UPPER TRIASSIC TO CRETACEOUS RADIOLARIA FROM NICARAGUA AND NORTHERN COSTA RICA - THE MESQUITO COMPOSITE OCEANIC TERRANE

Peter O. Baumgartner*,✉, Kennet Flores*, Alexandre N. Bandini*, France Girault*,° and **Daniel Cruz****

* *Institut de Géologie et Paléontologie, Anthropole, Université de Lausanne, Switzerland.*
** *CIGEO, Universidad Nacional Autónoma de Nicaragua, Managua, Nicaragua.*
° *Present address: Geologisches Institut, ETH Zürich, Switzerland.*
✉ *Corresponding author, e-mail: peter.baumgartner@unil.ch*

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ABSTRACT

We propose a new terrane subdivision of Nicaragua and Northern Costa Rica, based on Upper Triassic to Upper Cretaceous radiolarian biochronology of ribbon radiolarites, the newly studied Siuna Serpentinite Mélange, and published $^{40}Ar/^{39}Ar$ dating and geochemistry of mafic and ultramafic igneous rock units of the area.

The new *Mesquito Composite Oceanic Terrane* (MCOT) comprises the southern half of the Chortis Block, that was assumed to be a continental fragment of N-America. The MCOT is defined by 4 corner localities characterized by ultramafic and mafic oceanic rocks and radiolarites of Late Triassic, Jurassic and Early Cretaceous age: 1. The Siuna Serpentinite Mélange (NE-Nicaragua), 2. The El Castillo Mélange (Nicaragua/Costa Rica border), 3.The Santa Elena Ultramafics (N-Costa Rica) and, 4. DSDP Legs 67/84.

1. The Siuna Serpentinite Mélange contains, high pressure metamorphic mafics and Middle Jurassic (Bajocian-Bathonian) radiolarites in original, sedimentary contact with arc-metandesites. The Siuna Mélange also contains Upper Jurassic black detrital chert formed in a marginal (fore-arc?) basin shortly before subduction. A phengite $^{40}Ar/^{39}Ar$ -cooling age dates the exhumation of the high pressure rocks as 139 Ma (earliest Cretaceous).
2. The El Castillo Mélange comprises a radiolarite block tectonically embedded in serpentinite that yielded a diverse Rhaetian (latest Triassic) radiolarian assemblage, the oldest fossils recovered so far from S-Central America.
3. The Santa Elena Ultramafics of N-Costa Rica together with the serpentinite outcrops near El Castillo (2) in Southern Nicaragua, are the southernmost outcrops of the MCOT. The Santa Elena Unit (3) itself is still undated, but it is thrust onto the middle Cretaceous Santa Rosa Accretionary Complex (SRAC), that contains Lower to Upper Jurassic, highly deformed radiolarite blocks, probably reworked from the MCOT, which was the upper plate with respect to the SRAC.
4. Serpentinites, metagabbros and basalts have long been known from DSDP Leg 67/84 (3), drilled off Guatemala in the Nicaragua-Guatemala forearc basement. They have been restudied and reveal $^{40}Ar/^{39}Ar$ dated Upper Triassic to middle Cretaceous enriched Ocean Island Basalts and Jurassic to Lower Cretaceous depleted Island arc rocks of probable Pacific origin.

The area between localities 1-4 is largely covered by Tertiary to Recent arcs, but we suspect that its basement is made of oceanic/accreted terranes. Earthquake seismic studies indicate an ill-defined, shallow Moho in this area. The MCOT covers most of Nicaragua and could extend to Guatemala to the W and form the Lower (southern) Nicaragua Rise to the NE. Some basement complexes of Jamaica, Hispaniola and Puerto Rico may also belong to the MCOT.

The *Nicoya Complex s. str*. has been regarded as an example of Caribbean crust and the Caribbean Large Igneous Province (CLIP). However, $^{40}Ar/^{39}Ar$ - dates on basalts and intrusives indicate ages as old as Early Cretaceous. Highly deformed Jurassic and Lower Cretaceous radiolarites occur as blocks within younger intrusives and basalts. Our interpretation is that radiolarites became first accreted to the MCOT, then became reworked into the Nicoya Plateau in Late Cretaceous times. This implies that the Nicoya Plateau formed along the Pacific edge of the MCOT, independent form the CLIP and most probably unrelated with he Galapagos hotspot.

No Jurassic radiolarite, no older sediment age than Coniacian-Santonian, and no older $^{40}Ar/^{39}Ar$ age than 95 Ma is known from S-Central America between SE of Nicoya and Colombia. For us this area represents the trailing edge of the CLIP *s. str*.

INTRODUCTION

General scope

Classically, the southern limit of the (supposedly continental) Chortis Block (Dengo, 1969; 1985) has been placed at a hypothetical fault line connecting the E-W trending main fault in the Santa Elena Peninsula with the Hess Escarpment (Case and Holcombe, 1980; Escalante, 1990; Krawinkel and Seyfried, 1994.) For some authors this supposed fault is thought to have a still active major strike slip component (Beccaluva et al., 1996; Giunta et al., 2006). Mafic and ultramafic basement rocks south of this line have been associated with the Chorotega Block (Dengo, 1962; 1969; 1985). The ultramafics of the Santa Elena Peninsula together with the Nicoya Complex were originally considered as an ophiolitic suite (Dengo, 1962; Kuijpers, 1980; Azéma et al., 1985). More recently, these outcrops were still interpreted as MOR - remnants of an inter-American protocaribbean oceanisation (Giunta et al., 2006). A review of the history of hypotheses concerning the Nicoya Complex is given in Denyer and Baumgartner (2006).

Modern geochemistry (Hauff et al., 1997; 2000a; 2000b; Sinton et al., 1997; 1998; Beccaluva et al., 1999), and $^{40}Ar/^{39}Ar$ dating (Sinton et al., 1997; Hauff et al., 2000a; Hoernle et al., 2004) and radiolarian dating exposed in detail in this paper allow for a better distinction between four major units in this area: 1. The *Nicoya Complex s. str*. (NC, Denyer and Baumgartner, 2006), a composite plateau of Pacific origin, that shares geochemical characteristics and its youngest ages with the Caribbean Large Igneous Province (CLIP), but incorporates $^{40}Ar/^{39}Ar$ dated igneous rocks as old as 139 Ma (Hoernle et al., 2004). We will discuss further its relationship with the CLIP in this paper. 2. The *Islas Murcielagos* are made of massive and pillowed basalt flows with IAT-affinity and $^{40}Ar/^{39}Ar$ -dated as 109 Ma (Hauff et al., 2000a). 3. The *Santa Rosa Accretionary Complex* (SRAC, Baumgartner and Denyer, 2006), of middle Cretaceous age, contains both enriched alkaline OIB-type volcanics and depleted intrusives with evolved island arc affinities (Nancite layered gabbros, Hauff et al., 2000a; Arias, 2002). It contains blocks of highly deformed radiolarites of Jurassic age. 4. The *Santa Elena Ultramafics*, made of MOR-like, depleted mantle peridiotites that are largely serpentinized. This latter unit forms the *Santa Elena Nappe*, a regional SW-verging overthrust over the Santa Rosa Accretionary Complex (Tournon and Azéma, 1980; Tournon, 1994). Although the units 2, 3 and 4 share some geochemical characteristics, their relationships are clearly structural (3 with the other) or unknown (2 with the other). These units may have an independent geodynamic history.

At first hand, we can state that The *Nicoya Complex s. str*. represents the northernmost occurrence of CLIP-like plateaus and the *Santa Elena Ultramafics* represent the southernmost outcrop of several occurrences of ultramafic and mafic rocks further discussed in this paper (Fig. 1): 1. Rocks drilled by DSDP Legs 67 and 84 were previously considered as accreted CLIP (Nicaragua forearc basement of Hauff et al., 2000b; Hoernle et al., 2004). They have been restudied by Geldmacher et al. (2006, submitted), who recognize ultramafic and mafic rocks of Pacific origin most likely different from the CLIP. 2. The *Siuna Serpentine Mélange* (SSM, Fig. 1, NW-Nicaragua) first described as serpentinite unit (Sapper, 1937; Venable, 1994), currently under study by us (Baumgartner et al., 2004; Flores et al., 2006; 2007a; 2007b; 2007c); 3. Serpentinite outcrops of the El Castillo area (Fig. 1, S-Nicaragua, N-Costa Rica, Garayer and Viramonte, 1973; Astorga, 1992; Vargas and Alfaro, 1992; Tournon et al., 1995; Flores et al., 2007c); 4. Serpentinites and cherts of the Tonjibe well (Fig. 1, Pizarro, 1993) and, 5. Basalts, cherts and basaltic lavas interbedded with siliceous limestones of the unpublished wells Ostional-1 and Rivas-1 (Fig. 1) drilled on the Sandino Basin, Nicaragua (INE, 1995, Ranero et al., 2000). The Santa Elena, El Castillo, and Tonjibe peridotite occurrences have been interpreted as a 150 km long E-W trending ultramafic suture zone (Tournon et al., 1995), which was thought to be the boundary between the Chortis *s. str.* and the Chorotega blocks, seen in alignment with the Hess Escarpment (Dengo, 1985).

However, considering the rocks recovered by Legs 67/84, the outcrops of the Siuna area, and the other, bore hole information cited above, we are dealing with a polygon that extends over nearly 1000 km in E-W and 300 km in N-S directions and covers most of the territory of Nicaragua (Fig. 1). At present, there is no evidence of any pre-Tertiary continental basement between these corner localities characterized by ultramafic/mafic rocks of presumed Pacific origin. We therefore suspect that this area, largely covered by Tertiary to Recent arc volcanism, is underlain by a variety of accreted Pacific terranes for which we introduce here the

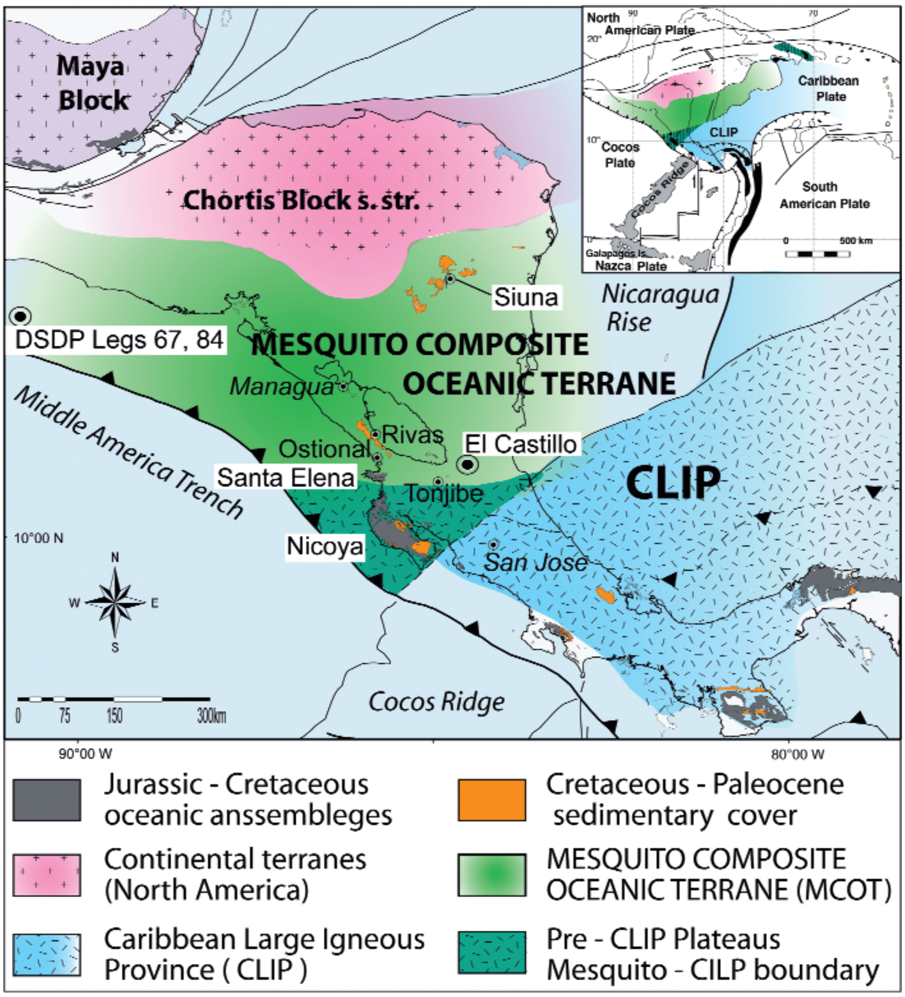

Fig. 1 - New Terrane map of Southern Central America with the general plate tectonic setting of the Caribbean Plate in inset (upper right). The Chortis Block *s. str*., characterized by Palaeozoic continental basement, is restricted to N-Nicaragua, Honduras and SE-Guatemala. Most of the basement of Nicaragua and northernmost Costa Rica is supposed to be made of the newly defined Mesquito Composite Oceanic Terrane (MCOT), sampled by DSDP Legs 67 and 84 and cropping out in Siuna, El Castillo and Santa Elena, localities discussed in this paper. The Nicaragua Rise shows a twofold bathymetry on GeoMap that is supposed to represent a twofold basement: shallow = continental to the N, deeper and irregular = oceanic to the S. The Caribbean Large Igneous Province (CLIP) to us is restricted to Upper Cretaceous terranes located SW of Nicoya and in Panama, a composite of plateaus. The Nicoya Complex *s. str*. and other terranes in NW-Costa Rica expose Pacific, pre- CLIP Plateaus formed in contact with the MCOT (see text).

name "*Mesquito Composite Oceanic Terrane*" (MCOT). This composite terrane must extend at least from the forearc area off El Salvador to the Santa Elena Peninsula in Northern Costa Rica. To the NE it must be present in the lower Nicaragua Rise and may extend into "basement" units of Jamaica, Hispaniola and Puerto Rico. The Chortis Block *s. str*., itself also possibly composed of several terranes of continental origin (Rogers, 2003; Rogers et al., 2007a; Ortega-Gutierrez et al., 2007), is largely restricted to Honduras and easternmost Guatemala (Fig. 1). The topography of the Nicaragua Rise is clearly twofold (e.g. James, 2006): The upper (northern) Rise has a continental basement, while the lower (southern) Rise has a deeper, more irregular topography that we associate with the MCOT. The Southern Nicaragua Rise has been correlated with the "Siuna Terrane" by Venable (1994) and Rogers et al. (2007a), which we include with the MCOT.

