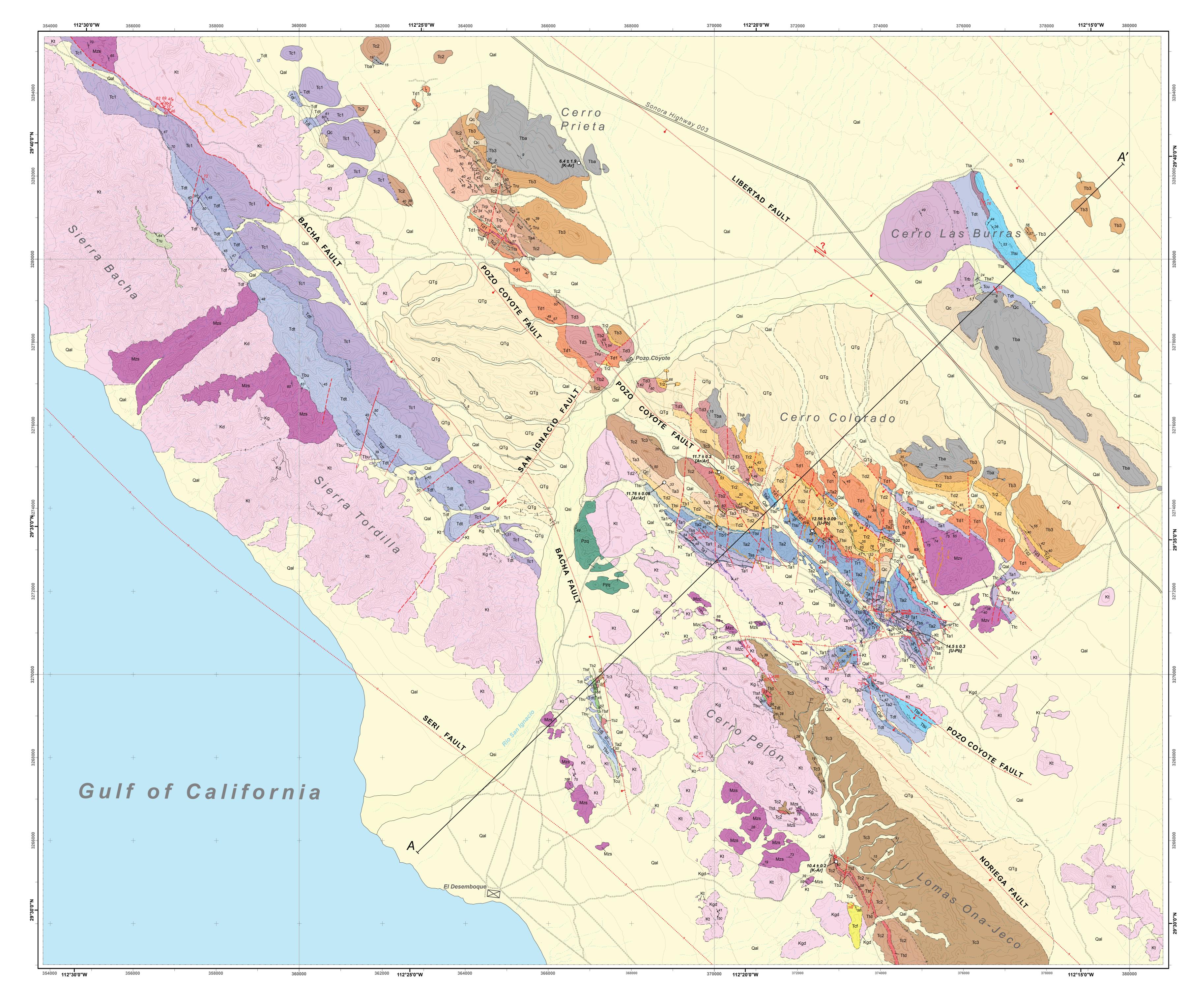
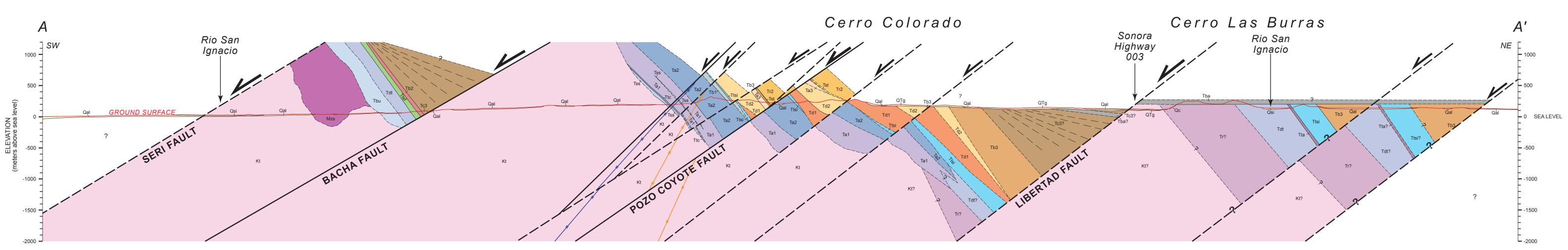
GEOLOGIC MAP OF THE SIERRA BACHA, COASTAL SONORA, MEXICO

