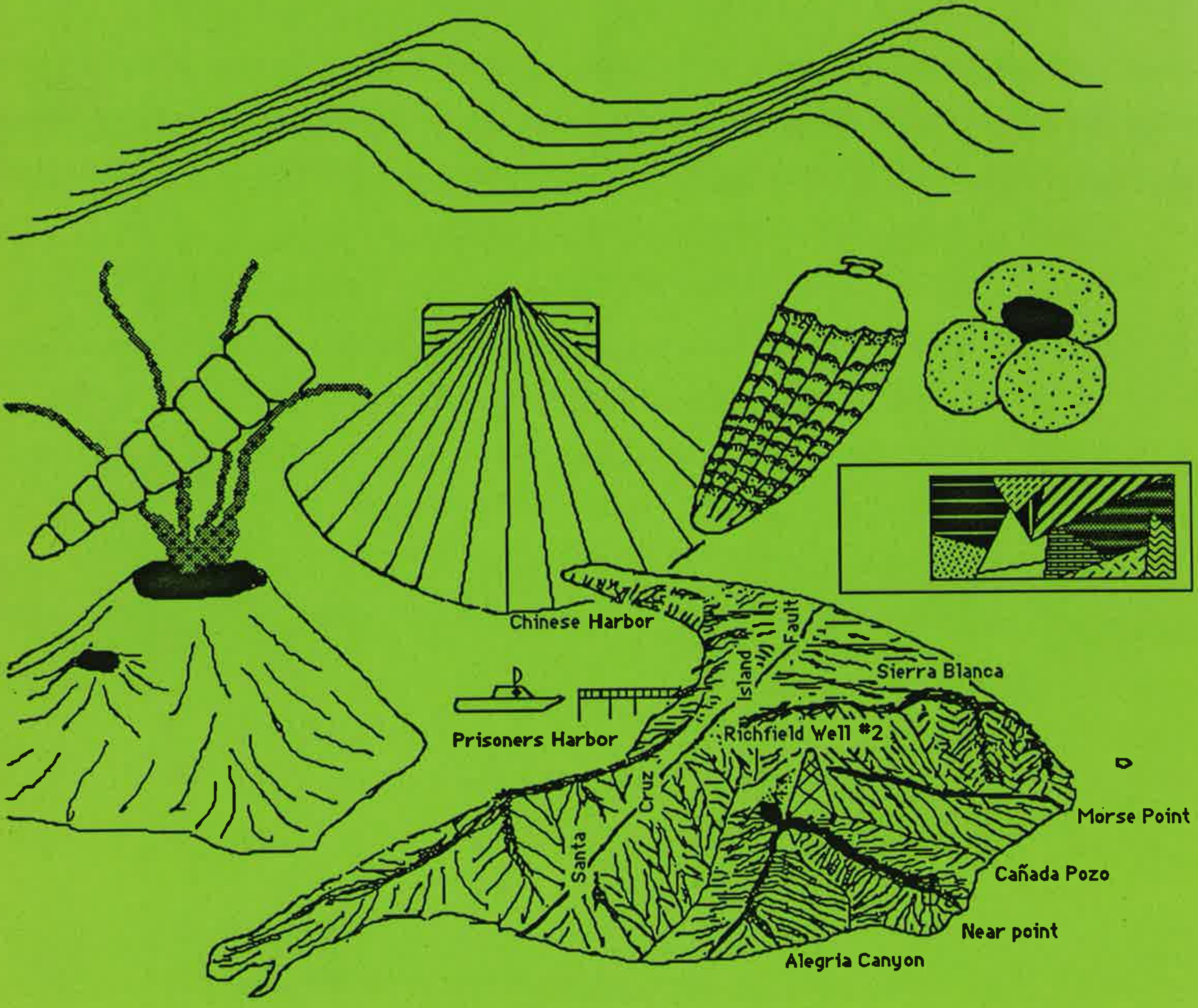
CSUN SIXTH ANNUAL FALL FIELD FROLIC

1988

SANTA CRUZ ISLAND



Version 2.1

CSUN SIXTH ANNUAL
FALL FIELD FROLIC

SANTA CRUZ ISLAND

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California State University, Northridge

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GUIDEBOOK BY
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Contents:

VERSION 2.1

RECENT HISTORY OF SANTA CRUZ ISLAND

Date	Event, people involved
Pleistocene	Aluvium deposited on marine terraces.
14,000 b.p.	Radiocarbon date for flora and vertebrate fossils (Douglas Fir forest and dwarf mammoths).
6,000 b.p.	Age of oldest human remains on island.
6,000 b.p. to 1820s	Chumash Indians ruled the island.
1542	First observations of island by Europeans made on Cabrillo's voyage.
1769	Portola's sea expedition claimed the island for the King of Spain. They named the island Santa Cruz ("holy cross") because a Catholic priest lost his ornamented walking staff here. The staff was returned to him by Chumash Indians as he was leaving the island.
1821	Dominion over Santa Cruz Island was transferred to Mexico because of the Mexican War of Independence.
1839	The first private ownership of the island was deeded to Castillero by a land grant.
1848	California became a United States territory by the Mexican Treaty of Guadalupe Hildago (though it was later argued that Santa Cruz Island was not officially included in the treaty).
1869	A group of 10 bankers from San Francisco bought the island and established the Santa Cruz Island Co.
1880	J. Caire, an original stock holder of the Santa Cruz Island Co., made his first visit to the island and became sole owner of the company.
1925	Caire's descendants divided ownership of SCI Co. into seven parts. Some of these descendants (the Gherini family) still retain the eastern 10% which will eventually be included in the Channel Island National Park.
1937	Edwin Stanton purchased the western 90% of the island to be run as a cattle-breeding ranch.
1966	The field station was established, first as the Channel Islands field station, then later (1973) as the University of California Nature Reserve field station.
1987	Carey Stanton (Edwin's son) died and ownership of the western portion passed to The Nature Conservancy via an arrangement made in 1978.

GEOLOGIC INTRODUCTION

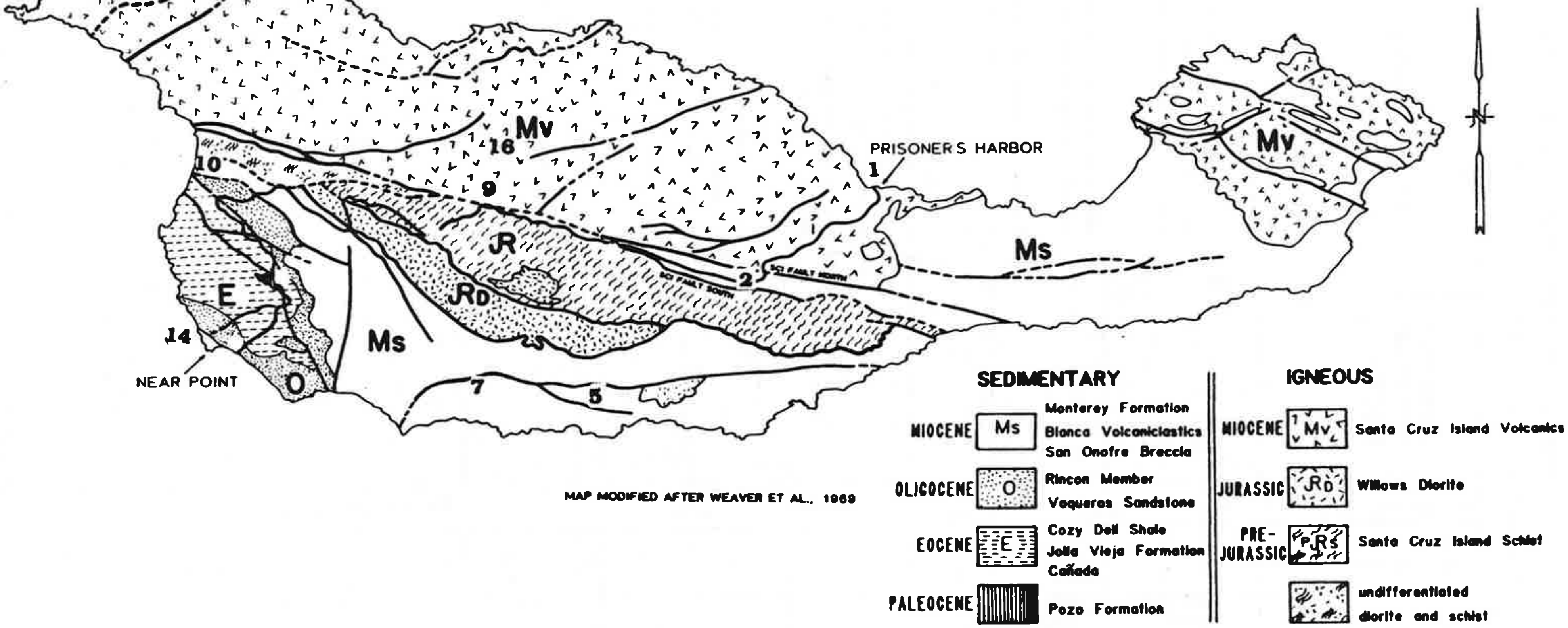
The first comprehensive description of the geology of Santa Cruz Island resulted from UCSB geology field camps of 1964 and 1965 and are compiled in Weaver (1969). This publication emphasizes biostratigraphy and sedimentary units on the island and includes a detailed geologic map. Recent ideas concerning the tectonic setting, nature of the basement rocks and sedimentology are compiled by Howell (1976). The only major addition to these works is the recognition of clockwise rotation of the island (Kamerling and Luyendyk, 1985).