The purpose of this first paper on South Central American terranes is to present new radiolarian data that provide both biochronologic age dates that are independent from isotopic ages in igneous rocks, and furnish strong arguments for a Pacific origin of the Mesquito Composite Oceanic Terrane (MCOT). We present here the so far oldest fossils from Southern Central America: upper Rhaetian (approx. 200 Ma, Gradstein et al., 2004) Radiolaria from El Castillo area, Southern Nicaragua. This radiolarian assemblage has strong affinities with faunas described from Pacific N-America and, above all, it cannot come from a hypothetical inter-American ocean, because it predates Pangea break-up. In addition, we intend to clarify the origin, tectonic history and juxtaposition of terranes in Northern Costa Rica based on radiolarian biochronology and isotope ages as well as on the recently published igneous geochemical data.

Previous work, Radiolaria

Mesozoic radiolarian biochronology has made great progress in the last 20 years and the dating of siliceous pelagic rocks has been essential to the understanding of complex terranes such as the Franciscan and many terranes in Japan (Baumgartner et al., 1995a; Baumgartner, 2006). Despite the widespread occurrence of radiolarites in the oceanic terranes of Southern Central America, comparatively little work has been published to date the radiolarian-bearing Mesozoic sediments related with basalts of Costa Rica and Nicaragua. Galli-Olivier (1977) was the first to collect a radiolarian sample from NW-Nicoya that was analysed by E.A. Pessagno and tentatively dated as Late Jurassic/Early Cretaceous (Galli-Olivier, 1977). Schmidt-Effing (1979) states the same age and illustrates some radiolarian specimens from NW-Nicoya. Schmidt-Effing (1980) illustrates and describes a well-preserved Upper Cretaceous (Cenomanian) radiolarian assemblage from the Santa Elena Peninsula; Kuijpers (1979; 1980) uses radiolarian data by Baumgartner to define units in the Nicoya Complex of the NW-Nicoya Peninsula. Baumgartner (1984b) gives the first range chart for radiolarian species found in NW-Nicoya and extends the age range of samples down to the Middle Jurassic (Bathonian/Callovian). These ages are later revised, based on the new biochronology in Baumgartner et al. (1995b) as Bajocian. DeWever et al. (1985) report radiolarian assemblages of late Early - early Middle Jurassic, Late Jurassic and middle Cretaceous ages from the sequences underlying the Santa Elena Ultramafic Nappe, unfortunately without illustrations. Denyer and Baumgartner (2006) establish radiolarian ages that range from Bajocian (Middle Jurassic) to Santonian (Late Cretaceous) in the Nicoya Complex *s. str*. and illustrate some specimens. North of the area studied here, adjacent to the Montagua Suture Zone between the Chortis and the Maya Blocks, Chiari et al. (2006) present poorly preserved, but distinctive radiolarians, that date the basalts of the El Tambor Group (southern Motagua Mélange) as Late Jurassic.

One of the reasons for the lack of radiolarian illustrations is the fact that most occurrences of Radiolaria in Costa Rica and Nicaragua are restricted to highly deformed siliceous sediments that occur in accreted terranes or as xenoliths in younger igneous units, such as the Nicoya Complex (Denyer and Baumgartner, 2006). Preservation is, in general, poor to moderate and the diversity of determinable radiolarians is low. However, the examination of multiple HF-residues of each sample, careful picking and SEM-observation allow for precise dating even in high grade metamorphic rocks.

Radiolarian biochronology used for dating

Upper Triassic (Rhaetian) radiolarian assemblages are now very well known and clearly differentiated form Lower Jurassic ones through the work of Carter et al. (1989); Carter (1990; 1993; 2007), Tekin (1999) and many other studies summarised in Carter (2007).

Middle Jurassic to middle Cretaceous radiolarian biozonations have become broadly based and are now reliable and precise to the substage level (O'Dogherty, 1994; Baumgartner et al., 1995b). Middle and Upper Jurassic samples were compiled *sensu* Baumgartner et al. (1995b), using the UAZ95 zonation. Some ranges have since been revised by Prela et al. (2000), Dumitrica and Dumitrica-Jud (2005), and Chiari et al. (2007). We used the zonation by

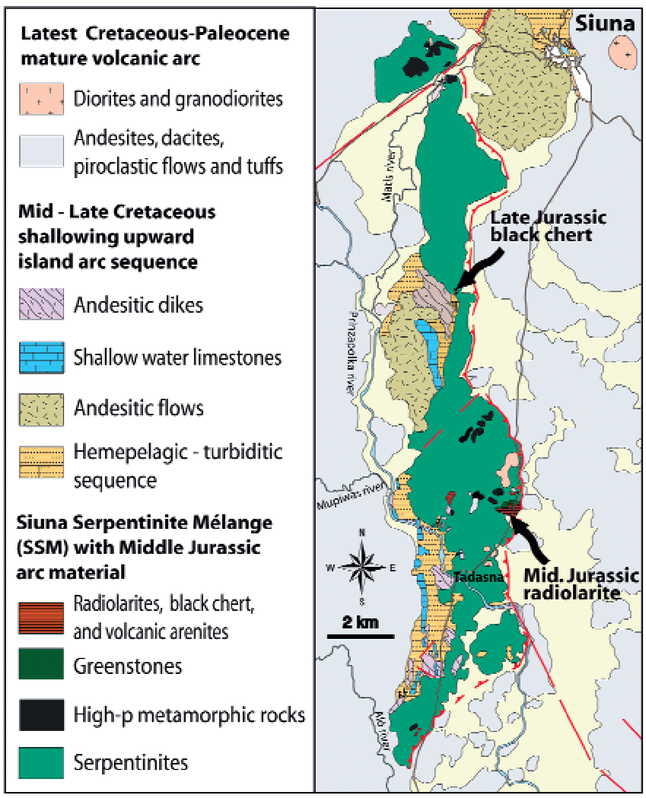

Fig. 2 - Geologic map of the Siuna area, showing the Siuna Serpentinite Mélange and its tectono-stratigraphic context. The two radiolarian sample localities are indicated. Geology partially after Venable (1994).

O'Dogherty (1994) for the middle Cretaceous assemblages. Additional information was derived from the zonation of Sanfilippo and Riedel (1985) for species that are not represented in the former zonations. To obtain the age range of the Upper Cretaceous samples we have principally used the zonations by Foreman (1975), Pessagno (1976), Taketani (1982), Sanfilippo and Riedel (1985) and O'Dogherty (1994).

NEW MESOZOIC RADIOLARIAN AND THEIR TECTONOSTRATIGRAPHIC CONTEXT

The Siuna Serpentinite Mélange (MCOT, NE Nicaragua): Middle and Late Jurassic

Geologic setting

In the area S and NE of Siuna (Fig. 2), we mapped three distinct tectono-stratigraphic units that have been globally called Siuna Terrane (Venable, 1994; Rogers et al., 2007a): 1. The Siuna Serpentinite Mélange (SSM, Flores et al., 2006; 2007a; 2007b; 2007c), further discussed below, forms a N-S trending outcrop of 30 x 5 km size located S of Siuna (Fig. 2). This basement unit (identified as part of the Mesquito Composite Oceanic Terrane, MCOT) crops out in an erosional window that formed in a generally low relief area due to reverse faults that have brought it to high levels. 2. Thin-bedded calcareous hemipelagites yielding Aptian/Albian planktonic Foraminifera rest unconformably on the SSM. Distal volcaniclastic turbitites are interbedded. The sequence shallows upsection into thick-bedded limestones, in which andesitic flows may be intercalated. We interpret this succession as a passage from a distal forearc basin into an island arc situation. 3- Upper Cretaceous andesitic to dacitic tuffs, pyroclastics and lava flows are intruded and overprinted by large diorite and granodiorite intrusions of latest Cretaceous-Paleocene age (Venable, 1994).

In the SSM tectonized serpentinite is by far the most abundant lithology (Fig. 2). It consists of metamorphosed, Ca-depleted ultramafic rocks with relict peridotite textures

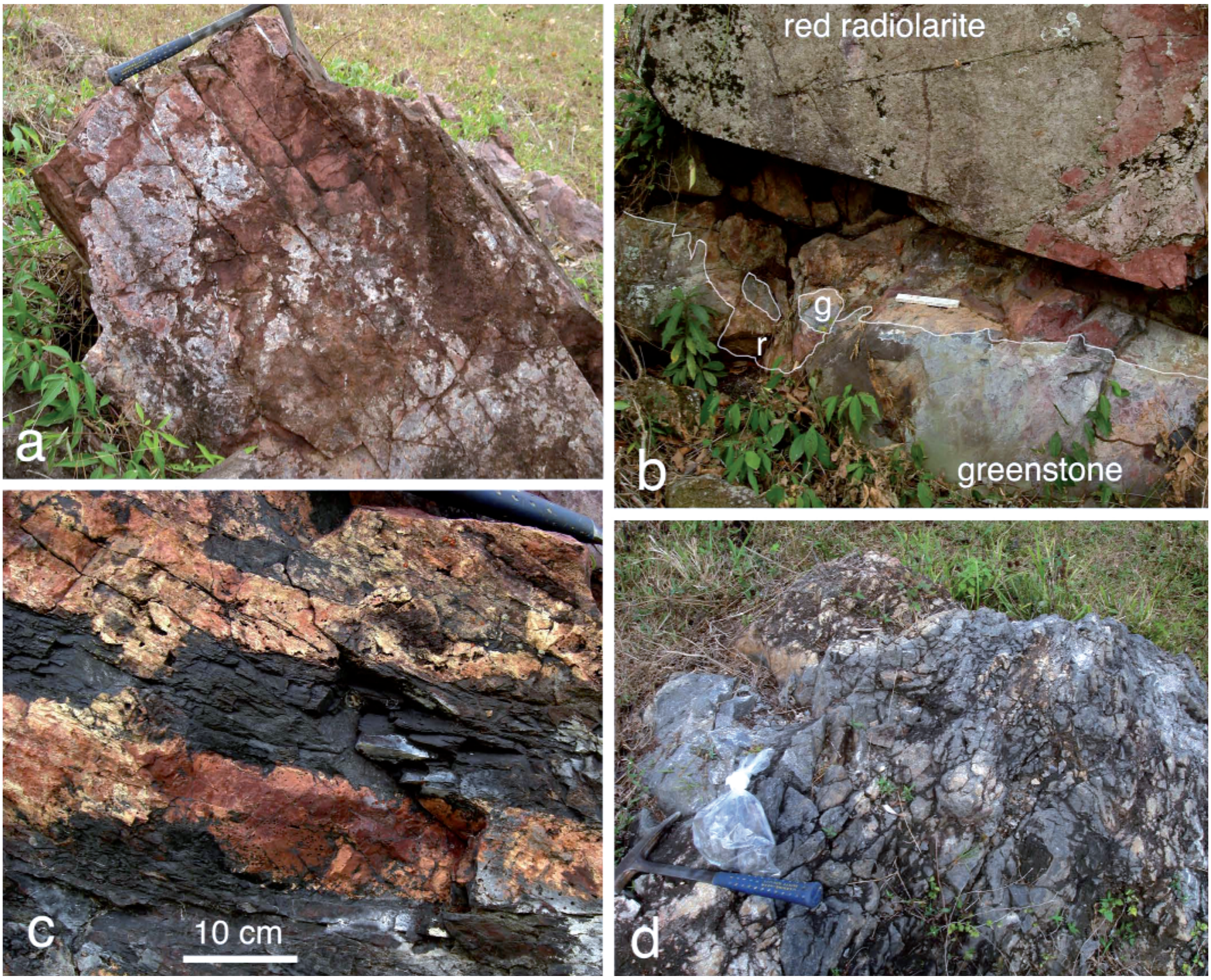

Fig. 3 - Outcrop illustrations of radiolarian-bearing rocks in the Siuna Serpentinite Mélange (NE-Nicaragua). **a)** Middle Jurassic red ribbon-bedded radiolarites (hammer = 40 cm, sample location UTM 1505.605N, 0738.383E). **b)** Contact between greenschist-grade metamorphic greenstones and Middle Jurassic red chert. The contact is interpreted as sedimentary as shown by its irregularity and greenstone boulders reworked in chert (white scale = 22 cm, N 13° 36.73', W 084° 47.71'). **c)** Alternation of red radiolarite and black Mn-rich chert of probable oceanic hydrothermal origin. Yet undated blocks near the Middle Jurassic radiolarian occurrences (N13° 36. 84`, W 084° 48.84'). **d)** Upper Jurassic black chert and siliceous mudstones that occur in scattered outcrops (hammer = 40 cm, N 13° 40.14', W 084° 48.81').

