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Evidence for middle Cretaceous accretion at Santa Elena Peninsula (Santa Rosa Accretionary Complex), Costa Rica

P.O. BAUMGARTNER [1] **and P. DENYER** [2]

[1] **Institut de Géologie et Paléontologie, Université de Lausanne**
BFSH2-1015 Lausanne, Switzerland. E-mail: Peter.Baumgartner@unil.ch

[2] **Escuela Centroamericana de Geología, Universidad de Costa Rica**
P.O. Box 214-2060, San José Costa Rica. E-mail: pdenyer@geologia.ucr.ac.cr

ABSTRACT

An oceanic assemblage of alkaline basalts, radiolarites and polymictic breccias forms the tectonic substratum of the Santa Elena Nappe, which is constituted by extensive outcrops of ultramafic and mafic rocks of the Santa Elena Peninsula (NW Costa Rica). The undulating basal contact of this nappe defines several half-windows along the south shores of the Santa Elena Peninsula. Lithologically it is constituted by vesicular pillowed and massive alkaline basaltic flows, alkaline sills, ribbon-bedded and knobby radiolarites, muddy tuffaceous and detrital turbidites, debris flows and polymictic breccias and megabreccias. Sediments and basalt flows show predominant subvertical dips and occur in packages separated by roughly bed-parallel thrust planes. Individual packages reveal a coherent internal stratigraphy that records younging to the east in all packages and shows rapid coarsening upwards of the detrital facies. Alkaline basalt flows, pillow breccias and sills within radiolarite successions are genetically related to a mid-Cretaceous submarine seamount. Detrital sedimentary facies range form distal turbidites to proximal debris flows and culminate in megabreccias related to collapse and mass wasting in an accretionary prism. According to radiolarian dating, bedded radiolarites and soft-sediment-deformed clasts in the megabreccias formed in a short, late Aptian to Cenomanian time interval. Middle Jurassic to Lower Cretaceous radiolarian ages are found in clasts and blocks reworked from an older oceanic basement. We conclude that the oceanic assemblage beneath the Santa Elena Nappe does not represent a continuous stratigraphic succession. It is a pile of individual thrust sheets constituting an accretionary sequence, where intrusion and extrusion of alkaline basalts, sedimentation of radiolarites, turbidites and trench fill chaotic sediments occurred during the Aptian-Cenomanian. These thrust sheets formed shortly before the off-scraping and accretion of the complex. Here we define the Santa Rosa Accretionary Complex and propose a new hypothesis not considered in former interpretations. This hypothesis would be the basis for further research.

KEYWORDS | **Santa Elena Peninsula. Accretion. Costa Rica. Radiolarites. Megabreccias. Middle Cretaceous. Subduction.**

INTRODUCTION

The Santa Elena Peninsula, located in northwestern Costa Rica, is 15 km wide and 40 km in a long east-west trend. It forms part of an extensive region, 500 km in length, geologically constituted by oceanic assemblages along the Pacific coast of Costa Rica (Fig. 1). These assemblages are formed by Cretaceous-Paleocene igneous suites of ultramafic and mafic to acidic intrusive rocks, massive and pillow basalts, dolerite sills and dikes, and Jurassic to Cretaceous radiolarian cherts (Donnelly, 1994; Meschede and Frisch, 1994). These occurrences are closely associated with an active margin, where the Cocos Plate is being subducted underneath the Caribbean Plate. This subduction process is also responsible for the existence of an active volcanic arc along the whole region (Fig. 1). The Panama Fracture Zone is a dextral transform fault that separates the Cocos and Nazca plates and forms a triple junction by the interaction with the Caribbean plate in the southeast, offshore of Costa Rica (Fig. 1). The Hess Escarpment and the western edge of the North Panama Deformed Belt are remarkable tectonic Caribbean intraplate features (Fig. 1). The Hess Escarpment, still of an obscure origin, is a linear northeast-trending escarpment of 100 to 3000 m variable relief (Holcombe et al., 1990). The North Panama Deformed Belt is a well defined seismically active offshore belt of Cretaceous-Neogene rocks (Mann and Kolarsky, 1995).

There are four localities containing peridotites in the Nicaraguan-Costa Rican region (Fig. 1): Santa Elena Peninsula (Harrison, 1953; Dengo, 1962, 1972; Astorga, 1997), Río San Juan (Astorga, 1992; Vargas and Alfaro, 1992; Tournon et al., 1995), Tonjibe drillhole (Pizarro, 1993) and Siuna (Venable, 1994; Rogers, 2003). The relationship between these four occurrences is not completely clear, but the Río San Juan, Tonjibe and Santa Elena Peninsula localities have been interpreted as a 150 km long E-W trending ultramafic suture zone (Tournon et al., 1995), which corresponds to the boundary between the Chorotega and the Chortis blocks, seen in alignment with the Hess Escarpment (Dengo, 1985).

The Santa Elena Peninsula belongs to a major south directed nappe emplaced during Upper Cretaceous that has a hanging-wall formed by ultramafic peridotites, (Azéma and Tournon, 1980; Tournon, 1984, 1994; Frisch et al., 1992). The footwall is constituted by an igneous-sedimentary sequence, which has been dated Middle Jurassic to Early Cretaceous (Schmidt-Effing, 1980; DeWeber et al., 1985; Hauff et al., 2000).

Originally, the Santa Elena Peninsula ultramafics were considered part of an ophiolitic suite (Dengo, 1962; Kuijpers, 1980), related to the oceanic assemblage that constitutes the Nicoya Peninsula (Fig. 1). Later, Bourgois et al. (1984), Baumgartner (1984) and Azéma et al. (1985) correlated the underlying "volcanosedimentary" tectonic unit (Santa Rosa Accretionary Complex, in this paper) to the Nicoya Complex, which is the geologic unit that comprises the oceanic assemblage of the Nicoya Peninsula and is formed predominantly by Upper Cretaceous plateau basalts ascribed to the main Caribbean Large Igneous Plateau event (Donnely, 1994; Sinton et al., 1997).

The relationship between the rocks of the Nicoya and Santa Elena peninsulas has been discussed and interpreted in various petrologic and geodynamic studies (Dengo, 1962; Tournon, 1984; Azéma et al., 1982; Burgois et al., 1984; Frisch et al., 1992; Astorga, 1997; Beccaluva et al., 1999; Hauff et al., 2000). However, the more recent geochemical analyses made by Beccaluva et al. (1999) and Hauff et al. (2000) suggest that the Santa Rosa Accretionary Complex does not correspond to the Galapagos mantle array. Instead, it corresponds to mantle reservoirs and geochemical characteristics different from those of the Nicoya Complex (Nicoya Peninsula).

