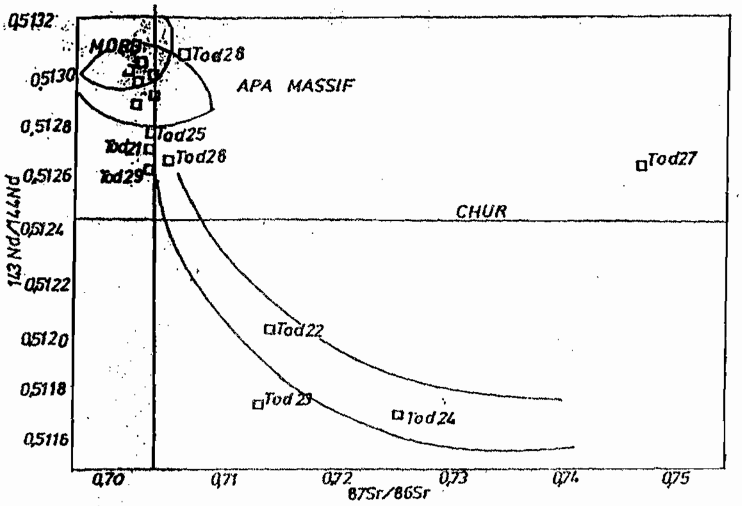

Fig.7 Nd-Sr correlation diagram of the different rocks studied from the Apa and Todasana massifs. CHUR - Chondritic Uniform Reservoir)

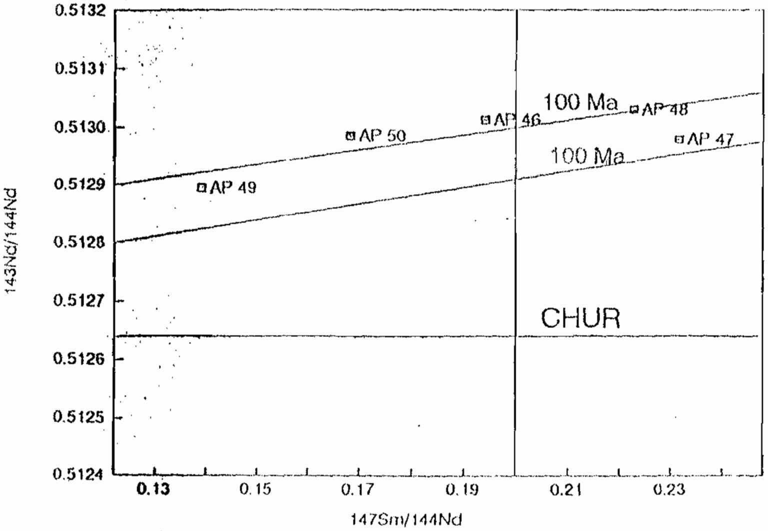

Fig.8 Nd-Sm isochron diagram of the different rock samples studied from the Apa massif. CHUR Chondritic Uniform Reservoir)

different types of magmas (tholeitic, calc-alkaline) (Pearce and Cann, 1973; Floyd and Winchester, 1975) The data from Apa massif in (fig.5 & 6) supports the previous conclusion in (a) above. In the Ti - Zr plot (fig.5), many samples fall outside the domain for magmas. A typical case is that of sample Ap 48 which contains a noticeable proportion of amphiboles. This explains the high Ti concentration in this sample and which supports its cumulate nature.

(c) Nd-Sr Isotopic Compositions.

Nd and Sr isotopic compositions of the analysed samples are presented in Tables.2 and 3 and exhibit the following characteristics: Their Nd isotopic compositions cover a relatively narrow range between 5 and 7.3. In the ((Nd - Sr) diagram (fig.7), three of the samples fall at the lower limit of the MORB field. Two other samples (Ap47, Ap49) fall slightly out of the MORB field. Nevertheless, these compositions fall within the range of subduction zone magmas. The Nd isotopic composition of rocks of Apa massif were also plotted in an isochron diagram (fig. 8). Considering an age of formation of these rocks about 100 Ma (Lar,1991 ' unpublished), there are noticeable variations in their initial compositions. It is worth noting that Ap49 originally considered to represent a magma falls within the range of compositions of other rocks interpreted as representative of cumulates. This character further supports a process of Assimilation during Fractional Crystallisation (AFC) i.e. the process of assimilation and contamination of magmas by crustal materials during differentiation (by

