Stratigraphic Evidence for Northwest to Southeast Tectonic Transport of Jurassic Terranes in Central Mexico and the Caribbean (Western Cuba)

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Jurassic and Early Cretaceous stratigraphic data from terranes in Central Mexico situated southwest of the Walper Megashear demonstrate similar records of paleobathymetry and tectonic transport. In general, each of these terranes shows the same paleobathymetric fingerprint: (1) marine deposition at inner neritic depths during the Callovian to early Oxfordian (Middle to Late Jurassic); (2) marine deposition at outer neritic depths during the late Oxfordian (Late Jurassic); (3) sudden deepening to bathyal or upper abyssal depths (ACD = aragonite compensation level) from the early Kimmeridgian (Late Jurassic) until the end of the Cretaceous. This paleobathymetric fingerprint differs markedly from that occurring to the east-northeast of the Walper Megashear in the Coahuiltecano terrane (emended herein: ~Sierra Madre Oriental terrane). In the Coahuiltecano terrane (e.g., Peregrina Canyon near C. Victoria, Tamps.), no Mesozoic marine deposits older than late Oxfordian occur. The paleobathymetric fingerprint of this terrane was (1) inner neritic during the late Oxfordian (Late Jurassic) to ~Barremian (Early Cretaceous) and (2) bathyal to abyssal during the remainder of the Cretaceous (Aptian to Maastrichtian). Though varying in detail, each succession that has been examined in the mosaic of suspect terranes to the southwest of the Walper Megashear shows evidence of tectonic transport from higher latitudes to lower latitudes during the late Middle Jurassic, the Late Jurassic, and the Early Cretaceous. For example, the paleolatitudinal signature of the San Pedro del Gallo terrane (Durango) supplied by faunal data (radiolarians and megafossils) and preliminary paleomagnetic data indicates that this terrane was transported tectonically from higher paleolatitudes (Southern Boreal Province: ≃40°N) during the Late Jurassic (Oxfordian) to lower paleolatitudes (Tethyan Realm: Northern Tethyan Province) by the Early Cretaceous (Berriasian). The Jurassic and Lower Cretaceous successions at Mazapil (Zacatecas), Sierra de la Caja (Zacatecas), Sierra de Zuloaga (Zacatecas), Symon (Durango), and Sierra de Catorce (San Luis Potosi) are all genetically related to that at San Pedro del Gallo. They are regarded as representing dismembered remnants of the San Pedro del Gallo terrane. Faunal data (radiolarians and megafossils) from the Mazapil succession (Sierra Santa Rosa) indicate that this remnant of the San Pedro del Gallo terrane was situated at Southern Boreal paleolatitudes (>30°N) during the Oxfordian and Kimmeridgian and at Northern Tethyan paleolatitudes (22 to 29°N) during the Tithonian and Berriasian. Preliminary paleomagnetic data from the upper Tithonian to Berriasian part of the Mazapil succession indicates 25°N. Farther to the southeast (San Luis Potosi, Hidalgo, Veracruz, Puebla) in the Huayacocotla segment of the Sierra Madre Oriental, previous investigations indicate tectonic transport from Southern Boreal paleolatitudes (>30°N) during the Callovian to Northern Tethyan paleolatitudes (22° to 29°N) during the Kimmeridgian and Tithonian and to Central Tethyan paleolatitudes (<22°N) during the latest Tithonian (Late Jurassic) and the Berriasian (Early Cretaceous).

Jurassic and Early Cretaceous successions in western Cuba (Sierra del Rosario and Sierra de los Organos, Piñar del Río Province) show lithostratigraphic, paleobathymetric, and paleolatitudinal signatures which are nearly identical to those of San Pedro del Gallo terrane remnants in central Mexico. They clearly represent portions of the North American Plate and are treated as remnants of the San Pedro del Gallo terrane herein. The Cuban remnants of the San Pedro del Gallo terrane were carried to eastern Yucatán by the Walper Megashear. By the Middle Cretaceous terrane amalgamation had occurred between the San Pedro del Gallo and Coahuiltecana terranes and all movement along the Walper Megashear had ceased. Subsequent southwest to northeast movement of the Caribbean Plate during the Late Cretaceous and Early Tertiary bulldozed the Cuban remnants of the San Pedro del Gallo terrane into their present position. Once the Cuban San Pedro del Gallo remnants were carried northward by the advancing Caribbean Plate, it is likely that they became part of an Atlantic-type margin.

Caribbean Basins. Sedimentary Basins of the World, 4 edited by P. Mann (Series Editor: K.J. Hsü), pp. 123–150.

INTRODUCTION

Mexico is the key component in plate tectonic reconstructions involving the break-up of Pangea and the subsequent formation of the Gulf of Mexico and the Caribbean (Figs. 1–3 and 7). The well-known overlap position of Mexico and South America in Atlantic reconstructions necessitates a mechanism for moving much of the Mesozoic succession of Mexico away from its present-day position (see Fig. 7, Inset A). Finding such mechanism has been a major task in geology since the first fit of the continents was suggested more than three decades ago by Carey (1958) and Bullard et al. (1965). Walper and Rowett (1972) suggested that the offset of the Mexico–Marathon–Ouachita–Appalachian structural belt resulted from transform movement along the Texas and Wichita megashears. Almost all plate tectonic reconstructions of the Atlantic, Gulf of Mexico, and Caribbean regions invoke megashears or transcurrent faults as mechanisms to transport crustal blocks in Mexico and to explain the overlap position of Mexico in the reconstruction of Pangea (Fig. 7, Inset A). More than twenty tectonic models have been proposed during the last two decades to explain the paleogeographic reconstruction of Mexico, the Gulf of Mexico, and the Caribbean (e.g., Bullard et al., 1965; Dietz and Holden, 1970; Walper and Rowett, 1972; Van der Voo et al., 1976; Buffler et al., 1981; Dickinson and Coney, 1981; Walper, 1981; Anderson and Schmidt, 1983; Pindell, 1985; Longoria, 1985a,b, 1987, 1994; and so forth).

The purpose of this report is to present stratigraphic data that not only demonstrate the presence of the Walper Megashear, but also demonstrate the northwest to southeast translation of remnants of the San Pedro del Gallo terrane along the southwest side of this megashear from higher Boreal paleolatitudes (>30°N) to lower Tethyan paleolatitudes during the Middle Jurassic, Late Jurassic, and Early Cretaceous.

IMPORTANCE OF FAUNAL AND FLORAL DATA IN PALEOGEOGRAPHIC RECONSTRUCTIONS

Much of Mexico west of the Walper Megashear of Longoria (1985a,b, 1986, 1987, 1994) consists of suspect terranes or displaced terranes (Fig. 1). Previous studies by Taylor et al. (1984), Pessagno and Blome (1986), Pessagno et al. (1986, 1993a,b), and Montgomery et al. (1992, 1994a,b) have established the importance of faunal and floral data in paleogeographic reconstructions in North America as well as in the Caribbean. Recognition of displaced tectonstratigraphic terranes depends primarily on paleolatitudinal data derived from paleontology and paleomagnetism. Faunal and floral data can be used to constrain existing paleomagnetic data and in some cases can also help determine whether tectonostratigraphic terranes originated in the Northern or Southern Hemisphere or in the Eastern or Western Pacific. For example, paleomagnetic data presented by Jones et al. (1977) indicate that the Wrangellia terrane originated 15° north or south of the Triassic paleoequator. During the Late Triassic and Early Jurassic both the molluscan and radiolarian assemblages tend to be predominantly Tethyan in origin (Tipper, 1981; Taylor et al., 1984; Pessagno and Blome, 1986). However, the discovery by Taylor et al. (1984, pp. 128, 135) of very rare Boreal ammonites (amaltheids) in the upper Pliensbachian por-

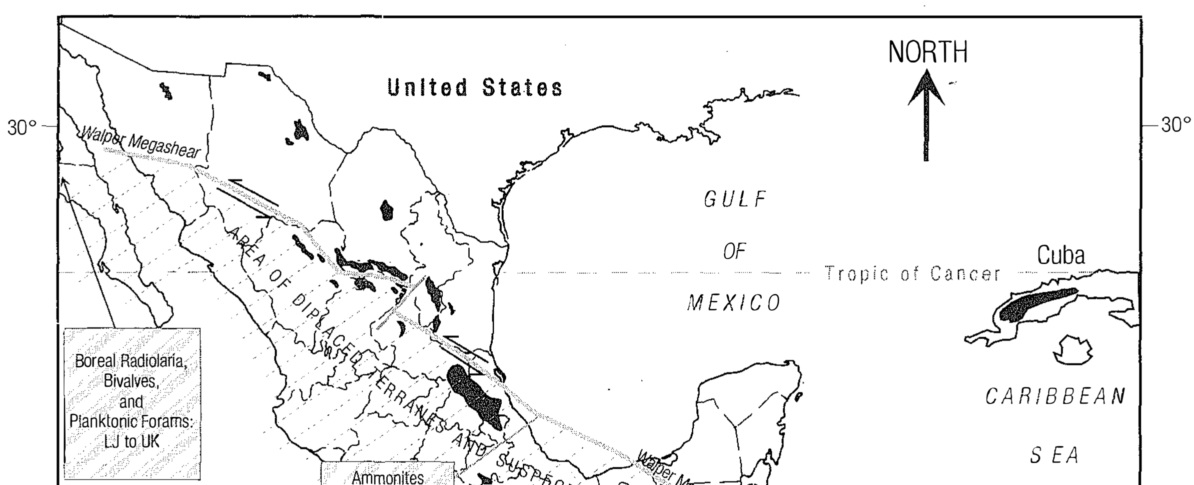

Fig. 1. Map showing approximate position of area of displaced and suspect terranes west of Walper Megashear of Longoria.

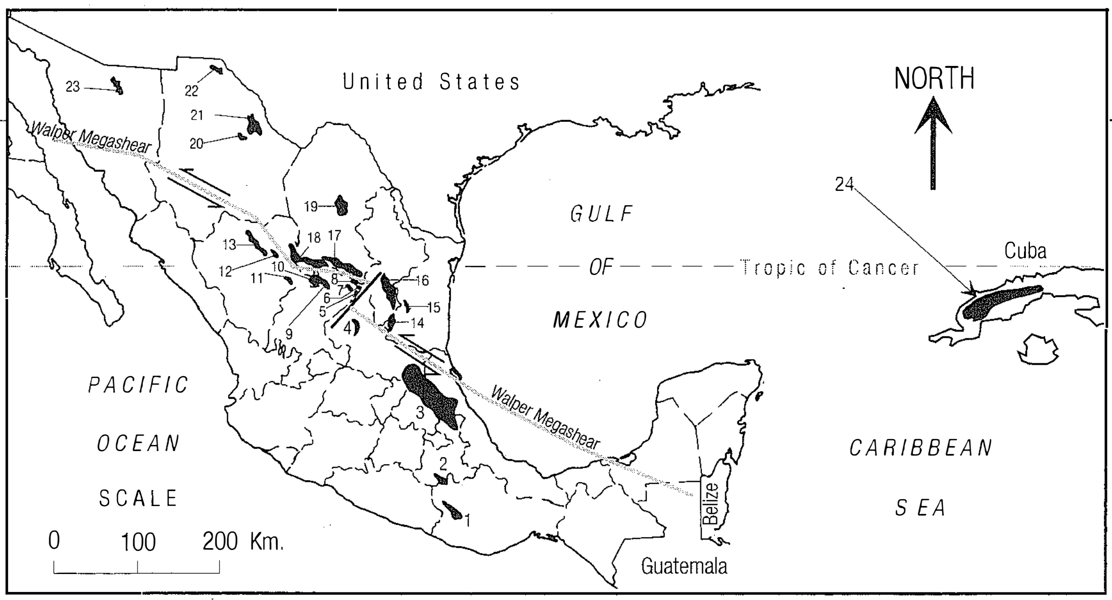

Fig. 2. Index map showing important Jurassic localities in Mexico and Cuba. The most important localities for this report are 3–18, 24. Key to localities: *1* = Tlaxiaco: Sierra Madre del Sur, Oaxaca. *2* = Pletalcingo: Sierra Madre del Sur, Puebla. *3* = Huayacocotla Anticlinorium: Taman-Tamazunchale, San Luis Potosi; Huayacocotla, Veracruz; Huachinango, Puebla. *4* = Sierra Catorce, San Luis Potosi. *5* = Sierra Santa Rosa, Zacatecas. *6* = Sierra de la Caja, Zacatecas. *7* = Sierra Cadnelaria, Zacatecas. *8* = Sierra Sombretillo and Sierra Zuloaga, Zacatecas. *9* = Sierra de Ramirez, Zacatecas-Durango. *10* = Sierra de Chivo, Durango. *11* = Sierra de Palotes, Durango. *12* = San Pedro del Gallo, Durango. *13* = Santa Maria del Oro, Sierra de la Zarca, Durango. *14* = Sierra Vieja-Arroyo Doctor, Tamaulipas. *15* = Huizachal Anticlinorium, Tamaulipas. *16* = Sierra Galeana-Iturbide, Nuevo Leon. *17* = Sierra de Parras, Coahuila. *18* = Sierra de Jimulco, Coahuila. *19* = Sierra Menchaca, Cohuila. *20* = Sierra Plomosas–Place de Guadalupe, Chihuahua. *21* = Sierra El Cuchillo Parado, Chihuahua. *22* = Sierra de Samalayuca, Chihuahua. *23* = Sierra de Cucurpe, Sonora. *24* = Cordillera de Guaniguanico, Cuba. Base map partly derived from that in Salvador et al. (1992).

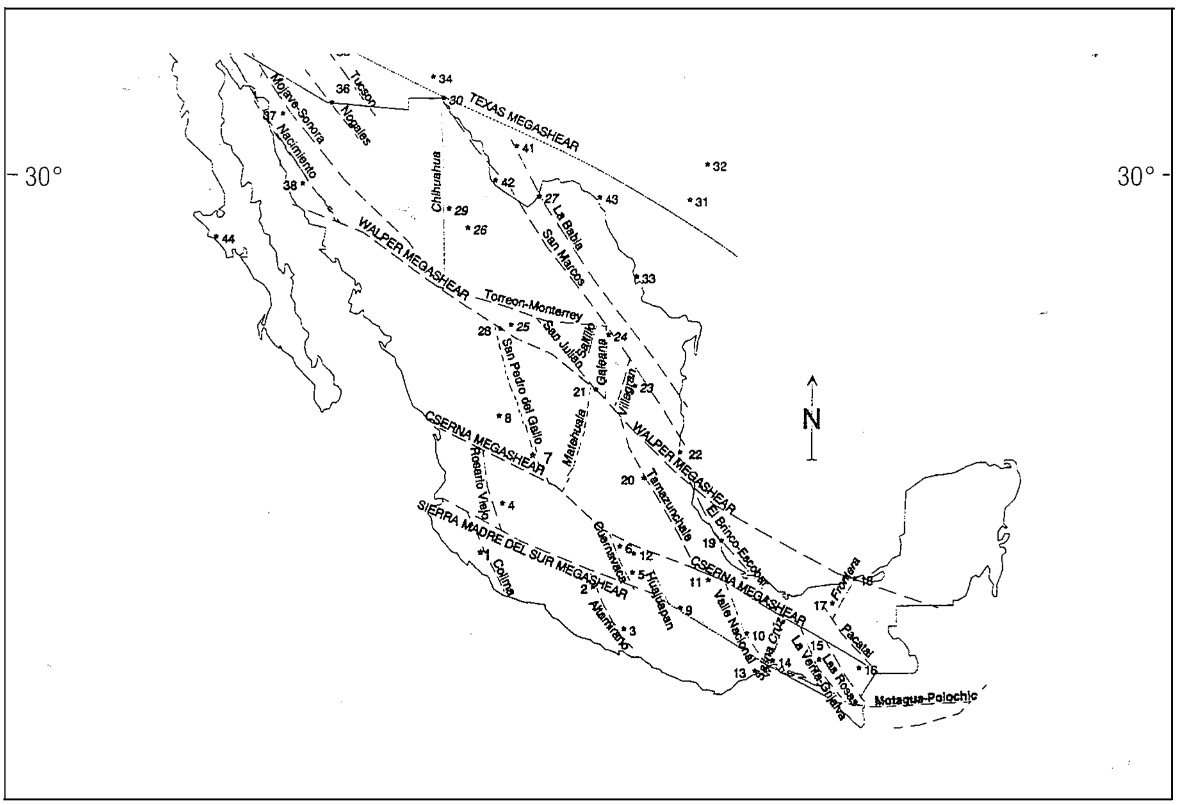

Fig. 3. Megashear map of Longoria (1994).

tion of the Maude Formation of the Queen Charlotte Islands (B.C.) indicates that Wrangellia was situated in the Northern Hemisphere. Moreover, the presence of the pectenacid *Weyla* in Lower Jurassic strata in the Queen Charlotte and other remnants of the Wrangellia terrane indicates that this terrane originated in the Eastern Pacific (Smith, 1980; Taylor et al., 1984; Pessagno and Blome, 1986; Pessagno et al., 1986).

