Two high-pressure–low-temperature serpentinite-matrix mélange belts, Motagua fault zone, Guatemala: A record of Aptian and Maastrichtian collisions

George E. Harlow Department of Earth and Planetary Sciences, American Museum of Natural History, Central Park West at 79th Street, New York, New York 10024-5192, USA
Sidney R. Hemming Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York 10964-8000, USA
Hans G. Avé Lallemant, Virginia B. Sisson — Department of Earth Science, MS-126, Rice University, Houston, Texas 77005-1892, USA
Sorena S. Sorensen Department of Mineral Sciences, NHB-119, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560-0119, USA

ABSTRACT

Left-lateral motion along the North American–Caribbean plate boundary has juxtaposed two high-pressure–low-temperature (HP-LT) belts from separate Cretaceous collisions. These two belts have quite different ages and different suites of high-pressure assemblages, yet they both contain jadeitite, a relatively rare rock type. This part of the plate boundary zone follows the Motagua River Valley in Guatemala, where it separates the Maya block (North American plate) from the Chortís block (Caribbean plate). On both sides of the bounding Motagua fault, tectonic slices of serpentinite-matrix mélange host the HP-LT rocks. South of the fault, the mélange slices contain eclogite, lawsonite eclogite, glaucophane eclogite, and blueschist blocks. North of the fault, the mélange slices contain omphacite metabasite, albitite, and garnet amphibolite blocks, but lack intact eclogite. In addition to the dissimilar rock assemblages, $^{40}Ar/^{39}Ar$ geochronology of phengitic micas yields 77–65 Ma for northern and 125–113 Ma for southern blocks. These data suggest that the southern belt formed during Early Cretaceous (Aptian), northeastward-dipping subduction of the Farallon plate and collision of the Chortís block with western Mexico. The block was then displaced southeastward along this suture. In contrast, the northern belt records subduction related to the Maastrichtian collision of an extension of the Chortís block, perhaps the Nicaraguan Rise, with the Maya block.

Keywords: jadeitite, eclogite, serpentinite, plate boundary, suture zone, high pressure, low temperature, metamorphism, metasomatism, $^{40}Ar/^{39}Ar$ dating, Guatemala.

INTRODUCTION

The tectonics and history of the boundary between the North American and Caribbean plates in Central America are critical components for understanding the evolution of the Caribbean plate (e.g., Pindell, 1994; Dixon et al., 1998; Rogers et al., 2002). In Guatemala, the boundary is a zone of anastomosing left-lateral strike-slip faults that separate the Maya block of the North American plate from the Chortís block of the Caribbean plate, inclusive of the Nicaraguan Rise (Figs. 1 and 2). The three major strands of the boundary zone between the Caribbean plate and North American plate are, from north to south, (1) the Polochíc-Chixoy fault; (2) the Motagua (San Agustín and Cabañas)-Jubuco-Cuyamel fault; and (3) the Jocotán-Chamelecón fault (Fig. 1). Many serpentinite bodies are exposed along the Polochíc and Motagua faults. Stratigraphic evidence suggests that some of these are parts of a dismembered ophiolite of Cretaceous age (Donnelly et al., 1990).

For 20 km on either side of the central Motagua River Valley, high-pressure–low-temperature (HP-LT) rocks occur in fault slices between the Chortís and Maya blocks. About half the slices are serpentinite bodies, assigned by some to an ophiolite complex called the El Tambor Group (e.g., McBirney, 1963; Donnelly et al., 1990; Beccaluva et al., 1995). Others point out that all these bodies have faulted contacts, which may indicate slices of deep isolated peridotite (McBirney and Bass, 1969). Some of the serpentinite bodies contain jadeitite blocks. Jadeitite is a rare HP-LT metamorphic rock that is globally associated with serpentinite (Harlow, 1994; Harlow and Sorensen, 2001). Jadeitite has been known from north of the Motagua (locally, Cabañas) fault for more than 40 yr (Foshag and Leslie, 1955; McBirney et al., 1967; Harlow, 1994). In addition, eclogite cobbles have been described from the Río El Tambor, a north-flowing tributary to the Motagua River that drains serpentinites south of the Motagua fault (McBirney et al., 1967; McBirney and Bass, 1969; Smith and Gendron, 1997). Recent exploration for jade has yielded jadeitite in other serpentinite bodies, both north and south of the Motagua fault. Serpentinites south of the Motagua fault contain eclogite, glaucophane eclogite, blueschist, and lawsonite eclogite, as well as jadeite + pumpellyite, jadeite + quartz ± rutile, jadeite + lawsonite, and lawsonite + omphacite + quartz rocks. The areal distribution of jadeitites, omphacite metabasites, garnet amphibolites (some appear to preserve eclogite garnet), albitites, and related rocks north of the fault is much larger than previously recognized.

