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Late Miocene volcanism and marine incursions in the San Lorenzo Archipelago, Gulf of California, Mexico

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ABSTRACT

During Late Miocene time extensional deformation and restricted volcanic activity related to the vanishing Miocene volcanic arc occurred in the margins of the northern part of the present Gulf of California. As a result, local basins with periodical influence of marine water were formed in some areas like Bahía de los Ángeles, Bahía Las Ánimas, Ángel de la Guarda Island and the San Lorenzo Archipelago.

The stratigraphic sequence of the San Lorenzo Archipelago is formed by a series of evaporitic and clastic deposits that overlie a crystalline basement and indicate alternate transgressive and regressive periods. Minor effusive andesitic volcanism, normal faulting and sedimentation occurred simultaneously; the end of local sedimentation coincides with an increase of basaltic to andesitic volcanic activity 5 ± 1 Ma ago. The stratigraphic sequences of San Lorenzo Island and eastern Sierra Las Ánimas in the peninsula are correlative. In the Sierra Las Ánimas, the volcanic and coarse-grained sedimentary rocks predominate, and represent the western limit of a basin. In the Sierra Las Ánimas, the age of andesitic lava underlying the sedimentary rocks is 7.8 ± 0.2 Ma, bracketing the age of the marine sedimentary sequence in the Late Miocene (approximately 7.8 to 5 Ma). The present position of the northern part of the archipelago with respect to the sierra indicates that the islands moved towards the southeast as a rigid block, along the San Lorenzo and Partida fault zones.

Keywords: Late Miocene, Pliocene, volcanism, marine incursions, San Lorenzo Archipelago, Gulf of California.

RESUMEN

Durante el Mioceno Tardío, las márgenes de la parte septentrional del Golfo de California actual experimentaron una deformación extensional y actividad volcánica restringida relacionada con el arco volcánico miocénico en extinción. Como consecuencia, en áreas como Bahía de los Ángeles, Bahía Las Ánimas, Isla Ángel de la Guarda y el Archipiélago San Lorenzo, se formaron cuencas locales con influencia de incursiones periódicas de agua marina.

La secuencia estratigráfica del Archipiélago San Lorenzo está formada por series de depósitos clásticos y evaporíticos que sobreyacen a un basamento cristalino e indican periodos alternados de transgresiones y regresiones. Sedimentación, volcanismo efusivo andesítico restringido y fallamiento normal son contemporáneos en el archipiélago; la finalización de la sedimentación coincide con un incremento en la actividad volcánica andesítica y basáltica fechada en 5 ± 1 Ma. Las secuencias estratigráficas de la Isla San Lorenzo y el oriente de la Sierra Las Ánimas en la península son correlacionables. En la Sierra Las Ánimas predominan las rocas rocas volcánicas y sedimentarias de grano grueso del extremo occidental de la cuenca formada por la sierra y el archipiélago. La *edad de una lava andesítica que infrayece a las rocas sedimentarias es 7.8 ± 0.2 Ma, restringiendo la edad de la secuencia sedimentaria marina al Mioceno tardío (aproximadamente entre 7.8 y 5 Ma). La posición actual de la parte norte del archipiélago con respecto a la sierra indica que las islas se movieron como un bloque rígido hacia el sureste a lo largo de las zonas de falla San Lorenzo y Partida.*

Palabras clave: Mioceno tardío, Plioceno, volcanismo, incursiones marinas, Archipiélago San Lorenzo, Golfo de California.

INTRODUCTION

The San Lorenzo Archipelago is one of a group of large islands detached from either the peninsular or the continental mainland, as a consequence of the extension and right lateral slip faulting during evolution of the Gulf of California. During the entire process, basins with ocean-like floor developed in the central and southern parts of the Gulf, while smaller and restricted basins formed along the eastern margin of the Baja California peninsula. The 27 km-long archipelago formed by the San Lorenzo and Las Ánimas islands is located 20 km northeast of Bahía San Rafael, in the central part of the Gulf of California (Figure 1). Previous works postulated that the main stage of the volcanic activity in the islands was Miocene (Gastil *et al*., 1975; Desonie, 1992). However, Gastil *et al*. (1979) suggested that a sequence formed by basaltic lava flows with interstratified marine sediments in the San Lorenzo Island could be Pliocene.

The volcanosedimentary sequence of the archipelago is similar to that exposed in the eastern side of the Sierra Las Ánimas. There, the basement is made up of Paleozoic metamorphic and Cretaceous granitic rocks. The western side, and part of the top of the Sierra Las Ánimas, is covered by felsic pyroclastic rocks, and andesitic to basaltic lavas ranging in age from middle to late Miocene (Delgado-Argote and García-Abdeslem, 1999). On the eastern side of the sierra, the volcanic rocks seem to be younger and are closely related to local sedimentary basins (Delgado-Argote, 2000).

The only available geologic map of the San Lorenzo Archipelago is at a scale of 1:250,000 (Gastil *et al*., 1975). In this map, Paleozoic schist and quartzite, Cretaceous tonalite, and Miocene felsic volcanic rocks form the main lithologic units.

In this paper we present new isotopic ages data of volcanic rocks from the San Lorenzo Island, a stratigraphic correlation with the volcanosedimentary sequence of eastern Sierra Las Ánimas, and a description of the stratigraphic units of the San Lorenzo and Las Ánimas islands, with emphasis on the Cenozoic cover. Also, we present the results of a provenance analysis and our interpretation of the sedimentary depositional environment.

REGIONAL GEOLOGIC FRAMEWORK

An overview of the geology of the State of Baja California and the islands of the northern Gulf of California is presented in Gastil *et al*. (1975). These authors show that Tertiary volcanic and sedimentary rocks, ranging in age from Miocene to Recent, occupy extensive areas of the eastern margin of the peninsula, and rest on Paleozoic metamorphic rocks and Cretaceous granitoids (Gastil *et al*., 1975).

The regional metamorphic basement is composed of a metasedimentary sequence and metalavas of Devonian age. Paleozoic environments of deposition in the northeastern margin of the peninsula range from continental slope to basin (Campbell and Crocker, 1993). The sequence that crops out in the Sierra La Asamblea correlates with similar sequences from northern Baja California and southern Sonora (Canal de Ballenas Group, in Campbell and Crocker, 1993). The metamorphic rocks are intruded by granitic Cretaceous plutons, that crop out extensively in the northern part of the peninsula to latitude 28°N (Gastil *et al*., 1975). Intrusive rocks are absent between Bahía San Rafael and Bahía Las Ánimas. However, at latitude 28.3°N, plutons crop out along a 30 km wide, E-W oriented continuous strip (Figure 1). After a reconstruction of the paleoposition of the archipelago, 60 km northwest of its present position, based on the closure of the major basins of the Gulf of California (Delgado-Argote, 2000), the granitic rocks of southern San Lorenzo Island are located East of the Sierra Las Ánimas, being part of the same plutonic complex. The volcanic and sedimentary sequence of the island can also be correlated with part of the Late Miocene (?) strata described in the northern and central parts of Bahía Las Ánimas (Vázquez-Jaimes, 2000).

According to Sawlan (1991), the age of the calc-alkalic arc-related volcanism in the eastern margin of the peninsula ranges from 24 to 12.5 Ma. Arc-like volcanic activity has occurred continuously around the Gulf since Late Miocene time, and it has been documented in the Puertecitos area (Martín-Barajas *et al.*, 1995), Ángel de la Guarda Island (Delgado-Argote, 2000), San Esteban Island (Desonie, 1992), La Reforma-El Aguajito-Tres Vírgenes volcanic complex (Demant, 1981; Sawlan,