Santa Cruz Island is divided geologically by the east-west trending Santa Cruz Island fault (see Figure 1). North of the fault, north-dipping Miocene volcanics are overlain by siliceous shales of the Miocene Monterey Formation. South of the fault, Mesozoic schist is intruded by Late Mesozoic plutons of intermediate composition. These basement rocks are overlain by >2037m of marine shales, sandstones and conglomerates of Upper Cretaceous through Miocene age. Stratigraphic columns (see Figure 2) compare Tertiary sections encountered south of the SCI fault, north of the faullt, and across the Santa Barbara Channel in the central Ventura Basin. Current indicators throughout the column generally show westerly to southwesterly transport directions. All of the sandstone units are relatively immature and those in the Tertiary section show a general trend of increasing lithic fragments (predominantly volcanic and schistose rock fragments) with decreasing age (see Figure 3).

Three unsuccessful hydrocarbon test wells were drilled in the 1950s and 1960s. The Richfield's Santa Cruz Island No. 1 and No. 2 wells bottomed in Cretaceous sediments at depths of a few thousand meters. The Union Gherini No. 1 well, drilled in the late 1960s, bottomed in possible non-marine red bed (Oligocene) rocks at about a depth of about 1500m.

The following sections present brief descriptions of the lithologic units and recent hypothesis about the structural history of the island. The lithologic unit descriptions, except where noted, are from Weaver et al. (1969).

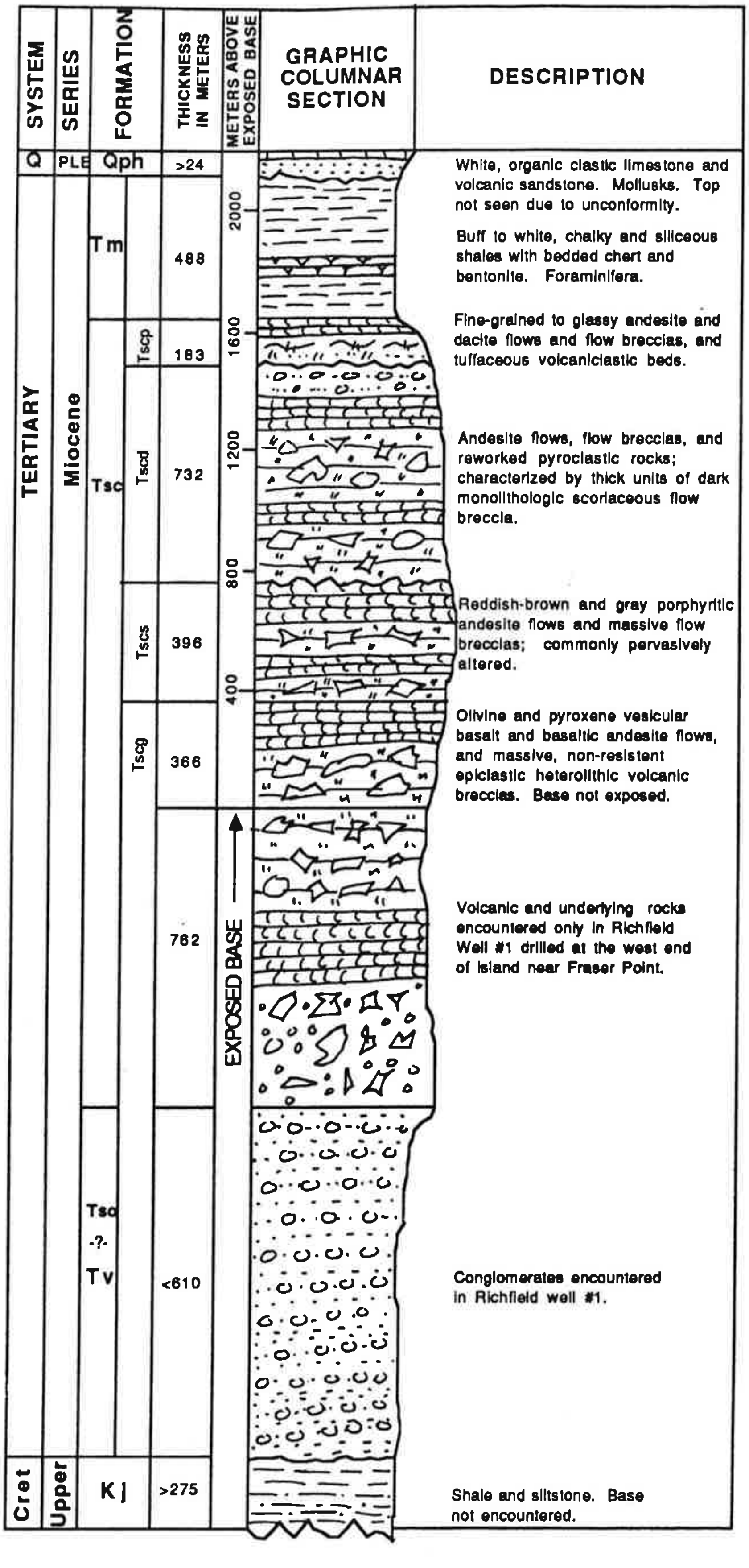
Geologic Map of Santa Cruz Island



MAP MODIFIED AFTER WEAVER ET AL., 1969

Figure 1. Geologic map of Santa Cruz Island. Numbers show selected locations described in this guidebook.

