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INSIDE

A 195 Ma Terrane in a 165 Ma Sea: Pacific Origin of the Caribbean Plate

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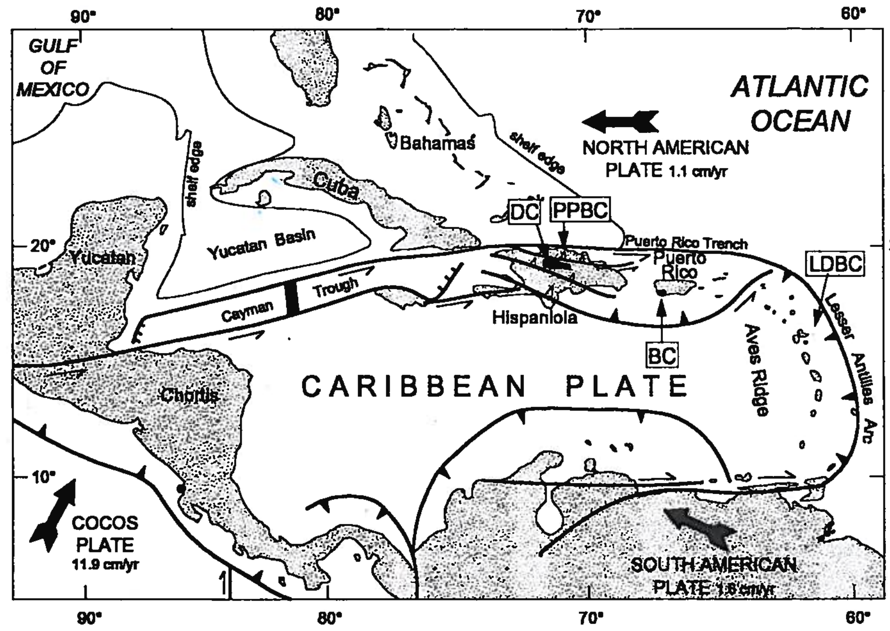

Figure 1. Geography of the Caribbean region. BC—Bermeja Complex, Puerto Rico; DC—Duarte Complex, Hispaniola; PPBC—Puerto Plata basement complex, Hispaniola; LDBC—La Désirade, Guadeloupe. Plate motions and velocities are after Mann et al. (1991).

ABSTRACT

Tectonic models purporting to describe the origin of the Caribbean plate can be divided into two broad categories conflicting on the point of in situ origin vs. genesis in the Pacific realm followed by eastward transport relative to the American plate. Important elements of Caribbean geology including Cayman Trough spreading, the presence of the Lesser Antilles and Aves volcanic arcs, incompatible crustal juxtapositions, complicated plate geometry, truncated structural trends, fossils that originated at higher latitudes, and a lengthy geologic record of eastward progression strongly suggest allochthonous origin. However, none of these is conclusive proof.

The discovery of a Caribbean plate island terrane significantly older than the Caribbean Sea assures that in situ models are incorrect. The Bermeja Complex of southwestern Puerto Rico, located on the northeastern corner of the Caribbean plate, exposes Lower Jurassic chert. Deposited on a deep ocean floor, radiolarian chert from the Bermeja is late Pliensbachian (~195 Ma) in age, predating an open marine connection between the North Atlantic and the Pacific by ~30 m.y.

INTRODUCTION

The origin of the Caribbean plate, a small plate intruding into the much larger Atlantic plate (Fig. 1), has remained a subject of intense controversy since the inception of plate tectonics. Did the Caribbean plate form more or less in place or was it entirely engulfed by large-scale westward movement of the Americas? Several plate-tectonic models interpreting the tectonic evolution of the Caribbean, such