The age relationships of blocks are poorly constrained to unknown. However, phengitic muscovite is present in many of the HP-LT mineral assemblages. Therefore, $^{40}Ar/^{39}Ar$ geochronology was employed to determine the exhumation and crystallization ages of various rock types on both sides of the Motagua fault. Clusters of different mica ages for jadeitites and associated HP-LT rocks appear north and south of the Motagua fault zone. In this paper we discuss the origin and emplacement of the HP-LT rocks and revise the tectonic history of the North American–Caribbean plate boundary zone.

SAMPLES

Mica was separated from 13 rock samples (Table 1), 6 north and 7 south of the Motagua fault. Petrography and microprobe analyses (Table DR1[1]) indicate that the micas are unaltered; however, several display late overgrowths of Ba-rich mica (Harlow, 1995). Samples chosen for $^{40}Ar/^{39}Ar$ analyses generally had small volume percentages of such overgrowths. All but one sample consisted of phengitic muscovite; one was an intergrowth of paragonite and preiswerkite

[1]GSA Data Repository item 2004002, Table DR1, mica compositions, and Table DR2, Ar-Ar geochronologic data, is available online at www.geosociety.org/pubs/ft2004.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

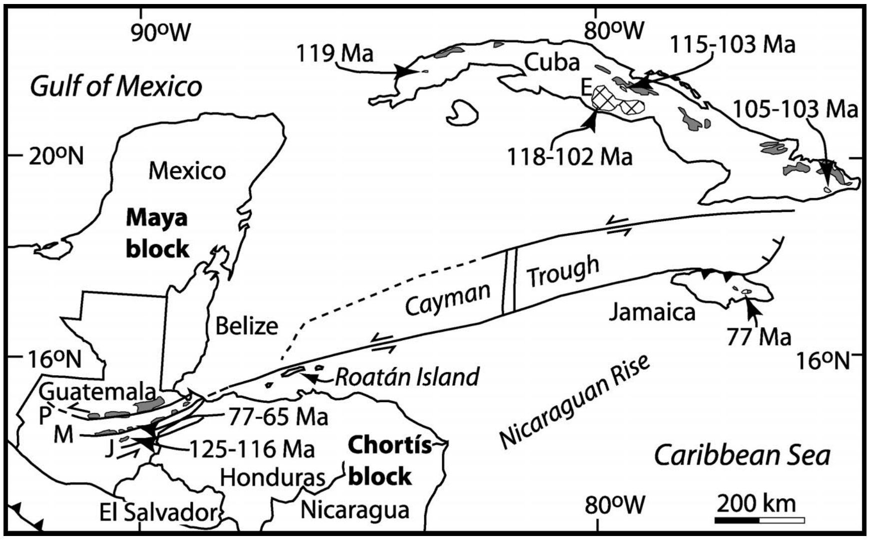

Figure 1. Tectonic map of northwestern Caribbean. Major faults in Guatemala are P—Polochíc, M—Motagua, and J—Jocotán. Dark gray—serpentinites that may contain high-pressure–low-temperature rocks in Guatemala, Cuba, and Jamaica. Cross-hachured pattern—high-pressure suite of Escambray complex, Cuba (E). Geochronologic data are from Draper (1986), Millán (1988), Hatten (1989), Grafe et al. (2001), Garcia-Casco et al. (2002), Maresch et al. (2003), and this paper.

$[Na_2(Mg,Fe)_4Al_2Si_4Al_4O_{20}(OH)_4]$. The latter mineral contained enough Ar for $^{40}Ar/^{39}Ar$ analyses, but appears to yield a problematic age (see following).

DATING TECHNIQUE

Samples were co-irradiated with the sanidine monitor standards Fish Canyon (27.84 Ma, Cebula et al., 1986) and Cima tuff (18.76 Ma, B. Turrin, 2003, personal commun.) in the Cd-lined in-core facility (CLICIT) of the Oregon State University reactor and then analyzed in the Ar geochronology laboratory at Lamont-Doherty Earth Observatory. Most samples were step heated with a CO_2 laser; one was step heated with a furnace. Ages were calculated from Ar isotope ratios corrected for mass discrimination, interfering nuclear reactions, procedural blanks, and atmospheric Ar contamination (Table DR2; see footnote 1).