B. GENERALIZED COLUMNAR SECTION FOR SANTA CRUZ ISLAND, NORTH OF THE SANTA CRUZ ISLAND FAULT, SANTA BARBARA COUNTY, CALIFORNIA.



White, organic clastic limestone and volcanic sandstone. Mollusks. Top not seen due to unconformity.

Buff to white, chalky and siliceous shales with bedded chert and bentonite. Foraminifera.

Fine-grained to glassy andesite and dacite flows and flow breccias, and tuffaceous volcaniclastic beds.

Andesite flows, flow breccias, and reworked pyroclastic rocks; characterized by thick units of dark monolithologic scoriaceous flow breccia.

Reddish-brown and gray porphyritic andesite flows and massive flow breccias; commonly pervasively altered.

Olivine and pyroxene vesicular basalt and basaltic andesite flows, and massive, non-resistent epiclastic heterolithic volcanic breccias. Base not exposed.

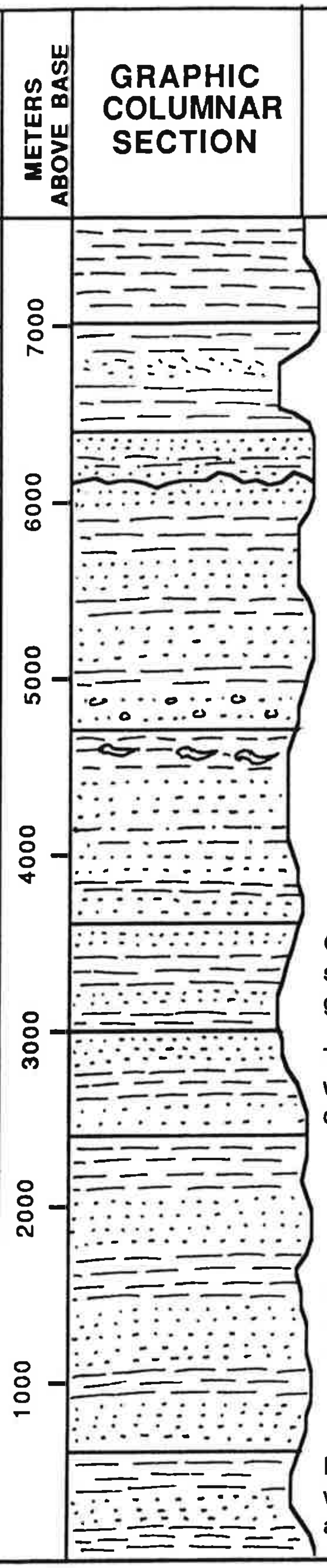
Volcanic and underlying rocks encountered only in Richfield Well #1 drilled at the west end of island near Fraser Point.

Conglomerates encountered in Richfield well #1.

Shale and siltstone. Base not encountered.

Figure 2B.

C. GENERALIZED COLUMNAR SECTION FOR CENTRAL VENTURA BASIN, VENTURA COUNTY, CALIFORNIA.



SYSTEM	SERIES	FORMATION	THICKNESS IN METERS	DESCRIPTION
TERTIARY	Miocene	Tm	610	Platy to brittle siliceous shale, locally cherty with soft, punky, brown semi-siliceous to clayey shale with minor thin calcareous strata.
		Tr	610	Poorly bedded gray shale with minor lenticular snadstone. Abundant micro-fossils.
	Miocene / Oligocene	Tv	305	Massive to thickly bedded, light greenish -gray to tan sandstone and minor siltstone, locally calcareous. Abundant shallow marine mega-fossils.
	Oligocene	Ts	1372	Brown to gray sandstone and inter-bedded maroon to green silty shale with a basal conglomerate composed of Franciscan clasts.
	Eocene	Tcw	<1068	Yellow-gray arkosic sandstone with minor interbeds of greenish-gray siltstone and shale. Common oysters in upper beds.
		Tcd	>610	Gray argillaceous to silty micaceous shale with minor interbeds of light gray to tan arkosic sandstone.
		Tma	610	Thick-bedded, tan arkosic sandstone with thin partings to thick interbeds of gray micaceous shale.
		Tj	1830	Dark gray micaceous shale with minor thin interbeds of tan arkosic sand-stone, and tan arkosic sandstone with minor interbeds of dark gray micaceous shale.
Cret.	Upper	Kj	>600	Dark gray to black micaceous shale with minor interbedds of hard tan arkosic sandstone.

Figure 2C.