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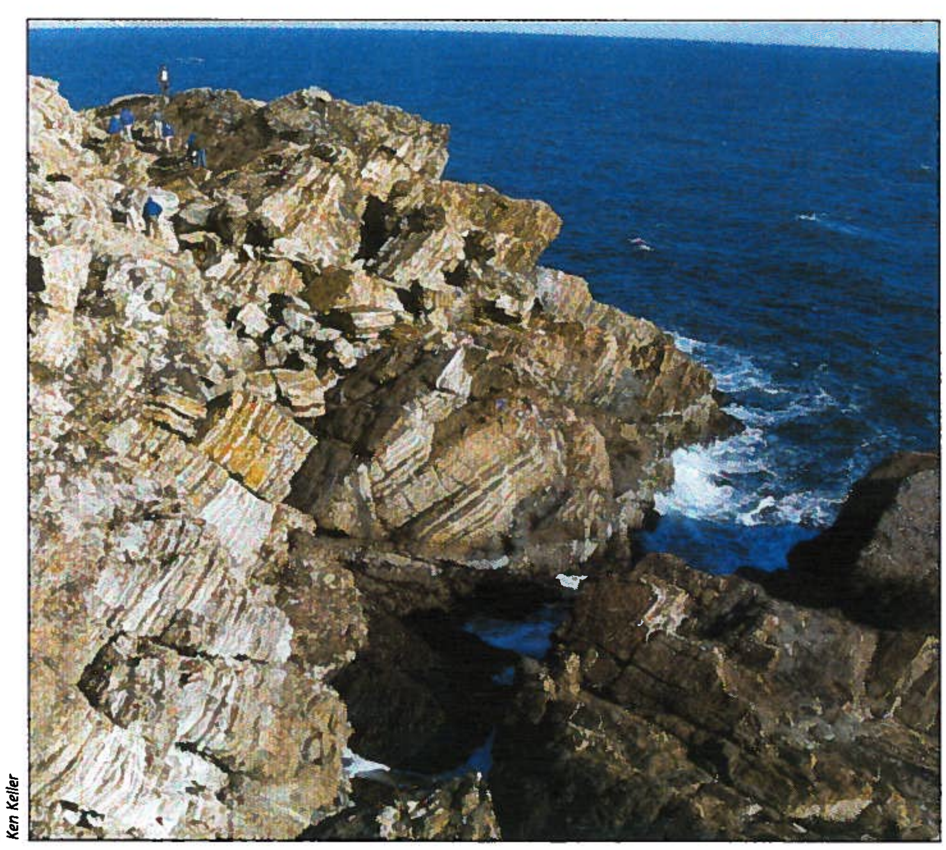
Thanks, Boston, for a Magnificent Meeting—6452 Attend

by Sandra Rush, Communication Consultant

Boston was a perfect host city for the 106th annual meeting of the Geological Society of America. We were treated to a week of perfect weather, and even the foliage stayed on the trees longer than usual, so that two weeks after the colors peaked, we still enjoyed a dazzling palette. Of course,



This field trip stop at Nahant Island, East Point, Boston Harbor, affords a view of the Lower Cambrian Weymouth Formation, composed of nodular mudstone and limestone, with intrusions of Ordovician Nahant Gabbro and numerous mafic dikes.

the Annual Meeting Committee, headed by General Chairman James W. Skehan, S. J., helped to make this meeting truly enjoyable with one of the most diverse and scientifically compelling technical programs we've seen.

It wasn't surprising that Boston turned out to be a well-attended meeting—6452 registrants—second only to the 1988 Centennial Celebration in Denver (7478 registrants). Of the 2349 abstracts accepted for this meeting, 615 were presented in 40 theme sessions and 254 in 25 symposia—a real logistical challenge to fit into the four-day meeting agenda. The range of topics was diverse, as usual, with an underlying theme of geological awareness related to health, education, environment, and other current public issues.

Field trips before, during (half-day), and after the meeting took advantage of the wealth of New England geology from the Atlantic Ocean to the White Mountains, from Connecticut to Maine, among some of the most picturesque environments in the nation. The spectacular, no-overcoat weather enhanced not only the field trip program, but also the guest tour program. All tours were filled to capacity as guests and *their* guests went bird watching, museum hopping, and investigating the nearby historic communities of the second-best-known "city by the bay."

Special Sessions Look Into Current Issues

But Boston's scenic setting, enhanced by its harbor, does not immediately reveal the environmental problems the harbor presents. The second Annual Environmental Forum, held Sunday afternoon and cosponsored by the GSA Institute for Environmental Education (IEE) and the GSA Geology and Public Policy Committee, addressed the cleanup of Boston Harbor and the effect of this cleanup on Massachusetts Bay. This topic is a locally controversial one, as the court-mandated plan to clean up the harbor involves discharging sewage effluent through a new ocean outfall into the bay, with as-yet-undetermined effects. Each year at the Annual Meeting, the environmental forum addresses issues involving effects on the environment and public policy of the meeting site.