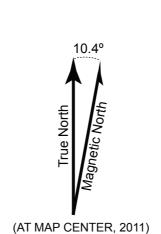
Geology by Michael H. Darin & Rebecca J. Dorsey

Datum: WGS 84 Projection: UTM Zone 12N Base map (contours & water drainage) constructed from 1:50,000 scale digital topographic maps from the National Institute of Statistics and Geography of Mexico (INEGI)



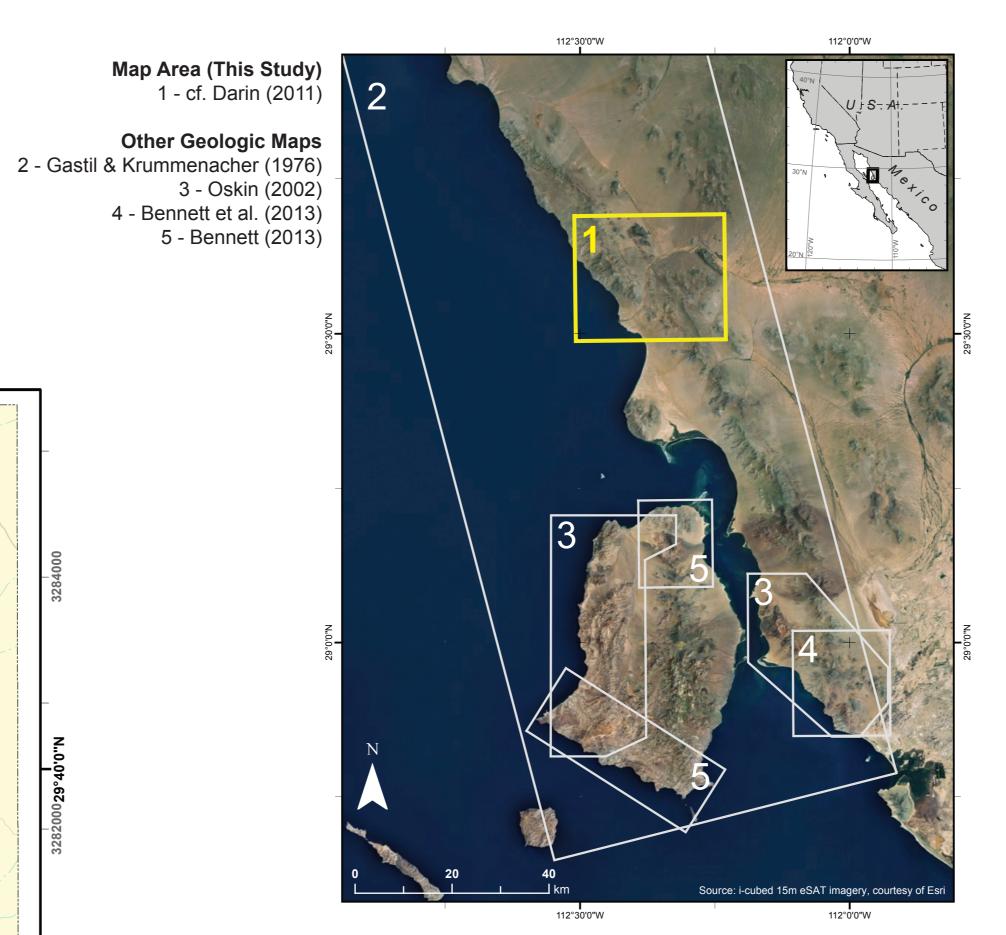


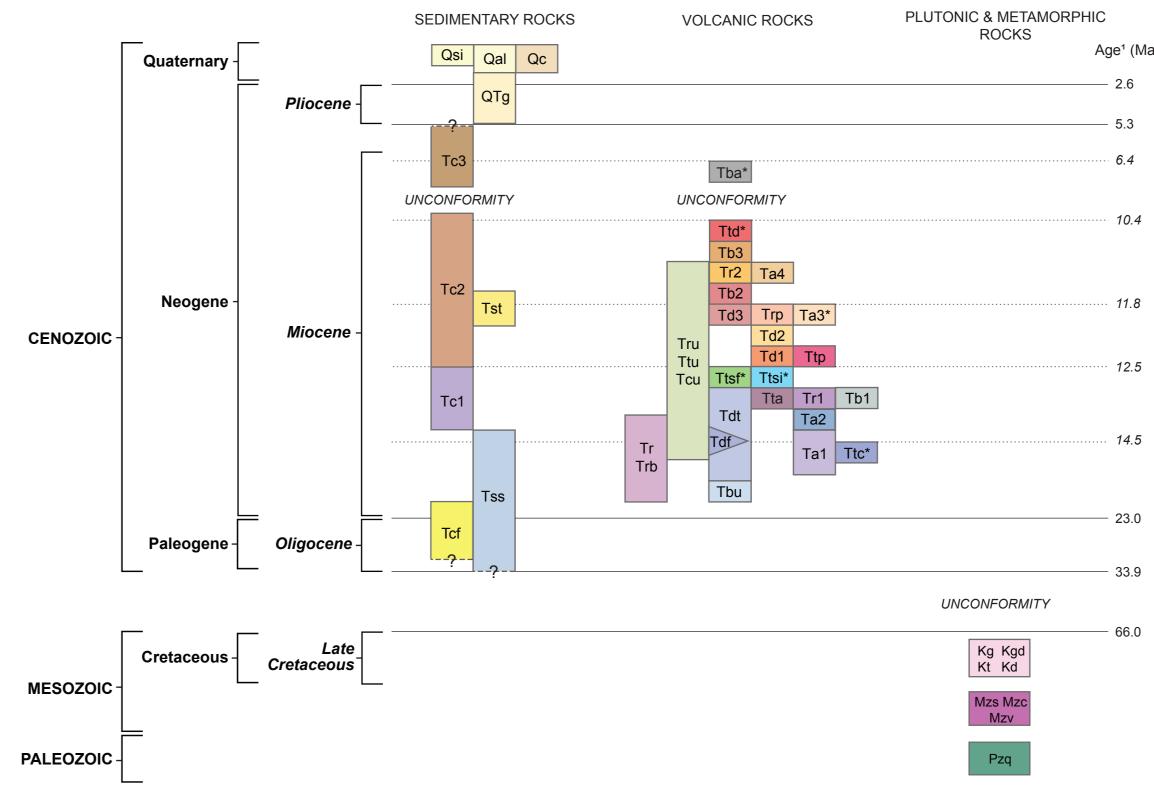
SCALE 1:30,000 **5 KILOMETERS** 3 4 CONTOUR INTERVAL: 20 METERS



LOCATION MAP

CORRELATION OF MAP UNITS





DESCRIPTION OF MAP UNITS*

	Qsi	Unconsolidated fine- to very coarse-grained sand and minor gravel alluvium of the Rio San Ignacio
[Qal	Unconsolidated sand and gravel alluvium
[Qc	Unconsolidated gravel colluvium consisting of pebbles to boulders of variegated volcanic clasts, except in the Cerro Las Burras and Cerro Prieta where clasts are only basalt. Typically confined to slopes near steep topography.
[QTg	Dissected, subhorizontally stratified pebbly sandstone and clast-supported sandy pebble conglomerate with local primary dip of up to 8° in the eastern Sierra Tordilla. Gravel fraction consists of mostly subangular to rounded pebbles, sparse cobbles, and rare boulders up to 90 cm in diameter. Bedsets are 7 to 35 cm thick and defined by mostly massive, clast-supported, pebble-rich beds lacking sedimentary structures except rare channel scour and upper plane-bed stratification. The clast assemblage is polymict consisting of volcanic (56%) and granitic and metamorphic clasts (44%). This unit is interpreted as widespread, locally derived debris flows and alluvium that cover and obscure older pre- and syn-extensional strata. Maximum exposed thickness is approximately 160 m.
	Tc3	Mostly massive, moderately sorted, volcaniclastic, pebble-cobble conglomerate and interbedded pebbly sandstone. This unit has mixed matrix- and clast-support and rare boulders up to 50 cm in diameter. The clast assemblage is heterolithic with angular to subrounded volcanic and basement clasts in a grussy, red sand matrix. This unit is characterized by bedding dips that decrease systematically up-section from about 39° to 0°, which is best exposed in the hanging wall of the concealed Noriega fault just east of the Cerro Pelón. In addition to the fanning dips, this unit has a significantly higher percentage of tonalite, metasedimentary, and metavolcanic clasts which further distinguish it from Tc2.
