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Modern Marine Sediments of Bahia Concepcion: Patterns, Processes, and Potential Analogues to Neogene Rift Basin Deposits of Baja California

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Abstract

Neogene strata in Baja California preserve a record of extensional basins produced during early phases of rifting in the Gulf of California. This actualistic study addresses the feasibility of using Holocene sediments of Bahia Concepcion - a rift basin forming a shallow marine bay in southern Baja California - as analogues for the interpretation of Neogene strata in the Pliocene Loreto Basin. Three major lithofacies occur in Bahia Concepcion: Mud sediments dominate most of the central portion of the bay. Moderately sorted sands occur adjacent to shorelines formed by coalesced alluvial fans and a broad alluvial plain, while carbonate sands dominate semi-restricted embayments and rocky shorelines. The distribution of these lithofacies is largely attributable to local geology and changes in base level. Eastern alluvial fans sourced in the foot-wall of a normal fault on the Concepcion Peninsula shed clastic sand far into the bay. In contrast, drainages on the west side of the bay appear to be backfilling in response to Holocene eustatic sea-level rise, resulting in clastic-starved conditions favorable to carbonate production. Comparisons of modern sediments of Bahia Concepcion with those of the Pliocene Loreto Basin suggest that modern lithofacies are most useful in interpreting sediments deposited during transgressive episodes.

Introduction

The Gulf of California is a premier example of a modern rifted ocean basin in its early stages of development. Its relevance has prompted the development of numerous models concerned with early phases of rifting and the later shift to dominantly transform motion (e.g., Lonsdale, 1989). These models are based primarily on marine data from the mouth of the gulf and the stratigraphy of transtensional basins in southern California. The study of Neogene strata in extensional basins along the coast of Baja California and mainland Mexico may also clarify the earliest phases of rifting. Umhoefer et al.'s (1994) research on the Pliocene Loreto Basin used dated tuffs and sequence stratigraphy to clarify the tectonic evolution of the basin and related this to development of the gulf. Environmental interpretations of rocks within these basins may also be useful for understanding basin history and its relation to Gulf development. A better understanding of these deposits can potentially be obtained through actualistic studies of sediments accumulating in a modern basin analogous to those existing in the Pliocene.

This study delineates the distribution and composition of Holocene sediments in Bahia Concepcion, Baja California Sur, Mexico. A semi-quantitative analysis of more than 100 samples yielded information on grain size distribution, carbonate content and carbonate composition throughout the bay. Based on this analysis, I group samples into recognizable lithofacies and relate these to environments of deposition. I then apply my actualistic data to the interpretation of Pliocene strata in the Loreto Basin. My results highlight the positive and negative aspects of using modern sediments in Bahia Concepcion as environmental analogues when interpreting Neogene rift basin strata of Baja California.

Field Areas

Bahia Concepcion

Geography

Bahia Concepcion lies along the eastern side of the Baja California Peninsula at approximately 26.5° North latitude (Figure 1). The bay is 40km long and ranges from 5 to 10km in width. It is oriented north-northwest and connects to the Gulf of California at its northern end. Steep rocky headlands form much of the shoreline on the west side of the bay, although small, semi-protected pocket bays are common, especially in the central portion of the shore near Bahia Coyote (Figure 2). Mangrove swamps commonly occur at the mouths of drainages adjacent to these pocket bays. Isolated alluvial fans are also found along the western shore at the mouths of large drainages such as San Juan, Armenta, and Cadeje. Inland, the land is very rugged, forming large, deeply incised river valleys in steep terrain reaching 710m. These flat-bottomed valleys form large drainages (Figure 3) and appear to be backfilling in response to Holocene sea-level rise. In the northwest, near the mouth of the bay, the shoreline is formed by coalescing alluvial fans draining the high country of Cerro San Pedro (500m). South of the bay lies a broad, low-lying alluvial plain which rises gradually to scattered hills further south. The 10 to 15 km wide Concepcion Peninsula sits between the bay and the Gulf of California. The west side of the peninsula abuts the bay as a broad bajada of coalescing alluvial fans commonly extending 3km to the bay. The core of the peninsula is dissected mountainous terrain, rising from a fault scarp behind the alluvial fans, and reaching its highest elevation of 720m at Cerro Blanco in the northwest portion of the peninsula (Figure 2). Drainages on both east and west sides of the peninsula are short and form small catchments (Figure 3).

Bathymetry

The only published bathymetry of the bay was conducted with a sounding line during a single pass in and out of the bay by the E.W. Scripps cruise in 1940 (Anderson, et al., 1950). More comprehensive data were obtained during sampling transects for the present study (Figure 4). These data show the floor of the bay to be relatively flat and symmetric, with most of the sampling stations between 20m and 30m depth. Deeper areas occur in the southwest corner of the bay and in an asymmetric channel at the mouth of the bay. The transition from shallow to deep water is generally abrupt along much of the western shore, relatively gradual offshore of the alluvial plain in the south, and moderate along the eastern shore and the northwest alluvial fans. Fishermen of the area have reported the existence of rocky shoals in the west-central portion of the bay offshore of San Juan Fan. These shoals were not encountered during any of the sampling transects, although bivalve shells collected at two deep water sampling stations may have been shed off of such shoals (Figure 4).

Geologic Setting

The underlying geology of the field area consists of Cretaceous schistose and granitic basement rocks overlain by 4000 meters of Oligocene and Miocene volcanics (McFall, 1968). The major formations are summarized in Figure 2). The basement rocks form a peneplaned batholith composed of granodiorite and quartz monzonite (K-A date of 78.4 ± 2.8 Ma) (McFall, 1968) and dark biotite schist. The volcanic rocks overlying this basement comprise the Comondu Group, consisting of tuffs and tuffaceous sandstones, agglomerates, basalt flows, and flow breccias.

McFall (1968) recognizes six formations within the Comondu Group in the region. Rocks exposed on the west and south sides of the bay are mostly of the Ricason Formation, the youngest in the Comondu (Figure 2). This formation is more than 1500m thick and consists of basalt flows and flow breccias alternating with tuffs and bentonitic clays. Northeast of the bay, in the core of the Mulege Anticline, are exposed the older tuffaceous conglomerates and gypsiferous tuffs of the Minitas Formation, and some of the 2,000 meters of basalt flows, conglomerates and tuffaceous sandstones of the still older Pelones Formation.

Most of the Concepcion Peninsula consists of the Pelones Formation (Figure 2). Also exposed in the south-central and west-central portions of the peninsula are the only local outcrops of the basement granite and the overlying tuffaceous sandstones of the Salto Formation, the oldest in the Comondu Group. An early Miocene tonolite stock occurs in the northwestern portion of the peninsula, underlying the highest peak on the peninsula, Cerro Blanco (Figure 2).

Marls, sandstones, and coquinas of the Late Pliocene Infierno Formation locally fill Pliocene valleys, abutting Comondu rocks at buttress unconformities. These deposits are exposed along the sides of arroyos in the southeast corner of the bay and as a prominent outcrop at the tip of the peninsula (Figure 2). Quaternary alluvium fills in low-lying topography throughout the area. Ortleib (1991) identified Pleistocene terraces occurring at 15-18m above present sea-level on Concepcion Peninsula. He assigned them to the oxygen isotope stage 5e (≈130-120ka) high stand, when eustatic sea-level was ≈6m above present.

Structure

The structure of Bahia Concepcion and Concepcion Peninsula is probably related to right-lateral transform motion along a plate margin between the Baja Peninsula and mainland North America. Shearing and rifting along this margin is now concentrated offshore in oceanic transform faults, but early phases of movement produced rift basins in the continental crust of Baja California and mainland Mexico (Umhoefer et al., 1994; Lonsdale, 1989). Both Bahia

Concepcion and the Loreto Basin to the south are examples of such basins.

The only published proposed structure for Bahia Concepcion is that of McFall (1968), who identified the Concepcion Bay Fault Zone, located along the west side of the Concepcion Peninsula (Figures 2, 5). McFall also proposed the existence of the Mulege Anticline, a northwest to southeast-trending structure split by 30km of right lateral strike-slip movement along the Concepcion Bay Fault Zone (Figure 5). This fault zone also accommodated up to 4km of vertical motion, uplifting the Concepcion Peninsula as a foot-wall. The structural depression underlying Bahia Concepcion is presumably a product of this faulting. Vertical uplift of the peninsula relative to mainland Baja is certain, considering that exposure of basement rocks and the older formations of the Comondu group occurs only on the peninsula. However, evidence for 30km of lateral motion along the fault is scant, and the existence of a large fault-offset anticline is equivocal. Many of the topographic and geomorphological features of the bay can be attributed to structures associated with normal faulting, with no need to invoke transform motion.

Loreto Basin

The Loreto Basin is a Pliocene extensional basin located approximately 50km south-southeast of Bahia Concepcion on the coast of the Gulf of California just north of the town of Loreto (Figure 6). Basin development was initiated at ≈3.4 Ma by dextral-normal movement along the Loreto Fault on the west and south sides of the basin (Figure 6) (Umhoefer, et al., 1994). Rapid subsidence of the resulting asymmetric half-graben was accompanied by deposition of terrestrial alluvial fans overlain by vertically stacked fan deltas (Figure 6). As basin evolution progressed, the east side of the progressively tilted hanging-wall fault block became a north-south trending structural high (the "Comondu High").

As a result, fan deltas sourced from both the east and west characterize later phases of basin development (Umhoefer, et al., 1994). The uppermost Pliocene rocks in the basin indicate a shift from clastic-dominated to shallow marine carbonate-dominated deposition. When the southern part of the Loreto Fault became inactive in the late Pliocene, many of the rocks in the south side of the basin were cut by northeast-dipping normal faults. After this time, the center of faulting activity and the depocenter migrated northward. Fluvial and lacustrine sediments are still accumulating adjacent to the projected northern extension of the Loreto fault (Umhoefer, et al. 1994).

Methods: Holocene of Bahia Concepcion

Field Work

Our team of seven investigators collected sediment and faunal samples in March 1994. 102 sediment samples of approximately 100cc were collected in offshore and shoreline transects (Figure 7). We collected offshore samples with a mechanical Ponar grab sampler from an inflatable boat along 13 east-west transects, and measured the depth of each sample against arm span as the sampler was being raised. Divers collected shoreline transects at approximately 1, 5, and 10 meters depth. A Global Positioning System provided the location of each offshore sampling station and the shoreline position of each nearshore transect to within 100m. I personally collected samples from stations at the head, middle, and mouth of three mangrove swamps. In total, the team collected 32 shoreline samples, 9 mangrove samples, and 61 offshore samples.

Lab Analyses

I chose a semi-quantitative approach to collecting sedimentological data; one that could be easily applied to future studies in the field. I began the lab analyses by transferring each sample to a plastic beaker assigned a random number, and then visually inspected each sample with a stereo microscope. I used a standardized data sheet (Figure 8) to record observations on a number of sediment characteristics. I assigned one of four values (absent, trace, minor or major) to each variable category based on its abundance in the sample. A major value meant that the particular category dominated or co-dominated the sample; minor values indicate the presence of that category was subordinate to others. Categories occurring in trace amounts were present but rare. During inspection, I compared samples to a grain size analysis card to estimate clastic grain size distribution and degree of rounding. I assigned samples to one of five groups, reflecting carbonate-clastic ratio by volume: 0-20%, 20-40%, 40-60%, 60-80%, and 80-100% clastic. Dilute HCl was useful as a means of distinguishing very fine carbonate sand from clastic material. I also identified carbonate fragments as gastropods, bivalves ('mollusca' in Figure 8); calcalgae ('algae' in figure 8); or none of the above. Calgalgae fragments are produced by rhodoliths, a type of calcareous red algae occurring as branched coralline growths commonly up to 10cm in diameter. I assumed the composition of unidentifiable carbonate sand to be the same as that of identifiable fragments.

After collecting data, I used two approaches to determine the distribution of sediment types throughout the bay: Quantitative groupings based on cluster analysis, and qualitative groupings based on visual inspection. The quantitative approach proved useful in isolating the distribution of distinct sediment characters throughout the bay, while my qualitative groupings served as the basis for my overall lithofacies.

Cluster analysis is a means of identifying groups of samples which are similar in multiple variables. I and

SYSTAT 5.0 computed the similarity between all pairs of samples using the Euclidean distance (d_{ij}):

$$d_{ij} = \frac{\sqrt{\Sigma^{m}_{k=1} (X_{ik}-X_{jk})^2}}{m}$$

where X_{ik} denotes the kth variable measured on object i, while X_{jk} is the kth variable as measured on object j. The Euclidian distance, therefore, can be thought of as a sum similarity between any pair of samples based on the similarity of all variables included in the equation. Calculation of the Euclidean distance between all possible pairs in a data set of size n yields an $(n \times (n-1))/2$ symmetrical matrix. The next step is to create a hierarchy in which samples with the mutually highest similarity are placed together. The correlations of these grouped samples with all other samples are averaged, and these values are used to form groupings at the next level of the hierarchy. This process is repeated until all objects have been placed in the hierarchy. The hierarchy is usually portrayed as a dendrogram in which similar samples cluster together, and dissimilar samples fall into different clusters.

Before performing cluster analyses on the samples, I coded grain size, carbonate composition, and carbonate fragment size variables for each site; I entered major, minor, trace, and zero values as 3,2,1, and 0, respectively. Carbonate-clastic ratio was coded as 0-4 from 0-100% clastic content in 20% intervals. Subsets of offshore, shallow water, and near-fan sampling sites made cluster analyses more manageable. I clustered groups with a variety of variable combinations, including clastic grain size only, carbonate composition only, and carbonate fraction sizes only. I plotted samples on a map of the bay according to their occurrence in clusters. I also averaged variables for each cluster.

I sought to better understand patterns of sediment distribution throughout the bay by examining controls on clastic input. I chose to quantify the characteristics of drainage basins surrounding the bay. I measured longitudinal drainage profiles in millimeters on a 1:50,000 topographic map, recording distance along the principle stream trace between 20m contours.

Methods: Pliocene of Loreto Basin

Field Work

Our team of seven measured four partial sections of Pliocene strata along Arroyo de Arce in the southeast part of the Loreto Basin in January 1995 (Figure 6). A Global Positioning System provided the location of each section to within 100m. We described and measured each section in detail. I collected 22 samples and recorded their location within the section.

Lab Analyses

I analyzed Pliocene samples using the same methods as for Holocene sediments of Bahia Concepcion. After recording characteristics of each sample, I compared samples to the visual lithofacies. These comparisons were recorded, and the environment of deposition of the lithofacies was compared to the interpreted environment of deposition of the Pliocene deposit.

Results: Holocene Sediments of Bahia Concepcion

Cluster analyses results

Clastic grain size

Cluster analysis of 102 modern samples according to clastic grain size yielded four major groups. The distribution of the four groups is shown in Figure 9.

1.) Primarily fine silt, lesser amounts of coarse silt, and minor to trace amounts of clay and very fine clastic sand.
2.) Well-sorted fine and very fine clastic sand with trace amounts of coarse silt or medium clastic sand.
3.) Moderately sorted medium to coarse clastic sand.
4.) Poorly sorted clastic sand and pebbles.

The silt-dominated samples of Group 1 (shown in green in Figure 9) are located throughout the center of the bay, often close to shore on the west side of the bay. Samples collected at 5m depth near Playa Coyote and Playa Santispac also fall into this category. Samples in Group 2 (yellow, Figure 2) usually lie between offshore silts and coarser nearshore sediments, but may be found adjacent to shore in the area of Bahia Coyote. These sediments also dominate deeper areas near the mouth of the bay. The moderately sorted medium to coarse sands of Group 3 are found adjacent to shore everywhere except in parts of the northern end of the bay on both the east and the west sides. In these areas, the coarser sediments of Group 4 occur near the shorelines of alluvial fans. The coarse sand and pebbles of Group 4 also occur near shore in very shallow water at Playa Santispac, Playa Coyote, and Santispac Mangrove.