Monday's keynote symposium focused on the highly dependent connection between human health and the environment, and linked health directly to the geological sciences. The symposium identified solutions to health-related geologic problems and the prudent use of geologic assets to ensure that future generations will have adequate natural resources and a nontoxic environment. The health and

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as that of Burke et al. (1984), relied on a Pacific origin for Caribbean terranes. A lightning rod for offbeat theories, the origin and development of the Caribbean plate have attracted numerous enduring alternative hypotheses based on the concepts of geosynclines, expansion, contraction, and mantle surge, all apparently attempting explanation without including plate tectonics. Antithetical ideas are well contrasted in sequential papers by Pindell and Barrett (1990) and Morris et al. (1990).

The Caribbean plate is a mosaic of poorly dated, over-thickened, oceanic, continental, intermediate, and accretionary crust that somehow filled the spreading gap between North and South America. The Caribbean plate collage is separated from adjoining plates by subduction zones on the east and west and by regions of strike-slip faulting along the north and south. Pindell (1990) presented seven arguments for a Pacific origin for the Caribbean plate. Additional stratigraphic and faunal data suggesting Pacific origin were also presented by Schellekens et al. (1990) and Montgomery et al. (1992). Given extensive justifications for the allochthonous nature of the plate, much, but certainly not all, of the work of the last decade has converged on a Pacific origin. In addition, broad plate-tectonic scenarios modeling the U.S. Cordillera and Tethys (Moores, 1970) and mantle flow models (Alvarez, 1982) essentially predicted Pacific origin for reasons mostly independent of Caribbean geology.

Dooming in situ formation is the discovery of Early Jurassic (upper Pliensbachian) radiolarians from the Bermeja Complex chert in southwestern Puerto Rico. This occurrence predates the Middle Jurassic opening of the North Atlantic Ocean and the Caribbean Sea. Here we review plate-tectonic evidence for Pacific origin of the Caribbean plate and present the first discussion of an Early Jurassic fauna from the region.

BERMEJA COMPLEX, PUERTO RICO

The Bermeja Complex, spread across the southwestern part of Puerto Rico, has long been recognized as geologically unusual to the island because of its greater age (in part), its lithologic character, and its clearly separate tectonic history. Stratigraphic studies in Sierra Bermeja are difficult to conduct and interpret because of the chaotic and discontinuous nature of the component serpentinite, amphibolite, basalt, and chert. Extensive deformation and metamorphism have destroyed most primary textures, bedding, and lithological relations. The lack of continuity of stratigraphic contacts and the inclusion of blocks of diverse size, lithology, and age (ranging through 100 Ma) with many adjacent to or "floating" in serpentinite suggest an ophiolitic melange.

Jurassic chert crops out along the northern and northwestern margin of Sierra Bermeja (Fig. 2) in patches ranging from suitcase-sized blocks to exposures a few tens of square metres in area mostly adjacent to basalt or serpentinite. Upper Jurassic red ribbon chert in the Bermeja Complex is similar in age and physical appearance (Fig. 3) to chert in the La Désirade Basement Complex, Guadeloupe, and in the Duarte Complex, Hispaniola (Montgomery et al., 1992).

Outcrop PR92.1 (Fig. 4) is located in an arroyo at the northwestern corner of Sierra Bermeja (Puerto Rico Grid Coordinates X = 78740 and Y = 19380; Volckmann, 1984). Highly tectonized and badly weathered greenish, grayish,

