Pre-Jurassic History

No unequivocally dated Paleozoic rocks have been identified from the Greater Antilles. As stated by H. A. Meyerhoff (1954, p. 149), "Attempts to decipher the pre-Jurassic evolution of the Antilles have been unsuccessful." Nevertheless the area must have had a pre-Jurassic history, whether as the site of oceanic crust, a segment of continental crust now basified, or a Paleozoic basin.

Another possibility is raised by the hypothesis of continental drift. This possibility seems to be the most remote of all, insofar as the history of the Greater Antilles is concerned. This opinion is supported by a wide variety of evidence. (1) If one accepts the reconstruction for Late Jurassic-Early Cretaceous time by Bullard and others (1965), then the southern tip of Florida would have been adjacent to the Republic of Guinea. In Guinea, the Cretaceous section is thin—almost nonexistent—and consists of terrestrial conglomerate and red beds (Reyre, 1966). The Florida-Bahamas-north Cuba Cretaceous is bank limestone and evaporite without terrigenous residue. (2) Late Jurassic (Tithonian) deep-marine deposits have been recovered during deep-sea drilling east of the Bahamas (Am. Geol. Inst., 1968). (3) The Florida Cambrian or late Proterozoic basement, or both (Bass, 1969), would have been adjacent to an early to middle Precambrian basement in Africa (Hurley and others, 1967). (4) The Cape Verde Islands are part of a fold belt of bathyal to neritic Late Jurassic, Cretaceous, and early Tertiary marine strata (Heinz, 1935; Stahlecker, 1935; Pires Soares, 1948) 400 mi west of Dakar. This belt, if involved in drift, would have overlain much of what is now Georgia and northeastern Alabama. (5) The Early and Middle Jurassic of Cuba is partly marine (Krömmelbein, 1956; Imlay, 1964). (6) The presence—and existence—of flat-lying, undisturbed, bathyal, Jurassic and Cretaceous sediments of the Hatteras plain (Fig. 9) (J. Ewing and others, 1966; Habib, 1969; Am. Geol. Inst., 1968) are impossible to explain if drift has taken place since Paleozoic time. Moreover, the almost complete lack of distortion of these beds beneath the continental shelf, on the slope and rise, and in mid-ocean fracture zones is one of the most remarkable phenomena of nature if sea-floor spreading has taken place (A. A. Meyerhoff, 1969, 1970). (7) Nearly 500,000 square miles of Precambrian and Paleozoic real estate, underlying Mexico, all of Central America, southern Florida, and probably most of the Bahamas, Cuba, and the Nicaragua Rise, must be omitted entirely from the Bullard and

others (1965) reconstruction. (8) The Tertiary and Cretaceous sediments in the Puerto Rico Trench are flat-lying and nearly undeformed. (9) The ammonites of the Greater Antilles, particularly the Jurassic ammonites, show that they developed in a distinct faunal province, widely separated from any known in Europe and Africa. It is true that there are some common genera and species, but the great differences are more difficult to explain than the similarities. (10) Finally, the volcanic history itself of the Greater Antilles suggests in-place development, that is, a period of long stability. Preliminary study of the potash-versus-silica variations from the few specimens studied of the Greater Antillean lavas, and chemical analyses in general, suggest that the Greater Antilles are a genetic unit whose lavas have evolved in place from a considerable depth in the mantle (Donnelly, 1966b; Dickinson and Hatherton, 1967; Dickinson, 1968; Donnelly and others, 1969; Kesler, 1968a, 1968b; Nelson, 1968b, 1969). If drift has occurred, a very thick section of the upper mantle (120 km thick or more, if Dickinson's conclusions are correct) has moved with the sea floor and the Greater Antilles arc above it.

NATURE OF CARIBBEAN SEA AND GULF OF MEXICO

Khudoley believes that there are no pre-Jurassic rocks exposed at the surface in Cuba, and that the present areas of both the Caribbean and the Gulf of Mexico were landmasses during Early Triassic time. The presence of such landmasses seems to be necessary to explain certain aspects of Jurassic history. First, the Early-Middle Jurassic San Cayetano Formation of western Cuba, and probably equivalent metasediments elsewhere on the island, are terrigenous clastic rocks, 1500 to 5000 m thick. A nearby landmass is required as a source for these rocks. A similar observation has been made by several geologists, and was expressed most forcefully by Bucher (1947, p. 104). Second, the vast Jurassic salt basins of the Gulf of Mexico-northern Cuba area required an effective barrier and the presence of a shallow-water basin for the salts to have precipitated. The last condition would obtain if the Caribbean, or at least the western part of it, and the Gulf of Mexico were continental blocks near or above sea level.

Meyerhoff, in contrast, believes that the site of the present Caribbean was a more open, unrestricted ocean basin than it is today. According to his concept, the Nicaragua Rise-Cayman Ridge complex was a Paleozoic orthogeosyncline, part of the Northern Central America orogen (A. A. Meyerhoff, 1967). South and east of the Nicaragua Rise, the Caribbean was open toward the Atlantic and no island barriers were east of eastern Cuba or Haiti. On the south and west, there was no Isthmus of Panama and the Caribbean was open into the Pacific basin. Therefore, during Paleozoic and early Mesozoic times, there was no Caribbean Sea south of the Nicaragua Rise, but a deep ocean strait connecting the Atlantic and the Pacific.

Meyerhoff also believes that, during the same period of time, the Gulf of Mexico was an oceanic basin. Meyerhoff's reasons for believing that both the Gulf of Mexico and Caribbean Sea always have been oceanic are given subsequently in the section on "Early and Middle Jurassic."

NICARAGUA RISE-BARTLETT TROUGH-CAYMAN RIDGE

According to Khudoley, the Nicaragua Rise and Cayman Ridge are remnants of the continental landmass which once occupied the present Caribbean Sea. Meyerhoff's concept is the reverse: whereas Khudoley advocates basification and foundering, Meyerhoff regards these submarine ridges as having resulted from continental accretion.

A possible origin of the Nicaragua Rise-Bartlett Trough-Cayman Ridge complex was outlined in more detail by A. A. Meyerhoff (1966, 1967). Meyerhoff believes, as did Suess (1909, p. 524–525), that this rise-trough-ridge system is part of a geosynclinal complex which originated in Paleozoic time. Presumably this geosynclinal complex was a site of deposition and orogenesis until Tertiary time. In this regard, the recent discovery of folded Oligocene or early Miocene deep-sea siltstone under the Miocene-Holocene limestone cover of Swan Island is significant (U.S. Geol. Survey, 1967b), because Oligo-Miocene shallow-water limestone of possibly the same age is undeformed on the Cayman Islands (Matley, 1926).

A. A. Meyerhoff (1966) compared this double ridge and trough system with the double arcs of the Bonin-Marianas, in the western Pacific, and the Lesser Antilles. About 160 to 200 km west of the Bonin-Mariana arcs is a parallel submarine ridge. Dietz (1954) called these the First and Second Honshu-Mariana Ridges. The deep trough between the two ridges is underlain by oceanic crust and a moderately thin layer of sediments. Similarly, the double arc of the Lesser Antilles is composed of the Limestone and Volcanic Caribbees (Lesser Antilles *s.s.*) on the east, and the Aves Ridge on the west (Fig. 1). The two arcs are separated by 150 to 180 km of oceanic crust overlain by a sedimentary layer 1.5 km thick (Bunce and others, 1968). This section is surprisingly thin if the two ridges continuously provided sediments to the intervening trough.