Although the focus of the present report is on geologic terranes immediately southwest of and adjacent to the Walper Megashear, it is worth noting that faunal data from a variety of sources suggest either northwest to southeast movement or southeast to northwest movement along other possible megashears (Fig. 3). In the states of Oaxaca and Guerrero Burckhardt (1927, 1930) was the first to record the presence of a Middle Jurassic (Bajocian to Callovian) ammonite assemblage which strongly resembles that in the Andes, specifically Argentina (Figs. 1 and 2). Subsequently, the strong Andean affiliation of the Middle Jurassic ammonite assemblage of Oaxaca and Guerrero has been noted by Arkell (1956), Imlay (1980), Sandoval and Westermann (1988), Sandoval et al. (1990), and von Hillebrandt et al. (1992). The fact that no Middle Jurassic ammonite faunas with strong Andean affiliation are known from elsewhere in Mexico and North America suggests that the Middle Jurassic (Bajocian to Callovian) succession in these states has undergone southeast to northwest tectonic transport along a more outboard megashear paralleling the Walper Megashear (i.e., the Cserna Megashear of Longoria, 1994; Fig. 3).

In the Vizcaino Peninsula (Baja California Sur; Fig. 1), radiolarians, though abundant and well-preserved in strata of Early Jurassic (Pliensbachian) to Late Cretaceous (Cenomanian) age, are representative of a poorly diversified Boreal assemblage (Whalen and Pessagno, 1984; Whalen, 1985; Davila-Alcocer, 1986; Pessagno et al., 1986). Foraminifers occurring in the Late Jurassic to Late Cretaceous strata of the Vizcaino Peninsula are likewise Boreal in nature and show strong affinity to those of the California Coast Ranges. In fact, studies made by Longoria (unpublished PEMEX report) indicate that the planktonic foraminiferal assemblage occurring in the Upper Cretaceous Valle Formation is like that described by Douglas (1969) from the Great Valley Supergroup (California Coast Ranges). This fauna is not well-developed south of the latitude of Bakersfield in California and occurs northward to Alaska and to Japan. In addition to the foraminifers and radiolarians the Late Jurassic (Tithonian) to Early Cretaceous (Valanginian) strata of the Eugenia Formation contain a Boreal bivalve assemblage characterized by species of *Buchia* (cf. Fig. 5).

RADIOLARIAN PALEOLATITUDINAL MODEL

It is now apparent from our analyses of radiolarian faunal data from North America and elsewhere in the world that radiolarians can be utilized in paleobiogeographic investigations and to monitor the tectonic transport of terranes both in the Northern and Southern Hemispheres. Much of the Circum-Pacific margin is comprised of a collage of tectonostratigraphic terranes. Many of these terranes have been displaced paleolatitudinally for hundreds, or in some cases, possibly thousands of kilometers. Circum-Pacific Jurassic paleogeography, as a result, is difficult to discuss in simplistic terms and must be viewed through this complex mosaic.

In the Northern Hemisphere Pessagno and Blome (1986) and Pessagno et al. (1986, 1987, 1993a,b) divided the Tethyan Realm into a Central Tethyan Province characterized by a radiolarian assemblage with high pantanelliid abundance and diversity and the absence of *Parvicingula/Praeparvicingula* and into a Northern Tethyan Province with high pantanelliid abundance and diversity and common *Parvicingula/Praeparvicingula* (Fig. 4). The Boreal Realm was subdivided into a Southern Boreal Province and a Northern Boreal Province. The Southern Boreal Province is characterized by a sharp decline in pantanelliid abundance and diversity and by the abundance and diversity of species of *Parvicingula/Praeparvicingula*; the Northern Boreal radiolarian assemblage is distinguished by abundant *Parvicingula/Praeparvicingula* and by its total lack of pantanelliids. In Fig. 4 the boundary between the Tethyan Realm and Boreal Realm is placed at ~30°N; the boundary between the Central Tethyan Province and the Northern Tethyan Province is established by associated paleomagnetic data at ~22°N (Pessagno et al., 1987; Yeh and Cheng, 1996). Pessagno and Blome (1986) originally proposed that the model for the Southern Hemisphere is the mirror image of that in the Northern Hemisphere. Subsequently, new data from the Southern Hemisphere has substantiated this model from Argentina (Pujana, 1989, 1991, 1993, 1996), New Zealand (Aita and Grant-Mackie, 1992), Antarctica (Kiessling, 1995; Kiessling and Scasso, 1996), and the Sula Islands (Pessagno and Hull, in prep.).

PALEOLATITUDINAL RECONSTRUCTIONS USING MULTIPLE CRITERIA

Although radiolarian paleobiogeographic reconstructions are useful and can stand alone, they are far more effective when combined with information derived from paleomagnetism, analysis of the total faunal and floral assemblage, and other criteria

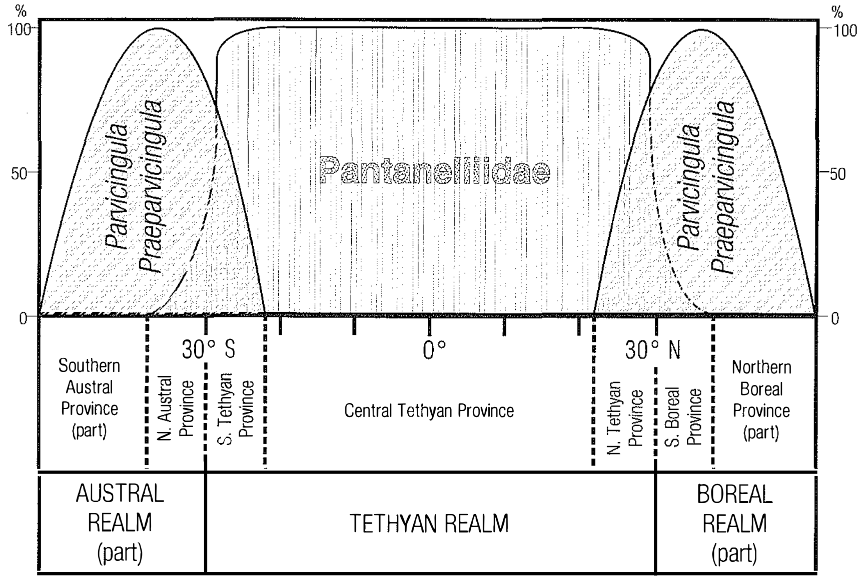

Fig. 4. Paleolatitudinal model based on distribution of selected radiolarians from the Jurassic and Lower Cretaceous.

having paleolatitudinal or paleolongitudinal significance (see Fig. 5). The tenet stressed herein is that paleogeographic reconstructions should use all criteria available, where possible, and should not focus on any one facet (e.g., analysis of only the ammonite assemblage). Nevertheless, even in eugeoclinal terranes, where other fossils are absent, it is often possible to determine the relative paleolatitudinal position of a given terrane from the study of the radiolarian assemblage alone. Conversely, in successions where megafossils are present and the radiolarians remain unstudied, it is possible to predict the character of the radiolarian assemblage from that of the paleogeographic character of the megafossil assemblage. This was, in fact, the case in our initial studies of the San Pedro del Gallo area. Because there was a mixture of Boreal ammonites such as *Amoeboceras* sp., cf. *alterans* (von Busch) (Burckhardt, 1930; Imlay, 1980) and *Buchia* associated with Tethyan ammonites, the senior author was able to predict that the radiolarian assemblage, if present in these strata, would be assignable to the Southern Boreal Province.

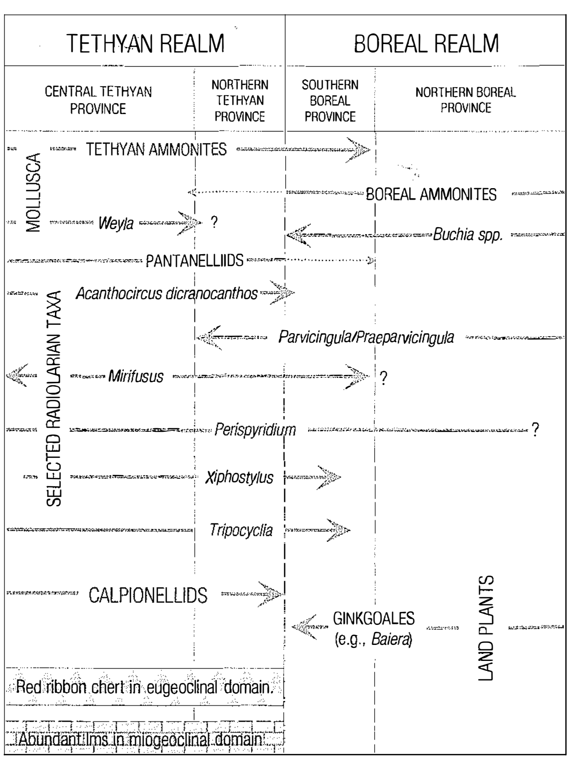

Fig. 5. Multiple criteria for use in paleobiogeographic reconstructions in the Northern Hemisphere.

CRITICISM OF THE MODEL OF PESSAGNO AND BLOME (1986) BY HAGSTRUM AND MURCHEY (1996)

Hagstrum and Murchey (1996) in a report entitled 'Paleomagnetism of Jurassic radiolarian chert above the Coast Range Ophiolite at Stanley Mountain, California and implications for its paleogeographic origins' challenged the validity of the methodology of Pessagno and Blome (1986) and Pessagno et al. (1987, 1993a). In spite of such criticism, we are appreciative of the paleomagnetic data that these authors obtained from the upper part of the volcanopelagic succession at Stanley Mountain (i.e., 32 ± 8°). These data support the previous conclusions of Pessagno et al. (1984) and Hopson et al. (1996) that this Coast Range Ophiolite remnant and its overlying sedimentary cover was at mid to high latitudes (Southern Boreal Province) by Tithonian times. As noted in the rebuttal by Hull et al. (1997), Hagstrum and Murchey's interpretation of the paleogeographic model presented by Pessagno and Blome (1986) and Pessagno et al. (1986) is inaccurate. The following points merit discussion herein.

(1) The distribution of *Praeparvicingula* and *Parvicingula* (= 'horned parvicingulids' of Hagstrum and Murchey) cannot be linked to the environment of deposition based on rock type as suggested by these authors.

(2) The distribution of pantanelliids as a criterion is still useful although it must be used with caution.

(3) Pessagno and Blome (1986) and Pessagno et al. (1986, 1987, 1989, 1993a,b 1993b) stressed the use of multiple criteria (see PALEOLATITUDINAL RECONSTRUCTION USING MULTIPLE CRITERIA) rather than just the presence of pantanelliids and *Praeparvicingula* and *Parvicingula* as indicated by Hagstrum and Murchey.

(4) The Pessagno and Blome model is not dependent on paleomagnetic data from Stanley Mountain as indicated by these authors.

These points will be discussed below. For a more in depth discussion the reader should refer to Hull et al. (1997).

(1) *The distribution of Praeparvicingula and Parvicingula (= 'horned parvicingulids' of Hagstrum and Murchey) cannot be linked to the environment of deposition based on rock type as suggested by these authors.* Hagstrum and Murchey (1996, p. 649) follow Baumgartner (1987) in stating that "In general, horned parvicingulids occur in hemipelagic rocks such as tuffaceous mudstone or gray, mudstone, and siltstone". This statement is erroneous. It infers that 'horned parvicingulids' only occur in coastal environments. *Parvicingula* and *Praeparvicingula* not only occur in hemipelagic strata, but they also occur in pelagic strata such as red manganiferous ribbon cherts at a number of localities throughout the world, some of which occur in Hagstrum and Murchey's own backyard in the California Coast Ranges. Examples of such occurrences are as follows: (a) thousands of meters of Upper Jurassic oceanic plateau-type basalt interbedded with red manganiferous ribbon chert in the Franciscan Complex at Wilbur Springs and Stoneyford (locs. 17, 18 of Hopson et al., 1981); (b) red ribbon cherts throughout the Greater Antilles in the Caribbean (e.g., volcanic member of ophiolite complex in La Désirade, ophiolite remnants in Bermeja Complex of southwestern Puerto Rico, and ophiolite remnants in the Duarte Complex of the Dominican Republic (Montgomery et al., 1992, 1994a,b); (c) subduction complex in the Philippines (Yeh and Cheng, 1996).

Red ribbon cherts from all of these localities contain *Parvicingula* and *Praeparvicingula* and clearly lack any sort of terrestrial input. It is apparent that these taxa flourished in a wide range of sedimentary environments ranging from open ocean beyond the reach of terrigenous or volcanic input (red ribbon cherts and also some pelagic limestone such as that occurring in the pillow lava at La Désirade) to open ocean down-wind from an island arc (e.g., tuffaceous chert above Coast Range Ophiolite at Point Sal, Santa Barbara County, California) to backarc, interarc, and forearc environments (e.g., 'chert member' of La Caja Formation at San Pedro del Gallo (= backarc), Rogue Formation, Klamath Mountains, Southwestern Oregon (= interarc), and Snowshoe Formation, Izee terrane, east-central Oregon (= backarc: see Pessagno and Blome, 1986)).

(2) *The distribution of pantanelliids as a criterion is still useful although it must be used with caution.* As noted by Pessagno et al. (1986, p. 8), the abundance and diversity of pantanelliids in radiolarian chert, siliceous mudstone is controlled by diagenesis. However, it is also influenced by the method of extracting the microfossils from rock samples using the hydrofluoric acid (Blome and Reed, 1993). The fragile nature of many pantanelliid taxa prevents them from being preserved in sedimentary strata which were metamorphosed or underwent lithification subsequent to deposition. Crushing and stretching of specimens extracted from radiolarian chert and shale is common and usually results in the total destruction of all fragile radiolarians. Only radiolarians with thick-walled, sturdy tests are preserved (e.g., *Parvicingula, Praeparvicingula, Mirifusus, Archaeocenosphaera*) although these forms may often be quite abundant. The best recovery of well-preserved pantanelliids, and indeed all radiolarians occurring in Mesozoic strata, comes from limestone. Radiolarian diversity is at least three times greater in limestone strata than it is in adjacent chert or mudstone layers. This is in part due to two factors: (1) the use of the hydrofluoric acid technique (Pessagno and Newport, 1972) to extract the radiolarians from siliceous strata and the use of HCl to extract radiolarians from limestone, and (2) the early lithification of limestone strata at the time of deposition as opposed to the post-depositional lithification of the chert. Blome and Reed (1993) demonstrated that the use of the HF technique invariably results in the destruction of radiolarians with more fragile tests (e.g., most pantanelliids). The most dramatic example exemplifying the early lithification of limestone close to the time of deposition comes from a study of Pessagno et al. (1993a) of the volcanopelagic succession overlying the Josephine Ophiolite (Smith River Subterrane, Klamath Mountains, Northwestern California). At this locality (Middle Fork of Smith River) volcanopelagic strata consisting of dark-gray to greenish-gray tuffaceous chert and light-gray pelagic limestone overlie the Josephine Ophiolite and underlie the flysch of the Galice Formation.

Identical radiolarian chert occurs within the volcanic member of the Josephine Ophiolite. In the interval including the volcanic member of the Josephine Ophiolite and the overlying volcanopelagic strata, the limestone strata produced about three times more radiolarian taxa than did the chert strata. Moreover, about four times more pantanelliid taxa occur in limestone strata than in chert strata. Other examples, of this sort are cited in studies by Blome and Reed (1993) and Hull (1995).

Although there are undoubtedly cases where pantanelliids can not be used in paleogeographic reconstructions because of the factors noted above, it is important to point out that this group of radiolarians has been successfully utilized to establish paleolatitudes by Pessagno and Blome (1986) for the Izee terrane (east-central Oregon) during the Late Triassic, Early Jurassic and Middle Jurassic, by Pessagno et al. (1984, 1987) for the Huayacocotla remnant of the San Pedro del Gallo terrane during the Late Jurassic and Early Cretaceous, and by Pessagno et al. (1993a) for the Smith River Subterrane during the Middle and Late Jurassic. In all of these examples, radiolarians were extracted from either bedded limestone or from limestone nodules using hydrochloric acid, were exposed to no higher than prehnite–pumpellyite to greenschist metamorphism, and were well-preserved. In the Izee terrane, for example, well-preserved, abundant and diversified pantanelliids associated with Tethyan megafossils characterize the Late Triassic (Karnian–Norian) Rail Cabin Formation, the Early Jurassic Nicely Formation (late Pliensbachian), the Early Jurassic Hyde Formation (early to middle Toarcian), and the Early Jurassic part of the Warm Springs Member of the Snowshoe Formation (middle to late Toarcian, part). Moreover, such an assemblage also characterizes the Aalenian, early Bajocian, and late Bajocian (Middle Jurassic) parts of the Snowshoe Formation (Warm Springs Member to lower part of the South Fork Member. However, as noted by Pessagno and Blome (1986) pantanelliid diversity and abundance and diversity drops dramatically in the late Bathonian part of the South Fork Member of the Snowshoe Formation and in early Callovian Lonesome Formation. The great drop in diversity and abundance of pantanelliids can be directly related to the first occurrence of Boreal ammonites such as *Kepplerites* and *Pseudocardoceras* in the upper part of the South Fork Member (Pessagno and Blome, 1986; Pessagno et al., 1986).

