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INCLUSIONS IN THE SERPENTINITE MELANGE OF THE MOTAGUA FAULT ZONE, GUATEMALA

BY

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ABSTRACT

Ultramafites of the Central Cordillera of Guatemala are found in two distinct zones oriented E-W.

Partly serpentinized peridotites occur in the northern belt; they are cut by dikes of hornblendite, gabbros, and diabases. These dikes have been only moderately deformed but some of them at least are rodingitized with development of prehnite, mesolite, epidote, chlorite and vuagnatite.

The southern belt, along the Motagua fault, has clearly the character of a melange zone. The ultramafites are completely serpentinized harzburgites with a tendency toward lherzolites. Whereas in the southern part of this zone the serpentine minerals are lizardite and chrysotile, antigorite appears near the northern margin. The serpentinites have undergone severe tectonic deformation and contains many inclusions which can be distributed into: rodingites derived mostly from strongly dismembered diabase dikes; sialic rocks (albitites and albite granites); diverses metamorphic rocks (amphibolites, antigorite serpentinites, etc.). A larger mass of pillow basalts metamorphized in the prehnite-pumpellyite facies with moderate spilitic trend is probably also to be considered as an important inclusion in the serpentinite zone.

K-Ar age determinations indicate, for the emplacement and metamorphism of some of these inclusions, an age near the limit Cretaceous-Tertiary.

The ultramafite zones of Guatemala represent probably the remnants of a highly dismembered, metamorphic and possibly incomplete ophiolite.

RÉSUMÉ

Deux ceintures distinctes d'ultramafites, orientées E-W, affleurent dans la Cordillère centrale du Guatémala.

Dans la ceinture nord, les péridotites, partiellement serpentinisées, sont traversées par des dykes de hornblendite, gabbros et diabases. Ces dykes ne sont que peu déformés mais cependant quelques uns d'entre eux sont rodingitisés et montrent des développements de prehnite, mésolite, épidote, chlorite et vuagnatite.

Le long de la zone faillée de Motagua, la ceinture méridionale présente tous les caractères d'une zone de mélange. La roche ultramafique, à l'origine harzburgitique ou à tendance lherzolitique, est totalement serpentinisée. Lizardite et chrysotile sont les constituants essentiels de ces serpentinites sauf à l'approche de la marge nord de cette zone où apparaît l'antigorite.

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Les serpentinites de la zone de mélange, très fortement tectonisées, renferment de nombreuses inclusions de divers types: des rodingites dérivant pour la plupart de dykes de diabases fortement disloqués; des roches sialiques (albitites et granites albitiques); des roches métamorphiques variées (amphibolites, serpentinites à antigorite, etc.). Une zone plus importante de basaltes sous-marins, métamorphisés dans le faciès pumpellyite-prehnite et présentant une tendance spilitique modérée, correspond très probablement aussi à une inclusion dans la zone de mélange.

Des déterminations d'âge K-Ar effectuées sur un certain nombre de ces inclusions indiquent, pour leur mise en place et métamorphisme, un âge proche de la limite Crétacé-Tertiaire.

Les deux ceintures de roches ultramafiques étudiées sont très probablement les témoins d'une séquence ophiolitique fortement démembrée, métamorphique et peut-être incomplète.