The Cayman Ridge and Nicaragua Rise are separated by a similar distance, 120 to 180 km; the Bartlett Trough is underlain by oceanic crust (J. Ewing and others, 1960); and, except at the western end, close to Honduras, the sedimentary layer at the bottom of the Bartlett Trough is thin (0.5 to 1.2 km: J. Ewing and others, 1960; Bowin, 1968). Therefore, the origin of the Nicaragua Rise-Bartlett Trough-Cayman Ridge complex is believed to be analogous to that of the First and Second Honshu-Mariana Ridges, and the Lesser Antilles-Aves Ridges.

This interpretation has been challenged for a variety of reasons by A. R. McBirney (1962, 1966, written communs.), McBirney and Bass (1969a), Dengo and Bohnenberger (1969), and T. W. Donnelly (November, 1967, oral commun.). McBirney argued that the Bartlett Trough would have been filled in the 300 m.y. or longer time span involved. This criticism is considered by Meyerhoff to be invalid for various reasons. For example, in the western Pacific, the Ryukyu arc, which is Permian and older (Kobayashi, 1954; Hanzawa, 1957, 1961), is separated from the mainland shelf on the west by more than 2000 m of water in the East China Sea. Even though the East China

Sea has been a sediment trap for more than 300 m.y., it still is not filled. A more striking example is the Sea of Japan, which is known to be a modified oceanic basin in some places and a typically oceanic basin in others (Korylin and others, 1966; Rikitake and others, 1968). The Japan arc has existed since earliest Ordovician or latest Cambrian time (Matsumoto and others, 1968), yet the Sea of Japan attains depths greater than 3000 m and has a sedimentary layer only 0.7 to 1.7 km thick (Korylin and others, 1966). If the sediment thicknesses of these western Pacific areas are compared with those of the Nicaragua Rise-Bartlett Trough-Cayman Ridge system, the thin sedimentary section in the central and eastern Bartlett Trough area should not be surprising. The presence of oceanic crust and thin sediments is even less surprising if the Nicaragua Rise and Cayman Ridge have been submerged during much of their existence. Edgar's (1968) seismic data from the Nicaragua Rise suggest that the rise has been a depositional site for much of its history. In fact, Arden (1969) wrote that thousands of square kilometers of the rise are underlain by approximately 6000 m of sedimentary strata. The present depth of the Bartlett Trough may be a more recently acquired characteristic, and unrelated to the thickness of the sediment fill.

If the Nicaragua Rise-Cayman Ridge complex is part of a Paleozoic orthogeosyncline, it probably is an eastward extension of the Northern Central America orogen (A. A. Meyerhoff, 1967) which extends from Chiapas State, Mexico, to eastern Honduras. In Guatemala, British Honduras, and Honduras, this orogen is underlain by at least two sequences of Paleozoic rocks: a younger nonmetamorphic Pennsylvanian-Permian sequence, and an older metamorphic sequence. Granitic rocks intruding the older metamorphic sequence have yielded a radiometric date of 345 m.y. (Late Devonian to Early Mississippian) and detrital zircon in the Chuacús series of uncertain age yielded a date of 1075 m.y. (Gomberg and others, 1968; McBirney and Bass, 1969b). Overlying the Paleozoic strata are a Jurassic red-bed sequence, a Cretaceous carbonate succession, and younger rocks.

The assumed Paleozoic age for the oldest geosynclinal rocks of the Nicaragua Rise and Cayman Ridge is based on the following observations: (1) the structural trends of Paleozoic and/or basement rocks in Honduras are on trend with the Nicaragua Rise and strike offshore directly toward Jamaica; in British Honduras, Paleozoic trends of the Maya Mountains strike toward the Cayman Ridge. (2) The basement-rock structural trends of the Bay Islands at the northwestern end of the Nicaragua Rise and just south of the Bartlett Trough parallel the rise and trough (McBirney and Bass, 1969a). (3) The Punta Gorda and Twara wells along the east coast of Nicaragua, just south of the map area of Figure 1, reached total depth in basement rocks (Hoylman and Chilingar, 1965); this fact shows that the southwestern part of the rise also is underlain by probable Paleozoic or older rocks. (4) The rise is continuous from onshore Nicaragua and Honduras to western Jamaica, although it may be broken locally by transverse faults close to Jamaica. (5) The Cayman Ridge projects completely across southern Oriente Province, Cuba, into an area of metamorphic rocks of unknown (but Jurassic or older) age in southeastern Oriente.

Although no one of these observations and possibilities is proof of age, together they support Meyerhoff's concept that the rocks and structural trends which underlie the present rise-trough-ridge complex may be as old as Paleozoic.

FLORIDA AND BAHAMAS PLATFORM

The oldest sedimentary rocks known to underlie parts of northern and central Florida are of Early Ordovician through Middle Devonian ages (Applin, 1951; Bridge and Berdan, 1952; Braunstein, 1958; Carroll, 1963, Berdan, 1965). These are nonconformable on a varied silicic plutonic, metamorphic, and volcanic basement, and are overlain with angular discordance by Early Cretaceous carbonates and evaporites in central and southern Florida, and by Early Cretaceous terrigenous clastics in northern and northwestern Florida. In some places, red beds and volcanic rocks of probable Late Triassic age underlie the Cretaceous. In southernmost Florida, Late Jurassic carbonates and evaporites are present below the Cretaceous. A structural contour map of the basement beneath southern Florida and the western Bahamas, by R. E. Sheridan and others, has been published by Drake (1966). This map shows that at least 11 km of sedimentary rocks overlies the basement rocks in this area.

Basement rocks in Florida yield radiogenic dates ranging from 480 to 530 m.y. (Muehlberger and others, 1966, their Table 4; Bass, 1969; Milton and Grasty, 1969). The 480-m.y. date is Early Ordovician on the Kulp (1961) time scale; because Early Ordovician sedimentary rocks overlie the basement, the minimum age is more likely to be 530 m.y. (Middle to Late Cambrian) or older.

Gravity and magnetic data (Richards and Malone, 1949; Lee, 1951; Davidson and Miller, 1956; Miller and Ewing, 1956; King, 1959; Talwani, 1960; Talwani and others, 1960; Bracey, 1963; Soloviev and others, 1964a, 1964b; Heirtzler and others, 1966; Gough, 1967; Oglesby, 1967) show that the continental crust underlying Florida extends southward to the southern edge of Cuba, and eastward to the easternmost Bahamas—possibly to the Turks and Caicos Islands. The Sheridan and others map (*in* Drake, 1966, p. 43) confirms the gravity and magnetic data. There is no assurance that the crust beneath Cuba and the Bahamas is of the same age as that beneath Florida, but the possibility is good that it is at least Paleozoic and possibly Precambrian.

TRIASSIC(?) AND PALEOZOIC(?) IN CUBA

Discussion

The age of various metamorphic rocks in Cuba (Fig. 6) has been the subject of controversy since the days of Crosby (1883) and Hayes and others (1901). The metamorphic rocks have been assigned variously to the Paleozoic, Trias-

sic-Jurassic, Jurassic, Early Cretaceous, Late Cretaceous, and even early Tertiary.

Ascertaining the age is a major problem because (1) fossils, if they were present, are no longer recognizable; (2) complicated folding and faulting have affected the rocks so that original depositional sequences are difficult to reconstruct; and (3) metamorphic grade shows considerable variety in different and even in the same areas.