The distribution of clastic sediments in the bay is clearly related to local geology, expressed in an asymmetry of clastic grain size between the east and west sides of the bay. The region of coarsest clastics in the northeastern side of the bay corresponds to the region of the peninsula with the highest elevation and steepest alluvial fans. Here sand shed from the bajada extends far off the eastern shore. In contrast, the location and size of drainages on the west side has a more limited effect on the distribution of coarse clastic sediments. Large alluvial fans in the northwest shed coarse clastics offshore, but elsewhere fine silt is the dominant sediment as little as 1km from shore, even near the mouths of large drainages such as Cadeje and San Juan.

Silt deposition occurs even closer to shore in the semi-restricted embayment of Bahia Coyote, where drainage catchments are short and steep. In this semi-restricted embayment, sand and pebbles occur in very shallow water while silt is deposited just offshore at 5m depth. The lack of coarse sediments offshore in these locations demonstrates that the sand and pebbles are not being actively transported and deposited here, but occur only very near shore as a product of local wave reworking.

Carbonate Abundance

I divided samples into one of five groups reflecting total carbonate content by volume. Distribution of the five groups is shown in Figure 10. Carbonate-dominated sediments clearly dominate along much of the western shore, especially in the semi-protected embayment of Bahia Coyote. Carbonates also dominate sediments near San Juan Fan and Armenta Fan, as well as in the southwest, offshore of the largest drainage into the bay, Cadeje. The scallop shells responsible for the high concentration of carbonate material in the center of the bay may have come from the shoals reported by local fishermen in that area. Low to moderate amounts of carbonate are found near the eastern shore and in the northwest. Shallow water samples collected adjacent to shore in these areas generally fall into the 20-40% carbonate category, while those slightly deeper are often more carbonate-rich. Carbonate material is largely absent in the central part of the bay and in the channel at the mouth.

Carbonate Composition

Cluster analysis of samples according to carbonate composition yielded four groups. The distribution of these groups is shown in Figure 11.

1.) Bivalve shells and shell fragments; calcalgal fragments are absent or occur in trace amounts.

2.) Bivalve shells and shell fragments with lesser amounts of calcalgal fragments.
3.) Calcalgal fragments with lesser amounts of bivalve shells and shell fragments.
4.) Calcalgal material; bivalve shell fragments are absent or occur in trace amounts.

Figure 11 shows that bivalves dominate deep water areas and the southeastern and southern shores of the bay, while calcalgae are restricted to the shallow margins of the bay. Bivalves and calcalgae co-dominate northern, west central, and southwest shores of the bay. Rhodoliths are more abundant along the east-central shoreline and in the semi-restricted embayments near Bahia Coyote. Only in a few areas do calcalgae overwhelmingly dominate sediments: between five and ten meters off Armenta Fan and Muertas Fan, and in shallow water near Playa Coyote and Los Cocos Mangrove. Aerial survey (Steller and Foster, in review) has revealed extensive live rhodolith beds along the western shore of the bay between 5 and 12m deep, but no live beds along the southern or eastern shores of the bay. The sources of rhodolith material on the eastern shore of the bay are presumably scattered plants not concentrated in beds.

Qualitative Lithofacies

After cluster analyses revealed patterns in sediment distribution throughout the bay, visual inspection yielded ten identifiable lithofacies correlatable to environment. The goal in such an analysis is to delineate distinctive, environmentally restricted lithofacies which may be applied to paleoenvironmental interpretation of ancient strata. The lithofacies occur in three broad categories: 1) green mud facies; 2) clastic sand facies; and 3) carbonate facies. A highly restricted yet distinct facies also occurs in mangrove swamps. The distribution of the lithofacies is mapped in Figure 12.

Green Mud Facies:

A) Well-sorted olive-green silt with trace amounts of clay. Carbonate material is largely absent, although some samples contain minor amounts of fine mollusc fragments. Sediments of this type dominate the central portion of the bay and occur almost exclusively at depths greater than 20m. A subset of this group (A'; marked with a circle in Figure 12) is less well sorted and contains very fine sand and rarely fine sand. These seven samples are found at some sampling stations close to the northeastern shore (O3, A4, C3) or offshore of large drainages on the west side (I2, I3, E2); one (C1) is located near Bahia Coyote.

B) Primarily whole bivalve shells and coarse shell fragments with lesser amounts of olive green silt and very fine sand. Most samples exceed 80% carbonate. These samples were collected in 3 small areas, one in the central part of the bay near San Juan Fan, and two in the south end of the bay. Their occurrence may be related to the existence of uncharted rocky shoals which provide an environment for hard substrate bivalves which are then shed off the shoals to the bay floor below.

C) Bivalve fragments with lesser amounts of moderately sorted mud and fine sand. Most samples are from 60-80% carbonate. These sediments occur on the western side of the bay near the northwest alluvial fans, near Bahia Coyote and further south, and offshore of Cadeje Fan. These samples are probably genetically more related to Lithofacies A' than to Lithofacies B; the carbonate material was probably washed offshore with the fine sand and not created on nearby shoals.

Clastic Sand Facies:

D) Moderately sorted very fine, fine, and medium clastic sand with varying amounts of fine carbonate material. This lithofacies is highly variable; some samples contain lesser amounts of silt, coarse sand, or pebbles. Many samples, primarily those collected near the south end of the bay, consist exclusively of very well-sorted fine sand. Total carbonate content varies widely but averages around 50%. Medium to fine bivalve fragments dominate the carbonate fraction; calcalgal fragments occur in minor to trace amounts at many sampling stations. This lithofacies dominates the eastern and southern shores of the bay and occurs along some of the western shore.

E) Poorly sorted sand and pebbles with lesser amounts of bivalve and calcalgal fragments. This is the only lithofacies in which coarse sand and pebbles are present in large amounts and silt is entirely absent. Bivalve and calcalgal fragments occur in approximately equal amounts and are poorly sorted. This lithofacies is found adjacent to alluvial fans in northeast and northwest portions of the bay.

Carbonate Facies:

F) Coarse rhodolith fragments with trace amounts of moderately to poorly sorted clastic silt, sand and fine pebbles. Rhodolith fragments between 1 and 10mm dominate every sample, and bivalve fragments are present in only trace amounts. This lithofacies only occurs near Muertas and Armenta fans on the west side of the bay, where extensive rhodolith beds have been mapped (Foster and Steller, in review).

G) Poorly sorted carbonate material with trace amounts of moderately to poorly sorted silt and sand. Bivalves and rhodoliths co-dominate these samples and occur as both sand and coarser fragments. This lithofacies occurs along the western shore in the semi-protected embayments of Bahia Coyote and in the area around Isla Requeson. A subset of this lithofacies (G') occurs in very shallow water at Playa Coyote and at the mouths of the Santispac and Los Cocos mangroves. G' contains minor amounts of very coarse sand and fine pebbles and a larger proportion of coarse bivalve fragments larger than 10mm.

An eighth distinct lithofacies (H) characterizes mangrove swamps but is not mapped on Figure 12 due to its highly restricted occurrence. It consists of dark brown silt and very fine sand with gastropod and bivalve fragments. This is the only lithofacies in which the carbonate fraction is dominated by gastropod fragments. Some samples also contained plant material, probably roots. The samples comprising H were collected at the middle and head sampling stations of the three mangrove transects.

Results: Drainage Patterns in the Bahia Concepcion area

The distribution of Holocene marine sediments is closely related to drainage patterns in the Bahia Concepcion area. Observations in the field suggest a distinct asymmetry in drainage patterns surrounding Bahia Concepcion (Figure 3). Drainages on the west side of the bay form large, deeply dissected canyons with steep sides and relatively flat bottoms, while those on the east side are considerably shorter, forming shallow drainages terminating on a bajada of coalescing alluvial fans. The size and distribution of drainages is largely a result of normal faulting along the Concepcion Bay Fault Zone. Based on research in the western United States and in Greece, Leeder and Jackson (1993) report that foot-wall catchments are commonly smaller and steeper than those on the hanging-wall. This is the case for drainages surrounding Bahia Concepcion; the western hanging-wall catchments are significantly larger than those draining the eastern foot-wall of the Concepcion Peninsula (Figure 3).

A better understanding of the distinct asymmetry of sediment distributions in the bay may be obtained by examining controls on clastic input into the bay. Both morphological characteristics of drainage basins and the bedrock geology control the character of clastic material they produce and transport. Field observations suggested that stream gradients vary distinctly between the east and the west sides of the bay. This variation is likely to exercise an important control on clastic input to the bay.

Early researchers in the field of stream development (e.g. Davis, 1902) recognized that drainages are constantly evolving towards an idealized equilibrium gradient which maximizes transportation capacity at a given slope. This equilibrium gradient takes the form of a concave-up curve, the slope of which increases exponentially upstream. However, variations in rock type, climate, changes in base-level, age of the drainage, and slope ensure that this equilibrium gradient is constantly shifting and rarely maintained. Mackin (1948) has recognized that streams respond to an increase in base-level through aggradation propagated upstream as a wave. This aggradation continues until a new graded profile is attained. The degree of parallelism between the new and old gradients is a function of how much the overall slope of the system has been decreased by the rise in base-level.

Since equilibrium stream profiles generally follow exponential functions, plotting them on logarithmic axes portrays the profile as a straight line with constant slope. Changes in gradient appear on log-log plots as distinct changes in the slope of straight lines.

Western Drainages (Figure 13)

Most western drainages show a moderate gradient from the mouth of the drainage to a well-defined inflection point generally located upstream of more than 80% of the stream's length. At this inflection point, the stream gradient increases dramatically. The most substantial increase in gradient occurs near the headwaters of San Pedro North, which drains onto a large alluvial fan at the mouth of the bay. Los Cocos, a relatively short drainage with a correspondingly small catchment area shows no such inflection point and maintains a moderate gradient along its entire length.

Southern Drainages (Figure 14)

Drainages on the south side of Bahia Concepcion are more variable than those on the west. All three exhibit steepening of the gradient in the upper reaches, although the inflection points are less well-defined than those in the western drainages. Santa Rosalita, the largest of the three, also shows a proportionally larger increase in gradient above the inflection point.

Eastern Drainages (Figure 15)

Drainages on the eastern side of the bay are distinctly different from those on the west and south sides. These streams exhibit a moderate gradient along their entire length, except in the upper reaches of La Mantita where it drains off the tonolite stock underlying the high peak of Cerro Blanco. It is important to note that these streams exhibit no significant change in gradient profile at the mountain valley/bajada transition.

The patterns observed in the profiles of streams surrounding Bahia Concepcion are related to the underlying geology of the area and the effects of Holocene eustatic sea-level rise. Sea level during the Late Pleistocene was >100m below present, and drainages worldwide responded to lowered base-level by downcutting their channels to achieve an equilibrium gradient (Chorley, et al., 1985). As sea level rose, equilibrium conditions changed and drainages underwent aggradation as a means of adjusting their gradients. In small, coastal drainages such as those in Bahia Concepción, this process is complicated by a transgression which flooded lower reaches of the drainages. The aggradation associated with a rise in base level was therefore accompanied by progradation into the flooded portions of the drainages. Oversteepened reaches at the heads of western drainages may represent relict gradients not yet reached by the upstream wave of aggradation.

Bathymetry of the bay (Figure 4) suggests that a drainage divide in the northern portion of the bay prevented axial through drainage when sea-level was more than 30m below present. During Pleistocene low-stands, most of the bay was probably an internally drained alluvial basin whose lowest point lay in the southwest corner of the bay at roughly 40m below present sea-level. San Pedro and the northernmost eastern drainages (possibly including La Mantita) were probably the only drainages which fed into the Gulf of California during these low-stands.

The existence of this closed basin has important implications for the recent history of the San Pedro drainage as opposed to the other western drainages. Over the past 18ka, San Pedro drainage has likely undergone >100m of base-level rise, while the other western drainages have experienced a maximum of 40m of base level rise (assuming moderate rates of marine sediment accumulation in the basin). However, this base-level rise must not have affected drainages in the internally closed basin until ≈10ka, when eustatic sea-level had risen to about -40m, and began to flood the basin. San Pedro, therefore, has had at least 8ka longer in which to respond to these changes. In neither case has aggradation returned the drainages to an equilibrium profile, but the extended period of progradation experienced by San Pedro has resulted in the only large coalesced alluvial fans occurring on the west side. These results suggest that continued progradation of the large western drainages will eventually produce large alluvial fans.

In contrast, the considerably shorter drainages on the east side of the bay appear to have aggraded sufficiently to maintain an equilibrium profile; progradation of alluvial fans appears to be the dominant process today. The factors influencing the rate of aggradation on this side are unclear. It is important to note, however, that the only equilibrium profile recorded on the west side of the bay is that of Los Cocos, a drainage comparable in area to those on the east. While small drainages have correspondingly small catchment areas, the volume of sediment required for aggradation to an equilibrium profile is also considerably smaller.

Implications for Holocene sediment distribution patterns

The response of drainages around Bahia Concepcion to base-level rise associated with Late Pleistocene-Holocene transgression largely determines the distribution of marine sediments today. Most drainages on the west side of the bay are still aggrading upstream, trapping coarse clastics in the canyons as backfill, so few clastic sediments reach the bay. The clastic-starved conditions on the west side of the bay promote the growth of many carbonate producers and the development of high concentrations of carbonate sand. In contrast, the smaller drainages on the east side of the bay have aggraded more quickly and now form a prograding bajada which sheds coarse clastics into the bay. The actively prograding condition of the San Pedro drainage can be attributed to a much longer period of equilibration since the onset of base-level rise as compared to the other western drainages. Continued progradation of these western drainages can be expected to end clastic-starved conditions.

Results: Pliocene of Loreto Basin

Measured Sections

I measured four sections (numbered 1-4 in stratigraphic order) in the southeast part of the Loreto Basin along Arroyo de Arce, a drainage running between the "Comondu High" to the north and the Loreto Fault to the south. Umhoefer et al. (1994) have divided the stratigraphy of this basin into four major depositional sequences (Figure 6). Sequence 1 is fully nonmarine, consisting of alluvial fan sediments sourced from the foot-wall block of the Loreto Fault to the southwest. These terrestrial sediments are overlain by clastic-dominated marine and marginal non-marine sediments of Sequence 2, recording rapid basin subsidence and infilling in the form of stacked fan-deltas A dozen concentrated shell beds are located within Sequence 2, and at least two are extensive enough to act as key marker horizons. Sequences 3 and 4 consist of a conglomeratic bioclastic limestone, reflecting a transition to carbonate-dominated deposition within the basin.

The four sections measured here lie mostly within Sequence 2; the basal conglomerate of Section 1 and the calcirudite at the top of Section 4 lie in Sequences 1 and 3, respectively.

Section 1 (Figure 17)

Section 1 spans the topmost alluvial fan sediments in Sequence 1 and three distinct packages of marine and marginal marine rocks at the base of Sequence 2. The basal 3.5m is a very poorly sorted conglomerate of subangular cobbles and occasional boulders in a sand and pebble matrix. Overlying this is massive unit of siltstone and fine sandstone containing subrounded gravel clasts in the lowest 0.5m. Articulated bivalve molds, apparently *in situ*, are common in the lowest 1m, but decrease in abundance upward, and are absent at the top of the unit. The silty sandstone is overlain by alternating layers of massively bedded medium to fine and medium to coarse sand. Root traces are common in the finer layers and horizontal burrows can be found in two of the coarser layers, one at 12.5m, and the other at 17m, immediately below the contact with the overlying unit. The topmost 7m of this section is medium to coarse sand with pockets of pebbles throughout, and lenses of pebbles and small cobbles in the upper half. Burrows, sand dollars, and shallow marine bivalves (*Tagelus*) are common; the sand is massive and bioturbated, and pockets of gravel have been extensively reworked.