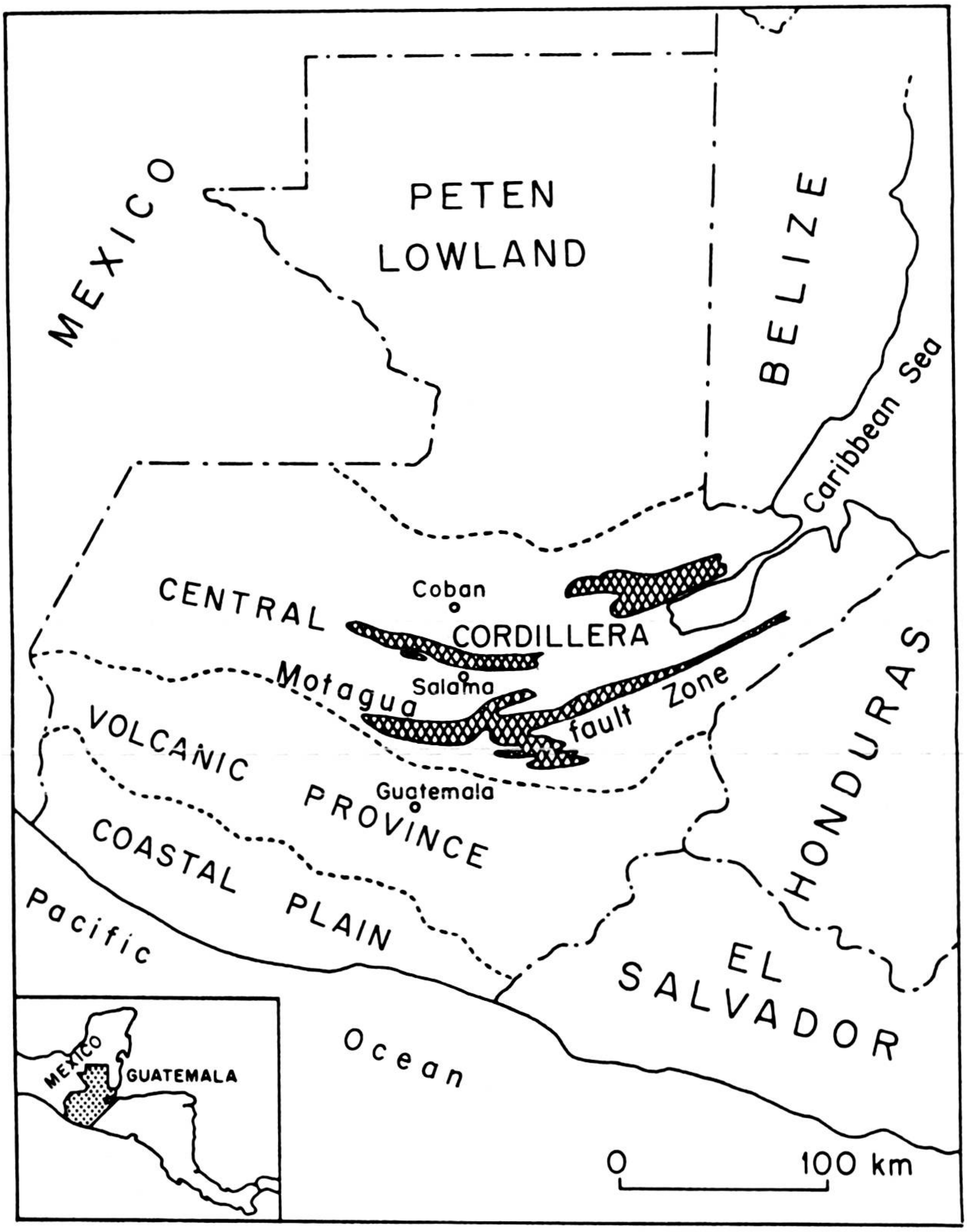

FIG. 1. — Physiographic Provinces of Guatemala with Location of the Ultramafic Belts (▩).

INTRODUCTION

Guatemala may be divided into four main geologic provinces (Bonis, 1967); from south to north: the Pacific Coastal Plain, the volcanic Province, the Central Cordillera and the Petén Lowland. Important bodies of ultramafic rocks, peridotites and serpentinites, are found in the Central Cordillera and have been studied in the last 20 years (McBirney, 1963; McBirney *et al.*, 1967; Bonis, 1967; Dengo *et al.*, 1969; Bertrand et Vuagnat, 1975, 1976, 1977; Bertrand et Sarp, 1976; Bertrand, Delaloye, Fontignie et Vuagnat, 1978).

These ultramafites outcrop roughly in two slightly curved main belts extending east-west and separated by other terranes (Fig. 1). In the northern belt the rocks are more massive and less transformed; in the southern one they have been submitted to intense deformations especially along the Motagua fault zone where we find a true serpentinitic melange with numerous tectonic inclusions.

This zone was sampled in 1970 and the results of the laboratory investigations of the specimens were published in several papers in the *Bulletin Suisse de Minéralogie et Pétrographie* (see references above). In this paper we intend to sum up the main results obtained so far.

The Motagua fault zone is bordered to the north by metamorphic formations of the Chuacús Series and to the south by the El Tambor Formation, where diabases and basalts are found. These mafic rocks have been submitted to a weaker metamorphism than those of the Chuacús Series.

THE SERPENTINITIC MATRIX

McBirney (1963) investigated the ultramafics of the Central Cordillera. He stressed the difference between the completely serpentinized peridotites of the southern belt and the partly fresh peridotites of the northern belt. In the first belt the degree of metamorphism increases from south to north as the lizardite-chrysotile serpentinites grade into antigorite-bearing rocks. In the northern belt the serpentine minerals are again lizardite and chrysotile. Our observations agree with those of McBirney, however we cannot consider that the southern peridotites are only harzburgites and the northern ones lherzolites. It seems that harzburgites predominate in both zones but are particularly abundant in the northern one.

Along the Motagua fault, in the typical melange zone, the primary peridotites, which here are almost completely transformed to lizardite-chrysotile serpentinites, show some relics of primary minerals (5-10%) in a few more massive specimens. Antigorite is not entirely absent but may be found in some schistose and shiny streaks. As mentioned before, antigorite progressively replaces the lizardite-chrysotile association toward the north.

In Table 1, some analyses of typical ultramafics are listed.

