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HIGH-PRESSURE, METASOMATIC ROCKS ALONG THE MOTAGUA FAULT ZONE, GUATEMALA

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ABSTRACT

The Motagua River of Guatemala follows the Motagua fault zone, the present plate boundary zone between the North American (Maya block) and Caribbean (Chortís block) plates. The central Motagua River valley is bordered by E-W-striking tectonic slices of serpentinite, some of which contain blocks of high pressure/low temperature (high P/T) eclogite, garnet amphibolite, and jadeitite. Recent exploration for commercial jadeitite (jade) has discovered considerable quantities of high P/T rocks in serpentinite bodies both further along and farther from the river. The southern bodies, south of the Motagua fault zone and adjacent to Chortís basement, also contain abundant eclogite, glaucophane eclogite, blueschist, jadeitite, and other high P/T rocks. The northern bodies, adjacent to Maya basement, include abundant jadeitite, albitite, and garnet amphibolite, but rare eclogite. Our initial studies find metasomatic signatures in most of the high-P/T rocks (e.g., phengite and quartz in veins, oscillatory zoning of jadeite and phengite, etc.). Mineralogical differences between jadeitites from the northern and southern bodies, and the different lithotectonic assemblages on the two sides of the Motagua fault zone suggest that either two high P/T events have occurred, or the two belts may be a single unit disrupted by strike slip duplexing.

INTRODUCTION

Guatemala is second only to Myanmar (Burma) as a modern jadeite jade source and is the most important archaeological source. Jadeitite is rare, with less than 10 identified deposits worldwide. It is found within serpentinite bodies that are typically associated with eclogite and blueschist (e.g., Harlow and Sorensen, 2000; Harlow, 1994). In Guatemala, jadeitite occurs in tectonized serpentinite bodies along the Motagua fault zone, which is part of the Caribbean-North American plate boundary zone (CARB-NOAM plate boundary zone). Past work has suggested that Guatemalan jadeitite and albitite crystallized from slab-derived, seawater-like fluids that entered serpentinizing peridotite in or above a subduction zone (Johnson and Harlow, 1999; Harlow, 1995; 1994).

Recent exploration for jade in the Motagua fault zone has discovered jadeitite in serpentinite bodies other than those previously studied. Some of these bodies contain abundant eclogite, glaucophane eclogite, blueschist, and jadeite-pumpellyite rock, as well as rare lawsonite eclogite, jadeite-quartz-rutile, and lawsonite-omphacite-quartz rocks; some of the latter are new types of high P/T assemblages. The jadeitite-bearing, E-W trending serpentinite slices straddle the Motagua River, the trace of the Motagua fault zone, for approximately 40 km on either side. This constitutes a far larger jadeitite source area than previously recognized. This paper will describe the two suites.

PLATE TECTONIC SETTING OF GUATEMALAN JADEITITE AND HIGH PRESSURE ASSEMBLAGES

In central Guatemala, the CARB-NOAM plate boundary is a zone of anastomozing left-lateral strike-slip faults that separate the NOAM Maya block from the CARB Chortís block (Figs. 1 and 2). The three most important strands of the CARB-NOAM plate boundary zone are, from N to S, the: (1) Polochíc-Chixoy fault; (2) Motagua (San Agustín and Cabañas)-Jubuco-Cuyamel fault; and, (3) Jocotán-Chamelecón fault (Fig. 1). The Motagua fault zone has an arcuate trend. In the west, the Motagua fault zone strikes EW and disappears under the Neogene volcanic cover, to merge with the Middle America trench. To the east, it curves northeastward and merges with the Swan Islands fracture zone. The Motagua fault zone is seismically active (e.g., Dewey and Suárez, 1991; White, 1991; Deng and Sykes, 1995; Guzmán-Speziale, 2001), and the displacement rate is about 21 mm/year (Rosencrantz and Mann, 1991; Dixon et al., 1998; Weber et al., 2001). Estimates of displacement along the Swan Islands fault zone since the Early Eocene are about 1100 km (Rosencrantz and Mann, 1991).