Sample MVE02–2-5, which consists of paragonite + preiswerkite, yields a different age than the other samples. Dahl (1996) showed that trioctahedral OH-bearing mica (such as biotite) tends to yield a younger $^{40}Ar/^{39}Ar$ age than dioctahedral mica (such as muscovite). Data comparing paragonite and phengite retention are not abundant, but the two should behave similarly, because they are both dioctahedral micas. In contrast, preiswerkite, a trioctahedral mica like biotite, may not retain Ar as well as dioctahedral micas. Because the age for MVE02-2-5 differs so greatly from the other data, it was excluded from the final data set, and although the effect of paragonite content upon Ar retention is unknown, the datum for MVJ84-37-1 is included.

RESULTS

The mica ages of HP-LT rocks correlate with geography: they are 77–65 Ma north of the Motagua fault zone and 125–113 Ma south of it. Our results for north of the Motagua fault zone are similar to previous K-Ar and Ar/Ar results (Bertrand et al., 1978; Sutter, 1979). The $^{40}Ar/^{39}Ar$ mica ages either record closure, when mica-bearing rocks were last at $\sim$300 °C, or crystallization, if the micas are part of a low-temperature mineral assemblage. The crystallization temperatures of jadeitite and albitite are 300–400 °C (Harlow, 1994). Consequently, $^{40}Ar/^{39}Ar$ mica ages for jadeitite and albitite samples likely reflect rock-crystallization ages. In contrast, the phengite in eclogites reflects late fluid infiltration, rather than metamorphism at temperatures of $\sim$350–500 °C recorded by garnet-clinopyroxene Mg-Fe exchange thermometry (Krogh-Ravna, 2000; Powell, 1985; Ellis and Green, 1979). The range of ages in each group of HP-LT rocks (i.e., north vs. south of the Motagua fault) is less than the differences between the two areas. Also, the difference between rock types in several locations is very small. It thus seems likely that each age cluster reflects the time of blueschist facies metamorphism in each area.

TECTONIC MODEL FOR THE EXHUMATION OF THE HP-LT ROCKS

On both sides of the Motagua fault in Guatemala, small bodies of jadeitite and eclogite occur together in serpentinite-matrix mélange. Because jadeitites primarily crystallize from Na-Al-Si–rich fluids flowing within serpentinite (Sorensen and Harlow 1999; Harlow and Sorensen, 2001), and blueschist facies retrograde metasomatism is pervasive in eclogite, at least some serpentinization took place at considerable depth within the parental paleo-subduction zones. Ductile deformation structures related to the exhumation are synchronous with greenschist facies metamorphic isoclinal and similar-type folds, cleavages, and stretching lineations. In Guatemala, such fold axes and lineations (collectively, flow lines) are parallel to the plate boundary. Brittle deformation structures in Guatemala are primarily thrust and strike-slip faults parallel to the present plate boundary. Thrust faults are south-dipping north of the Motagua fault and north-dipping south of the fault.

Exhumation of HP-LT rocks may result from (1) buoyancy forces (Ernst, 1988), (2) low-angle, plate-boundary-parallel normal faulting (Platt, 1986), (3) formation of megascopic flower structures (Donnelly et al., 1990; Beccaluva et al., 1995), and (4) thrusting and subsequent back thrusting (typical for many orogenic belts), or a combination of the above. All these models have merit, and may apply to other areas, but none is completely consistent with the observed structure, petrology, and age dates in central Guatemala.

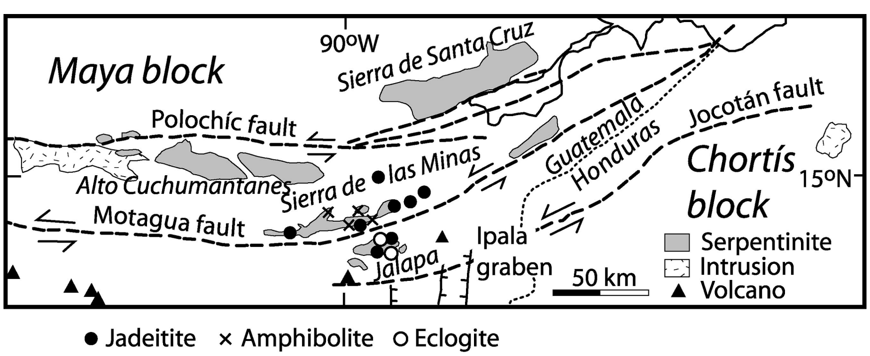

Figure 2. Map of central Motagua Valley showing selected jadeitite and eclogite localities (adapted from Burkart, 1994). This map shows additional localities beyond those discussed in this paper.