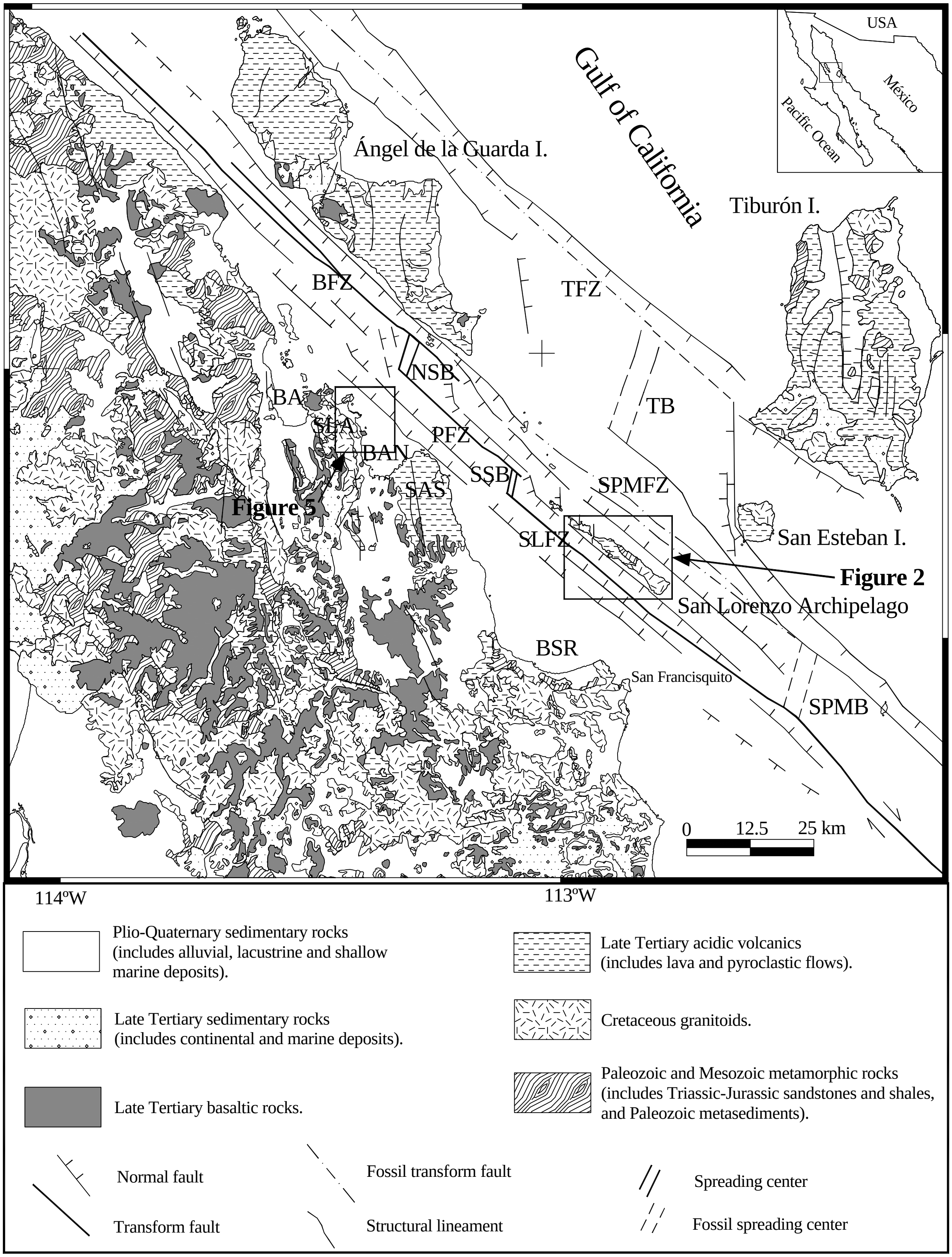

Figure 1. Lithologic units and regional structural features of central Gulf of California and Baja California peninsula. Abbreviations: BA: Bahía de los Ángeles, BAN: Bahía Las Animas, BFZ: Ballenas Fault Zone, BSR: Bahía San Rafael, NSB: North Salsipuedes Basin, PFZ: Partida Fault Zone, SAS: Sierra Agua de Soda, SLA: Sierra Las Animas, SSB: South Salsipuedes Basin, SLFZ: San Lorenzo Fault Zone, SPMB: San Pedro Mártir Basin, SPMFZ: San Pedro Mártir Fault Zone, TB: Tiburón Basin, TFZ: Tiburón Fault Zone (modified from Delgado-Argote, 2000).

1991, Capra *et al*., 1998; Garduño-Monroy *et al*., 1993), La Purísima area (Sawlan, 1991) and at the Mencenares volcanic field and Coronado Island (Bigioggero *et al*., 1995). In some of these places, this post-subduction, localized volcanism has a structural control associated with the evolution of the Gulf of California (Sawlan, 1991; Bigioggero *et al*., 1995).

Most of the exposed lithologic units between Bahía de los Ángeles and Bahía San Rafael are Neogene volcanic rocks (Delgado-Argote, 2000; Figure 1). Geologically, the best-known region near the study area is Bahía de los Ángeles, where the oldest recognized rocks resting on the granitic basement are 18.8 ± 1.0 Ma old andesitic flows. The andesitic flows are pillowed and include undifferentiated sandstones in the interpillow cavities. The andesitic flows are covered by 14.0 ± 0.1 Ma old ignimbrites and 12.1 ± 0.1 Ma old basaltic flows (Delgado-Argote *et al*., 2000 and Delgado-Argote and García-Abdeslem, 1999). The islands of the Gulf of California have been poorly studied. Regional geologic mapping of Angel de la Guarda Island was initially made by Gastil *et al*. (1975), and later, Escalona-Alcázar and Delgado-Argote (1998) conducted a detailed study in the region of El Paladar, located in the southwestern coast of Ángel de la Guarda Island, where the stratigraphic sequence is made up of air-fall tuffs deposited in a low energy marine environment, andesitic lavas and dacitic pyroclastic flows. The close spatial relationships between the andesitic lavas and dacitic domes dated at 3.0 ± 0.1 Ma (Delgado-Argote, 2000), indicate that the volcanic rocks located in the southern part of the island extruded contemporaneously. Late Pliocene volcanic activity is widespread in the central part of the Gulf of California and it has also been documented in the San Esteban (Desonie, 1992), Tiburón (Gastil and Krummenacher, 1977; Gastil *et al*., 1979) and Coronado (Bigioggero *et al*., 1995) islands (Figure 1), and in Cerro Mencenares (Bigioggero *et al*., 1995) and Puertecitos (Martín-Barajas *et al*., 1995) in the peninsular mainland (the last three areas are not shown in figures).

Marine fossil invertebrates with Caribbean affinities are found in the present gulf region since middle Miocene times (Smith, 1991). Marine incursions probably occurred during the early Miocene, since fossiliferous marine sediments occur in the matrix of 17.7 ± 0.6 Ma old brecciated andesitic to dacitic flows emplaced into sandstones in the northeastern part of Ángel de la Guarda Island (Delgado-Argote, 2000). These rocks, together with the pillow lavas of the Sierra Las Ánimas, which probably are also associated with marine environments, are the oldest evidences of marine incursions in the Gulf area. Mollusk distribution around the Gulf of California indicates that during Middle Miocene time the proto-gulf extended as far north as the Salton Trough (Smith, 1991). Bivalve-bearing Middle Miocene marine sediments have been documented in Tiburón Island (Gastil *et al*., 1979; Smith, 1991) and Bahía de los Ángeles (Delgado-Argote *et al*., 2000). Most of the Neogene sediments in the largest islands of the northern Gulf of California, as well as in the Loreto, Santa Rosalía, San Felipe, Laguna Salada and Imperial Valley areas are Late Miocene to Pliocene in age (Smith, 1991).

Methods

Since topographic maps of San Lorenzo and Las Ánimas islands are not available, geologic mapping was conducted with aerial photographs (INEGI, scale 1:20,000). Structural mapping and sampling of representative lithologic units was made during field verification of the photogeologic map. For the petrographic analyses, we adopted the modal point counting method of Gazzi-Dickinson (more than 500 points per section; Ingersoll *et al*., 1984); for volcanic rocks, crystals less than 0.1 mm long were considered matrix. Texture names used for igneous and metamorphic rocks follow MacKenzie *et al*. (1991) and Phillpotts (1989) respectively, and the classification and nomenclature used for sedimentary rocks is that of Adams *et al*. (1991) and Pettijohn *et al*. (1987).

Volcanic rock samples were dated in the Laboratorio de Geocronología of CICESE by the K-Ar method. The potassium analyses were run by duplicate on a Cole-Parmer flame photometer Model 2655-00 and in a Thermo Jarrell AA-Scan 1 atomic absorption spectrometer. Sample preparation techniques are described in Mora-Álvarez and Moreno-Rivera (1994) and Moreno-Rivera and López-Martínez (1996). Argon isotopic analyses were made by triplicate with a MS10 mass spectrometer, and sample preparation techniques are after Moreno-Rivera and López-Martínez (1996).

STRATIGRAPHY OF THE SAN LORENZO AND LAS ÁNIMAS ISLANDS

Paleozoic (?) greenschist facies metamorphic rocks and a tonalitic pluton crop out extensively in the central and southern part of San Lorenzo Island forming the crystalline basement. Metamorphic rocks of the central part of San Lorenzo Island include metapelites, metadiorite and metalavas (Figure 2). Metadiorite from the base of the metamorphic sequence shows poorly defined foliation, and it is composed mainly by plagioclase (An_{28}-An_{40}), biotite and quartz (sample 3, Table 1). Metapelites occupy the upper part of the sequence in central and western San Lorenzo Island, where foliation is well defined by the distribution of biotite and sillimanite (sample 4, Table 1); locally, euhedral andalusite and poorly defined crenulation cleavage is also observed. In the western part of San Lorenzo, the metasedimentary rocks are cut by E-W trending felsic dikes less than 20 cm thick; the uppermost part of the metamorphic sequence in the eastern part of San Lorenzo Island is intruded by a 2 to 4 m thick andesitic sill (sample 2, Table

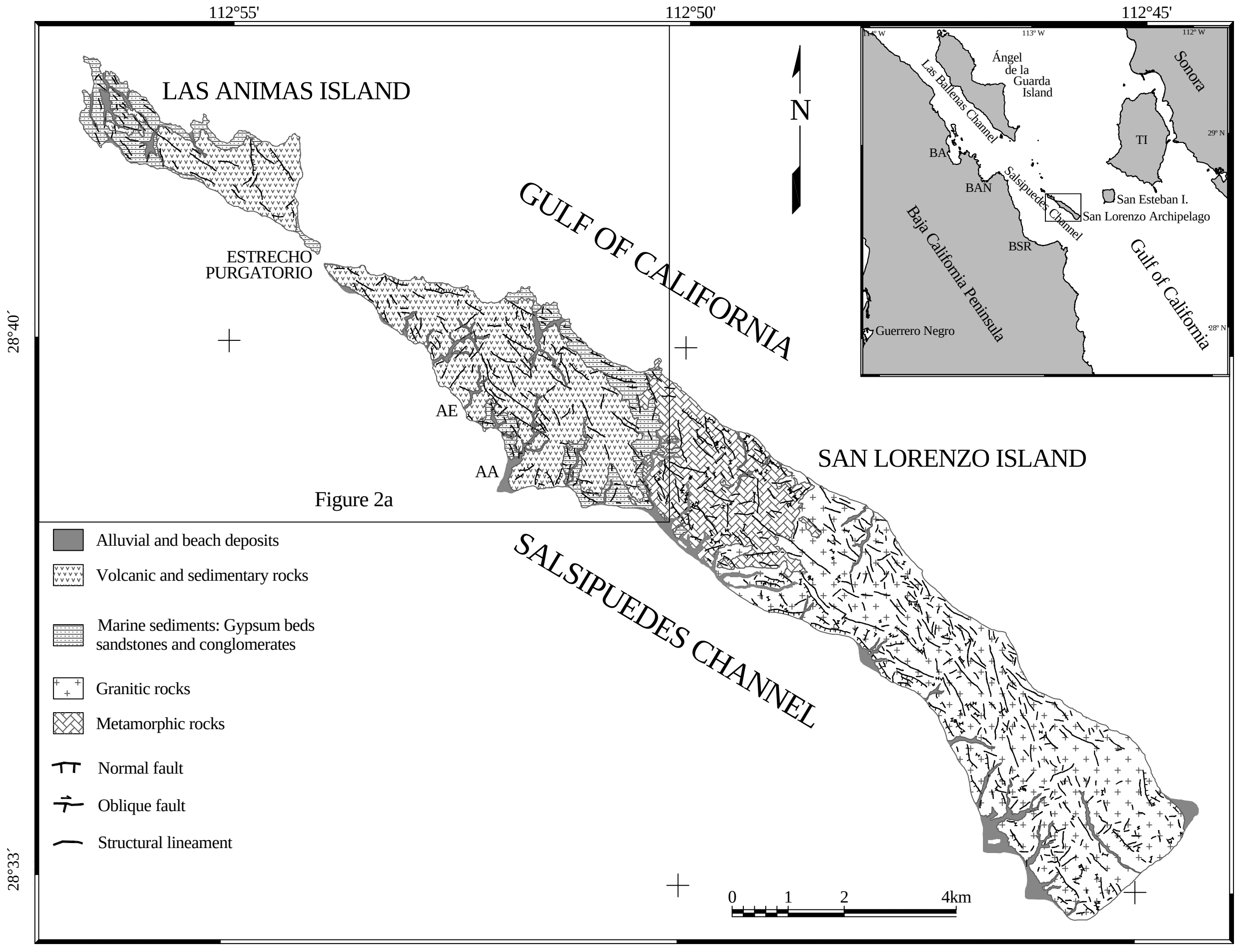

Figure 2. Simplified geologic map of San Lorenzo and Las Ánimas islands. AA= Arroyo Las Águilas and AE= Arroyo Los Esqueletos.