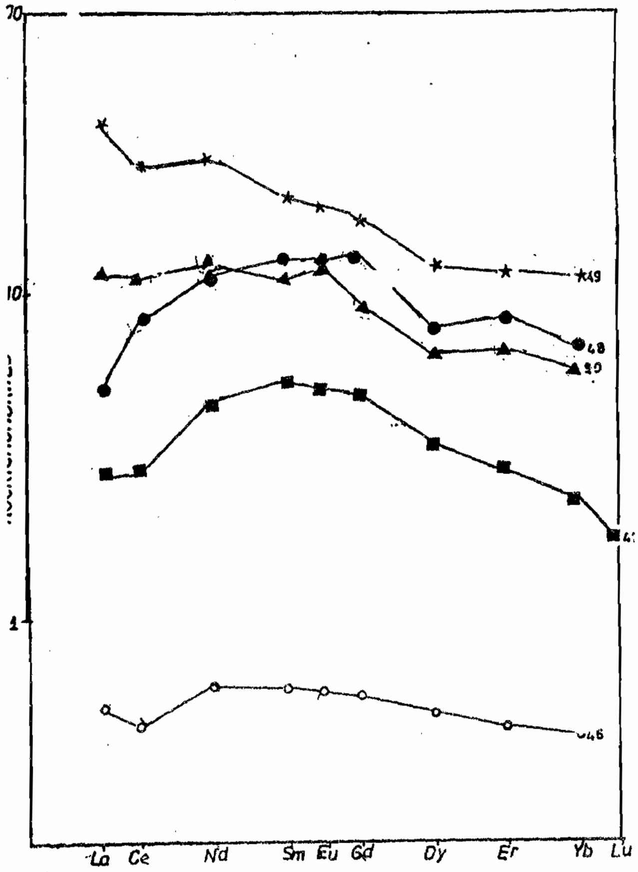

Fig.9 Chondrite normalized REE spectra of the diverse rocks from the Apa massif.

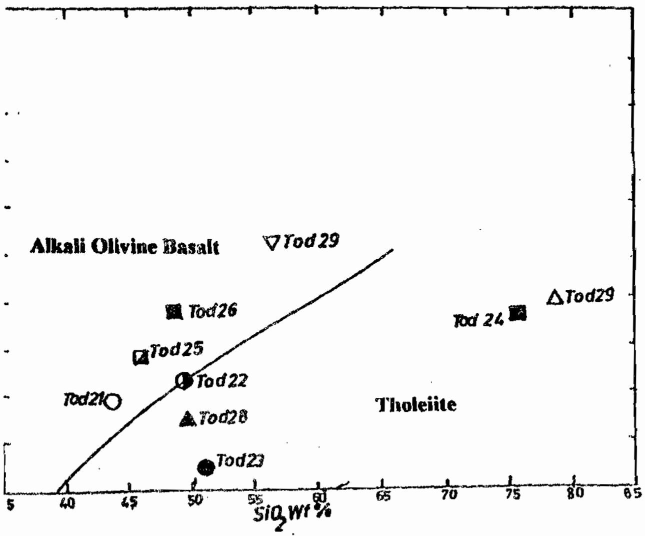

Fig.10. Na_2O Versus K_2O/SiO_2 diagram for rocks from the Todasana basic massif.

actional crystallisation) in a magma chamber. his contamination of magmas could be a result f the assimilation of the surrounding rocks of ıe magma chamber during magmatic ifferentiation. It is a phenomenon that has een reported from similar diverse sites such as Kiglapait (Labrador), Depaolo, (1980), (1985); Rhum (Scotland), Palacz (1985), Palacz and Tait, (1985); Skaergaard: Stewart et al., (1990).

(d) Rare Earth Element (REE) Compositions.

REE spectra normalised to chondrites of the rocks studied (fig.9) clearly show a large range of concentrations from 0.5 X chondrites to 30 X chondrites. However, these spectra have common characteristics: a progressive enrichment in LREE, with an inflexion of the curve at Sm and Nd with a significant depletion of Ce and finally an enrichment of La relative to Ce. These REE spectra show clearly that they are representative of materials derived from the same source. Three of the samples exhibit characteristics typical of cumulates: The spectrum of Ap50 shows a positive anomaly in Eu indicative of plagioclase crystallisation. The hornblendite Ap48 has a spectrum very impoverished in LREE similar to that attained by sample Ap46 (a cumulate with high amphibole).