The conglomeratic rocks at the base of Section 1 are the youngest terrestrial alluvial fan sediments in Sequence 1. The contact between this unit and the silty sandstone above represents the first marine flooding surface in the basin. The fine sediments above were deposited in a fully marine environment, and the gravels at the base of this silt may represent a transgressive lag. Fully marine deposition at this site was succeeded by marginal marine sedimentation on a nearshore flat possibly subject to periods of submergence. Sediment was probably deposited on the flat as broad washes of sand which were then reworked by plant growth and bioturbation. The return to a shallow but fully marine environment is indicated by burrows, shells, and sand dollars present in the coarse sand above 17m. The gravel present in this unit may record channels or individual pulses of coarser sediments.

Section 2 (Figure 18)

Section 2 records a transgression in three distinct packages: distal alluvial fan deposits; transitional marine sediments; and a fully marine shell bed. This is overlain by a prograding fan-delta deposit. The lower 10m of Section 2 is an overall fining upward package of planar and cross-bedded sand and gravel conglomerates. Three smaller units may be broken out of this package, each of which contains a pebble or gravel conglomerate lying on a sharp, scoured basal contact; alternating layers of pebbly sand and sand above; and a massive fine sandstone or mudstone containing caliche or root traces at the top. The 3m thick transitional package above these conglomerates consists of four smaller units. The lower two fine upward from fine sand to mud. Root traces are present throughout the lower unit and at the top of the upper one. Above these two, at 11.5m, is a medium to coarse sand containing gravel and a small amount of shell hash. Root traces are present in this sand just below the undulating upper contact at 12.2m and throughout the siltstone which overlies it. This siltstone contains oysters (apparently *in situ*) and is riddled with large burrows filled with shelly material from the massive shell bed above 13m. The shell bed contains pebbles at its base and minor amounts of fine sand throughout. The bivalve fragments in this unit are very coarse and well cemented. The sandstone unit at the top of the section consists of alternating layers of pebble-rich fine sand and coarse sand with cobbles, oyster shells and shell fragments. Dip of the beds is approximately 6° steeper than, and in the same direction as, regional dip to the northeast.

The sharp-based, fining-upward sequences which characterize the lower half of this section were deposited in braided outwash channels, probably at the distal end of an alluvial fan. A supratidal flat then developed, possibly in a coastal interfan environment, where sandstones and siltstones were deposited. The shelly sand above this level indicates that shallow marine conditions followed this supratidal phase. This shelly sand was later eroded and rooted when a mangrove community developed there, depositing silt and providing a home for oysters and large burrowing organisms, probably crustaceans. When the area was fully submerged, the burrows were filled with shell material probably deposited in a small protected bay subject to minor clastic input. A major shift in deposition occurred when a fan delta sourced from the southwest prograded across the area and deposited sand and pebbles in low angle cross-beds on the delta front.

Section 3 (Figure 19)

The lower half of Section 3 comprises various deposits of shallow marine and marginal marine rocks, while the upper 15m are fully marine conglomerates. The basal 11 meters consists of burrowed and poorly sorted sandy conglomerates containing pebble and cobbles. Shell material is present in minor amounts throughout, but is concentrated in two finer layers towards the bottom of the section. Two cross-bedded layers occur near the top of the unit. Above 11 meters is an extensively burrowed medium to coarse sand containing isolated pebble-rich layers. Root traces and *Tagelus* shells are also present. This sand coarsens up to a sand and cobble conglomerate containing coarse shell fragments below the upper contact at 16m. Above this contact are 6m of extensively burrowed medium sandstone with scattered pebbles. Coarse shell material is common in this deposit as burrow fill, as pockets 20-40cm across, and in a shell bed at 18m. Deposits in the 2m above this layer contain a larger proportion of fine carbonate material. Approximately 20m of covered section lies between this shell bed and the upper part of the section, which consists of >20m of poorly sorted conglomerate. This unit consists of repeating sharp-based, fining upward sequences of sandstone and conglomerate. These units are from 5-50cm thick and all show a sharp, gently undulating base which is generally scoured into the unit below. Shell material occurs throughout but is more common and coarser in the gravel-rich layers at the base of the units.

Much of Section 3 represents deposition in a shallow marine environment with moderately high clastic input. The shell-rich layers near the base of the section probably represent periods of reduced clastic input. The gravel present in the lower 8m was probably deposited as distinct beds like those at 8m and 10m but was later reworked by bioturbation. Above 11m to 15m is a marginal marine deposit, indicated by the presence of both roots and *Tagelus* shells. The existence of gravel in distinct layers indicates less bioturbation than in underlying units. The fully marine sediments above 15m are associated with a decrease in clastic input and/or a dramatic increase in shell production. As in Section 2, the transition to the conglomerates capping Section 3 records a shift to fan-delta deposition. This transition is recorded by the distinct shift from highly bioturbated beds in the lower 22m to physically stratified beds in the upper 20m. The 20m of conglomerates at the top of the section record individual gravity-driven slump events which carried coarse sediment down the steep slope of the delta front. These slumps scoured underlying units and then deposited material in fining-upward beds as they settled.

Section 4 (Figure 20)

The three major packages of rock in Section 4 record a shift from coarse clastic deposition to carbonate deposition; conglomerate is overlain by shelly and pebbly sand capped by a massive limestone. The lowest 10m is dominated by channelized sandstone and cobble conglomerate. Individual deposits within this unit have sharp, scoured bases and fine up from a shelly cobble and coarse sand conglomerate to medium sand. Most are scoured by deposits above and pinch out laterally over 2m to 5m. Interspersed with the channel deposits are planar-bedded and cross-bedded medium-grained sandstones. These sands often contain thin laminae of shell material and are commonly capped by coarse shell material and gravel. The medium-fine sandstone capping the topmost channel deposit at 10m is planar bedded at its base but extensively burrowed and bioturbated above. The undulating upper contact of this bed is scoured by the unit above, and may be gradational due to reworking of sediment from below. The second distinct package of rocks in this section begins above this contact at 11m. This package consists of ≈5m of medium and fine sands, gravel-rich and poorly bedded in the lower portion but massive and well-sorted towards the top. Shell material is abundant below and dominant in the upper portion. At 16.5m, the uppermost unit in this package is truncated at a very low angle by the unit above, a series of alternating calcarenite and medium-coarse sandstone beds. The calcarenite beds are tabular and cross-bedded, and contain rare mudstone rip-ups. The sand beds are planar or cross-bedded; individual laminae are well sorted fine or coarse sand, and may contain shell material. Contacts between calcarenite and sand layers are sharp and broadly undulating over 5m-10m. This calcarenite/sandstone interval is overlain by >20m of cliff-forming planar-bedded calcirudite with coarse sand and gravel scattered throughout. Most of the limestone is coarse shell material, but red algae fragments are present and form much of the matrix and cement. The fragmented and encrusted shells forming this bed commonly occur stacked in a concave-down orientation.

The lower 10m of this section are marine channel deposits probably representing a channelized fan-delta front. The planar sands record shallow marine deposition occurring between channels; the 5m of gravel-rich and shell-rich sand above 11m is the most well-developed of these interchannel deposits, with background sand deposition and occasional overwashes of coarser material reworked by bioturbation. The angular nature of the contact between the units above and below 16.5m may be a result of renewed tectonic activity in the Comondu High. Clastic input decreased markedly at 18m; wave energy remained high enough to work shells into a nested orientation, suggesting carbonate shelf conditions.

Comparison of Pliocene samples to Holocene lithofacies

I compared 22 samples collected in the Loreto Basin to the lithofacies delineated from the Bahia Concepcion samples. Many samples are very similar to Bahia Concepcion lithofacies, while others did not resemble any of the modern samples. The varying amounts of similarity between sediments of Bahia Concepcion and the Loreto Basin are attributable to their different tectonic settings as well as to influences of base-level rise and fall. Sedimentation patterns in Bahia Concepcion appear to be dominantly influenced by recent tectonic quiescence and rising sea-level since 18ka. In contrast, sedimentation patterns in the Loreto Basin were developed under active tectonic conditions and in both transgressive and regressive settings. Regressive deposits of the Loreto Basin, therefore, can be expected to not resemble sediments of Bahia Concepcion, while those deposited during transgressions should better match modern lithofacies.

Samples PL 22, PL 21, and PL 7, inferred to have been deposited in a carbonate bay or on a carbonate shelf, compare very favorably with Lithofacies G. In the modern environment, sediments of this type are found in the semi-restricted embayments near El Coyote and further south between San Juan and Armenta Fans. The two shell beds from which these three samples were collected both cap transgressive sequences in which distal fan deposits are overlain by marginal marine sediments. Presumably, the transgressions recorded here resulted in the same clastic-starved conditions which promote the development of carbonate bays in Bahia Concepcion. PL 19, collected from an inferred interfan deposit in Section 4, is very similar but is dominated by very coarse bivalve fragments and whole shells; it lacks fine carbonate sand. It is possible that the existence of carbonate sand indicates clastic-starved conditions in which shells sit on the seafloor and are abraded for long periods of time.

Samples PL 8, PL 16, PL 18, PL 2, PL 3, PL 5, and PL 12 all resemble Lithofacies D. This highly variable lithofacies occurs along shorelines and slightly offshore in the modern environment. The first three samples are primarily medium and coarse sand. PL 8 was collected from a deposit containing large-scale, low angle cross beds interpreted to have been deposited on a delta front. Sample PL 16 and PL 18 were collected in shallow marine deposits probably situated in an interfan setting. Samples PL 2, PL 3, PL 5 and PL 12 are more similar to the well-sorted fine sand sediments in Lithofacies D. Samples PL 2, PL 3, and PL 12 were collected from marginal marine/nonmarine deposits situated between fully marine units above and below; PL 5 occurred in a transgressive sequence between distal fan channel deposits below and shallow marine sands above. All four samples were deposited in a marginal environment subject to both marine and nonmarine influence. In Bahia Concepcion, slight fluctuations in sea level could produce such a deposit on the broad, low relief alluvial plain at the south end of the bay.

Sample PL 6 is very similar to the mangrove-specific Lithofacies H. This dark-brown silty sample contains roots, and the deposit in which it was collected also yielded oysters, common to mangroves. This deposit is located within a transgressive sequence in the unit and is overlain by a shell bed. Continued transgression in Bahia Concepcion would likely produce a similar sequence; mangrove deposits in Santispac and Los Cocos would be overlain by carbonates deposited in a semi-restricted embayment.

Sample PL 1 is very similar to Lithofacies B, comprised of olive mud and whole bivalve shells. This is the only sample which resembles the deep water muds of Bahia Concepcion, and the unit from which it was collected overlies the first flooding surface in the Loreto Basin. The effect of this flooding, whether eustatically or tectonically induced, appears to have been similar to that of the Holocene sea-level rise in Bahia Concepcion. In the modern case, coarse clastic material appears to be trapped on land in backfilled canyons and aggraded alluvial fans, resulting in a mud-dominated, clastic-starved bay.

Samples PL 4 and PL 11 both resemble the sediments of Lithofacies E, but lack carbonate material. These poorly sorted sands and pebbles were collected in the distal fan deposits of Section 2 (PL 4) and shallow marine sediments of Section 3 (PL 11).

Samples PL 9, PL 10, PL 13, PL 14, PL 15, PL 17, and PL 20 do not closely resemble any of the lithofacies recognized at Bahia Concepcion. These samples consist of very poorly sorted silt, sand, and pebbles and contain very coarse bivalve fragments, but rarely whole shells. Samples in this groups are more poorly sorted than those in Lithofacies E and contain more very coarse shell fragments. All are inferred to have been deposited in shallow marine environments, but differ in their stratigraphic setting. PL 17 is from a prograding delta front deposit, while PL 20 lies in a sequence of decreasing clastic input. PL 9, PL 10, PL 13, PL 14, and PL 15 are not part of any recognizable transgressive or regressive package, but record local variations in clastic input.

Discussion and Conclusions

Sediments of Bahia Concepcion are dominantly controlled by influences of local geology and a rise of >100m in sea-level since 18ka. Normal faulting along the Concepcion Bay Fault Zone has largely controlled the location and size of catchments. Small, shallow drainages characterize the eastern foot-wall, while large, deep drainages incise the western hanging-wall. Changes in base-level influence the character of sediments shed from these drainages. As a result of these two controls, large, coalescing alluvial fans dominate the east side of the bay. These fans are sourced from small drainages on the Concepcion Peninsula which are in equilibrium following Late Pleistocene-Holocene sea level rise. In contrast, drainages on the west side of the bay have not reached equilibrium following sea-level rise. Coarse clastic sediment is being trapped upstream as backfill, and only recently have the largest of these drainages prograded enough to form small, isolated alluvial fans amidst rocky headlands. The large alluvial fan at the mouth of San Pedro drainage in the northwest suggests that continued progradation of the western drainages will result in large, coalesced alluvial fans.

The result of these differences in drainage patterns is distinct variation of sediment types within the bay. Three major lithofacies groups occur in distinct environments throughout the bay: green mud facies, clastic sand facies, and carbonate facies. The green mud facies dominate the central portion of the bay. The lack of coarse clastic sediment in deep water may be attributed either to recent tectonic quiescence in the Bahia Concepcion area or to the rapidity of the Holocene transgression. In either case, coarse clastic sediments are unable to reach deep water. Clastic sand facies are limited to the eastern shore, the south end of the bay, and in the northwest portion of the bay offshore of coalescing fans. Most of the western shore is characterized by the carbonate facies, which occur in both protected pocket bays and offshore of alluvial fans at the mouths of large drainages. The occurrence of these facies is clearly related to limited clastic input resulting from backfilling of these drainages. Low rates of clastic input contribute to the formation of carbonate sand by providing an environment in which carbonate producers can thrive and carbonate sand can accumulate in high concentrations. Continued progradation of drainages on the west side of the bay would result in further fan development and possibly the development of a bajada. The stratigraphic record of such an occurrence would take the form of carbonate sediments, potentially overlain by mangrove deposits (especially in restricted pocket bays), followed by terrestrial alluvial fan sediments.

In contrast to modern sediments of Bahia Concepcion, Pliocene rocks of the Loreto Basin accumulated during active tectonic conditions and multiple transgressive and regressive episodes. As a result, these deposits often fdo not correspond closely to the modern sediments of Bahia Concepcion.

Sediments similar to the offshore mud facies of Bahia Concepcion are found only in the unit overlying the first marine flooding surface in the basin (Section 1, Figure 17). The transgression responsible for this flooding appears to have been large and/or rapid enough to prevent deposition of coarse clastic material in deep marine environments. After this time, active tectonics were intense enough to shed coarse clastics throughout the basin, even during transgressions.

Many of the transgressive sequences in the Loreto Basin contain shallow marine and marginal marine deposits similar to those of Bahia Concepcion. Carbonate sand and mangrove swamp deposits, both very similar to those collected in Bahia Concepcion, occur overlying marginal marine sand and mud deposits similar to the sediments found on the low-lying southern alluvial plain and the adjacent nearshore shelf (Section 2, Figure 18). Fine grained sediments of this type also occur in marginal marine deposits overlying the mud deposited during the first marine flooding event in Section 1 (Figure 17). Shallow water deposits in the Loreto Basin often contain clastic sand similar to that found in nearshore environments in Bahia Concepcion.

The influences of active tectonism distinguish many deposits of the Loreto Basin from those in Bahia Concepcion and demonstrate disadvantages of using modern sediments as analogues for Neogene deposits. Many pebbly sandstones and conglomerates deposited in interfan, distal fan, and fan-delta environments do not resemble any Holocene sediments. Furthermore, some samples very similar those collected in the modern were probably deposited in very different environments. Clastic sands resembling those adjacent to the largest fans in Bahia Concepcion were not deposited in a nearshore environment but as foresets on a fan-delta front. The calcarenite at the base of Sequence 3, similar to those deposited nearshore in Bahia Coyote, was probably not deposited in a protected pocket bay but rather on a broad, wave-washed carbonate shelf.