Hull et al. (1997) stated "Thus facing both successes and questions about pantanelliids, we agree that much remains to be solved concerning the paleoceanographic and/or paleolatitudinal preferences of this group of radiolarians. It must be remembered that the recovery of pantanelliids and, indeed, all radiolarians, is greatly influenced by the care taken in sample processing. The recovery of abundant pantanelliids in the Oxfordian and Kimmeridgian parts of other CRO remnants could also be influenced by other factors, such as preferred high-fertility upwelling areas. Although Hagstrum and Murchey selectively point to pantanelliids as favoring high-fertility upwelling areas, it could be equally expected that parvicingulids flourished in such areas, subject, however, to different water temperature (paleolatitude) controls. The published literature notably lacks any reference to the comparative preference of pantanelliids over parvicingulids for high fertility upwelling areas.

Regarding this link between high fertility and radiolarian assemblages, we also question Hagstrum and Murchey's use (their fig. 8) of Lisitizin's 1972 map, showing spatial distribution of the annual production of silica by marine organisms in the world ocean, for the purpose of advancing their thesis that 'the tuffaceous Stanley Mountain cherts (CRO) were likely deposited at ~30°N within a high productivity zone near the western margin of North America'. This map for the modern ocean illustrates silica production predominantly for diatoms near continental coast lines. Diatoms are chief silica producers in modern oceans and are responsible for more than seventy percent of the total marine silica (Kennett 1982); silica production from radiolarians ranks a distant second among siliceous plankton, and presumably, silicoflagellates and siliceous sponge spicules contribute silica as well. Moreover, it is well known that radiolarians generally are not as abundant in nearshore waters of modern oceans (Kennett 1982) as diatoms in such settings, particularly in eastern boundary regions. We believe that the high production of biogenic silica in the coastal regions bordering North America during the Recent (Hagsrum and Murchey, fig. 8) reflects diatom production and therefore, once again, provides no clue to the geographic distribution of Stanley Mountain radiolarians in the Late Jurassic ocean."

(3) *Pessagno and Blome (1986) and Pessagno et al. (1986, 1987, 1989, 1993a) stressed the use of multiple criteria rather than just the presence of pantanelliids and Praeparvicingula and Parvicingula as indicated by Hagstrum and Murchey.* As noted by Hull et al. (1997), in their discussion of the paleogeographic foundation for the Pessagno and Blome model Hagstrum and Murchey neglect to mention that the model's realms and provinces, are *by definition* (Pessagno and Blome, 1986), always constructed on *multiple criteria.* This thesis was repeatedly stressed subsequently in a series of reports by Pessagno et al. (1986, 1987, 1993a,b) and Blome (1987) (see PALEOLATITUDINAL RECONSTRUCTION USING MULTIPLE CRITERIA).

(4) *The Pessagno and Blome model is not dependent on paleomagnetic data from Stanley Mountain as indicated by these authors.* Hagstrum and Murchey (p. 650) indicate that model presented by Pessagno and Blome (1986) incorporates little quantitative paleolatitudinal control. Moreover, they suggest that the placement of the Central Tethyan–Northern Tethyan boundary at 22°N was based on the Stanley Mountain paleomagnetic data (i.e., 14 ± 7°N/S presented by McWilliams and Howell (1982). This statement is totally erroneous. The province boundary was tentatively placed at 22°N because of the presence of Central Tethyan Berriasian faunas occurring at 20°N at DSDP Site 534 (Blake Bahama Basin: Ogg, 1983; Baumgartner, 1984; Pessagno et al., 1987, p. 7). In addition, it is now supported by new data from the Philippines (Yeh and Cheng, 1996). Quantitative data was also cited by Hopson et al. (1996) for the Llanada and Point Sal remnants of the CRO and by Pessagno (1995) for west-central Mexico. There is little question, however, that more paleomagnetic data are needed by workers in future studies. It should be pointed out, however, that 'quantitative' paleomagnetic data for the Phanerozoic is completely dependent on biostratigraphically derived chronostratigraphic data. The Phanerozoic chronostratigraphic scale is based on fossil biozones. Moreover, the geochronologic scale ('geologic time scale') is derived from the integration of biostratigraphic and chronostratigraphic data with geochronometric data (e.g., U/Pb dates).

REMNANTS OF THE SAN PEDRO DEL GALLO TERRANE

The San Pedro del Gallo terrane (SPG) was first defined by Pessagno et al. (1993b) for the area first studied in 1910 by the famous Swiss geologist, Carlos Burckhardt in the state of Durango (Fig. 2: Loc. 12; Fig. 8). Burckhardt's contributions to the geology of San Pedro del Gallo were five-fold: (1) he established the succession/superposition of Jurassic and Cretaceous strata by utilizing ammonite biostratigraphy and chronostratigraphy; (2) he monographed the rich megafossil assemblage (largely ammonites; Burckhardt, 1912); (3) he made the first geologic map as well as the first topographic map of the area; (4) he interpreted the structure and produced numerous structural profiles; and (5) he assessed the mineral deposits of the area. Burckhardt's study was so thorough that few workers have been able to improve on it.

Fig. 6 shows a comparison of the geology of the San Pedro del Gallo terrane (SPG) to that of adjacent Parral and Coahuiltecana terranes. The SPG terrane is flanked to the north by the flysch of the Parral terrane (Coney and Campa, 1984) and to the east by the Sierra Madre Oriental terrane (= Coahuiltecano terrane of Sedlock et al., 1993; emend. herein; see Fig. 7). According to Coney and Campa (1984, p. D-3) the 'Parral Terrane' includes "highly deformed, partly calcareous Upper Jurassic and Lower Cretaceous turbiditic sandstone". "The Sierra Madre Oriental Terrane" includes "deformed upper Mesozoic sedimentary rocks of the Gulf of Mexico transgressive sequence and their diverse basement rocks which include, at different places, Pre-Cambrian crystalline rocks and structurally juxtaposed Paleozoic sedimentary rocks, Lower Jurassic sedimentary rocks, structurally associated with Pre-Cambrian and Paleozoic rocks, and pre-Late Jurassic red beds and volcanic rocks." Our data indicate that the San Pedro del Gallo area includes strata that were deposited in the Boreal Realm during the Late Jurassic. The San Pedro del Gallo succession is juxtaposed (along the Walper Megashear) against strata to the east ('Sierra Madre Oriental Terrane') which are both miogeoclinal and Tethyan in character. West-southwest of the Walper Megashear the geology is considerably more complex and is indicative of a back-arc setting. The presence of common basaltic andesite clasts in coeval Upper Jurassic to Lower Cretaceous olistostromal deposits coupled with beds of green and red silty tuff and associated graywacke at the village of Cinco de Mayo to the north of San Pedro del Gallo (Fig. 8) reflects a more proximal back-arc origin.

Pessagno et al. (1993b) suggested that the Jurassic successions at Mazapil and in the Huayacocotla segment of the Sierra Madre Oriental (Longoria, 1984) are genetically related to that at San Pedro del Gallo and were possibly remnants of the SPG terrane. Subsequent investigations have proven this to be the case. In this report we regard the Upper Jurassic and Lower Cretaceous successions at San Pedro del Gallo, Symon and Sierra Ramirez, Mazapil (Sierra Santa Rosa), Sierra de la Caja, Sierra Zuloaga and Sierra Sombretillo, Sierra Cadnelaria, Sierra de Catorce, and in the Huayacocotla Anticlinorium to represent remnants of the SPG terrane (see Fig. 2: Locs. 12, 9, 5, 8, 7, 6, and 3; Burckhardt, 1930, 1931; Imlay, 1980). Moreover, it is clear that the Middle Jurassic to Lower Cretaceous succession in western Cuba (Fig. 2: Loc. 24) also includes remnants of the SPG terrane. In addition to displaying the similar lithostratigraphic and paleobathymetric signatures, all of the remnants of the SPG terrane show evidence of tectonic transport from higher latitudes to lower latitudes. The mechanism for this displacement in Central Mexico is the Walper Megashear (Figs. 2, 3 and 7). Tectonostratigraphic data to support this thesis is presented below.

Characteristics	Parral terrane	San Pedro del Gallo terrane	Coahuilatecana terrane
Lithologic Characteristics	Flysch: Rhythmically bedded graywacke and shale. "Turbiditic sandstone" of Coney and Campa (1984). Thickness unknown. Rocks partially coeval with those of San Pedro del Gallo terrane.	Massively bedded quartzite and interbedded nerineid limestone, organic-rich, black shale, and mudstone with numerous limestone nodules, black radiolarian chert, graywacke, tuff, and thin bedded micritic limestone.	Thin-bedded to massively bedded gray sandstone, pink silty siliceous shale and mudstone with interbedded pink to buff, silty micritic limestone, and chalky mudstone, etc.
Domain	Eugeoclinal: Back Arc	Eugeoclinal: Back Arc	Miogeoclinal
Water Depth	Bathyal to Abyssal	Bathyal to upper abyssal. Above depth of compensation of aragonite	Neritic. Mostly shallow neritic
Paleolatitudinal Signature during Jurassic and Cretaceous	Unknown	Southern Boreal to Tethyan	Entirely Tethyan
Geomorphic Expression	Hummocky, irregularly trending ranges	Hummocky, irregularly trending ranges	Parallel, linearly arranged ranges
Structural Style	Folds relatively small scale. Folding tight, intricate. Rocks more faulted than those of SMO terrane	Folds relatively small scale. Folding tight, intricate. Rocks more faulted than those of SMO terrane	Folds open, parallel, more regularly trending, very large scale..

Fig. 6. Comparison of San Pedro del Gallo terrane to Coahuiltecano terrane.

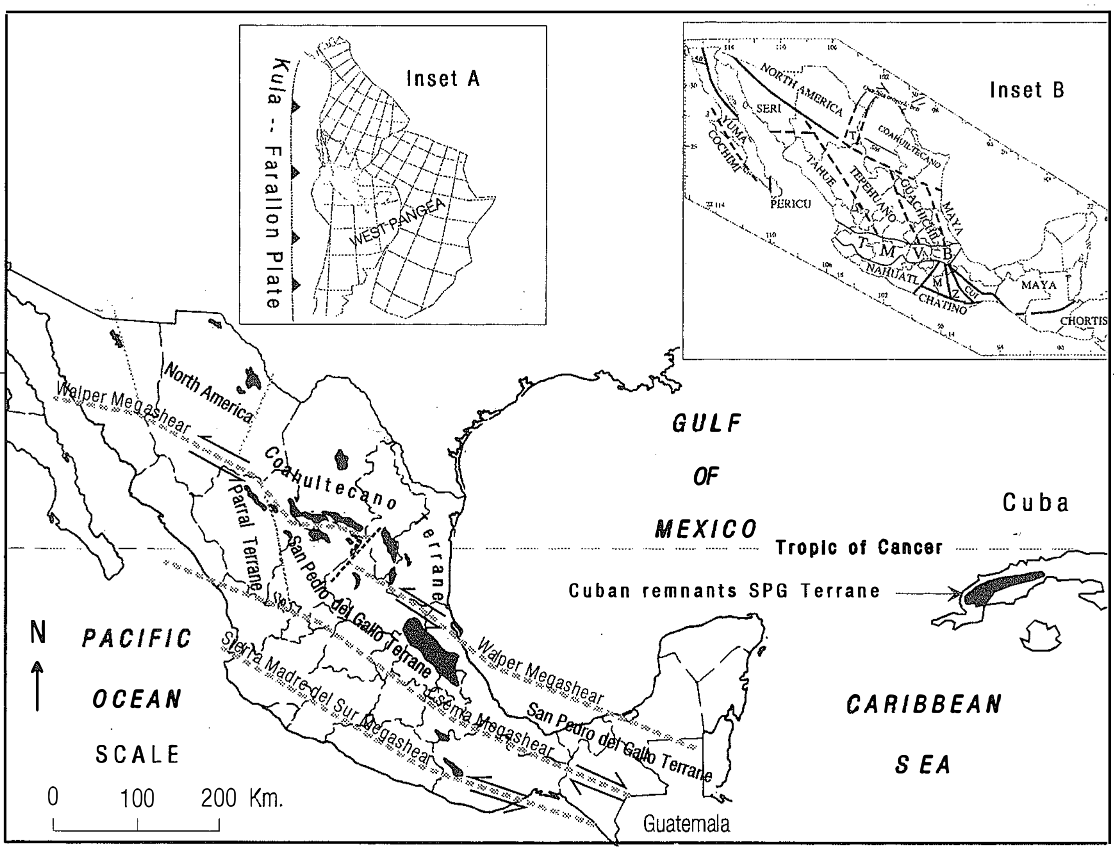

Fig. 7. New map showing terranes, first-order megashears, Sedlock et al.'s terrane map, and Pangea at end of Pe.

ANALYSES OF SAN PEDRO DEL GALLO TERRANE REMNANTS

Figs. 2 and 7 shows the position of San Pedro del Gallo (SPG) terrane remnants to the west of the Walper Megashear. Moreover, Fig. 7 shows the terranes utilized by Sedlock et al. (1993), some of which are emended or abandoned herein (see Inset B of Fig. 7). Fig. 9 is a correlation chart showing the correlation of lithostratigraphic units in each

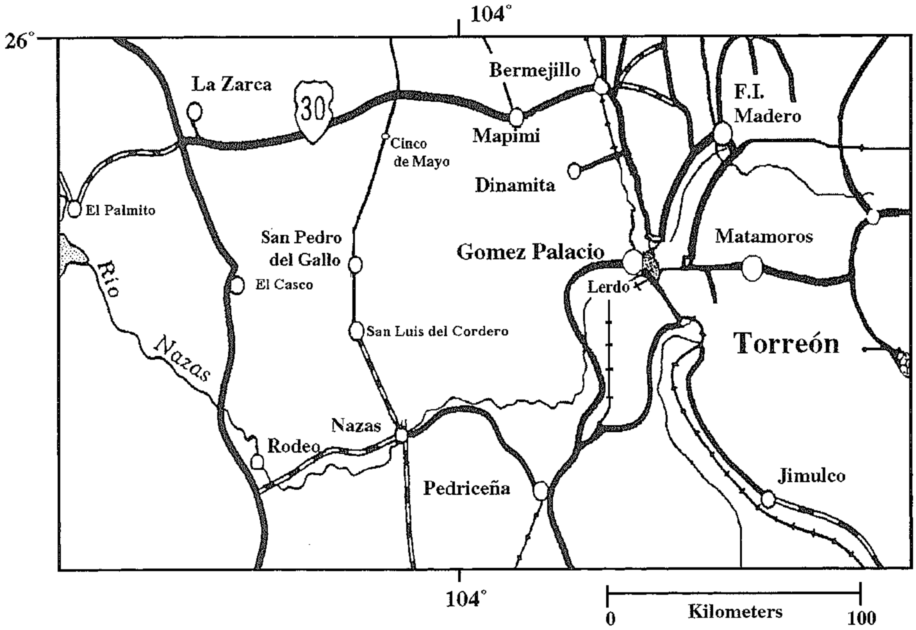

Fig. 8. Index map for San Pedro del Gallo.

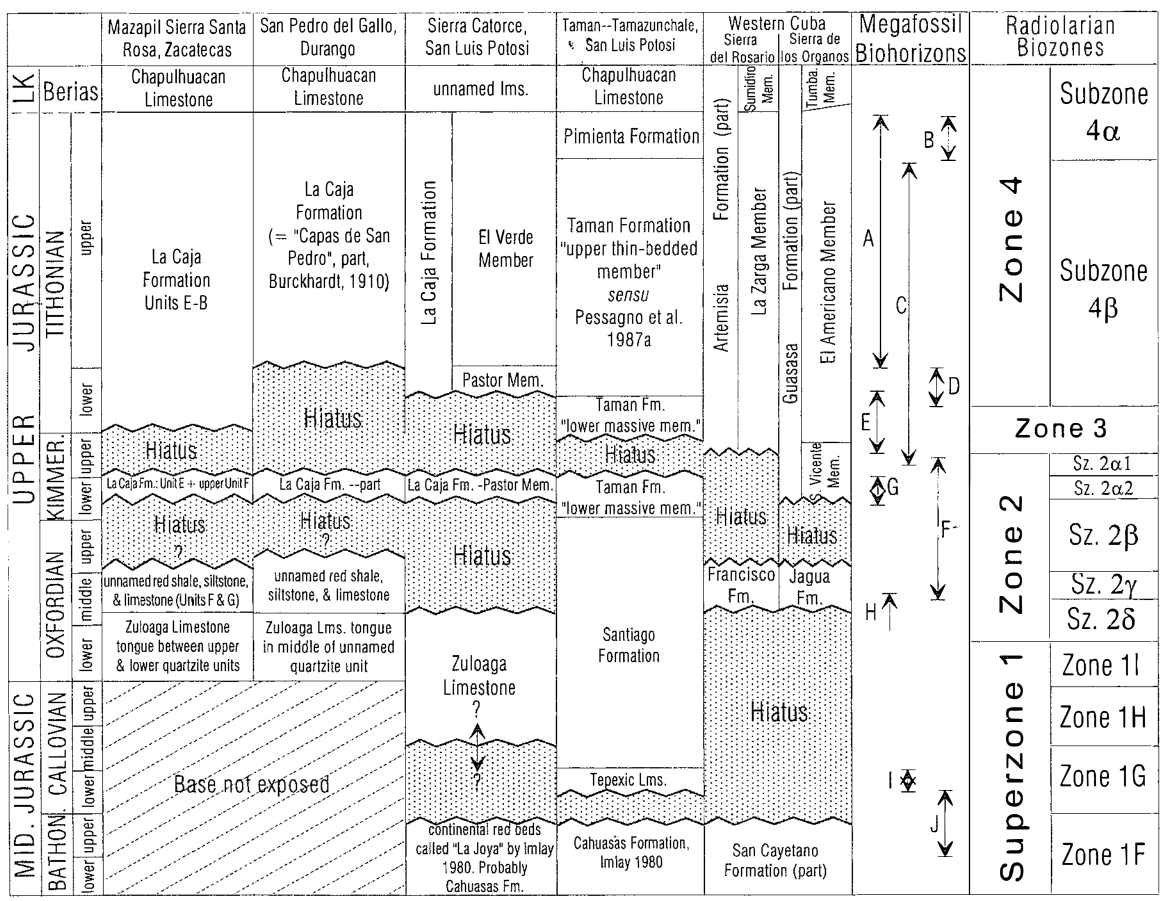

Fig. 9. Correlation chart showing radiolarian biozones and ammonite and *Buchia* markers, and correlation of litho units in all SPG terrane remnants.