Plate reconstructions suggest that the Gulf of Mexico formed between 160 and 130 Ma, and the Caribbean from 160 to ~ 70 Ma (e.g., Pindell and Barrett, 1990). An active west-facing magmatic arc separated the Farallon plate in the west from the Americas and the Proto-Caribbean in the east. At ~120 Ma, collision of an oceanic plateau (?) with the arc caused the subduction polarity to change along the Central American segment, forcing this segment to move northeastward in-between the Maya block and South America. This segment later became the Greater/Lesser Antilles arc.

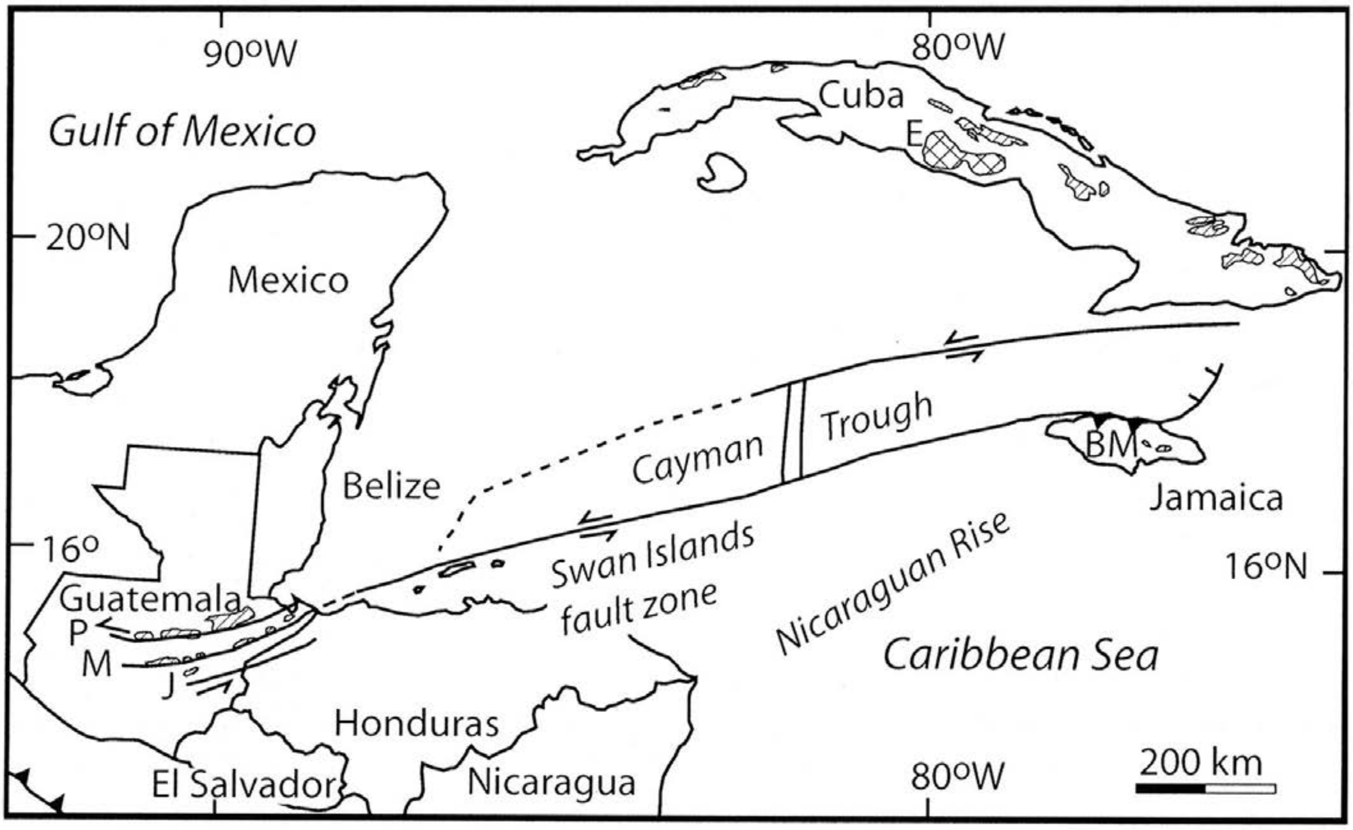

Fig. 1 - Northern Caribbean tectonic map. Major faults in Guatemala are P- Polochíc, M- Motagua, and J- Jocotán; Diagonal ruled regions- serpentinites, cross-hatched region- high pressure suites including the Escambray [E] eclogite-bearing belt in Cuba and Blue Mountain [BM] blueschist belt in Jamaica.