TABLE 1. — *Chemical analyses of ultramafics*
(analytical procedure: wet analysis; results in weight %)

	P 1	P 3	Scl 5	Sa 16	Sa 17
SiO_2	42.70	39.10	40.90	41.40	39.90
TiO_2	0.00	0.00	0.00	0.09	0.00
Al_2O_3	1.55	1.14	3.21	2.46	2.64
Fe_2O_3	2.51	3.53	3.73	3.91	8.57
Cr_2O_3	0.57	—	0.39	0.43	0.50
FeO	5.25	4.01	0.33	3.48	0.40
MnO	0.12	0.11	0.10	0.09	0.16
MgO	40.50	40.22	37.30	36.96	35.00
CaO	2.08	0.77	(< 0.20)	(< 0.10)	(< 0.20)
Na_2O	(< 0.10)	(< 0.10)	(< 0.10)	(< 0.10)	(< 0.10)
K_2O	(< 0.10)	(< 0.10)	(< 0.10)	(< 0.10)	(< 0.10)
P_2O_5	0.00	0.00	0.00	0.00	0.00
H_2O^+	4.46	10.94	13.65	11.70	13.13
H_2O^-	—	—			
CO_2	0.83	0.00	0.39	0.11	0.33
	100.57	99.95	99.76	100.63	100.63

Analyses P1 and P3: partly fresh peridotites, respectively 10-15% and 50% serpentinization.
Mode: olivine, enstatite, ± diopside, chrysotile, lizardite, spinels, talc, chlorite.
Occurrence: northern belt.

Analysis Scl 5: chrysotile-lizardite serpentinite (100% serpentinization).
Mode: chrysotile, lizardite, spinels, talc, chlorite, carbonate.
Occurrence: southern belt; Motagua melange zone.

Analyses Sa 16 and Sa 17: antigorite serpentinites.
Mode: antigorite, magnetite, carbonate, chlorite, talc.
Occurrences: Sa 16: northern part of southern belt.
Sa 17: block in the Motagua melange zone.

In the Motagua zone the serpentinites are intensely sheared and dissected by numerous irregular tectonic discontinuities. However, it is often possible to find more massive lumps where the primary texture is preserved. Some of the fractures are obviously ordinary fissures or diaclases. Other more important ones are quite continuous undulating shear surfaces which dissect the rock into lenses, sometimes connecting adjacent portions of boudinaged dikes; still others correspond to faults along which lenses of rock, sometimes exotic to the ultramafic body, have penetrated during the phases of deformation.

Tectonic inclusions in the Motagua serpentinites are varied in size, shape, composition and origin. The smaller ones are decimetric, the larger ones may extend over tens of meters; however most are in the meter sizes for the larger dimension. Many elongated inclusions still look like dikes, others are lens-shaped and some more or less perfectly rounded; we also see some with extremely irregular shapes.

In composition the inclusions vary from ultramafic to acidic rocks. We can also divide them in three categories according to their origin: those which were originally in the ultramafic body, as dikes or layers, etc; those composed of rocks associated with the ultramafites but not part of it, deriving from other terms of the ophiolite; finally, those deriving from adjacent non-ophiolitic rocks. This classification is of course too rigid and in many cases it is difficult to determine if a given inclusion has been derived from ophiolitic rocks or the country rocks.

We shall examine successively the different kinds of inclusions; the rodingites, the volcanics (pillow basalts, etc.), the leucocratic and the metamorphic ones.

THE RODINGITES

McBirney (1963) first mentioned the existence of diabasic inclusions, some fresh, some rodingitized, in the Motagua serpentinites.

Rodingites are frequent, for instance along the CA 9 highway east of the bifurcation of the Coban road and along the road leading to the locality of Morazan. Often the shape of the primary dikes is more or less preserved, but by progressive boudinage these dikes grade to fish-shaped lenses or rounded masses. The rock is always whitish to grayish, black margins, if present, are generally thin and often schistose.

In almost all cases where relics of primary features are preserved the rodingites show a doleritic texture and it is clear that the dikes derive from diabases. Sometimes the texture becomes finer grained toward the rim indicating a chilled margin with some fluidal arrangement of the plagioclase.

Generally the rock has been extensively transformed. The plagioclase is always replaced either by a lime silicate (garnet to hydrogarnet, vesuvianite, prehnite) or by chlorite. The garnet is either a grossular or, more commonly, a hydrated variety; both types may coexist in the same specimen. The dark component is a diopsidic augite which probably crystallized as an augite but was later modified by calcic metasomatism during rodingitization. The pyroxene is also frequently partially or totally replaced by an amphibole of the tremolite-actinolite series and finally by chlorite. In the dark rims of the rodingites the pyroxene is entirely chloritized; several varieties of chlorite (Mg-Fe, Fe-Mg and Mg-chlorites) are found, often intimately associated.

The most common mineral associations are: hydrogarnet-garnet, pyroxene $\pm$ chlorite; vesuvianite, hydrogarnet-garnet, chlorite; hydrogarnet-garnet, pyroxene, vesuvianite, actinolite-tremolite, chlorite; vesuvianite, chlorite.

Often vesuvianite, and to some extent garnet and prehnite, is found in more coarsely crystallized agregates within late veinlets, etc.

A few rodingites differ from the diabasic ones. For instance, a rock with a microbreccia structure, rich in lime (16.97% CaO, analysis R 15, Table 2) and with a chlorite-pumpellyite-epidote-hydrogarnet(?) assemblage. This rock derives very probably from a pillow basalt microbreccia with a sedimentary cement.