	Tba	BASALT OF ARIVAIPA - Horizontal to sub-horizontal, 10- to 15-m-thick basalt flows containing plagioclase micro- phenocrysts in a fine-grained aphanitic groundmass consisting of plagioclase >> olivine \approx pyroxene \approx magnetite. Individual flows contain a 1- to 3-m-thick red to black basal flow breccia, vesicular upper and lower contacts, and well-defined vertical joints with 0.5 m-spacing. Gastil and Krummenacher (1977) obtained a radiometric age of 6.4 ± 1.9 Ma [K-Ar] for this unit where it dips shallowly to the northeast in the Cerro Prieta above an angular unconformity with older late Miocene volcanic strata. Maximum exposed thickness is 90 m.
	Tc2	Stratified to massive, pebbly sandstone to sandy pebble conglomerate and interbedded pebble-cobble conglomerate. Heterolithic clast assemblage includes andesite, dacite, basalt, rhyolite, and granitic and metamorphic basement lithologies. In the western Cerro Colorado, this unit shows locally well-developed planar stratification and mixed matrix- and clast-support in 5- to 15-cm-thick, and mostly subangular to subrounded intermediate volcanic clasts with less common basement clasts and outsized boulders up to 35 cm in diameter. In the Lomas Ona-Jeco (southeastern map area), this unit is mostly massive with local planar stratification of 20- to 50-cm-thick bedsets defined by variations in grain size. This unit is interpreted to be pre-kinematic based on its consistent dip with underlying units throughout the study area. The Tuff of Desemboque (Ttd, 10.4 Ma) is interbedded in the upper part of this unit. Total unit thickness is up to 350 m.
	Ttd	TUFF OF DESEMBOQUE - Pink to white, welded rhyolite ash-flow tuff. The base is characterized by a 0.5- to 1-m- thick, discontinuous, porphyritic black vitrophyre overlain by a 5-m-thick pink, ashy crystal-rich zone; both of these ones contain abundant euhedral phenocrysts (plagioclase > quartz > biotite > alkali feldspar). The base grades upward into a 10- to 15-m-thick, moderately to densely welded zone with abundant 4- to 12-cm-long yellow pumice fiamé and 10-15% phenocrysts (feldspar > biotite \approx quartz). The upper 30 m show extensive vapor phase alteration and abundant quartz-filled spherules in a pink groundmass that decrease in abundance upsection. The uppermost part of the unit is gray to white and not welded. Gastil and Krummenacher (1977) determined an age of 10.4 ± 0.2 Ma [K-Ar] for this unit, which they report as an unnamed rhyolite tuff (their sample S2G-114A). Total unit thickness is 40 to 50 m.
[Tb3	Thick sequence of dark purple to black, aphanitic vesicular basalt flows with only up to 1-2% plagioclase phenocrysts in a glassy groundmass. Total exposed thickness up to 1100 m.
	Tr2	Gray to light purple, aphanitic rhyolite lava flows. Gray lenses with glassy or frothy textures create a locally well- defined flow foliation. Secondary quartz precipitation along foliation is pervasive in some locations. This resistant unit consists of one or two 60- to 90-m-thick flows. The base of each flow contains a unique pink to red to white ash-fall tuff below a discontinuous 1- to 3-m-thick, greenish-black vitrophyre. An unpublished age of 11.7 \pm 0.2 Ma [Ar/Ar] has been determined for this unit (A. Iriondo, personal communication, 2011). Total unit thickness is up to 240 m.