Caribbean *continued on p. 4*

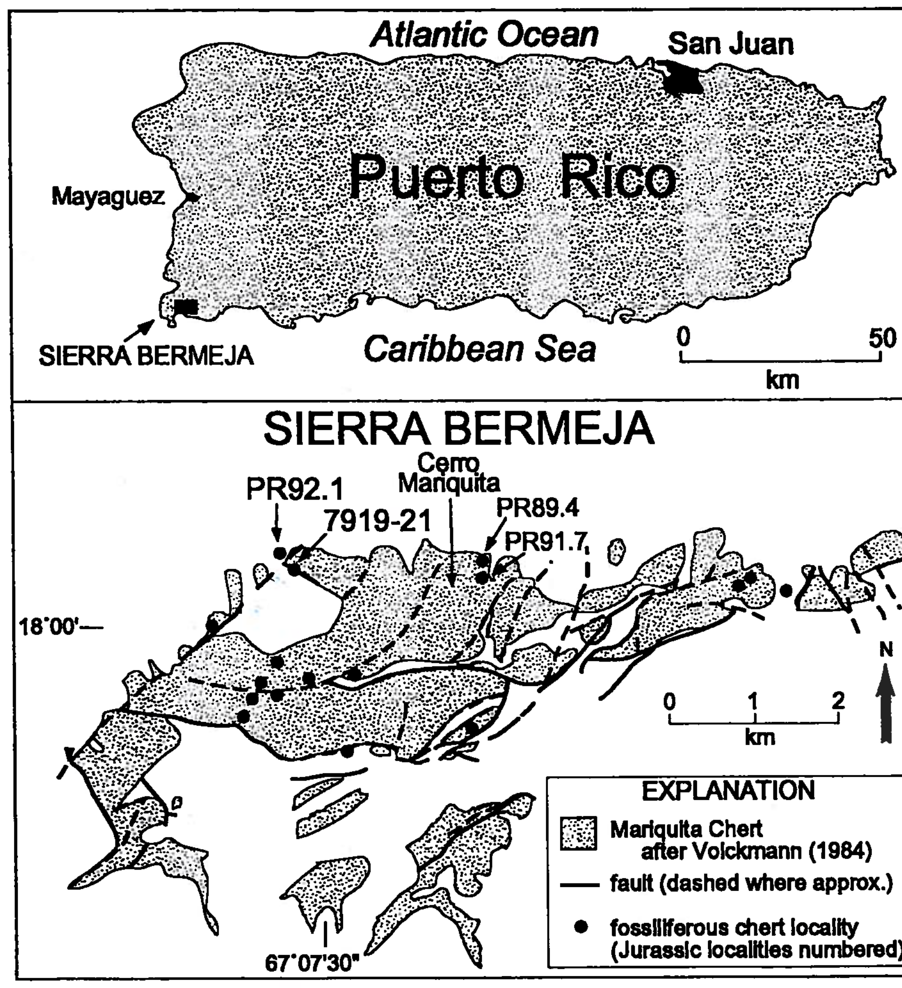

Figure 2. Chert outcrop map of Sierra Bermeja, Bermeja Complex (black rectangle in lower left of top map), southwestern Puerto Rico. Outcrop 7919-21 was sampled by Mattson and Pessagno (1979).

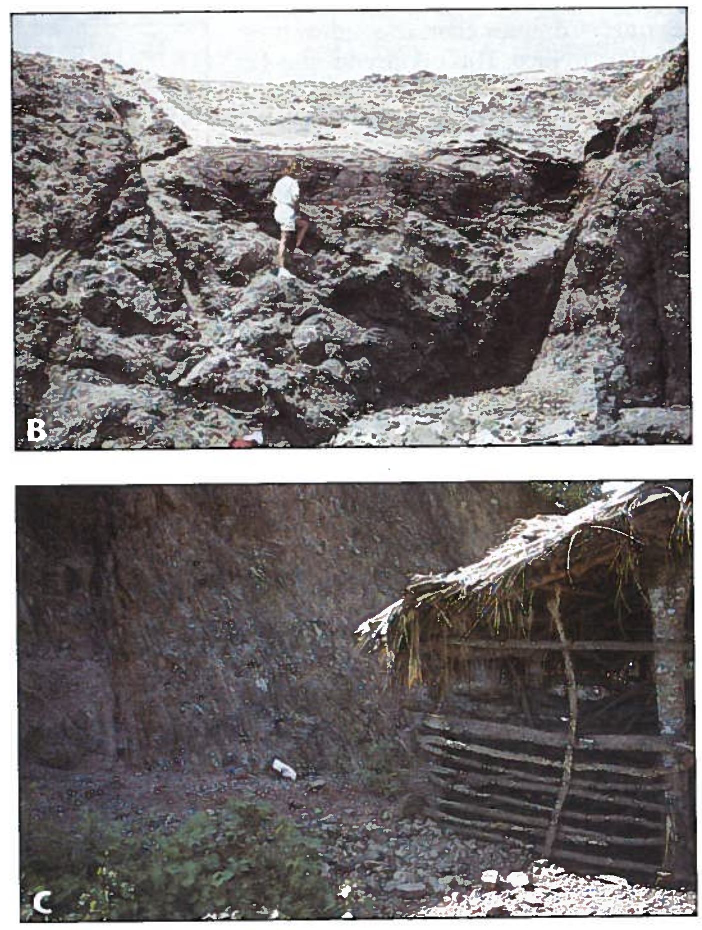

Figure 3. Jurassic red ribbon cherts of the northern and eastern Caribbean. A: Outcrop 7919-21, Sierra Bermeja, Bermeja Complex, Puerto Rico. B: Interbedded with pillow lavas on east end of La Désirade, Guadeloupe. C: Quarry near El Aguacate, Duarte Complex, Dominican Republic.