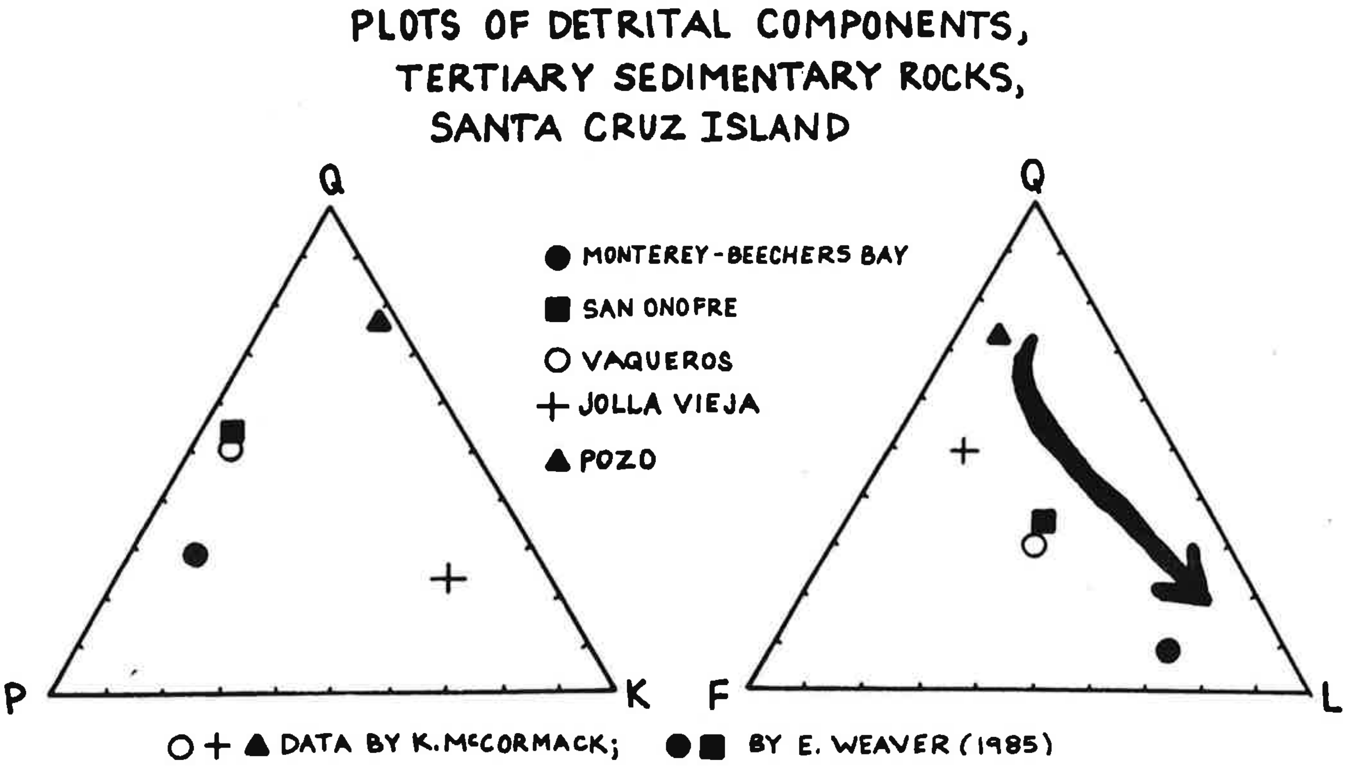


Figure 3. Modal compositions of sandstones and conglomerates exposed on Near Point shown by ternary plots of detrital components: quartz (Q), plagioclase (P), potassium feldspar (K), feldspars (F) and lithics (L).

LITHOLOGIC UNITS

SANTA CRUZ ISLAND SCHIST

Lithology: olive to grey-green chlorite schist, weathers to a brick red color: minor greenstone and milky quartz veins.

Thickness: up to 1500m (Hill, 1976).

Age: unknown. Pre-late Jurassic based on intrusion by Willows Diorite (162 ± 3 Ma; Mattinson and Hill, 1976).

Comments: These are the oldest rocks on Santa Cruz Island. Schist consists chiefly of intermediate composition volcanic rocks altered to a quartz-albite- epidote assemblage (Rand, 1933; Hill, 1976). Metamorphic, plutonic and sedimentary rocks are less common than altered volcanics. A 120-130 Ma K/Ar date on the schist suggests a Late Jurassic-Early Cretaceous thermal event (Mattinson and Hill, 1976). Structural grain, bedding and schistosity are oriented NW-SE, approximately parallel to SCI fault. Location #7.

WILLOWS DIORITE

Lithology: hornblende diorite, hornblende quartz diorite, less abundant leucotonalite, gabbro and ultramafic rocks.

Age: Late Jurassic, based on 162 ± 3 Ma U/Pb date from zircon (Mattinson and Hill, 1976).

Comments: Willows Diorite intrudes Santa Cruz Island Schist. Location #7.

ALAMOS TONALITE

Lithology: Leucocratic tonalite (60-65% albite, 30-35% quartz).

Age: Early Cretaceous based on 141 ± 3 Ma U/Pb date from ziron (Mattinson and Hill, 1976).

Comments: Interpreted by Mattinson and Hill (1976) and Hill (1976) as the youngest plutonic rock on the island.

JALAMA FORMATION

Lithology: marine sandstone and conglomerate

Thickness: 567m+ (Richfield No. 2 well)

Age: Late Cretaceous based on *Globotruncana arca* (foraminifera)

Comments: Cretaceous strata on Santa Cruz are found only in the subsurface.

The general lithology is reported to be similar to Late Cretaceous outcrops on San Miguel Island. Late Cretaceous Cenomanian strata are known from the subsurface of Santa Rosa Island.