[Ta4	Light gray-purple, rubbly, vesicular basaltic-andesite lava flow with up to 10-20% altered red pyroxene phenocrysts. This unit only occurs in the Cerro Prieta. Total unit thickness is 45 m.
[Tb2	Black, glassy, plagioclase-phyric basalt flows with up to 10% phenocrysts (plagioclase > orthopyroxene >> amphi- bole) and cindery pyroclastic breccias up to 5 m thick. Individual flows are typically 10 to 20 m thick. Total unit thickness is up to 210 m.
[Tst	Well-laminated lithic tuff and tuffaceous sandstone with yellow to white to light green pumice and dark volcanic lithics in a yellow ashy matrix. Individual beds are 30 to 100 cm thick and show normal grading of pumice and lithics. Total unit thickness is up to 25 m.
[Td3	Gray trachydacite lava flows containing 10-15% altered phenocrysts (plagioclase > alkali feldspar ≈ amphibole >> apatite). Exposures of this unit are rare and discontinuous in the central and eastern study area. Total unit thickness is up to 430 m.
[Тгр	Pink, porphyritic trachydacite lava flows containing up to 15% phenocrysts of feldspar (up to 5 mm long) and accessory quartz and biotite. Flows commonly display a non-planar, distorted flow foliation. The base of each lava flow consists of a 1- to 10-m-thick yellow ash-fall tuff, which is usually overlain by a discontinuous 1- to 3-m-thick vitrophyre. Individual flows are up to 130 m thick. Total unit thickness is up to 650 m.
[Ta3	Black, aphanitic basaltic-andesite lava flows containing rare lath-shaped plagioclase phenocrysts up to 2 mm long and vesicles commonly filled with white or yellow zeolite. Microlitic groundmass consists of plagioclase and altered pyroxene; no olivine is observed. This unit is well exposed ~3 km south of Pozo Coyote where it is intercalated with 2- to 3-m-thick red tuffaceous sandstones and pyroclastic breccias. An isochron age of 11.76 ± 0.08 Ma [Ar/Ar] was determined for this unit (Darin, 2011). Total unit thickness is up to 240 m.
[Td2	Purple to gray, aphanitic trachydacite lava flows containing up to 5% blocky sanidine and plagioclase phenocrysts and accessory pyroxene in a microlitic plagioclase groundmass. Like Td1, this unit consists of multiple 20- to 60-m- thick flows with 1- to 4-m-thick red basal flow breccias in the Cerro Colorado. This unit commonly displays a well- defined 1- to 4-cm-spaced flow foliation, which helps to distinguish it from Td1. Total unit thickness is up to 330 m.