Table 1. Petrographic synthesis of representative intrusive and metamorphic rocks from San Lorenzo Island.

L	C	Coord	Qz	Plg	K	Bio	Chl	Calc	Sil	And	PlgMz	PlgF	HbMz	HbF	Indif.	Classification and Texture
1	V-98-4	112°52.2'/ 112°52.2'	29.4	56.7a	1.5	11.6c	0	x	0	0	0	0	0	0	0	Tonalite. Granular anhedral.
2	X-98-32	112°49.3'/ 112°49.3'	1.6		0	0	0	0	0	0	21.9a	37.4a	6.2c	19.3c	12.8	Andesitic sill. Inequigranular anhedral.
4	X-98-18	112°50.0'/ 112°50.0'	42.7	0	0	29.4	0	0	18.6	9.2c	0	0	0	0	0	Metapelite. Shistose recrystallized
3	X-98-17	28°38.0'/ 112°49.5'	4.9	42.5	0	29.1c	23.2	x	0	0	0	0	0	0	0	Metadiorite. Recrystallized

ABBREVIATIONS: L= laboratory sample number, C= field sample number. CONTENT: And= andalusite, Bio= biotite, Calc= calcite, Chl= chlorite, HbF= hornblende phenocrysts, HbMz= hornblende matrix, Indif.= undifferentiated (possibly quartz and/or feldspar), K= potassium feldspar, Plg= plagioclase, PlgF= plagioclase phenocryst, PlgMz= plagioclase matrix, Qz= quartz, Sil= sillimanite. MISCELLANEOUS: a= hydrothermal alteration, c= chloritization, x= abundance <1%.

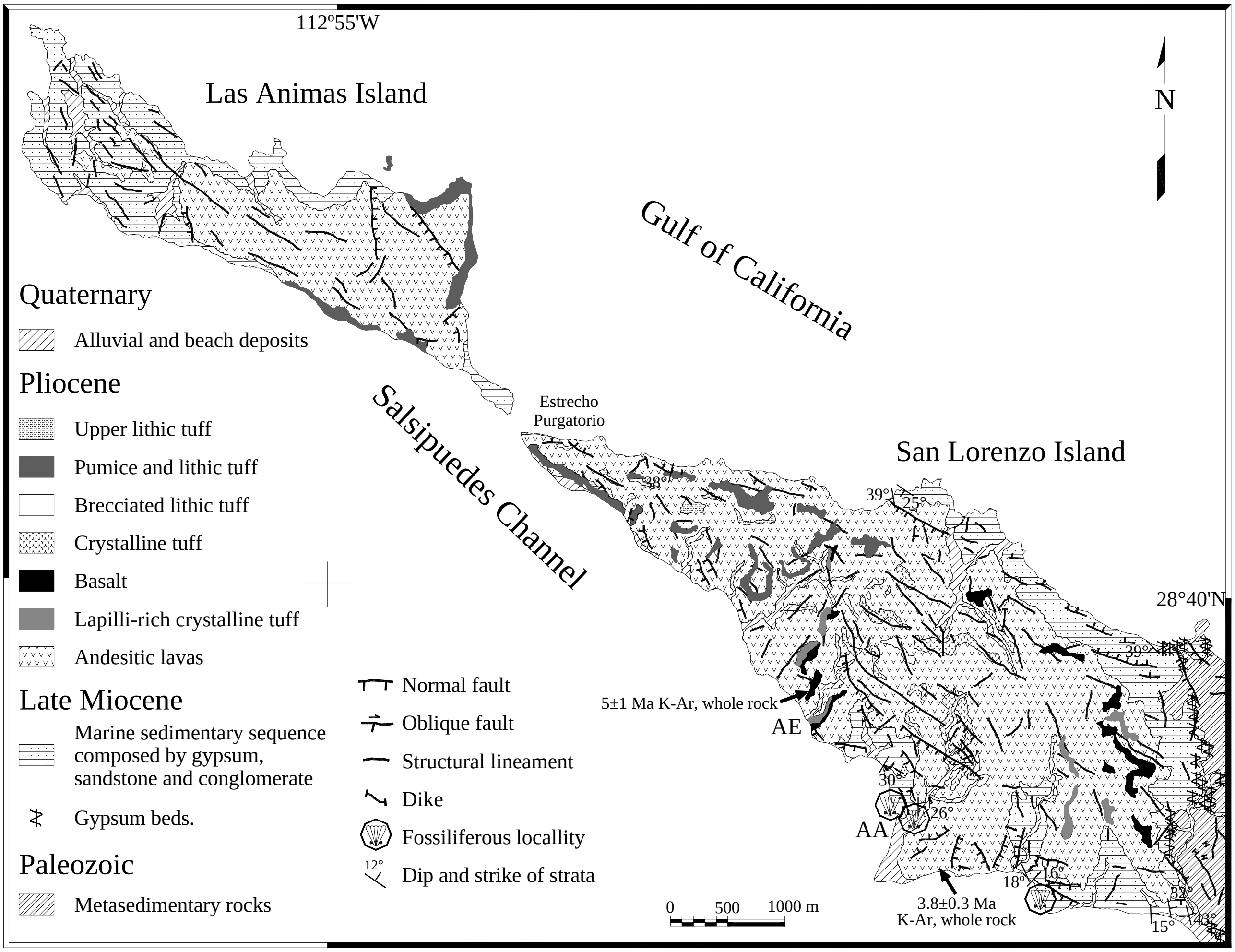

Figure 2a. Detailed geologic map of northern San Lorenzo and Las Ánimas islands. See Figure 2 for location and abbreviations.

1). A strong silicification and brecciation extends approximately 3 m around the sill. Since the metamorphic sequence of San Lorenzo Island is lithologically similar to that described in the Sierra La Asamblea (Campbell and Crocker, 1993) and the Sierra La Libertad (Delgado-Argote and García-Abdeslem, 1999), we assume that they are part of the same lithodemic unit.

The southern part of the San Lorenzo Island is formed by a biotite-hornblende bearing tonalite pluton that intrudes the metamorphic rocks. Contact relationships are sharp, schist screens are scarce, and moderate foliation is locally observed. A petrographic analysis of a representative tonalite is given in Table 1. Andesitic dikes 40 to 50 cm thick intrude the pluton in the western side of San Lorenzo.

The basement of the northern part of the San Lorenzo Archipelago is unconformably overlain (locally by normal faults) by a tertiary volcano-sedimentary sequence (Figures 2 and 2a). The bottom of the sequence is formed by a gypsum unit, which is 5 to 30 m thick on the western coast, and less than 7 m thick on the eastern coast. From the central part of San Lorenzo Island, the evaporitic beds thin rapidly towards the northwest and gradually to the northeast. In the western coast the first five meters of the basal section contains two interbedded silicified sandstone strata and an andesitic dome cuts the gypsum deposit. The dome is markedly argillitized and oxidized (sample 5, Figure 3, Table 2).

On the eastern coast, the central part of the evaporitic sequence contains interbedded sandstones and a 60 cm-thick tuff horizon. The evaporite deposits of the top of the western coast sequence are interbedded with yellow and gray arcosic arenite; differences in color and granulometry indicate lateral facies change (samples 6 and 7, Table 3, Figure 3). The 25 to 60 m thick yellow sandstone (Unit M, Figure 3) is comprised of 10 cm to 1 m thick, well-consolidated beds. This is a well-sorted deposit varying from mature to submature sand and cemented by calcite. To the southeast, outcrops of the yellow sandstone changes laterally to a gray sandstone (Unit L, Figure 3) showing thickness variations from 30 to 60 m, with beds 10 cm to 1 m thick. Both, the yellow