TABLE 2. — *Chemical analysis of rodingites*
(analytical procedure: wet analysis; results in weight %)

	R 4-5	R 6	R 10	R 15	dc 3	db 4
SiO_2	31.15	27.10	39.40	37.20	54.40	52.30
TiO_2	0.71	0.70	0.43	0.74	0.81	0.76
Al_2O_3	18.40	21.82	13.00	18.08	14.78	15.21
Fe_2O_3	3.97	0.66	6.42	4.27	3.15	1.00
Cr_2O_3	0.00	traces	0.00	0.00	0.00	0.00
FeO	5.23	13.97	1.00	3.44	7.34	6.92
MnO	0.21	0.40	0.08	0.13	0.17	0.18
MgO	10.24	14.10	3.97	9.55	5.74	6.38
CaO	21.60	9.82	34.00	16.97	7.18	8.17
Na_2O	(< 0.10)	(< 0.10)	0.13	(< 0.10)	4.19	4.28
K_2O	(< 0.10)	(< 0.10)	(< 0.10)	~ 0.10	0.45	0.12
P_2O_5	0.09	0.10	0.02	0.18	0.08	0.15
H_2O^+	6.76	10.25	1.03	8.09	2.01	4.04
H_2O^-		(< 0.08)	(< 0.05)			—
CO_2	1.43	0.70	0.79	1.04	—	0.12
	99.79	99.62	100.27	99.79	100.30	99.63

Analysis R 4-5: central part; mean of two analyses.
Mode: vesuvianite, hydrogarnet-garnet, chlorite.

Analysis R 6: rim of rodingite R 4-5.
Mode: chlorite, hydrogarnet-garnet.

Analysis R 10: central part.
Mode: hydrogarnet-garnet, pyroxene, vesuvianite, chlorite.

Analysis R 15: rodingitic diabasic microbreccia.
Mode: chlorite, pumpellyite, epidote, hydrogarnet (?).

Occurrences of analyses R 4-5, R 6, R 10, R 15: Motagua melange zone.

Analyses dc 3 and db 4: doleritic dike, respectively internal part and chilled margin.
Mode: plagioclase (An_{80-50} and more sodic), hornblende, actinolite-tremolite, biotite, prehnite, pumpellyite, ilmenite, chlorite (in the margin, replacing plagioclase).
Occurrence: northern belt.

As we have said previously, most rodingites derive from diabase dikes in the ultramafic rock. In Table 2, we compare the composition of typical rodingites with that of a doleritic dike which cuts a peridotite in the northern belt (analyses dc 3 and db 4, Table 2).

It is well known that the process of rodingitization leads to metasomatic changes of composition. SiO_2 decreases from 50% or more to about 30%, K_2O and Na_2O disappear, CaO increases massively from about 8% to 30% or more, MgO and Al_2O_3 are not strongly affected. The difference between the main part of the dyke and the black wall is marked by a great increase of MgO, Al_2O_3 and H_2O and a decrease of CaO.

Concerning the origin of the excess of lime, there is no doubt that a sufficient quantity of this oxide is released during the serpentinization of the peridotites, even if they are harzburgites. In Table 1 we see that CaO decreases from 2.08% (slightly serpentinized peridotite) to 0.77 (50% serpentinization) to less than 0.20% in completely serpentinized rocks.

THE VOLCANICS

Pillow basalts, pillow breccias and massive diabases were found along the highway Ca 9 east of Manzanal between the kilometric markers 109 and 110 (Bertrand et Vuagnat, 1975). There are several outcrops, some strongly weathered others fresher.

The main primary minerals are: plagioclase (albite to sodic oligoclase), frequently altered to pumpellyite and chlorite; augite, often corroded and replaced by chlorite, pumpellyite and calcite; olivine microphenocrysts, entirely pseudomorphosed mostly to chlorite; brown spinel associated with the olivine crystals and granules of sphene; some fine grained ore minerals. Secondary minerals are abundant, some have already been mentioned: pumpellyite and chlorite, often replacing olivine microphenocrysts, prehnite, calcite, quartz and stilpnomelane.

Apart from the microlites there are dispersed microphenocrysts which are in order of decreasing frequency of olivine, plagioclase, augite and spinel. Amygdules may be frequent in outer zones of pillows; they are filled by pumpellyite, chlorite, calcite, quartz, albite.

The massive diabases have intersertal to doleritic textures; they may be dikes or thicker lava flows. The pillows are common; their shapes are unmistakable with diameters reaching 1.50 m. In some places the skin of the pillow is made up a variolitic rock with individualized spherulites.

There is a typical textural variation from the center to the rim of the pillows grading from divergent intersertal to arborescent, subvariolitic and, in some instances, truly variolitic. The matrix of the pillows is a hayloclastite, the glass shards being entirely transformed to secondary minerals.

Different types of breccias are observed. Pillow breccias with or without a sedimentary cement are well represented. This cement can be calcitic or made up of a mixture of fine grained volcanic material and sediments; there are also breccias with coexisting pillow and diabase fragments. An interesting detritic rock must be mentioned: an extremely fine grained groundmass of phyllitic minerals and quartz containing fragments of pyroxene, volcanic glass and pillow basalts; other clasts are composed of sedimentary material similar to that of the matrix and may be interpreted as reworked fragments. This rock is probably a graywacke, however a tuffaceous origin cannot be excluded without further field investigation.