EXPLANATION OF MAP SYMBOLS

	lithologic contact, dashed where approximate, dotted where concealed, '?' where queried
	fault, dashed where approximate, dotted where concealed, '?' where queried; ball and bar on downthrown side; arrows indicate relative lateral motion
× × ×	felsic dike (dashed where inferred)
× × ×	intermediate dike (dashed where inferred)
× ⁴⁵	strike and dip of inclined bedding
×9	approximate strike and dip of bedding
\ \	approximate strike and dip direction
\oplus	horizontal bedding
× ⁵¹	eutaxitic foliation
×	vertical eutaxitic foliation
77	metamorphic foliation
4	vertical metamorphic foliation
~60	strike and dip of fault
$\boldsymbol{\lambda}$	vertical fault
¥ 42	strike and dip of minor fault; arrow shows trend of kinematic indicator and direction of hanging wall transport
25	joint
73	dike
	paved highway
	improved dirt road
=======================================	unimproved dirt road
\bowtie	settlement
0 10.4 ± 0.2 [K-Ar]	radiometric age (± 2σ error) in Ma; isotopic system in brackets

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¹Approximate ages from timescale of Walker et al. (2012). Radiometric ages of dated units from within field area (indicated by asterisks) are italicized; see Darin (2011) for summary.

Unconsolidated fine- to very coarse-grained sand and minor gravel alluvium of the Rio San Ignacio

Ramos-Velázquez, E., Calmus, T., Valencia, V., Iriondo, A., Valencia-Moreno, M., and Bellon, H., 2008, U-Pb and (40)Ar/(39)Ar geochronology of the coastal Sonora batholith: New insights on Laramide continental arc magmatism: Revista