in some places. Relict Cr-rich spinel (Cr# 0.57-0.79) in serpentinites and chromite pods indicates a high degree of melting. Serpentinite forms a tectonic matrix for a variety of mappable blocks grouped into the following categories: Gabbros and metagabbros, ophicarbonates, metaturbidites, metacherts, metasandstones, quartzites, greenschists, metamafics displaying a variety of metamorphic conditions, micaschists, greenstones and ribbon-bedded radiolarian cherts, Mn-radiolarites and black cherts, bearing Middle and Upper Jurassic Radiolaria reported here. The mineral assemblages in the metamafic blocks reveal metamorphic conditions that range from typical greenschist and amphibolite facies to high pressure barroisite-bearing greenschists. Possible blueschist to eclogite facies conditions are indicated by blocks containing garnet with inclusions of aegirine/omphacite and blocks of micaschists bearing silica-rich phengites. We obtained $^{40}Ar/^{39}Ar$ phengite cooling age of 139.2±0.4 Ma (Flores et al., 2007b; 2007c). In some blocks, greenstones (mainly altered metabasalts and metandesites locally reworked as meta-volcarenites) are associated with ribbon-bedded radiolarites and siliceous shales suggesting an original sedimentary contact of sediments on an oceanic crust (Fig. 3). The geochemistry of the metamorphic blocks clearly indicates that the protoliths originated in an intraoceanic arc setting (Flores et al., in preparation). The SSM resembles (though it is more polymict) the subduction mélanges of the Franciscan (Blake and Jones, 1981; Jones et al., 1983) and indicates that it is part of the Mesquito Composite Oceanic Terrane, as defined here.

Radiolarian occurrences

Red ribbon-bedded radiolarites (Fig. 3a) occur in scattered outcrops that represent large blocks embedded in the serpentinite matrix (Fig. 2, "Middle Jurassic radiolarite"). Radiolaria are abundant in most outcrops, but metamorphism destroyed most of the fine textures of the rocks: Radiolarian ghosts appear in thin section usually as flattened quartz spherules without any morphologic features left. In one case it was, however, possible to extract the Middle Jurassic assemblage presented here (sample 05-01-21-03, located at 1505.400N, 738.254E UTM, Plate 1). In some blocks of the same small (1 x 1 km) area the red radiolarites are associated with greenstones (Fig. 3b), which are, in general, metandesites and associated minor basaltic metasandstones. Irregular contacts between the two lithologies and greenstone boulders that seem embedded in the radiolarite suggest original sedimentary contacts between ocean floor basalt/andesite and oceanic sediment. Many blocks of the same area show interlayering at dm-scale of dark brown to bluish-black Mn-Fe-rich chert with pink to brick red radiolarian-bearing chert (Fig. 3c). This, so far undated lithology could represent ocean floor hydrothermal fall-out interbedded with radiolaritic deposits.

In another area about 7 km to the N (Fig. 2 "Upper Jurassic black chert") we found outcrops scattered over an entire hill of dm-bedded black radiolarian-rich chert, minor shales and siliceous mudstones (Fig. 3d). At present, we favour the hypothesis, that these outcrops represent a large block embedded in the SSM. It cannot be excluded that this lithology forms a separate small tectonic unit. In one place we could extract a reasonably preserved Upper Jurassic radiolarian assemblage (sample 05-01-16-02 located at 1511.727N/736.628E UTM, Plates 1, 2). The black, organic-rich lithology is unusual in Upper Jurassic Pacific open Ocean palaeo-environments. In the Franciscan and the Japanese Mino Terrane black radiolarites are restricted to the major Oceanic Anoxic Events recognised worldwide (e.g. late Toarcian, Hori, 2001). We therefore speculate that this slightly detrital and organic-rich lithology was deposited in an E-Pacific marginal palaeo-environment, when its area of deposition was approaching subduction.

Biochronology

The Middle Jurassic sample (05-01-21-03, Plate 1, 1-7), though poorly preserved yielded some species characteristic of Unitary Association Zones (UAZ) 4-6 of Baumgartner et al. (1995b), which corresponds to a late Bajocian-middle Bathonian age (approximately 168-163 Ma according to Palfy et al., 2000; 169-165 Ma according to Gradstein et al., 2004). The age is principally constrained by the total range of *Williriedellum* sp. S (= *Tricolocapsa* sp. S) sensu Baumgartner et al. (1995a). *Williriedellum marcucciae* Cortese has the same first appearance but may range up to the middle Callovian - early Oxfordian. *Linaresia* sp. cf. *L. chrafatensis* (El Kadiri) is a poorly preserved specimen, but this form is restricted to the Middle Jurassic. Despite of a poor preservation and diversity, this assemblage resembles central Pacific, low fertility assemblages of the Franciscan, ODP-Site 801, and the Mino Terrane, rich in forms associated with the radiolarian family Williriedelidae (Murchey, 1984; Matsuoka, 1995).

The Upper Jurassic sample (05-01-16-02, Plate 1, 8-13, Plate 2) is slightly better preserved and more diverse that the

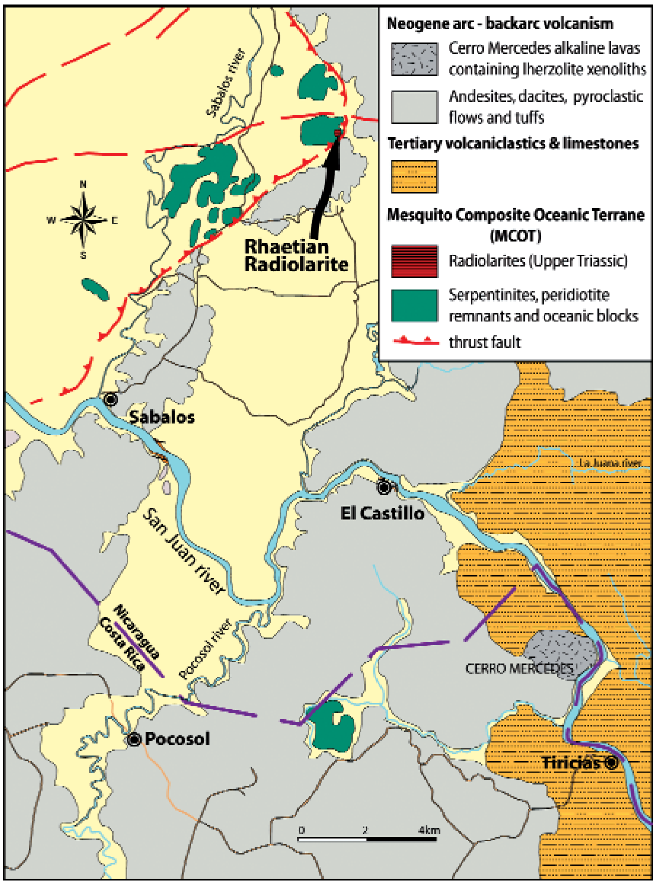

Fig. 4 - Geologic map of the El Castillo area (Nicaragua/Costa Rica border, Rio San Juan) showing serpentinite occurrences and the location of the Rhaetian radiolarian sample. Modified after Rivier (1968), Martinez (1972) and Tournon and Alvarado (1997).

Middle Jurassic one. The concurrent range of the observed species is UAZ 9-11 of Baumgartner et al. (1995b), which corresponds to a middle Oxfordian to late Kimmeridgian/early Tithonian time span (156-149/145 Ma according to Channell et al., 1995; 159 - 151/148 Ma according to Gradstein et al., 2004). This age is constrained in the first place by the total range of *Zhamoidellum ovum* Dumitrica. In addition, several other species do not range higher that UAZ 11 (see Plate 2), and one form that compares to *Sethocapsa uterculus* with a range of UAZ 11-22 could possibly restrict the age of the sample to UAZ 11, i.e. late Kimmeridgian/early Tithonian. However, poor preservation and diversity of this sample does not allow further precision of the age. This assemblage resembles both Pacific and Tethyan assemblages of the same age span.

El Castillo Mélange (MCOT, Nicaragua/Costa Rica border): Rhaetian (Late Triassic)

Geologic setting

In the El Castillo area, straddling the border between Nicaragua and Costa Rica (Fig. 4), we observed three tectono-stratigraphic units: 1. A Mesozoic oceanic terrane largely composed of serpentinite that we associate with the MCOT, 2. A Tertiary turbiditic sequences overlain by interbedded (redeposited?) shallow water limestones, sandy limestones and volcaniclastic sandstones and, 3. A Neogene volcanic arc-derived cover sequence.

The serpentinite unit was first described by Astorga (1992), Vargas and Alfaro (1992), and from the Tonjibe drill hole by Pizarro (1993). The unit appears in small outcrops in road cuts and quarries mined for road gravel on the Nicaraguan side, and as blocks on a small hill in the Costa Rican area (Fig. 4). It was further recovered from the Tonjibe well 25 km SW of the study area (Fig. 1), in which Pizarro (1993) reports the perforation of 193 m of serpentinite containing some chert. Tournon et al. (1995) called the El Castillo Mélange “San Juan peridotites”. We prefer the name “El Castillo” because it refers more precisely to the outcrop area. So far no other serpentinite localities have been found along the 150 km course of the San Juan River. Tournon et al. (1995) compared geochemical data based on Cr-rich spinels and concluded on a very similar origin of the “San Juan” (= El Castillo) peridotites and the Santa Elena Ultramafic Unit (see next paragraph).

Radiolarian occurrence

So far, one outcrop of radiolarite, located at Las Brenes (Fig. 4 “Rhaetian Radiolarite”) has been found. Astorga (1992) and Tournon et al. (1995) describe 4-5 m of red ribbon-bedded radiolarite that crop out on the south end of the Las Brenes quarry and apparently dip 45° northwards, beneath the highly tectonised serpentinites of the quarry. Although no actual contact is described, the authors suspect a tectonic superposition of the two lithologies recalling the Santa Elena overthrust over radiolarites of the Santa Rosa Accretionary Prism (Tournon et al., 1995). Our own observations in 2006 and 2007 do not confirm this interpretation: Unfortunately, the radiolarite outcrop is now completely quarried. Only a small (1 m high) elevation with radiolarites in place still exists (N 11° 06’ 42.6”, W 064° 24’ 37.7”) besides a large flattened area of radiolarite debris, that is being built on by settlers. We found, however, serpentinite debris dug out of a water hole just south of the radiolarites. We therefore suspect that the radiolarite is not an extended unit, but represents a block in a tectonic mélange similar to blocks that occur in the SSM. So far, one out of several treated samples (Plate 3, sample 06-04-19-01 location 1229.397N/0782.818E UTM) has yielded a moderately preserved, diverse radiolarian assemblage presented here.