Several analyses of these rocks have been made. In Table 3 we reproduce 4 of them: a massive coarse grained diabase, a core and rim of pillow, a hyaloclastite. Although they all have a basaltic character, it is evident that they have been submitted to metasomatic processes during metamorphism; the abundance of pumpel-

TABLE 3. — *Chemical analysis of volcanics*
(analytical procedure: wet analysis; results in weight %)

	9	1	2	3
SiO_2	47.60	40.40	49.50	39.20
TiO_2	1.57	0.94	1.13	1.69
Al_2C_3	14.94	13.97	16.49	17.23
Fe_2O_3	4.22	3.48	3.05	4.33
Cr_2O_3	0.23	0.00	0.00	0.00
FeO	5.28	4.72	4.78	10.50
MnO	0.19	0.18	0.14	0.28
MgO	5.63	4.67	5.26	10.08
CaO	11.18	18.50	8.77	4.37
Na_2O	3.67	2.76	4.82	0.89
K_2O	0.57	0.20	0.81	2.25
P_2O_5	0.17	0.11	0.13	0.09
H_2O^+	(3.51)	(4.11)	(3.53)	(8.94)
CO_2	1.26	6.46	1.51	0.58
	100.02	100.50	99.92	100.49

Analysis 9: massive diabase.
Analyses 1, 2 and 3: respectively center, rim and hyaloclastitic matrix of the same pillow.
Modes: albite-oligoclase, augite, pumpellyite, chlorite, calcite, spinel (analyses 9, 1 and 2).
chlorite, pumpellyite, sphene-leucoxene (analysis 3).
Occurrences: southern belt: Motagua melange zone.

lyite and the sodic character of the plagioclase are results of these processes. Under these circumstances, without further studies in the field and in the laboratory (trace element determinations for instance) it is difficult to determine the nature of the primary basalt. If we compare analyses No. 1 and 2 and (center and rim of pillow) we see an increase in Na_2O and SiO_2; this corresponds to the general cases in alpine-type pillows, but there are also examples where the opposite is true. The hyaloclastite (analysis No. 3) is richer in magnesium, iron and water and poorer in silica. This reflects the fact that the primary glass, sideromelane, has been mostly replaced by chlorite.

It is likely that the pillow basalts are a large tectonic inclusion in the serpentinites but we cannot exclude, without further field studies, the possibility that they were emplaced on the serpentinites. However, we have described above a rodingitized pillow breccia inclusion.

The pillow basalts and associated rocks (massive diabase, breccias, etc.) have undergone a regional metamorphism in the pumpellyite-prehnite facies, the first mineral strongly predominating over the second. We cannot exclude earlier alterations and metamorphism in the ocean crust, probably spilitization. It is also possible that there was some calcic metasomatism near the serpentinite contact.

THE LEUCOCRATIC INCLUSIONS

We have encountered two types of leucocratic inclusions: albitites and trondjhemitic granites. Both types look rather similar; they are white to whitish blocks of metric size. Sometimes a thin skin of chloritized biotite schist adheres to the surface of granitic inclusions.

The albitites are granular rocks. The albite crystals are either slightly altered, with development of minute flakes of white mica, or recrystallized and very pure. Quartz may be present in small quantities as well as more or less chloritized biotite, actinolite and apatite. There are many indications of tectonic deformation. It is clear from the analyses of Table 4 that some albitites are practically pure albite. We have reported in the same table an analysis of an alpine albitite associated with alpine-type serpentinite from the Montgenèvre ophiolite (Pusztaszeri, 1969). There is a strong similarity between this analysis and those of the Guatemalan rocks.

Albitites associated with ophiolites are thought to be the result of an extreme differentiation of a gabbroic magma. They probably originated as dikes in the ultramafics and were dislocated to lenses by tectonic deformation. This origin seems quite clear in the Apennines for instance. However, in the case of the albitites from the extremely disrupted melange zone of the Motagua fault, further investigations would be necessary to test this hypothesis.

Trondjhemitic granites are made up of almost pure albite (An_{0-10}), quartz, hornblende; green biotite, sphene and apatite are accessory minerals. It seems likely that the green biotites and the cataclastic texture of some of the samples are due to some metamorphic process.

TABLE 4. — *Chemical analysis of leucocratic inclusions*
(analytical procedure: wet analysis; results in weight %)

	11	12	15	036
SiO_2	67.30	65.70	61.80	66.02
TiO_2	0.09	0.00	0.08	0.30
Al_2O_3	19.06	20.17	20.54	16.39
Fe_2O_3	0.11	0.00	1.27	0.68
FeO	0.20	0.22	0.23	1.12
MnO	0.00	0.00	0.00	0.01
MgO	(< 0.20)	0.75	2.06	1.66
CaO	0.47	1.89	3.32	1.47
Na_2O	12.08	9.87	8.79	11.52
K_2O	0.15	0.24	0.33	0.01
P_2O_5	0.09	0.02	0.20	0.05
H_2O^+	(< 0.20)	0.35	0.38	0.52
H_2O^-	(0.04)	(0.07)	(0.09)	—
CO_2	0.28	0.32	0.21	0.00
	99.83	99.53	99.21	99.85

Analysis 11: albitite.
Mode: albite (almost pure).