Maya block

The Maya block underlies SE Mexico (east of the Isthmus of Tehuantepec), northern Guatemala, and Belize. The oldest units consist of metasedimentary rocks and granites of Grenville age (Burkart, 1994), which are cut by Late Silurian (Steiner and Walker, 1996), Mississippian, Upper Permian, Lower Jurassic, and Cretaceous granites (Burkart, 1994). Similar metamorphic rocks in Guatemala are the Chuacús Group (McBirney, 1963). ^{40}Ar-^{39}Ar ages of 78 to 63 Ma (Sutter, 1979) indicate that portions of the Chuacús Group were metamorphosed and deformed during the Late Cretaceous. The serpentinites of the Sierra de Santa Cruz and probably the Alto Cuchumantanes (= Baja Verapaz of Beccaluva et al., 1995), north of the Chuacús rocks, are thrust-emplaced slices, which are apparently devoid of high P/T metamorphic rocks. Further generalizations are difficult, because Tertiary successor basins cover the older rocks.

Chortís block

The Chortís block underlies southern Guatemala, El Salvador, Honduras, the Nicaragua Rise, and Jamaica. Its geologic evolution is poorly understood. High-grade metamorphic rocks of assumed Precambrian or Paleozoic age (Cacaguapa Schist) are ubiquitous in Honduras (Gordon, 1991) and are probably coeval with the Guatemalan schists and gneisses of the Las Ovejas Group. These are overlain (?) by the phyllites of the San Diego Formation, but valid radiometric dates are lacking. The oldest paleontologically dated sedimentary rocks are the Upper Triassic Agua Fría Formation (Newberry, 1888), and Middle Jurassic to Lower Cretaceous sandstones, siltstones, and shales of the Honduras Group (Gordon, 1991). These are overlain conformably by the shallow-water Aptian to Albian Altima Limestone. The Valle de Angeles Group conformably overlies the Cretaceous rocks. It is a sequence of red conglomeratic sandstones that grades upwards into the Cenomanian/Turonian limestones of the Jaitique and Esquias Formations (Finch, 1981) and fine-grained red sandstone of Campanian age. Volcanic and plutonic rocks are found throughout this sequence. Abundant Tertiary and Quaternary volcanic rocks of the Central America arc overlie most of southwestern Guatemala.

The Chortís block may have originated near northwestern Mexico and been displaced along arc-parallel, left-lateral, strike-slip faults to its current position. Field studies (e.g., Donnelly et al., 1990) suggest that the Chortís block collided with the Maya block in Campanian / Maastrichtian time. The exhumation of high-P rocks may have been aided by formation of a major restraining bend (Mann and Gordon, 1996).