Td1	Stony, purple-gray, aphanitic trachydacite lava flows with <2% altered sanidine phenocrysts and accessory pyroxene in a microlitic plagioclase groundmass. In the Cerro Colorado, this unit consists of multiple ~20- to 60-m-thick flows each containing a 1- to 4-m-thick reddish (oxidized) basal flow breccia. Individual flows are separated by 2- to 3-m- thick beds of yellow to green tephra in the northern Cerro Colorado. Total unit thickness is 80 to 300 m.
Ttp	TUFF OF CERRO PRIETA - Pink, densely welded trachydacite tuff with a 1- to 2-m-thick basal vitrophyre, eutaxitic foliation defined by flat recrystallized pumice fiamé, and 10 to 15% phenocrysts (sanidine > biotite > quartz). This unit bears a slight resemblance to the Tuff of San Ignacio (Ttsi) in both mineralogy and the abundance of spherules in the vapor phase alteration zones. However, this unit overlies both Td1 and Ttsi, has a higher abundance of phenocrystic quartz and biotite, and has a distinctly different bulk geochemical signature (Darin, 2011).
Ttsf	TUFF OF SAN FELIPE - Maroon to brown to orange, densely welded tuff containing abundant yellow to white pumice, 10-15% anorthoclase phenocrysts, rare zoned pyroxene, and absolutely no phenocrystic quartz. Abundant flattened pumice fiamé reach lengths of up to 25 cm and form a well-defined eutaxitic foliation. Trachyte-rhyolite inclusions containing abundant alkali feldspar in a dark glassy groundmass are a common diagnostic feature of this unit. This unit is a well-documented and regionally extensive rhyolite ignimbrite exposed over an area of greater than 4,000 km ² in northern Baja California and Sonora, Mexico that serves as a key stratigraphic marker and geologic tie-point across the Gulf of California (e.g., Stock et al., 1999; Oskin et al., 2001; Oskin and Stock, 2003a). Bennett et
	al. (2013) report a high-precision age of 12.50 ± 0.08 Ma [Ar/Ar] for this unit. It is only exposed in two localities within the study area, representing the northernmost identified outcrops of the Tuff of San Felipe on the eastern rifted margin of the Gulf of California. Northeast of El Desemboque, the unit is ~25 to 70 m thick with a thin (<1 m) discontinuous black vitrophyre. The lower densely welded, fiamé-rich member (20 to 40 m thick) grades upward into a non-welded zone with intact, undeformed pumice (5 to 30 m thick).
Ttsi	TUFF OF SAN IGNACIO - Bright pink to white or orange, ashy, crystal-poor, spherulitic rhyolite ash-flow tuff. This unit contains uncommon cm-scale, white to pink pumice fiamé and unique subrounded to angular, vesicular, plagioclase-phyric andesite lithics with an average diameter of 1 cm (max. 5 cm). Abundant 0.5- to 3-cm-diameter quartz-filled spherules and lithophysae in a pink to white, ashy groundmass are especially diagnostic of this tuff and pervasive throughout the vapor-phase alteration zone. Very rare small pumice fragments and partially dissolved potassium feldspar, quartz, and biotite phenocrysts are also observed. The base is commonly a 1- to 5-m-thick, dense black to brown vitrophyre with rare feldspar micro-phenocrysts. A 0.5- to 1.5-m-thick, orange to brown, laminated basal surge deposit in the central and southern Cerro Colorado locally contains abundant subrounded tonalite (Kt) pebbles and
	cobbles. The basal unit is overlain by a 5- to 8-m-thick, pink to orange, crystal- and lithic-rich welded zone with uncommon phenocrysts (quartz >> feldspar > biotite). The welded zone grades upward into a spherulitic, partially welded zone of vapor-phase alteration 10 to 30 m thick in most exposures. Internal rheomorphic flow deformation in the form of disharmonic folds and recrystallized pumice fiamé is characteristic of this unit in the Cerro Las Burras. Flow-banding is densely-spaced (<1 cm) and rheomorphism is local and irregularly distributed within the unit; pumice lineations show various degrees of deformation, with some stretched up to 30 cm long (1:50 aspect ratio). A high precision age of 12.56 ± 0.09 Ma [U-Pb] has been determined for this unit (Darin, 2011). Typical unit thickness is 20 to
	40 m; maximum thickness is 350 m in the Cerro Las Burras.
Tta	TUFF OF ARIVAIPA - Deep maroon to red, partially welded, crystal- and lithic-rich rhyolite tuff only exposed in the Cerro Las Burras. Up to 5% quartz and plagioclase phenocrysts and undeformed yellow, ashy pumice are diagnostic of this tuff. This unit contains a 1- to 4-m-thick, white to red breccia at its base, which grades upward into a partially welded lithic-rich zone containing 15% brown, red, purple, and black, subangular volcanic lithics and rare granitic xenoliths. The upper 2 to 3 m of the unit are nonwelded and contain abundant yellow and white pumice clasts with no phenocrysts. A white, discontinuous, ashy, quartz-rich layer up to 10 m thick is observed approximately 30 m below the top of the unit. Total unit thickness is 50 to 80 m.