As regards the other two rocks Ap47 and Ap46, because of their very low REE concentrations they cannot be considered as magmas. They therefore represent cumulates. The similarity of these two spectra could indicate:- either a process of impregnation by a magmatic fluid or a control of fractionation of REE by a major phase during crystallisation (amphibole).

In the first case (process of impregnation), it is reasonable to think that there must have been a certain evolution of REE spectra of these magmas during differentiation where there was a remarkable enrichment of LREE relative to HREE as the differentiation progressed. Such an evolution could also be compatible with AFC process.

The inflexion of REE spectra at the level of LREE with a significant enrichment at the level of La is a character that has been found in a number of magmas from subduction zones. This enrichment is also found in boninites which are equaly considered to have been formed in a geodynamic environment of subduction. This enrichment is attributed either to contamination by sediments or to an introduction of fluids (Hickey and Frey, 1981, Pearce, 1983). Finally, this enrichment in La could be considered as a typical characteristic of a magma formed in a subduction zone.

(ii) The basic Todasana massif.

Analyses were carried-out for major, minor elements and Nd and Sr isotope compositions. Results of these analyses are presented in Tables (1, 2 and 3) and then plotted in diverse geochemical diagrams (1)

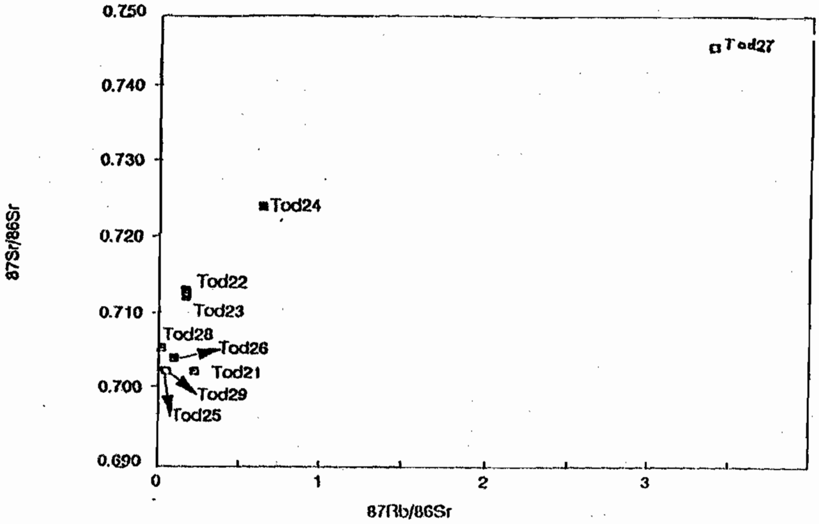

Fig.11 $^{87}Sr/^{86}Sr$ versus $^{143}Nd/^{144}Nd$ isotopic compositions of the different rocks from the basic Todasana massif.

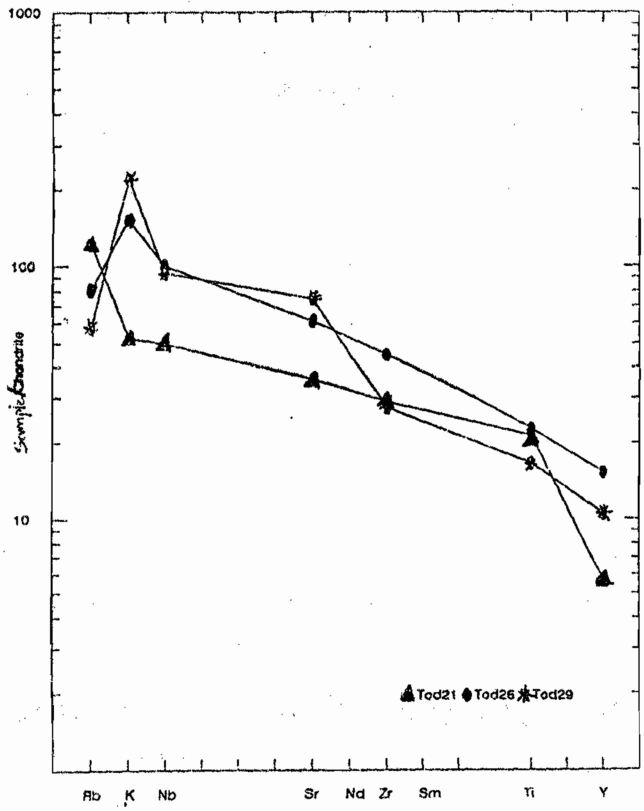

Fig 12. Generalized REE representation of samples Tod21, 26 and 29 representative of magma (s).

major elements diagram (AFM) (Fig.4); (2) $Na_2O\% + K_2O\%$ versus $SiO_2\%$ diagram (Fig.10); (3) Isotopic composition $^{87}Sr/^{86}Sr$; $^{143}Nd/^{144}Nd$ (Fig.7); (5) Isochron diagram ($^{87}Rb/^{86}Sr$; $^{87}Sr/^{86}Sr$) (Fig.11).