Caribbean *continued from p. 3*

and brownish chert collected across an exposure of a few square metres yielded two poorly preserved but abundant Jurassic radiolarian faunas of nonoverlapping ages (Fig. 5).

The younger fauna (PR92.1A) is early late Tithonian (Zone 4, middle Subzone 4α to lowermost Subzone 4α) in age. The older fauna (PR92.1B, Fig. 6) is clearly of Early Jurassic age and is broadly comparable with Radiolaria of the Maude Formation (Pliensbachian to Toarcian) in the Queen Charlotte Islands, British Columbia (Pessagno and Whalen, 1982) and of the Nicely (upper Pliensbachian) and Hyde (lower Toarcian) formations, in east-central Oregon (Yeh, 1987). Numerous partial specimens of *Parasaturnalis*(?) n. sp. are solid evidence of Lower Jurassic strata, because the genus is restricted to a range from upper Pliensbachian to middle Toarcian (Yeh, 1987).

The specimen *Laxtorum*(?) *jurassicum* is recorded as late Pliensbachian to Bajocian (?) by Isozaki and Matsuda (1985) from the Mino belt. Circular *Bernoullius* sp. with twisted spines is considered to be a primitive representative of this group. Common *Acanthocircus hexagonus* and rare *Pantanellium* spp. (Late Triassic to Early Cretaceous) are of little biostratigraphic utility. Poorly preserved specimens of *Lupherium* spp. (late Pliensbachian to Bajocian) are abundant. Broken *Ares* spp. are similar to specimens shown by De Wever (1982) from the Liassic (Early Jurassic) of Turkey and to *Ares* and *Parares* spp. shown by Takemura (1986) from the Mino belt.

Fossil age assignments based on Mino belt biostratigraphy are highly suspect, because the Mino belt is a melange with no megafossils associated with the chert. Also problematic is that the Mesozoic (Jurassic) Japanese radiolarian zonation is not calibrated by utilizing ammonite-based chronostratigraphic data. Comparisons of Caribbean radiolarians with closely calibrated Early Jurassic faunas from Oregon and the Queen Charlotte Islands are valid. PR92.1B specimens of *Parasaturnalis*(?) are identical to an unnamed species in our collection restricted to the upper Pliensbachian part of the Queen Charlotte Maude Formation. Similar, but not identical morphotypes were shown by Yao (1972) from the Mino belt, Japan. The particular *Parasaturnalis*(?) morphotype common in the Bermeja and the upper Pliensbachian part of the Maude Formation indicates that the PR92.1B fauna is of late Pliensbachian age (~195 Ma with reference to the 1983 Decade of North American Geology [DNAG] time scale).

PLATE-TECTONIC EVIDENCE FOR PACIFIC CARIBBEAN PLATE ORIGIN

Geologic evidence presented by Pindell (1990) suggests a Pacific origin for the Caribbean plate. First, the Lesser Antilles and Aves Ridge volcanic arc complexes in the eastern Caribbean plate provide a continuous record of westward-dipping subduction since early Late Cretaceous, indicating relative convergence for that entire time span. In addition, at least 1000 km of offset has clearly occurred on the Cayman Trough since middle or late Eocene time as indicated by the deeper, probably oceanic crustal part of the Cayman Trough and by the paleogeographic reconstruction of Cuba, Hispaniola, Puerto Rico, and the Aves Ridge fragments of the once-continuous Greater Antillean arc (Draper and Barros, 1988; Pindell and Barrett, 1990).

Figure 4. PR92.1 outcrop, Bermeja Complex, Puerto Rico. Mixed Upper and Lower Jurassic radiolarian cherts are in no coherent stratigraphic order.