TABLE 1. SUMMARY OF MICAS AND GEOCHRONOLOGY

Sample	Rock type	Location	Micas*	No.†	Age§ (Ma)
North of the Motagua fault					
AMNH33399	Jadeitite	Manzanal	ph	2	75
MVJ84-3-2	Albitite	Manzanal	ph	1	76
MVJ84-29-1	Mica-albite rock	Usumatlán	ph/phl	3	71
MVJ84-37-1	Mica rock	Río Hondo	ph/pg	4	65
MVE02-2-5	Jadeitite	Panaluya	pg+prs	1	53
01GSn6-2a	Mica-albite rock	Sierra de las Minas	ph	1	77
South of the Motagua fault					
JJE01-3-2	Phengite jadeitite	Quebrada El Silencio	ph/phl	4	119
JJE01-3-4	Jadeite whiteschist	Quebrada El Silencio	ph	2	116
JJE01-3-5	Eclogite/blueschist	Quebrada El Silencio	ph	2	120
JJE01-6-1	Phengite jadeitite	Río La Puerta	ph	4	125
JJE01-X-3	Jadeitite	Near El Rosario	ph	3	120
01GSn2-3	Altered eclogite	Río El Tambor	ph	2	120
01GSn2-6	Altered eclogite	Río El Tambor	ph	2	113

*Mica: pg—paragonite, ph—phengite, phl—phlogopite, prs—preiswerkite.
†Number of Ar extractions.
§Integrated age.

Therefore, we have devised a complex three-stage model. First, postcollision buoyancy forces caused the HP-LT rocks to ascend to the mantle-crust boundary. Second, orogen-parallel stretching occurred due to oblique convergence and displacement partitioning, causing these rocks to ascend to even shallower levels (Avé Lallemant and Guth, 1990). The last stage consists of thrusting perpendicular to the boundary and erosion that ultimately results in exposure.

The close juxtaposition of two HP-LT terranes of similar metamorphic histories and protolith assemblages but of different ages is a remarkable and perhaps globally unique feature of the northern Caribbean plate boundary. Based on the new $^{40}Ar/^{39}Ar$ ages and structures presented here and on maps published by the Guatemalan government, theses from various universities, unpublished geological maps (T.W. Donnelly, 1990, personal commun.), and reconnaissance geological observations made between 2001 and 2003, we present a modification of Pindell's (1994) tectonic model for the Chortís and Maya blocks (Fig. 3).

From ca. 160 Ma to 120 Ma, the Chortís block moved southeastward and the seafloor subducted along a northeast-dipping subduction zone off western Mexico. The block collided with Mexico ca. 120 Ma, and caused subduction to cease. The HP-LT metamorphic rocks were exhumed according to the three-stage scheme described herein. A new subduction zone, into which the Farallon plate was subducted, formed outboard of the Chortís block. Convergence was strongly left oblique, and the Chortís block was displaced to the southeast along a left-lateral strike-slip fault zone, perhaps the old subduction-collision zone (Fig 3A).

Plate motions were reorganized ca. 110 Ma (Engebretson et al., 1985; Pindell, 1994). Northeast-dipping subduction changed to southwest-dipping subduction, and the Farallon plate with the fringing ''Great Arc of the Caribbean'' (Burke, 1988) started moving to the northeast. Between 110 and 70 Ma, the Atlantic (North American) plate was subducting to the southwest beneath the Farallon-Caribbean plate. The Chortís block and the Nicaraguan Rise collided with the Maya block ca. 70 Ma. Subduction was choked and the second HP-LT belt was exhumed (Fig. 3B). At this time the Sierra de Santa Cruz ophiolite in Guatemala and Siuna ophiolite in Nicaragua were emplaced (Rosenfeld, 1981; Rogers, 2003). From ca. 70 Ma to the present, the Chortís block moved to the northeast along the left-lateral Motagua Valley plate boundary, which juxtaposed the HP-LT metamorphic rocks (shaded and cross-hachured rectangles; Fig. 3C). In our model the Chortís block rotated ~50° counterclockwise, somewhat earlier than paleomagnetic studies suggest (Gose, 1985; Emling et al., 2001). The plate boundary zone is curved, creating a restraining bend. This, in turn, may have caused the high mountains to form (Mann and Gordon, 1996), and created rapid erosion and exposure of the HP-LT blocks.