SPG remnant with chronostratigraphic and biostratigraphic units. Fig. 10 shows the depth distribution of important Mesozoic fossil groups used in paleobathymetric interpretations. Fig. 11 shows the correlation of lithostratigraphic units with paleobathymetry and paleogeographic position; moreover, it attempts to

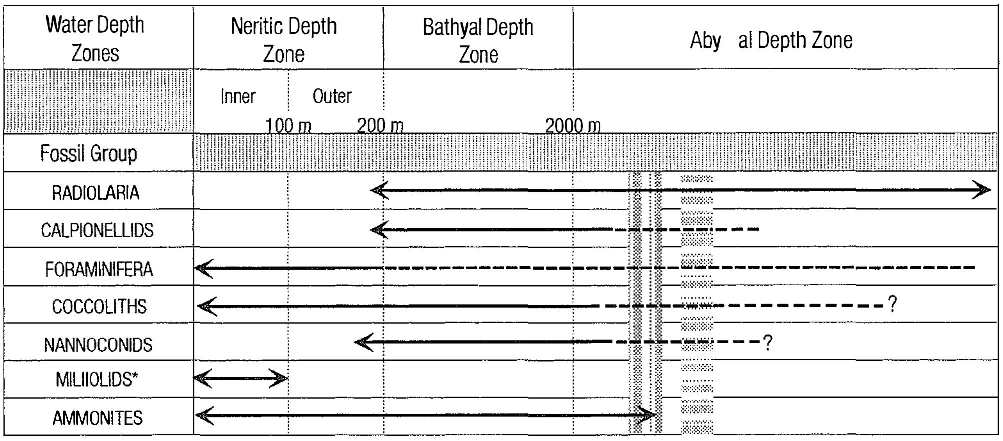

Fig. 10. Depth distribution of various Mesozoic fossil groups.

demonstrate the significance of lithostratigraphic features (e.g., unconformities) that record regional North American tectonostratigraphic events. Figs. 12–17 are detailed stratigraphic summaries of each terrane remnant that supplement Figs. 9 and 11.

San Pedro del Gallo remnant

The analysis of the San Pedro del Gallo remnant is based on ongoing investigations since 1990 (Pessagno et al., 1993b; Martin, 1996; Meng, 1997) as well as previous observations by Burckhardt (1910, 1912, 1930) and Imlay (1939). Fig. 2 shows the position of the San Pedro del Gallo terrane to the west of the Walper Megashear (see Fig. 2: Loc. 12). The understanding of the stratigraphy of the San Pedro del Gallo succession was hampered for many years by miscorrelation of several lithostratigraphic units. Web Fig. 5.1[1] is a space shuttle image showing the western front of the Sierra Madre Oriental (right). The boundary between the Coahuiltecana terrane (emended herein) and displaced terranes to the west occurs immediately west of the mountain front along the Walper Megashear.

Examination of the type Zuloaga Limestone in the Sierra Sombreretillo (Zacatecas) has established that Burckhardt's 'nerineid limestone' at San Pedro del Gallo is its lithostratigraphic equivalent. At San Pedro del Gallo the Zuloaga Limestone (Web Figs. 5.2 and 5.3) occurs as a tongue in Burckhardt's (1910) quartzite unit which Imlay incorrectly correlated with the La Gloria Formation (type locality = Sierra la Gloria, ~50 km east-southeast of Parras (Fig. 2: Loc. 17), Imlay, 1937).

The base of the succession at San Pedro del Gallo is not exposed. In that neither the Zuloaga Limestone nor the lower and upper quartzite units possess age diagnostic fossils, their age can only be established as middle Oxfordian or older via the superposition of overlying strata containing middle Oxfordian ammonites (Figs. 9, 11 and 12). Martin's (1996, p. 105) microfacies analysis of the Zuloaga Limestone indicates that it consists of bioturbated micrite ('lime mudstone') and peloidal lime grainstone. The faunal assemblage of the Zuloaga Limestone is characteristic of inner neritic depths. It contains nerineids, other gastropods, rare corals, echinoid fragments, and rare benthonic Foraminiferida (Miliolina and Textulariina) (Martin, 1996). The presence of miliolids in the Zuloaga Limestone indicates that it was deposited at depths no greater than 100 m (Fig. 10). Martin noted that most of the allochems are well-sorted peloids. He noted that many of the peloids have poorly defined rims that may indicate that they were formed by the rolling action of near-shore waves. Moreover, he suggested that the bioturbated micrite was deposited upon a gently sloping carbonate bank in an area that was isolated from the winnowing action of wave energy. The 'upper quartzite unit' consists of thick-bedded, well-sorted quartz arenite with symmetrical ripple marks, trough cross-beds (Martin, 1996, p. 105), and occasional large gastropods. Martin indicated that the uppermost beds of this unit are peloid lime grainstone similar to those occurring within the Zuloaga Limestone tongue. Moreover, according to Martin the well-sorted nature of the quartz sand and micrite peloids suggests that the 'upper quartzite unit' may have been deposited at even shallower inner neritic depths near a shore face where sediments would be subjected to higher wave energy.

The 'upper quartzite unit' (Figs. 9, 11 and 12) is overlain by a unit consisting of pink siltstone, mudstone, and silty limestone with middle and upper Oxfordian ammonites, brachiopod shell fragments, *Buchia concentrica,* common nodosarids (benthonic foraminifers), and miliolids (benthonic foraminifers) (senior author's observation and those of Martin, 1996). Martin noted that the calcareous siltstone is

[1] Available at: http://www.elsevier.nl/locate/caribas/

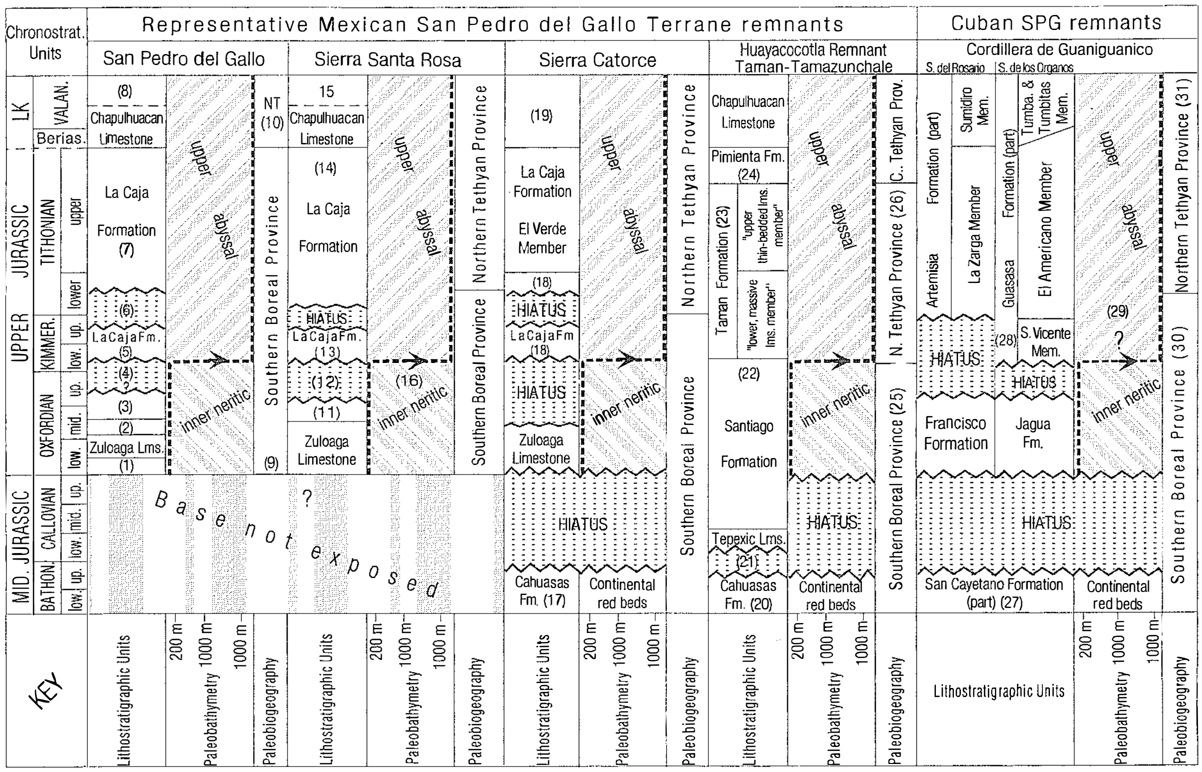

Fig. 11. Lithostratigraphy, chronostratigraphy, paleobathymetry, and paleobiogeography. (*1*) "Lower quartzite unit" of Burckhardt (1910). Unfossiliferous massively bedded, white to pink sandstone. (2) "Upper quartzite unit" of Burckhardt (1910). Unfossiliferous massively bedded sandstone. Overlies Burckhardt's "nerineid limestone" = Zuloaga Limestone of Imlay (1938). (*3*) Unnamed pink silty limestone, mudstone, and siltstone. Contains *Buchia*, common ammonites, and Radiolaria (upper part only). Chronostratigraphically significant megafossils include the ammonites *Dichotomosphinctes* and *Discosphinctes* and the *Buchia concentrica* (middle to upper Oxfordian). (*4*) Lower Kimmeridgian *Ataxioceras* Zone and probably part of *Idoceras* Zone (ammonites) missing. Upper part of upper Oxfordian probably missing. Regional unconformity in much of western North America. Corresponds approximately to onset of deposition of flysch during middle Oxfordian times in Klamath Mountains of northwestern California and southwestern Oregon (Galice Formation) and in Sierra Nevada (Mariposa Formation, Monte del Oro Formation). See Pessagno et al. (1993a). Possibly reflecting pre-Nevadian orogenic pulse in backarc domain. (*5*) "Lower shale member" of La Caja Formation = lower part of "Capas de San Pedro" of Burckhardt (1910). Dark gray calcareous to siliceous mudstone with micrite nodules containing abundant Radiolaria, common ammonites and *Buchia*. Basal strata assignable to *Idoceras* Zone (upper half of lower Kimmeridgian) and radiolarian Subzone 2 alpha-1 (Meng, 1997; Meng and Pessagno, in prep.). (*6*) Regional unconformity in western North America recognizable in Nevadian back arc terranes (e.g., all San Pedro del Gallo remnants in Mexico and in Cuba) and in Nevadian forearc terranes (e.g., volcanopelagic (VP) strata overlying Stanley Mountain remnant of Coast Range Ophiolite, San Luis Obispo Co., California and Point Sal remnant of Coast Range ophiolite, Santa Barbara Co., California). See Hull (1991, 1995), Hull et al. (1993); Hopson et al., (1996). (*7*) Includes upper part of "Capas de San Pedro" of Burckhardt (1910) and "chert", "upper shale", and "Cerro Panteon quarry unit 2" members of La Caja Formation herein (see Figs. 8 and 10 for more detailed litho description, biostratigraphic data and chronostratigraphic data). Note that the La Caja Formation at San Pedro del Gallo was miscorrelated lithostratigraphically by Imlay (1939) with his La Casita Formation. All members of La Caja Formation at San Pedro del Gallo with abundant Radiolaria. Sudden influx of silty wacke at Cerro Panteon and at La Peña (10 km north of San Pedro del Gallo) reflects onset of Nevadian orogeny. Contact of Great Valley Supergroup (flysch) and underlying VP sequence at Stanley Mountain above Stanley Mountain remnant of Coast Range Ophiolite occurs in lower part of Subzone 4 alpha (uppermost upper Tithonian). At San Pedro del Gallo equivalent strata contain the ammonite *Durangites* and *Buchia piochii*. (*8*) Unnamed thin-bedded, tan to pink mudstone and micrite with common ammonites and calcified Radiolaria. These strata overly the massive to medium bedded tan micrites of the Chapulhuacan Formation (type area in Taman-Tamazunchale area to southeast. Imlay (1937) miscorrelated these strata with shallow neritic Taraises Formation (type area = Sierra de Parras). (*9*) Paleomagnetic data ("upper quartzite unit") from Ogg indicates ~40°N/S of Jurassic paleoequator (Pessagno, 1995). Presence of the Boreal megafossils *Buchia concentrica* and *Amoeboceras* sp. in overlying Oxfordian strata associated with Tethyan ammonites such as *Dichotomospinctes* indicate Southern Boreal Realm. Overlying La Caja Formation with *Buchia concentrica*, *B. rugosa*, *B. mosquensis*, and *B. piochii* associated with Southern Boreal radiolarian assemblage characterized by high diversity and abundance of *Parvicingula* and *Praeparvicingula*. Upper part of La Caja Formation with *Buchia* associated with *Parvicingula/Praeparvicingula* and abundant calpionellids (Tethyan: see Pessagno et al., 1996). Late Tithonian portion of La Caja Formation formed ~ at boundary between Boreal Realm and Tethyan Realm. (*10*) Abundant calpionellids together with lack of *Buchia* and presence of only Tethyan ammonites suggests Northern Tethyan Province (Meng, 1997). (*11*) Units G and F of Fig. 13. (*12*) Regional unconformity noted in (4) above. (*13*) Unit E (pt. cf. Fig. 11). The discovery of the lower Kimmeridgian ammonite *Idoceras* in a limestone nodule 1.5 m below contact between units E and F, indicate that the uppermost part of unit F is lower Kimmeridgian (identification by Dr. Cantú-Chapa, Instituto Politecnico Nacional, Mexico); the middle Oxfordian ammonite, *Dichotomosphinctes* was recovered 7 m below this horizon (identification by Dr. Cantú-Chapa, Instituto Politecnico Nacional, Mexico). (*14*) Units E (pt)–B of Fig. 13. Note that silty wacke occurs in upper part of Unit B in lower Subzone 4 alpha. This horizon occurs below final occurrence of *Durangites* and *Substeueroceras* (Pessagno et al., in prep.; identification by Dr. Cantú-Chapa, Instituto Politecnico

slightly laminated and contains 10 to 35% angular to subangular, well-sorted quartz grains. The upper part of this unnamed Oxfordian unit contains common radiolarians. The sudden occurrence of the radiolarians in this part of the succession reflects a rapid shift in paleobathymetry from inner neritic to outer neritic depths during the late Oxfordian (Figs. 10 and 11).

Imlay (1939) correlated the informal unit which Burckhardt called the 'Capas de San Pedro' with the La Casita Formation (see Figs. 9, 11 and 12). Although these lithic units are approximately equivalent chronostratigraphically, it is clear from our examination of the La Casita in its type area (Sierra de Parras, Fig. 2: Loc. 17) as well as in the Sierra Jimulco (Fig. 2: Loc. 18) that the 'Capas de San Pedro' are not correlative lithostratigraphically with the La Casita Formation (see Martin, 1996). The La Casita Formation consists of gypsiferous gray to pinkish-gray silty, calcareous to siliceous mudstone, silty micritic limestone, and siltstone deposited at inner neritic depths containing ammonites, brachiopods, bivalves, and a sparse, poorly diversified foraminiferal assemblage (five species, largely Textulariina: senior author's observations). In contrast, Burckhardt's 'Capas de San Pedro' consists of upper abyssal dark-gray calcareous to siliceous mudstone with common black, thin-bedded radiolarian chert in its upper part and common radiolarian-rich micrite nodules in its lower part. Although the 'Capas de San Pedro' was informally named by Burckhardt, it is clearly genetically related to the La Caja Formation. We have observed black radiolarian chert in the La Caja Formation thus far at Cañon San Matias (Sierra Santa Rosa) near Mazapil, at its type locality in the Sierra de la Caja, in the Sierra de Catorce, and at other localities where the La Caja Formation has been reported (see Imlay, 1980).