Khudoley believes that all of the metamorphic rocks are most likely to represent sedimentary and associated rocks of Early and Middle Jurassic ages. Khudoley bases his opinion on the facts that (1) the San Cayetano Formation of Pinar del Río Province (Fig. 6) contains Middle Jurassic fossils; (2) certain metamorphic rocks of the Isle of Pines, Sierra de Trinidad (southern Las Villas Province), and eastern Oriente Province (Fig. 4) resemble the nonmetamorphic to very low-grade metamorphic San Cayetano strata; and (3) radiogenic dates thus far do not substantiate ages older than Jurassic. However, Khudoley (1967a, p. 672) recognizes the possibility that the Isle of Pines and Trinidad metamorphic rocks are not Early and Middle Jurassic. In another article, Khudoley (1967b, p. 789) wrote, "The age problem of the metamorphic rocks in the Sierra de Trinidad of southern Las Villas Province, Isla de Pinos, and in eastern Oriente Province is not solved now and we can only guess at the ages of these rocks." He grants that Triassic and Paleozoic rocks probably are present on the island but believes that they are not exposed.

Figure 6. Index map of Cuba; shows principal phenomena and localities mentioned in text, including radiometric date localities of Table 4. Shows location of Figure 15.

Meyerhoff believes that Paleozoic, and possibly Triassic, rocks are exposed on Cuba. Triassic rocks, if present, could comprise the lower part of the San Cayetano Formation of Pinar del Río Province. However, the San Cayetano is so lithologically monotonous and so severely deformed that it has not been possible to reconstruct a complete section. The marine fauna (Krömmelbein, 1956; Imlay, 1964) and terrestrial flora (Vakhrameyev [Vachrameev], 1965, 1966) which have been collected are believed to be from the upper part of the San Cayetano. If this is correct, the age of the lower part of the formation is yet to be determined.

The presence of Paleozoic, and possibly Triassic, in Cuba is suspected by Meyerhoff for the following reasons:

1. In the Sierra de Trinidad, southern Las Villas Province, at least two metamorphic series are present (Hatten and others, 1958). It is possible that two sequences are present also on the Isle of Pines. The younger is an incipiently metamorphosed to low-grade metamorphic sequence (generally less than greenschist facies)—including altered shale, altered siltstone, quartzite, and marble—that is very similar lithologically to the Jurassic San Cayetano and Artemisa Formations. These younger metamorphic rocks are exposed in several localities along the north flank of the Sierra de Trinidad, and possibly on the Isle of Pines. They are especially well exposed 8 to 9 km south of Manicaragua, Las Villas Province (Fig. 6).

The second, or older, metamorphic sequence is exposed within the Sierra de Trinidad and its flanks. It has been described by Thiadens (1937), Hill (1959), Tijomirov (1967), and A. A. Meyerhoff and Hatten (1968); similar rocks on the Isle of Pines have been described by L. Rutten (1934), Page and McAllister (1944), Kuman and Gavilán (1965), and Tijomirov (1967).

Generally the older sequence consists of medium-grade metamorphic rocks (the range is from low to high grade) of both volcanic and sedimentary origin, and is very different from the first sequence both in composition and degree of metamorphism (Hatten and others, 1958; Tijomirov, 1967). Two gross units are identifiable in the Sierra de Trinidad: (1) the San Juan Marble of Hatten and others (1958), and (2) the Trinidad Formation (Trinidad series of Hatten and others, 1958; "Schist series" of Thiadens, 1937). Hatten and others placed the San Juan Marble at the base of the section, whereas Hill (1959), Rigassi (1961), R. Engel (1962), and many others placed it above the Trinidad Formation and correlated it with the Late Jurassic Viñales Limestone of Pinar del Río Province (*see* Fig. 8, this paper). Most workers have correlated the Trinidad Formation with the Early to Middle Jurassic San Cayetano Formation (Fig. 8).

The type area of the San Juan Marble is the Sierra de San Juan at the western end of the Sierra de Trinidad, Las Villas Province (Fig. 6). The estimated thickness is 3000 to 4500 m. According to Hill (1959), the San Juan Marble is dynamically metamorphosed, and consists of 90 percent limestone. The remainder is dolomite with gypsiferous bands, and some brucite limestone. No evidence of contact metamorphism by batholithic intrusions has been reported.

Typical exposures of the Trinidad Formation, representing an estimated thickness of 4500 to 5000 m, are along the Río Jibacoa (Fig. 6), north of Magua, on the southeastern side of the Sierra de Trinidad and are observed to the northern side of the Sierra de Trinidad. Just north of the Trinidad Formation, and separated from it by a major, north-dipping fault, are exposures of the San Cayetano(?) equivalent. Much of the Trinidad Formation belongs to the epidote-amphibolite facies of Barth (1962). The strata are intensely deformed, and isoclinal folding is characteristic (Hill, 1959). For this reason, no accurate thickness measurement has been made. Rock types include epidote-quartz-mica schist, graphitic schist, gneissic quartzite, garnet-bearing graphitic quartzite, coarsely crystalline gneiss, chlorite schist, actinolite schist, and serpentinitic schist derived from peridotitic rocks. Amphibolite and metagabbro also are present. The ultrabasic rocks are believed (without proof) to be much older than the Mesozoic serpentinites farther north. The Trinidad Formation underlies most of the eastern and central Sierra de Trinidad, and Hill's (1959, p. 1461) statement that ". . . the Trinidad Mountains consist predominantly of limestone" applies only to the western part.

On the Isle of Pines, the San Juan Marble apparently is absent, or, if the San Juan Marble of the Sierra de Trinidad overlies the Trinidad Formation, may be equivalent to the Gerona Marble. The Gerona Marble is believed by most writers to be a Viñales Limestone (Late Jurassic) equivalent (Fig. 8). The rocks which have been regarded as equivalents of the Trinidad Formation include a wide variety of metamorphic grades: quartzitic phyllite, quartzite, and graphite-sericite schist (greenschist facies); biotite schist, biotite-staurolite schist, and garnet muscovite schist (epidote-amphibolite facies); and sillimanite schist with sphene (amphibolite facies). The Isle of Pines section is intruded by peridotite (metamorphosed to serpentinite), gabbro (some gabbro is metamorphosed to amphibolite), and granodiorite. Only the granodiorite and some gabbro are unmetamorphosed. In addition, some gneiss aureoles surround the silicic intrusive bodies. Two differences between the Isle of Pines sequence and the Trinidad Formation are the greater abundance of quartzite on the Isle of Pines and the wide range of metamorphic grades within a small area. Although igneous intrusion may have caused the diverse metamorphic facies, it is possible that two metamorphic units of different ages are present. The quartzitic and phyllitic rocks resemble the Early-Middle Jurassic San Cayetano Formation, although the percentage of quartz appears to be less than that in the San Cayetano (Rigassi, 1963). The higher grade metamorphic rocks on the Isle of Pines suggest that part of this section is equivalent to the San Juan Marble and Trinidad Formation.

The correlation of the Gerona Marble, however, is a problem. Kuman and Gavilán (1965, p. 24) wrote: "Concordantly above the quartz schist sequence is a thickness of marble, which corresponds to the Viñales sequence in Pinar del Río Province." On page 26 they wrote: "Concordant above the marbles are metamorphic, graphitic schist, whose composition is not clear because of deep weathering. . . . Apparently the schists are analogous to the graphite-

sericite and graphitic quartz-muscovite schists of the [underlying] quartz schists."