The Central Motagua Fault Zone

For 40 km on either side of Motagua River Valley lies a complicated boundary zone of fault slices between the two blocks where high-P/T rocks occur (Fig. 2). These are typically between two subparallel strands, the San Augustín and Cabañas, of the Motagua fault zone. Although the Cabañas fault appears to bound the areas that contain fragments of basement, which belong to either the Maya or Chortís blocks, poor exposures and extensive valley sedimentation could disguise a more diffuse or interdigitated boundary of fault slivers. About 50% of the exposures in the Motagua River valley consist of serpentinite bodies (e.g., McBirney, 1963; Donnelly et al., 1990). Some have interpreted these to be integral parts of an ophiolite complex. Others do not agree because all the serpentinites have faulted contacts (McBirney and Bass, 1969). In this region, sheeted dikes and gabbros of a complete ophiolite are rare. Metamorphosed basaltic rocks (prehnite-pumpellyite facies and, in cases, actinolite-bearing), radiolarian cherts, and greywackes occur sporadically within fault slices and make up the fundamental elements of the El Tambor Formation (as defined by McBirney and Bass, 1969). These rocks appear to be restricted to areas south of the San Agustín fault. The metabasalts, most of which were sampled south of the Motagua fault zone, show incompatible element ratios that suggest MORB protoliths (Beccaluva et al., 1995). To the east in the Sierra de Santa Cruz ophiolite sequence, foraminifera in overlying cherts are Aptian to Albian in age (Rosenfeld, 1981). It is not known if these are contemporaneous with the El Tambor Formation. Serpentinized peridotites from north of the Motagua fault zone have been described as dunitic to harzburgitic (e.g., Bertrand and Vuagnat, 1976; 1977; 1980). Some host metarodingite and metabasalt enclaves (e.g., Bertrand and Vuagnat, 1980), which suggest low-grade metamorphism, whereas others contain inclusions that show evidence for high P/T metamorphism, as described below. These are probably part of a serpentinite-matrix melange and not part of an ophiolite sequence. The age of serpentinization is not clear and may vary across the region, but the lack of quartz in jadeitites argues for coeval serpentinization and jadeitite crystallization (Harlow, 1994), at least for serpentinites that host such inclusions. K-Ar ages of greenschist-facies altered basalts, amphibolites, and albitite inclusions in serpentinite north of the Cabañas fault (Bertrand and Vuagnat, 1980) indicate Upper Cretaceous metamorphism and exhumation. Either the El Tambor Formation combines a low-pressure ophiolite sequence and serpentinite bodies that host high-P/T assemblages, or the latter should not be grouped with the El Tambor. This latter interpretation was argued by McBirney and Bass (1969). Overlying the El Tambor Formation and the serpentinite bodies are Eocene-Paleocene redbeds and conglomerates of the Subinal Formation, late-Tertiary sediments of the Guastatoya Formation, and sporadic cover of Quaternary (and Tertiary?) volcanic rocks.

JADEITITE, ECLOGITE, AND RELATED ROCKS IN GUATEMALA

In Central America, the high-P/T rocks eclogite and jadeitite, have been found only in the CARB-NOAM plate boundary zone (e.g., Foshag, 1955; McBirney et al., 1967; Harlow, 1994; Fig. 2). Until a few years ago, eclogite was only reported from the Río El Tambor (= Río Jalapa), just south of the Motagua fault (McBirney et al., 1967, Smith and Gendron, 1997), and jadeitite had been found only in the foothills of the Sierra de las Minas, north of the Motagua fault zone. However, increased commercial exploration for jade was assisted by the considerable erosional effects of Hurricane Mitch in 1998. Jade prospectors have made many alluvial finds and even discovered outcroppings of high-P/T rocks on both sides of the Río Motagua. In the serpentinite foothills of the Sierra de las Minas, jadeitite, albitite and omphacite-bearing metabasite occurrences now extend from Río Morazán, just east of Morazán, to Río Hondo, a distance of about 40 km. In the Sierra de las Minas, commercial jadeitite extraction has been reported between Ríos Uyus and La Palmilla to the first ridge line, with the northernmost discovery being an ancient mine on the north flanks of Cerro Bandera Perdida, which contains both jadeitite and albitite (northernmost jadeitite point in Fig. 2; Seitz et al., 2001). Thus, jadeitite occurs in at least one locality that is in the Maya block *sensu stricto* and is abundant on the north side of the Motagua River valley. In subsequent descriptions, we group all high P/T occurrences north of the Río Motagua because of their petrologic similarities. South of the Río Motagua, in the drainages of Río El Tambor (also called Río Jalapa in the Department of Jalapa), we have collected abundant eclogite, lawsonite eclogite, blueschist, jadeitite, and other high-P/T rocks in sheared serpentinite bodies (southern points in Fig. 2; Sisson et al., 2002).