The La Caja Formation (= 'Capas de San Pedro' part of Burckhardt, 1910) is divided into this report into four informal members (in ascending order): (1) the 'lower shale member', (2) the 'chert member', (3) the 'upper shale member', and (4) the 'Cerro Panteon quarry unit 2' member.

(1) *'Lower shale member'*. The 'lower shale member' consists of 52 m (min.) of dark-gray siliceous to calcareous mudstone with common dark-gray micrite nodules. Lenticular masses of thin-bedded, dark-gray micrite are present locally. The bedded micrite and micrite nodules contain abundant radiolarians, rare to common ammonites, and *Buchia* (see Figs. 11 and 12). This unit is assignable to late early Kimmeridgian to the early late Kimmeridgian (Figs. 9, 11 and 12). It rests unconformably on the middle to early late Oxfordian strata of the unnamed red, siltstone, limestone and shale unit (Figs. 9, 11 and 12).

Nacional, Mexico). (*15*) Unnamed limonitic mudstone and limestone of Burckhardt (1930 = Burckhardt's unit B). (*16*) Change from inner neritic to outer neritic occurs in upper part of unit F (Fig. 13). Martin (1996) noted the first occurrence of common Radiolaria in upper unit F. This horizon may also correspond to regional unconformity noted in 12 above. (*17*) Called La Joya Formation by Imlay (1980). Lower Jurassic strata below this unit contain ammonites and probably are equivalent to the Huayacocotla Group (see Imlay, 1980). (*18*) El Pastor Member of La Caja Formation (Verma and Westermann, 1973). Massively, bedded medium gray micrite with thin-beds of black radiolarian chert and wacke. Wacke often with displaced shallow neritic megafossils. Overlying El Verde member consisting of thin-bedded dark gray micrite and black radiolarian chert together with wacke. Graded-bedding and displaced shallow water fossils noted in wacke (*19*). Incorrectly correlated with shallow neritic La Taires Formation by Verma and Westermann (ibid.). (*20*) Overlies Huayacocotla Group in Huayacocotla remnant. (*21*) Cantú-Chapa, (1969) recovered the Boreal ammonite *Kepplerites* in the subsurface of the Huayacocotla remnant from the shallow neritic Palo Blanco Formation. This ammonite is common in terranes in the Sierra Nevada, in the Izee Terrane of east-central Oregon, and in western terranes north to Alaska. It is indicative of the uppermost Bathonian or lower Callovian (Imlay, 1980) In the surface the Cahuasas Formation is overlain by the Tepexic calcarenite (see Fig. 13 for more detailed description). (22) All but uppermost part of Santiago Formation contains an inner neritic molluscan assemblage. Common Radiolaria (including *Praeparvicingula*) first occur near top of unit (Pessagno et al., 1987a). (*23*) Taman Formation characterized by abundant Radiolaria, common pectenacids, and rare ammonites. The rarity of ammonites suggests deposition in the upper abyssal depth zone just below the depth of composition of aragonite. See Pessagno et al. (1987a). Co-occurring throughout the Taman Formation in the area south of Taman (e.g., near Huauchinango Puebla) are discontinuous masses of inner neritic calcarenite (San Andres Member, Cantú-Chapa, 1969, 1971; Imlay, 1980) that either represent shallow neritic carbonate sedimentation on sea mounts or turbidites. Definition of Taman Formation following that of Pessagno et al. (1987a). (*24*) The Pimienta Formation differs from the Taman Formation by consisting of light to medium gray, thin-bedded micrite interbedded with black radiolarian chert and occasional layers of green vitric tuff. (*25*) See annotation 21 above. Taman Formation with rich Northern Tethyan radiolarian assemblage including *Parvicingula* and *Praeparvicingula* and abundant diversified pantanelliids associated with Tethyan ammonites and calpionellids (Tithonian). (See Pessagno et al. 1987a). (*26*) Pimienta Formation and overlying Chapulhuacan Limestone with abundant calpionellids, tethyan ammonites, and lacking *Parvicingula/Praeparvicingula*. Central Tethyan Province. (*27*) Data from Imlay (1980), Haczewski (1976), Lewis and Draper (1990), and Myczyński and Pszczółkowski (1994). Imlay indicates that marine bivalves of probable Middle Jurassic age occur in upper part of this unit. (*28*) San Vincente Member (Myczyński, 1994) is anomalous and appears to be an analog of San Andres Member of Taman Formation in Huayacocotla remnant. See Annotation 23 above. (*29*) Radiolarian-rich strata comprising all of the Artemisa Formation and most of Guasasa Formation (except for San Vincente, see above) were deposited at upper abyssal depths either above or slightly above the CCD of aragonite. (*30*) The presence of *Parvicingula/Praeparvicingula* in the radiolarian assemblage associated with Tethyan ammonites and *Buchia* (Myczyński, 1994) indicates that the Cuban SPG remnants were at Southern Boreal paleolatitudes. (*31*) Northern Tethyan paleolatitudes indicated by same association as in (*30*), but with common to abundant calpionellids (Myczyński and Pszczółkowski, 1994).

Litho Unit		Description	Age	Diagnostic Faunal Elements	Paleobathymetry	Faunal Realm/Province
Chapulhuacan Limestone		Medium to massive bedded light gray to tan, very aphanitic micrite with abundant calpionellids, common Radiolaria, and rare ammonites. Some horizons with phosphate nodules.	Berriasian	Abundant calpionellids (1)	Upper Abyssal	N. Tethyan Province
La Caja Formation	"Cerro Panteon quarry unit 2 member"	Red, pink, and pinkish gray limestone, calcareous siltstone (wacke), and calceous mudstone with common ammonites, common belemnites, *Buchia*, common Radiolaria, and abundant calpionellids. Thickness = 6 to 77 m.	late Tithonian	*Durangites, Substeueroceras*, belemnites, *Buchia piochii* + abundant calpionellids, abundant Radiolaria (Subzone 4α).		Southern Boreal Province
	"upper shale member"	Dark gray siliceous mudstone minor thin-bedded, dark gray micrite and dark gray micrite nodules. Rare ammonites. *Buchia rugosa & B. mosquensis.* Common calpionellids. Thickness = 36 m.	late Tithonian	*Durangites* + *Buchia rugosa, B. mosquenfsis* + Subzone 4α Radiolaria		
	"chert member"	Dark gray siliceous mudstone interbedded with black, thin-bedded radiolarian chert and minor dark gray micrite. Common ammonites & *Buchia* + abundant Radiolaria. Common calpionellids Thickness = ~316 m.	late early Tithonian to late Tithonian	*Buchia rugosa, B. mosquensis* + *Kossmatia, Durangites* + Subzone 4β Radiolaria. *See* Meng (1997).		
	"lower shale member"	Dark gray siliceous to calcareous mudstone with common dark gray micrite nodules throughout. Lenticular masses of thin-bedded, dark gray micrite present locally. Micrite nodules and bedded limestone with abundant Radiolaria, rare to common ammonites and *Buchia.* Rests unconformably on Oxfordian strata below. Thickness = 52 m (minimum).	early Kimmeridgian to early late Kimmeridigan	*Buchia concentrica, B. rogusa, & B. mosquensis* in same bed with *Glochiceras* gp. *fialar sensu Burckhardt* *Idoceras* spp. Subzone 2α1 Radiolaria		
unnamed red siltstone, limestone, and shale		Interbedded red sility limestone, silty mudstone, and siltstone containing *Buchia* and common ammonites. Radiolaria first occurring in upper part. Thickness = 21.2 m.	middle Oxfordian to late Oxfordian	*Discospinctes* *Buchia concentrica* *Dichotomosphinctes*	Outer Neritic	
"upper quartzite unit"		Massively bedded white to red sandstone. Cross-beds and symmetrical ripple marks. *See* Martin (1996). Paleomagnetic data = 40°N/S Thickness = 3.3 m.	middle Oxfordian or older	No fossils	Inner Neritic	
Zuloaga Limestone		Massively bedded micritic limestone with nodules of black chert.		*Nerinea*, bivalves, corals, and sponge spicules *See* Burckhardt (1910, 1930)		
"lower quartzite unit"		Massively bedded red and white fine grained sandstone. Base not exposed.		No fossils		

Fig. 12. Stratigraphic summary for SPG remnant.

(2) *'Chert member'*. This unit includes ~316 m of early to late Tithonian dark-gray siliceous mudstone interbedded with thin-bedded, black radiolarian chert, and minor dark-gray micrite which rest unconformably on the underlying 'shale member' (Web Fig. 5.4). Occasional thin-layers of quartz-rich silty wacke often display graded bedding and may possibly represent turbidites. This unit contains common ammonites, abundant radiolarians, abundant siliceous sponge spicules, common calpionellids, and common *Buchia* (Fig. 1).

(3) *'Upper shale member' (= top of Burckhardt's 'Capas de San Pedro').* The 'upper shale member' consists of 36 m of dark-gray siliceous mudstone and minor amounts of thin-bedded dark-gray micrite. The mudstone contains common micrite limestone nodules. Abundant radiolarians and rare ammonites occur in the siliceous mudstone and in the micrite. Rare ammonites, *Buchia,* and abundant calpionellids occur in the micrite beds and nodules. The late Tithonian strata of the 'upper shale member' rest conformably above the 'chert member' and below 'Cerro Panteon quarry unit 2' (Figs. 9, 11 and 12).

(4) *'Cerro Panteon quarry unit 2' member.* This member of the La Caja Formation at San Pedro del Gallo consists of 6 to 77 m of red, pink, and pinkish-gray micritic limestone, calcareous siltstone, and calcareous mudstone with common ammonites, belemnites, calpionellids, and radiolarians (reddish color probably result of hydrothermal alteration by Tertiary intrusives) (Web Fig. 5.5). At La Peña, 10 km to the north of San Pedro del Gallo, the senior author observed 92 m of interbedded black siliceous shale, thin-bedded siltstone (wacke), and thin-bedded dark gray micrite containing belemnites, abundant radiolarians, *Buchia,* and common ammonites. Abundant calpionellids were reported from this unit by Adatte et al. (1995). Contreras-Montero et al. (1988) recorded abundant ammonites, *Buchia piochii* as well as abundant radiolarians and belemnites from this locality.

Imlay (1939) correlated strata assignable to 'Cerro Panteon quarry unit 2' and the Chapulhuacán Limestone (Figs. 9, 11 and 12) with the inner neritic Taraises Formation (type area = Sierra de Parras, Fig. 2: Loc. 17). Where the latter unit has been observed during the course of this study, it consists of rhythmically bedded chalky mudstone and interbedded medium-gray, medium-bedded micritic limestone. Whereas the Taraises Formation contains a poorly diversified foraminiferal assemblage, brachiopods, echinoids, and ammonites, the San Pedro units contain common ammonites and foraminifers as well as abundant radiolarians and calpionellids (see Fig. 10).

The Chapulhuacán Limestone (type area = Chapulhuacán, Hildago near Taman-Tamazunchale, San

Luis Potosi; Fig. 2: Loc. 3) consists of ~20 m of medium- to massively-bedded light-gray to tan very aphanitic micrite with abundant calpionellids, common radiolarians, and rare ammonites assignable to the Berriasian. Some horizons contain large phosphate nodules (12 cm).

The La Caja Formation as well as the Chapulhuacán Limestone contain abundant radiolarians and siliceous sponge spicules, rare benthonic foraminifers, and common ammonites (see Figs. 9, 11 and 12). Deposition took place at upper abyssal depths somewhat above the ACD (compensation level of aragonite) during early Kimmeridgian to Berriasian times and continued at these depths through the Late Cretaceous (see Burckhardt, 1930). The radiolarian cherts usually contain nearly 50% radiolarian tests. As a result, it is likely that they formed as radiolarian ooze.

The Oxfordian to upper Tithonian part of the succession is characterized by containing a mixture of Tethyan and Boreal ammonites (e.g., *Amoeboceras, Idoceras, Durangites*), common *Buchia* (e.g., *Buchia concentrica, B. mosquensis, B. rugosa*) as well as an abundance of *Parvicingula* and *Praeparvicingula* and rare pantanelliids among the radiolarians. The megafossil and radiolarian assemblage coupled with preliminary paleomagnetic data indicate that this terrane remnant originated at Southern Boreal paleolatitudes (~40°N: Ogg, in Pessagno et al., 1995) during the Oxfordian (see Figs. 4 and 5). The appearance of abundant calpionellids coupled with the presence of *Buchia* and the presence of common *Parvicingula* and *Praeparvicingula* in the 'Cerro Panteon quarry unit 2' member of the La Caja Formation demonstrate that the San Pedro del Gallo remnant had been transported to close to the boundary (~30°N) between the Northern Tethyan Province and the Southern Boreal Province by the latest Tithonian (Late Jurassic) (Figs. 4 and 5). The lack of Boreal elements such as *Buchia* in overlying Early Cretaceous strata may suggest transport of the San Pedro del Gallo remnant to the Northern Tethyan Province (>22° to <30°N) by the Berriasian. Based on Ogg's paleomagnetic data and the faunal data cited above, Meng (1997) estimated the rate of movement of the San Pedro del Gallo remnant along the Walper Megashear to be 4.9 cm/yr.

The Mazapil remnant

The Mazapil remnant of the SPG terrane was examined at Canyon San Matias in the Sierra Santa Rosa (Fig. 2: Loc. 5). As in the case of the San Pedro del Gallo remnant, the base of the succession at Canyon San Matias is not exposed (Figs. 9, 10 and 14). The oldest unit exposed at this locality is the Zuloaga Limestone (Unit H in Fig. 13). The Zuloaga consists of massive to medium-bedded, medium-gray micritic limestone strata with nodules of black chert (Web Fig. 5.4). Microfacies analysis of the Zuloaga at this locality indicates that the micrite contains encrusting coralline algae, nerineid gastropods, bivalves, foraminifera, and siliceous sponge spicules (Martin, 1996, p. 67). The faunal and floral data suggests that the Zuloaga Limestone at Canyon San Matias was deposited at inner neritic depths (<50 m). on a carbonate bank free of wave energy. The age of the Zuloaga, like the oldest beds at San Pedro del Gallo, can only be established as middle Oxfordian or older via the superposition of overlying strata (Units G and F) containing middle Oxfordian ammonites (Fig. 13).

Unnamed units G and F consists of pink, silty mudstone, micritic limestone, and siltstone rich in bivalves and with common ammonites. Common radiolarians are present in the upper part of Unit F. All of the Zuloaga Limestone, Unit G, and all but the upper part of Unit F were deposited at inner neritic depths. The sudden appearance of common radiolarians in the upper part of Unit F reflects a rapid change in paleobathymetry from inner neritic depths to outer neritic depths (~200 m) in the late Oxfordian (Web Figs. 5.6 and 5.7).