These statements show that the Gerona is sandwiched between two schist series and leave the correlation of the Gerona in doubt and confusion. Possibly the sandwiching resulted from faulting, but this is speculation.

In Meyerhoff's opinion, the grade of metamorphism is an important factor in the correlation of Cuban metamorphic units because, in the Sierra de Trinidad, the incipiently metamorphosed to low-grade metamorphic San Cayetano Formation is present together with the medium-grade Trinidad Formation, and the two units thus are readily differentiated in the field. Careful mapping of metamorphic facies in the Isle of Pines is necessary to determine whether both the San Cayetano-Viñales and an older metamorphic series are present.

2. Exotic blocks of the Trinidad types of metamorphic rocks, especially actinolite schist, are present in the Mesozoic serpentinites north of the Sierra de Trinidad and south of Santa Clara, Las Villas Province, and in Camagüey Province (M. Rutten, 1936; MacGillavry, 1937; Flint and others, 1948; Wassall, 1956) (Fig. 6). Other inclusions in the serpentinites are phyllite, tactite, hornblende-diorite gneiss, glaucophane schist, and eclogite-like rocks. According to Turner (1958, p. 225), the glaucophane assemblages in Cuba can be shown to be retrograde metamorphic products of the eclogite assemblage. The presence of several grades of metamorphism within the included blocks shows that these rocks were metamorphosed *before* incorporation in the serpentinite, which belongs to the Late Jurassic(?)-Cretaceous eugeosynclinal sequence of southern Cuba. This sequence *overlies* with angular unconformity the metamorphic rocks of both the Sierra de Trinidad and Isle of Pines (Rigassi, 1961; Kuman and Gavilán, 1965). Recently, in 1970, a well drilled in the Jatibonica oil field (well no. 78), 30 km southeast of the Jarahueca fenster (Fig. 6), penetrated 159 m of chloritic schist (depth 4208 to 4367 m) below Jurassic(?) and Cretaceous serpentinite and volcanic rocks.

3. Hatten and others (1958) described medium-grade metamorphic rocks from an area 20 km east of the Jarahueca fenster of Las Villas Province (*see* Fig. 6 and Hatten's [1967] Fig. 2). These metamorphic rocks crop out on the median welt (marginal elevation of Furrazola-Bermúdez and others, 1964, 1965; *see* Tables 2, 3, and Figs. 6, 8) of the Late Jurassic-early Tertiary geosyncline and are overlain by Neocomian, Aptian, and Albian limestone, shale, arkose, and basic volcanic rocks (Khudoley believes that there is no proved Neocomian in Cuba). The metamorphic rocks of the Jarahueca area consist of silicified and magnesian hornfels, calcic hornfels, cordierite schist, hornblende-plagioclase schist, and metagraywacke. They are intruded by troctolite, and both the metamorphic rocks and troctolite are intruded by quartz monzonite. A K-Ar date (by Lamont Geol. Observatory, *see* Table 4) from the monzonite (Fig. 6) gave a minimum age of 61 m.y. (A. A. Meyerhoff and others, 1969; erroneously given as 67 m.y. by A. A. Meyerhoff and Hatten, 1968), but the age apparently was determined from secondary biotite formed during the "Laramide" orogeny, because the monzonite is overlain by fossili-

TABLE 2. RELATIONS BETWEEN LARGE STRUCTURAL FEATURES OF ORTHOGEO-
(LATE JURASSIC TO

Authors	*Volcanic*		*Mixed*	
Rutten (1936)		Southern facies		
Brönniman (1954)†, *in* Furrazola and others (1964); *see* Brönnimann and Pardo (1956)	Cabaiguán belt	Domingo belt	Cifuentes belt	Placetas belt
Wassall (1956)	Clastic-volcanic facies			
Hatten and others (1958), *in* Solsona and Judoley (1964)*	Manicaragua tecto-unit	Zaza tecto-unit	Las Villas tecto-unit	
Ducloz and Vuagnat (1962) and Meyerhoff and Hatten (1968)	Santa Clara zone		Placetas zone	
Solsona and Judoley (1964), Khudoley (1967a; this paper)*	Zaza facies-structural zone (eugeosyncline)		Las Villas facies-structural zone (marginal elevation of the	
Meyerhoff (this paper)	eugeosyncline		median welt	

*Note: Boundaries between facies-structural zones as drawn by Hatten and others (1958), as shown in this table. This table is simplified to minimize confusion.
†Unpublished report.

ferous earliest Cretaceous (or latest Jurassic) strata. Therefore, 61 m.y. cannot be the true age of the metamorphic-igneous complex of the median welt.

4. Kozary (1953) described exotic blocks of metamorphic rocks, derived from the south, in early Tertiary (middle Eocene?) Wildflysch in the Cubitas Mountains-Lomas de Camaján area (Fig. 6), northern Camagüey Province. Hatten (1957; and *in* A. A. Meyerhoff and Hatten, 1968, p. 321) found similar exotics, mainly of garnet-mica schist, in Maestrichtian-early Eocene Wildflysch south of La Palma, northern Pinar del Río Province (Fig. 6). The metamorphic grade of these exotic blocks is much higher than that of the San Cayetano Formation but is similar to that of the older metamorphic sequence of the Isle of Pines and Sierra de Trinidad.

5. North of the Trinidad Mountains, Hatten and others (1958) reported that a major fault (north-dipping to vertical) separates the Sierra de Trinidad sequence from a band of meta-igneous rocks along the north side of the mountains. Hatten and others wrote that most, but not all, of the meta-igneous rocks are amphibolite and that they are equivalent to the Early-middle Cretaceous eugeosynclinal sequence of southern Cuba. Hill (1959) confirmed the presence of this fault and reported that, locally, the meta-igneous sequence overlies the Trinidad Formation.

Intruding the amphibolite is the Sancti Spiritus batholith (Fig. 6), a large east-west-striking body of granodiorite, quartz diorite, and diorite on the northern side of the amphibolite. Hatten and others (1958) reasoned that this batholith, which parallels the entire north flank of the Sierra de Trinidad, was intruded during a middle Cretaceous orogeny. The intrusive relations between

SYNCLINE AND FACIES-STRUCTURAL ZONES IN CENTRAL CUBA-BAHAMAS REGION
MIDDLE EOCENE)

Deep-Water Carbonate		*Bank Carbonate*		*Bank Carbonate-Evaporite*		
Northern facies						
Las Villas belt	Jatibonico belt	Sagua la Chica belt	Yaguajay belt	Coastal belt		
Limestone facies		Evaporite facies				
Zulueta tecto-unit		Remedios tecto-unit		Cayo Coco tecto-unit		
Camajuaní zone		Remedios zone				
		Remedios facies-structural zone		Cayo Coco facies-structural zone	Old Bahama Channel facies-structural zone	Bahamas platform
geosyncline)		(miogeosyncline)				(parageosyncline)
miogeosyncline (leptogeosyncline)		platform (including autogeosyncline)				

and by Solsona and Judoley (1964), and Khudoley (1967a) actually do not precisely coincide

the granodiorite and the amphibolite are seen clearly in the field. The north side of the amphibolite-granodiorite complex is a major reverse and wrench fault which Hatten (*in* Hatten and others, 1958) called the "Tuinicú fault" (*see* Furrazola-Bermúdez and others, 1964, 1965; *see also* Fig. 6).