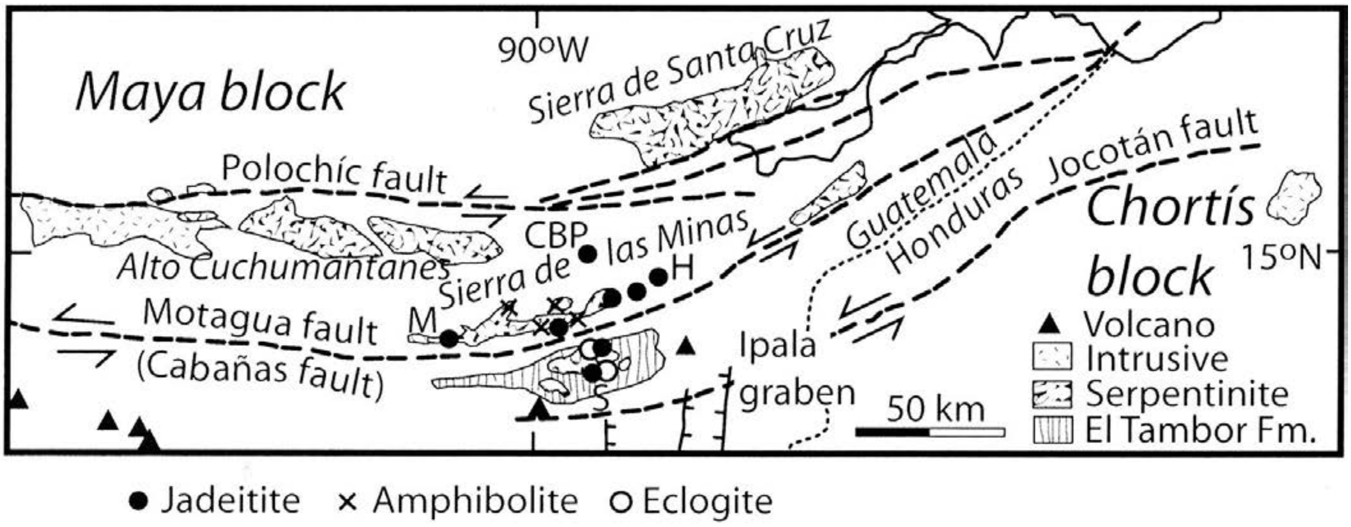

Fig. 2 - Map of central Motagua Valley showing selected jadeitite and high-pressure metamorphic (eclogite and garnet-amphibolite) rock localities (adapted from Burkart, 1994). Also shown is the distribution of Cretaceous-Tertiary intrusives, serpentinites, the El Tambor Formation and Quaternary volcanoes. Only the major fault traces are shown at this scale. In this region, the Motagua fault zone has two subparallel strands: the San Augustín to the north and the Cabañas to the south. These connect with the Jubuco and Cuyamel faults to the east. The Polochíc has two major strands: the Chixoy and Polochíc. The Chamelecón fault is the westward extension of the Jocotán fault. Jadeitite is found between Morazán (M) and Río Hondo (H) and as far north as Cerro Bandera Perdida (CBP) and Montaña del Silencio (S) to the south.

The outcrops south of the Motagua River valley display eclogite and blueschist blocks in sheared serpentinite and metasomatized ultramafic rock matrices. Preliminary descriptions of eclogite from the Motagua fault zone (all sourced in the Department of Jalapa, though some were carried down the Río Jalapa/El Tambor and found in the Department of Zacapa) report almandine-grossular garnet, omphacite, titanite-mantled rutile and zircon, and pyrite, with variable quantities of secondary phengite, glaucophane, lawsonite, albite, zoisite, phlogopite and chlorite (McBirney et al., 1967; McBirney and Bass, 1969; Bosc, 1971; Lawrence, 1975; this work). Cores of some omphacite grains contain clusters of primary fluid and solid inclusions, similar to those described by Giaramita and Sorensen (1994) in the Samaná Peninsula, Dominican Republic. Estimates of maximum temperatures recorded in several eclogites using Mg-Fe-exchange thermometers for coexisting omphacite-garnet (Krogh Ravna, 2000; Krogh, 1988; Powell 1985; Ellis and Green, 1979) yield values between 400 and 550 ºC, consistent with a low-T eclogite origin (Fig. 3). The association of eclogite, lawsonite-omphacite-quartz and jadeite-pumpellyite rocks suggests a sampling trend downward along a steep P/T slope (~2-3 MPa/deg) to low T (~200 ºC). Not only is there more eclogite (and other high P/T rocks) in the Motagua fault zone than previously recognized, but also these rocks evidently contain internal evidence of a complex retrogression history.