Units E, D, C, and B (lower Kimmeridgian to Berriasian) are included in the La Caja Formation of Imlay (1938, 1939); see Figs. 9, 11 and 13. All La Caja units at Canyon San Matias are characterized by the presence of common to abundant beds of thin-bedded black, radiolarian chert identical to that in the 'chert member' of Burckhardt's (1910) 'Capas de San Pedro' (Web Figs. 5.8 and 5.9). The chert is interbedded with thin- to medium-bedded, dark-gray micritic limestone and dark-gray siliceous to calcareous mudstone commonly containing dark-gray micritic limestone nodules. Unit D, as noted by Burckhardt (1930), is unique in that it is characterized by the presence of beds of phosphate and phosphatic limestone. All La Caja strata are characterized by containing a microfauna with abundant radiolarians, abundant siliceous sponge spicules, and rare benthonic foraminifera and a megafossil assemblage with common to abundant ammonites. Deposition of La Caja strata at this locality during the Late Jurassic and Early Cretaceous (Berriasian) occurred at upper abyssal depths, or perhaps lower bathyal depths, above the ACD (compensation level of aragonite) and continued at these depths until the end of the Cretaceous (see Burckhardt, 1930). Radiolarian chert formed consists of about 50% by volume of radiolarian tests and test fragments; hence, it is likely that it formed as a radiolarian ooze. The phosphate horizon occurring in Unit D is puzzling. Frequently, phosphate-rich sediments occur today along coast lines with narrow continental shelves

Litho Unit		Description	Age	Diagnostic Faunal Elements	Paleobathymetry	Faunal Realm/Province
Unnamed limestone Unit (1)		Medium bedded buff calcareous mudstone and micritic limestone. Micrite with common limonite nodules. Thickness (fide Burckhardt, 1930+ 50-70 m.	Valanginian	*Thurmannites* spp., *Asteria* aff. *psilostoma* *fide* Burckhardt (1930).	Upper Abyssal	Northern Tethyan Province
Chapulhuacan Limestone "UNIT A"		Massively bedded, very fine grained micritic limestone weathering to cream or buff color. Calpionellids. Radiolaria. Sparse ammonites. Thickness (fide Burckhardt 1930) = 15 m.	Berriasian ?	Calpionellids calcified Radiolaria		
La Caja Formation	"UNIT B"	Upper 5.64 m consisting of medium-bedded light gray micrite and thin-beddded black chert. Remainder of unit consisting of thin-bedded, buff-weathering calcareous siltstone and black chert (2). Abundant Radiolaria and ammonites. Thickness = 23.5 m	late Tithonian. upper part may be Berriasian	*Substeueosceras* spp. *Paradontoceras* aff. *callistoides*, *Durangites* sp.		
	"UNIT C"	Medium-bedded to thick-bedded (0.9--1.2 m) micrite, thin to medium-bedded black chert, and minor siltstone Abundant Radiolaria and ammonites. Thickness = 21.1 m.	late Tithonian	*Kossmatia* spp. Boundary between Subzone 4β and 4α in upper part of Unit B.		
	"UNIT D"	Interbedded phosphatic limestone, black chert and red calcareous mudstone. Abundant Radiolaria and ammonites. Thickness = 13.3 m	late Tithonian	*Hybonoticeras* spp., *Kossmatia* spp. +Subzone 4β Radiolaria.		
	"UNIT E"	Thin-bedded black chert, dark gray, siliceous mudstone often with interbedded limestone nodules (up to ~ 4 m in maximum dimension). Red calcareous mudstone in upper part. Some mudstone beds up to 0.6 m in lower part. Abundant Radiolaria in all lithofacies. Abundant ammonites. Thickness = 27.9 m.	early late Kimmeridgian + hiatus early to late Tithonian	*Idoceras* spp, *Glochiceras* grp. *fialar*, *Buchia concentrica*, *Hyboniticeras*, and Zone 2α1, Zone 3, and Zone 4, Subzone 4β Radiolaria.		Northern Tethyan Province (upper part); Southern Boreal Province (lower part)
"UNIT F"		Red silty calcareous mudstone with 1.5 m dark gray micrite nodules in upper part. Common ammonites, bivalves. Common Radiolaria at top. Thickness = 7.8 m	late early Kimmeridgian at top	*Idoceras* spp. at top of "UNIT F"	Outer Neritic	Southern Boreal Province
"UNIT G"		Red medium-bedded silty limestone and mudstone. Thickness = 6.6 m	middle Oxfordian	*Dichotomosphinctes*	Inner Neritic	
"UNIT H" Zuloaga Limestone		Massively bedded micritic limestone with nodules of black chert. Base not exposed.	middle Oxfordian or older	*Nerinea*, bivalves, corals, and sponge spicules *See* Burckhardt (1910, 1930)		

Fig. 13. Stratigraphic summary for Mazapil remnant.

and steep continental slopes at sites of upwelling of nutrient-rich waters. Whether this scenario could exist in the distal backarc setting characterizing all San Pedro del Gallo remnants is questionable. Phosphatic limestones and shales were recorded by Burckhardt (1930) in the Sierra Santa Rosa, Sierra de la Caja, and Sierra de Zuloaga (Fig. 2.: Locs. 5, 6, 8). They are not known from San Pedro del Gallo, Sierra Catorce, the Huayacocotla Anticlinorium, or from western Cuba (Fig. 2: Locs. 3, 4, 12, 24). An alternative to the upwelling model may be a large kill of fish and other organisms by a red tide, producing an abundance of phosphatized bones and other material at lower bathyal or upper abyssal depths.

The upper Oxfordian to lower upper Tithonian part of the La Caja Unit E (Fig. 7) contains *Buchia*, Tethyan ammonites, abundant *Parvicingula/Praeparvicingula*, and poorly diversified pantanelliids indicative of Southern Boreal paleolatitudes. The remainder of Unit E and all of Units D, C, B, and A are assignable to the Northern Tethyan Province based on the presence of abundant, diversified pantanelliids, abundant to common *Parvicingula/Praeparvicingula*, and the presence of calpionellids (Units A and B, Fig. 5). These data indicate that the Mazapil remnant of the SPG terrane has been transported from Southern Boreal paleolatitudes (>30°N) to Northern Tethyan paleolatitudes (<30°N to >22°N) during the early Kimmeridgian to late Tithonian interval. It should be noted that Ogg's preliminary paleomagnetic data for the late Tithonian indicate 25°N/S.

Sierra de Catorce remnant (Fig. 2: Loc. 4; Figs. 9, 11, 14)

Erben (1956, p. 46), Carrillo-Bravo (1961, p. 42), and Imlay (1980) noted the presence of red phylitic shale with Sinemurian ammonites in the Sierra de Catorce. These strata are the chronostratigraphic equivalent (part) of the Huayacocotla Formation of east-central Mexico.

The Upper Jurassic succession at the Sierra de Catorce is much like that of other remnants in terms of its lithostratigraphic and paleobathymetric signatures. The Sierra de Catorce succession begins with the massively bedded, micritic, inner neritic Zuloaga Limestone which is identical to that at San Pedro del Gallo and at Mazapil (Web Fig. 5.10). Verma and Westermann (1973) divided the La Caja Formation in the Sierra de Catorce into two members: a lower El Pastor Member and upper El Verde Member. The El Pastor Member consists of massively bedded dark- to medium-gray micritic limestone with interbedded black chert, siltstone, sandstone, and shale. The El Verde Member includes thin-bedded micritic lime-

Litho Unit		Description	Age	Diagnostic Faunal Elements	Paleobathymetry	Faunal Realm/Pr vince
unnamed limestone unit		Light gray, massively bedded micrite with yellow, oval chert concretions. Correlated incorrectly by Verma and Westermann (1973) and Imlay (1980) with the La Taraises Formation which has its type area in Sierra de La Parra. Probably the Chapulhuacan Limestone. Thickness is unknown.	Valanginian Berriasian?	*Olcostephanus* spp.	Upper Abyssal	Northern Tethyan Province
La Caja Formation	El Verde Member	Thin-bedded medium gray micrite, black chert, light gray siltstone and sandstone . Chert and micrite with abundant Radiolaria. Siltstone and sandstone are carbonate wacke (turbidite) frequently showing graded bedding with grading of molluscan fragments. Chert and micrite with abundant Radiolaria. Abundant ammonites occur in micrite. Thickness = ~ 25 m.	late Tithonian	*Kossmatia* spp, *Durangites* spp. *Corongoceras* spp, *Substeueroceras* spp., *Berriasella* spp.		
	El Pastor Member	Massively bedded medium to dark gray micrite interbedded with thin-bedded black radiolarian chert and siltstone or sandstone. Siltstone and sandstone representing carbonate wacke occurs in layers up to 0.4 m thick and shows grading of molluscan fragments. Massive micrite beds averaging about 0.8 . Closely resemble micrites of "lower massively bedded limestone member" of the Taman Formation in Huayacocotla remnant. Micrite and black chert with abundant Radiolaria. Micrite with abundant ammonites. *Buchia* noted by Burckhardt (1930). Thickness = ~ 28 m.	late early Kimmeridgian to early Tithonian; late Kimmeridgian is missing; early Tithonian strata assumedly overlie early Kimmeridgian strata unconformably	Mazapilites mexicanus, Pseudolissoceras zitteli Abundant Radiolaria *Idoceras* spp, in lower part together with *Buchia concentrica*		Southern Boreal Province
Zuloaga Limestone		Massively bedded micritic limestone with nodules of black chert.. According to Imlay (1980, p. 45) Zuloaga rests unconformably on the continental red beds of the Cahuasas Formation. Thickness = 200 m *fide* Verman and Westermann (1973).	middle Oxfordian or older	*Nerinea*, bivalves, corals, and sponge spicules *See* Burckhardt (1910, 1930)	Inner Neritic	
Cahuasas Formation		Continental red beds. Red shale, sandstone, and siltstone. Congomerate at base. Overlies Lower Jurassic (Sinemurian) strata of Huayacocotla Group. The latter unit contains Sinemurian ammonites. This unit was assigned to the La Joya Formation by Imlay. However, because it overlies the Huayacocotla Group, it is assigned here to the Cahuasas. *See* Figure 13. Thickness = 120 to 160 m.	Probably Bathonian to Bajocian based on age in Huayacocotla remnant.	Unfossiliferous	NON MARINE	

Fig. 14. Stratigraphic summary for Sierra Catorce remnant.

stone, black thin-bedded radiolarian chert, thin-bedded siltstone and sandstone, and shale. The siltstone and sandstone in both members often display graded bedding with graded molluscan fragments and are interpreted as turbidites (Web Figs. 5.10 and 5.11). These strata were deposited at upper abyssal depths rather than inner neritic depths as incorrectly suggested by Verma and Westermann (1973) and Salvador et al. (1992). Most stratigraphers in the past have totally ignored the far more abundant microfauna. Because they failed to examine the rocks in thin-section, they reached erroneous conclusions concerning water depth.

Burckhardt (1930) recorded the presence of several species of *Buchia* from the Kimmeridgian portion of La Caja Formation at Sierra de Catorce. These Boreal bivalves are associated with Tethyan ammonites and *Parvicingula/Praeparvicingula* (thin-section analysis). Hence, we conclude that the Sierra de Catorce remnant was situated in the Southern Boreal Province during the Oxfordian to Kimmeridgian interval. Tithonian La Caja strata contain Tethyan ammonites, *Parvicingula/Praeparvicingula* and lack *Buchia*. Hence, during the Tithonian the Sierra de Catorce remnant was probably situated in the Northern Tethyan Province. Our investigations of the strata in this area are not, however, as complete as they are in the San Pedro del Gallo remnant, the Mazapil remnant, and the Huayacocotla remnant.

Huayacocotla remnant (Figs. 9, 11, 15)

The Mesozoic succession begins in this area with the deposition of the Lower Jurassic (Sinemurian to lower Pliensbachian) Huayacocotla Formation which consists of black shale, mudstone, and graywacke. A rich ammonite assemblage occurs in the lower and middle parts of the unit (Burckhardt, 1930; Erben, 1956; Imlay, 1980). Bivalves and land plants have been recorded from the upper part.

The Huayacocotla Formation overlies the Mississippian to Lower Permian strata of the Guacamaya Formation with marked hiatus associated with an angular unconformity. According to Nestell (1979) the Guacamaya Formation contains fusulinids with South American affinities. This likewise seems to be true of fusulinids occurring in the Guacamaya Formation at Peregrina Canyon near Ciudad Victoria (Tamps.). The thickness of the unit varies from 560 to 1200 m.

As far as can be determined, references to the presence of the Upper Triassic Huizachal Formation (continental red beds) in this area are erroneous. The Huizachal has largely been confused with the Middle Jurassic Cahuasas Formation which also consists of continental red beds (cf. Imlay, 1980).

Litho Unit	Description	Age	Diagnostic Faunal Elements	Paleobathymetry	Faunal Realm/Pr vince
Chapulhuacan Limestone	Medium to massively bedded very fine-grained cream to light gray micrite with abundant Radiolaria, calpionellids, and rare ammonites. Micrite with black chert nodules and lenses. Thickness = ~ 30 m.	Berriasian to Valanginian.	*Subthurmannia* sp. *Neolissoceras* sp. *Spiticeras* sp. *Thurmanniceras* sp.	Upper Abyssal	Central Tethyan Province
Pimienta Formation	Thin-bedded cream colored to light gray micrite interbedded with dark gray shale, common black radiolarian chert, and light green vitric tuff. Micrite with abundant Radiolaria and calpionellids together with rare ammonites and common sponge spicules. Thickness = ~ 200 m.	late Tithonian	*Paradontoceras* aff. *callistoides* *Durangites*, *Substeueroceras* + Subzone 4α Radiolaria at some localities to south		
Taman Formation T = 200-500 m. "upper thin-bedded limestone member"	Thin-bedded dark gray to medium gray micrite with thick interbedds of dark to medium gray shale. Shale layers with abundant micrite nodules. Micrite nodules and beds with abundant Subzone 4β Radiolaria siliceous sponge spicules and commonammonites.	late Tithonian	*Durangites*, *Kossmatia*, *Salinites grossicostatum* + very abundant Subzone 4β Radiolaria.		Northern Tethyan Province
Taman Formation "lower massively bedded limestone member"	Massively bedded dark gray to medium gray micrite interbedded with thin-bedded to medium bedded shale. Upper part of unit with numerous dark gray micrite nodules. Massive micrites and micrite nodules with abundant Radiolaria rare to common ammonites and common pectenacids (*Aulacomyella*). Hyaline calpionellids occur in basal Zone 4, Subzone 4β strata at same horizon as lower Tithonian ammonite *Mazapilites*.	early Kimmeridgian to early Tithonian	*Ataxicoceras*, *Idoceras*, "*Glochiceras fialar*" *Mazapilites*, *Virgatosphinctes* + Radiolaria assignable to Subzone 2α1, Zone 3, & Subzone 4β.		
Santiago Formation	Silty black shale, mudstone, micrte. Containing ammonites. Radiolaria occurring in upper-most part. Thickness = ~169 m.	early Callovian to late Oxfordian	*Reineckeia*, *Dichotomosphinctes*, *Discosphinctes*, *Ochetoceras*.	Outer Neritic / Inner Neritic	Southern Boreal Province
Tepexic Limestone	Calcarenite containing ammonites and bivalves. Thicknes = ~ 39 m.	late early Callovian	*Reineckeia* *Neuqueniceras*		
Cahuasas Formation	Continental red beds. Dominantly red shale, siltstone, sandstone, and conglomerate. Commonly cross-bedded. Overlies Lower Jurassic (Sinemurian) strata of Huayacocotla Group. The latter unit contains Sinemurian ammonites. Thickness = 40-1200 m. (1)	Bathonian to Bajocian.	Fossil plants.	NON MARINE	

Fig. 15. Stratigraphic summary for Huayacoccotla remnant.

The Cahuasas Formation consists of 40 to 1200 m of red arkosic sandstone, conglomerate, and shale that rest with angular unconformity on the Huayacocotla Formation (Imlay, 1980, p. 49). Imlay indicates that the Cahuasas must be older than Callovian because where it crops out on the surface it lies disconformably below marine beds of early to middle Callovian age. In the subsurface, however, it underlies latest Bathonian to early Callovian marine shale of the Palo Blanco Formation (see Palo Blanco below). Imlay also indicates that the Cahuasas must be younger than Toarcian (Early Jurassic) in that it passes downward into plant-bearing beds which are early Middle Jurassic.

The Cahuasas Formation is overlain disconformably in surface outcrops by the inner neritic early Callovian Tepexic Limestone. The Tepexic is a calcarenite containing common to abundant *Liogryphaea nebrascaensis* and ammonites such as *Neuquenisceras neogaeum* and *Reineckeia* (Cantú-Chapa, 1969, p. 19; Imlay, 1980, p. 50). In the subsurface and at some surface localities a inner neritic black shale unit, the Palo Blanco Formation (Cantú-Chapa, 1969, p. 5; Imlay, 1980, p. 49), underlies the Tepexic Limestone and rests disconformably on the Cahuasas. The Palo Blanco Formation contains the late Bathonian to early Callovian ammonite *Kepplerites* (Cantú-Chapa, 1969, p. 5; Imlay, 1980).

The Tepexic Limestone is overlain conformably by silty black shale, siltstone, and silty micritic limestone constituting the Santiago Formation (middle Callovian to upper Oxfordian). The lower and middle parts of the Santiago contain bivalves (e.g., small Ostrea, senior author's observations) and ammonites; microfacies analysis by Longoria (1984) indicates that most of this unit was deposited at inner neritic depths. The uppermost (upper Oxfordian) part of the Santiago Formation (e.g., at Taman, S.L.P.) contains common radiolarians as well as ammonites (Pessagno et al., 1987). These Santiago strata reflect the same sudden change in water depths from inner neritic to outermost neritic during the late Oxfordian that was noted in the San Pedro del Gallo and Mazapil remnants. The Santiago Formation is overlain conformably by the Taman Formation (sensu Pessagno et al., 1984, 1987).

The Taman Formation (thickness about 30–60 m) consists of two informal units (Web Figs. 5.12 and 5.13): (1) a massively bedded to medium-bedded micritic limestone member (lower Kimmeridgian to upper Tithonian), and (2) a thin-bedded micritic limestone member (upper Tithonian) (Pessagno et al., 1984, 1987). Both members of the Taman Formation contain profusely abundant radiolarians, rare foraminifera (chiefly Textulariina), common siliceous sponge spicules, ammonite aptychi, and occasional ammonites. The abundance of radiolarians together with the sparse benthonic foraminiferal assemblage and the rarity of ammonites suggests that Taman strata were deposited at upper abyssal depths at or somewhat below the ACD (aragonite compensation level) (see microfacies analysis in Longoria, 1984).

The Taman is overlain conformably by the latest Tithonian (Late Jurassic) to Berriasian (Early Cretaceous) Pimienta Formation (sensu Pessagno et al., 1984, 1987) and overlain conformably by the Chapulhuacán Limestone Berriasian to Valanginian). The Pimienta Formation includes 200–400 m of light-gray thin-bedded micritic limestone with thick shale intervals, thin-bedded black radiolarian chert, and light green vitric tuff; it contains abundant radiolarians, calpionellids, siliceous sponge spicules, and common ammonites (Fig. 10). Pimienta deposition likewise took place at upper abyssal depths somewhat above the ACD (compensation level of aragonite).