Recently, the problem was complicated even more. A whole-rock radiogenic date of 180 m.y. ± 10 m.y. was obtained for the Sancti Spiritus granodiorite by the Laboratory of the All-Union Institute of Geological Researches, Leningrad (Table 4). This date is Late Triassic or Early Jurassic on the Kulp (1961) scale, and is Early Jurassic on the Afanassyev and others (1964) scale (*see* Soc. Belge Géologie, 1967). Khudoley questions the validity of the date, as does Hatten (*in* A. A. Meyerhoff and others, 1969), on the grounds that the granodiorite appears to intrude the meta-igneous rocks of possible Early to middle Cretaceous age along the north flank of the Sierra de Trinidad. Meyerhoff believes that it is too soon to dismiss this 180-m.y. date as an error, because (1) the relations between the Sancti Spiritus granodiorite and the meta-igneous (amphibolite) complex are not clear and (2) the age of the meta-igneous complex is not known. It is clear that more field work and radiometric dates are needed from this area.

The metamorphic rocks of eastern Oriente Province, on strike with the Cayman Ridge, were not studied carefully by the writers. M. T. Kozary (1958, oral commun.) stated to Meyerhoff that some of these rocks closely resemble the San Cayetano of western Cuba.

The 190-m.y. date reported by Kuman and Gavilán (1965) from the Isle of Pines is an error (Khudoley, 1967b; A. A. Meyerhoff and others, 1969); the

TABLE 3. K. M. KHUDOLEY'S BASIS FOR SUBDIVISION OF CUBA INTO FACIES-STRUCTURAL ZONES (CRETACEOUS-PALEOGENE)

	Eugeosyncline		*Median Welt (Marginal Elevation)*	*Miogeosyncline*			*Parageosyncline*
Facies-structural zones	Cauto	Zaza	Las Villas	Remedios	Cayo Coco	Old Bahama Channel	Bahamas platform
Lithofacies	Terrigenous clastic, volcaniclastic, and volcanic (Paleogene* and Cretaceous)	Terrigenous clastic and carbonate (Paleogene).* Terrigenous clastic, volcaniclastic, and volcanic (Cretaceous)	Carbonate	Carbonate and evaporite	Carbonate and evaporite	Carbonate and evaporite	Carbonate and evaporite
Thickness	Great	Great	Slight	Great	Great	Great	Intermediate
Dislocations (folds and faults)	Large	Large	Large	Large	Intermediate	Small	Very small
Magmatism	Dioritic intrusives, volcanic flows, pyroclastic rocks (Paleogene)*	Very little (Paleogene)*. Ultramafic, mafic, and granodioritic intrusives; volcanic flows and pyroclastic rocks (Cretaceous)	Very little	None	None	None	None
Vertical sense of crustal movement	Downward	Downward	Upward	Downward	Downward	Downward	Downward
Economic minerals	Metallic (Mn, Cu)	Metallic (Ni, Co, Cr, Cu)		Nonmetallic			

*Note: Paleogene includes the Paleocene, Eocene, and Oligocene Series; Neogene includes the Miocene, Pliocene, Pleistocene, and Holocene Series.

TABLE 4. RADIOMETRIC DATES FROM GREATER ANTILLES (*SEE* FIGS. 6, 7)

Location	*Type of Rock*	*Stratigraphic Date*	*Method*	*Analyst*	*Age in m.y.*	*Remarks, Published Source*
CUBA						
1. From stream bed (Río Carramayaná) along road south of Tres Guanos, Las Villas Province, at east end of Jarahueca fenster (700 m, S. 12° W. from Tres Guanos)	Quartz monzonite	Pre-Neocomian	K-Ar†	Lamont Geol. Obs.	61±3%	Biotite. Reported erroneously as 57 m.y. by Khudoley (1967b) and as 67 m.y. by Meyerhoff (1967) and Meyerhoff and Hatten (1968). Biotite believed to be secondary and formed during "Laramide" orogeny. Hatten and others (1958) believed that this is a late Paleozoic intrusive. Khudoley disagrees. Date supplied by A. Abdel Monem and J. D. Weir
2. Near Manicaragua, southern Las Villas Province, north side of Sierra de Trinidad	Granodiorite	Pre-Paleocene	K-Ar†	Laboratory of All-Union Geol. Inst., Leningrad	180±10%	Whole rock. Khudoley is skeptical regarding the validity of this date (Khudoley, 1967b). Hatten and others (1958) and Khudoley regard it as middle Cretaceous. Meyerhoff suggests that it is late Paleozoic
3. 20 km south of Nicaro, northern Oriente Province	Pegmatite	. .	K-Ar	Laboratory of All-Union Geol. Inst., Leningrad	119±10%	Whole rock. Pegmatite dike cuts metamorphic rocks of Jurassic(?) age (Adamovich and Chejovich, 1964; Khudoley, 1967b)
4. Isle of Pines, Habana Province	Muscovite schist	Pre-Albian	K-Ar	Laboratory of All-Union Geol. Inst., Leningrad	76±2 m.y.	Kuman and Gavilán (1965) erroneously reported 190-m.y. date (Khudoley, 1967b, p. 789, footnote 4). Dates from Isle of Pines probably reflect "Laramide" events

TABLE 4. *(Continued)*

Location	Type of Rock	Stratigraphic Date	Method	Analyst	Age in m.y.	Remarks, Published Source
5. Isle of Pines, Habana Province	Muscovite	Pre-Albian	K-Ar	Laboratory of USSR Acad. Sci., Moscow	78±4 m.y.	(Laverov and others, 1967)
6. Isle of Pines, Habana Province	Muscovite schist	Pre-Albian	K-Ar	Laboratory of USSR Acad. Sci., Moscow	73±4 m.y.	(Laverov and others, 1967)
7. Daiquirí area, 20 km east of Santiago de Cuba, southern Oriente Province	Quartz diorite	Pre-Oligocene	K-Ar	Laboratory of USSR Acad. Sci., Moscow	49±6 m.y.	Whole rock. Sierra Maestra (Laverov and others, 1967)
8. Nima-Nima area, 20 km west of Santiago de Cuba, southern Oriente Province	Plagiogranite	Pre-Oligocene	K-Ar	Laboratory of USSR Acad. Sci., Moscow	46±6 m.y.	Whole rock. Sierra Maestra (Laverov and others, 1967)
9. Nima-Nima area, 20 km west of Santiago de Cuba, southern Oriente Province	Diorite	Pre-Oligocene	K-Ar	Laboratory of USSR Acad. Sci., Moscow	58±8 m.y.	Whole rock. Sierra Maestra (Laverov and and others, 1967)
JAMAICA						
10. Hall Green, 20 km NNW. of Kingston	Sheared granodiorite	Pre-middle Eocene	K-Ar	Shell Devel. Co., Houston	56±5 m.y.	Low-grade metamorphism probably caused loss of Ar (Chubb and Burke, 1963)
11. Troja, 30 km NW. of Kingston	Sheared granodiorite	Pre-middle Eocene	K-Ar	Shell Devel. Co., Houston	75±5 m.y.	Low-grade metamorphism probably caused loss of Ar (Chubb and Burke, 1963)
12. Zion Hill Bridge, 20 km NW. of Kingston	Unaltered granodiorite	Pre-middle Eocene	K-Ar	Shell Devel. Co., Houston	64±5 m.y.	Fresh sample (Chubb and Burke, 1963)
			Rb-Sr	Shell Devel. Co., Houston	67±5 m.y.	Fresh sample (Chubb and Burke, 1963)
			U-Pb	Shell Devel. Co., Houston	64±5 m.y.	Fresh sample (Chubb and Burke, 1963)
HAITI						
13. Memé Mine 1600-ft level, about 4 km west of village of Bassin, Terre	Quartz monzonite	Pre-Paleocene	K-Ar	R. J. Fleck, Univ. California (Berkeley)	66±1 m.y.	Sample No. 1600-13 (KA-1924). Terre Nueve quartz monzonite stock (Kesler and Fleck, 1968; Kesler, 1968a, 1968b). Detailed data kindly