In this work, we study the stratigraphic and structural relations of the volcano-sedimentary sequence that outcrops along the south coast of the Santa Elena Peninsula beneath the Santa Elena Nappe (Fig. 2), reinterpreting and discussing the previous radiolarian biochronology (Schmidt-Effing, 1980; Dewever et al., 1985; Astorga, 1992). Our intention is to propose a new hypothesis, not considered by previous authors, which states that the footwall block of the Santa Elena Nappe is not a continuous sequence, but a piled-up accretionary sequence, that we named the Santa Rosa Accretionary Complex. We are aware that more petrologic, micropaleontologic and tectonic studies must be made for a better understanding of the whole picture, but our hypothesis represents a starting point to further studies.

GEOLOGIC SETTING

The Santa Elena Nappe is constituted by three petrological affinities: 1) mantle serpentinized peridotites 2) pegmatitic gabbros, layered gabbros and plagiogranites and basaltic dikes, and 3) doleritic dykes (Burgois et al., 1984; Tournon, 1984; Frisch et al., 1992; Hauff et al., 2000). Radioisotopic Ar^{39}/Ar^{40} dating was done on a gabbro sample from this unit, and it gives an age of 124.0 ± 4.0 Ma (Hauff et al., 2000; Fig. 2).

The oceanic assemblage underlying the Santa Elena Ultramafic Nappe defined herein as the Santa Rosa Accretionary Complex crops out in the Potrero Grande tectonic window and in several half-windows along the southern coast of the Santa Elena Peninsula (Azéma and Tournon, 1980; Azéma et al., 1982; Tournon and Alvarado, 1997; Fig. 2). The upper boundary of this complex is the Santa Elena thrust which separates it from the peridotites of the Santa Elena Nappe. This thrust has associated thick fault megabreccias with house-sized blocks, which were formed during the emplacement of the nappe

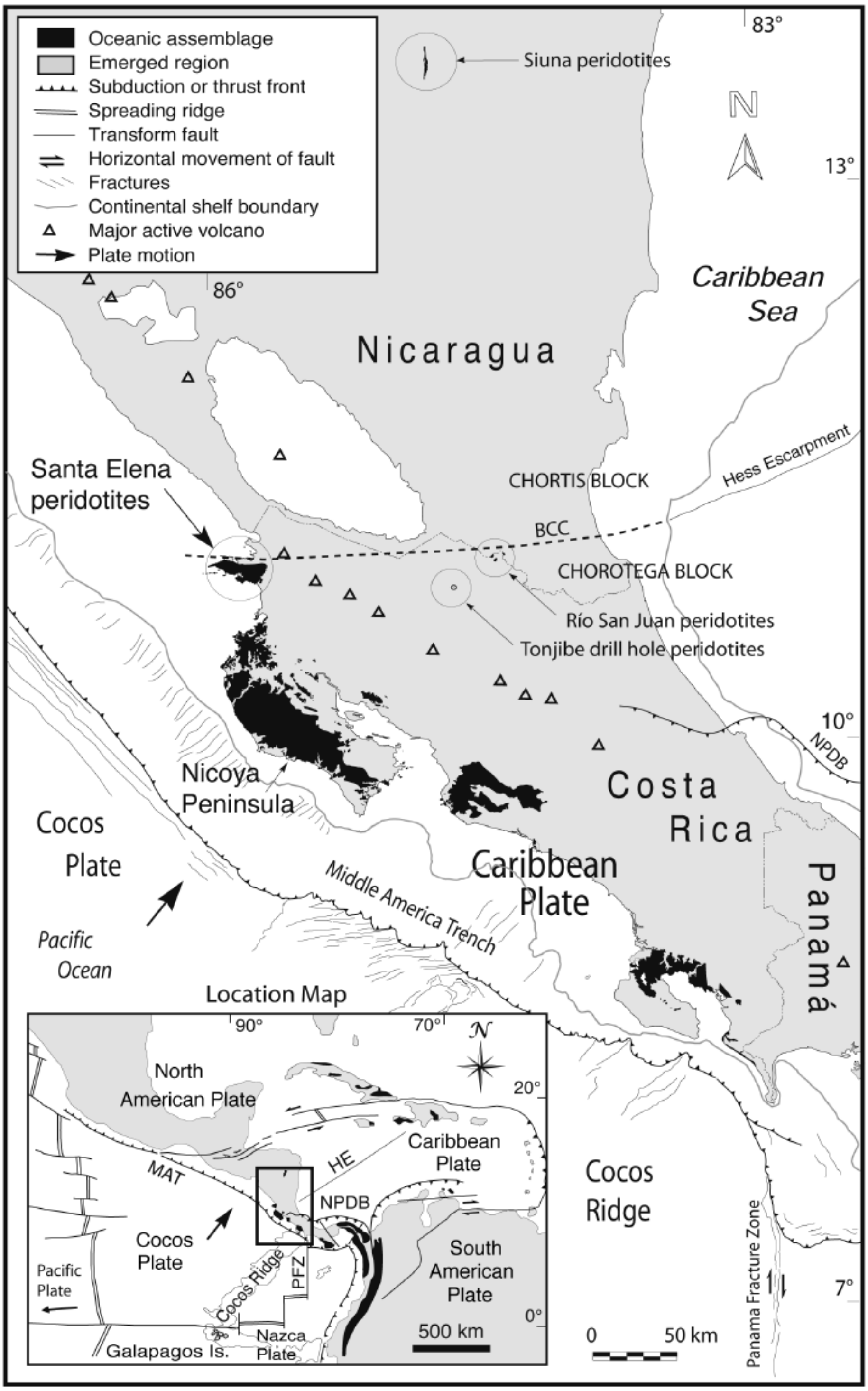

FIGURE 1 | **Present day geotectonic setting of Central America and the Caribbean, showing the oceanic assemblages and the peridotite occurrences of Costa Rica and Nicaragua. NDPB: North Deformed Panama Belt, PFZ: Panama Fracture Zone, MAT: Middle America Trench, BCC: Boundary between Chortis and Chorotega blocks, HE: Hess Escarpment. Map based on DeMets et al. (1990), Donnelly (1994), Meschede and Frisch (1994), Venable (1994), Tournon et al. (1995), Ranero and von Huene (2000), Ranero et al. (2003) and Rogers (2003).**

(i.e., outcrops in western Playa Carrizal, Pelada Island and northern Playa Naranjo). The composition of the fragments of the magabreccias vary from place to place and generally include fragments of dolerites, basalts, gabbros. Sometimes they are set in a tectonically deformed serpentinite matrix (Tournon, 1984). The thrust fault plane is roughly horizontal with steep undulations. As a result of these undulations, the thrust dives in several places below the present shoreline, causing the underlying Santa Rosa Accretionary Complex to appear as isolated outcrops. They are at most a few tens of meters above mean sea level (Figs. 2 and 3).