Using modern sediments as analogues for ancient strata can be a powerful approach to paleoenvironmental interpretation. The modern setting of Bahia Concepcion is comparable in many ways to that of the Pliocene Loreto Basin. In both cases, extensional tectonics produced moderately shallow, semi-restricted bays of approximately the same size, and both are characterized by an asymmetry in the source of clastic sediments. Foot-wall blocks in both basins are the primary clastic sediment source, while exposed portions of the hanging wall blocks only rarely produce large clastic deposits. Both basins also had high biological productivity, generating abundant carbonate sediments in certain shallow water settings where clastic input was limited. However, the conditions of transgression and tectonic quiescence which control the distribution of modern sediments in Bahia Concepcion characterize only portions of the Pliocene history of the Loreto Basin. Intense tectonic activity and regressive episodes occurred throughout much of the history of the Loreto Basin. It is probably not appropriate to use Holocene analogues to interpret these phases of basin evolution.

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Figure 1: Location of Bahia Concepcion.

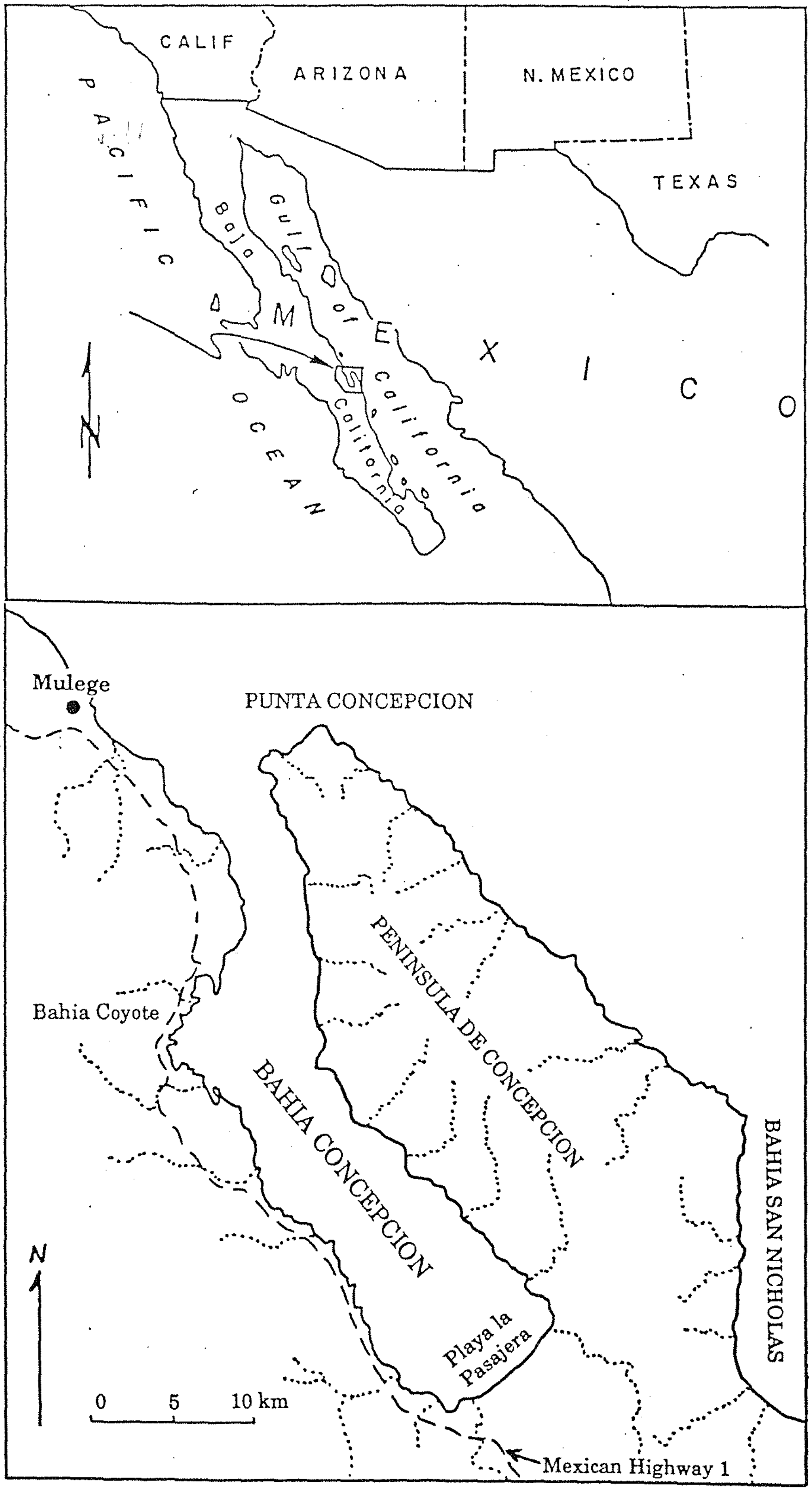


Figure 2: Generalized geologic map of the Bahia Concepcion area.

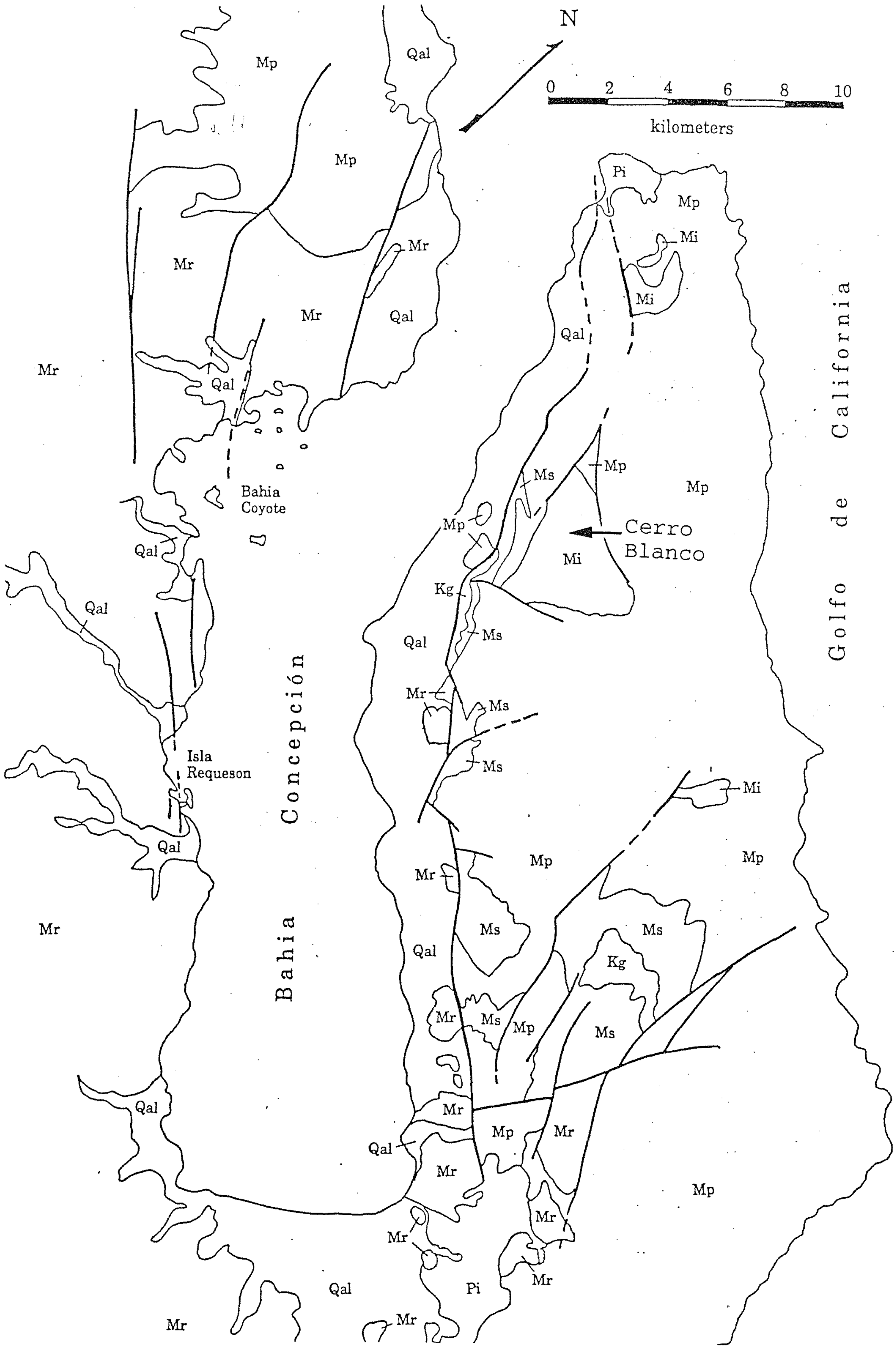


Figure 2, continu ed: Summary of major geologic units in the Bahia Concepcion area.

Qal	Quaternary Alluvium	volcaniclastic sand and conglomerate of alluvial fans, stream beds, stream terraces
Pi	Pliocene Infierno Formation	marginal marine to shallow marine sandstones, siltstones, cherts and coquinas
Mr	Miocene Ricasón Formation	andesitic and basaltic flows, agglomerates and tuffs
Mi	Miocene intrusions (post-Pelones Fm)	gabbro or tonalite
Mp	Miocene Pelones Formation (Includes the overlying Hornillos and Pilares Formations at the base of Concepcion Peninsula; includes the overlying Minitas Formation northwest of the bay mouth and on the east side of the Concepcion Peninsula.)	andesitic agglomerates, flows and tuffs
Ms	Miocene Salto Formation	cross-bedded sandstone and interbedded tuffs
Kg	Cretaceous basement	granodiorite and quartz monzonite with schist inclusions

Figure 3: Map of selected drainages catchments and measured stream traces in Bahia Concepcion.

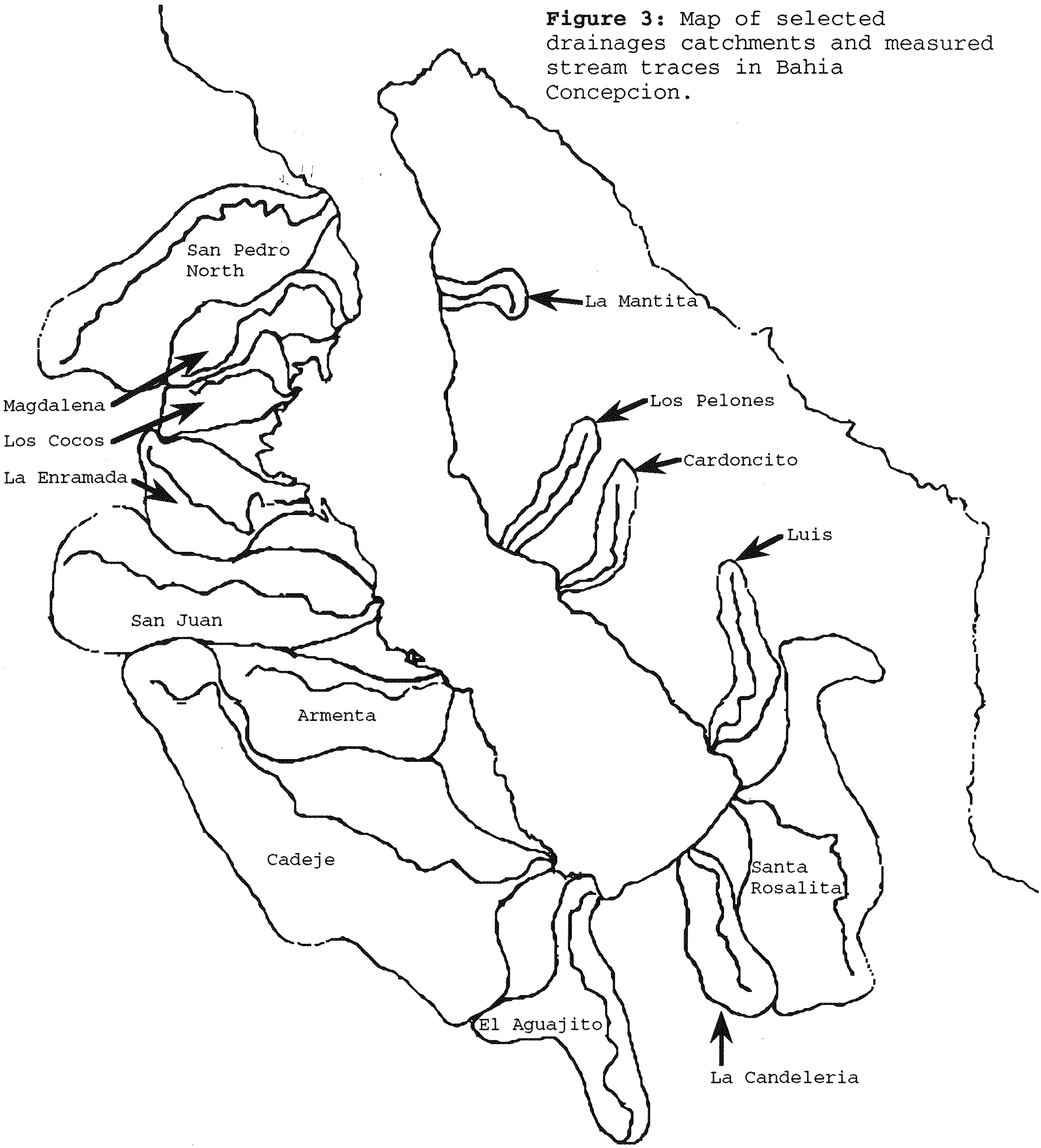


Figure 4: Bathymetry of Bahia Concepcion; sample sites are shown with depths in meters; contour lines are at 10m intervals. Patterned oval shows approximate location of reported shoals.

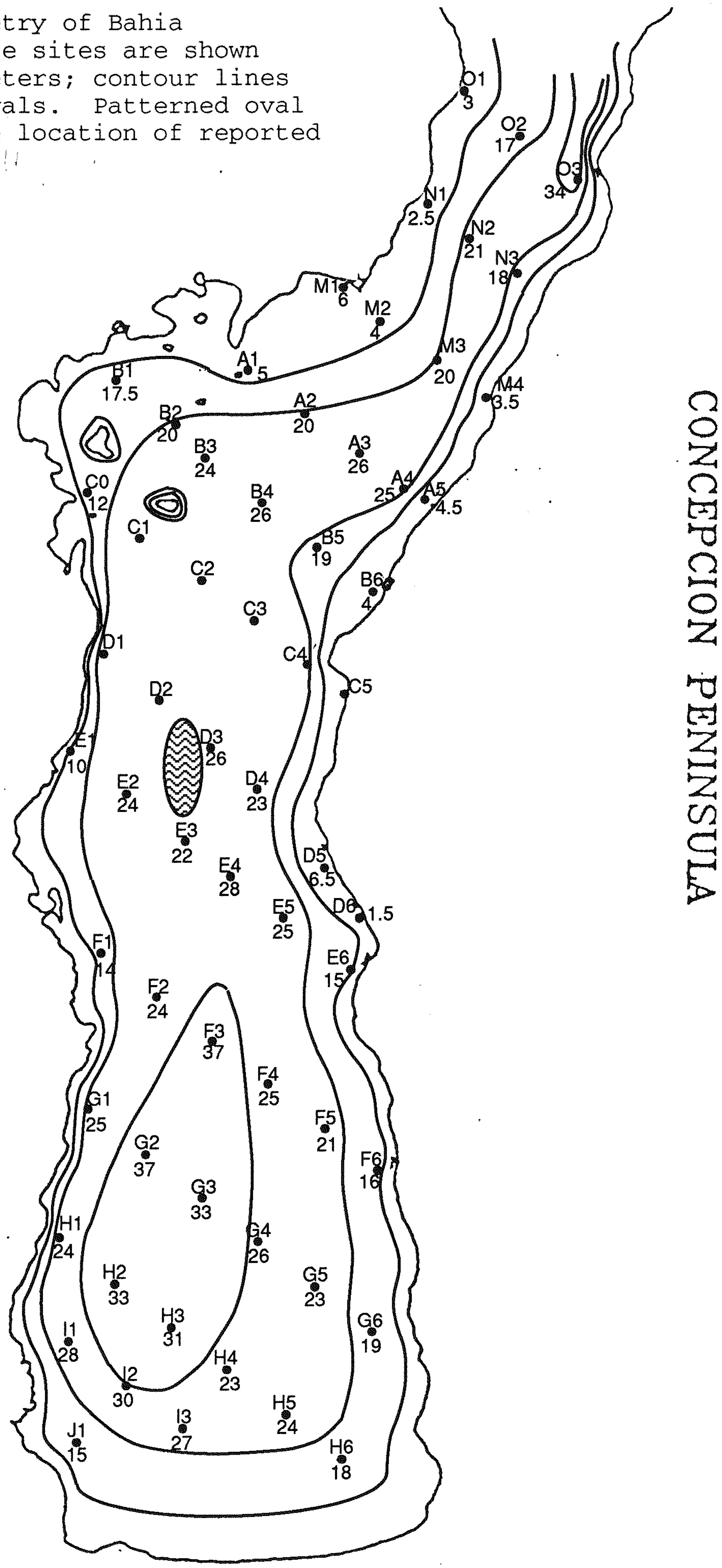


Figure 5: McFall's (1968) model of dominantly strike-slip motion along the Concepcion Bay Fault Zone.