Analysis 12: albitite.
Mode: albite, quartz, biotite, chlorite, sericite, actinote.

Analysis 15: trondjhemitic granite.
Mode: albite, quartz, hornblende, biotite, apatite, sphene.

Occurrences for analyses 11, 12 and 15: southern belt; Motagua melange zone.

Analysis 036: albitite.
Mode: albite, quartz, hornblende and accessories.
Occurrence: Montgenèvre ophiolite, French-Italian Alps.

At present it is impossible to say if these lenses of granite derive from trondjhemitic bodies primarily associated with the ophiolites, as in many other instances in the world, or from trondjhemitic plutons found in the Paleozoic and Mesozoic series located south of the Motagua fault zone (McBirney, 1963).

THE METAMORPHIC INCLUSIONS

A variety of metamorphic rocks are found as tectonic inclusions of different sizes in the Motagua serpentinites.

Eclogites, jadeitites and actinolitic rocks have been described by McBirney (1963) and McBirney, Aoki and Bass (1967).

Eclogites can show typical omphacite-garnet assemblages or, probably retro-morphosed, glaucophane-lawsonite-omphacite-garnet associations.

Looking at the analyses No. 20, 17 and 19 in Table 5 we see a sufficient similarity with analyses of pillow lavas (Table 3) to admit that the eclogites could be oceanic basalts metamorphosed under high pressure conditions in a subduction zone. However, we cannot exclude the possibility that they are wedges of basic rocks which were part of the Chuacús series.

TABLE 5. — *Chemical analysis of metamorphic rocks*
(analytical procedure: wet analysis; results in weight %).

	14	26	20	17	19	21
SiO_2	59.18	65.04	49.32	47.35	47.82	53.00
TiO_2	0.00	0.28	1.60	2.29	1.79	0.12
Al_2O_3	23.73	17.40	14.52	12.92	13.22	4.63
Fe_2O_3	0.31	1.91	3.50	3.23	2.74	2.19
Cr_2O_3	—	—	0.02	—	0.01	—
FeO	0.11	0.28	7.00	9.66	9.70	4.99
MnO	0.02	0.02	0.18	0.19	0.21	0.35
MgO	0.95	0.99	6.57	7.34	9.48	20.61
CaO	0.95	1.90	11.25	9.87	10.06	9.95
Na_2O	14.36	11.35	3.94	4.15	3.03	0.74
K_2O	0.00	0.10	0.81	0.28	0.02	0.24
P_2O_5	—	0.07	0.06	0.31	0.08	0.02
H_2O^+	0.04	0.24	0.12	2.29	1.60	2.23
H_2O^-	(0.06)	(0.07)	(0.93)	—	(0.18)	
CO_2	—	0.35	—	0.09	—	0.82
	100.17	99.93	99.82	99.97	99.94	99.89

Analysis 14: jadeite (from McBirney, Aoki and Bass, 1967).
Mode: jadeite.
Occurrence: southern belt; block in the Motagua melange zone near Manzanal.

Analysis 26: metaalbitite (from Steen, 1972).
Mode: jadeite, aegyrinic augite, albite, quartz, epidote, apatite, sphene, zircon.

Analysis 20: eclogite (from McBirney, Aoki and Bass, 1967).
Mode: omphacite, garnet, muscovite, sphene, rutile, lawsonite, chlorite.
Occurrence: southern belt; pebble in the Motagua melange zone.

Analysis 17: garnet amphibolite (mean of two analyses).
Mode: hornblende, albite, garnet, epidote, sphene.
Occurrence: southern belt, Motagua melange zone.

Analysis 19: garnet amphibolite (from McBirney, 1963).
Mode: hornblende, albite, garnet, epidote, sphene, ore mineral, biotite, rutile.
Occurrence: Chuacús series.

Analysis 21: actinotite.
Mode: actinote, mica, chlorite.
Occurrence: southern belt; pebble in the Motagua melange zone.

Jadeitites are found in blocks near Manzanal. They are made up of practically pure jadeite. Tentatively we may admit that they derive from the albitites which, under high pressure conditions, have been transformed to jadeite and quartz. Of course, we must allow some mechanism for disposing of the silica. It is noteworthy that in the French Alps, in the highly metamorphosed region of Haute-Ubaye, south of the Montgenèvre ophiolite, where albitite inclusions are known, jadeite-rich rocks are found as lenses in serpentinites (Steen, 1972, 1975).

It is interesting to note that antigorite serpentinites are found not only as part of the southern ultramafic belt but also as inclusions in the chrysotile-lizardite serpentinites of the Motagua valley. They show mostly antigorite with very subordinate magnetite, carbonate, chlorite and talc. Analysis indicate that they are slightly richer in SiO_2 and poorer in MgO and H_2O^+ than the chrysotile-lizardite serpentinites.

It seems probable that these inclusions are tectonic blocks detached from more metamorphic, probably deeper zones of the ultramafic body. Through intense tectonic deformation they reached their present position.

Garnet amphibolites may form quite large inclusions; they vary in grain size and also in the intensity of schistosity. Under the microscope they show a poikiloblastic texture. The main mineral is an amphibole varying from a common green hornblende to an actinolitic variety. It is accompanied by albite, rarely twinned, garnet more or less transformed to calcite and chlorite, pistacite-clinozoïsite and abundant sphene.