Beneath the main thrust, numerous flat-lying, top-to-west to southwest thrusts, some asymmetric folds (Azéma and Tournon, 1980; Tournon, 1984) and fabric studies (Frisch et al., 1992) are associated to the main Santa Elena thrust and affect the Santa Rosa Accretionary Complex, indicating a south to southwest emplacement of the Santa Elena Nappe (Azéma and Tournon, 1980; Frisch et al., 1992). These successions show predominantly subvertical and steep eastward dips. Locally, dips are more gentle northwards resulting in nearly horizontal intersections of strata with the generally E-W oriented cliffs (Playa Carrizal to north of Playa Naranjo, Fig. 2).

Tournon (1984, 1994) described a tectonized and possibly isoclinally folded sequence of alkaline pillow basalts, basalt breccias, red and brown radiolarites, radiolarite-basalt breccias, tuffs and a distinct package of ribbon-bedded chert with intervening sills of potassic alkaline basalts at Sitio Santa Rosa. Based on the presence of radiolarite fragment inclusions occurring within sills with chilled margins, he concluded that they were produced in an oceanic environment. This ocean was considered to be as old as early Middle Jurassic and to range up to the Cenomanian; an age that agrees with radiolarian dates (Tournon, 1984; DeWever et al., 1985). Tournon (1984) suggested an anticline structure based on the fact that strata dated as Middle Jurassic are flanked by rocks dated as middle Cretaceous. The sequence of Santa Rosa had been considered the most complete Jurassic-Lower Cretaceous section of Costa Rica (Tournon, 1994; Astorga, 1997).

From eastern Punta Santa Elena and from Respingue (Fig. 2), Tournon (1984; 1994) described thick piles of alternating pillowed and massive basalts and dolerites cut by basaltic dykes and rare trachytes without intervening sediments. Tournon (1984, 1994) emphasized on an undersaturated alkaline trend, evidenced in part by enrichment in Light Rare Earth Elements. Frisch et al. (1992) and Hauff et al. (2000) confirmed these findings and interpreted the basalts in terms of an intraplate, seamount origin.

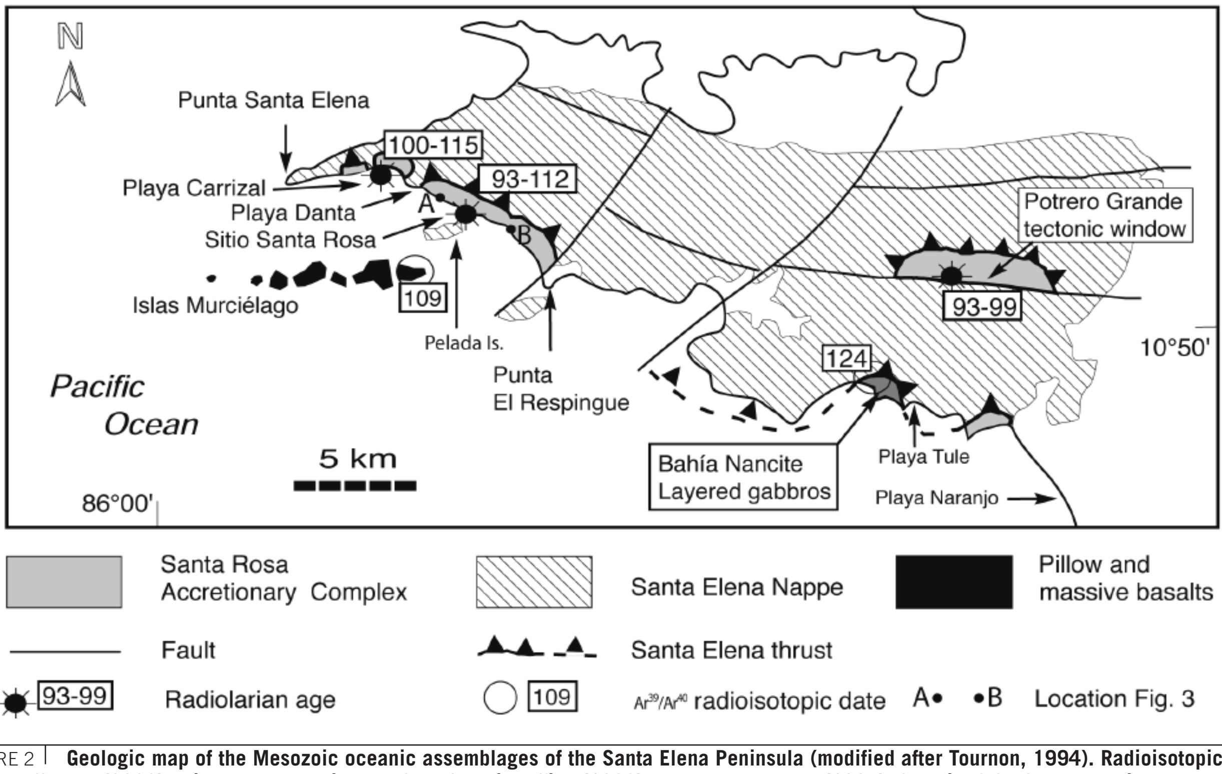

FIGURE 2 | **Geologic map of the Mesozoic oceanic assemblages of the Santa Elena Peninsula (modified after Tournon, 1994). Radioisotopic ages from Hauff et al. (2000). Micropaleontologic ages from Schmidt-Effing (1980) and DeWever et al. (1985). See Fig. 3 for further detail on the studied outcrops.**

The easternmost outcrops of the Santa Rosa Accretionary Complex (Playa Tule, north of Playa Naranjo; Fig. 2) were signed out by Tournon (1984, 1994) because of the occurrence of breccias with andesitic and even acidic arc-derived clasts.

Offshore and westwards of the coastal outcrops of the Santa Rosa Accretionary Complex, the Islas Murciélago form a continuous 10 km long archipelago, consisting of columnar, pillow and massive basalts, with a general steep northward dip. The basalts forming the Islas Murciélago are geochemically (Hauff et al., 2000) very different from the igneous rocks of the Santa Rosa Accretionary Complex. Hauff et al. (2000) presented a radioisotopic Ar^{39}/Ar^{40} date of 109.0 ± 2.0 Ma and related their origin to a primitive island arc.