Nueve Mountains, NW. Haiti						supplied by S. E. Kesler (Sept. 24, 1968, written commun.)
DOMINICAN REPUBLIC						
14. Bowin (1966) loc. 450, west of El Puerto (18°46′ N., 70°16′ W. on Bowin, 1966, map)	Foliated tonalite	Pre-late Maestrichtian(?); pre-Eocene	K-Ar	Unknown	68	Probably reflects time of intrusion of associated hornblende tonalites (Palmer, 1963, p. 221–222)
15. Tonalite, from near center of El Río batholith (19°01′ N., 70°37′ W., on Bowin, 1966, map)	Hornblende in tonalite	. .	K-Ar	S. Hart, Carnegie Inst. of Washington	86±3%	Bowin loc. 328. Pub. with permission of Carl O. Bowin (Bowin, 1966, p. 66)
16. Durate Fm. (18°47′ N., 70°19′ W., on Bowin, 1966, map)	Amphibolite schist, hornblende	Pre-Albian	K-Ar	S. Hart, Carnegie Inst. of Washington	91±1%	Reheated? Bowin loc. B-92. Pub. with permission of Carl O. Bowin (Bowin, 1966, p. 23)
17. Hornblendite intrusion (18°51′ N., 70°20′ W., on Bowin, 1966, map)	Hornblendite	Pre-Albian	K-Ar	S. Hart, Carnegie Inst. of Washington	127±5%	Bowin loc. B-27. Pub. with permission of Carl O. Bowin (Bowin, 1966, p. 63–64)
PUERTO RICO						
18. Bermeja complex of southwestern part of island	Hornblende-feldspar gneiss or amphibolite	Pre-Cenomanian	K-Ar	S. Hart, Carnegie Inst. of Washington	110±3%	Bowin loc. 57b. Gneiss is intruded by serpentinite (Mattson, 1964, p. 9; sample collected by Carl Bowin, written commun., March 29, 1968)
19. Bermeja complex, 17°54′ N., 67°08′ W.	Gneissic amphibolite	Pre-Cenomanian	K-Ar	Isotope Geology Branch, U.S. Geol. Survey	85±10%	Ditto. Sample No. CRTA-5. Specimen is 400 m east of No. 17. Probably the result of reheating by serpentinite. Date supplied by Othmar T. Tobisch (*see* Tobisch, 1968)
20. San Lorenzo batholith area, near Limones	Granodiorite	Post-early Campanian and pre-Oligocene	Pb-alpha	H. W. Jaffe, U.S. Geol. Survey	53 m.y.	Sample JPO-1, collected by J. P. Owens. Age considered to be only ap-

TABLE 4. *(Continued)*

Location	Type of Rock	Stratigraphic Date	Method	Analyst	Age in m.y.	Remarks, Published Source
						proximate (T. W. Stern, written commun., May 22, 1968; *see* Jaffe and others, 1959, p. 79; Berryhill and others, 1960, p. 140, reported this date as 51 m.y.)
21. San Lorenzo batholith area, near Humacao	Granodiorite	Post-early Campanian and pre-Oligocene	Pb-alpha	H. W. Jaffe, U.S. Geol. Survey	58 m.y.	Sample JPO-3, collected by J. P. Owens. Age considered to be only approximate (T. W. Stern, written commun., May 22, 1968; *see* Jaffe and others, 1959, p. 79; Berryhill and others, 1960, p. 140, reported this date as 46 m.y.)
22. Near Utuado pluton, west-central Puerto Rico	Quartz diorite	Post-Santonian and pre-late Paleocene or pre-early Eocene	Pb-alpha	C. Annell, H. Westley, and T. W. Stern, Isotope Geology Branch, U.S. Geol. Survey	60±10 m.y.	Sample JMI-382, Rte. 527, 25 m south of Km. 0.6. Approx. 18°10′ N., 66°40′ W. Date supplied by P. H. Mattson (*see* Nelson, 1968a)
23. Near Utuado pluton, west-central Puerto Rico	Granodiorite	Post-Santonian and pre-late Paleocene or early Eocene	Pb-alpha	C. Annell, H. Westley, and T. W. Stern, Isotope Geology Branch, U.S. Geol. Survey	60±10 m.y.	Sample JMI-405, Rte. 140, near jnct. of Ríos Grande de Jayuya and Jauca. Approx. 18°10′ N., 66°40′ W. Date supplied by P. H. Mattson (*see* Nelson, 1968a)
24. Utuado pluton, west-central Puerto Rico	Biotite quartz diorite	Post-Santonian or pre-late Paleocene or early Eocene	Pb-alpha	H. H. Thomas, R. F. Marvin, F. Walthall, Isotope Geology Branch, U.S. Geol. Survey	50±10 m.y.	Sample JMI-415, Rte. 144, Km. post 3.2. Date supplied by P. H. Mattson
25. Utuado pluton, west-central Puerto Rico	Biotite quartz diorite	Latest Cretaceous or early Tertiary	K-Ar	C. Annell, H. Westley, and T. W. Stern,	65±3 m.y.	Sample JMI-415, Rte. 144, Km. post 3.2. Date

				Isotope Geology Branch, U.S. Geol. Survey		supplied by P. H. Mattson
26. Ciales stock, north-central Puerto Rico	Granodiorite	Pre-Oligocene-post-Late Cretaceous	Pb-alpha	C. Annell, H. Westley, and T. W. Stern, Isotope Geology Branch, U.S. Geol. Survey	70±20 m.y.	Sample XC-1340, zircon date, lat. 18°20′19″ N., long. 66°28′33″ W. Courtesy of F. A. Hildebrand and U.S. Geol. Survey (*see* Berryhill, 1965, p. 68, and Nelson, 1968a, p. 16)
27. Unnamed stock near Naranjito, eastern north-central Puerto Rico	Quartz diorite	Late Cretaceous to early Tertiary	Pb-alpha	C. Annell, H. Westley, and T. W. Stern, Isotope Geology Branch, U.S. Geol. Survey	60±10 m.y.	Sample 616, U.S. Geol. Survey. Approx. 18°20′ N., 66°16′ W. (*see* Nelson, 1968a, p. 17, for exact loc.)
28. Unnamed stock near Naranjito, eastern north-central Puerto Rico	Quartz diorite	Late Cretaceous to early Tertiary	Pb-alpha	C. Annell, H. Westley, and T. W. Stern, Isotope Geology Branch, U.S. Geol. Survey	60±10 m.y.	Sample 620, U.S. Geol. Survey. Approx. 18°17′ N., 66°20′ W. (*see* Nelson, 1968a, p. 17, for exact loc.)*
VIRGIN ISLANDS						
29. Water Island Fm., Lindbergh Bay, St. Thomas	Keratophyre tuff with celadonite	Pre-Albian	K-Ar	Shell Devel. Co., Houston	58 to 62±5 m.y.	Ar leakage or late formation of celadonite may have caused this anomalous date (Donnelly, 1966a, p. 130)
30. Water Island Fm., Lindbergh Bay, St. Thomas	Hydrothermally altered keratophyre	Pre-Albian	K-Ar	Shell Devel. Co., Houston	106±10 m.y.	(Donnelly, 1966a, p. 130)
31. Water Island Fm., Lindbergh Bay, St. Thomas	Hydrothermally altered keratophyre	Pre-Albian	K-Ar	Shell Devel. Co., Houston	110±10 m.y.	(Donnelly, 1966a, p. 130)

*Nelson (1968a, p. 16) mentions a 60±10 m.y. age for ". . . granodiorite and quartz diorite collected south of the report area," but does not give a location. He cites T. W. Stern as the source of this information. This may be either locality 21 or 22. The fact should be mentioned that the writers were told that localities 22 and 23 are the same as localities 27 and 28. Other sources reported that localities 21, 22, 27, and 28 are different. For this reason, all four localities are reported here as distinct and separate.