POZO FORMATION

Lithology: fine-grained, thin-bedded, well-sorted, calcareous cemented, arkosic sandstone and siltstone.

Thickness: 69m of surface exposure (122m encountered in Richfield No. 2 well).

Age: Paleocene based on *Turritella pachecoensis.*

Comments: oldest exposed sediments on Santa Cruz Island. Unit contains extremely large (20+ cm length) *Turritella* fossils. Location #12.

CAÑADA FORMATION

Lithology: grey to bluish-grey marine shales, thin-bedded siltstones, minor fine-grained sandstones. Thin basal conglomerate.

Thickness: 427m+

Age: Eocene (early to medial) based on rich foraminiferal and molluscan fauna.

Comments: The most extensively exposed Tertiary sedimentary unit in the Christy Anticline area. Location #13.

JOLLA VIEJA

Lithology: buff, medium-grained, massive to thick-bedded sandstone. A basal conglomerate of igneous clasts becomes increasingly dominant to the northwest.

Thickness: extremely variable - 268m at its thickest but pinches out over a lateral distance of a few miles.

Age: Medial Eocene

Comments: This unit appears to be a conglomerate/sandstone-filled channel which thickens and coarsens to the northwest. Locations #13 and 14.

COZY DELL FORMATION

Lithology: greenish to bluist-grey micaceous shale and silty shale with abundant forams.

Thickness: 279m maximum.

Age: Eocene (late Narizian) based on foraminifera.

Comments: Southwest (190°) paleotransport and paleoslope directions measured from ripples and slump folds in upper part. Several feet of red shale (a possible Sespe red bed equivalent) are reported at top of unit in Alegria Canyon. Locations #13 and 14.

VAQUEROS FORMATION

Lithology: brown, thick-bedded conglomerte overalin by brown sandstone.

Thickness: 166m of conglomerate; 73m of sandstone.

Age: Oligocene (late Zemorrian or early Saucesian) based on molluscan faunal assemblages.

Comments: The formation disconformably overlies the Cozy Dell Formation. Southwest transport directions are shown by rare clast imbrication. Clast types include hornblende diorite (40-60%), acidic volcanics (20-30%) and quartz-chlorite schist (5-15%); see McLean et al. (1976a). Blueschist-type clasts are absent. Calcite-filled fractures are common on outcrops. Locations #13 and 14.

RINCON FORMATION

Lithology: grey to brown calcareous shale and mudstone.

Thickness: 76m

Age: Miocene (Saucesian) based on foraminifera.

Comments: Contact with overlying San Onofre Breccia is gradational, with blueschist conglomerates interfingering with Rincon shale. Locations #13.

SAN ONOFRE BRECCIA

Lithology: bluish-grey conglomerate, sandstone, mudstone.

Thickness: 99m

Age: Miocene (Saucesian) based on foraminifera (see McLean et al., 1976a).

Comments: San Onofre contains a distinct assemblage of metamorphic clasts including blueschist. McLean et al. (1976a) report that the San Onofre is a coarse facies of the Rincon Formation. Westerly transport directions are indicated by ripples. Locations #13.

MONTEREY FORMATION - BEECHERS BAY MEMBER

Lithology: grey thin-bedded siltstone, fine-grained sandstone.

Thickness: 177m (minimum).

Age: Miocene (Relizian) based on foraminifera.

Comments: Abundant slump structures and ripple cross laminations on beach exposures show westerly-directed paleocurrent and paleoslope. The sandstone has an abundant first-cycle volcanic component. The characteristic siliceous facies of the Monterey Formation is missing south of the SCI fault. Locations #13.

BLANCA FORMATION

Lithology: light grey to buff, thick-bedded volcaniclastic conglomerate, tuffaceous sandstone and tuff.

Thickness: up to 1200 m locally .

Age: Miocene (Late Saucesian-Early Luisian equivalent) based on K-Ar dates that range 13-15 Ma (McLean et al., 1976b).

Comments: The Blanca Formation conformably overlies the San Onofre Breccia and contains some blueschist detritus in the lower part. There is a buttress unconformity between the paleocurrent indicators that suggests a southerly to southerwestely transport (Minck, 1982). The Blanca Formation is probably not sourced from the Santa Cruz Island Volcanics as suggested by Weaver (1969). The SCI volcanics are generally older and more mafic in composition than the Blanca Formation (see discussion in Minck, 1982). Location #7.

SANTA CRUZ ISLAND VOLCANICS

Lithology: pyroxene andesite flows, flow breccias and minor pyroclastic flows and volcanic conglomerates: more basic in composition at base, more silicic at the top.

Thickness: 1677m of surface exposure: additional 762m inferred from the subsurface.

Age: three of four K-Ar dates cluster between 16.0-16.5 Ma (Turner, 1970; Crowe et al; 1976).

Comments: These volcanic rocks are located only north of the SCI fault. Possibly non-marine during early eruptions but definitely marine at the top. The eruptive center is east of Devil's Peak. Location #17.