SANTA ROSA ACCRETIONARY COMPLEX UNITS

The Santa Rosa Accretionary Complex is made up of 8 units at Sitio Santa Rosa, separated from the neighboring unit by decimeter to meter wide intensive and roughly bed-parallel shear zones (Figs. 2, 3 and 4). We interpret these units as tectonically stacked, based on the field tectonic features, sedimentological inconsistencies and age distribution .

Unit 1

Not represented in Fig. 4, it is more than 100 m thick and includes a lower part formed by pillowed basalts with minor basalt breccias, and an upper part constituted by ribbon red radiolarites exposing intense soft sediment deformation interpreted as slumping.

Unit 2

It is composed of 300 m of mostly disorganized, poorly stratified polymictic breccias that include radiolarite blocks of up to 10 m size, and several meter thick volcanoclastic debris flow breccias that crop out in the upper part of the unit. The reworking of poorly lithified breccias as blocks is shown by sharp changes in breccia fabrics along irregular contacts.

Unit 3

It is about 300 m thick and dominated by thin-bedded ribbon-radiolarites with intervening alkaline basalt sills (Fig. 5A) that overlie a basalt breccia and tuffaceous mudstone, including a large (slumped?) radiolarite block. The basaltic breccia is also intruded by basaltic sills suggesting a related origin of the pillowed/layered basalt flows and the sills of Sitio Santa

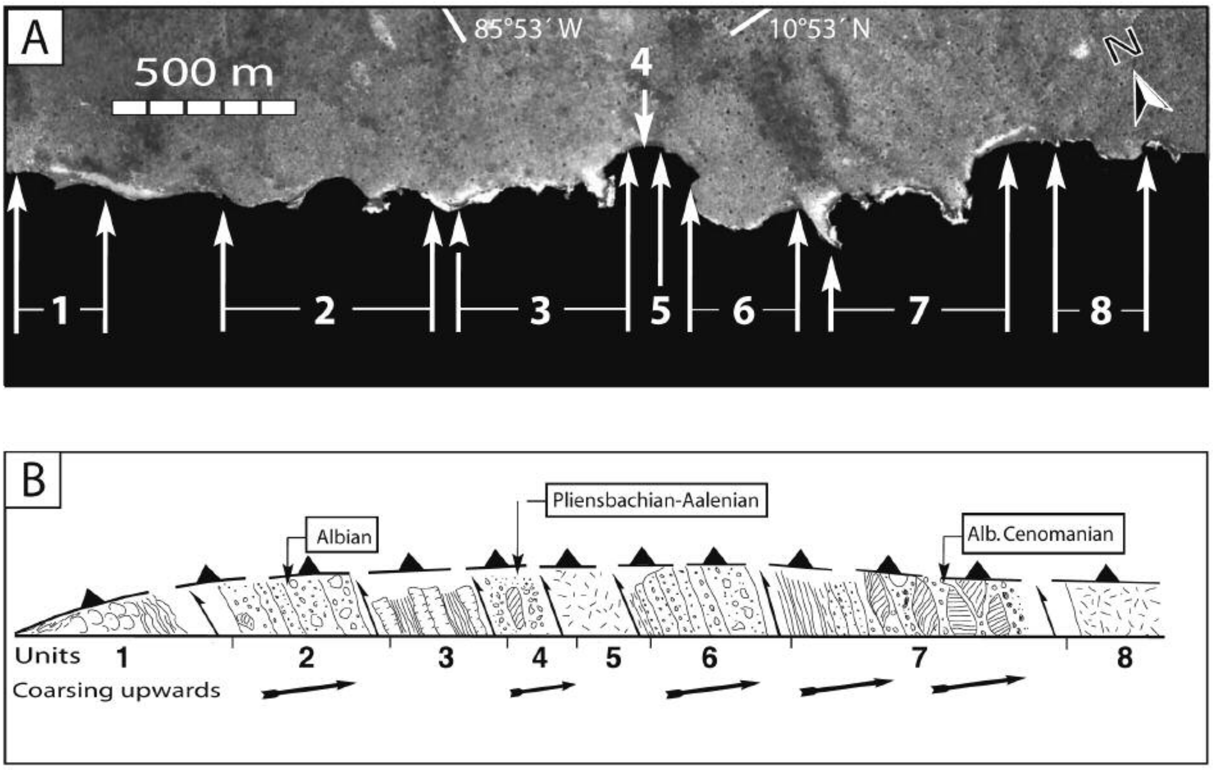

FIGURE 3 | **Aerial photograph (Instituto Geográfico Nacional of Costa Rica) with location of units described in the text B) Schematic cross section, based on the units described by Tournon (1984). See location in Fig. 2 and details on sedimentology in Fig. 4.**

Rosa. In the thin-bedded ribbon-radiolarites, gravitational emplacement of the sills along bedding planes must be assumed to explain the lack of disturbance of the delicate radiolarite bedding (Fig. 5A). This contrasts with the topmost sills, which enclose meter-sized contorted rip-up clasts of radiolarite and show internal flow structures.

Unit 4

This is 125 m thick chaotic breccia unit including giant (10 x 10 x 20 m) blocks of very deformed radiolarites (Fig. 5B) that denote a complex sedimentary and/or tectonic reworking, which include: 1) gravitational emplacement of the blocks into a bedded pebbly to cobbly polymictic breccia that coarsens upwards, and/or 2) gravitational or tectonic mixing of this breccia.

Unit 5

This unit is 100 m thick and is entirely made of massive alkaline basalt.

Unit 6

It is 150 m thick and constitutes a coarsening upwards succession that begins with centimeter bedded volcanoclastic turbidites interbedded with brown siliceous mudstones (Fig. 5C). This unit finishes with meter to 10-m thick strata of debris flows.

Unit 7

In this 300 m thick unit, ribbon-bedded radiolarites grade upsection into grey tuffaceous mudstones with muddy trubidites at the base (Fig. 5D) that represent non-channelized distal fan facies. Upwards, over the first decimeter-thick debris flows (Fig. 5E), the succession is truncated by an erosion surface and overlain by a megabreccia with decameter-sized radiolarite slide-blocks set in a polymictic boulder breccia (Fig. 5F).

Unit 8

It is represented by layered flows of pillowed and massive basalts that crop out along the shoreline 1.5 km to the east.