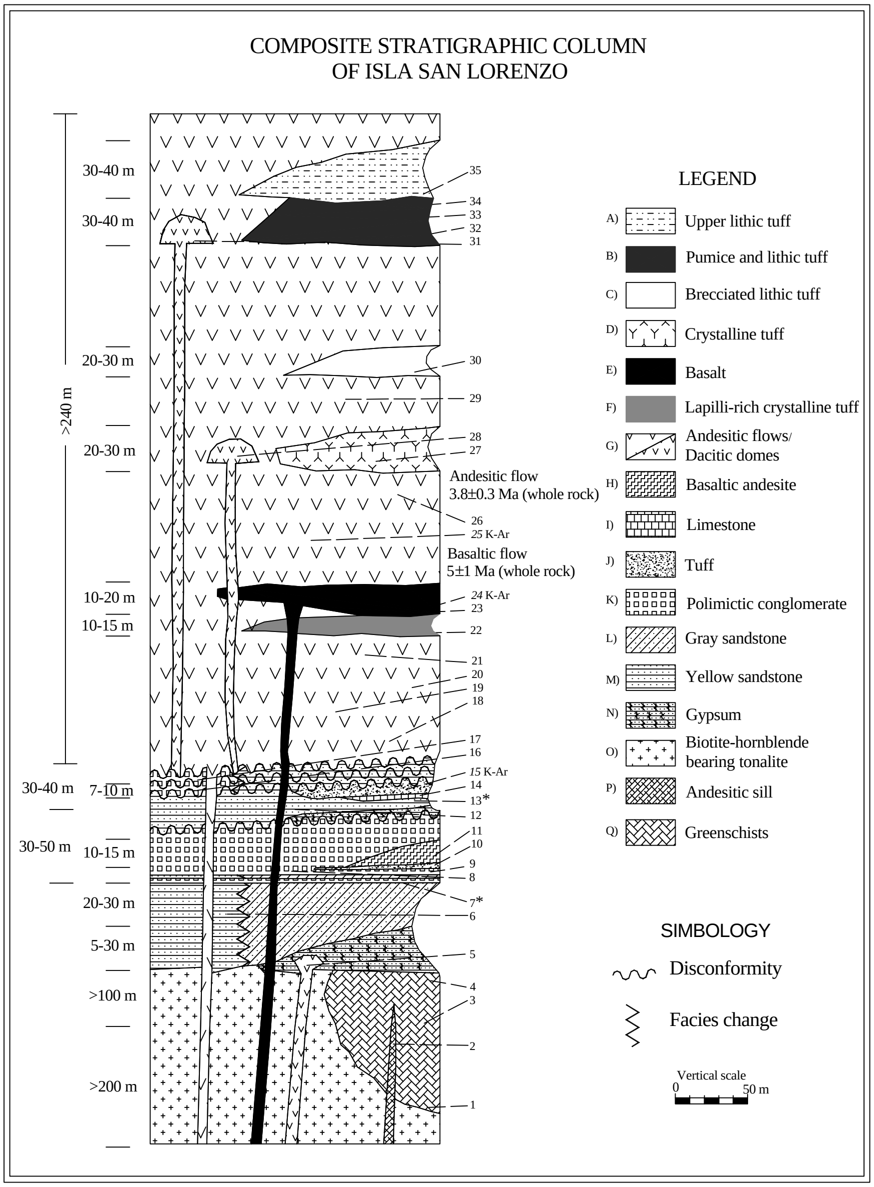

Figure 3. Composite stratigraphic column of San Lorenzo Island. Right side numbers indicate petrographic samples, K-Ar dated samples (italics), and asterisk indicates location of fossil samples. Units (G) of andesitic lavas and dacitic domes, (O) tonalite and (Q) greenschists (the last two units are out of scale). For clarity, domes are shown as part of unit (G).

and gray sandstones gradually change upwards to a polimictic conglomerate. The transition zone is more than 1.5 m thick, and it is characterized by 30 cm thick alternating strata of sandstone (sample 7, Figure 3, Table 3) and conglomerate. The gray clastic deposits in the transition zone are cemented by calcite, and are poorly sorted. One sample from this zone contains fragments of pectinids and benthic foraminifers (Figures 4a and 4b, respectively). The conglomeratic unit is reddish brown to brown, 30 to 50 m thick, formed by 1 m wide strata, and including conglomeratic sandstones (Unit K, Figure 3). It is composed of poorly sorted subangular fragments of granite, schist, dacite, andesite, tuff and minor quartzite and basalt in a coarse-sand matrix. In the southwestern part of San Lorenzo Island, near to the top of the unit, the conglomerate includes a tuff deposit (Unit J, Figure 3) covered by basaltic andesite lava (Unit H, Figure 3) whose petrographic characteristics are shown in Table 2 (samples 10 and 11, respectively). The conglomeratic unit is covered by gypsum beds that, in turn, are overlain by yellow arcosic arenite (sample 12, Table 3). Near the mouth of the Arroyo Las Águilas (Figure 2), this sandstone contains interbedded calcareous mudstone (Unit I, Figure 3) with fragments of bivalves (pecten) (Figure

Table 2. Petrographic synthesis of selected volcanic rocks from San Lorenzo and Las Ánimas Islands.

LAVA FLOWS

L	C	Coordinates	Mz	PlgMz	PlgF	HbMz	HbF	CpxMz	CpxF	OlMz	OlF	Op	R.C.	Textures
29	V-98-15	28°39.18’/ 112°51.5’	46adv	17	22gy	3	6agop	0	3g	0	0	3	A	Porphyrotrachytic and pilotaxitic
26	V-98-12	28°39.2’/ 112°51.5’	51adv	17	23gy	0	3go	2	4ag	0	0	x	A	Porphyritic and pilotaxitic
25	***V-98-1***	28°38.7’/ 112°51.7’	33	21	32	2	6	0	1	0	0	5	A	Porphyrotrachytic, seriated and poikilitic
24	***X-98-27***	28°39.5’/ 112°52.4’	49o	11	28g	6	5g	0	0	0	0	x	B	Porphyrotrachytic, seriated and pilotaxitic
23	X-98-26	28°39.6'/ 112°52.3'	50adv	25	19g	1	5go	x	0	0	0	x	B	Porphyritic and hyalopilitic
21	V-98-11	28°39.1'/ 112°51.7’	35o	33	20	4	5aop	0	x	0	0	2	A	Porphyrotrachytic
20	V-98-10	28°39.0'/ 112°51.8'	63aev	9	14a	x	3o	0	x	0	0	x	A	Hypocrystalline, seriated and axiolitic
19	X-98-25	28°39.6'/ 112°52.2'	56a	21	17g	3o	5op	0	0	0	0	0	A	Porphyritic and pilotaxitic
18	V-98-5	28°39.3'/ 112°52.2'	51o	15	23agy	3	7ag	0	x	0	0	x	A	Porphyritic and pilotaxitic
11	X-98-22	28°38.5'/ 112°50.5'	22	35	8ay	13	3	0	0	6o	12o	1	AB	Porphyro-trachytic and pilotaxitic

DOMES

L	C	Coordinates	Mz	PlgMz	PlgF	HbMz	HbF	CpxF	Op	R.C.	Textures
31	X-98-28	28°40.5'/ 112°53.6'	88s	x	3	x	xa	1co	0	D	Porphyritic
28	***V-98-14***	28°39.2'/ 112°51.5'	54dov	22	16gy	x	7go	0	2	D	Hypohyaline and trachytic
5	X-98-19	28°38.3'/ 112°50.1'	43adev	19	9	2o	10op	0	4	D	Porphyritic and hyalopilitic

TUFFS

L	C	Coordinates	Mz	PlgMz	PlgF	HbMz	HbF	Qz	BioMz	Pmz	Lt.V.	Lt.M.	Op	U	Textures
35	X-98-29	28°40.5'/ 112°53.1'	62o	x	X	0	0	1	xa	0	36	0	0	Tls	Fragmental
34	X-98-35	28°41.5'/ 112°54.2'	33cetv	x	X	0	0	0	0	39c	28	0	0	Tpl	Fragmental and vitroclastic
33	X-98-34	28°41.5'/ 112°54.2'	58adtv	0	X	0	0	0	0	5	36	0	0	Tpl	Fragmental.
32	X-98-33	28°41.5'/ 112°54.2'	67av	1	X	0	0	0	0	21	10	1.1	0	Tpl	Vitroclastic and fragmental.
30	V-98-16	28°39.2'1/ 12°51.5'	43	28	19gy	3	6ag	0	0	0	0	0	x	Tlb	Porphyritic and pilotaxitic
27	V-98-13	28°39.2'/ 112°51.5'	48dov	19	13	3a	3ap	1	0	0	10	0	3	Tc	Fragmental.
22	X-98-24	28°39.4'/ 112°52.4'	49adv	10a	14a	0	0	1	4a	0	21	0	x	Tl	Fragmental.
15	V-98-9	28°39.0'/ 112°51.8'	51av	x	12	0	0	0	2c	17	7	7	0	Dt	Fragmental and vitroclastic
10	X-98-23	28°38.5'/ 112°50.5'	58adv	31	5	0	0	3	0	0	x	0	0	Dt	Hypocrystalline and fragmental.

Table 3. Petrofacies analyses of selected sedimentary rocks from San Lorenzo Island.

L	C	Coord.	Qm	Qp	K	Plg	Lp	Lv	Lm	M.P.	Mz	Calc	Sc	Mi	Bi.	Red.	Sph.	Size	Classification
17	X-98-31	28°40.5'/ 112°51.9'	0	0	0	3.1	4.4	28.7	45.2	0	0	18.7	0	0	0	SR	LS	500-700 µm	Cgl with Mz of Lithic arenite
16	X-98-30	28°40.5'/ 112°51.9'	x	0	0	x	x	x	x	0	x	x	0	0	0	SR-SA	LS	> 2 mm	Conglomerate matrix
14	V-98-8	28°38.9'/ 112°51.8'	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	Limestone (micrite)
13	V-98-7	28°38.9'/ 112°51.8'	3.5	4.6	x	10.2	5.8	9.1	4.9	x	4.2	32.7	0	1.2	23.2	SA-SR	HS	1.0-2.0 µm	Lithic arenite
12	V-98-6	28°38.9'/ 112°51.9'	2.6	7.2	0	32.4	3.1	8.1	2.7	0	3.8	1.7	25.7	12.7	0	SA-SR	LS	200-350 µm	Arcosic arenite
9	X-98-21	28°38.5'/ 112°50.5'	2.1	18.0	x	39.4	1.6	x	2.4	0	8.6	x	26.1	0	0	SA-SR	HS	80-150 µm	Arcosic arenite
8	X-98-20	28°38.5'/ 112°50.3'	6.3	7.6	x	25.5	19.0	x	x	x	7.9	0	23.6	5.1	0	SR-SA	HS	100-300 µm	Arcosic arenite
7	V-98-3	28°38.5'/ 112°51.1'	8.9	4.3	0	25.8	0	15.5	3.9	3.2	12.9	23.1	0	1.4	x	SA	LS	150-900 µm	Arcosic arenite
6	V-98-2	28°38.7'/ 112°51.2'	20.2	6.1	x	25.1	0.5	6.3	6.3	0	10.5	13.9	0	9.8	0	SA	LS	100-150 µm	Arcosic arenite

ABBREVIATIONS: L= laboratory sample number, C= field sample number. CONTENT: Bi.= bioclasts, Calc= calcite, K= potassium feldspar, Lm= metamorphic lithic, Lp= plutonic lithic, Lv= volcanic lithic, Mi= mica, M.P.= heavy minerals, Mz= matrix, Plg= plagioclase, Qm= monocrystalline quartz, Qp= polycrystalline quartz (includes chert), Sc= silica. MISCELLANEOUS: Sph.= sphericity, HS= high sphericity, LS= low sphericity, Red. = rounded, SA= subangular, SR= subrounded, x= abundance <1% (x in sample 16 just indicates the presence of components).

4c), cirripeds (*Balanus sp.*) (Figure 4d), bryozoans (Figure 4e), echinoderms (*Eucidaris*?) (Figure 4f), tube worms (Figure 4g) and gastropods (*Epitonium sp.*; Figure 4h). The calcareous mudstone layer is 5 m thick and, near its upper contact it is interbedded with a 7 to 10 m thick air fall tuff (Unit J, Figure 3) showing normal gradation of lithic fragments and reverse gradation of pumice fragments (sample 15, Table 2). The tuff is covered in erosional unconformity by a coarse grained yellow sandstone which, in turn, is unconformably overlain by a similar yellow sandstone. In the eastern coast of San Lorenzo Island, both sandstone units change laterally to polimictic conglomerates (unit K, Figure 3). Along this coast, conglomerates have more homogeneous clast sizes. The sandy-matrix (sample 16) of one of these conglomerates (sample 17) is described in Table 3.