†Decay constants which were used in Cuba are in Meyerhoff and others (1969).

only dates obtained from that island are K-Ar dates from muscovite and average about 74 m.y. (Table 4; *see* A. A. Meyerhoff and others, 1969). These are from the schist sequence and reflect the effects of the "Laramide" orogeny.

Observations by Tijomirov

Tijomirov (Tikhomirov) (1967) recently summarized the entire problem and concluded that many of the metamorphic rocks of the Isle of Pines, Trinidad Mountains, and eastern Oriente Province are pre-Jurassic. His reasons are quoted here (p. 16–17):

The oldest magmatic association known to date from Cuba is an effusive one, probably of spilite-keratophyre type, that is closely related to the metamorphic complex of the Isle of Pines, Escambray Mountains [Sierra de Trinidad], in the zone south of Santa Clara, and in the eastern part of Oriente Province. This association consists of amphibolite schist, plagioclase-amphibole schist, albite-muscovite-amphibole schist, albite-muscovite schist and, less commonly, talc. In places the schist contains relict porphyry structures which demonstrate their effusive origin, and they are concordant with other metamorphic rocks (mica and graphite schist, other types of schist, quartzite, marble, gneiss), which are a product of the regional metamorphism of marine deposits and terrigenous-carbonate rocks to the greenschist or epidote-amphibolite facies.

This metamorphic complex does not contain organic remains, and it is customary for most investigators to compare these rocks with the fossiliferous Lower to Middle Jurassic strata [San Cayetano Formation] of Pinar del Río Province. The latter consist of sandstone, siltstone, and less commonly of carbonaceous shale, carbonaceous, quartzose, sericitic shale, and quartzose-chloritic shale. Among the Lower and Middle Jurassic rocks, neither volcanogenic rocks nor marbles are present; however, such rocks are widely developed in the metamorphic complex. On the bases of their composition, grade of regional metamorphism, and structural attitude, the metamorphic rocks differ vastly from the faunally dated Early to Middle Jurassic deposits. Analogous metamorphic rocks also are developed in the Antillean arc in Jamaica and Haiti. On the basis of composition and metamorphic grade, the Antillean metamorphic rocks may be compared with those in central and northern South America that are referred to the Paleozoic or Precambrian. Probably they are fragments of a pre-existing vast folded zone in which the Caribbean-Antillean geosyncline developed during Late Triassic or Early to Middle Jurassic time. Today the concept that this metamorphic complex is early Paleozoic or Precambrian is held by some geologists for local areas in Cuba. This concept is at least 30 years old, and each day its validity becomes more confirmed and accepted.

Therefore, on the basis of the distinctive characteristics mentioned, the age of the oldest magmatic association of Cuba is determined to be either Paleozoic or Precambrian.

Conclusions

The evidence presented here, in Khudoley's opinion, is inconclusive and does not prove the existence of pre-Jurassic rocks in Cuba. Meyerhoff believes that the data, particularly the marked differences between the sedimentary

San Cayetano and the volcanic metamorphic rocks, indicate that pre-Jurassic rocks are exposed in several areas of Cuba. If Meyerhoff is correct, these pre-Jurassic rocks originally were graywacke, arkose, quartz sandstone, siltstone, shale, limestone, and mafic to intermediate volcanic rocks and their pyroclastic equivalents; and later those rocks were intruded by mafic to ultramafic rocks, troctolite, and quartz monzonite. Cuba may, therefore, have been the site of a pre-Jurassic orthogeosyncline.

OTHER POSSIBLE PRE-JURASSIC(?) EXPOSURES IN GREATER ANTILLES

Butterlin (1956, p. 312; 1960, p. 19) wrote that ". . . there is no proof of a Variscan orogenesis in the Antilles." He applied this statement to all of the Antilles. Nevertheless, Butterlin left open the possibility that pre-Jurassic rocks are present. The localities discussed in this section are shown in Figure 7.

Jamaica

A long dispute has characterized the investigation of Jamaican geology: Are pre-Mesozoic rocks present, or are the metamorphic rocks of the so-called "Basal Complex" of Cretaceous age? Numerous metamorphic rocks are present in the "Basal Complex" of the Blue Mountains of northeastern Jamaica. Matley (1951, p. 22) wrote, of the "Basal Complex" (Fig. 7) of northeastern Jamaica, the following:

> The fundamental complex is metamorphic, consisting chiefly of sedimentary and volcanic rocks of great thickness, dynamo-metamorphosed into schists, marbles, amphibolites, and granulites; but also thermally metamorphosed into hornfelses. They are probably pre-Mesozoic in age. . . . Some serpentine (an altered harzburgite) also occurs. The granodiorite intrusion, though possibly Cretaceous, is probably older, since no granodiorite invasion of any recognised Cretaceous rock is known in Jamaica.

Raw (1951) agreed with Matley. Detailed descriptions of the metamorphic rocks were provided by Matley and Raw (1951).

Chubb (1962, p. 2, and *in* Zans and others, 1962, p. 17) wrote:

> It is possible that there may be older rocks in the Blue Mountain region but this has yet to be proved. . . . Matley's contention that the metamorphosed rocks of this area are Palaeozoic or Pre-Cambrian in age cannot be sustained. . . . There is no reasonable doubt that these rocks are Cretaceous in age, and owe their metamorphism to the Laramide Orogeny of late Cretaceous and early Eocene age. However, in the absence of fossils, there is nothing to show to what part of the Cretaceous succession they belong.

The Blue Mountains granodiorite has since been shown to be 65 m.y. old (Chubb and Burke, 1963; *see* Table 4).