CONCLUSIONS

Two serpentinite-matrix mélanges, both of which contain HP-LT blocks (including jadeitite, which is rare on Earth), are exposed in the Caribbean plate–North American plate boundary zone in Guatemala. One is within the Chortís block, south of the Motagua fault zone, and the other is within the Maya block, north of the fault zone. Lithologic assemblages and $^{40}Ar/^{39}Ar$ ages are distinct, suggesting that the two represent discrete terranes. The rocks appear to record two subduction-collision events (one in Aptian and the other in Maastrichtian time) and amalgamation via the movement of the Chortís block from west to east during the inception of the northern Caribbean plate boundary.

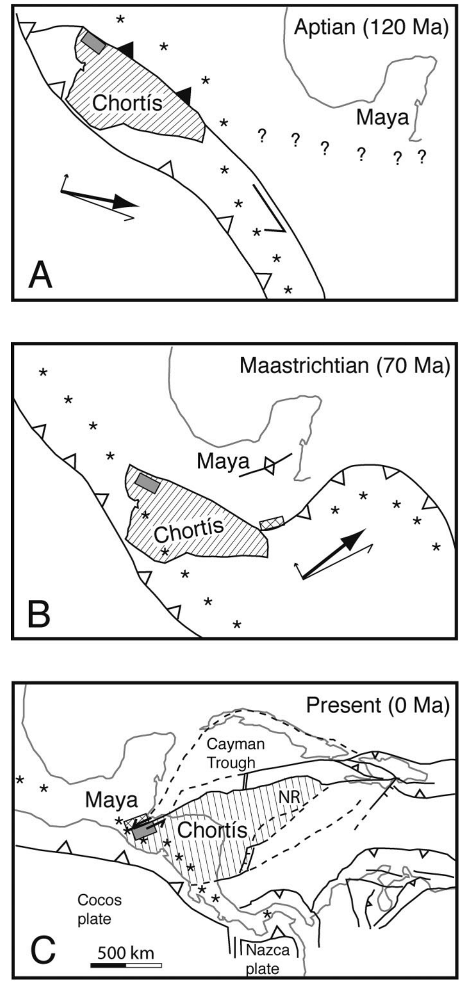

Figure 3. Tectonic history of Chortís and Maya blocks, modified from Pindell (1994). A: Ca. 120 Ma, northeast-directed subduction (line with black teeth) caused Chortís block (diagonally ruled area) to collide with Mexico; high-pressure–low-temperature (HP-LT) rocks were exhumed (shaded rectangle); new northeast-directed subduction zone formed outboard (line with white teeth). Heavy arrow shows plate motion from Engebretson et al. (1985), and lighter arrows indicate relative amounts of displacement partitioning. B: Between 120 and 70 Ma, subduction polarity around Caribbean switched and Chortís migrated southeastward and started to rotate counterclockwise. Ca. 70 Ma, south-directed subduction zone became choked, and upper plate was thrust over Maya block, as HP-LT rocks were exhumed (cross-hachured rectangle). C: Between 70 Ma and present, Chortís block migrated ~1100 km east, juxtaposing two HP-LT belts. NR—Nicaraguan Rise. Adapted from Pindell (2003, personal commun.).

ACKNOWLEDGMENTS

Funds from the Astor Expedition Fund of the American Museum of Natural History, the Sprague and Becker Funds of the Smithsonian Institution, and a grant from the Frohlich Charitable Trust (to Harlow) supported our field work in Guatemala in 2001–2002. Discussions with Rob Rogers helped clarify our understanding of Chortís block tectonic evolution. We thank Russell Seitz for the impetus to do this work and Carlos Gonzalez, Carlos Morales, José Loyo, Raul Marroquin, and Jerry Leach for helping us with our studies south of the Motagua fault zone. We also thank Paul Mann and Kevin Burke for helpful reviews.