Middle Cretaceous stratigraphic sequences of the Caribbean and Proto-Caribbean, the original seaway between North and South America, have been juxtaposed at suture zones around the Caribbean. The Caribbean sequence includes intrusive and volcanic rocks, volcaniclastic sandstone, tuff, and limestone on most of the islands, as well as allochthonous thrusts of Colombia and Venezuela and the interior of the Caribbean plate. The Proto-Caribbean suite includes mainly Jurassic rift-related deposits and subsequent passive margin sections without tuffs in autochthonous sequences of Yucatan, Florida-Bahamas, and northern South America, implying spatial separation at least until the Campanian.

Geometrical incompatibility is obvious between a pre-Aptian Caribbean plate and the Aptian size and shape of the Proto-Caribbean seaway. Plate separation by the Aptian was far insufficient to have accommodated a Caribbean plate of nearly its present size without a huge part being created by spreading or extended by stretching (Pindell et al., 1988).

Structural trends of the southwestern margin of Mexico have been truncated. The eastward movement of the Mexican trench–Middle America trench–Motagua-Polochic transform triple junction truncated the basement of southwest Mexico, resulted in the eastward inception of arc magmatism along the Trans-Mexican volcanic belt coeval with continued magmatism in the Chortis block, and uplifted the northern transform margin (southwest Mexico) as subduction began behind the moving triple junction.

Radiolaria of Puerto Rico (Schellekens et al., 1990) and La Désirade (Montgomery et al., 1992) are of Pacific affinity and originated at higher latitudes than is possible assuming in situ deposition.

After separation between North and South America ceased during the Late Cretaceous, shelf margins around the Proto-Caribbean underwent loading subsidence on the approach of the Caribbean plate (Pindell et al., 1988), thus terminating passive margin subsidence. Progressively eastward development of these basins documents relative movement of the Caribbean plate. Pindell (1990) suggested that a total migration of 1500 km is recorded by basin development since Campanian time. This figure is consistent with an extrapolation of the migration predicted by studies of the development of the Cayman Trough (Rosencrantz et al., 1988).

DISCUSSION

When did an ocean first occupy the spreading gap between North and South America? Part of the answer can be found in the Atlantic Ocean. Cores drilled at Deep Sea Drilling Project Site 534A in the Blake-Bahama Basin in the western Atlantic reached basalt below middle Callovian sedimentary rocks (Sheridan, 1983). The Blake Spur magnetic anomaly marking the birth of the modern North Atlantic Ocean was thus determined as early Callovian in age (Sheridan, 1983). Anderson and

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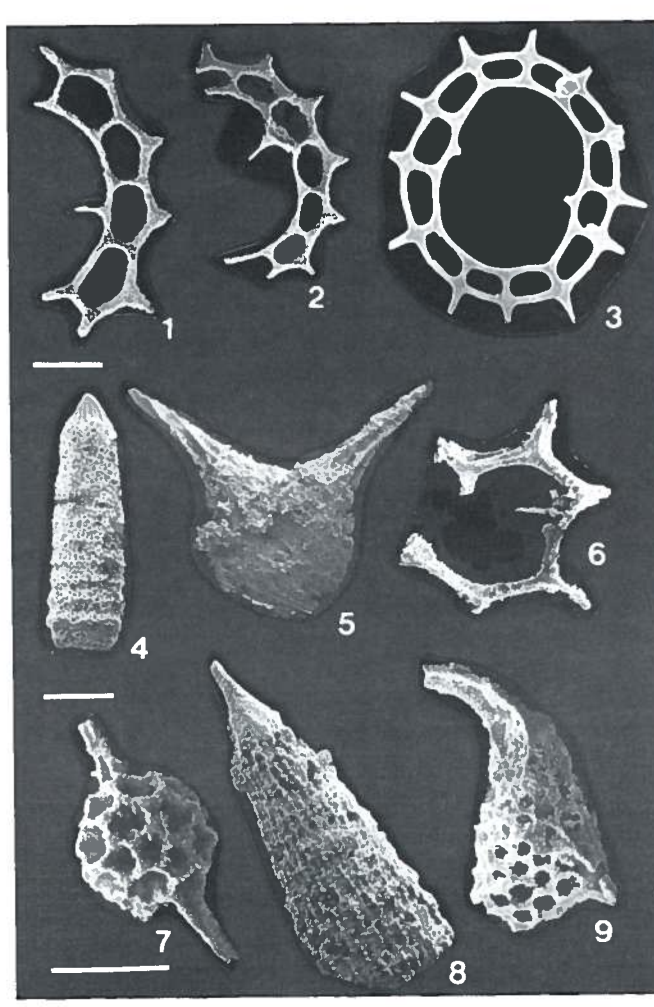