Marine sediments are overlain by a subaerial volcanic sequence composed at its base of porphyritic andesitic lava flows with plagioclase (An_{16} to An_{37}) and hornblende phenocrysts (Table 2, samples 18 to 21). Plagioclase commonly shows a spongy structure that suggests thermal unbalance (Cox *et al*., 1979). The andesitic lava flows are interbedded with pyroclastic deposits and occasionally with basaltic lavas. Unit F (Figure 3) is represented by a widely exposed pyroclastic deposit extending along the Arroyo Los Esqueletos (Figure 2a). Lithic fragments of this unit are formed by dacite, andesite and tuff, ranging in size from 4 to 6 cm, although, occasionally they can reach 25 cm in diameter (sample 22, Table 2). Underlying the tuff is a basaltic lava flow (sample 23, Table 2; Unit E in Figure 3 and Figure 2a) that is brecciated and mixed up with the pyroclastic unit.

ABBREVIATIONS: L= laboratory sample number, C= field sample number. MINERALOGY: BioMz= biotite matrix, CpxF= clinopyroxene phenocryst, CpxMz= clinopyroxene matrix, HbMz= hornblende matrix, HbF= hornblende phenocryst, Lt.M.= metamorphic lithic, Lt.V.= volcanic lithic, Mz= matrix, OlF= olivine phenocryst, OlMz= olivine matrix, Op= opaque minerals, PlgMz= plagioclase matrix, PlgF= plagioclase phenocrysts, Pmz= pumice, Qz= quartz. R.C.: ROCK CLASSIFICATION OR LITHOLOGIC UNIT (Figure 3): A= andesite, AB= basaltic andesite, B= basalt, D= dacite, Dt= tuff deposit, Tc= crystalline tuff, Tl= lithic tuff, Tls= upper lithic tuff, Tlb= brecciated lithic tuff, Tpl= pumice and lithics tuff. MISCELLANEOUS: a= hydrotermal alteration, , c= chloritization, d= desvitrification, e= spherulites, g= glomerocrysts, o= oxidation, p= pseudomorph, s= silicification, t= shards, v= glass , y= spongy structure, x= abundance <1%. Dated samples are in italics.

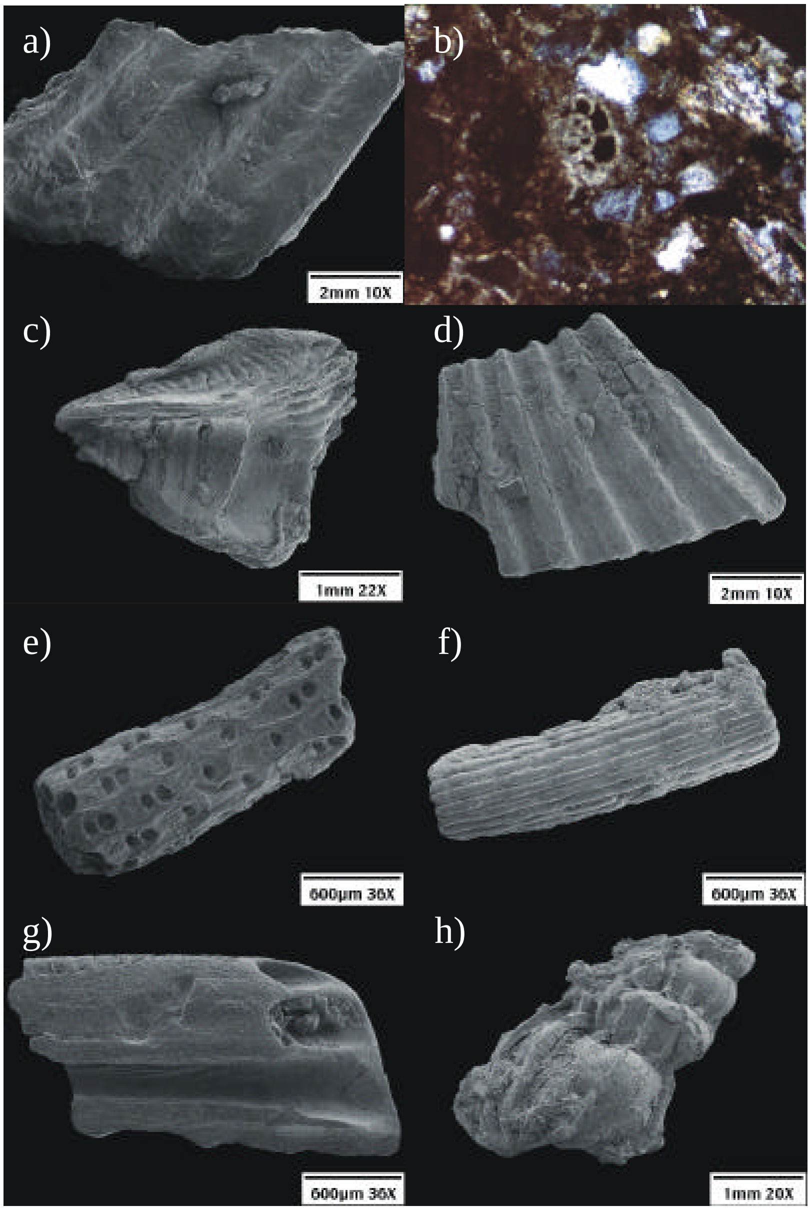

Figure 4. Fossil fauna of the marine sequence of San Lorenzo Island. From sample 7 are: a) fragment of pecten and b) benthonic foraminifer; from sample 13 are: c) fragment of pecten, d) cirriped (*Balanus sp.*), e) bryozoan, f) echinoderm (*Eucidaris*?), g) shell drilled by tubeworms and h) gastropod (*Epitonium sp.*).

A K-Ar age of 5 ± 1 Ma (Table 4) was obtained on basalt sample 24 (Table 2) taken from the massive central part.

In the southern part of the Arroyo Las Águilas (Figure 2a) andesitic lava flows cover the basaltic unit. Andesite shows a porphyritic texture with plagioclase phenocrysts (An$_{16}$-An$_{35}$) and hornblende (sample 25 and 26, Table 2). A whole rock K-Ar analysis of sample 25 yielded a 3.8 ± 0.3 Ma age (Table 4). In the same arroyo a pyroclastic flow overlies the lavas (sample 27, Table 2; unit D, Figure 3). This flow includes lithic fragments of andesite and dacite in a brecciated matrix. Andesitic lithic fragments are less than 5 cm in diameter, while dacitic fragments can be as large as 50 cm across. The dacitic fragments are petrographically similar to those from a nearby dome (sample 28, Table 2). Both, the tuff and the dacitic dome are overlain by andesitic lava flows (sample 29, Table 2) that, in turn, are covered by a brecciated monolithologic lithic tuff composed of dacitic fragments (unit C, Figure 3 and sample 30, Table 2).

In northern San Lorenzo and Las Ánimas islands a pumiceous lithic tuff (unit B, Figure 3) is widely exposed (samples 32, 33 and 34, Table 2). This unit is locally covered by the lithic tuff of unit A (Figure 3) that

Table 4. K-Ar cooling ages of selected volcanic rocks from San Lorenzo Island.

L	R.T.	Coordinates	K %	^{40}Ar*ccSTP	^{40}Ar* %	Age	Error (Ma)	A.A.
24	B	28°39’33” / 112°52’22”	1.4303±0.02	3.0598×10^{-7}	10.44	5.500×10^{6}	1.1432×10^{6}	5±1
24	B		1.4303±0.02	2.2625×10^{-7}	7.97	4.7867×10^{6}	7.2599×10^{5}	
25	A	28°38’41” / 112°51’40”	1.5593±0.08	2.2174×10^{-7}	23.99	3.6790×10^{6}	3.2492×10^{5}	3.8±0.3
25	A		1.5593±0.08	2.3986×10^{-7}	27.65	3.9793×10^{6}	4.7599×10^{5}	

Patassium was obtained by flame photometry and atomic absorption, ccSTP = cubic centimeters at standard conditions of pressure and temperature, ^{40}Ar* = radiogenic argon derived from ^{40}Ar. Error is in 1σ. ABBREVIATIONS: L = sample number, R.T. = rock type, A = andesite, B = basalt, A. A. = average age

shows a more restricted distribution (Figure 2a).

Volcanic activity in San Lorenzo Island is early Pliocene (Figure 3 and Table 4), slightly older than that reported in San Esteban Island (2.5 to 2.9 Ma; Desonie, 1992). It is contemporary to the dacitic lavas from southern Ángel de la Guarda Island (3.0 ± 0.1 Ma; Delgado-Argote, 2000), but younger than basaltic flows from northeastern Sierra Las Ánimas (7.8 ± 0.2 Ma; Delgado-Argote, 2000). As discussed later, the volcanic sequence of San Lorenzo and Las Ánimas islands is lithologically similar to other sequences of the central part of the Gulf of California and its margins, which suggest extensive volcanic activity along the Gulf margin corresponding to early rift extension and the vanishing magmatic arc.

STRATIGRAPHY OF NORTHEASTERN SIERRA LAS ÁNIMAS

On the eastern side of the Sierra Las Ánimas, detailed mapping along the coast between Punta El Soldado and Punta El Alacrán (Figure 5a) shows similar stratigraphy as San Lorenzo and Las Ánimas islands (Figure 5b). The basement is also formed by Cretaceous and Paleozoic granitic and metamorphic rocks, respectively. The plutonic rocks, which are partially covered by Miocene basaltic lavas in the upper part of the sierra, are widely distributed while the metamorphic rocks are restricted to the northern part of the study area.

In Punta El Alacrán, the metamorphic basement is composed of metalavas and metagreywacke, that is considered part of the lithodemic unit described by Campbell and Crocker (1993) north of Bahía de los Angeles along the western margin of Canal Las Ballenas. The sequence is cut by andesitic dikes and partly covered by discrete tuffaceous deposits cropping out in several places along the coast (Figure 5a). Andesitic fragments decrease in size and concentration upwards, but dominate the base of each pyroclastic unit. Up to 10 cm large pumice fragments are abundant in the middle part of the units suggesting a relatively near source. Fumarolic pipes as long as 35 cm are present in the upper part of some units, which were apparently immediately covered by another tuffaceous unit. It is inferred from the restricted distribution of the pyroclastic units, as well as from the presence of short erosion channels filled up by fluvial deposits, that deposition of the pyroclastic rocks was restricted to small depressions along the eastern flank of the Sierra Las Ánimas.