Biochronology and palaeobiogeography

The Rhaetian sample (06-04-19-01, Plate 3) contains several tens of species of which many are undescribed in literature. For this preliminary report we have compared our material with taxa formally and informally described by Carter (1990; 1993), Tekin (1999), and other authors. Carter (1993) published a detailed biochronology using Unitary Associations of Rhaetian Radiolaria, based on data from continuous Upper Triassic - Lower Jurassic sections studied in the Queen Charlotte Islands (Sandilands Formation, British Columbia, Canada). Our assemblage has many species in common with assemblage 3 of Carter (1993) defined as the *Globolaxtorum tozeri* Zone. In fact, our species association fits exactly with Unitary Association (UA) 26, the second last in Carters zonation. A number of species range through most of the Rhaetian but disappear in UA 26, before the end of the Rhaetian, such as: *Ferresium triquetrum* Carter (UA 3-26), *Risella tledoensis* Carter (UA 15-26), *Laxtorum capitaneum* Carter (UA 21-26), On the other hand, *Globolaxtorum*? sp. A *sensu* Carter 1993 (UA 26-27) and other forms are restricted to the latest Rhaetian. The concurrent range of the species determined is UA 26. We can therefore state that our sample is late (probably latest) Rhaetian in age (201-199.6 Ma according to Gradstein et al., 2004).

Carter (2007) reviews the global distribution of Rhaetian Radiolaria. Among the 16 radiolarian localities compared by Carter, the faunal association of our sample resembles most the one of the Queen Charlotte Islands, which can be considered as a low-middle palaeolatitude Pacific margin assemblage. While the Sandilands Formation of the Queen Charlotte Islands shows a clear forearc influence (Carter, 1993) our red ribbon radiolarites must represent an open ocean abyssal paleoenvironment, such as the Mino Terrane in Japan (Hori, 2001). The faunal resemblance underlines the cosmopolitan nature of the recovered upper Rhaetian assemblage that preceded the global radiolarian turnover at the Triassic/Jurassic boundary observed worldwide (Carter and Hori, 2005). The fact that these Rhaethian radiolarian faunas correlate throughout Panthalassa is essential to the interpretation of the MCOT. At least this part of the oceanic terranes cannot be originated in a hypothetical inter-American seaway, because its radiolarites predate Pangea breakup in this area and the radiolarians are typical for Panthalassa.

Santa Elena Peninsula (MCOT, N-Costa Rica): Middle Cretaceous and reworked Early to Late Jurassic

Geologic setting

The Santa Elena Peninsula and the Islas Murcielagos south of it (Fig. 5) have been the subject of two recent papers by us: 1. Baumgartner and Denyer (2006) describe the *Santa Rosa Accretionary Complex* (SRAC) cropping out along the South coast of the peninsula beneath the Santa

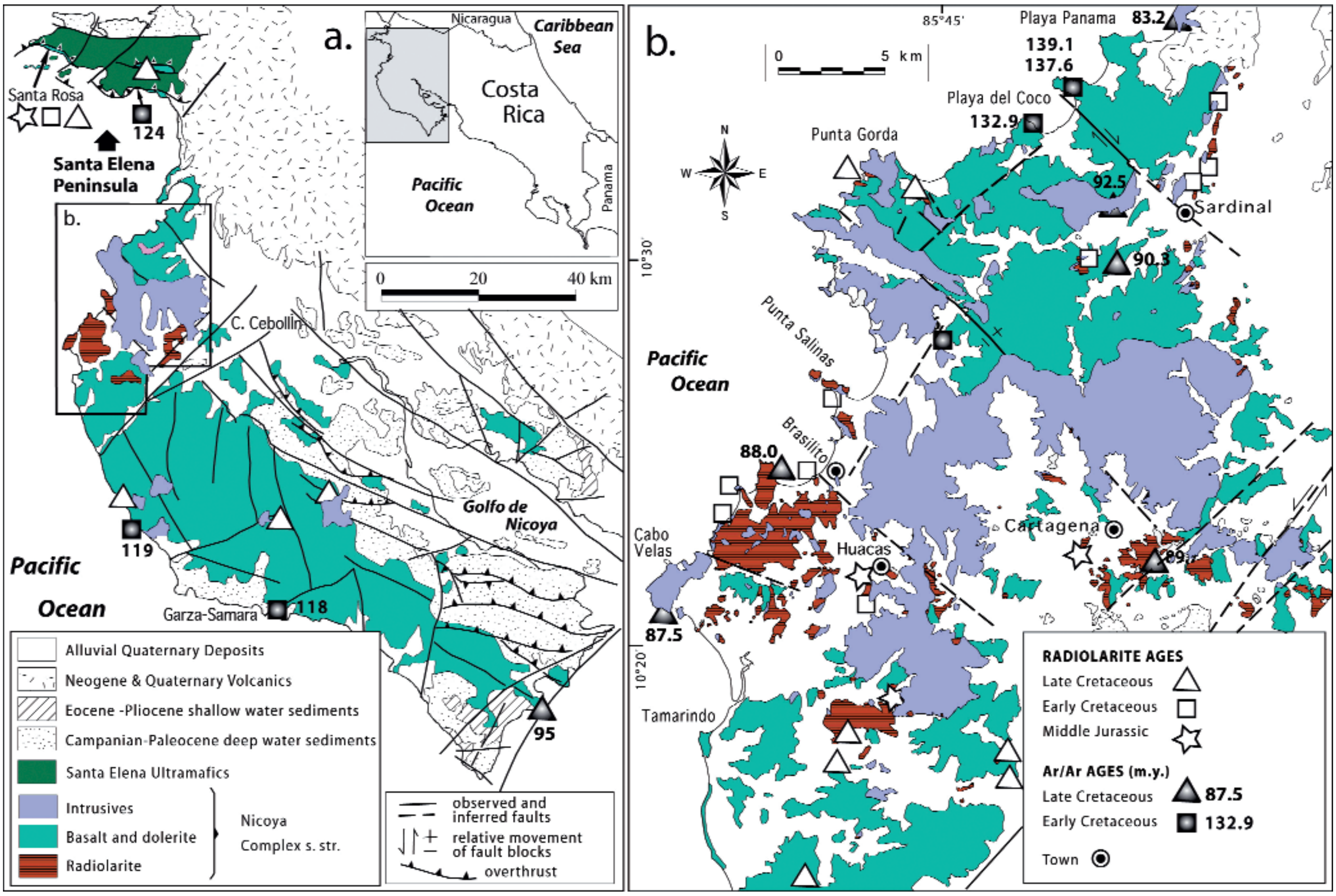

Fig. 5 - a) Geologic map of NW-Costa Rica indicating the major geologic units, and the location of radiolarian and radioisotopic ages discussed in this paper (modified after Denyer and Baumgartner, 2006). b) detailed geologic map of the NW-Nicoya Peninsula showing geologic relationships between Middle Jurassic to Upper Cretaceous radiolarites and Cretaceous basalts and intrusives (after Denyer and Baumgartner, 2006). Radiolarian ages after Baumgartner (1984a) and Denyer and Baumgartner (2006). $^{40}Ar/^{39}Ar$ ages after Sinton et al. (1997), Hauff et al. (2000a) and Hoernle et al. (2004).

Elena overthrust. 2. Gazel et al. (2006) summarize and interpret the geochemistry known from that area. The principal features, relevant to the interpretation of this area as the present day southernmost outcrops of the MCOT and its differences with the Nicoya Complex and the CLIP are summarized here. For further detail, the reader is referred to the above papers.

We distinguish from bottom to top 3 tectonic units in the area of the Santa Elena Peninsula:

1. The Islas Murciélagos pillow and massive basalts show no clear structural relationship with the following 2 units. Their geochemistry suggests a primitive island arc origin similar to the dolerites of the Santa Elena Nappe. A pillow basalt from Islas Murciélagos yields an $^{40}Ar/^{39}Ar$ date of 109.0±2.0 Ma (Hauff et al., 2000a). No fossil-bearing sediments are known from this unit.
2. The relative autochthonous of the Santa Elena Nappe is composed of the *Santa Rosa Accretionary Complex* (SRAC) and the Nancite layered gabbros, plagiogranites and associated basaltic dykes. Baumgartner and Denyer (2006) describe the SRAC as a tectonic pile of sedimentary and volcanic packages. Polarity indicators in all sedimentary packages show youngling to the East. Sedimentary environments within individual stratigraphic packages range from oceanic (radiolarites with alcaline basalt sills) to trench fill (arc-derived turbidites and collapse megabreccias). Bedded radiolarites yield middle Cretaceous ages throughout, whereas reworked blocks of highly deformed radiolarite in breccias yield Jurassic ages (see below). The Nancite Complex has been erroneously included with the Santa Elena Ultramafics by Gazel et al. (2006). According to Arias (2002) and our own field examination in 2007, the Nancite Complex is clearly exposed in a tectonic window beneath the main overthrust of the Santa Elena Nappe. Geochemical affinities between these two units can, therefore, not be regarded as evidence for a common geodynamic origin. Low TiO_2 contents and high LREE depletion suggests a primitive island arc origin for the Nancite Complex (Arias, 2002). Hauff et al. (2000a) report a $^{40}Ar/^{39}Ar$ date of 124.0±4.0 Ma from the layered gabbros. Both the Nancite Complex and the Islas Murcielagos basalts have an age range that makes them approximately contemporaneous with the formation of the SRAC, suggesting a genetic relationship between these units. Underway geochemical analyses of arc-derived clasts sampled from breccias of the SRAC will elucidate this hypothesis.
3. The Santa Elena Ultramafics, form a regional SW-vergent overthrust, the Santa Elena Nappe, over the units discussed before. They consist of depleted (MORB-like) serpentinized mantle peridotites, with very low TiO_2 and high Ni and Cr contents. Cross-cutting doleritic dykes represent a later phase with a geochemistry that suggests a primitive island arc origin (Gazel et al., 2006). Again, these dykes show geochemical similarities (Gazel et al., 2006) with the basaltic dykes cutting through the Nancite

layered gabbros located in the relative autochthonous beneath the Santa Elena Nappe, but this does not warrant for a genetic relationship between the two units. Moreover, the Santa Elena Ultramafics and the cross-cutting dolerites are, so far, undated. Sr, Nd, and Pb isotopic ratios of the Santa Elena Nappe and the Santa Elena Accretionary Complex samples do not correspond to the Galapagos Mantle array, and suggest different mantle reservoirs and geochemical characteristics than the CLIP and the Nicoya Complex. Of the above units, only the SRAC contains radiolarian-bearing sedimentary sequences further discussed below.

Radiolarian occurrences

The Santa Rosa Accretionary Complex (SRAC) has yielded many, in part well-preserved radiolarian assemblages that come from: 1. Intact stratigraphic sedimentary sequences (late Early to early Late Cretaceous) that form individual tectonic units of the SRAC. 2. From radiolarite clasts and blocks (Early, Middle, and Late Jurassic) incorporated into debris flows and collapse megabreccias associated with gravitational and/or tectonic reworking in a near-trench environment (Baumgartner and Denyer, 2006).

1. Individual stratigraphic sequences are composed of multiple alkaline basaltic flows that exhibit massive to extremely vesicular pillow basalts with clear ocean island basalt affinities (Hauff et al., 2000b). Brick-red, ribbon-bebbed radiolarites are interbedded with the basalt flows, or form up to 300 m thick sequences intruded by multiple sills of alkaline basalts, which are chemically similar to the flows. Some units (e.g. Unit 7 of Baumgartner and Denyer, 2006) contain a stratigraphic sequence in which the oldest rocks are ribbon-bedded radiolarites that gradually give way up-section to tuffaceous mudstones, arc-derived volcanic turbidites, debris flows and finally disorganized megabreccias. This sequence is interpreted as (1) formed on an ocean floor (or seamount) approaching the trench, (2) received trench fill sedimentation including material resulting from gravitational prism collapse and, (3) detached from its substrate and accreted in the SRAC.
2. Several tectonic units of the SRAC contain sequences of debris flows and megabreccias that include clasts and blocks of highly deformed radiolarites. Many of these blocks show also differences in lithology with respect to the bedded radiolarites.

Biochronology

The radiolarian biochronology was established by DeWever et al. (1985) and Schmidt-Effing (1980) and reinterpreted by Baumgartner and Denyer (2006). We have resampled all the localities and are in the process of producing a detailed biochronology of the SRAC in comparison with Radiolaria from other localities form Central America and the Caribbean (Bandini et al., in progress).

1. Intact stratigraphic sequences. **Middle Cretaceous** radiolarian assemblages have been recognized in the successions of the SRAC from all localities. They come from samples collected in stratified radiolarites, as well as from some clasts of disorganized polymictic breccias (Tournon, 1994). In the Potrero Grande tectonic window, a well-preserved Upper Cretaceous radiolarian assemblage was first attributed to the late Albian to early Cenomanian (Schmidt-Effing, 1980). According to the ranges by O'Dogherty (1994) this sample should be early Cenomanian in age.
   Late Aptian-Albian to Cenomanian time represents most likely the time of formation of the radiolarite successions, their intrusion by alkaline sills, as well as their partial reworking in the polymictic breccias that occurred soon after in a near-trench environment.
2. Radiolarite clasts and blocks. **Late Early Jurassic** (Pliensbachian-Toarcian. The radiolarite assemblage dated by DeWever et al. (1985) as late Early or early Middle Jurassic has been identified in a breccia composed of a green volcanoclastic boulders with several meter-sized, basalt and radiolarite blocks (Unit 4 of Baumgartner and Denyer, 2006) The sample SE85 of DeWever et al. (1985) was collected in a 10 x 10 x 20 m sized block that shows dm-scale isoclinal folding of cm-thick radiolarite ribbon beds. This block does not date the breccia, but implies reworking of an older, previously deformed rock. In relation to its age, several species listed by DeWever et al. (1985) are now considered as restricted to the late Early Jurassic. Based on the current information, an age range of Pliensbachian to Toarcian is probable. Thus, this age dates the oldest sediments found so far in Costa Rica.
3. **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 in the Potrero Grande tectonic window clearly indicates a Middle Jurassic age (Bajocian-Callovian). Again, this corresponds to the age of a reworked block, since in the same area Cenomanian Radiolaria were described (Schmidt-Effing, 1980, see above).