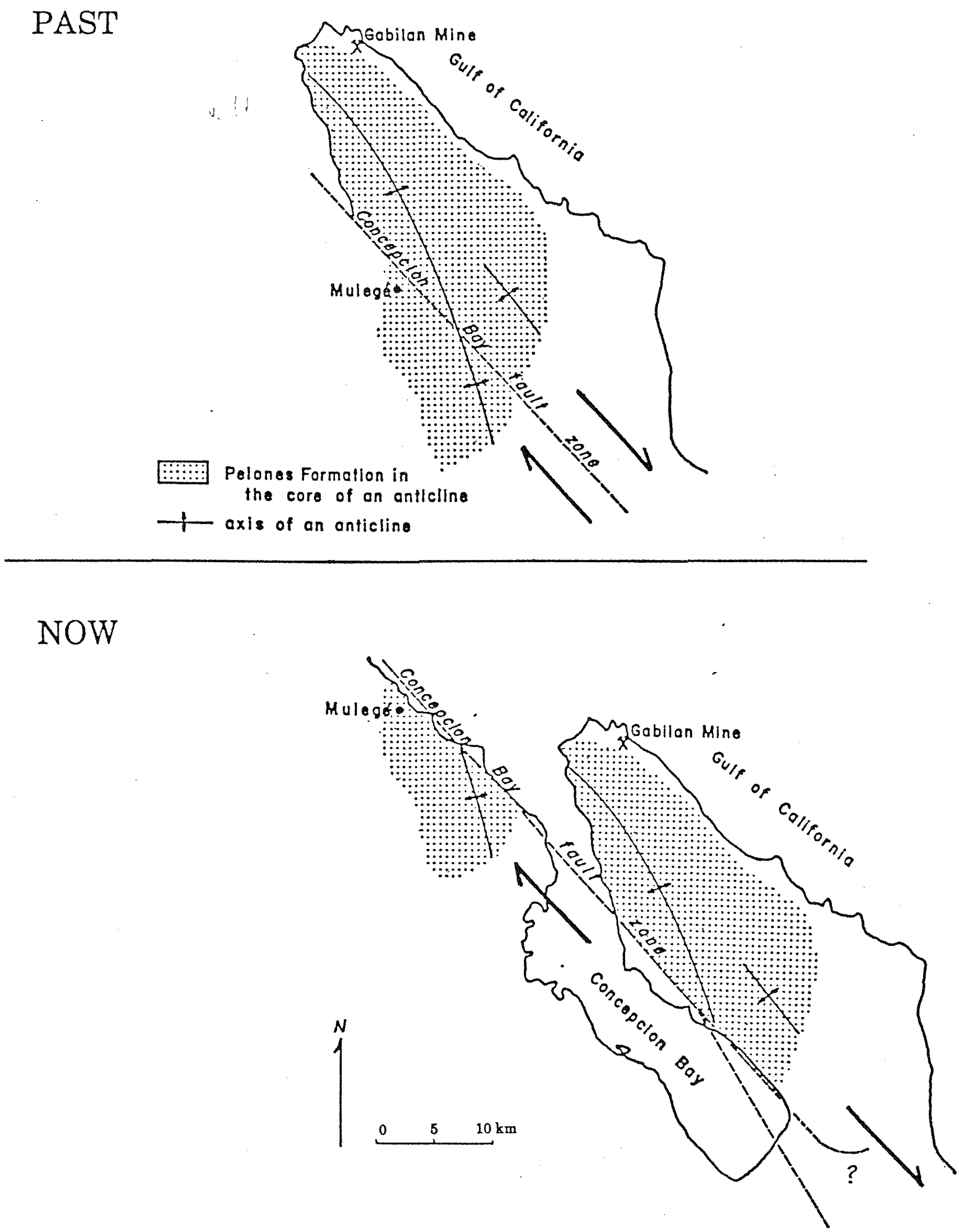


Figure 6: Generalized stratigrapic map and structural cross-section of the Loreto Basin. (from Umhoefer ey al., 1994)

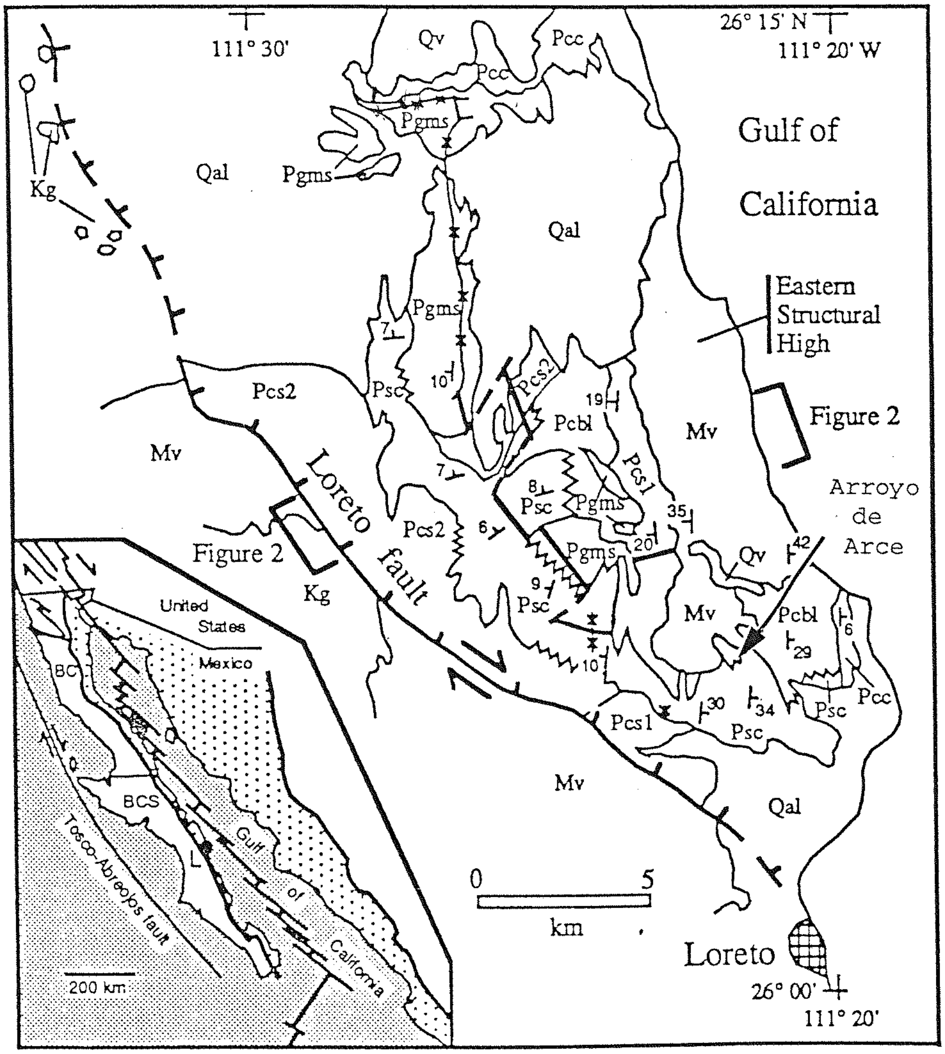


Figure 1. Simplified geologic map of southern Loreto basin, showing major lithofacies, Loreto fault, eastern structural high, and location of composite measured section. Inset shows Baja California and Gulf of California in modern plate tectonic setting. Dotted pattern is Gulf extensional province. Parts of map are after McLean (1988). BC = Baja California, BCS = Baja California Sur, L = Loreto basin.

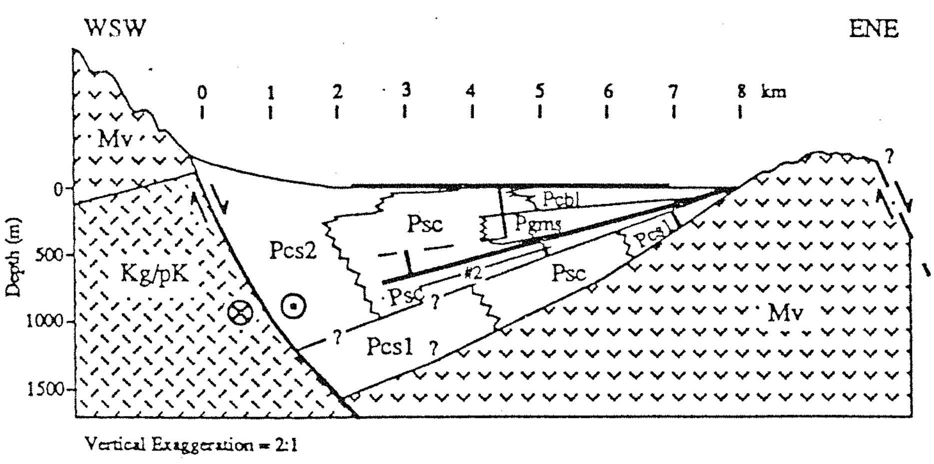


Figure 2. Stratigraphic panel of reconstructed facies architecture across southern Loreto basin. Map abbreviations are same as in Figure 1. Vertical lines represent segments of measured section shown in Figure 3. Thick lines parallel to strata indicate two shell beds that are key marker horizons. Line marked #2 is tuff #2 in Figure 3. Loreto fault is major fault to west.

Figure 7: Location of sampling sites in Bahia Concepcion

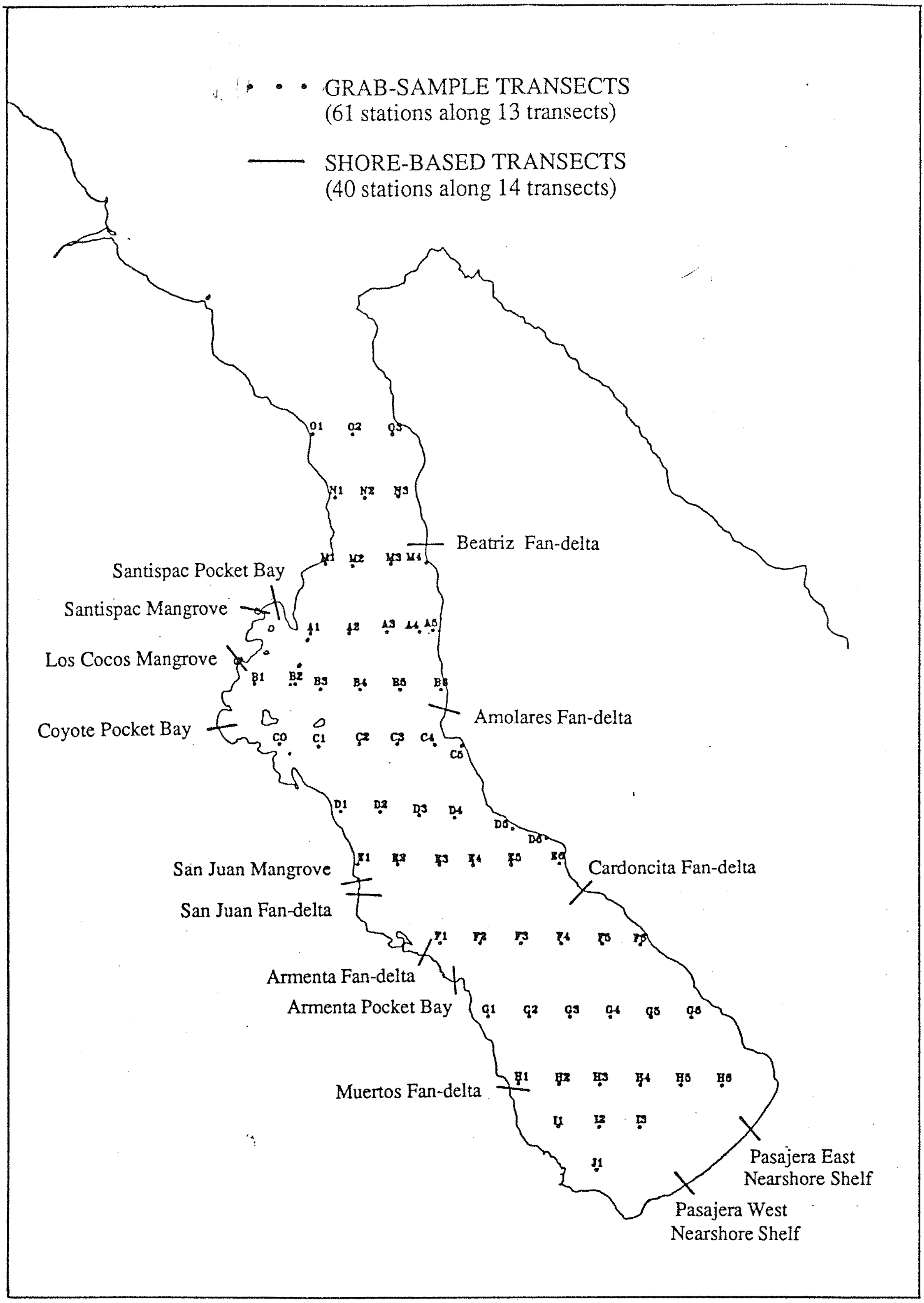


Figure 8: Sample standardized data sheet.