In Punta El Soldado, the pyroclastic rocks are covered by sandstone and conglomerate with interbedded ash-fall tuffs commonly altered to bentonite. Sandstone beds include reworked tuffaceous material and conglomerates contain pumice and lithic fragments in a sandy matrix. Sandstones have a broader exposure than tuffs and laterally change to conglomeratic sequences, including marine and fluvial deposits. Silica nodules, andesitic and pumice fragments, and carbonaceous material in an ash-rich matrix compose the upper part of the volcanosedimentary sequence at Punta El Soldado. Hornblende separates from a basaltic andesite lava flow overlying the sedimentary sequence yielded a K-Ar age of 7.8 ± 0.2 Ma (Delgado-Argote, 2000).

Polimictic conglomerates composed of fragments of the underlying rocks cover the entire sequence. The unsorted conglomerates, which are poorly consolidated, resulted of debris flows transport.

Plio-Pleistocene (?) conglomerates containing bivalves, corals and tubeworms in a calcareous sandy matrix constitute the youngest sedimentary unit in Punta El Alacrán. Its maximum thickness is 18 m and their distribution is restricted to local depressions in metamorphic rocks.

PROVENANCE AND SEDIMENTARY ENVIRONMENTS

On the basis of the petrographic analyses synthesized in Table 3 and Figures 6 and 7, a provenance and environmental interpretation of seven sedimentary rocks is discussed in this section.

Five sandstone samples collected at San Lorenzo

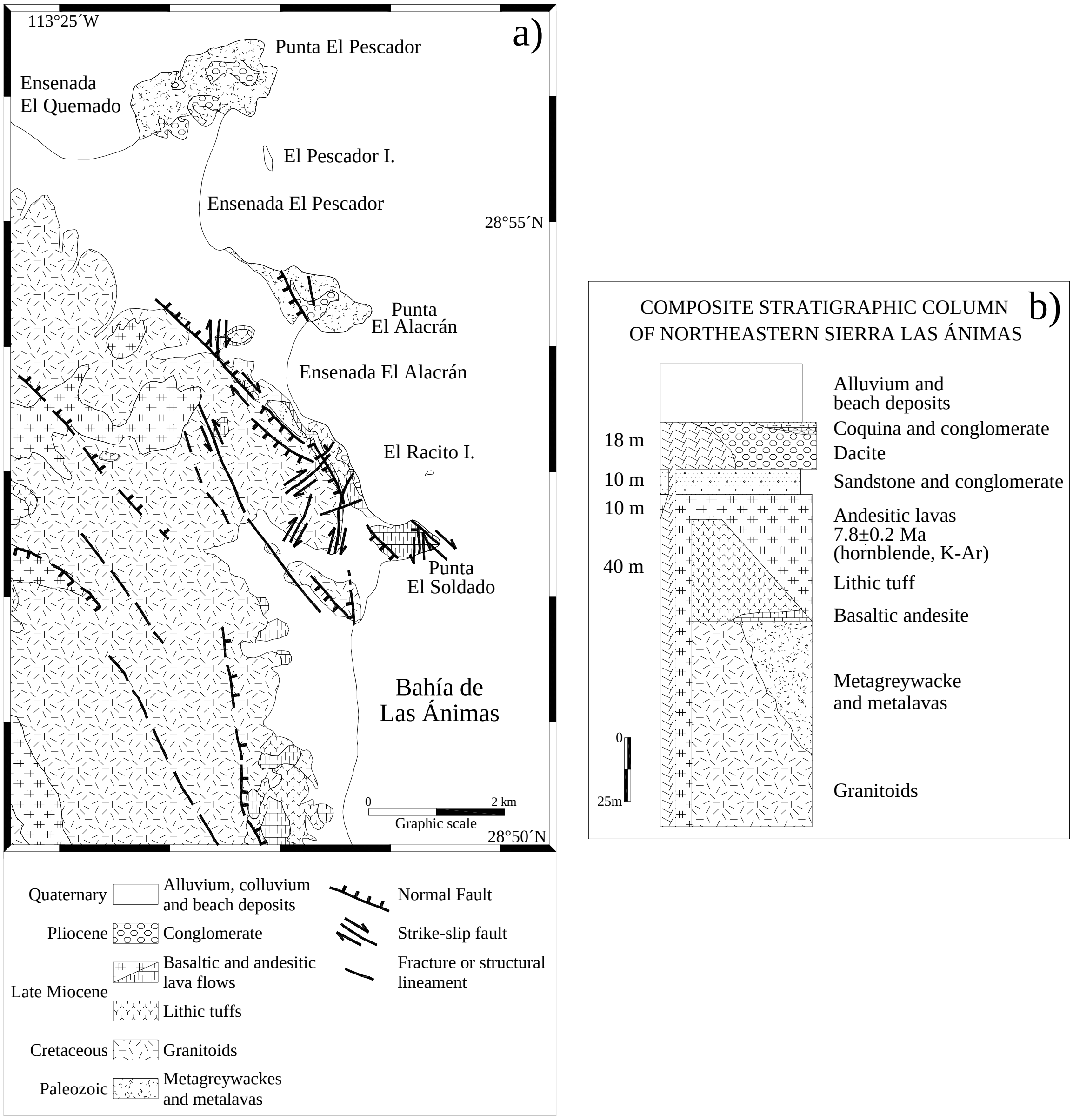

Figure 5. a) Simplified geologic map of northeastern Sierra Las Ánimas. Location is indicated in Figure 1 (modified from Delgado-Argote, 2000). b) Composite stratigraphic column of northeastern Sierra Las Ánimas, between Punta El Alacrán and Punta El Soldado (modified from Delgado-Argote, 2000).

Island are arcosic arenite and two other are lithic arenite (Figure 6a, Table 3). The rocks are mostly cemented by calcite and minor silica; potassium feldspar is practically absent, and clinopyroxene, epidote and glauconite are rarely present.

Sandstones formed under the same tectonic environment tend to form clusters in a ternary tectonic discrimination diagram (Dickinson and Suczek, 1979; Dickinson *et al.*, 1983). Figure 6b shows samples 8 and 9, which are related to an uplifted continental block; while, in Figure 6c, these rocks fall in the field of a transitional magmatic arc. This apparent discrepancy in provenance can be produced by the scarcity of lithic fragments that reflects local distribution of recycled pre-existing rocks (Dickinson *et al.*, 1983). It is also probable that the volcanic units did not completely cover the granitic basement and both types of rock are present in the arenites (Carozzi, 1993; Dickinson *et al.*, 1983). The high plagioclase content related to quartz and K-feldspar observed in the two rocks (Figure 6d) indicates a high plutonic to volcanic component ratio, suggesting that sands were derived from a transitional magmatic arc. A similar inference applies to sample 17 where provenance can be associated to an undissected

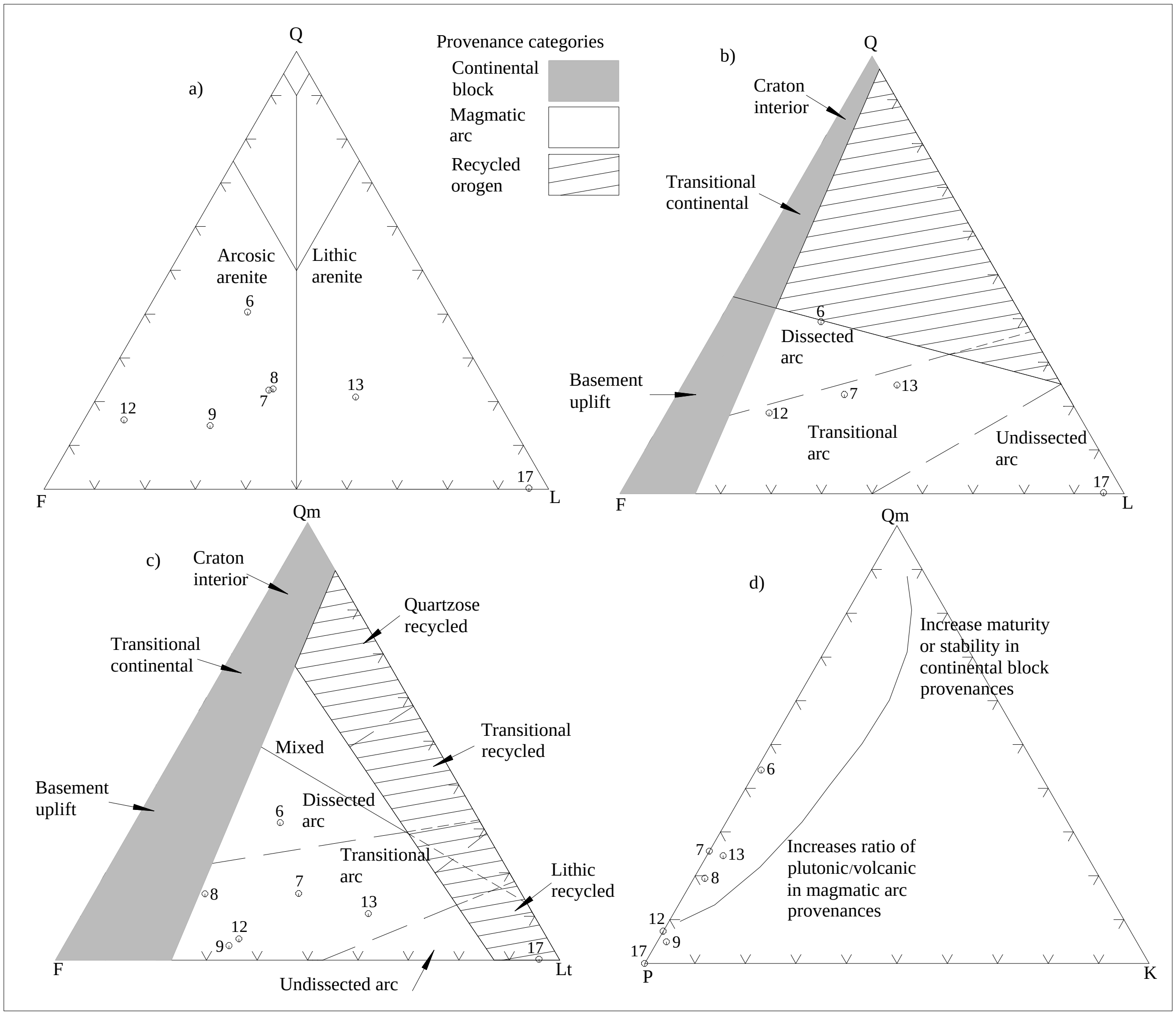

Figure 6. San Lorenzo Island sandstones: a) sandstone classification diagram after Pettijohn *et al.* (1987); Q= monocrystalline and polycrystalline quartz (chert not included), F= plagioclase and potassium feldspar, and L= plutonic, volcanic and metamorphic lithics. b) QFL diagram after Dickinson and Suczeck (1979) and Dickinson *et al.* (1983); Q= monocrystalline, polycrystalline quartz and chert, F= plagioclase and potassium feldspar, and L= volcanic and metamorphic lithics. c) Qm-F-Lt diagram after Dickinson and Suczeck (1979) and Dickinson *et al.* (1983); Qm= monocrystalline quartz, F= plagioclase and potassium feldspar, and Lt= plutonic, volcanic, metamorphic lithics, polycrystalline quartz and chert. d) Provenance discrimination diagram after Dickinson and Suczek (1979); Qm= monocrystalline quartz, P= plagioclase and K= potassium feldspar. See Table 3 for sample descriptions.