LITHOLOGIC ASSOCIATIONS AND SEDIMENTOLOGY OF THE SANTA ROSA ACCRETIONARY COMPLEX

In this section, we describe the principal lithologic associations, the sedimentology and the tectonostratigraphic succession of the Santa Rosa Accretionary Complex cropping out near Sitio Santa Rosa, between Playa Danta and Punta El Respingue (Fig. 2), and also at Playa Carrizal and Northen Playa Naranjo.

Sitio Santa Rosa

Some of the described associations are repeated many times along the coast and others are unique (Figs. 3 and 4). One or more lithologic associations occur in the 8 tectonic units. In order to obtain stratigraphic polarity, we systematically observed grading in the turbidites and small debris flows of the detrital intervals. In the radiolarite successions, the geopetal mud infill in large, spherical radiolarian tests was determined under the hand lens (15x) and verified in thin sections. From this analysis, we conclude that all sedimentary strata have their top towards the east.

Vesicular pillow and massive basalt, basaltic breccias, vesicular pillow basalt and alkaline basaltic sills with chilled margins

These lithologies form 10 to 100 m packages between Punta Santa Elena and Punta El Respingue. In the Sitio Santa Rosa outcrops, they form the tectonic Unit 1, base of Unit 3, and the ensemble of units 5 and 8 (Figs. 2 and 3). They represent a succession of flows, each several tens of meters thick. They can be detected on aerial photos NW of El Respingue (Unit 8).

Flows are often massive and brecciated. They represent monomichtic disorganized basaltic breccias with pillow fragments in a more or less sheared matrix of tuffaceous (hyaloclastic?) material. There seems to be a genetic relationship between pillowed/brecciated basalt flows and the sills described from Unit 3. Tournon (1984; 1994), based on whole rock principal element analyses, notes a potassic alkaline geochemistry of these basalts.

Numerous centimeter and meter wide sills form part of Unit 3. The thickest sills show the same lithologies as the interior of basalt flows of the vesicular pillow and massive basalt association, especially those belonging to units 3 and 5. This suggests a genetic relationship between pillowed/brecciated basalt flows and the sills described here from Unit 3.

Ribbon bedded red radiolarian chert

It constitutes the middle and upper part of the Unit 3 (Fig. 3). It is an association dominated by 2-5 cm bedded brown and brownish red ribbon radiolarites with cm-sized ripple marks in some beds recording some current activity. These radiolarites are intruded by numerous sills, which could represent more than half of the thickness of Unit 3 (Fig. 4). The adjacent radiolarites, in turn, are hydrothermally altered to more massive brick red to yellow jasper. Sills show greenish-yellowish weathering; they are alkaline basalts that show chilled margins both at the base and the top.

Tuffaceous mudstones and muddy tuffaceous turbidites, and red ribbon-bedded radiolarites

The lower parts of the units 6 and 7 in the Sitio Santa Rosa are composed of red, 2-10 cm thick ribbon-bedded radiolarites that grade upsection into less well-bedded reddish brown to dark grey tuffaceous siliceous mudstones with interbeds of thin, muddy turbidites (Figs. 5C, 5D, 5E). These interbeds formed by Tc-d and Tb-d Bouma sequences increase in frequency and thickness upwards, from a few centimeters to several decimeters.

Radiolarian siliceous mudstone and volcanoclastic turbidites/debris flow breccias

This lithologic association is formed by reddish-brown siliceous radiolarian mudstones (brown radiolarites