Nicoya Complex (*s. str*., composite Pacific plateau, NW Nicoya Peninsula): Middle Jurassic to Late Cretaceous

Geologic setting

In a recent paper (Denyer and Baumgartner, 2006) we synthesized the existing $^{40}Ar/^{39}Ar$ dates, the igneous petrology and the field relationships between the igneous rocks and Jurassic-Cretaceous radiolarites in the Nicoya Complex *s. str*. (NC) of the NW-Nicoya Peninsula (Fig. 5). At the same time, we presented new radiolarian biochronologic data that confirm and enhance our earlier reports of Middle Jurassic to Upper Cretaceous Radiolaria in that area (Baumgartner, 1984a; 1984b; Baumgartner et al., 1995b) The purpose of this chapter is to review these data in the light of the position of the NC between the (today) NW-edge of the CLIP and the SE-margin of the MCOT (Fig. 1). In addition, we illustrate more radiolarian specimens from Middle Jurassic (Plate 4) and Upper Cretaceous (Plate 5) radiolarian assemblages of the NW-Nicoya Peninsula.

Overall, the NC can be regarded as a composite set of Cretaceous plateaus that formed, according to $^{40}Ar/^{39}Ar$ ages, between 139 and 83 Ma (Valanginian - Santonian), with the most abundant ages between 92 an 83 Ma (Turonian - Santonian, Fig. 6). Intrusives, dolerites and basalts of the NC enclose kilometric blocks of radiolarite that show leached and baked contacts with the igneous rocks. Radiolarite lithologies allow for the distinction of two major groups: 1. The *Mn-radiolarites*, which have yielded radiolarian assemblages of Middle Jurassic (Plate 4) to middle Cretaceous age. Most of these occurrences are clearly older than the encasing igneous rocks (Figs. 5b, 6), a fact that is confirmed by its chilled margins and hydrothermal radiolarite leaching. 2. The *Fe-radiolarites* have yielded radiolarian assemblages restricted to a Coniacian-Santonian age (Plate 5). They are contemporary with the latest stages of the igneous plateau activity (Fig. 6). It must be noted that radiolarite blocks dated older than Coniacian (Late Cretaceous) occur only in the NW- corner of the Nicoya Peninsula. Elsewhere in the Peninsula, radiolarite occurrences are Coniacian-Santonian in age. However, Lower Cretaceous portions of the plateau extend throughout the Nicoya Peninsula as indicated by $^{40}Ar/^{39}Ar$ ages of 118-119 Ma along its SW-coast (Fig. 5a), and by the siliceous organic-rich claystones of the Loma Chumico Formation (*sensu* Flores et al., 2003) dated as late Albian by ammonites (Azéma et al., 1979) that rest apparently on the same basement in the W and SW-Nicoya Peninsula (Flores et al., 2003).

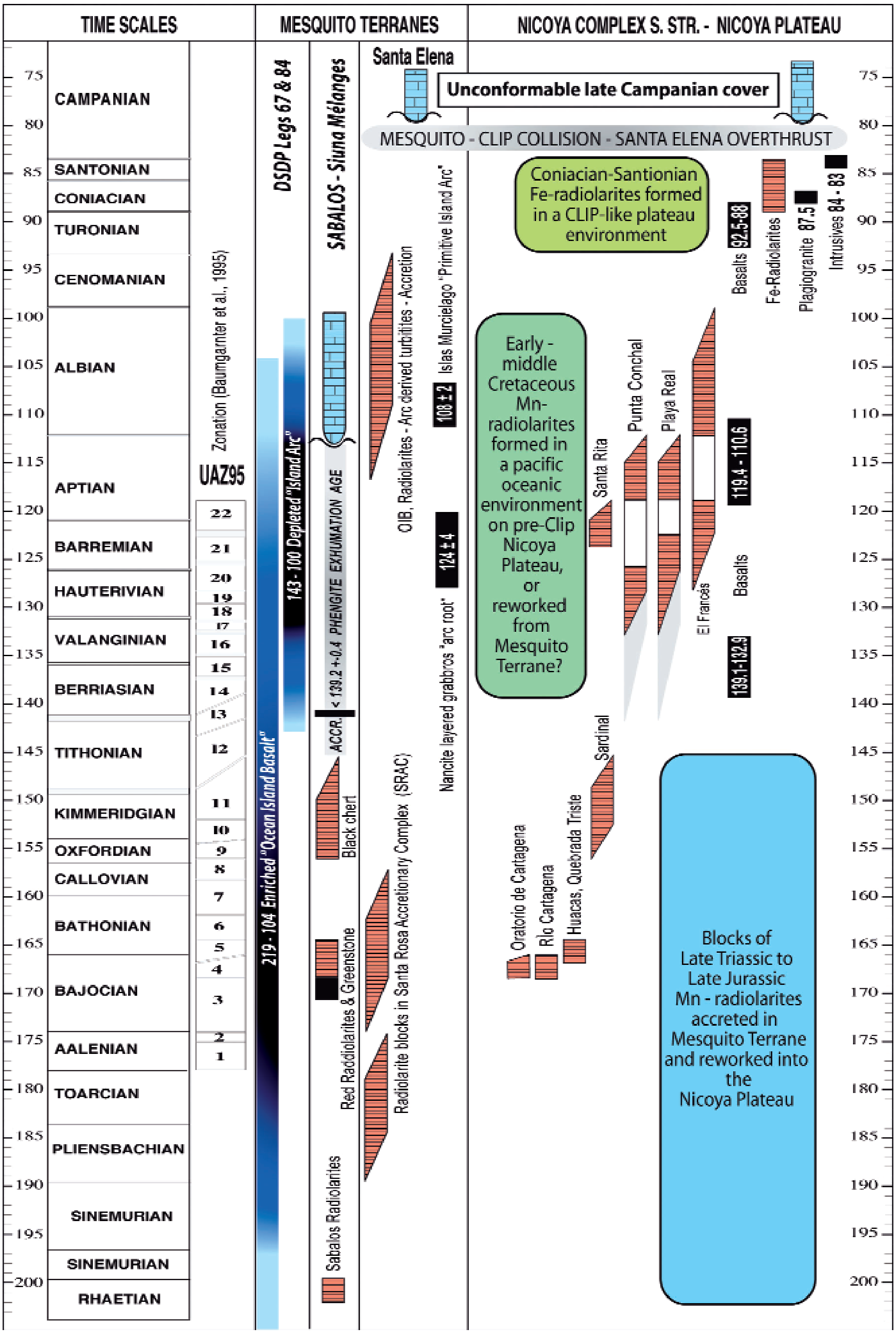

Fig. 6 - Synopsis of bio- and geochronologic ages determined in boreholes and outcrops of the Mesquito Composite Oceanic Terrane and the Nicoya Complex *s. str.* (the latter after Denyer and Baumgartner, 2006). Horizontally lined fields represent biochronologic age ranges of radiolarian samples, oblique upper and lower ends of fields indicate age uncertainties. Connected fields (e.g. Punta Conchal) indicate stratigraphic sections with ages of the lowest and the highest sample indicated, lightly shaded fields indicate poorly defined ages, due to poor preservation. Age range of igneous rock is given in black/grey, the numbers are Ar^{39}/Ar^{40} ages (Sinton et al., 1997; Hauff et al., 2000a; Hoernle et al., 2004; Geldmacher et al., 2006; submitted). Time scale based on Channell et al. (1995), Gradstein et al. (2004) and Palfy et al. (2000).

Radiolarian occurrences, biochronology and palaeobiogeography

Radiolarian occurrences can be grouped into 2 major groups (see above): The 1. *Mn-radiolarites* occur as highly deformed and geothemally affected blocks that have yielded poorly to moderately preserved Middle Jurassic to Albian Radiolaria. 2. The *Fe-radiolarites*, are contemporaneous with the latest plateau extrusions, are much less deformed and yielded well-preserved radiolarian assemblages. Several new taxa illustrated here for the first time with open nomenclature will be described in a forthcoming paper.

1. **Mn-Radiolarites (Bajocian-Albian).** Several Middle Jurassic radiolarian assemblages (Plate 4, Denyer and Baumgartner, 2006, Fig. 6) were recovered from inland outcrops of heavily deformed, ribbon-bedded radiolarites. In Baumgartner (1984a; 1987) these faunas were assigned to a Bathonian-Callovian age by using the Baumgartner (1984b) zonation. More recent revisions of ammonites resulted in an older calibration of the same radiolarian assemblages. The oldest assemblage of the NW-Nicoya Peninsula, from a radiolarite quarry near Oratorio de Cartagena, 1 km S of Cartagena (261.900/353.250), now correlates with Unitary Association Zones (UAZ) 4 of Baumgartner et al. (1995b) dated as late Bajocian (Plate 4), based on the presence *Unuma typicus* Yao, *Protunuma fusiformis* (Yao), *Protunuma turbo* Matsuoka, *Cyrtocapsa mastoidea* Yao, and *Transhsuum maxwelli* (Pessagno). Another sample, (2-18-1-79) from lower part of Quebrada Triste, near Guatemala, 2.75 km E of Santa Rosa (255.200/340.340.600), correlates with UAZ 5, late Bajocian-early Bathonian (Plate 4), based on the concurrent ranges of *Guexella nudata* (Kocher), *Mirifusus guadalupensis* Pessagno, and *Hexasaturnalis suboblongus* (Yao).

The Middle Jurassic assemblages of Nicoya compare faunistically with North American assemblages from the Marin Headlands, the Yolla Bolly or other Franciscan terranes (Murchey, 1984), rather than with Tethyan assemblages. *Ristola turpicula* Pessagno is a typical "Pacific" species in these assemblages.

No middle Bathonian-lower Oxfordian assemblages could be identified in Nicoya. This suggests the presence of a stratigraphic gap spanning at least this interval (Fig. 6). Stratigraphic gaps are common to other Pacific oceanic sections such as the Marin Headlands (Murchey, 1984) and ODP-Site 801 in the Western Pacific (Matsuoka, 1995). The only clearly Upper Jurassic assemblages in this data set were recovered north of Sardinal (Fig. 6) but further work may reveal more samples of this age range. Schmidt-Effing (1979) cites *Eucyrtidiellum ptyctum* from the Playa Real or Punta Conchal. Since this species (and even the genus) is restricted to the Late Jurassic, this could indicate latest Jurassic maximum ages at these localities, whereas our data contains only Lower Cretaceous radiolarians (see below).

By far most localities yielded Lower Cretaceous assemblages that range in age from late Valanginian (determined by the presence of *Cecrops septemporatus*) to Aptian for most localities (such as Playa Real, Punta Conchal, etc.) and in the case of El Frances to Albian (Fig. 6). Several mid-Cretaceous assemblages are dominated by *Pantanellium* spp. and other Pantanellids, such as *Protovalupus* sp. The dominance of this group can even be recognised in thin section. We interpret this monophyletic abundance as blooms of opportunistic species in a tropical upwelling zone. A similar setting has been suggested for the *Valupinae* by Matsuoka (1995).

The youngest determined age is the Albian, indicated by the presence of *Pseudodictyomitra pseudomacrocephala* and other characteristic species. No younger assemblages were found in the Mn-bearing radiolarites suggesting that magmatic activity of the Nicoya Plateau could have started as early as Albian (110 Ma), a fact that is confirmed by Middle Cretaceous $^{40}Ar/^{39}Ar$ ages of the Nicoya Plateau (Hoernle et al., 2004).

2. **Fe-Radiolarites.** Small outcrops of limonite-hematite-bearing, bright red-orange, thin-bedded chert are widespread in the NW, central and southern part of the Nicoya Peninsula. This suggests a high position in, or on top of the mid Cretaceous plateau. The radiolarian assemblages of these outcrops are very homogeneous and contain all very similar assemblages (Plate 5), which can be tentatively assigned to a Coniacian-Santonian age by the presence of the following, biostratigraphically important species: *Alievium praegallowayi* Pessagno, (Coniacian - early Santonian); *Hemicryptocapsa polyedra* Dumitrica, (Santonian and older), *Alievium gallowayi* (White), (Coniacian to Maastrichian); *Praeconocaryomma californiaensis* Pessagno, (Turonian - Santonian), *Theocampe urna* Foreman (late Coniacian - middle Campanian).