magmatic arc or a recycled orogen, although the nearby metamorphic rocks were probably also an important source of sediments. Additionally, samples 7, 12 and 13 are associated to a transitional magmatic arc, far from the field of an undissected arc, whereas sample 6 is associated to a dissected magmatic arc (Figures 6b and 6c).

The arenite samples 6 and 7 (unit M, Figure 3), from the base of the stratigraphic column were deposited in the same local basin. They represent different facies of the same stratigraphic level, derived from different source lithology.

The overlying sandstones represented by the samples 8 and 9 (units L and K, Figure 3), and 12 and 13 (unit M, Figure 3), are locally separated by a tuffaceous deposit (sample 15, unit J, Figure 3) and a calcareous mudstone layer (sample 14, unit I, Figure 3). These sandstones were derived from an uplifted basement partially covered by volcanic rocks. It is interpreted that during the deposition of the conglomerates represented by samples 16 and 17, the volcanic rocks of the magmatic arc were widely exposed, although a change in the source location due to tectonic evolution of the depocenter is an alternative explanation.

The gypsum deposits from the base of the sedimentary sequence indicate the existence of a small and shallow marine basin of restricted circulation (Figure

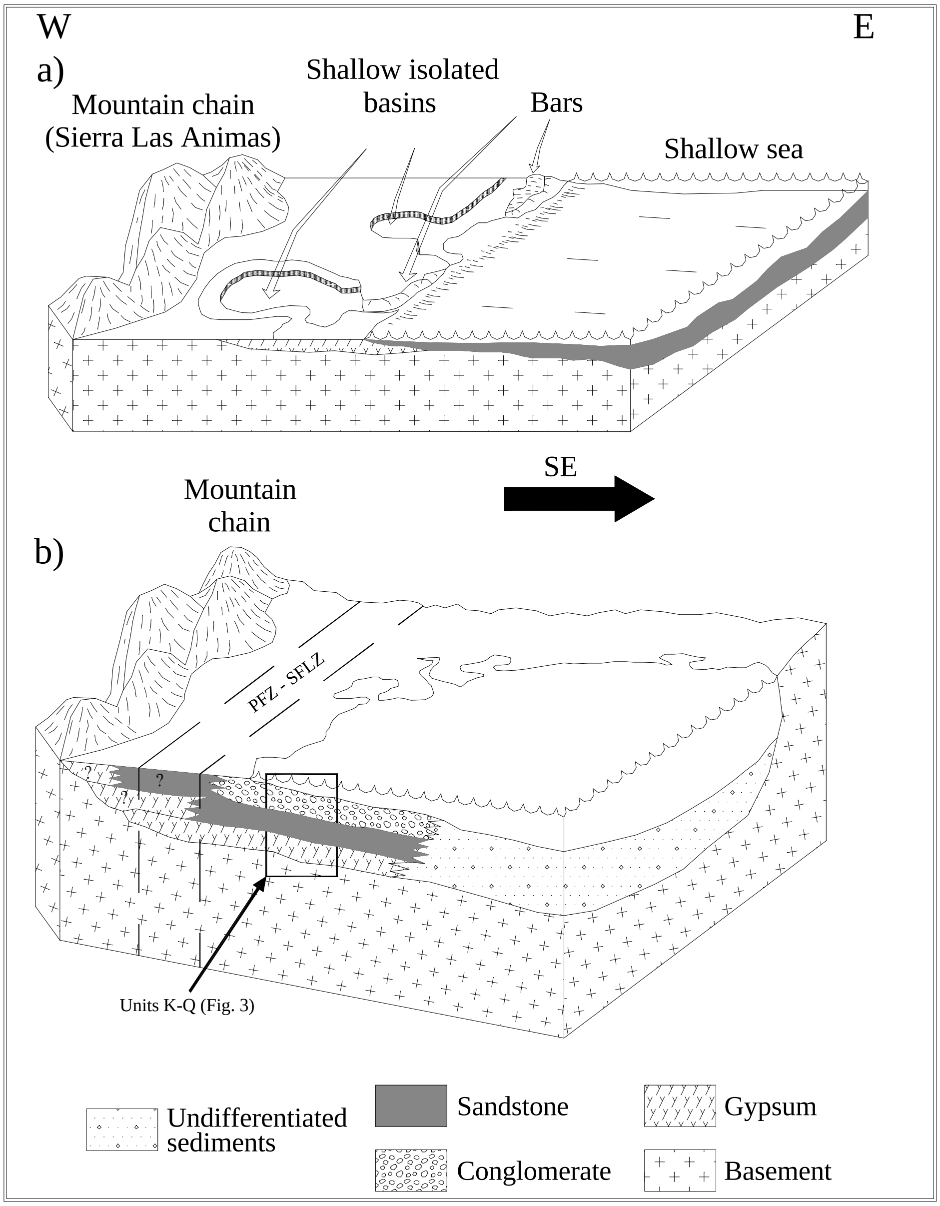

Figure 7. Schematic block diagram of sedimentary facies showing the inferred sedimentary environments and location of the marine sequence of San Lorenzo Island. a) Initial shallow sea with restricted seawater access to small isolated basins and deposition of gypsum beds from the base of the sequence. b) Transgressive stage where seawater covers the gypsum beds, sandstone and conglomerates are deposited in a higher energy environment. The box in b) indicates the location of the basement and the marine sedimentary sequence of San Lorenzo Island, and PFZ-SLFZ shows the approximate location of the Plio-Pleistocene Partida and San Lorenzo fault zones of Figure 1. See text for discussion. Adapted from Kendall and Harwood (1996) and Reading and Collinson (1996).

7a). Semiarid conditions promoted the precipitation of evaporites and minor sandstone deposition during the first stages of the basin evolution. The overlying arcosic sandstones (samples 6 and 7, Figure 3) mark a period of transgression probably associated to subsidence. The fossil assemblage of sample 7 (pectens and benthonic foraminifers) suggests a sandy substrate of moderate to low energy (Dodd and Stanton, 1981). Although they were not properly identified, it is believed that these fossils live in waters 25 m deep or shallower (Dodd and Stanton, 1981). The ornamented valves shown by the pectens form San Lorenzo Island (Figure 4a) are a common characteristic of tropical species living in $CaCO_3$ saturated waters (Dodd and Stanton, 1981; Pettijohn *et al*., 1987).

The appearance of conglomerates can indicate lower relative sea level due to volcanic activity or uplifting. During this regressive period, restricted thin beds of gypsum precipitated too. A new transgressive stage was characterized by marine sandy deposits that contain more diverse fossil assemblage (Figures 4c to 4h, Figure 7b). The most abundant forms are echinoderms, bryozoans and pectens which are thought to have lived in warm water conditions at depths less than 25 m on rocky substrates in high energy environments (Dodd and Stanton, 1981). Cirripeds, tubeworms and gastropods are less abundant. The collected fossils are reworked and occur in clastic strata interbedded with calcareous mudstone. Carbonates could be precipitated in the interior of a platform within the intertidal zone; deposition depths of 10 to 20 m are considered since light penetration favors carbonate precipitation and, additionally, the observed laminar structures are indicative of low energy environment (Wright and Burchette, 1996). It is interpreted that the limestone horizons were deposited during or after a transgressive stage, which ended with the subaerial deposition of the tuffaceous unit J (Figure 3).

After the explosive activity the basin was uplifted, as evidenced from detritic deposits lacking fossil fauna, separated by unconformities. Structural blocks also created local areas of deposition of conglomerates with clasts without preferred orientations. This interpretation agrees with Gastil *et al.* (1975), who stated that marine sediments in northern Baja California were deposited in fault bounded shallow isolated basins.

DISCUSSION

A chronological correlation of volcanic and sedimentary sequences of several areas along the western margin of the Gulf of California is synthesized in Figure 8. A compilation of absolute and paleontological ages is included, indicating marine sections around the Gulf. Most fauna rich sediments suggest affinities with Caribbean waters. The oldest known marine strata south of the study area belong to the Early Miocene Isidro Fm., which crops out in western Baja California Sur (Hausback, 1984). Sedimentary rocks of similar age have been reported in northern Ángel de la Guarda Island, western Sierra Las Ánimas (Delgado-Argote *et al.*, 1998; Delgado-Argote, 2000), or younger (middle Miocene), in Tiburón Island (Gastil and Krummenacher, 1977; Gastil *et al.*, 1979), suggesting the incursion of marine water during proto-Gulf time (Karig and Jensky, 1972) in the central part of the present Gulf of California and the eastern margin of the Baja California peninsula.