In southwestern Jamaica, in the Cornwall-Middlesex zone, St. Elizabeth Parish, Jamaican Stanolind (Pan American) drilled the No. 1 Santa Cruz well (Fig. 7) in 1957 to a depth of 2665 m. A. A. Meyerhoff and Spangler (1958) reported that total depth was in Cretaceous volcanic rocks. Zans (1960) called

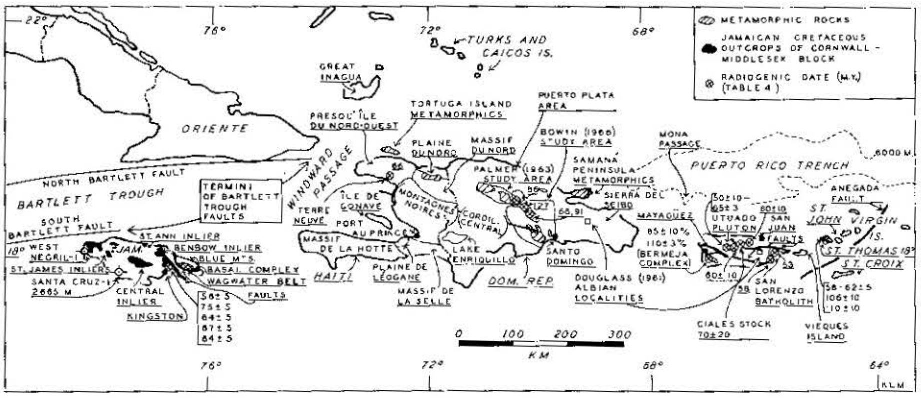

Figure 7. Index map of Jamaica, Hispañola, Puerto Rico, and Virgin Islands; shows principal phenomena and localities mentioned in text, including radiometric date localities of Table 4.

these rocks "metamorphic basement." Greiner (1965) published the first lithologic description. The section from 2411 to 2665 m consists of amphibolite, anorthosite, and basic volcanic rocks of unknown age. They underlie 444 m of unmetamorphosed Cretaceous volcanic rocks. These metamorphic and igneous rocks are unlike any known in western Jamaica. They very possibly are Early Cretaceous, but this is only speculation. Similar rocks (amphibolite schist and granulite) crop out in different parts of the Cornwall-Middlesex zone (Geol. Survey Dept. of Jamaica, 1966).

The identification of the anorthosite should be checked with great care. Although anorthosite inclusions in ultramafic rocks are known in Cuba, the relative scarcity of anorthosite away from Precambrian terranes and the multitude of problems regarding its formation make its identification in this well of potential regional importance.

Haiti

According to Butterlin (1960), in the Léogane Plain of the Massif de la Selle, southeastern Haiti (Fig. 7), and in the Plaine du Nord of northern Haiti, there is float of medium-grade mica schist, including garnet-muscovite schist. Also in the Plaine du Nord area are outcrops of meta-igneous rocks: amphibolite, hornblende schist with serpentinite, and talc schist derived from enstatite-rich rock. Chlorite schist, also of igneous origin, crops out in the nearby Massif du Nord. Just northwest of this area, on Tortuga Island, banded schistose marble crops out. This marble contains chlorite, epidote, and quartz, is strongly folded, and is intruded by unmetamorphosed quartz diorite.

On strike toward the east-southeast in the northeastern Dominican Republic, similar schistose marble is exposed on the Samaná Peninsula (Fig. 7).

Weyl (1966, p. 102–106) published a good summary of the state of knowledge concerning metamorphic rocks in Haiti and the Dominican Republic.

Dominican Republic

Southwest and west of the Samaná Peninsula, H. Palmer (1963) described the Amina Formation of the northwest-central Dominican Republic as a sequence of epidote-chlorite-albite-quartz schist. The Amina is in a northwest-southeast–striking belt of metamorphic rocks that crosses much of the central Dominican Republic (Fig. 7; *see* Bowin, 1966, p. 20). Palmer wrote that the composition of the schist suggests that originally it was graywacke. However, he rejected a sedimentary origin (p. 28) and wrote that "The sedimentary origin from quartz-rich terrigenous sediments . . . is rather unlikely for rocks presumably formed early in the history of the Greater Antilles as no source for these types of sediments is known." He postulated that the rock originally was quartz keratophyre into which hydrothermal silica was introduced during metamorphism. He correlated the Amina tentatively with Bowin's (1960, 1966) Maimón Formation which is in the central Dominican Republic on strike with the Amina (Fig. 7). The Maimón consists of schistose sericitic quartz metakeratophyre and epidote-rich-quartz-sericite rocks. These rocks belong to the muscovite-chlorite subfacies of the greenschist facies. Although the ages of the Amina and Maimón are unknown, it is probable that they are Mesozoic, pre-middle Aptian-Albian.

Both Palmer and Bowin found metamorphosed mafic igneous rocks of the greenschist facies (complete range: subgreenschist to amphibolite facies) exposed in a belt south of and close to the Maimón-Amina; a band of peridotite separates the two metamorphic belts in most of the areas studied. These rocks, to which the name "Duarte Formation" was given, are of probable Mesozoic, pre-middle Albian age.

Puerto Rico

According to Mattson (1966a, p. 125),

> The oldest rocks yet found in Puerto Rico are serpentinite, gneiss, and amphibolite which outcrop in the southwestern corner of the island. . . . The relations between these rocks are still not clear. They are unconformably overlain by an undated sequence of bedded, radiolarian-bearing cherts, and both they and the cherts are uncomformably overlain by Campanian . . . limestones and volcanic rocks. Hornblende in the gneiss was dated by the potassium-argon method as 110 million years (S. R. Hart, personal communication, 1963).

Mattson (1960a) called the ultramafic and metamorphic rocks the "Bermeja complex" (Fig. 7). Subsequently, Tobisch (1968) reported an 85 m.y. date (Senonian) from the same gneissic body in the Bermeja complex.

The 110 m.y. date is Aptian-Albian on the Harland and others (1964) time scale (*see also* Soc. Belge Géol., 1967). The 85 m.y. date is Coniacian to Santonian. Very possibly these dates reflect the latest thermal episodes in the area of these rocks, as Tobisch concluded.

According to Donnelly and others (1968), the amphibolite in the Bermeja complex has a chemical composition totally different from that of other Antillean rocks, and shows a relation with the basaltic clan, possibly with "abyssal basalt."

The serpentinites of the Bermeja complex have been interpreted to be oceanic crust by Hess (1960, 1964), and the work of Hurley and others (1964) supports Hess' interpretation. However, Renz and Verspyck (1962) suggested that part of the crust underlying Puerto Rico could be gneissic rock (that is, metamorphic basement). Tobisch (1966, 1968) wrote that Renz and Verspyck's conclusion is not necessarily correct. The degree to which this problem has become controversial is illustrated in the following quotations. Tobisch (1968, p. 572) wrote, "The present study has shown that the gneissic amphibolite is the oldest rock in the basal complex at Las Palmas, Puerto Rico. . . . The serpentinite has intruded the amphibolite, and has caused contact metamorphism of the wall rocks."

In contrast, Mattson (1968a, p. 52–53) wrote, "The gneiss is in fault contact with other rocks except at one complex and controversial contact with serpentinite. . . . [The] data suggest that the gneiss intrudes the serpentinite. . . ."

The need for additional studies, including drilling and radiometric dating, is apparent. However, none of the known facts eliminates the possibility that the amphibolite and gneiss were derived from oceanic crust and that the serpentinite originated either in the oceanic crust or in the upper mantle.

Virgin Islands

Metamorphic (but unfoliated) rocks of the Virgin Islands appear to belong entirely to the Cretaceous volcanic series (Helsley, 1960; Donnelly, 1964, 1966a; Whetten, 1966).

Conclusions

The writers believe that most of the metamorphic rocks east of Cuba accumulated as sediments and igneous flows or intrusions during the Mesozoic, and that they belong to the Cretaceous orthogeosynclinal cycle. Meyerhoff believes that most are Late Jurassic-Early Cretaceous, and that the metamorphism took place during middle Cretaceous or earlier time. Possible exceptions are some of the metamorphic rocks of southern and northern Haiti, the Samaná Peninsula of the northeastern Dominican Republic, and the amphibolite and gneissic rocks of southwestern Puerto Rico. These rocks, although metamorphosed during Cretaceous time, may represent much older rocks.