Figure 5. Scanning electron photomicrographs of Radiolaria from Lower Jurassic chert, Sierra Bermeja, southwestern Puerto Rico (PR92.1B) and British Columbia. Scale bars are 100 µm for each row. 1 and 2—*Parasaturnalis*(?) sp.; 3—*Parasaturnalis*(?) n. sp. from the Maude Formation, Queen Charlotte Islands, British Columbia; 4—*Laxtorum*(?) *jurassicum*; 5—*Bernoullius* sp.; 6—*Acanthocircus hexagonus*; 7—*Pantanellium* sp.; 8—*Lupherium* sp.; 9—*Ares* sp.

Schmidt (1983) presented evidence of a Callovian age for the origin of the Caribbean. Therefore, we assume that a fully open Proto-Caribbean–Atlantic seaway was a Callovian event with an age of ~165 Ma (1983 DNAG time scale).

How old is the Caribbean plate? The answer to this question depends on where you look. Deep sea drilling of oceanic crust south of Hispaniola yielded Turonian basalt (Edgar et al., 1973), but drilling did not reach true oceanic basement. At least part of the Caribbean plate (La Désirade, Bermeja, and Duarte) is Jurassic. Lower Jurassic radiolarian chert establishes Bermeja as the oldest known island terrane on the Caribbean plate.

What is the significance of red ribbon chert? Red ribbon chert interbedded with basalt in ophiolitic complexes was presumed to have originated at mid-ocean ridges (Hopson et al., 1981). The characteristic MnFeO-rich umbers of the chert are probably due to hydrothermal activity at an active ridge-crest such as has been observed at the Galapagos and East Pacific rise spreading ridges (Hopson et al., 1981). The Caribbean Jurassic red cherts are dark and MnFeO-rich, and most are interbedded, or at least associated, with basalt.

Discussion of one other possible Jurassic terrane is of importance. The Puerto Plata basement complex exposed along the north coast of the Dominican Republic contains pillow lavas with jasper rinds and other volcanic rocks with chert and limestone nodules and limestone masses. The limestones contain Late Cretaceous (early Campanian) radiolarians in HCl-acid residues. A few samples of greenish chert produced rare and poorly preserved Radiolaria including possible *Vallupus hopsoni*, a Late Jurassic (Tithonian) form. The Puerto Plata basement complex is located on the northern side of the Greater Antillean arc and thus is thought to be a remnant of Proto-Caribbean crust. This exposure is unlike the La Désirade, Bermeja, and Duarte terranes because it lacks red ribbon chert.

Development of the Greater Antillean arc during Cretaceous time remains a subject of debate: did subduction proceed from the south or the north? Island-arc magmatism occurred in Hispaniola, Puerto Rico, the Virgin Islands, Jamaica, and Cuba during the Early Cretaceous. The arc probably began subducting the Farallon plate from the south with polarity flipping during the Aptian (Pindell, 1993), and moving in a relative northeastward direction into the gap between North and South America (Fig. 7) subducting the Proto-Caribbean plate.