Sample Number 15 **Sample Site** CARDONCITO FAN

Depth 10 m

X	√	--
major	minor	trace

Clastic Grain Sizes

medium pebbles	fine pebbles	vcs	cs	ms	fs	vfs	coarse silt	fine silt	mud	clay
			-	√	X	X	X	√		

Clastic Grain Rounding

angular	subangular	subrounded	rounded	well-rounded
	X	X		

Clastic Grain Colors

black	grey	brown	rust	pink	white	clear	other	Mt
	√	√	√		√	√		√

Carb-Clastic Ratio (by volume)

carbonate |______|______|___X___|______|______| clastic

Carbonate Composition

gastropods	mollusca	algae	other
	X		

Mollusca Fragment Size

>20mm	10-20 mm	5-10 mm	1-5 mm	<1 mm
		√	X	X

Red Algae Fragment Size

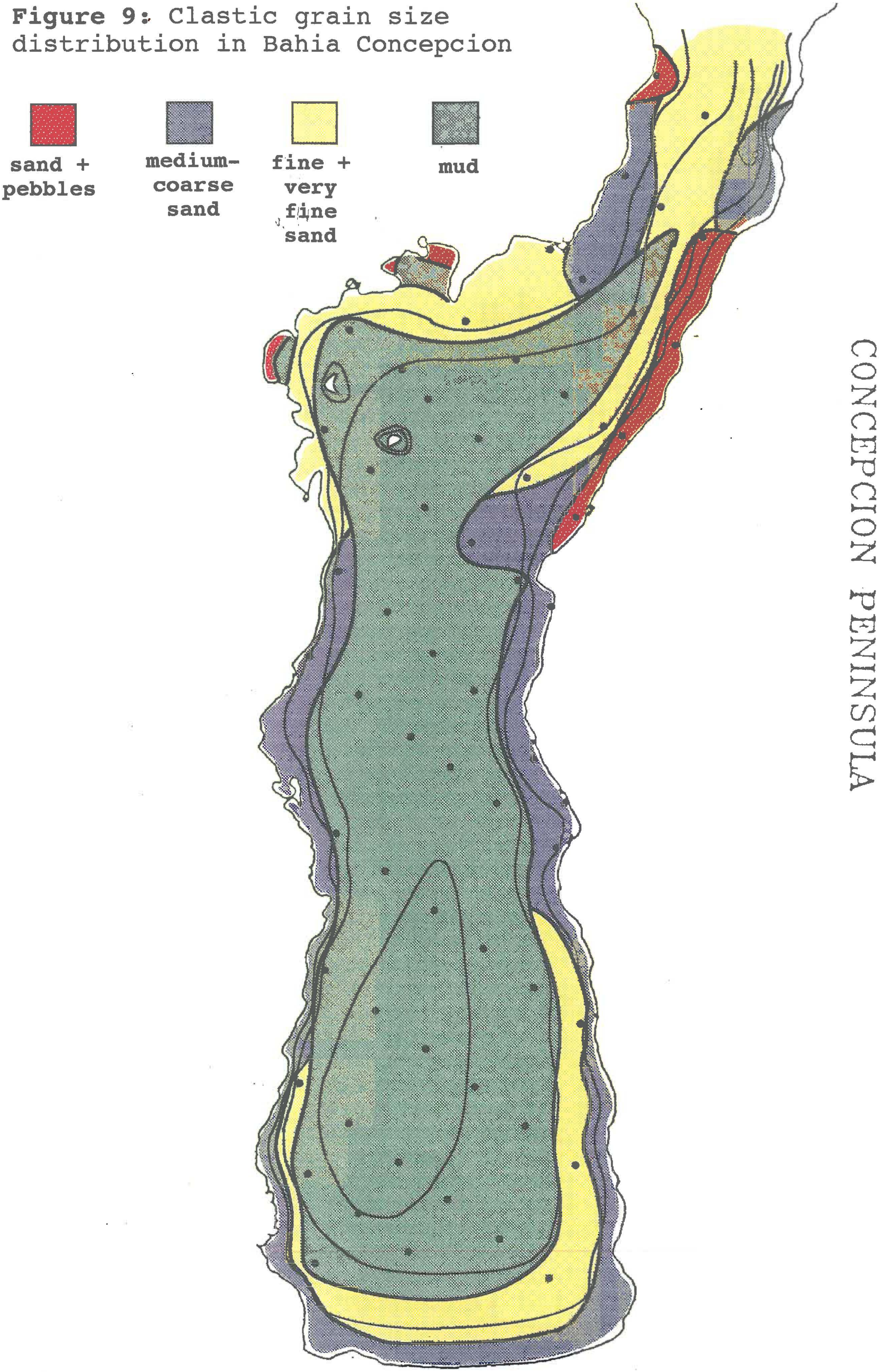
>20mm	10-20 mm	5-10 mm	1-5 mm	<1 mm

Overall Color

flat brown	deep brown	dark grey	light grey	black	olive	pink	white	dun	other
	L		X						

Other Comments

Figure 9: Clastic grain size distribution in Bahia Concepcion



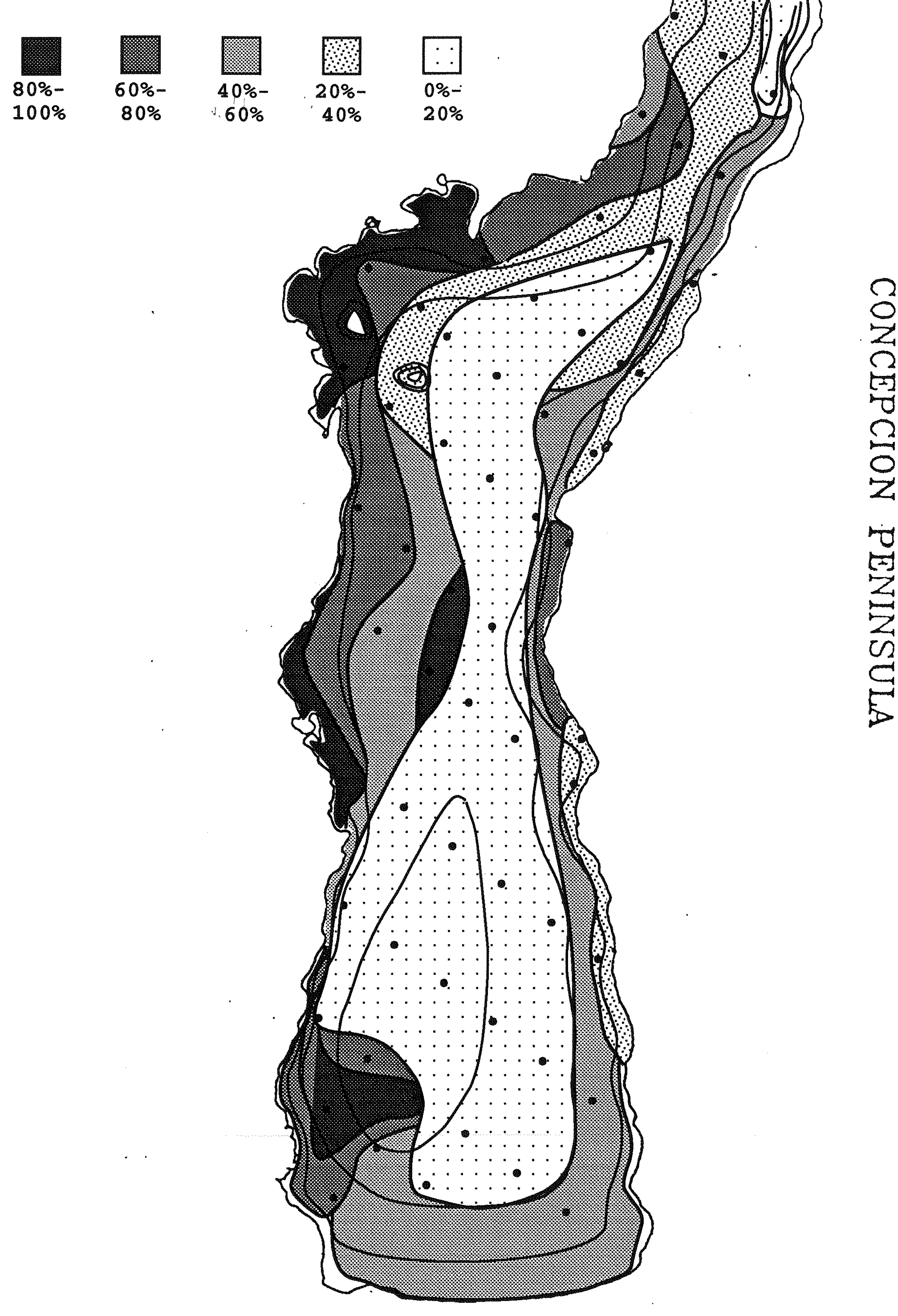


Figure 10: Carbonate abundance in Bahia Concepcion

Figure 11: Composition of carbonate sediments in Bahia Concepcion

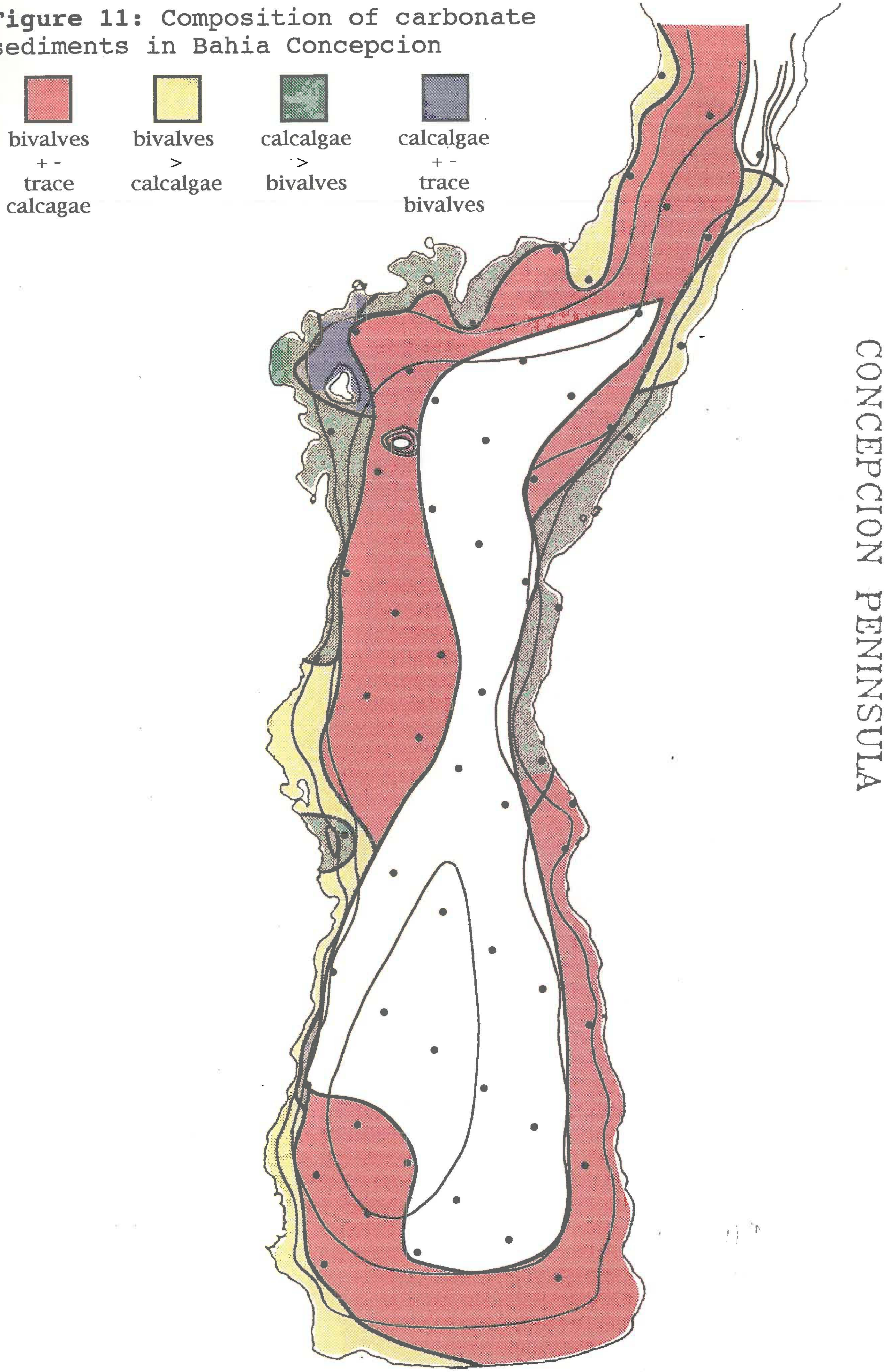


Figure 12: Lithofacies of Bahia Concepcion

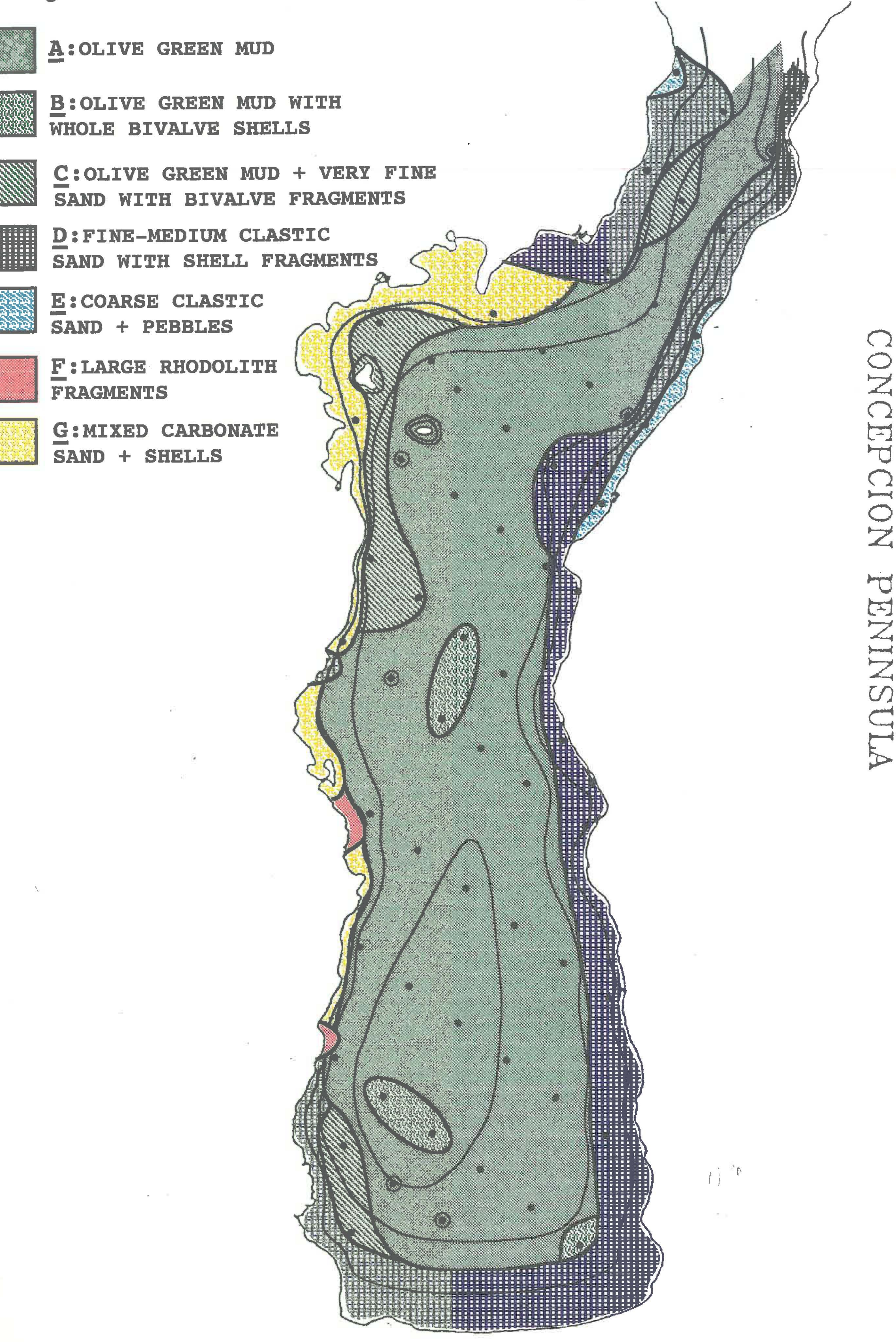


Figure 13: Stream profiles for drainages on the west side of Bahia Concepcion.