MONTEREY FORMATION

Lithology: cream-colored, thin-bedded siliceous and tufaceous shale with minor thin-bedded limestone at the base.

Thickness: >457m in China Harbor area.

Age: Miocene (late Luisian to early Relizian).

Comments: This typical siliceous facies of the Monterey Formation is only exposed north of SCI fault.

STRUCTURAL SETTING

The northern Channel Islands, including Anacapa, Santa Cruz, Santa Rosa and San Miguel, form an east-west mountain chain along the southwest border of the Transverse Range physiographic province. Santa Cruz, at 96 km^2, is the largest of the islands. The whole chain appears to be a highly faulted east-west trending anticlinorium (Weaver, 1969).

Santa Cruz Island (SCI) is divided into distinct northern and southern geologic provinces by the east-west trending Santa Cruz Island fault (see Figure 1). Miocene volcanics on the north side are faulted against Cretaceous and older basement rocks on the south side of the fault. The fault has two main strands which form a pronounced valley across the center of the island. The main trace of the fault follows the axis of the anticlinorium and offsets stream drainages in a left lateral sense, possibly by as much as 579m in Recent times (Patterson, 1979). The southern province is dominated by northwest-southeast trending faults and folds. We will see one of these folds, the Christy Anticline, at the southwest corner of the island when we visit the lower Tertiary marine sedimentary section. Left separation of EW faults and NW-SE orientation of folds suggests the Northern Channel Islands are or were within a left shear couple. Luyendyk et al. (1983) think they found the Christy Anticline separated left laterally approximately 10km across the offshore extension of the Santa Cruz Island fault.

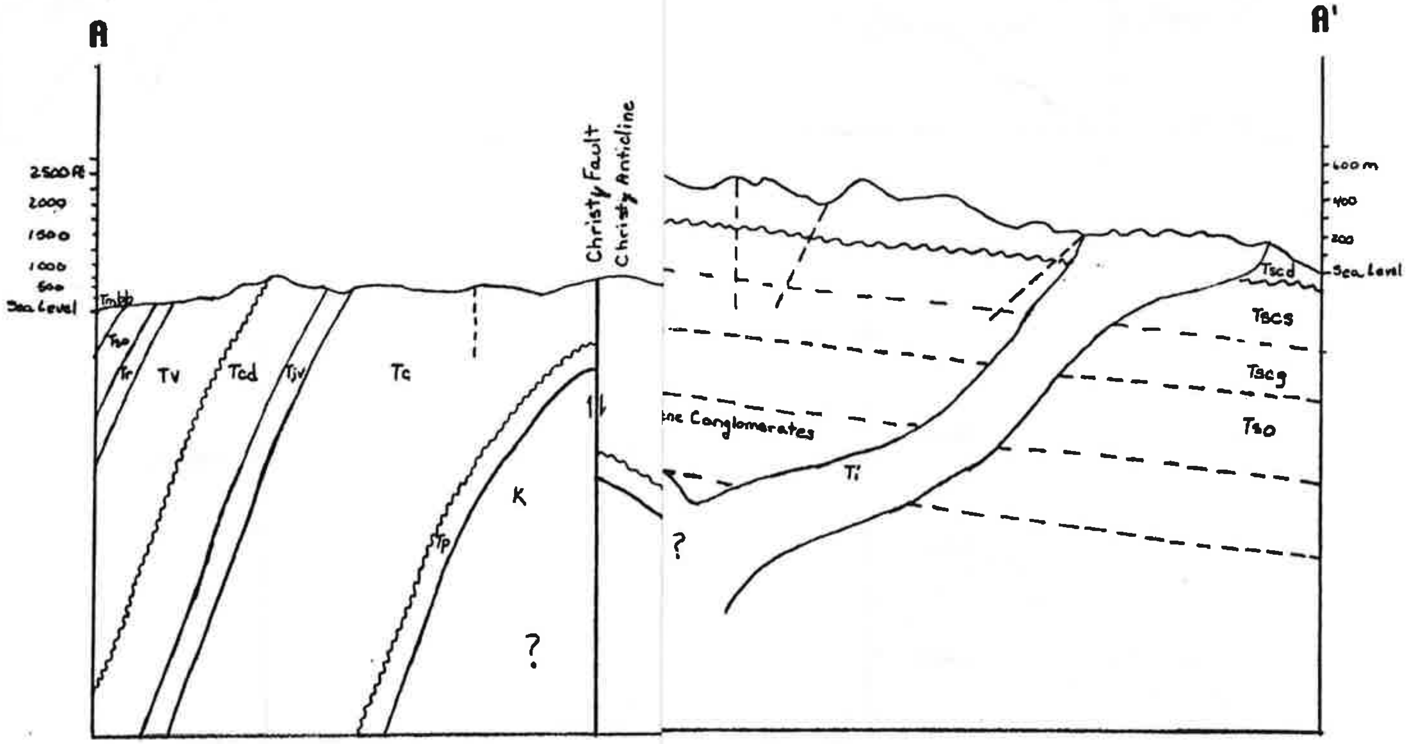
A geologic cross-section through the Christy Anticline and Devil's Peak (see Fig. 4) shows the folded and faulted Tertiary section south of the SCI fault, and the north-dipping homocline of volcanic rocks north of the fault. Topographic profiles are shown in Fig. 5.