The co-occurrence of these species suggests a tentative late Coniacian - Santonian age (Fig. 6) according to their ranges listed above. It should be noted, that these ranges are not completely known and more detailed biochronologic work has to be done to better constrain the age of these assemblages.

INTERPRETATIONS AND CONCLUSIONS

The SRAC - A witness for mid-Cretaceous reworking of Jurassic MCOT

Jurassic, highly deformed radiolarite blocks are incorporated into debris flows and megabreccias that form the stratigraphic tops of individual accreted slices of the SRAC (Baumgartner and Denyer, 2006, Fig. 4). These very proximal breccias contain, besides radiolarite blocks, abundant basaltic and arc-derived volcanic clasts. We conclude that the SRAC became accreted during the middle Cretaceous against a backstop formed of Jurassic MCOT, which became eroded. It supplied the prism with mafic clasts and Jurassic radiolarite blocks. We are currently working on the detailed geochemistry of igneous clasts in the SRAC to strengthen this hypothesis.

The Nicoya Complex *s. str*. - a witness of Pacific plateau formation facing the MCOT

The Nicoya complex *s. str*. (NC) has been considered as the type locality for the Caribbean crust or the CLIP by many authors (Dengo, 1962; 1985; Kuijpers, 1980; Sinton et al., 1997; Hauff et al., 1997). However, the presence of radiolarite blocks of Middle Jurassic to Early Cretaceous age and $^{40}Ar/^{39}Ar$ ages significantly older than the "normal" 92-80 Ma CLIP make the NC quite unique and different from all other basaltic basements cropping out between SE of Nicoya and Colombia (Fig. 1).

The geochemical similarities between the NC and Upper Cretaceous CLIP occurrences have been the main argument for speculations on a very long history of the Galapagos hotspot (e.g. Hoernle et al., 2004). This is, however, not the only possible interpretation of the NC. Its long, complicated geologic history leads us to argue for the formation of the *Nicoya Plateau* in the Pacific facing the MCOT, independent form the CLIP and most probably unrelated with the Galapagos hotspot. Similar plateaus with ages as old as 130-140 Ma have been reported from Colombia and Ecuador (e.g. Kerr et al., 1997). On the other hand, no older sediment age than Coniacian-Santonian and no older $^{40}Ar/^{39}Ar$ age than 90 Ma is known from S-Central America between SE of Nicoya and Colombia. For us this area represents the trailing edge of the CLIP *s. str.* (Fig 1).

The concentration of Jurassic and Lower Cretaceous radiolarite blocks in the NW - Nicoya Peninsula, closest to the MCOT, are to us a clear indication, that this area exposes the deepest portions of the Nicoya Plateau, where Middle Jurassic to middle Cretaceous radiolarites became exhumed from a substrate and reworked into the younger plateau. Denyer and Baumgartner (2006) assumed the substrate to be a hypothetical oceanic crust with a radiolarite sedimentary cover typical for any Jurassic Pacific Plate, such as the Farallon Plate. However, the problem with this hypothesis is the high degree of tectonic deformation commonly observed in the radiolarites, but not in the surrounding igneous rocks. This deformation predates their reworking into the igneous rocks, because the baked and leached margins of the blocks do not show the folds observed in the radiolarite blocks.

If we look for a different origin of the radiolarite blocks, then the MCOT is a good candidate. In this paper we have reported the presence of very deformed Jurassic (and Upper Triassic) radiolarite blocks from the Siuna and El Castillo mélanges, that became probably reworked into the Santa Rosa Accretionary Prism (Santa Elena, see above) from a hypothetical MCOT back-stop that probably also was the substrate of the Nicoya Plateau. The Jurassic radiolarites must have originated indeed on an (Upper Triassic-) Jurassic Pacific Plate. They became first accreted into the MCOT, deformed and partly subducted, and then became exhumed and incorporated into the base of the Nicoya Plateau.

A variety of processes can be imagined for the exhumation and emplacement of the radiolarites. Chert blocks are more resistant to weathering and magmatic reworking than mafic and ultramafic rocks. One can imagine the weathering-out of the blocks in submarine exposures along fault scarps and their gravitational emplacement onto the adjacent plateau ocean floor, where they became covered and hydrothemally affected by succeeding flows. Or, one can speculate on magmatic reworking of the radiolarites by successive flows that penetrated the substrate as illustrated by Denyer and Baumgartner (2006). This process can be demonstrated in the Central Cordillera of the Dominican Republic (demonstration by Javier Escuder Viruete, field work 2008). The Upper Jurassic Aguacate Chert normally rests with a stratigraphic contact on the Loma La Moncha MOR-type basalts (Escuder Viruete et al., 2007). In some places doleritic dikes and flows of the intruding and overlying Lower Cretaceous Duarte Complex result in detachment and incorporation of mappable radiolarite bodies into the lower Duarte Complex. In any case, the presence of Jurassic radiolarites incorporated into the Cretaceous Nicoya Plateau is a witness for its ancient contact with the MCOT. We can imagine that this contact was a strike slip paleo-fault. It must, however, have ceased its activity by Campanian times, when compression between the MCOT and the CLIP locally caused the Santa Elena overthrust, uplift and emergence of all terranes in between, and the overlap of upper Campanian shallow water limestones (Fig. 6, Azéma et al., 1985; Denyer and Baumgartner, 2006).

The Mesquito Composite Oceanic Terrane, Mesozoic Franciscan-type mafic and ultramafic terranes of paleo-Pacific and arc origin

A number of observations and arguments, partly exposed in this paper, have allowed us to establish the hypothesis of a collage of Pacific oceanic terranes that form the southern half of the classically defined Chortis Block, i.e., a major part of the Nicaragua basement. We call this collage of tectonostratigraphic terranes the "Mesquito Composite Oceanic Terrane", in honour of the Mesquito (or Mezquito) Indians who are the original inhabitants of most of the area. Today, we ignore the exact extension of this terrane, but it is likely to extend from the Guatemala - Nicaragua forearc basement (von Huene, 1989; Hauff et al., 2000b; Hoernle et al., 2004, and Geldmacher et al., 2006; submitted) in the West, to the lower Nicaragua Rise and possibly into "basement" complexes of Jamaica, Hispaniola and Puerto Rico in the East. Here, we have only discussed its contact with the Nicoya Plateau and the CLIP, likely to be a paleo-strike slip fault that ceased its activity by the latest Cretaceous. The contacts with the continental Chortis Block *s. str*. remain to be studied (Flores et al., in progress).

The MCOT is defined by the following observations.

Biochronology and facies of radiolarite blocks

The biochronology of radiolarians allows to date radiolarites of the MCOT for now as Late Triassic to Late Jurassic. The Rhaetian radiolarian faunas correlate throughout Panthalassa and indicate that at least part of the MCOT must be Pacific in origin, because its radiolarites predate Pangea breakup and the radiolarians are typical for Panthalassa. Also Lower and Middle Jurassic ribbon-radiolarites are characteristic of Circum-Pacific regions. This facies is unknown from the Jurassic passive margins and the ocean floors of the Central Atlantic or the Gulf of Mexico, where Middle and Upper Jurassic facies are either claystones (beneath CCD) or siliceous limestones (Cat Gap Fm) above the CCD.

The occurrence of ribbon-radiolarites on the Caribbean Plate is in itself characteristic of their Pacific origin. These facies occur in the MCOT, in the Nicoya Plateau, in the Motagua Suture Zone (Chiari et al., 2006) and in the Antilles (Hispaniola, Puerto Rico and La Désirade, Montgomery et al., 1994a; 1994b). They are absent from the CLIP. The terranes containing Jurassic ribbon radiolarites were first accreted along the Pacific convergent margins of N-American blocks and then smeared out westwards by the emplacement of a Pacific Plate that later hosted the CLIP (Pindell et al., 2006).

Presence of ultramafic rocks

Ultramafic rocks are typical of major suture zones of the world. Mantle-derived serpentinites have not been reported from the CLIP area. They are one of the characteristic lithologies of the MCOT.

$^{40}Ar/^{39}Ar$ ages and geochemistry of mafic igneous rocks

Preliminary $^{40}Ar/^{39}Ar$ ages of mafic rocks confirm the radiolarian biochronologic ages of the MCOT. Geldmacher et al. (2006; submitted) indicate the presence of accreted seamounts as old as 219 Ma and arc rocks as old as 143 Ma in the MCOT. The first age largely predates Pangea breakup. The geochemistry of both enriched "OIB" and depleted "arc" mafic rocks is different from that of the CLIP (Gazel et al., 2006; Geldmacher et al., 2006; submitted).

Other, circumstantial evidence supports the existence of the MCOT.

Presence of ultramafic xenoliths in Neogene volcanic arc rocks

The terrestrial area of the MCOT is almost entirely covered by uppermost Cretaceous and Tertiary to Recent arc volcanics and volcaniclastic sequences. Abundant ultramafic xenoliths have been reported from the Cerro Las Mercedes (Lindsay et al., 2006): a Quaternary vent located 70 km east of the today active volcanic front. The authors place it near the northern edge of the CLIP and see it as a window into the mantle of that area. The Cerro Mercedes is only a few km West of serpentinite outcrops of the El Castillo area (Fig. 4). To us it seems likely that the xenoliths are derived from serpentinite mélanges of the MCOT and not directly from the upper mantle.

Morphology of Southern - Central Nicaragua and the Lower Nicaragua Rise

The terrestrial morphology of central and eastern Nicaragua is of low relief without any major elevations. The only hills are related to either volcanic sources or some minor tectonic structures such as anticlines. We believe that this low topography is the expression of a low buoyancy "crust" made of mafic and serpentinized ultramafic rocks. These lowlands are in clear contrast with the rugged topography of the mountain ranges than form the borderland between Nicaragua and Honduras, from where continental basement has been reported (Rogers, 2003). The morphology of the Nicaragua Rise is clearly twofold. The Upper Rise is in continuity with the continental Chortis Block *s. str*. The Lower Rise shows a more irregular topography that could correspond to accreted terranes of the MCOT (see also Venable, 1994; Rogers et al., 2007a).

Geophysical evidence

Walther et al. (2000) noted the presence of high velocity mantle material in an upper crustal position in the area of W Nicaragua. The MOHO is ill-defined or absent in a transect North of the Costa Rica/Nicaragua borderline (Marino Protti, personal communication). These observations are in agreement with a largely ultramafic composition of the MCOT.

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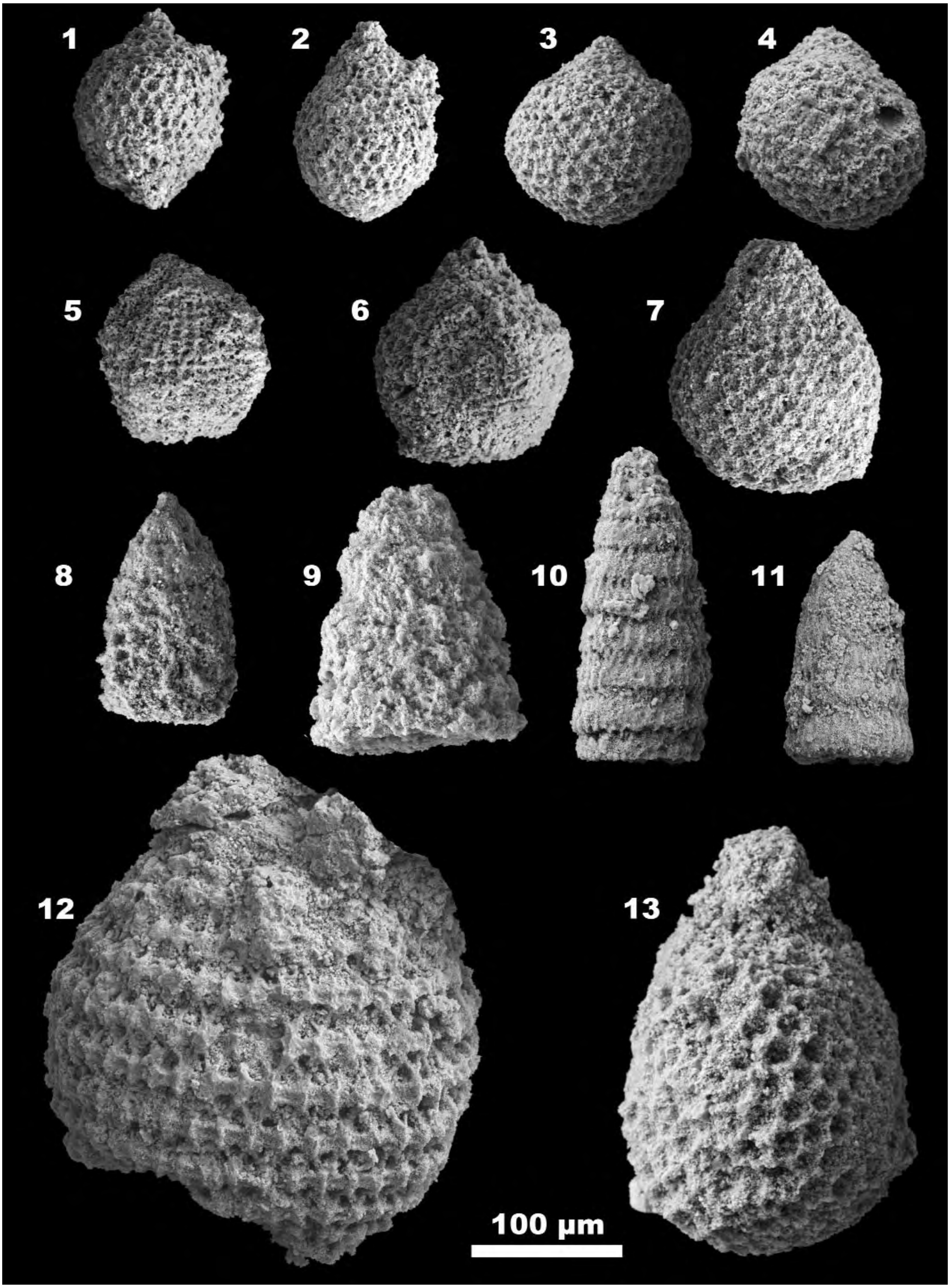