The Chapulhuacán Limestones consists of about 30% of medium to massively bedded, very fine-grained, cream to light-gray micrite with abundant radiolarians, calpionellids, nannoconids, and planktonic foraminifera, and rare ammonites at most localities (senior author's observations and those of Longoria, 1984, p. 69); Chapulhuacán strata were also deposited at upper abyssal depths somewhat above the ACD. Deposition continued at these depths during the remainder of the Cretaceous.

The upper Bathonian (Middle Jurassic) to upper Oxfordian (Upper Jurassic) part of the succession contains Boreal megafossils such as the ammonite *Kepplerites* in the Palo Blanco Formation (Cantú-Chapa, 1969, p. 5; Imlay, 1980, p. 50). Elsewhere in western North America this ammonite is known from Middle Jurassic strata in the Sierra Nevada, from the upper Bathonian part of the Snowshoe Formation, Izee terrane (east-central Oregon), and from Boreal Middle Jurassic strata as far north as Alaska (Imlay, 1980; Pessagno and Blome, 1986; Pessagno et al., 1986, 1987).

The lower Kimmeridgian to upper Tithonian (Upper Jurassic) part of the succession (Taman Formation sensu Pessagno et al., 1984, 1987) contains a rich Northern Tethyan radiolarian assemblage characterized by the abundance and diversity of pantanelliids and by the presence of common to abundant *Parvicingula* and *Praeparvicingula*. Calpionellids (Tethyan) occur in the upper Tithonian part of the Taman Formation. Moreover, the megafossil assemblage is Tethyan in aspect (Figs. 4 and 5) (see Imlay, 1980; Cantú-Chapa, 1989). The Pimienta Formation as well as the overlying Chapulhuacán Limestone is characterized by a Tethyan ammonite assemblage and by a microfossil assemblage including abundant calpionellids and nannoconids lacking *Parvicingula*/*Praeparvicingula*. This association of faunal elements is indicative of the Central Tethyan Provinces (Figs. 4 and 5).

These data indicate that the Huayacocotla remnant of the SPG terrane underwent tectonic transport from Southern Boreal paleolatitudes (>30°N) during the late Bathonian (Middle Jurassic) to Northern Tethyan paleolatitudes by the early Kimmeridgian (Late Jurassic) to Central Tethyan paleolatitudes (<22°N) during the Berriasian (Early Cretaceous).

Remnants of the San Pedro del Gallo terrane in western Cuba (Figs. 9, 11, 16)

Remnants of the SPG terrane in western Cuba crop out in the Sierra del Rosario and the Sierra de los Organos (Figs. 9, 11, 16 and 17). Our data are derived from field observations by Longoria and by examination of Jurassic rocks from western Cuba by Pessagno in the collections of the U.S. Geological Survey. Moreover, they are derived from data presented by Brönnimann (1954), Arkell (1956), Meyerhoff (1964), Khudoley and Meyerhoff (1971), Kutek et al. (1976), Imlay (1980), Myczyński (1989, 1994), Lewis and Draper (1990), Myczyński and Pszczółkowski (1976, 1994).

The Sierra del Rosario remnant

The succession in the Sierra del Rosario begins with the Middle Jurassic (Bajocian?) to Upper Jurassic (middle Oxfordian) San Cayetano Formation. The San Cayetano Formation includes 1500 to 3000 m of reddish weathering carbonaceous shale, white to grayish quartzose siltstones and sandstones, mica-rich gray shales, and friable arkoses (see Lewis and Draper, 1990 and Haczewski, 1976). Imlay (1980, p. 39) indicates that its upper part contains marine bivalves of probable Middle Jurassic age. The San Cayetano is the lithic equivalent of the Cahuasas Formation in the Huayacocotla remnant of the SPG terrane in east-central Mexico. Most of the San Cayetano except for its upper 609 m appears to be non-marine. The upper 609 m of the San Cayetano contains bivalves like *Ostrea* and *Vaugonia* which are interpreted herein as being inner neritic.

The overlying Francisco Formation includes 13 to 25 m of shale, limestone, and some sandstone with middle to early late Oxfordian ammonites such as *Discosphinctes* and *Dichotomosphinctes*. These strata are interpreted herein as being neritic. Whether these late Oxfordian strata contain radiolarians as do coeval strata in the Mexican remnants of the San Pedro del Gallo terrane cannot be established at present. The Francisco Formation is overlain conformably by the late Oxfordian to

Litho Unit		Description	Age	Diagnostic Faunal Elements	Paleobathymetry	Faunal Realm/Province
Artemisia Formation (part)	Sumidiro Member	Thin-bedded black micrite and black radiolarian chert.	Berriasian to Valanginian	*Leptoceras* *Protancyloceras* *Olcostephanus* *Buchia*	Upper Abyssal	Northern Tethyan Province
	La Zarga Member	Thin-bndded dark gray to black micritic limestone with thin interbeds of shales, siltstones, and sandstones. Abdundant Radiolaria and ammonites. Thickness = 40 m.	early Tithonian to Berriasian	*Peeddolissoceras zitteli* *Virgatosphinctes* *Corongoceras sp.* *Salinites* *Durangites* *Microacanthoceras* *Paradontoceras* *Buchia* Calpionellids (1) Radiolaria		Southern Boreal Province
Francisco Formation		Shale, limestone and sandstone with ammonites. Thickness = 13 -- 25 m.	early to late Oxfordian	*Dichotomosphinctes* + *Discosphinctes*	Neritic. Proably mostly inner neritic.	
San Cayetano Formation (part)		Reddish weathering carbonaceous shale, white to grayish quartzone siltstone and sandstone, mica-rich shale, and friable quartzite. Upper 609 m with marine bivalves (e.g., *Ostrea*). *See* Lewis and Draper (1990). Thickness =1500 -- 3000 m.	miildle Oxfordian to Bajocian	None	All but upper 609 m consisting of continental red beds. Upper 609 m inner neritic.	

Fig. 16. Stratigraphic summary for Sierra de Rosario, Cuba.

Litho Unit		Description	Age	Diagnostic Faunal Elements	Paleobathymetry	Faunal Realm/Province
Guasasa Formation (part)	Tumbitas Member	Light gray, thin-bedded limestone with intercalations of dark gray chert.	Valanginian	Ammonites poorly preserved. Abudant calpionellids + Radiolaria	Upper Abyssal	Northern Tethyan Province
	Tumbadero Member	Dark gray, laminated, medium-bedded with thin intercalations of shale, chert, and numerous dark gray chert nodules. Thickness = ~ 15 m.	Berriasian			
	El Americano Member	Hard , compact dark gary to black micritic, thin to thick-bedded micrititc limestone . Abundant Radiolaria throughout. Abundant calpionellids in upper lower Tithonian and upper Tithonian. Abundant ammonites. This unit includes the Viñales Limestone of older literature. Thickness = 300-400 m.	early to late Tithonian	*Mazapilites* *Hyboniticeras* *Salinites grossicostatum* *Durangites* *Kossmatia* *Buchia*		Southern Boreal Province
	S. Vicente Member	Dark gray to black mostly massively bedded micrite with some lenses and concretions of chert. Poorly fossiliferous.	Poorly dated. Possibly Kimmeridigian.	None	Inner Neritic (2)	
Jagua Formation		Divided into 3 members (ascending order):1] Azucar Membv (48-76 m): Gray to black, thinibedded micritic limestone loally sandy & oolitic (Hatten, 1967, p. 782); 2] Jagua Vieja Member (50-60 m): dark gray silty to sandy shale, mudstone, and limestone with many limestone nodules; 3] Pimienta Member (40-60 m): Gray dense, platey limestone. Overlies San Cayetanof Formation unconformably (*See* Figure 9).	early to late Oxfordian	*Dichotomosphinctes* + *Discosphinctes* (1)	Mostly inner neritic.	
San Cayetano Formation (part)		Reddish weathering carbonaceous shale, white to grayish quartzone siltstone and sandstone, mica-rich shale, and friable quartzite. Upper 609 m with marine bivalves (e.g., *Ostrea*). *See* Lewis and Draper (1990). Thickness =1500 -- 3000 m.	miildle Oxfordian to Bajocian	None	All but upper 609 m consisting of continental red beds. Upper 609 m inner neritic.	

Fig. 17. Stratigraphic summary for S. de los Organos, Cuba.

Valanginian Artemisa Formation. The Artemisa Formation as a whole consists of dark-gray, mostly thin to medium-bedded, dense cherty limestone, and tuffaceous shale (Imlay, 1980, p. 39). Pszczółkowski (1978) divided the formation into three members; they are in ascending order: (1) the San Vicente Member (upper Oxfordian–Kimmeridgian; (2) the La Zarza Member (Tithonian); and (3) the Sumidero Member (Berriasian to Valanginian). The San Vincente Member consists of massive inner neritic limestone probably formed as a bank deposit (Myczyński, 1994). The massive limestone strata are apparently localized in their distribution and may be analogous to those of the San Andres Limestone of the Huayacocotla remnant (SPG) in east-central Mexico (see Cantú-Chapa, 1969). The Zarza Member in the southern part of the Sierra del Rosario includes about 40 m of thin-bedded black to dark-gray micritic limestone with thin interbeds of shale, siltstone, and sandstone (see Myczyński and Pszczółkowski, 1994). These strata include black ammonite-bearing limestones, aptychi, and ammonite shell coquina in the upper part of the member. The Zarza Member grades up into the overlying Sumidero Member. The Sumidero Member includes 'ammonite-free' black, thin-bedded micrite with interbedded radiolarian chert. Examination of limestones from the Tithonian and Berriasian parts of the Artemisa Formation in Mesozoic USGS collections from Cuba indicate that many of these rocks contain abundant radiolarians. This observation was also confirmed by Myczyński and Pszczółkowski (1994, p. 11, fig. 3). The presence of radiolarians as well as calpionellids in the La Zarza Member indicates that deposition occurred at bathyal to upper abyssal depths above the ACD (compensation level of aragonite). The absence of the ammonites in the Sumidero Member coupled with the presence of abundant radiolarian chert suggests that deposition during the early Berriasian (Early Cretaceous) was at upper abyssal depths below the ACD (compensation level of aragonite).

For the most part the Upper Jurassic faunal assemblage of the Artemisa Formation includes Tethyan ammonites and calpionellids. However, species of the Boreal bivalve *Buchia* are present throughout the Tithonian (Upper Jurassic) to Valanginian (Lower Cretaceous) interval. *Praeparvicingula/Parvicingula* was observed by Pessagno in micritic limestones from the Mesozoic collections of the USGS formerly housed at the US National Museum. The composite faunal data suggest that the Sierra del Rosario remnant of the SPG terrane remained near the boundary between the Northern Tethyan Province and Southern Boreal Province during the Late Jurassic and Sierra de los Organos remnant (Figs. 9, 11 and 17)

As in the case of the Sierra del Rosario remnant the succession begins in the Sierra de los Organos with the deposition of the Middle Jurassic (Bajocian?) to Upper Jurassic San Cayetano Formation (see description above). The San Cayetano Formation in the Sierra de los Organos is overlain by the Jagua Formation (Hatten, 1967; Wierzbowski, 1976). The Jagua Formation is divided locally into three members: (1) a lower Azucar Member; (2) a middle Jagua Vieja Member; and an upper Pimienta Member. The Azucar Member (48 to 76 m) consists of gray to black, thin-bedded micritic limestone that is in some places oolitic and sandy (Hatten, 1967, p. 782). The Jagua Vieja Member (50 to 60 m) consists of dark-gray silty to sandy shale, marl, and limestone and contains many limestone nodules in the shale beds. The upper Pimienta Member (40–60 m) consists of gray, dense platy thin-bedded limestone. Imlay (1980), p. 39) indicates that ammonites from the Azucar Member are of middle or late Oxfordian age. The Jagua Formation appears to be lithic equivalent of the Santiago Formation in the Huayacocotla remnant (SPG).

The remainder of the Jurassic succession (Kimmeridgian to upper Tithonian) above the Jacaguas Formation in the Sierra de los Organos is included in the Guasasa Formation (Herrera, 1961; Kutek et al., 1976; Wierzbowski, 1976; Imlay, 1980). The Guasasa Formation in the more recent literature includes the Viñales Limestone of the older literature. The Jurassic part of the Guasasa includes two members: (1) a lower San Vicente Member (1000 m) consisting of dark-gray to black, mostly massively bedded micrite with some lenses and concretions of chert, and (2) an upper El Americano Member (300–400 m) consisting of hard, compact gray to black micritic, highly fossiliferous thin- to thick-bedded limestone. The presence of common to abundant radiolarians in the El Americano Member in association with ammonites and calpionellids suggests that these strata were deposited at upper abyssal to bathyal depths above the ACD (compensation level of aragonite). The Lower Cretaceous part of the Guasasa Formation includes three members: the Tumbadero Member (Berriasian), the Valanginian Tumbitas Member, and the Albian–Aptian Infierno Member (cf. Myczyński, 1989). The Tumbadero Member consists of 15 m of dark and dark-gray, laminated medium-bedded limestone with thin intercalations of shale, chert, and numerous dark-gray chert nodules. The Tumbitas Member contains about 50 m of light gray, thin-bedded limestone with intercalations of dark-gray chert. The uppermost member, the Infierno Member, consists of about 50 m of dark-gray micritic limestone interlayered with lighter-colored micritic limestone and dark-gray chert. The occurrence of radiolarians as well as calpionellids in the Tumbadero and Tumbitas members coupled with the absence of ammonites suggests that these strata were deposited below the ACD (compensation level of aragonite) at upper abyssal depths.

The presence of Tethyan ammonites together with calpionellids, *Parvicingula/Praeparvicingula*, and *Buchia* (Myczyński, 1994) in the Upper Jurassic Tithonian part of the Guasasa Formation indicate a paleolatitudinal position close to the boundary between the Northern Tethyan Province and Southern Boreal Province (~30°N). It should be noted that *Buchia* is unknown from the North Atlantic Province except for occurrences in Greenland. Elsewhere it is known from Jurassic and Lower Cretaceous strata from Baja California Sur to Alaska. Hence, its occurrence in the Jurassic of western Cuba is entirely anomalous.

Origin of San Pedro del Gallo terrane (= Guaniguanico terrane) in western Cuba

In Chapter 4, Pszczółkowski includes what we refer to as remnants of the 'San Pedro del Gallo terrane' in the 'Guaniguanico terrane' of Iturralde-Vinent (1994, 1996). We treat the Guaniguanico terrane as a junior synonym of the San Pedro del Gallo terrane (Pessagno et al., 1993b) herein.

Pszczółkowski followed Iturralde-Vinent (1994, 1996) in suggesting that the Guaniguanico terrane (= San Pedro del Gallo terrane) was situated along the eastern margin of the Yucatán platform. He admits, however, that the original position of the Guaniguanico terrane is difficult to establish with any degree of certainty during the Jurassic and Cretaceous. In this report we advocate a similar origin for the Guaniguanico terrane as that advocated by Iturralde-Vinent (1994, 1996). As can be seen from the examination of Figs. 2, 3 and 7, the Walper Megashear cuts the Yucatán Peninsula. Hence, there is a strong case for an eastern Yucatán origin for the Guaniguanico terrane as advocated by Iturralde-Vinent (1994, 1996). As noted, previously both the San Pedro del Gallo terrane and the Coahuiltecana terrane show similar paleobathymetric records and stratigraphic records by the Middle Cretaceous. We suggest that terrane amalgamation had occurred by the Middle Cretaceous and that all movement along the Walper Megashear had ceased. Subsequent southwest to northeast movement of the Caribbean Plate during the Late Cretaceous and Early Tertiary bulldozed the Cuban remnants of the San Pedro del Gallo terrane into their present position (see Montgomery et al., 1992, 1994a,b).

Jurassic and Early Cretaceous successions in western Cuba (Sierra del Rosario and Sierra de los Organos, Piñar del Río Province) show lithostratigraphic, paleobathymetric, and paleolatitudinal signatures which are nearly identical to those of San Pedro del Gallo terrane remnants in central Mexico (Figs. 9, 11, 16 and 17). Even the presence of the inner neritic 'San Vicente Member' (Guasasa Formation) has an analogue in the San Andres Limestone of the Huayacocotla remnant (Fig. 2: Loc. 3). This record, at least during the Jurassic and Early Cretaceous, is distinctly North American. Unconformities and hiatuses are regional in distribution and can be traced as far north as the California Coast Ranges and Klamath Mountains (see Fig. 11). Moreover, these unconformities reflect tectonic events that affect the Nevadian forearc, interarc, and backarc in western North America. Although a backarc origin is advocated for the pre-latest Tithonian (radiolarian Subzone 4 alpha: Fig. 9), such an origin is related to the Nevadian island arc and not the Antillean island arc. Once the Cuban San Pedro del Gallo remnants were carried northward by the advancing Caribbean Plate, it is likely that they became part of an Atlantic-type margin as suggested by Gordon et al. (1998).