The geochemical characteristics of the samples studied are as follow:

(a) Metasedimentary rock (Tod24)

The geochemical characteristics of this rock clearly supports its sedimentary origin: high SiO_2 content (75.84 (Fig.11), low Sm/Nd ratio (Fig.12), low Nd isotopic composition ($^{143}Nd/^{144}Nd$ = 0.5117) and high Sr ratio ($^{87}Sr/^{86}Sr$ = 0.7249) suggestion a rock of crustal origin (Fig.8).

(b) Amphibolite-Hornblende Series Tod28:

As observed in the AFM (Fig.4) and $SiO_2\%$ versus $Na_2O\%$ + $K_2O\%$ (Fig. 10) diagrams and the composition in Ti and Cr, this rock exhibits tholeitic character that distinguishes it from the other members of the series. In the representation ($^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$) (Fig.7), this rock exhibits Nd and Sr isotopic compositions typical of MORB.

(c) Tod21, Tod26,Tod29 (Hornblendite-Gabbro)

These rocks present similar geochemical characteristics suggesting that they are cogenetic:- similar Nd isotopic composition and similar normalised trace elements spectra (Rb, K,Nb,Sr Zr,Sm,Ti,Y).

In respect of trace elements, there is a progressive enrichment of the slightly incompatible elements to the most compatible ones. In the $Na_2O\% + K_2O\%$ versus $SiO_2\%$ diagram (fig.10) these rocks fall at the upper portion enriched in Na_2O and K_2O. They have very high Ti content. All these characteristics are indicative of magmas of alkaline basalts.

There is a noticeable evolution in composition from Tod21 to Tod26 and then to Tod29. This compositional evolution could be of two origins:- either they correspond to distinct primary magmas. i.e. compositional variations induced by fusion processes or either they correspond to products resulting from different stages of differentiation by fractional crystallisation of the same magma. However, the latter hypothesis is more plausible.

Considering the first hypothesis, where these rocks are considered to have been formed from distinct primary magmas, their Nd compositions, on the contrary, indicate that they must have resulted from fusion of the same source. Equally, their incompatible element ratios suggest that they must have been formed at a low percentage of fusion. Under these conditions, such products of fusion should exhibit a narrow range in major element composition. The law of trace element variations indicates that during partial melting, primary magma should equally exhibit similar tenors in compatible elements (Arth, 1976). The large range of major element compositions (SiO_2%: 44 to 56.5%, CaO% 8.5 to 3.30% and minor elements (compatible (Ni = 350pm to 71pm then 1pm. Cr = 684 to 186 then 3 ppm. are incompatible with a fusion process. On the other hand, the process of differentiation by fractional crystallization could induce some significant variations in major element composition as well as compatible and relatively incompatible element ratios.

(d) Tod22, Tod23 (Hornblendite- Amphibole Gabbro)

In view of the similarities of these two rocks, they have been grouped as one. They exhibit very close Nd and Sr isotope compositions (Tables 2 and 3). The position of Tod23 in the AFM diagram clearly indicates it is a cumulate. Its negative Sr anomaly coupled with a high Cr tenor are in conformity with its culmulate nature. The cumulate, according to the generalised REE data, crystallised from a magma rich in incompatible elements and rich in LREE relative to HREE. Such a magma could be of the same origin as Tod22. As regards the origin of these rocks, two hypotheses could be proposed:- these two rocks could be considered as resulting from a magma different from the previous amphibolitic group. Their very low Nd compositions (Tod22 = 0.512035; Tod23 = 0.511767) are indicative of an ancient time of formation of these rocks and could correspond to geological formations associated with the Basement of the Cordillera or as being issued from the same magma as that of the previous series (Lar, 1991 unpublished Thesis). The difference in composition with the previous rocks could then be explained by the fact that they must have undergone deep transformation giving rise to an important interaction with the Basement during their emplacement or later.