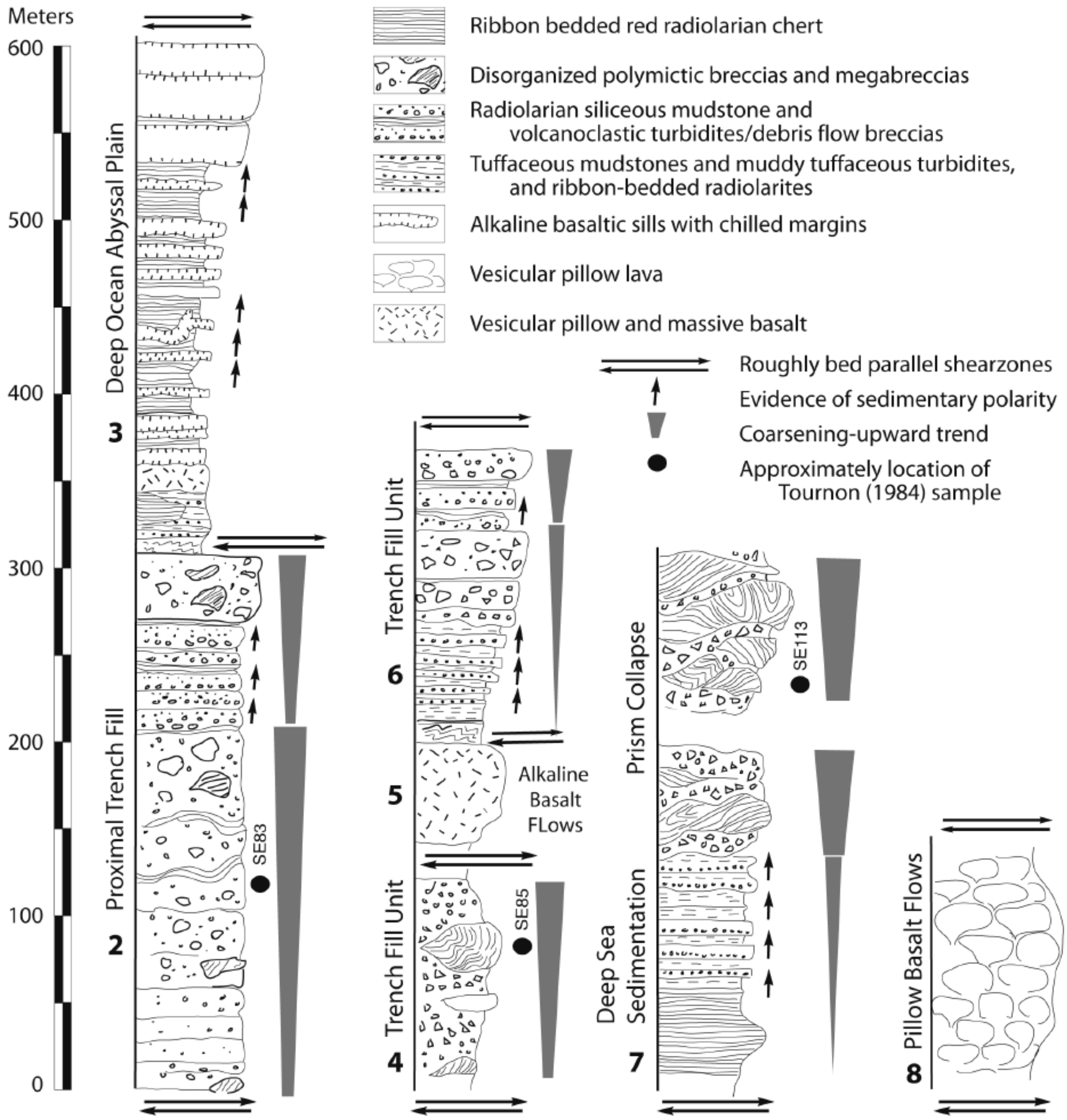

FIGURE 4 | **Sedimentological logs and paleoenvironmental interpretation of Santa Rosa Accretionary Complex (Southwest Santa Elena Peninsula). Thick numbers correspond to the stratigraphic-sedimentological units described in the text. See Figs. 2 and 3 for location and structural features.**

of Tournon 1984, 1994) that are centimeter to meter interbedded with graded volcanic sandstones and pebble-breccias. All beds are distinctly coarse-tail graded and show a very rapid coarsening upwards trend. Bed thickness of the sandstones and breccias is almost proportional to clast size: sandy turbidites are a few centimeters thick whereas pebbly breccias are 15-30 cm thick, and breccias with boulder-sited outsized clasts set in a pebbly, sandy polymodal matrix make up meter-thick beds. The clasts of the breccias are mainly reworked radiolarian chert, basalts and few coarser grained dolerites. Inverse grading can be observed for the coarsest of these clasts, although each individual bed of breccia is followed by a normally graded sandy turbidite. According to the characteristics of the matrix, the heterogeneity of clasts and the thickness variations, the breccias of this association have to be interpreted as rather proximal debris flows.

Disorganized polymictic breccias and magabreccias

This is the most abundant rock association in the Sitio Santa Rosa outcrops. It is present in the tectonic units 2, 4, 6 and 7 (Fig. 4). It is made of disorganized breccias and megabreccias in which clasts are from less than a meter up to 30 m sized slabs of radiolarites (Figs. 5D, 5E). The thickness of the breccias and megabreccias in beds is highly variable, reaching more than 100 m. In relation to bed thickness, three major kinds of disorganized breccias could be distinguished, 1) Decimeter to meter thick beds of moderately organised breccias 2) Meter thick beds of poorly organized breccias with soft sediment deformation (however, intervening contorted layers of radiolarian mudstone and graded breccias can be interpreted as originally interstratified in several 100 m thick units; Unit 2, Fig. 4); and 3) Decameter thick beds of totally disorganized megabreccias including meter to decameter-size blocks of basalt, soft-sediment-deformed radiolarite and reworded breccias (Unit 7) which overlie the turbidite/debris flow association with an erosive unconformity (Fig. 4).

These breccias are commonly associated with ribbon-bedded and knobbly radiolarian. The association of disorganized polymictic breccias and megabreccias can easily be distinguished from that of the monomictic breccias of the vesicular pillow and massive basaltic flows association which do not show organization in beds with grading, clast orientation, and have different lithologic composition.

Playa Carrizal

West of Playa Carrizal (Fig. 2), 50-100 m thick-units of 5-20 cm-bedded, brick red parallel-bedded to knobbly radiolarian chert occur (Fig. 5G), overlying pillow basalts (Fig. 5H) Individual chert beds are separated from each other by claystone layers and sometimes black shales. Grey shales can be observed in the outcrops located 1 km west of Playa Carrizal (Tournon 1984; Astorga 1997). Organic matter is preserved in clay-rich lithologies. The knobbly nature of the radiolarian chert suggests original presence of carbonates that may have dissolved away during diagenesis (Bosellini and Winterer, 1975). The clay partings suggest that radiolarite sedimentation was interrupted by episodes of sedimentation of volcanic-derived smectite.

Northern Playa Naranjo

The outcrops just north of Playa Naranjo are part of the Santa Rosa Accretionary Complex, but show different sedimentary and igneous facies. They are composed of pink pelagic limestones interbedded with graded turbidites and pebbly igneous breccias with andesitic and even acidic clasts. This succession could be much more proximal with respect to the middle Cretaceous arc. In the eastern Pacific, pre-Campanian pelagic limestone facies are restricted relatively shallow (above CCD) sites (Thierstein, 1979). However, they are found today in the same structural position under the Santa Elena Nappe and are therefore included within the Santa Rosa Accretionary Complex.

PALEONVIRONMENTAL INTERPRETATION OF THE SANTA ROSA ACCRETIONARY COMPLEX UNITS

From the previously described rock associations and their stratigraphical succession, the Santa Rosa units 1 to 8 (Figs. 3 and 4) have been interpreted as formed in the following volcano-sedimentary paleoenvironments.

Unit 1: The slumped radiolarites, vesicular pillow and massive basalts, and basaltic breccias of this unit may have formed on the slopes of a submarine seamount (Frish et al, 1992; Tournon, 1994; Hauff et al., 2000).

Unit 2: This unit is interpreted as a very proximal trench-fill succession that documents mass wasting of already accreted oceanic and trench fill lithologies.

Unit 3: Rock associations present in this unit indicate that it was probably deposited in a deep ocean abyssal plain located in the vicinity of an intraplate seamount or plateau providing the sources of the numerous basaltic sills and the gravitational flows.

Unit 4: It is interpreted as the result of mass wasting occurring in the trench area.

Unit 5: This massive unit is interpreted as the result of several flows of massive alkaline basalts.