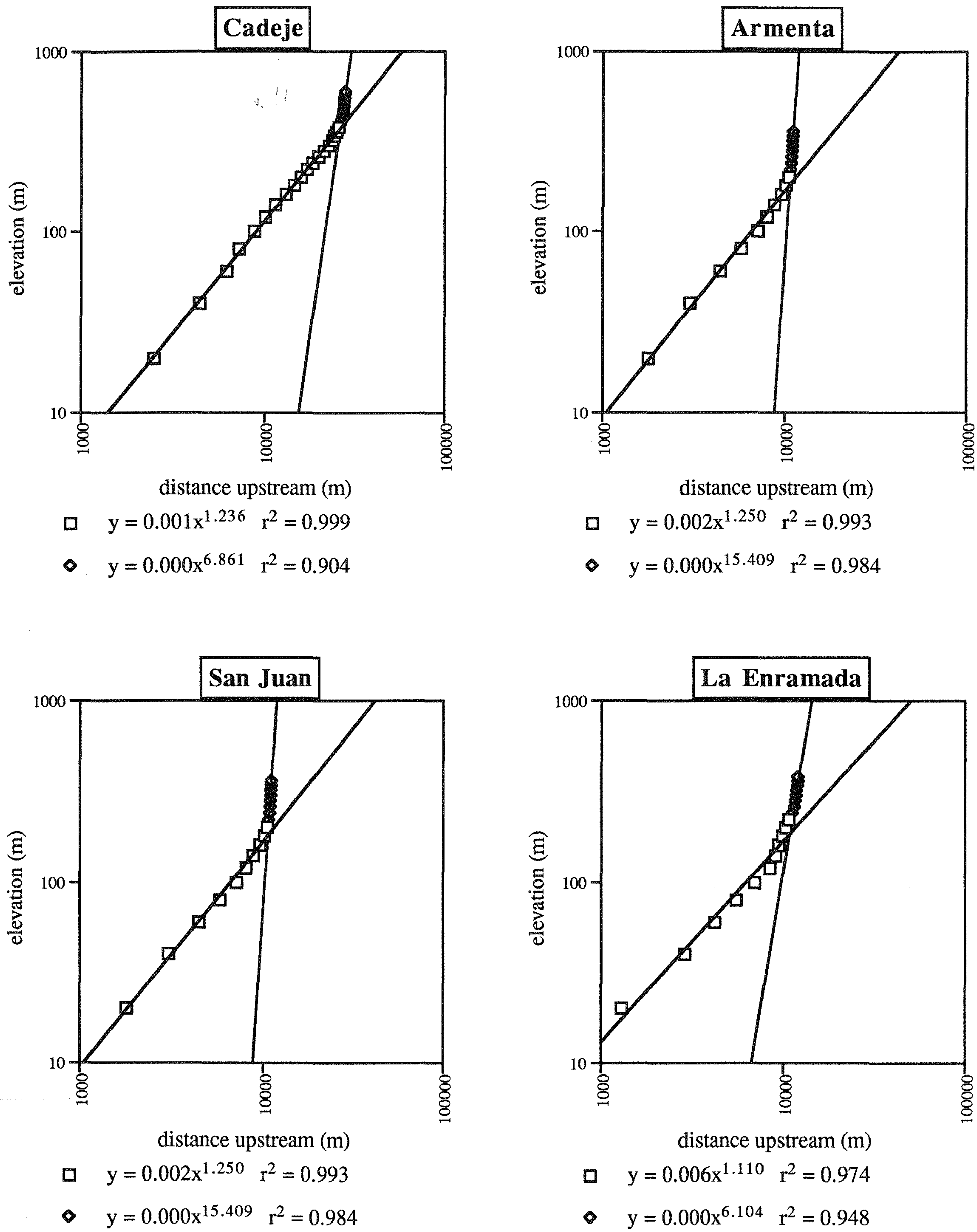
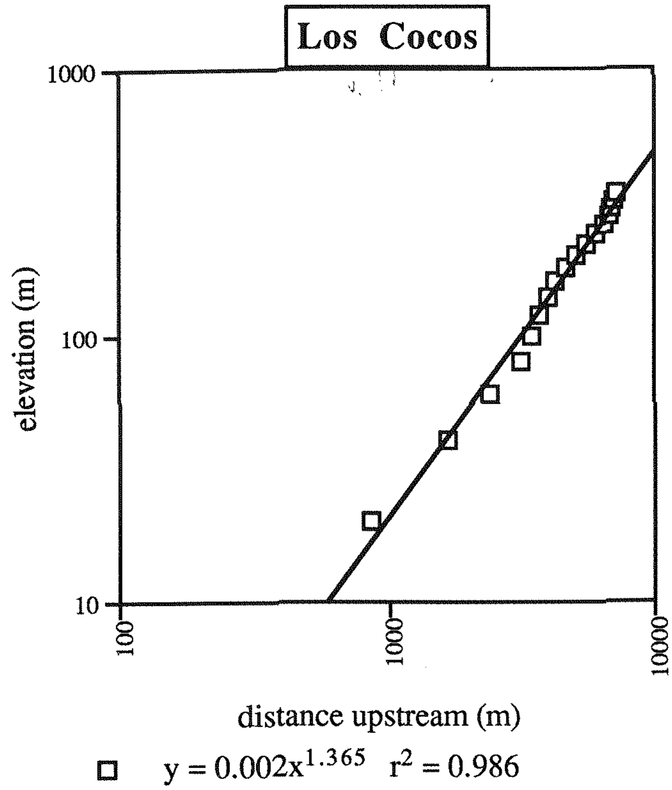
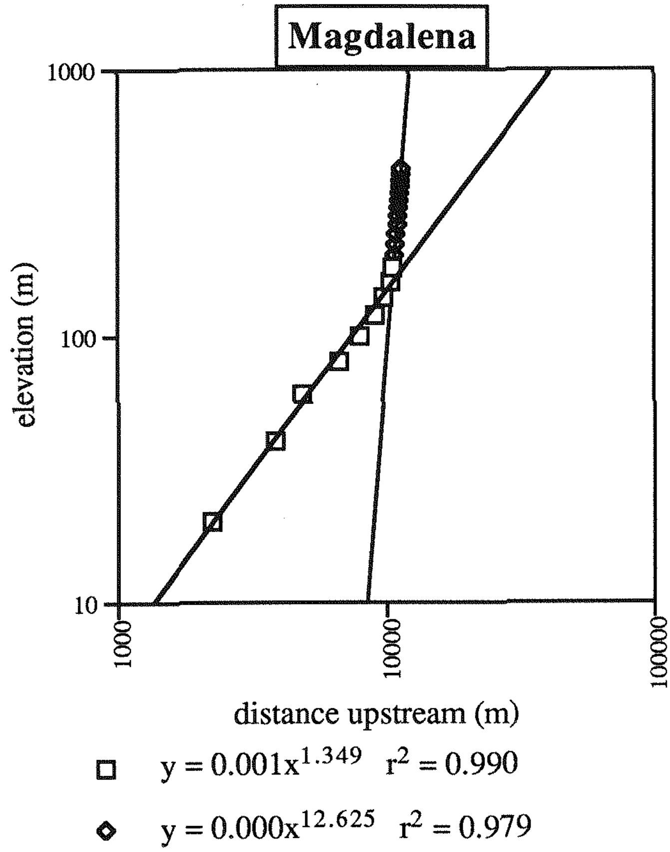


Figure 13, continued: Stream profiles for drainages on the west side of Bahia Concepcion.





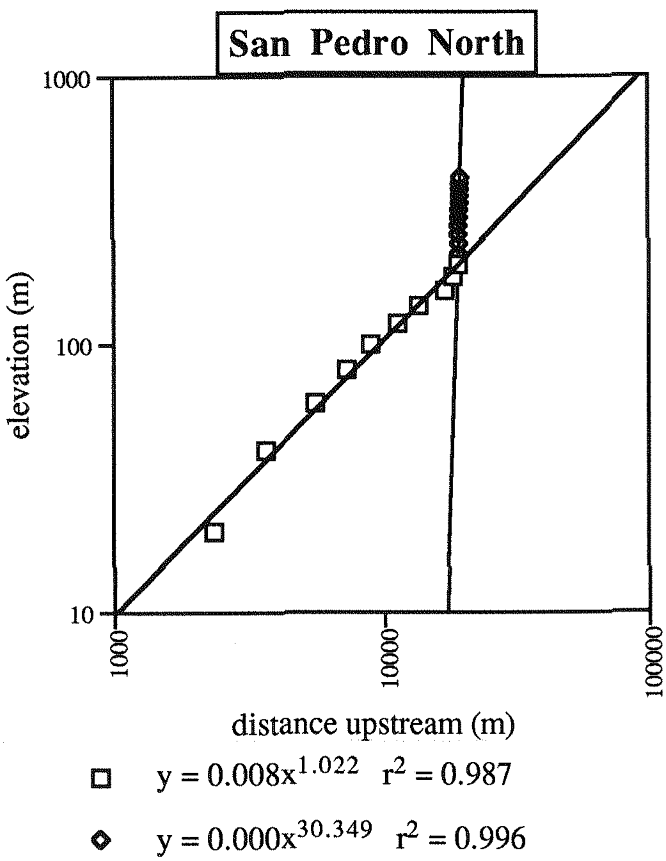
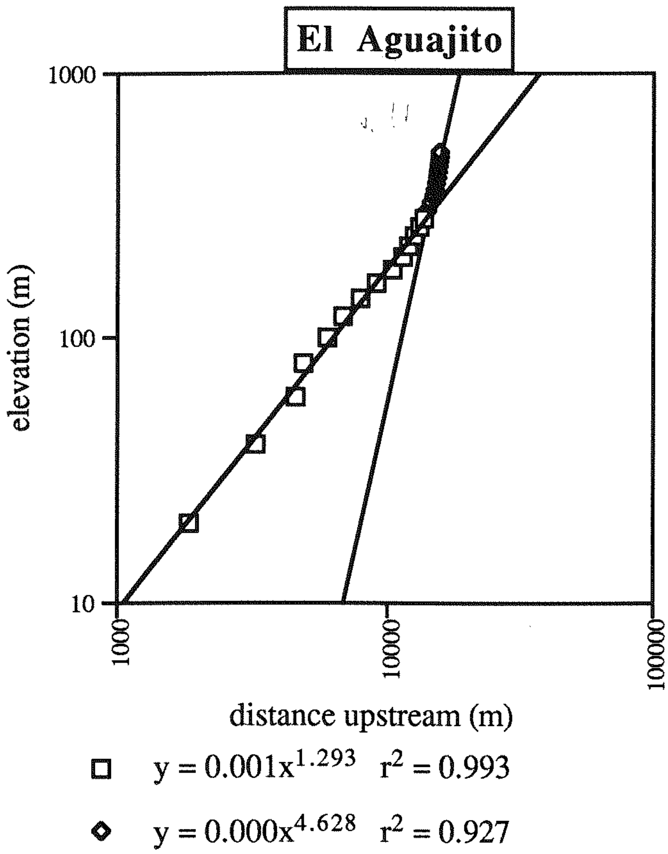
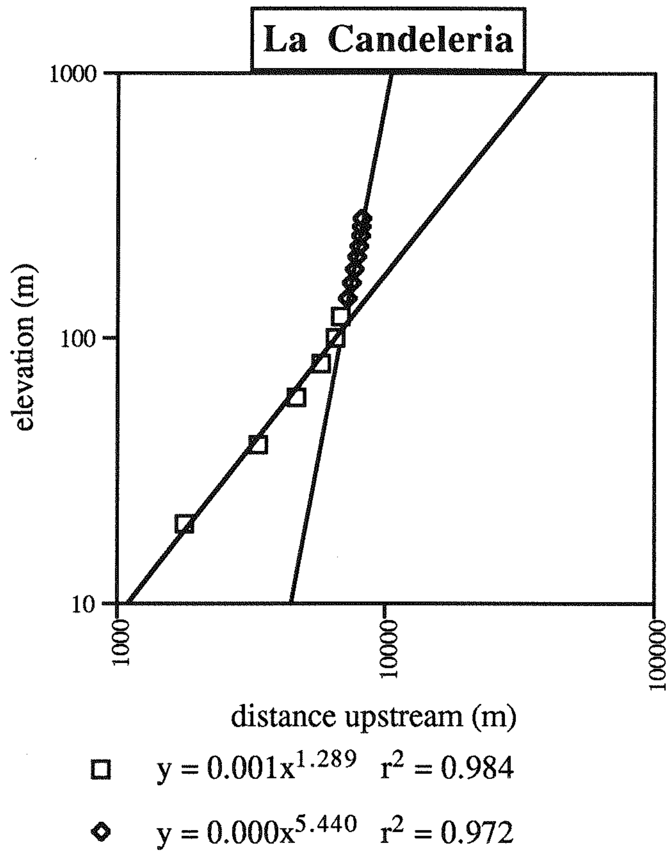


Figure 14: Stream profiles for selected drainages on the south side of Bahia Concepcion.





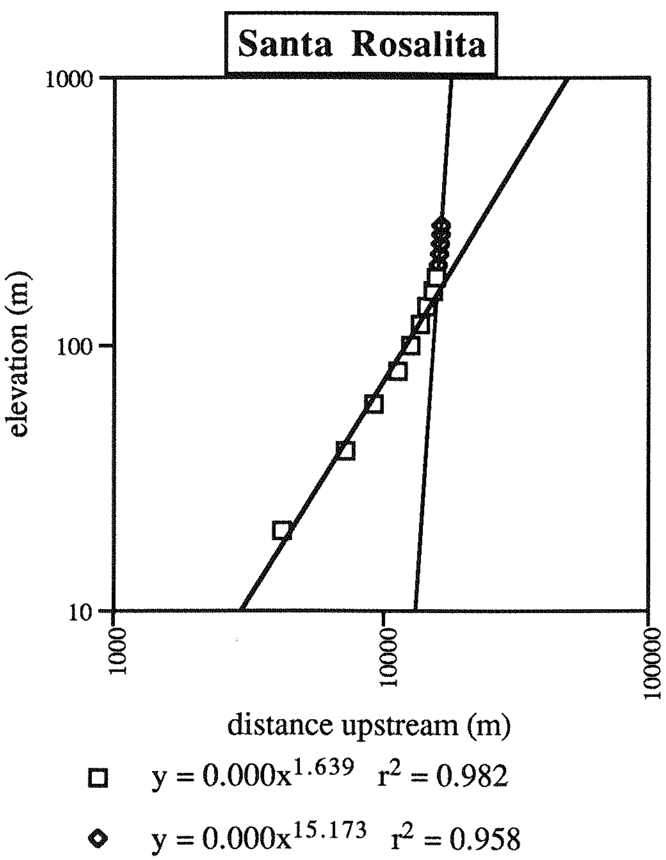


Figure 15: Stream profiles for drainages on the east side of Bahia Concepcion.