Plate 1 - Middle and Upper Jurassic Radiolaria from the Siuna serpentinite mélange (NE Nicaragua) scale bar = 100µm for all figures. 1-7) Sample 05-01-21-03, Middle Jurassic (UAZ 4-6) red radiolarite associated with greenstones. 8-13) Sample 05-01-16-02, Upper Jurassic (UAZ 9-11) black chert.
1, 2- *Williriedellum marcucciae* Cortese, UAZ 4-8; 3- *Williriedellum* sp. S (= *Tricolocapsa* sp. S, *sensu* Baumgartner et al., 1995a), UAZ 4-5 (4-6 after Prela et al., 2000); 4- *Williriedellum* sp. cf. *W*. sp. S (= *Tricolocapsa* sp. S, *sensu* Baumgartner et al., 1995a); 5- *Linaresia* sp. cf. *L. chrafatensis* (El Kadiri); 6, 7- *Zhamoidellum* sp.; 8, 9- *Xitus* spp.; 10- *Pseudodictyomitra primitiva* Matsuoka and Yao, UAZ 7-12; 11- *Archaeodictyomitra* (Mizutani), UAZ 9-12; 12- *Mirifusus dianae* s. l. (Karrer), UAZ 9-20; 13- *Sethocapsa* sp. cf. *S. dorysphaeroides* Neviani, *sensu* Schaaf.

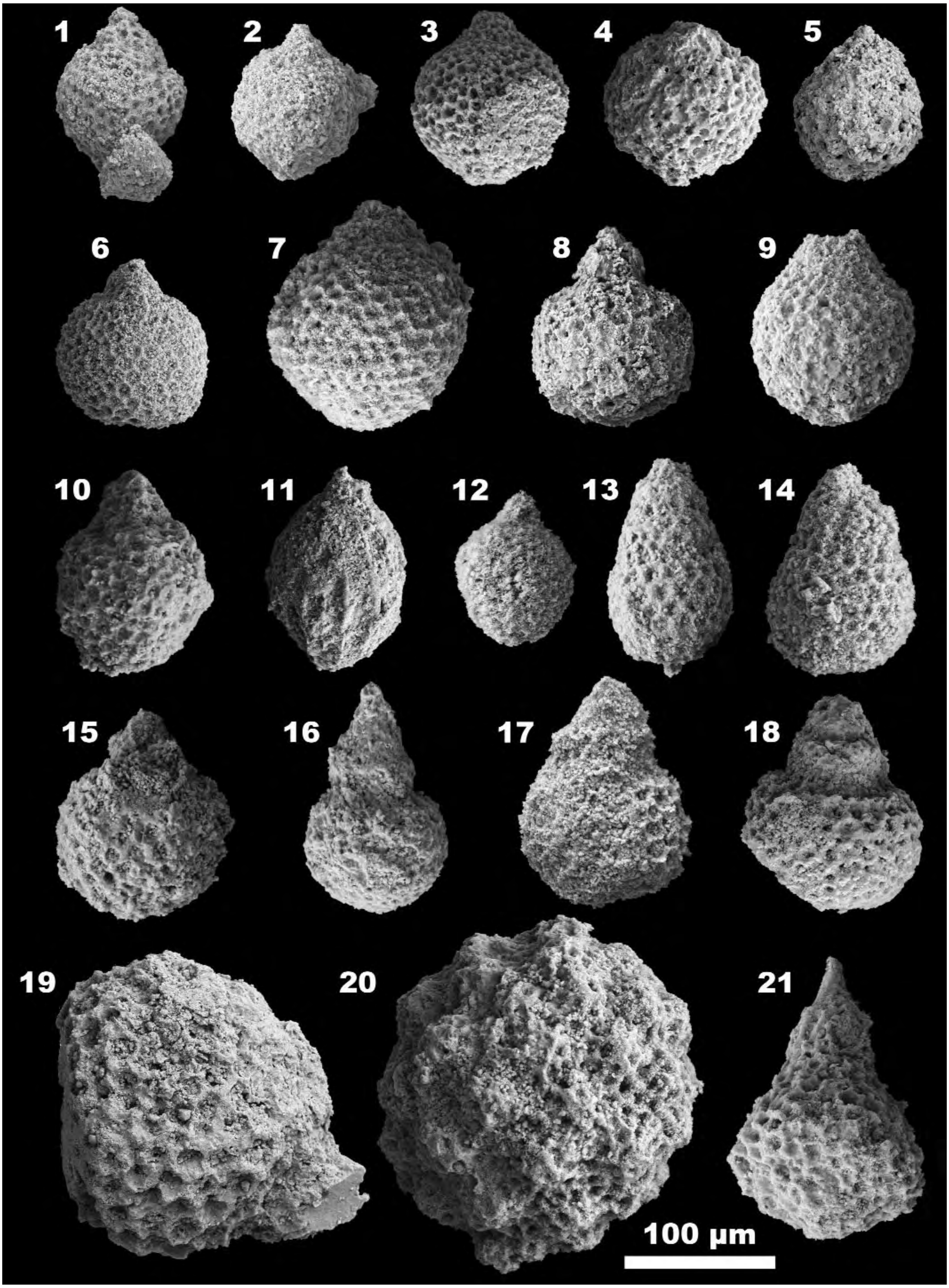

Plate 2 - Upper Jurassic Radiolaria from the Siuna serpentinite mélange (NE Nicaragua) scale bar = 100µm for all figures. Sample 05-01-16-02, Upper Jurassic (UAZ 9-11) black chert. 1, 2- *Zhamoidellum ovum* Dumitrica, UAZ 9-11; 3, 4- *Williriedellum carpathicum* Dumitrica, UAZ 7-11; 5- *Zhamoidellum* sp. 2 *sensu* O'Dogherty et al. (2006); 6- *Zhamoidellum ventricosum* Dumitrica, UAZ 8 -11, (6-11 after Marcucci et al., 1998); 7- *Williriedellum* sp.; 8-10- *Zhamoidellum* spp.; 11- *Protunuma japonicus* Matsuoka and Yao, UAZ 7-12; 12- *Tricolocapsa* sp. or *Zhamoidellum* sp.; 13- *Stichomitra* (?) sp. cf. *S.* (?) *acuta* (Hull); 14- *Sethocapsa* sp. cf. *S. zweilii* Jud; 15- *Zhamoidellum* sp. cf. *Z. calamin* O'Dogherty, Gorican and Dumitrica; 16-17- *Sethocapsa* spp.; 18- *Sethocapsa* sp. cf. *S. uterculus* (Parona) *sensu* Foreman; 19- *Triactoma* sp. Base of the broken off spines suggests *T. jonesi* (Pessagno) group, UAZ 2-13; 20- *Acaeniotyle* (?) sp.; 21- *Hiscocapsa* (?) sp.

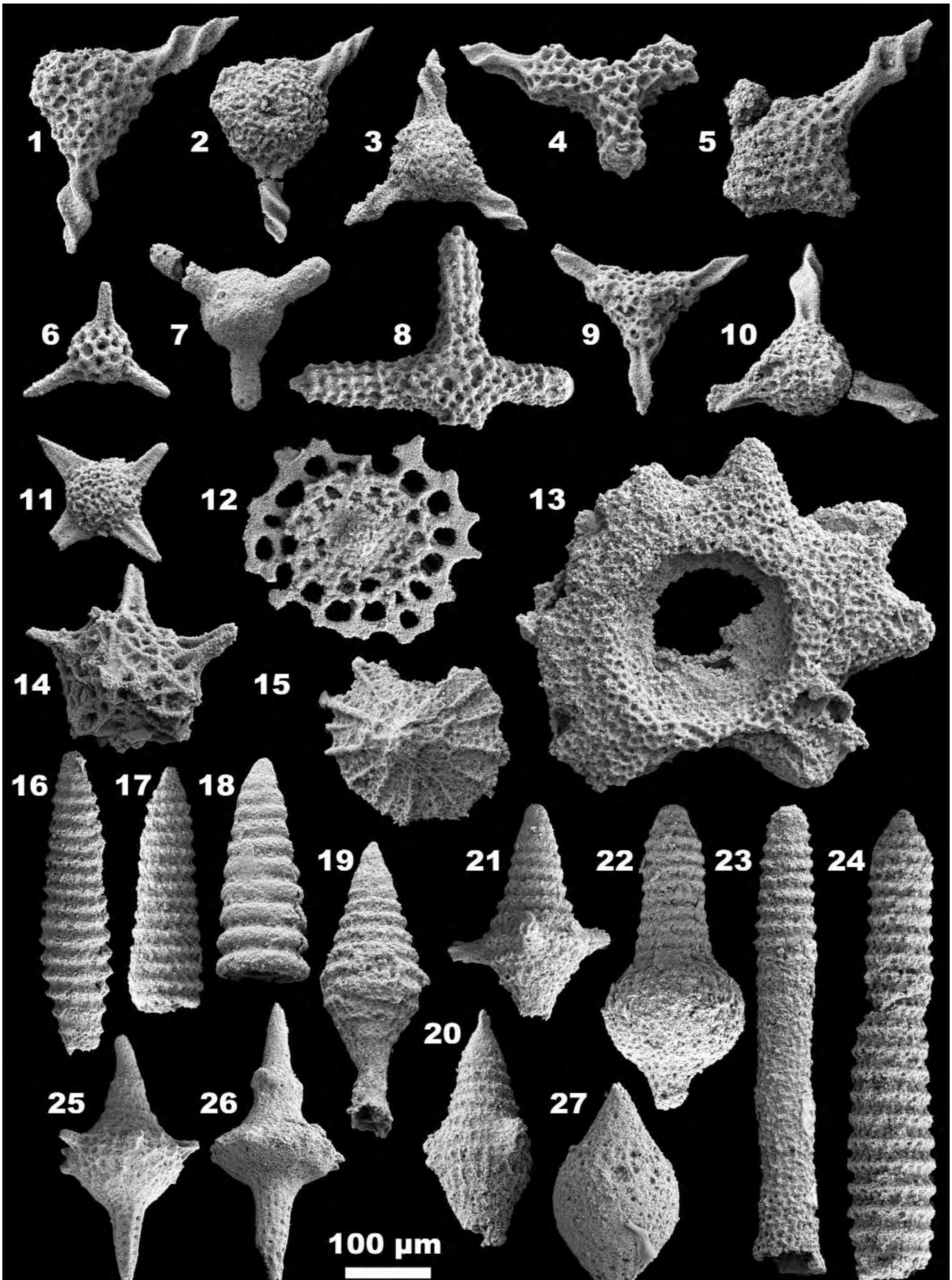

Plate 3 - Uppermost Triassic (upper Rhaetian) Radiolaria from an abandoned radiolarite quarry N of Sabalos, near El Castillo, Southern Nicaragua. Scale bar = 100 µm for all illustrations. Sample06-04-19-01.