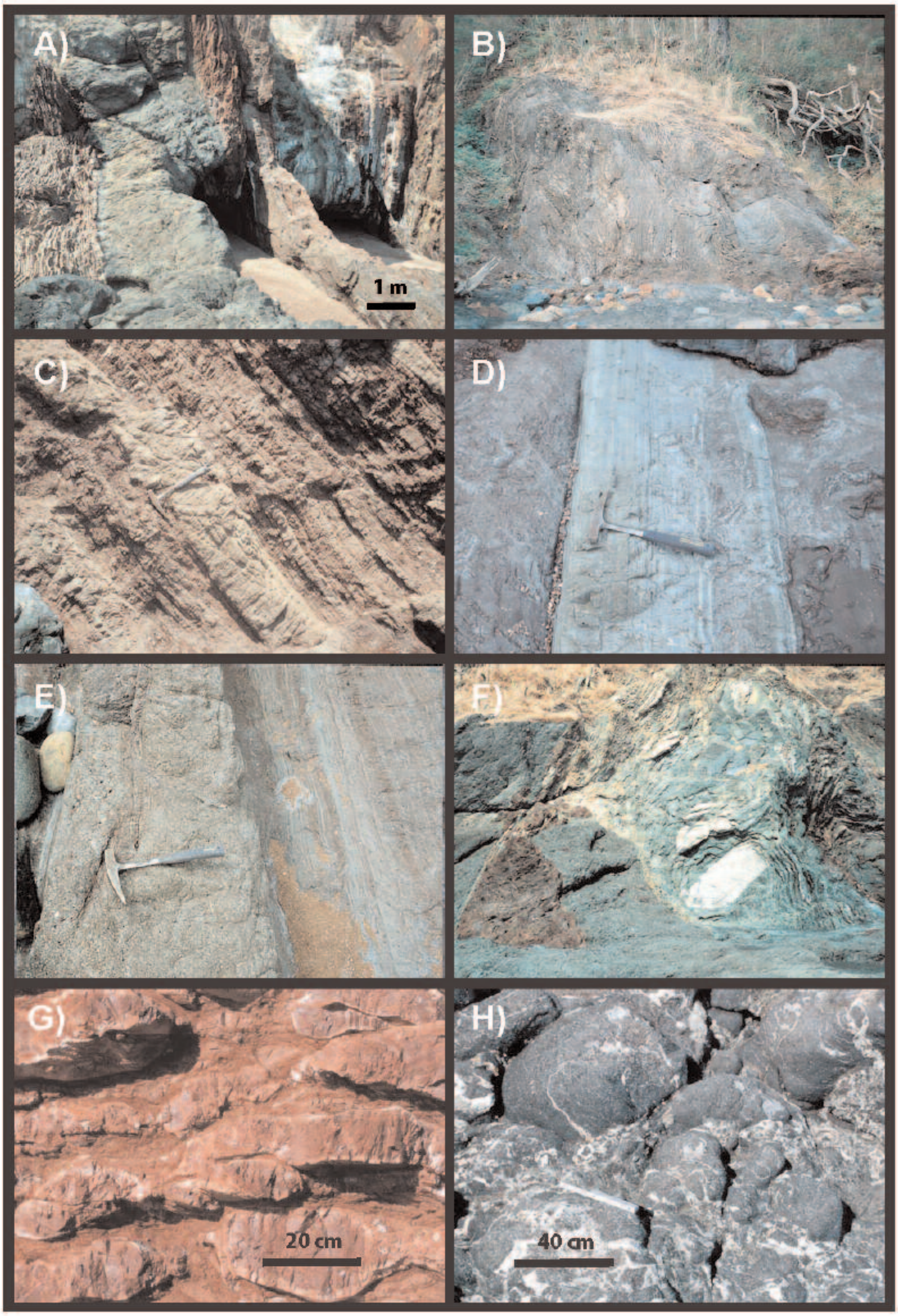

FIGURE 5 | **Some outcrops of the Santa Rosa Accretionary Complex from the south coast of the Santa Elena Peninsula (see location in Fig. 3). A) Thin ribbon-bedded radiolarian cherts with intervening alkaline basaltic sills located near the top of Unit 3; the sill in the foreground is about 2 m thick; Sitio Santa Rosa (Fig. 2). B) Polymictic breccia of Unit 4 with giant block of highly folded, thin bedded lower Middle Jurassic radiolarite at Sitio Santa Rosa. C) Siliceous radiolarian mudstones with thin turbitite beds and a pebbly volcanoclastic debris flow located near the base of Unit 6 at Sitio Santa Rosa; note the dipping fault planes parallel to the Santa Elena Overthrust cutting Santa Rosa Accretionary Complex. D) Poorly bedded tuffaceous siliceous mudstones with interbeded tuffaceous thin-bedded turbidites; near base of Unit 7, just above radiolarites at Sitio Santa Rosa. E) Tuffaceous mudstones with a mainly volcanoclastic pebbly debris flow overlain by a graded turbidite of the middle part of Unit 7 at Sitio Santa Rosa. F) Collapse megabreccia made of green and red radiolarite slide blocks set in a polymictic volcanoclastic breccia on top of Unit 7; the triangular block at the lower left is about 2 m large. G) Knobbly radiolarite of Late Aptian-Albian to Cenomanian age at Playa Carrizal. H) Strongly calcitized vesicular alkaline pillow lavas near Playa Carrizal; clay-rich interbeds may have contained carbonates before diagenesis. Photographs A to F are showing the top of the stratigraphic section to the right.**

Unit 6: It represents more and more proximal sedimentation of channelized debris flows encroach over thin-bedded turbidites as a result of a rapid approach of the site of sedimentation to a trench area. This succession resembles much the Dhimaina and Potami Formations from the Pelagonian Upper Jurassic (Baumgartner, 1985).

Unit 7: The presence of volcanic rocks together with the deep-sea nature of the sediments documents gravitational emplacement of slope sediments that can be interpreted as slumping in an inner trench wall. In this setting, the over 100 m thick megabreccia can be interpreted as a prism collapse and gravitational emplacement on the trench floor.

Unit 8: This unit is a consequence of massive and vesicular pillowed basaltic flows.

We deduce that these oceanic successions were originally sedimented in an oceanic abyssal plain environment that evolved to a trench where successively coarser and more proximal sediments coming from the inner trench wall were deposited. These sediments were accreted together with the basalts.

DISCUSSION OF RADIOLARIAN BIOCHRONOLOGY

Radiolarian assemblages of the Santa Rosa Accretionary Complex cropping out between Playa Carrizal and Sitio Santa Rosa were dated by DeWever et al. (1985). Unfortunately, no illustrations are available for these assemblages, which makes it difficult to judge the biochronologic assignments. However, considering radiolarian determinations as correct, age assignments could be reassessed based on the biozonations proposed by Baumgartner et al. (1995) for the Middle Jurassic to Early Cretaceous and by O'Dogherty (1994) for the middle Cretaceous.

The radiolarian ages are discussed in this section together with the chronostratigraphic meaning and value of these re-dated radiolarian assemblages considering the sedimentological features of the rocks in which the radiolarian assemblages were sampled.