Tb1	Indurated, glassy basalt flows containing up to 10% altered olivine and subordinate pyroxene phenocrysts. Total unit thickness is up to 40 m.
Tr1	Densely foliated rhyolite flow containing up to 5% phenocrysts (quartz ≈ sanidine > feldspar) in a pink to purple groundmass. Found only in the Cerro Colorado. Maximum unit thickness is 50 m.
Tc1	Massive, poorly sorted, volcaniclastic pebble-cobble conglomerate and breccia with a gray, ashy matrix. This unit has a monolithologic assemblage of clasts from underlying dacite flows and tuffs (Tdf, Tdt) in the northwestern study area. Virtually all clasts are porphyritic dacite, which is diagnostic of this unit. Total unit thickness is up to 750 m.
Tdt	Monolithologic, lithic-rich dacite tuffs with subordinate interbedded tuff breccias and dacite lava flows (Tdf). Tuffs and breccias have a nearly homogeneous composition of porphyritic dacite (Tdf) clasts. The matrix is ashy and varies from yellow, orange, and white to pink. Outcrops are typically hard and non-friable. This unit is interpreted as a proximal to medial dacite stratovolcano facies. Typical unit thickness is 100 to 200 m, with a maximum of 660 m.
Tdf	Porphyritic dacite lava flows with abundant diagnostic euhedral plagioclase phenocrysts (10 to 20%) up to 6 mm long, sub- to euhedral biotite (2 to 5%) and quartz (2 to 5%) phenocrysts in a gray to red groundmass. Locally exposed basal flow breccias are up to 3 m thick. Intercalated with Tdt in the Sierra Bacha and Sierra Tordilla. Total unit thickness is up to 270 m.
Ta2	Purple, aphyric peraluminous trachyandesite flows containing 1 to 2% microlitic plagioclase and probable pyroxene in an aphanitic groundmass. Some flows contain a 1- to 2-m-thick red basal flow breccia. Dikes of similar composition and agglomeritic breccia zones are common in the southwesternmost Cerro Colorado. A similar aphyric andesite flow is also observed just west of the Cerro Pelón in the hanging wall strata of the Bacha fault. Total unit thickness is up to 330 m.
Ta1	Gray to purple, plagioclase-phyric, peraluminous vesicular basaltic-trachyandesite lava flows. Locally abundant vesicles are commonly filled with white to yellow zeolite. Exposures are typically weathered and rubbly. The age of this unit is partly constrained by the interbedded Tuff of Cerro Colorado (Ttc, 14.5 Ma). Total unit thickness is up to 290 m.
Ttc	TUFF OF CERRO COLORADO - Yellow to red, crystal-lithic rhyolite tuff. This unit either directly overlies the basement nonconformity or is interbedded within Ta1 throughout most of the Cerro Colorado. The base contains a 2-to 8-m-thick, yellow to orange, nonwelded member with yellow, red, and purple tephra and subangular volcanic lithics, grading upward into a brick-red, partially welded crystal-lithic tuff with up to 5% yellow and gray pumice and up to 10% phenocrysts (quartz > feldspar). Locally this unit contains multiple cooling units several meters thick and/or a purple densely welded upper member with significantly less pumice and smaller lithic fragments. The uppermost welded members form resistant ridges flanked by colorful talus slopes on both sides. A maximum eruption age of 14.5 \pm 0.3 Ma [U-Pb] has been determined for this unit (Darin, 2011). Total unit thickness is 10 to 40 m.
Tr Trb	Gray to light purple rhyodacite flows (Tr) with 5 to 15% phenocrysts (quartz > plagioclase >> biotite) and compositionally similar rhyolitic breccias (Trb) found only in the Cerro Las Burras. Total unit thickness is up to 1100 m.
Tbu	Thin, discontinuous exposures of indurated, glassy basalt flows. Some flows have an aphanitic texture while others contain up to 10% phenocrysts, including altered olivine, pyroxene, and less common plagioclase. Total unit thickness is up to 60 m.
Tss	Red to orange, massive to laminated, fine- to coarse-grained sandstone consisting of moderately sorted, subangular to subrounded grains of quartz >> alkali feldspar ≈ biotite, and up to 10% red lapilli locally. Overall grussy composition resembling the underlying granitic basement units. Typically found in depositional contact with Mesozoic basement units or intercalated with Ta1. Typical unit thickness is 1 to 3 m, with a maximum of 15 m.