1- *Ferresium triquetrum* Carter.; 2, 3- *Ferresium* (?) sp.; 4- *Risella tledoensis* Carter; 5- *Paricrioma cistella* (Carter); 6- *Betraccium* sp.; 7- *Livarella densiporata* Kozur and Mostler; 8- *Tetraporobracchia* sp. C *sensu* Carter 1993; 9- Spumellaria gen. et sp. indet. A; 10- Spumellaria gen, et sp. indet. B *sensu* Tekin 1999; 11- Spumellaria gen, et sp. indet. B *sensu* Carter 1993; 12- *Veghycyclia austrica* Kozur and Mostler; 13- *Orbiculiformella multibrachiata* (Carter); 14- *Kungalaria newcombi* Dumitrica and Carter; 15- *Praecitriduma mostleri* Kozur 1984; 16- *Canoptum* sp. aff. *C. unicum* Pessagno and Whalen, *sensu* Carter 1993; 17- *Praeparvicingula* (?) sp.; 18- *Canoptum triassicum* Yao; 19- *Laxtorum capitaneum* Carter. 20, 21- *Globolaxtorum* (?) sp. A *sensu* Carter 1993; 22- *Globolaxtorum* sp. B (?) *sensu* Tekin 1999; 23- Nassellaria gen. et sp. indet. A; 24- *Proparvicingula* sp.; 25, 26- *Globolaxtorum* spp.; 27- *Canutus* (?) *beehivensis* Carter.

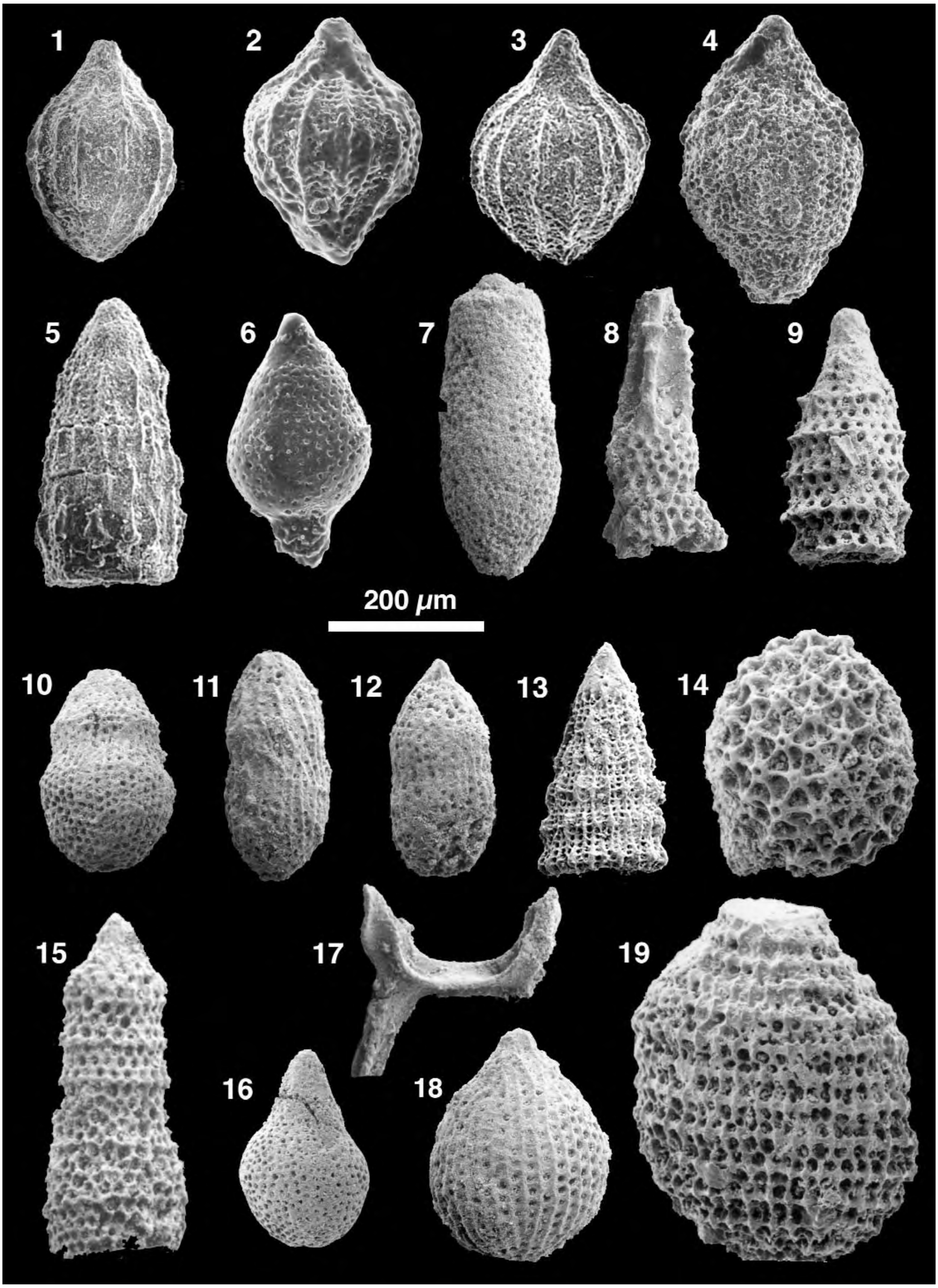

Plate 4 - Middle Jurassic radiolarians from the NW Nicoya Peninsula.
1-6: Sample from a radiolarite quarry near Oratorio de Cartagena, 1 km S of Cartagena (261.900/353.250). Age: UAZ 4, late Bajocian.
7-19: Sample 2-18-1-79 (collected by E. Kuijpers in 1979), Lower part of Quebrada Triste, near Guatemala, 2.75 km E of Santa Rosa (255.200/340.340.600). Age: UAZ 5, Upper Bajocian-early Bathonian. Scale bar for all specimens = 200 µm.
1- *Protunuma fusiformis* Matsuoka. UAZ 3-5; 2, 3- *Protunuma turbo* Yao. UAZ 4-7; 4- *Unuma typicus* Ichikawa and Yao. UAZ 3-4; 5- *Transhsuum maxwelli* (Pessagno) group. UAZ 3-10; 6- *Cyrtocapsa mastoidea* Yao. UAZ 3-4; 7- *Guexella nudata* (Kocher). UAZ 5-8; 8- *Podobursa helvetica* (Rüst). UAZ 3-10; 9- *Tethysetta dhimenaensis* ssp. A (Baumgartner). UAZ 3-8; 10- *Theocapsommella* sp. aff. *T. medvednicensis* (Gorican); 11- *Helvetocapsa* (?) sp. aff. *H.* (?) *lemanensis* O'Dogherty, Gorican and Dumitrica; 12- *Theocapsommella* sp. aff. *T. bicornis* Baumgartner; 13- *Transhsuum* sp. aff. *T. maxwelli* (Pessagno) group; 14- *Leugeo hexacubicus* (Baumgartner) group. UAZ 4-8; 15- *Ristola* (?) *turpicula* Pessagno and Whalen. UAZ 5-6; 16- *Stichocapsa convexa* Yao. UAZ 1-11; 17- *Hexasaturnalis suboblongus* (Yao). UAZ 3-5 (after Dumitrica and Dumitrica-Jud, 2005; Chiari et al., 2007); 18- *Striatojaponocapsa synconexa* O'Dogherty, Gorican and Dumitrica. UAZ 4-5 (4-6 after Prela et al., 2000); 19- *Mirifusus guadalupensis* Pessagno. UAZ 5-11.

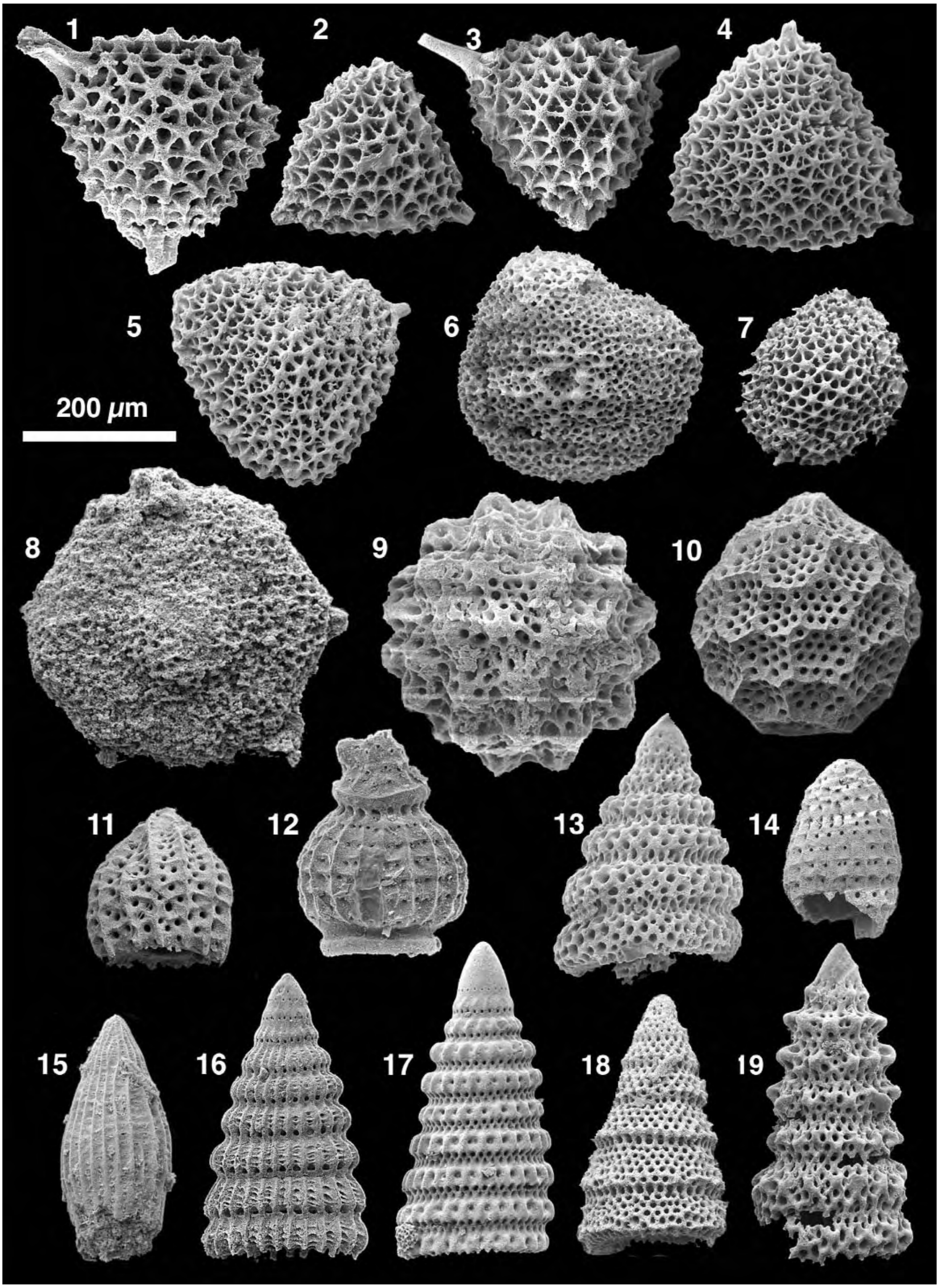

Plate 5 - Upper Cretaceous (Coniacian-Santonian) radiolarians from sample M.A. (except 8 and 13), near Playa Matapalo 4 km SE of Punta Gorda: 278.500/344.150.
8: sample Belen and 13: Cuesta de Matambu. All samples collected by E. Kuijpers in 1977-78. Scale bar = 200 µm.
1, 2- *Alievium praegallowayi* Pessagno. Range: Coniacian - early Santonian; 3- *Alievium gallowayi* (White). Coniacian - Maastrichian; 4, 5- *Alievium murphyi* Pessagno. Coniacian - Maastrichtian; 6- *Patellula* sp. aff. *P. verteroensis* Pessagno; 7- fragment of *Pseudoaulophacus lenticulatus* (White). Turonian - early Maastrichtian; 8- *Patellula* sp.; 9- *Praeconocaryomma californiaensis* Pessagno. Turonian - Santonian; 10- *Hemicryptocapsa polyedra* Dumitrica. Santonian and older; 11- (?) *Rhopalosyringium* sp.; 12- *Theocampe urna* Foreman. Upper Coniacian - middle Campanian; 13- *Stichomitra communis* Squinabol. Coniacian - Santonian; 14- *Theocampe* sp.; 15- *Dictyomitra* sp. aff. *D. montisserei* (Squinabol); 16- *Dictyomitra formosa* (Squinabol). Albian - early Maastrichtian; 17- *Pseudodictyomitra nakasekoi* Taketani. Turonian - Coniacian-Santonian?; 18- *Amphipyndax* sp. in: Taketani, 1982. Coniacian - early Santonian?; 19- *Crolanium* sp. aff. *C. pulchrum* Squinabol *sensu* O'Dogherty (1994).