Early to Middle Jurassic (Pliensbachian-Aalenian)

The radiolarite assemblage dated by DeWever et al. (1985) as early Middle Jurassic has been identified near the top of Unit 4 (Fig. 3), in the disorganized polymictic boulder breccia that constitutes this unit at Sitio Santa Rosa. Concretely, the sample SE85 of DeWever et al. (1985) was collected in a 10 x 10 x 20 m sized block (Figs. 4 and 5F). Thus, although DeWever et al. (1985) consider that this sample dates the unit 4, it comes from a large reworked block that only allows to precise that the age of the breccia is younger than the sample age.

In relation to this age, several species mentioned by DeWever et al. (1985) were known from the Piensbachian of Greece and Turkey at that time. However, a complete revision of the Lias to earliest Dogger radiolarian biochronology is underway (Gorican et al., 2003) and ranges of age that are more complete can be expected for many of the cited species. Based on the current information, an age range of Pliensbachian to Aalenian is probable. Thus, this age could well correspond to the oldest rocks found so far in Costa Rica.

Apart from these discussed radiolarite assemblages, Astorga (1977) provided images of "Pliensbachian" radiolarians collected at the Sitio Santa Rosa. However, the precise location of these specimens is unknown and none of the illustrated radiolarian specimens can be determined to species level. They seem to correspond to an upper Lower or lower Middle Jurassic radiolarian assemblage.

Middle Jurassic (Bajocian-Callovian)

The co-occurrence of two forms of *Bernoullius* in sample SE138 of DeWever et al. (1985) from the Santa Rosa Accretionary Complex cropping out at Potrero Grande tectonic window (Fig. 2) clearly indicates a late Middle Jurassic age (Bajocian-Callovian).

Late Jurassic-Early Cretaceous

Upper Jurassic-Lower Cretaceous radiolarian species are mentioned by DeWever et al. (1985) as reworked radiolarians in samples that also include radiolarians of late Aptian to Cenomanian age. These mixed assemblages occur in clasts of the disorganized polymictic breccias of the San Rosa Accretionary Complex. Therefore, just as the Pliensbachian-Aalenian radiolarian assemblages, these mixed assemblages only date the age of the blocks but not that for the breccias, which should be younger.

Early to Late Cretaceous (Late Aptian-Albian to Cenomanian)

Upper Aptian-Albian to Cenomanian radiolarian assemblages have been recognized in the successions of Santa Rosa Accretionary Complex cropping out at Playa Carrizal, Sitio Santa Rosa and in the Potrero Grande tectonic window (Tournon, 1984; DeWever et al., 1985). They come from samples collected in stratified radiolarites at Playa Carrizal (samples CR548, SE50, SE113 of Tournon, 1984) and at Portrero Grande tectonic window, as well as from clasts of disorganized polymictic breccias of units 2 and 7 at Sitio Santa Rosa (SE83, SE113, of

Tournon, 1984 and DeWever et al., 1985) (Fig. 4). In the Portrero Grande tectonic window, the well-preserved Upper Cretaceous radiolarian assemblage was first attributed to the late Albian to early Cenomanian, with Cenomanian being the most probable age (Schmidt-Effing, 1980). However, according to O'Dogherty (1994) we would rather place this sample in the early Cenomanian, based on the co-occurrence of *Pseudoaulophaxus sculpus* (=*Alievum superbum* of Schmidt-Effing, 1980) and *Dactylosphaera silviae* (=*Pseudoaulophacus putahensis* of Schmidt-Effing, 1980).

Taking into account that upper Aptian-Albian to Cenomanian radiolarian assemblages are present in the stratified turbidites and breccia blocks, and that no radiolarian assemblages younger than Cenomanian have been found in the Santa Rosa Accretionary Complex, it can be inferred that this age span represents most likely the time of formation of the radiolarite succession as well as its partial reworking in the polymictic breccias occurred soon after.

REMARKS AND CONCLUSIONS

The sequence of Sitio Santa Rosa, constituted by sediments and basalt flows showing predominant subvertical dips at first view, represents a complete, continuous and abnormally extremely thick oceanic sequence. Previously it had been also interpreted as to show isoclinal folding of the subvertical radiolarite successions (Tournon, 1984, 1994), but this is not supported by our study, because we found that all polarity indicators show that the top of each unit is systematically towards the east. The numerous repetitions of the described lithologies and the very similar age of the whole oceanic succession of sediments are evidences that support that this sequence can be interpreted as an accretionary complex, constituted by coherent individual packages separated by roughly bed-parallel thrust planes. We define this sequence as the Santa Rosa Accretionary Complex.

We estimate that the total thrust-repeated volcanic-sedimentary sequence of the Santa Rosa Accretionary Complex reaches more than 25 km in thickness, based on the relatively vertical attitude and the continuity between the tip of the Santa Elena Peninsula and the Potrero Grande tectonic window. However, the thickest continuous and coherent separate unit reaches only 300 m.

The successions described from the south coast of the Santa Elena Peninsula were formed during a relatively short late Aptian-Albian to Cenomanian time interval, first in an oceanic environment (late Aptian-Cenomaninan), and later in a trench environment (Cenomanian), when the plate approached subduction. The successions of the Santa Rosa Accretionary Complex could have formed on a plate, like the Farallon Plate (Frisch et al., 1992), which became subducted before the emplacement of the main Caribbean Large Igneous Plateau.

The Albian-Cenomanian interpreted subduction/accretion sequence of the studied area must have formed near an intraoceanic island arc, as suggested by the arc derived clasts of northern Playa Naranjo (Tournon, 1984). Structural relationships, although not studied in detail, preliminarily indicate that the sills intruded into soft radiolaritic sediment during pre-accretion times. The island arc tholeiites of the Islas Murciélago, dated as early Albian (Hauff et al., 2000), could be part of a primitive island arc. Its relationship to the Santa Rosa Accretionary Complex is not clear.

Neither the sedimentary palaeoenvironment nor the petrogenetic affinities of the igneous rocks allow for a correlation of the Santa Rosa Accretionary Complex with the nearest oceanic assemblage, the Nicoya Complex, which crops out in the Nicoya Peninsula.

Reworked radiolarite blocks and clasts in the Santa Rosa Accretionary Complex yielded Jurassic and Neocomian radiolarian ages, similar to those found in blocks in the Nicoya Complex. This could be an indication that both Complexes may have formed on a similar Jurassic-Early Cretaceous oceanic assemblage. The Jurassic radiolarite blocks may have originated from the back-stop of the prism, or may represent remnants of an older oceanic basement underlying the Cretaceous igneous material dominating in the accretionary prism. In any case, the Jurassic radiolarites are important land marks that are still enigmatic and call for an explanation in the plate-tectonic context.

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