Here again we may propose two hypotheses. According to the first one, the amphibolites originate from the Chuacús series where levels of similar rocks have been mentioned and ascribed to the metamorphism of eugeosynclinal pre-Carboniferous basic eruptive rocks. These amphibolites could have been incorporated into the melange zone without major modifications or, alternatively, could have been transformed to eclogites during metamorphism along a subduction zone and later retrogressed to amphibolites. In the second hypothesis the amphibolite inclusions would result from the metamorphism of pillow basalts associated with the ultramafics. This hypothesis seems less likely if we take into consideration some differences in composition revealed by analyses of both rocks.

Some inclusions are crystalline schists of a probable sedimentary origin. They exhibit a foliation and a lamination composed of alternating dark and light coloured beds. They contain quartz, more or less sericitic albite, biotite partly chloritized, relics of pistacite-clinozoisite, zircon, apatite and grains of an opaque mineral. In the light coloured beds, quartz and albite predominate. Associated with the crystalline schists are some marbles; they are mainly composed of large calcite crystals with accessory white mica, chlorite and ore minerals with intercalated beds of quartzite.

Further we must mention a granular green rock found along the contact between a crystalline schist inclusion and the schistose antigorite serpentinite; it is composed mainly of a ferromagnesian mica, partly chloritized, and of pistacite with some albite.

There is no doubt that these crystalline schists and marbles have been derived from rocks of the Chuacús series.

Finally, some actinolite-rich rocks are found, often coarsely crystalline; in some specimens a ferromagnesian mica, often chloritized, may accompany the amphibole. The chemical analysis (Table 5, analysis 21) refers to a variety where actinolite is almost the only constituent. It is suggested that such rocks may represent the result of metasomatic reactions between serpentinites and more siliceous inclusions. McBirney (1963) has mentioned similar rocks in contact zones between antigorite serpentinites and amphibolites.

Photomicrographs of some of these inclusions are shown in Plate I.

AGE OF INCLUSIONS

Thirteen K-Ar age determinations on samples of the rocks associated with the Guatemalan ultramafics were made in the laboratory of Dr. Michel Delaloye, University of Geneva. Except for the doleritic dike cutting the peridotite of the Northern ultramafic belt (Table 2, analyses dc 3 and db 4) all the samples come from the Motagua zone. They include 3 basalts, 4 amphibolites and 3 leucocratic rocks (albitites, granite). Specimens with a K content above 0.2% were chosen (Bertrand *et al.*, 1978).

Except for an albitite which gives an even younger age, the results are dispersed between 40 and 80 m.y. However, in a $^{40}Ar/^{36}Ar - {}^{40}K/^{36}Ar$ diagram all analyses except one lie along a straight line intercepting the y axis ($^{40}Ar/^{36}Ar$) at 295.5 (no argon overpressure) giving an age of $58.5 \pm 3.7 \cdot 10^6$y.

We must not forget that all these rocks have been metamorphosed. Their K-Ar isochron age means that the last metamorphic event took place about 60 m.y. ago. This opposes the suggestion of Palaeozoic orogeny and with regard to the pillows this shows that they have nothing to do with the Neogene volcanics of the Coast Range.

CONCLUSIONS

The ultramafic-mafic association found in the Central Cordillera is very probably a true ophiolite, the three main types of ophiolitic rocks being: ultramafics, gabbros (however the latter are very scarce, as dikes or layers in the peridotites-serpentinites) and submarine volcanics. Albitites and trondjhemites may possibly be other representatives of the same sequence.

This ophiolite has been dismembered, is incomplete and has been metamorphosed.

The Motagua melange zone is characterized by its great variety of inclusions, some "comagmatic", e.g. the antigoritite lenses, the rodingites and the pillow basalts. Others are derived from series adjacent to the serpentinites: most amphibolites, the crystalline schists and marbles. In a third group the inclusions are of uncertain origin; they may derive either from an ophiolitic rock or from the adjacent formations (the El Tambor Formation for instance).

Different kinds of metamorphism have affected the inclusions. Some were probably already metamorphic when they were incorporated into the serpentinites: regional metamorphism for rocks of the Chuacús Series, and a possible subseafloor metamorphism for the pillow basalts. Others were subjected to regional metamorphism during an episode of subduction; the coexistence of eclogites, or jadeitites with amphibolites and/or pillow lavas in the pumpellyite-prehnite facies suggests subduction to different depths. The same can be said for the existence of antigorite serpentinite lenses in a chrysotile-lizardite serpentinite environment.

A third type of metamorphism is linked with metasomatic processes in serpentinites: here we find the transformations typical of the rodingites formation.

It is obvious that the same inclusion may, during its history, have been submitted to successive episodes of metamorphism. In fact, many are probably polymetamorphic.