A tectonic protogulf existed from Middle Miocene throughout Early Pliocene time as a result of N to NNW normal faulting (Karig and Jensky, 1972; Gastil *et al.*, 1979). During Middle Miocene time the area experienced an extensive marine incursion indicated by the 12 to 13 Ma deposits of Tiburón Island (Gastil *et al.*, 1979; Smith, 1991) and Bahía de los Ángeles (Delgado-Argote *et al.*, 2000). Marine incursions probably were more extensive between 9 and 7 Ma, as indicated by the abundance of marine deposits in the western margins of the Gulf of California (Figure 8). Marine sediments in Puertecitos, San Felipe and Imperial Valley indicate a regional transgression at the end of Late Miocene and the beginning of Pliocene time (Martín-Barajas *et al.*, 1993). Based on fossil assemblages of mixed cool-tropical characteristics, Helenes and Carreño (1999) suggest the existence of a seaway across the peninsula in its central part; however, no deposits have been described to support this connection. Such a connection between the Pacific Ocean and the Gulf of California should trend almost N-S, paralleling the regional structural trend marked by the Bahía de los Ángeles and Bahía Las Ánimas basins (Figure 1; Delgado-Argote, 2000). A transgression occurred during Pliocene time and marine environments varied from ephemeral basins to continental talus (Ingle, 1974; Gastil *et al.*, 1979; Martín-Barajas *et al.*, 1993; Vázquez-Hernández, 1996). The transgression seems to be contemporaneous in Puertecitos and San Felipe (Martín-Barajas *et al.*, 1993). There, sedimentary rocks older than Pliocene basaltic lavas (Figure 3) derived from a transitional magmatic arc and the granitic basement. This suggests that since the late Miocene the morphology was similar to the present one and the arroyos drained eastward from the central part of the peninsula (Delgado-Argote and García-Abdeslem, 1999).

We interpret the area between the San Lorenzo archipelago and the peninsula as a basin that developed in the interior of the exposed basement. Felsic explosive volcanism was deposited along the eastern and southern margins of the Sierra Las Ánimas while widespread discrete andesitic to basaltic lava flows extruded in the basin since, at least, 7.8 ± 0.2 Ma in the present eastern side of Sierra Las Ánimas (Delgado-Argote, 2000). The overlying sedimentary sequence here can correlate with the sequence that underlies the 5 ± 1 Ma old basaltic flows at San Lorenzo Island (Figures 3 and 5b). The sedimentary rocks apparently extend to the western central part of Bahía Las Ánimas (Vázquez-Jaimes, 2000). The sequence of Sierra Las Ánimas-San Lorenzo Island can be associated to a local structural basin formed during a period of WNW-ESE extension in Late Miocene as documented by Escalona-Alcázar and Delgado-Argote (2000). This is a period of extensive marine sedimentation in the Gulf area (Figure 8). It is documented that the area of Salton Sea, Tiburón Island and San Felipe basin had minimum depths of 150 m while Santa Rosalía and Loreto basins, in Baja California Sur (Helenes and Carreño, 1999), as well as the region of Bahía Las Ánimas-San Lorenzo Archipelago, represent marine sedimentation in shallower environments. Upper Miocene to Lower Pliocene sedimentation is also reported in the southern part of Ángel de la Guarda Island (Escalona-Alcázar and Delgado-Argote, 1998; Gastil *et al.*, 1975). Since Pleistocene times, before the southeastward migration of the San Lorenzo

Archipelago along the San Lorenzo and Partida fault zones (Figure 1), the archipelago was located in front of the Sierra Las Ánimas and Bahía Las Ánimas.

Contemporaneous sedimentation and volcanic activity has been continuous since Miocene time in many places of the central part of the Gulf of California (Figure 8). The basin located between the eastern Sierra Las Ánimas and the San Lorenzo Archipelago was formed in late Miocene time and the sedimentary sequence is well constrained between 7.8 ± 0.2 and 5 ± 1 Ma (Figure 8). Sedimentation was interrupted in many places due to local uplifting while new basins developed since the Pliocene, associated to the evolution of the San Andreas-Gulf of California transform system.

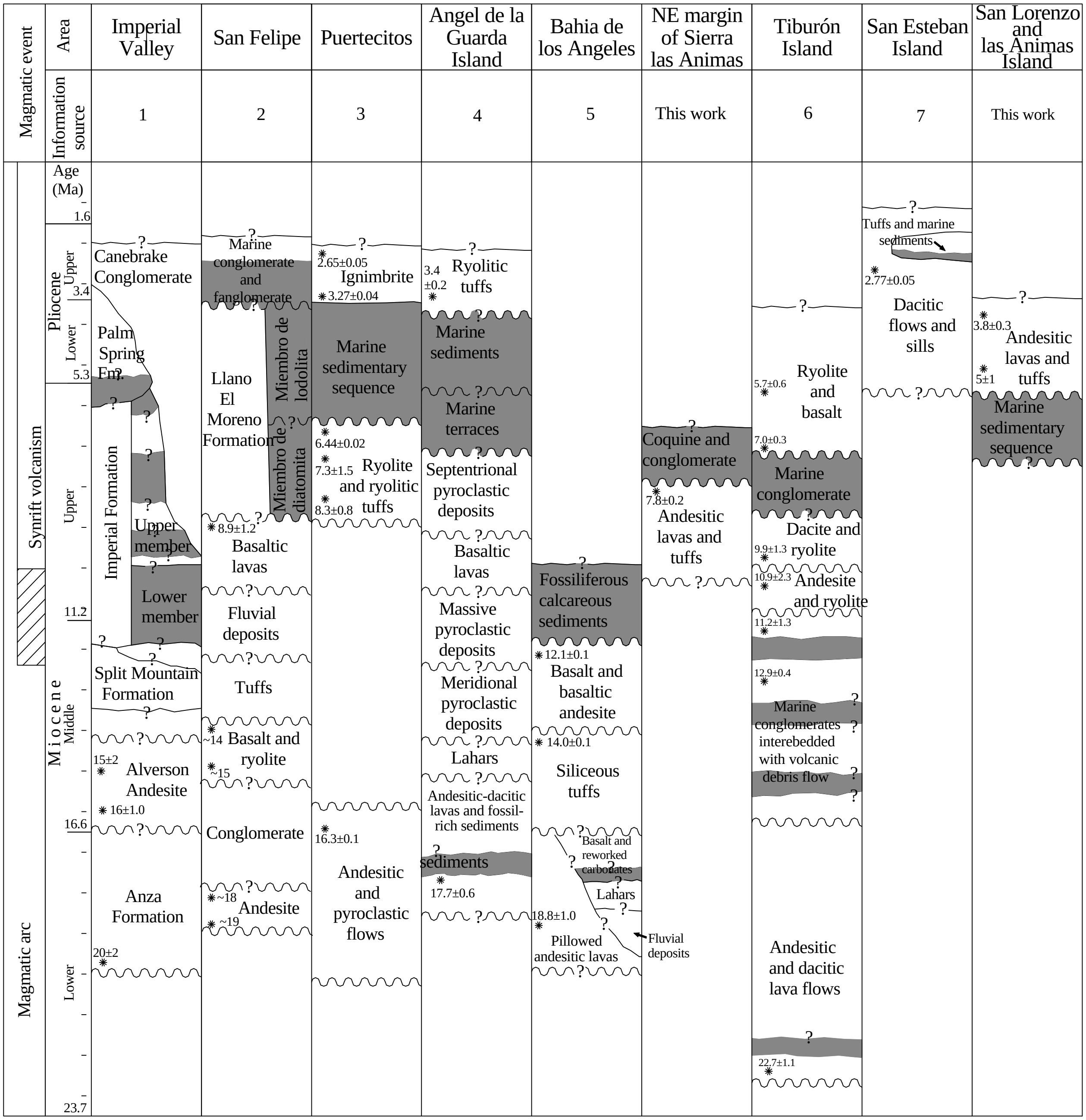

Figure 8. Correlation chart of San Lorenzo and Las Ánimas islands and northeastern Sierra Las Ánimas with other volcanosedimentary sequences around the Gulf of California. In the left column is indicated the period of volcanic activity in the peninsula throughout Neogene; diagonal lines indicate a transitional stage. Absolute ages are in millions years, paleontological dates are indicated with (**~**). Shaded areas indicate marine sediments with or without fossils. Information source are as follows: 1) Woodard, 1974; Ingle, 1974; Gastil *et al*., 1979; Smith, 1991; 2) Ingle, 1974; Gastil *et al*., 1979; Boehm, 1984; Smith, 1991; 3) Dokka and Merriam, 1982; Stock and Hodges, 1989; Smith, 1991; Martín-Barajas *et al*., 1993, 1995; 4) Gastil *et al*., 1975; Escalona-Alcázar, 1996; Escalona-Alcázar and Delgado-Argote, 1998; Delgado-Argote, 2000; 5) Delgado-Argote, 2000; Delgado-Argote and García-Abdeslem, 1999; 6) Gastil and Krummenacher, 1977; Gastil *et al*., 1979; 7) Desonie, 1992.

CONCLUSIONS

During Late Miocene to Pliocene, marine sedimentation took place in a structural basin developed in a vanishing magmatic arc environment, where a Paleozoic metamorphic and Cretaceous granitic basement was exposed. A paleogeographic reconstruction of the central part of the Gulf of California based on the closure of the large basins showing oceanic-like floor, and right lateral translation along the San Lorenzo and Partida transform faults (Delgado-Argote, 2000) shows that during Pliocene time San Lorenzo Island was located in front of Bahía Las Ánimas and Sierra Las Ánimas. The San Lorenzo Archipelago and the eastern side of Sierra Las Ánimas are characterized by the presence of proximal pyroclastic rocks and lava flows probably associated with fissures. A restricted ignimbrite deposit in the northern part of Bahía Las Ánimas basin was probably derived from a composite volcano located in the central part of the basin. Most sedimentary rocks in the San Lorenzo Archipelago-Eastern Sierra Las Ánimas area were deposited in the interval between 7.8 ± 0.2 to 5 ± 1 Ma. These deposits derived from the exposed basement and contemporaneous volcanic activity and show restricted transport. Evaporites at the base of the sedimentary sequence suggest a restricted water circulation and semiarid conditions. Basin depths were less than 25 m as indicated by shallow water calcareous organisms.

The small Late Miocene-Pliocene basins along the peninsular margin of the Gulf of California were probably fed by water entering from the mouth of the present gulf since the hypothetical seaway in the central part of the peninsula connecting the Gulf of California with the Pacific Ocean was likely closed due to the Miocene-Pliocene volcanic activity. The most important vol-canism during that period is represented by the San Ignacio (11.1 ± 0.8 to 2.99 ± 0.12 Ma) and San José de Gracia (11.9 ± 0.3 to 0.7 ± 0.1 Ma) volcanic fields (Rojas-Beltrán, 1999). Uplift of the peninsula and subsidence of its eastern margin due to extension associated with the San Andreas-Gulf of California system created connected basins along the northern Gulf of California.

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