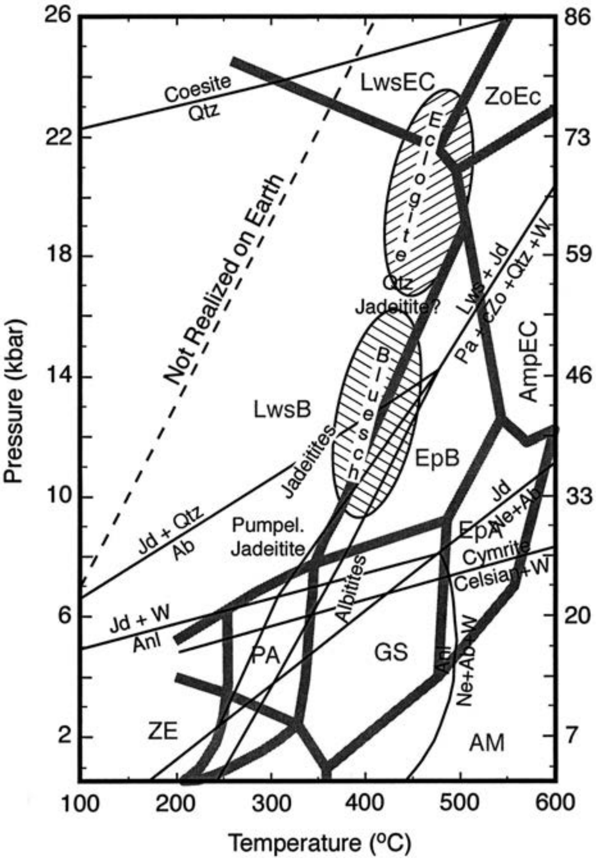

Fig. 3 - Pressure-temperature diagram showing approximate conditions of formation of the high P/T rocks examined from the Motagua Fault zone region. A petrogenetic grid is shown for metabasites that uses facies boundaries from Peacock (1993) at pressures to about 20 kbar and Katayama et al. (2001) at higher pressures. Reactions are limits for jadeitite and albitite formation (Harlow, 1994). Metamorphic facies include: ZE- zeolite facies, PA- prehnite-actinolite facies, LwsB- lawsonite blueschist facies, EpB- epidote blueschist facies, EpA- epidote amphibolite facies, LwsEC- lawsonite eclogite facies, ZoEC- zoisite eclogite facies, AmpEC- amphibole eclogite facies, GS- greenschist facies, and AM- amphibolite facies. Mineral abbreviations include: Jd- jadeitite, Qtz- quartz, Lw- lawsonite, Pa- paragonite, cZo- clinozoisite, W- water, Ab.- albite, Anl- analcime, Pumpel- pumpellyite, and Ne- nepheline.

In contrast, north of the Motagua fault zone, most of the metamorphosed high P/T mafic rocks are either omphacite-taramite metabasites or garnet-amphibolites with relict omphacite. There is no obvious glaucophane and the amphiboles are complex solid solutions ranging from actinolite to katophorite. At present, we do not have P-T estimates for either peak metamorphism or the retrograde history of this assemblage.

The jadeitites and albitites occur as highly dismembered tectonic blocks in sheared serpentinite (Harlow, 1994); however, we recently located jadeitites in primary contact with serpentinite, in both Maya and Chortís terranes. Jadeitite found north of the Cabañas fault consists mostly of jadeite, with minor omphacite, phengitic muscovite or paragonite, rutile (sometimes mantled by titanite), and minor zircon, and apatite, with late or secondary albite, omphacite, zoisite, taramitic amphibole, preiswerkite, analcime, nepheline, graphite, banalsite, cymrite, hyalophane/celsian and sulfides (Foshag, 1955; Silva 1967; 1970; Harlow, 1994; 1995). The albitite bodies contain mostly pure albite, with variable amounts of phengitic muscovite (typically barian) and zoisite (some strontian) plus minor quartz, actinolite, and diopsidic pyroxene (Silva, 1967; 1970; Bosc, 1971; Harlow, 1994; 1995), and appear to be restricted to north of the Cabañas fault.