Very tentatively we can suggest the following hypothesis for the emplacement of the ultramafic-mafic belt of the Central Cordillera: During the Cretaceous the sialic crust was rifted and a narrow oceanic basin or trough created with submarine basaltic flows; later, probably near the limit Cretaceous-Paleocene, the movement reversed during a compression phase and the oceanic basin closed. The oceanic crust was subducted together with some slices of the adjacent older crust and a regional metamorphism of high P-low T developed. This episode may be related to the Laramic phase.

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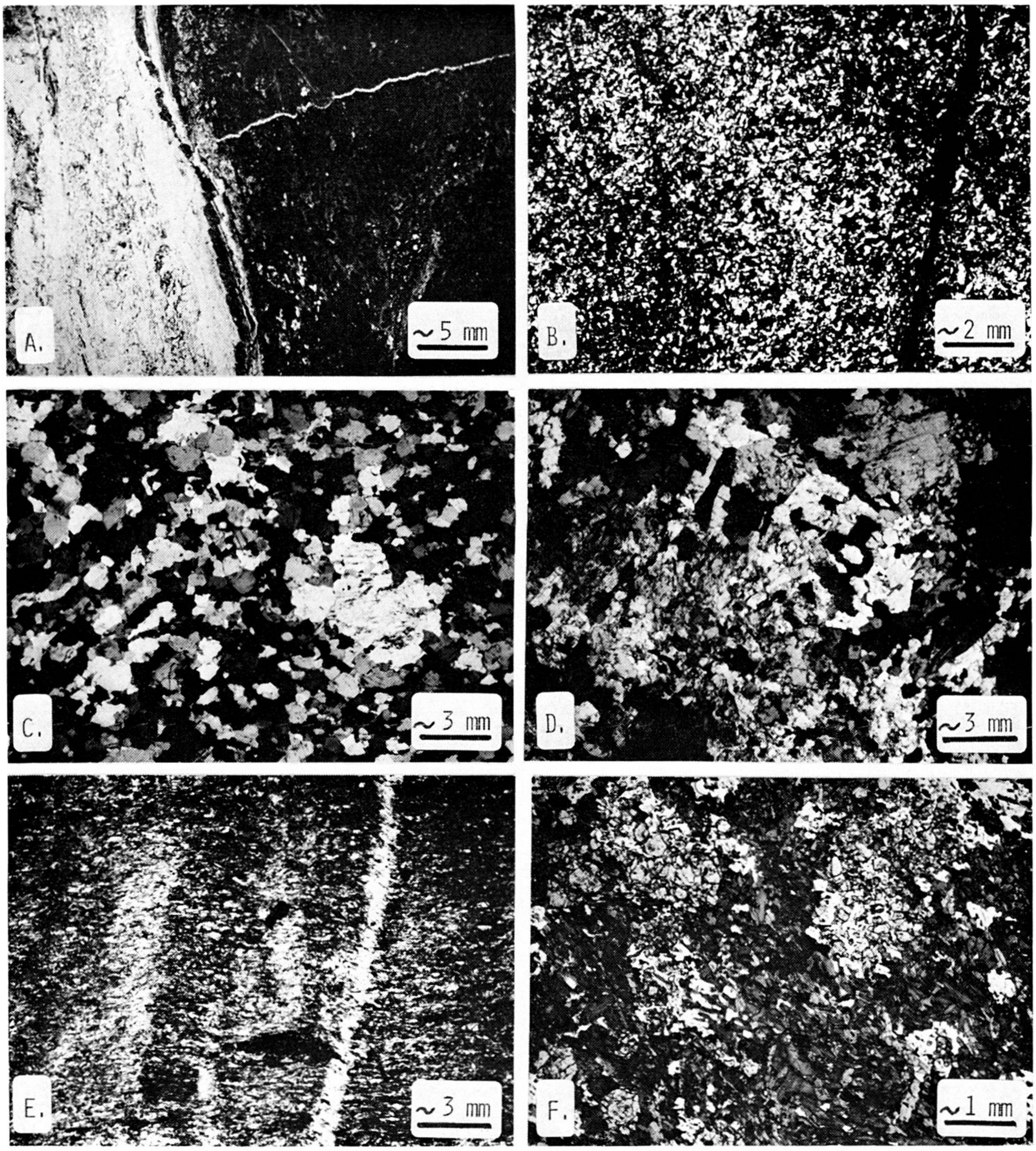

Photomicrographs of some rocks described

A. Diabasic rodingite (plane light). Internal part (right): garnet-hydrogarnet with some chlorite. Rim (left): chlorite and rare garnet-hydrogarnet. Note the tectonization at the contact. The original doleritic texture has almost disappeared.

B. Diabasic rodingite (X-nicols). Garnet-hydrogarnet (dark) replacing plagioclase and in vein. Pyroxene more or less replaced by secondary amphibole and chlorite (light). The doleritic texture is still recognizable.

C. Trondjhemitic granite (X-nicols). albite and quartz with some hornblende and green biotite. Texture is locally cataclastic.

D. Albitite (X-nicols). Mainly albite but with quartz, biotite more or less chloritized and chlorite as accessories.

E. Antigorite serpentinite (X-nicols). Antigorite with very rare magnetite and carbonate. Note the schistosity and folding.

F. Garnet amphibolite (plane light). Hornblende (dark) and garnet-albite-hornblende poikiloblasts (light patches).