ANALYSIS OF PREVIOUSLY DESCRIBED TERRANES IN MEXICO (SEE FIG. 7: INSET B): VALIDITY OF MAYA, GUACHICHIL, TEPEHUAÑO, AND COAHUILTECANO TERRANES OF SEDLOCK ET AL. (1993)

According to Howell et al. (1985, p. 4; see also Howell, 1995): "A tectonostratigraphic terrane is a fault-bounded package of rocks of regional extent characterized by a geologic history which differs from that of neighboring terranes. Terranes may be characterized internally by a distinctive stratigraphy, but in some cases a metamorphic or tectonic overprint is the most distinctive characteristic. In cases where juxtaposed terranes possess coeval strata, one must demonstrate different and unrelated geologic histories as well as the absence of intermediate lithofacies that might link the two terranes. In general, the basic characteristic of terranes is that the present spatial relations are not compatible with the inferred geologic histories."

The Mexican SPG terrane remnants occur within the Tepehuaño, Guachichil, and Maya terranes of Sedlock et al. (1993). It is clear that these terranes, as presently defined, are incompatible with the SPG terrane. The focus of Sedlock et al. (1993) in their definition of these terranes seems to have been mostly on the Paleozoic and Pre-Cambrian basement rocks rather than on important differences in the Mesozoic stratigraphic record. This Mesozoic stratigraphic record is critical in plate-tectonic reconstructions bearing on the break-up of Pangea, the opening of the Gulf of Mexico, and the origin of the

Caribbean Plate. The break-up of Pangea heralds a new cycle of terrane formation that crosscuts terrane and plate boundaries that characterized the Pre-Cambrian and Paleozoic. The Tepehuaño and Guachichil terranes are too generalized and all encompassing to be useful in plate reconstructions. Sedlock et al. (1993) failed to relate the geologic history of coeval rock packages (see Longoria, 1994).

The Maya terrane and the Coahuiltecano terrane in an emended form may still be usable. The Coahuiltecano terrane is emended herein (see below).

Objections to the Maya terrane

Sedlock et al. (1993, p. 28) divide their Maya terrane into three 'geographic' provinces:

(1) *A northern province*. This province includes southern Tamaulipas, Veracruz as far southeast as the Isthmus of Tehuantepec, and thin transitional crust along the western margin of the Gulf of Mexico.

(2) *The Yucatán platform*. The Mexican states of Tabasco, Campeche, Quintana Roo, and Yucatán as well as Belize, northern Guatemala, and thinned transitional crust in the adjacent Gulf of Mexico.

(3) *A southern province*. This province is said to include central Guatemala, Chiapas, and northeastern Oaxaca.

Although all three provinces of the Maya terrane may show remnants of Pre-Cambrian and Paleozoic Gondwana crust that remained behind after the break-up of Pangea and the opening of the Gulf of Mexico, the northern province displays two completely different stratigraphic records during the Jurassic and Early Cretaceous. Most of the Mayan terrane in the state of Veracruz should be assigned to the SPG terrane (Huayacocotla remnant) as described herein. That portion of Mayan terrane said to be in the state of Tamaulipas should be reassigned to the Coahuiltecano terrane (emend. herein); it is clearly a portion of the 'Victoria segment' of the Sierra Madre Oriental as described by Longoria (1985a,b, 1986, 1987, 1994). In east-central Mexico the Huayacocotla remnant of the SPG terrane has been juxtaposed against the Coahuiltecano terrane along the Walper Megashear at approximately the latitude of the Tampico–Ciudad Valles line.

Objections to the Guachichil terrane and Coahuiltecano terrane

Sedlock et al. (1993) divided the Guachichil terrane into provisional northern and southern subterranes based on the outcrop of Paleozoic sedimentary and metamorphic rocks. The southern terrane corresponds to the Huayacocotla remnant of the SPG terrane herein and to the Huayacocotla segment of the Sierra Madre Oriental of Longoria (1985a,b) and the Huayacocotla terrane of Longoria (1994). The northern subterrane corresponds to the Victoria segment of the Sierra Madre Oriental of Longoria (1984). We see no significant differences in the Mesozoic (Pangea and post-Pangea) paleobathymetric, paleolatitudinal, and lithostratigraphic signatures of the northern subterrane of Sedlock et al.'s Guachichil terrane and their Coahuiltecano terrane. In this report the northern subterrane is included within the Coahuiltecano terrane and the term *Guachichil* is abandoned. The Coahuiltecano terrane is emended herein to include the northern subterrane and exclude the southern subterrane of the Guachichil terrane; moreover, it is emended to include all parts of the Tepehuaño terrane east of the Walper Megashear. As so defined, the southern boundary between the Coahuiltecano terrane and the Huayacocotla remnant of the SPG terrane would correspond to the Walper Megashear (Fig. 7).

Objections to Tepehuaño terrane

The Tepehuaño terrane as defined by Sedlock et al. (1993) encompasses the San Pedro del Gallo remnant, the Symon remnant, and the Sierra de Catorce remnant of the SPG terrane. Moreover, it includes the Parral and Sierra Madre Oriental Terranes of Campa (1983), Campa and Coney (1983) and Coney and Campa (1984) (= in part Coahuiltecano terrane emended herein). As presently defined it embraces totally unrelated scraps of real estate on both sides of the Walper Megashear. It is obvious that the chief problem with the definition of the Tepehuaño terrane is the placement of the Mojave Sonora Megashear in that the alleged position of this structure defines the Tepehuaño terrane's eastern boundary. As noted under the discussion of the Coahuiltecano terrane above, all of the Tepehuaño terrane east of the Walper Megashear is included in the Coahuiltecano terrane.

At present the geology of the area west of the Walper Megashear is still too poorly understood and too complex to warrant establishing terranes as large as the Tepehuaño terrane. Stratigraphic packages are present in different structural blocks each representing different tectonostratigraphic settings: Parral terrane (Upper Jurassic and Lower Cretaceous flysch: backarc? or forearc?), SPG terrane (Upper Jurassic to Upper Cretaceous distal backarc), Zacatecas area (Triassic to Jurassic Interarc). The northern boundary of the San Pedro del Gallo terrane occurs at the village of Cinco de Mayo (Fig. 8) and is tentatively taken to be Longoria's (1994) San Pedro del Gallo Fault (see Fig. 3). At Cinco de Mayo one can observe a complex jumble of structural blocks that include Upper Jurassic–Lower Cretaceous sandstones (graywacke), shales, limestone, green and red tuffaceous siltstone, and olistostromal units with basaltic andesite clasts.

COMPARISON OF PALEOBATHYMETRY IN THE SAN PEDRO DEL GALLO TERRANE (SPG) AND THE ADJACENT COAHUILTECANO (COAH) TERRANE (EMEND. HEREIN)

Fig. 18 shows a comparison of the composite paleobathymetry of the SPG terrane and the COAH terrane along opposing sides of the Walper Megashear. The paleobathymetry of the SPG remnants has been discussed above. As can be seen in Fig. 18, the paleobathymetric signature of the COAH is totally different. The COAH paleobathymetric signature can be substantiated by examining the succession exposed at Peregrina Canyon and elsewhere along the eastern front of the Sierra Madre Oriental. Moreover, it can be documented by examining published well records from the Tampico Embayment area presented by Burckhardt (1930), Muir (1936), Imlay (1980), López-Ramos (1985), and numerous other workers. Burckhardt (1930, p. 95) reported inner neritic megafossils (including *Ostrea* and hydrocorals) in upper Tithonian oolitic limestone from a depth of 986–1029 m in well Chocoy No. 2 about 50 km northwest of Tampico. Inner neritic strata continue upward into the Berriasian and Valanginian (lower part of Tamaulipas Formation).

To the southwest of Tampico near Panuco Well Panuco No. 82 includes Upper Jurassic (lower Tithonian) black carbonaceous limestones and shales with *Aptychus*, pectenacid *Aulacomyella,* and ammonites

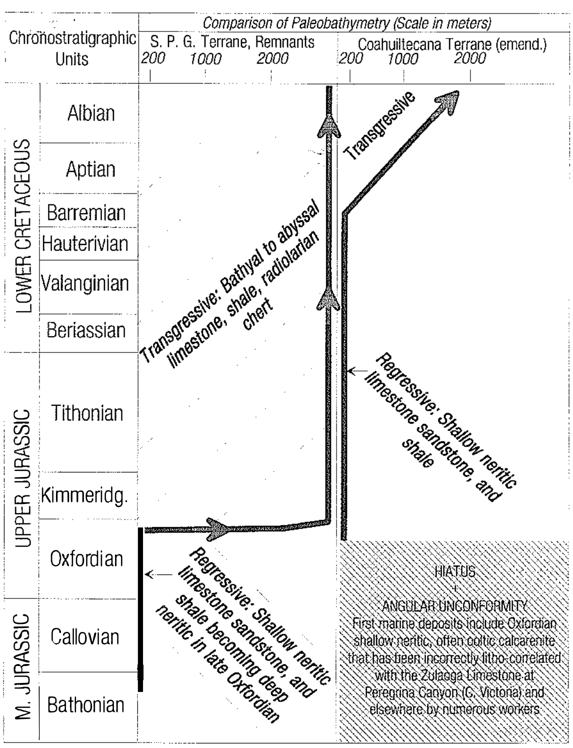

Fig. 18. Comparison of paleobathymetry between Cohuiltecana terrane and SPG terrane.

like *Mazaplites zitteli* Burckhardt. These strata lithologically appear to be similar to those of the Taman Formation and the La Caja Formation. *Ostrea*, bryozoans, and the remains of conifers occur at two horizons. These may represent inner neritic forms that have been displaced by turbidity currents to bathyal or abyssal depths.

By Late Cretaceous times the paleobathymetric record of the Mexican SPG terrane remnants and COAH terrane remnants become similar. Both terranes show a similar lithostratigraphic record during the remainder of the Late Cretaceous. At this point in time (~Albian/Cenomanian) it would appear that terrane amalgamation had occurred and movement along the Walper Megashear had ceased.

Anomalies to the scenario described above are inner neritic platform deposits (e.g., El Abra Limestone: rudistid reef complex in Sierra del Abra west of Tampico) that formed during the Albian to Turonian interval (Murray, 1961). These strata (rudistid and miliolid limestones) were probably deposited on seamounts at inner neritic depths and relate to a remnant horst and graben topography resulting from previous rifting.

CONCLUSIONS

(1) Stratigraphic data from displaced terranes situated to the west of the Walper Megashear (Mexico) demonstrate similar records of lithostratigraphy, paleobathymetry, and tectonic transport from higher latitudes to lower latitudes.

(2) In general, the stratigraphic successions in each of these areas show the same paleobathymetric fingerprint: (a) marine deposition at inner neritic depths during the Callovian to early Oxfordian (Middle to Late Jurassic); (b) marine deposition at outer neritic depths during the late Oxfordian (Late Jurassic); (c) sudden deepening to bathyal or upper abyssal depths (above the ACD of aragonite) from the early Kimmeridgian (Late Jurassic) until the end of the Cretaceous.

(3) This paleobathymetric fingerprint differs markedly from that occurring to the east of the Walper Megashear in the Coahuiltecano terrane (emend.) (e.g., Sierra Jimulco, Coahuila; Peregrina Canyon, Tamaulipas).

(4) In this report we regard the Upper Jurassic and Lower Cretaceous successions at San Pedro del Gallo, Symon and Sierra Ramirez, Mazapil (Sierra Santa Rosa), Sierra de la Caja, Sierra Zuloaga and Sierra Sombretillo, Sierra Cadnelaria, Sierra de Catorce, and in the Huayacocotla Anticlinorium to represent remnants of a single terrane, the *San Pedro del Gallo terrane*, that has undergone dismemberment and tectonic transport to varying degrees (NW

to SE) along the west (southwest) side of the Walper Megashear (see Fig. 2: Locs. 3, 5, 6, 7, 8, 9, and 12; Burckhardt, 1930; Imlay, 1980). The San Pedro del Gallo remnant of the San Pedro del Gallo terrane originated at Southern Boreal paleolatitudes (~40°N according to preliminary paleomagnetic data) during the Oxfordian and was tectonically transported to Northern Tethyan paleolatitudes (22° to 29°N) by latest Tithonian or earliest Berriasian times. Faunal data (radiolarians and megafossils) from the Mazapil succession (Sierra Santa Rosa) indicates that this remnant of the San Pedro del Gallo terrane was situated at Southern Boreal paleolatitudes (>30°N) during the Oxfordian and Kimmeridgian and at Northern Tethyan paleolatitudes (22° to 29°N) during the Tithonian and Berriasian. Preliminary paleomagnetic data from the upper Tithonian to Berriasian part of the Mazapil succession indicates ~25°N. Farther south in the state of San Luis Potosi, the Sierra de Catorce remnant was situated in the Southern Boreal Province during the Oxfordian to Kimmeridgian interval. During the Tithonian the Sierra de Catorce remnant was probably situated in the Northern Tethyan Province. Farther to the east (San Luis Potosi, Hidalgo, Veracruz, Puebla) in the Huayacocotla segment of the Sierra Madre Oriental previous investigations indicate tectonic transport from Southern Boreal paleolatitudes (>30°N) during the Callovian (Middle Jurassic) to Northern Tethyan paleolatitudes (22°to 29°N) during the Kimmeridgian and Tithonian (Late Jurassic) to central Tethyan paleolatitudes (<22°N) during the Berriasian (Early Cretaceous). The kinetics of terrane remnants along the Walper Megashear can be likened to blocks of ice in an ice flow with most blocks being episodically rotated during transport, some blocks moving along at steady rate (e.g., Huayacocotla remnant and San Pedro del Gallo remnant), and still others moving very little while rotating in place (e.g., Mazapil remnant).

(5) In western Cuba the Sierra del Rosario and Sierra de los Organos successions are likewise regarded to be remnants of the SPG terrane and show stratigraphic, paleobathymetric, and paleolatitudinal signatures which are nearly identical to those of San Pedro del Gallo terrane remnants in Mexico (Figs. 9, 11, 16 and 17). Even the presence of the inner neritic 'San Vicente Member' (Guasasa Formation) has an analogue in the San Andres Limestone of the Huayacocotla remnant (Fig. 2: Loc. 3). This record — at least during the Jurassic and Early Cretaceous — is distinctly North American. Unconformities and hiatuses are regional in distribution and can be traced as far north as the California Coast Ranges and Klamath Mountains (see explanation for Fig. 11). Moreover, these unconformities reflect tectonic events that affect the Nevadian forearc, interarc, and backarc in western North America. Although a backarc origin is advocated for the pre-latest Tithonian (radiolarian Subzone 4 alpha: Fig. 9), such an origin is related to the Nevadian island arc and not the Antillean island arc. In addition, these Cuban remnants are allochthonous when compared to surrounding Central Tethyan successions in the nearby Blake Bahama Basin and elsewhere in Cuba. They contain high latitude bivalves such as species of *Buchia* that can only be derived (exclusive of Greenland) from a Pacific source. The presence of Southern Boreal/Northern Tethyan faunas (~30°N) in the Sierra de los Organos and Sierra del Rosario remnants as late as the Early Cretaceous (Valanginian) suggests much later tectonic transport by northwest to southeast movement along the Walper Megashear and by subsequent southwest to northeast movement as the Caribbean Plate plowed its way through the gap between the North American and South American plates. As suggested by Pszczółkowski (see Chapter 4) and by Iturralde-Vinent (1994, 1996), the Guaniguanico terrane (= San Pedro del Gallo terrane) was situated along the eastern margin of the Yucatán platform. This hypothesis is supported by the fact that the Walper Megashear cuts the Yucatán Peninsula. We suggest that terrane amalgamation had occurred by the Middle Cretaceous and that all movement along the Walper Megashear had ceased. Subsequent southwest to northeast movement of the Caribbean Plate during the Late Cretaceous and Early Tertiary bulldozed the Cuban remnants of the San Pedro del Gallo terrane into their present position (see Montgomery et al., 1992, 1994a,b). Once the Cuban San Pedro del Gallo remnants were carried northward by the advancing Caribbean Plate, it is likely that they became part of an Atlantic-type margin as suggested by Gordon et al. (1998).

ACKNOWLEDGEMENTS

This investigation was in part supported by grants from the National Science Foundation: EAR-9418194 to Pessagno and Montgomery and EAR-9304459 to Pessagno, Hull, and Ogg. It has also been supported by a grant from CONOCYT to Urrutia Fucugauchi. We also wish to thank Dr. Jurgen Remane (Institut de Géologie, Université de Neuchâtel, Switzerland) for identifying Late Jurassic and Early Cretaceous calpionellids. Finally, we would like to thank Dr. Norman Silberling (U.S.G.S., Denver, Colorado), Dr. Charles D. Blome (U.S.G.S., Denver, Colorado), and Dr. Gyorgy L. Marton, Amoco Exploration and Production Company, Houston, Texas for their review of the manuscript. Contribution No. 826, Programs in Geosciences, The University of Texas at Dallas.

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