In respect of major element data, Tod22 presents close similarities with Tod26 and more especially Tod25 (Fig.10 and Table. 1). Thin section study of sample Tod21 reveals the presence of biotite and calcite veinlets. It is known that the formation of biotite is often accompanied by Sr remobilisation especially in granulite complexes. (Mattson and Seyler, 1989). In the isochron diagrams $^{147}Sm/^{144}Nd$; $^{143}Nd/^{144}Nd$) and ($^{87}Sr/^{86}Sr$; $^{87}Rb/^{86}Sr$), it is observed that samples Tod22 and Tod23 fall on a mixing trend between the rocks of amphibolite series (Tod22, Tod26 Tod29 and the metasedimentary rock (Tod24). This kind of mixing could explain the entire characteristics of these rocks:- the proportion of mixing being a function of the initial rock type. Thus, it is logical to suggest that the process of contamination affected the initial magma deep at the base of the crust.

(e) Tod27 (Gneiss)

One would have thought that this gneiss represents the Basement of the Cordillera. However, it exhibits a composition significantly different from the gneiss of the Basement:- high Nd isotopic composition similar to that of the rocks of the amphibolite series (Tod21, Tod26, Tod29).

It exhibits very low tenors in incompatible elements e.g Zn: 17 X chondrites, Sr = 9.5 X chondrites). Its Nb/Zn ratio is similar to those of the amphibolite series and is typical of alkaline basalts. It is logical in respect of the above statement, to propose that the gneiss Tod27 could also belong to the amphibolite series and respresent within this series a highly differentiated unit. The position of this sample in different correlation diagrams (AFM and MgO% versus CaO%) is in good agreement with this hypothesis.

(f) Volcanic rock (Tod25)

This rock is a dyke cross-cutting other litho-structural units studied. It exhibits progressive enrichment in less incompatible elements towards the highly incompatible ones being typical of alkaline basalts (Table.1). Considering a Cretaceous age of intrusion (i.e. age of the orogenesis of the Cordillera) the composition of this rock as observed in the isochron diagram $^{147}Sm/^{144}Nd$; $^{143}Nd/^{144}Nd$ (Fig.8) appears to be similar to those of amphibolite rocks. The characteristics earlier enumerated point to a close similarity with the amphibolitised basic intrusives.

CONCLUSION.

The geochemical characteristics of the different samples studied from the Apa massif suggest a cogenetic nature of the rocks. These characteristics are in good agreement with the formation of these rocks from the same magmatic chamber beneath a subduction zone (Lar et al., 1998). The majority of the samples are representative of cumulates. Only one is considered a liquid. The slight Nd isotopic variation observed in these rocks conforms with the process of assimilation during fractional crystallization (AFC).

Analyses of the data obtained from the study of the basic massif of Todasana suggest an alkaline-type parent magma. The different samples (Tod21, Tod 26, Tod27 Tod29) correspond to different stages of differentiation by fractional crystallisation of this magma. Other samples from this massif, exhibiting isotopic and trace element compositions different from the previous group (Tod22, Tod23), could be linked to this same group. The variation in isotopic composition must have resulted from interaction with the Basement during emplacement or later.

The geochemical characteristics observed could be explained by the following model :
(i) emplacement of a magmatic body (alkaline type) at the base of the crust by fusion of a peridotite mantle of the "Tinaquillo type" (Lar et al, 1998) followed by differentiation of this body at a high pressure. Magmas of tholeiitic character (Tod 28) may have been introduced much later. (ii) uplift of the crust and the massif resulting in the destabilisation of the mineralogical equilibrium leaving a trace of blueschist metamorphism.
(iii) a mantle diapir followed this uplift. Fusion of the mantle at a much later stage gave rise to bodies which intruded in the form of dykes and sills at the base of the continental crust (Todasana massif). This model is in conformity with the petrographic observations which have revealed the existence of two successive stages of metamorphism; high pressure (eclogite) followed by very low pressure (greenschist facies).

Finally, in the general geodynamic context of the development of the Caribbean chain, the two massifs studied correspond to the process of evolution of the mantle and diverse mantle-crust interactions. Fusion below a zone of subduction in the case of the Apa massif; giving rise to a diapiric uprise of the mantle within the context of an opening ridge, and the injection at the base of the crust of the primary magmas formed by fusion as in the case of the Todasana massif.

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