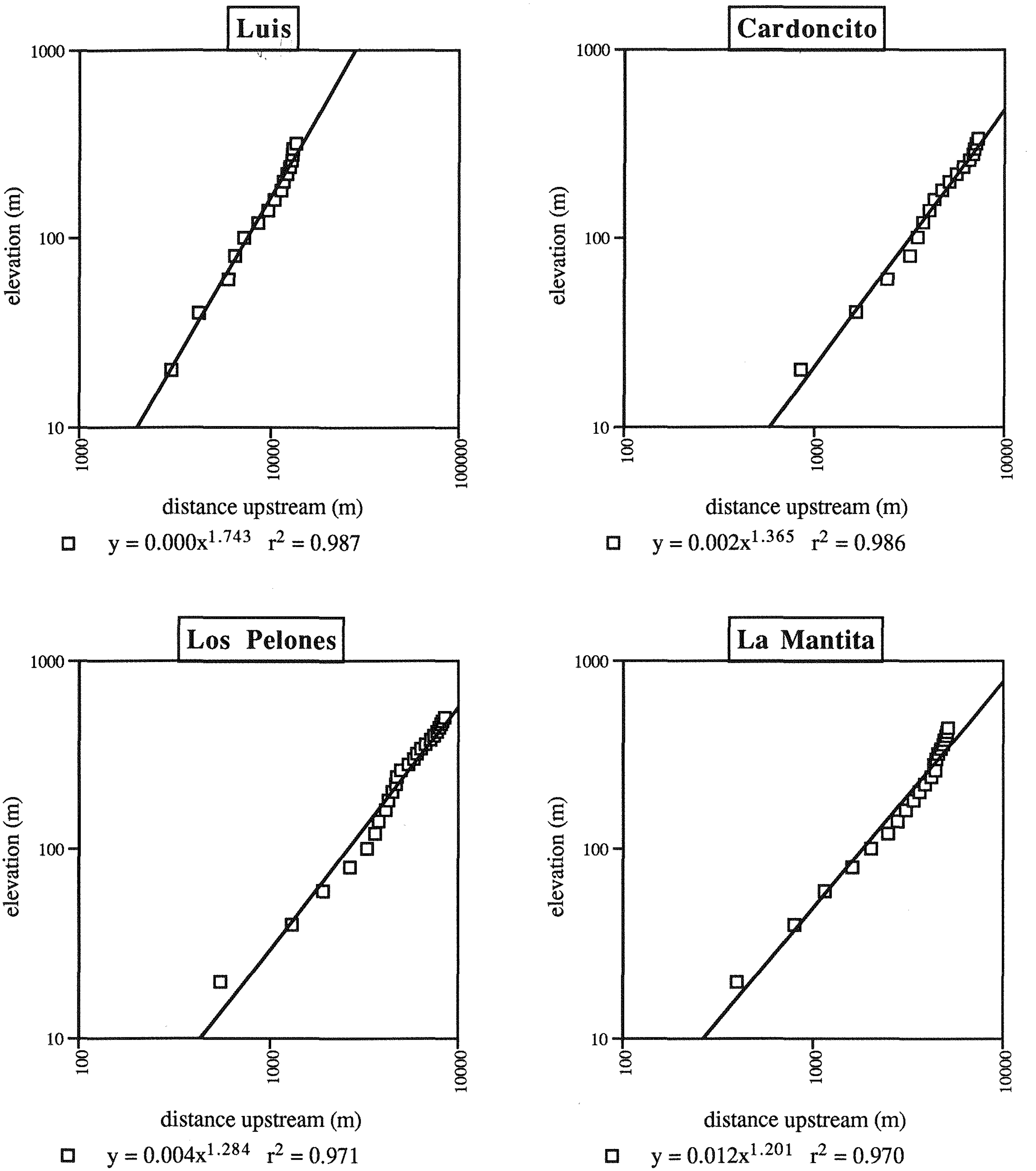


Figure 16: Key to section symbols.

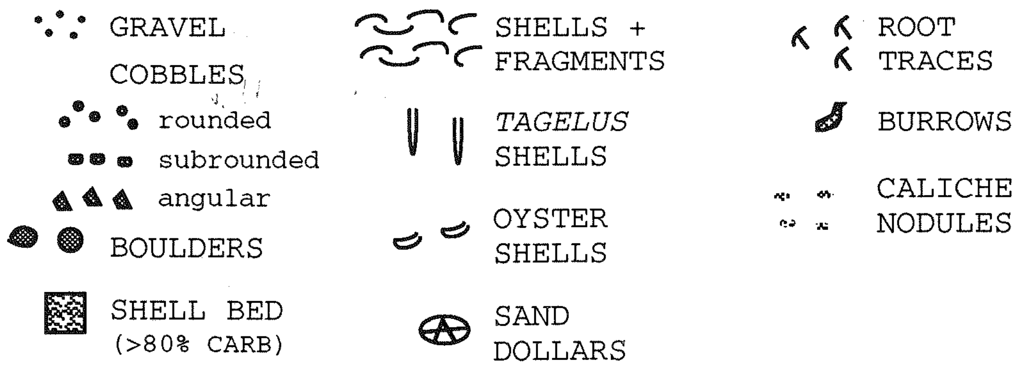


Figure 17: Section 1; measured on north bank of Arroyo de Arce; N 26°04.789', W 111°22.258'; Strike: 0° N; Dip 38° E

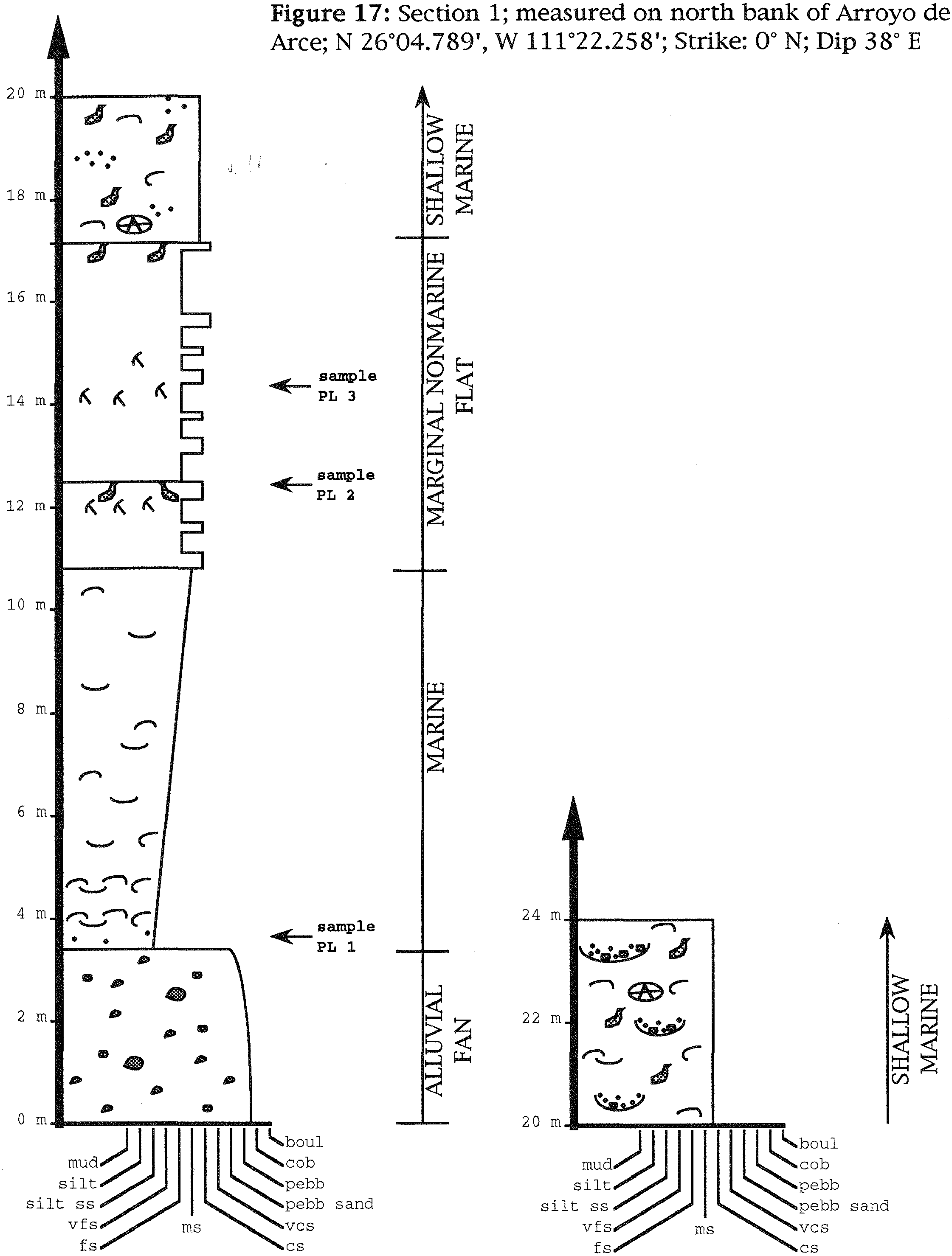


Figure 18: Section 2; south side of Arroyo de Arce; N 26°04.701', W111°22.087'; strike: 21°N, dip: 39°E

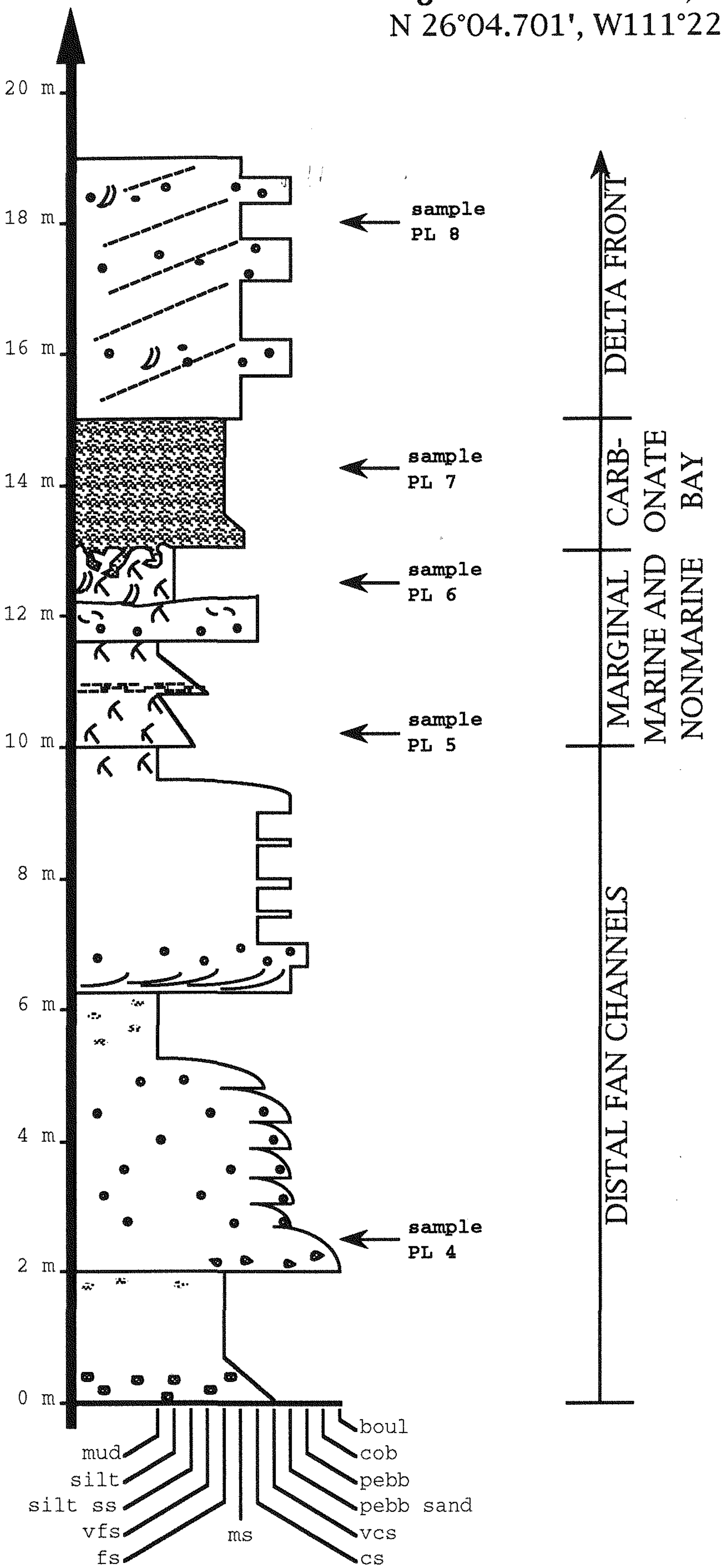


Figure 19: Section 3; measured on south side of Arroyo de Arce; N 26°04.829', W 111° 21.747'; strike: 32°N; dip: 22°E

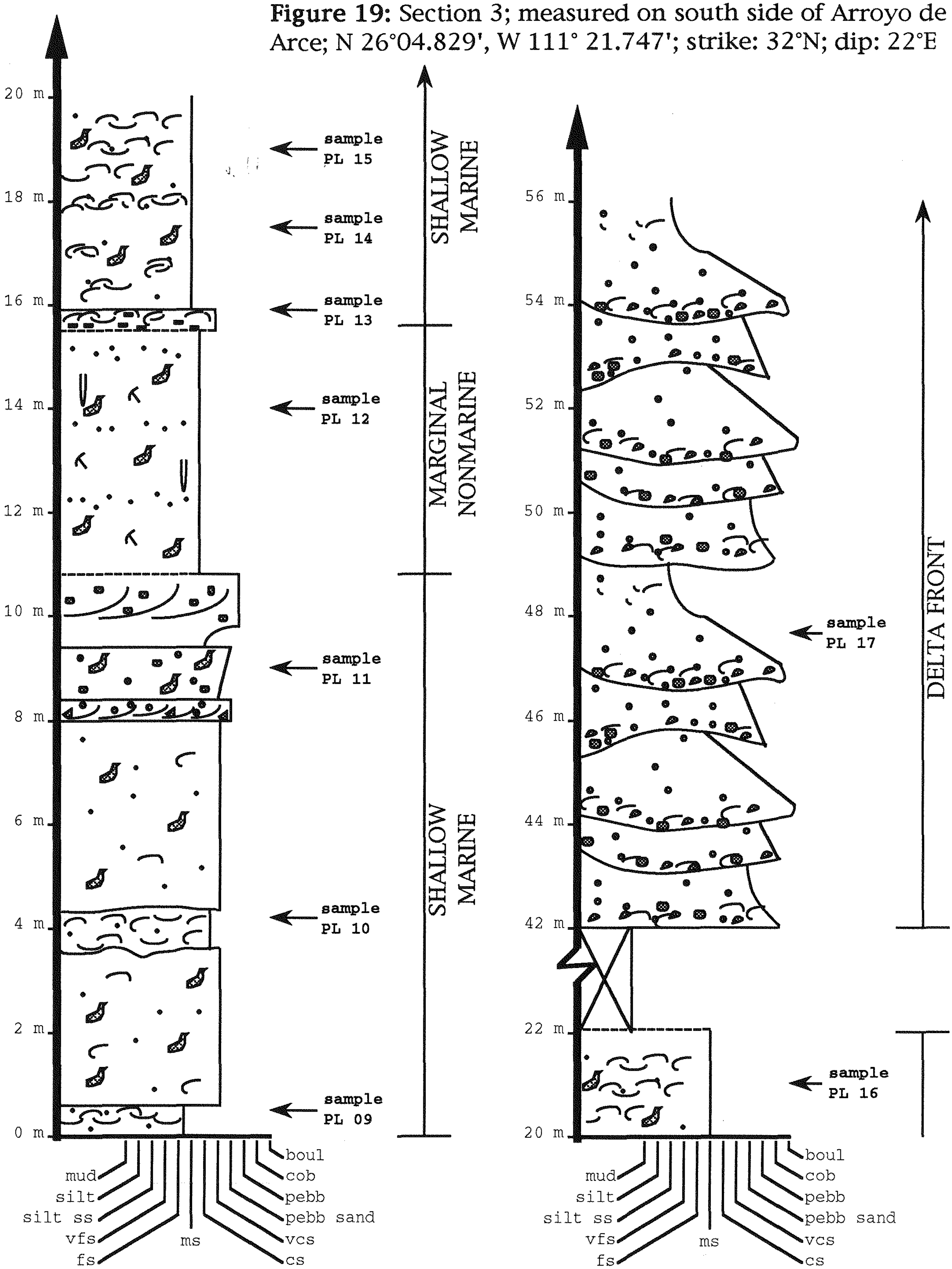


Figure 20: Section 4; north side of Arroyo de Arce; N26° 4.820', W 111° 21.066'; strike: N18°, dip: 30°E