Tcu Tru Ttu	Undifferentiated conglomerate (Tcu), rhyolite lava- and ash-flows (Tru), and rhyolite ash-fall tuffs (Ttu). Ttu is yellow to white to pink, nonwelded to welded, thinly laminated tuffs with an ashy, quartz-rich matrix, volcanic lithics, and up to 10% euhedral phenocrysts of plagioclase, biotite, quartz, and sanidine. Individual tuffs are up to 20 m thick.
Tcf	Well-stratified, clast-supported pebble-cobble conglomerate and interbedded pebbly sandstone. Conglomerate beds contain a white to red granular, grussy matrix and sparse boulders up to 60 cm in diameter. Well to very well rounded clasts include quartzite, tonalite, chert, limestone, and various metamorphic lithologies along with subordinate volcanic clasts. This unit is correlated with the distinctive conglomerate unit of Gastil et al. (1973) and Bryant (1986) based on the exotic clast assemblage, the presence of similarly unique Permian limestone clasts containing fusulinid and gastropod fossils, and proximity to previously mapped outcrops along strike to the southeast in the Sierra Seri (Gastil & Krummenacher, 1976). Correlatable outcrops in Baja California are overlain by and intercalated with volcanic flows as old as ca. 20-21 Ma (Lewis, 1994; Stock, 1989); additional stratigraphic constraints on Baja (e.g., Dorsey & Burns, 1994; Oskin & Stock, 2003b) suggest an Oligocene to middle Miocene age for this unit.
Kg Kgd	Medium- to coarse-grained tonalite (Kt), granodiorite (Kgd), granite (Kg), and quartz diorite (Kd). Kt is composed of plagioclase > quartz > biotite >> alkali feldspar, and contains locally abundant metasedimentary enclaves typical of S-type granites formed from sedimentary protoliths. Kgd is composed of plagioclase > quartz > alkali feldspar ≈
Kt Kd	biotite. Kg contains microcline megacrysts up to 3 cm in length and quartz > alkali feldspar >> biotite ≈ plagioclase; it is only found in the central study area as 10- to 30-m-thick dikes and a single concentric pluton that forms a prominent peak in the Cerro Pelón, where cross-cutting relationships and the presence of tonalite xenoliths within Kg indicate that it postdates emplacement of Kt. Kd consists of fine- to medium-grained quartz diorite containing plagioclase > amphibole ≈ biotite > quartz ± orthopyroxene; it is only present as a single intrusion in the Sierra Tordilla. A Late Cretaceous age has been assigned to these units based on radiomentric ages from proximal areas with similar lithologies representing the coastal Sonora batholith (Gastil et al., 1974; Gastil and Krummenacher, 1977; Ramos-Velázquez et al., 2008).
Mzs Mzv Mzc	Mostly black to gray, low-grade hornfels facies metasedimentary rocks (Mzs) with a coarse-grained to granular texture and abundant primary quartz and secondary muscovite. Metavolcanics (Mzv) include dense, glassy black basalt and andesite(?) flows commonly containing plagioclase and amphibole phenocrysts and showing a streaky black and white schistosity locally. Metacarbonates (Mzc) consist primarily of 5- to 25-cm-thick beds of low-grade meta-limestone and intercalated calcite-cemented sandstone; this unit contains 1- to 3-cm-long unidentified, fragmentary, silicified fossils(?) with both cylindrical and 4- to 6-sided prismatic/angular forms that are very rare, but
	locally abundant in densely packed layers up to 10 cm thick (29.52353°N, 112.31983°W). Low-grade metamorphism is likely the result of contact metamorphism during emplacement of the Late Cretaceous coastal Sonora batholith (Ramos-Velázquez et al., 2008); protolith ages are inferred to be Mesozoic, although older ages are possible.
Pzq	Very fine-grained quartzite. Outcrops are usually weathered and rubbly. Only exposed in one locality, just southwest of Pozo Coyote. This lithology is not observed elsewhere in Mesozoic strata of Sonora, leading some to interpret it as an unusual facies of Paleozoic strata west of the miogeoclinal margin (Gastil and Krummenacher, 1977; Stewart and Poole, 2002).
	*Petrologic descriptions of volcanic units are based on a combination of whole-rock geochemical analysis, petrography, and texture. Geochemical data are presented in Darin (2011).

DIGITAL MAP AND CHART SERIES DMCH021 DOI:10.1130/2014.DMCH021

Published by

The Geological Society of America, Inc. 3300 Penrose Place • P.O. Box 9140 Boulder, Colorado 80301-9140

Darin, M.H., and Dorsey, R.J., compilers, 2014, Geologic map of the Sierra Bacha, coastal Sonora, Mexico: Geological Society of America Digital Map and Chart Series 21, doi:10.1130/2014.DMCH021.

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