The newly discovered jadeitites south of the Cabañas fault differ from counterparts to the north of it. First, these jadeitites do not show late-stage alteration, grain boundary alteration, and albitization, that is, albite + taramite + omphacite + zoisite ± analcime ± preiswerkite alteration halos and veins. The Jalapa jadeitites tend to be more translucent and darker in color than those from north of the Cabañas fault. Phengite is the sole white mica, and in many specimens it is so abundant that the rocks look like white schists. Jadeitite blocks commonly contain multiple generations of omphacite, (in the absence of albitization), and some display a late-stage, titanium-rich blue variety (Harlow et al., 2003). The pumpellyite-jadeite assemblage is a new one that is as yet absent north of the Cabañas fault.

Previous investigators of Guatemalan jadeitite and albitite from north of the Cabañas fault concluded the rocks

Fig. 4 - Cathodoluminescent image of jadeitite (sample MVJ84-9D-1) from Río La Palmilla, Guatemala. Everything in the field of view is jadeite. Rhythmic bright- and dull-gray overgrowths upon variably corroded whitish grains suggest growth into an open space.

were metasomatized tectonic inclusions of granites, plagiogranites or Chuacús gneisses (Silva, 1967, 1970; Bosc, 1971). However, petrographic studies by Harlow (1994) and Sorensen and Harlow (1998; 1999) did not find relict textures or protolith phases derived from any of these rock types, with the possible exceptions of rare rutile, and zircon grains and one spessartine-rich almandine grain. Furthermore, the significant differences in bulk composition between proposed protoliths and jadeitites require the gain and loss of many components besides desilicification. In addition, cathodoluminescence (CL) shows ubiquitous vein features and rhythmic zoning in jadeite, from jadeitites and albitites, suggesting both of these rocks probably crystallized from a fluid (e.g., Fig. 4). Finally, the oxygen and D/H isotopic signatures of coexisting pairs of jadeite, albite, and phengitic muscovite from jadeitite and albitite collected north of the Cabañas fault yield $\delta^{18}O$ and δD values of 6 ± 2 and -4 ± 11 ‰, respectively, for H_2O in the presumed metasomatic fluid (Johnson and Harlow, 1999). Combined with the high P/T conditions required to form the phase assemblage, the stable isotope data suggest either that the fluid was derived from the breakdown of hydrous minerals in the subducting slab, followed by deuterium enrichment from serpentinization at low water-to-rock ratios, or that the fluid was an isotopically modified marine pore water. In either case, seawater was evidently an important component of the process. Thus, jadeitite and albitite likely form from seawater-like fluids derived from the subducting slab, which entered a serpentinizing peridotite in or above a subduction zone. The jadeitite crystallized at $100 < T < 400$ ºC; $5 < P < 11$ kbar with $0.0 > \log_{10} a_{SiO_2} \geq 0.7$, whereas albitite crystallized at $T < 400$ ºC and ~ 3 to 8 kbar (Harlow, 1994; 1995; Sorensen and Harlow, 1999). Although tropical weathering makes it difficult to find contacts with host rocks, some of the jadeitite appears to occur as veins within serpentinite. Whether the jadeitites found south of the Cabañas fault form under the same conditions is an open question.

CONCLUSIONS

Two jadeitite occurrences, each associated with distinctive high P/T rocks, are exposed in the CARB-NOAM plate boundary zone, one within the Chortís block, south of the Cabañas fault (a strand of the Motagua fault zone) and one within the Maya block, north of the Motagua fault zone. The Maya jadeitites may be in a displaced segment of the Maya block in the Motagua fault zone. The jadeitites (and associated high P/T rocks) in the two belts show different mineral assemblages. Thus, the Motagua fault zone may record two collisional events. Alternatively, these two belts may represent different structural levels of one subduction complex that were disrupted first by north-directed thrusting and then by south-directed back folding and thrusting (retrocharriage), all during their emplacement over (or into) the Maya and Chortís blocks. A careful examination of tectonic evidence, combined with radiometric dating of key events will resolve this question.

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