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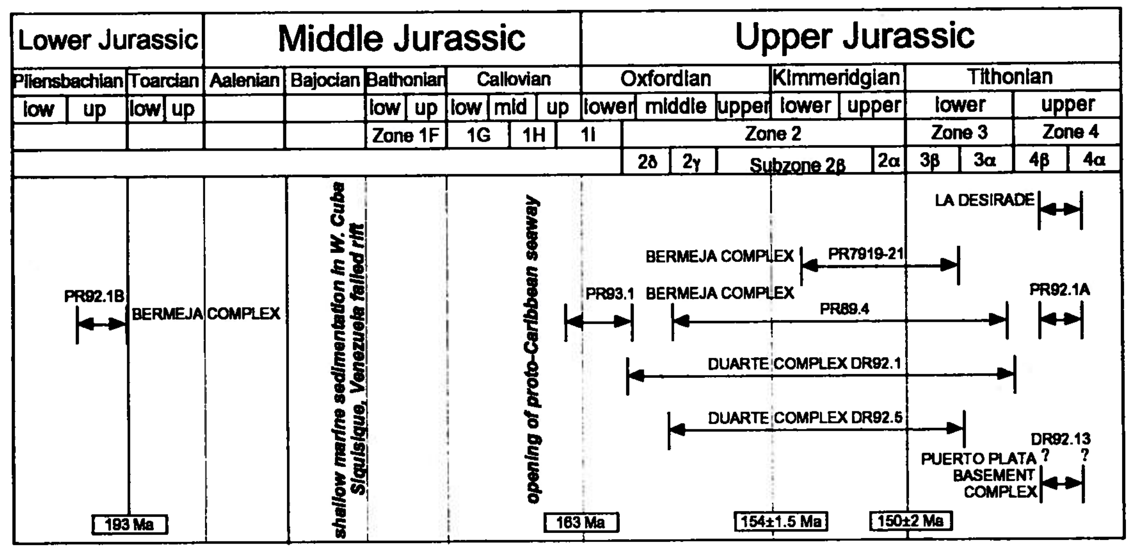

Figure 6. Age ranges of radiolarian chert from Jurassic Caribbean terranes. The lines are maximum possible age ranges and are longer where biostratigraphic control is weaker. Kimmeridgian-Tithonian picks are after Pessagno and Blome (1990). Pliensbachian-Toarcian pick is after 1983 DNAG time scale. Some of the Puerto Rico (PR) sample locations are shown in Figure 2. Dominican Republic sample DR92.1 was taken near Janico, DR92.5 near El Aguacate, and DR92.13 from the Puerto Plata basement complex east of Maimon Bay. La Désirade samples are from cherts on the east and west ends of the island.

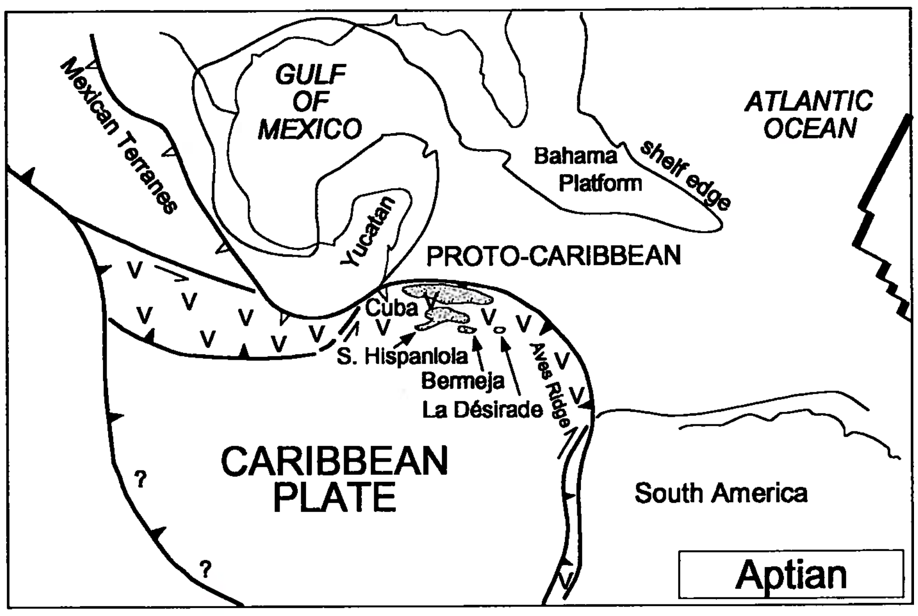

Figure 7. Reconstruction of the Caribbean region during the Early Cretaceous (Aptian) immediately after subduction zone polarity flipped from west-facing to east-facing, marking the entrance of the Caribbean plate into the spreading gap between North and South America.

Caribbean *continued from p. 5*

The plate-tectonic arguments presented cannot be explained within the confines of in situ Caribbean plate evolution. The discovery of Early Jurassic radiolarians in Puerto Rico significantly predating the opening of the Proto-Caribbean and North Atlantic seaway is strong justification for an allochthonous origin of the Caribbean plate. At ~195 Ma, the oldest Bermeja Complex chert certainly cannot be obducted Proto-Caribbean crust. The presence of Lower Jurassic chert in a Middle Jurassic sea cannot be explained without arguing that Pangea never existed.

ACKNOWLEDGMENTS

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