REFERENCES CITED

Avé Lallemant, H.G., and Guth, L.R., 1990, Role of extensional tectonics in exhumation of eclogites and blueschists in an oblique subduction setting, northwestern Venezuela: Geology, v. 18, p. 950–953.

Beccaluva, L., Bellia, S., Coltorti, M., Dengo, G., Giunta, G., Mendez, J., Romero, J., Rotolo, S., and Siena, F., 1995, The northwestern border of the Caribbean plate in Guatemala: New geological and petrological data on the Motagua ophiolitic belt: Ofioliti, v. 20, p. 1–15.

Bertrand, J., Delaloye, M., Fontignie, D., and Vuagnat, M., 1978, Ages (K-Ar) sur diverses ophiolites et roches associées de la Cordillère centrale du Guatemala: Bulletin de Suisse Minéralogie et Pétrographie, v. 58, p. 405–412.

Burkart, B., 1994, Northern Central America, *in* Donovan, S.K., and Jackson, T.A., eds., Caribbean geology: An introduction: Kingston, Jamaica, University of West Indies Publishers' Association, p. 265–284.

Burke, K.C.A., 1988, Tectonic evolution of the Caribbean: Annual Review of Earth and Planetary Sciences, v. 16, p. 201–230.

Cebula, G.T., Kunk, M.J., Mehnert, H.H., Naeser, C.W., Obradovich, J.D., and Sutter, J.F., 1986, The Fish Canyon Tuff, a potential standard for the ^{40}Ar-^{39}Ar and fission-track dating methods: Terra Cognita, v. 6, p. 139–140.

Dahl, P.S., 1996, The crystal-chemical basis for Ar retention in micas: Inferences from interlayer partitioning and implications for geochronology: Contributions to Mineralogy and Petrology, v. 123, p. 22–39.

Dixon, T.H., Farina, F., DeMets, C., Jansma, P., Mann, P., and Calais, E., 1998, Relative motion between the Caribbean and North American plates and related boundary zone deformation from a decade of GPS observations: Journal of Geophysical Research, v. 103, p. 15,157–15,182.

Donnelly, T.W., Horne, G.S., Finch, R.C., and López-Ramos, E., 1990, Northern Central America: The Maya and Chortís blocks, *in* Dengo, G., and Case, J.E., eds., The Caribbean region: Boulder, Colorado, Geological Society of America, Geology of North America, v. H, p. 37–76.

Draper, G., 1986, Blueschists and associated rocks in eastern Jamaica and their significance for Caribbean plate margin development in the northern Caribbean: Geological Society of America Bulletin, v. 97, p. 48–60.

Ellis, D.J., and Green, D.H., 1979, An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria: Contributions to Mineralogy and Petrology, v. 71, p. 13–22.

Emling, S.-A., Layer, P., and Ubieta, K., 2001, A paleomagnetic study and age determinations of Tertiary rocks in Nicaragua, Central America: Geophysical Journal International, v. 147, p. 294–309.

Engebretson, D.C., Cox, A., and Gordon, R.G., 1985, Relative motions between oceanic and continental plates in the Pacific basin: Geological Society of America Special Paper 206, 59 p.

Ernst, W.G., 1988, Tectonic history of subduction zones inferred from retrograde blueschist *P-T* paths: Geology, v. 16, p. 1081–1084.

Foshag, W.F., and Leslie, R., 1955, Jadeite from Manzanal, Guatemala: American Antiquity, v. 21, p. 81–83.

Garcia-Casco, A., Torres-Roldan, R.L., Millán, G., Monié, P., and Schneider, J., 2002, Oscillatory zoning in eclogitic garnet and amphibole, northern serpentinite melange, Cuba: A record of tectonic instability during subduction?: Journal of Metamorphic Geology, v. 20, p. 581–598.

Gose, W.A., 1985, Paleomagnetic results from Honduras and their bearing on Caribbean tectonics: Tectonics, v. 4, p. 565–585.

Grafe, F., Stanek, K.P., Baumann, A., Maresch, W.V., Hames, W.E., Grevel, C., and Millán, G., 2001, Rb-Sr and ^{40}Ar/^{39}Ar mineral ages of granitoid intrusions in the Mabujina unit, central Cuba: Thermal exhumation history of the Escambray massif: Journal of Geology, v. 109, p. 615–631.

Harlow, G.E., 1994, Jadeitites, albitites and related rocks from the Motagua fault zone, Guatemala: Journal of Metamorphic Geology, v. 12, p. 49–68.

Harlow, G.E., 1995, Crystal chemistry of barian enrichment in micas from metasomatized inclusions in serpentinite, Motagua Valley, Guatemala: European Journal of Mineralogy, v. 7, p. 775–789.

Harlow, G.E., and Sorensen, S.S., 2001, Jade: Occurrence and metasomatic origin: Australian Gemologist, v. 21, p. 7–10.

Hatten, C.W., 1989, Rocas metamórficas de alta presión: Nuevos datos acerca de sus edades: Havana, Cuba, Primero Congreso Cubano de Geología, p. 118.

Krogh-Ravna, E., 2000, The garnet-clinopyroxene Fe^{2+}-Mg geothermometer: An updated calibration: Journal of Metamorphic Geology, v. 18, p. 211–219.

Mann, P., and Gordon, M.B., 1996, Tectonic uplift of blueschist belts along transpressional strike-slip faults, *in* Bebout, G.E., et al., eds., Subduction top to bottom: American Geophysical Union Geophysical Monograph 96, p. 143–154.

Maresch, W.V., Stanek, K.-P., Grafe, F., Idleman, B., Baumann, A., Krebs, M., Schertl, H.-P., and Draper, G., 2003, Age systematics of high-pressure metamorphism in the Caribbean: Confronting existing models with new data: Havana, Cuba, 5th Cuban Geological Congress, Abstracts (http://www.ig.utexas.edu/CaribPlate/reports/cuba_2003.htm#abstracts).

McBirney, A.R., 1963, Geology of a part of the central Guatemalan cordillera: University of California Publications in Geological Sciences, v. 38, p. 177–242.

McBirney, A.R., and Bass, M.N., 1969, Structural relations of pre-Mesozoic rocks of northern Central America, *in* McBirney, A.R., ed., Tectonic relations of northern Central American and the northern Caribbean—The Bonacca Expedition: American Association of Petroleum Geologists Memoir 11, p. 269–280.

McBirney, A.R., Aoki, K.-I., and Bass, M., 1967, Eclogites and jadeite from the Motagua fault zone, Guatemala: American Mineralogist, v. 52, p. 908–918.

Millán, G., 1988, La asociación glaucofana-pumpelleita en metagabroides de la faja metamórfica Cangre (The glaucophane-pumpellyite association in metagabbroids of the Cangre metamorphic band): Boletín de Geociencias, v. 3, p. 35–36.

Pindell, J.L., 1994, Evolution of the Gulf of Mexico and Caribbean, *in* Donovan, S.K., and Jackson, T.A., eds., Caribbean geology: An introduction: Kingston, Jamaica, University of West Indies Publishers' Association, p. 13–39.

Platt, J.P., 1986, Dynamics of orogenic wedges and the uplift of high-pressure metamorphic rocks: Geological Society of America Bulletin, v. 97, p. 1037–1053.

Powell, R., 1985, Regression diagnostics and robust regression in geothermometer/geobarometer calibration: The garnet-clinopyroxene geothermometer revisited: Journal of Metamorphic Geology, v. 3, p. 231–243.

Rogers, R.D., 2003, The Cretaceous margins of the extreme southwestern corner of the North American plate: Geological Society of America Abstracts with Programs, v. 35, no. 4, p. 75.

Rogers, R.D., Kárason, H., and van der Hilst, R., 2002, Epeirogenic uplift above a detached slab in northern Central America: Geology, v. 30, p. 1031–1034.

Rosenfeld, J.H., 1981, Geology of the western Sierra de Santa Cruz, Guatemala, Central America: An ophiolite sequence [Ph.D. thesis]: Binghamton, State University of New York at Binghamton, 313 p.

Smith, D.C., and Gendron, F., 1997, New locality and a new kind of jadeite jade from Guatemala: Rutile-quartz-jadeitite, *in* Fifth International Eclogite Conference, Abstracts Supplement 1: Terra Nova, v. 9, p. 35.

Sorensen, S.S., and Harlow, G.E., 1999, The geochemical evolution of jadeitite-depositing fluids: Geological Society of America Abstracts with Programs, v. 31, no. 6, p. 101.

Sutter, J., 1979, Late Cretaceous collisional tectonics along the Motagua fault zone, Guatemala: Geological Society of America Abstracts with Programs, v. 11, p. 525–526.

Manuscript received 1 July 2003
Revised manuscript received 15 September 2003
Manuscript accepted 16 September 2003

Printed in USA