TECTONIC HISTORY

Various researchers have attempted to explain the origin of Santa Cruz and the other Channel Islands using mainly petro-provenance and structural evidence (see Howell, 1976; Howell and Vedder, 1981; Howell et al., 1987). More recent studies have added paleomagnetic evidence to constrain the timing and movement of blocks which make up the Continental Borderland (see Kamerling and Luyendyk, 1985; Champion et al., 1986; Luyendyk and Hornafius, 1987). Still, a complete and satisfactory explanation of the tectonic evolution of the islands remains somewhat elusive.

Howell (1976) proposed a right lateral strike slip model for movement and eventual joining of the two provinces on SCI. He correlated clast assemblages from Eocene sandstones in San Diego to those on the islands in order to tie the islands to their source area.

Kamerling and Luyendyk (1983) and Luyendyk and Hornafius(1987) suggest that the Northern Channel Islands are part of the Western Transverse Ranges tectonic block. The islands arrived at their present position along with the rest of the block as a result of approximately 90° of clockwise rotation and 10° northward translation within the dextral shear zone between the Pacific and North American plates as the Farallon plate broke up and was subducted. This rotation began in earliest medial Miocene time and may be continuing today.


A
A'
2500 ft
2000
1500
1000
500
Sea Level
Tmbb
Tso
Tr
Tv
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?
Christy Fault
Christy Anticline
ene Conglomerates
Ti
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600 m
400
200
Sea Level
Tscd
Tscs
Tscg
Tso

Howell and Vedder (1981) defined four terranes in the southern California borderland based on the distribution of basement rocks and on the stratigraphic contrasts in adjacent fault-bounded regions. Bottjer and Link (1984) and Champion et al. (1986) join these four terranes together with others in the Malibu area, the Peninsular Ranges, and the Baja peninsula into a large "Peninsular Range" or "Baja-Borderland" allochthon. Apparently the terranes amalgamated by Late Cretaceous time somewhere south of, but still attached to, the western edge of cratonic North America. The allochthon mimicked North American cratonal motion throughout the Paleogene. It evidently broke free and moved rapidly northward during the Eocene and finally, arrived near its present latitude sometime prior to the Miocene rotation documented by others.

Santa Cruz Island is positioned at a complicated structural boundary at the intersection of radically different blocks or terranes in each of these models. This fact makes a thorough investigation and understanding of the geology of SCI extremely important if the history of the borderland is to be resolved.

VOLCANIC ROCKS

Two recent studies at CSUN have focused on 1) the Santa Cruz Island (SCI) Volcanics located north of the SCI fault (Weigand, 1988) and 2) the Blanca Formation located south of the fault (Shelton, 1988). Continuing studies will look at the volcanic clasts in sedimentary units out of the fault older than the Blanca.

The volcanic rocks on Santa Cruz are part of a larger group of volcanic centers that erupted in the Los Angeles and California Borderland areas about 13-18 million years ago. These areas represent the culmination in southern California of Cenozoic volcanism that began in the eastern Mojave Desert about 30 million years ago and swept irregularly west and north. This extensive extrusive activity was related closely to complex tectonic activity that included subduction of the Farallon plate whose subduction angle was steepening, and interaction of the Pacific and North American plates along a lengthening transform boundary; this activity additionally involved rotation and possible northward translation of crustal blocks.

The origin of the volcanic rocks in this area has been variously ascribed to subduction of the Farallon plate (Weigand, 1982, 1988; Crowe et al., 1976; Higgins, 1976), subduction of the Pacific-Farallon spreading center (Dixon and Ferrar, 1980), mantle diapirism into a slab-free window (Dickinson and Snyder, 1980), extensional melting at a migrating triple junction (Hurst et al., 1982), upper mantle and crustal dilation related to the East Pacific Rise (Hawkins, 1970) and extension related to the formation of coastal California Cenozoic basins (i.e., Crowell, 1987).

SANTA CRUZ ISLAND VOLCANICS

The rock types and stratigraphy of the SCI Volcanics were first systematically studied by Nolf and Nolf (1969). The following brief summary is from their work, with additional information from Crowe et al. (1976). The lowermost Griffith Canyon Member consists of flows and epiclastic volcanic breccias of basaltic and andesitic composition, deposited in a subaerial environment. The overlying Stanton Ranch Member is composed of andesite flows, flow breccias and subordinate tuff breccias erupted on the flanks of a volcanic edifice. Next younger is the Devil's Peak Member containing a variety of scoriaceous andesitic and dacitic flows, flow breccias, and reworked pyroclastic rocks. These rocks were apparently emplaced on the slopes of, and adjacent to, a volcanic center. The uppermost Prisoners" Harbor Member is composed of andesitic and dacitic flows, flow breccias and tuffaceous volcaniclastic beds, probably deposited in a submarine environment.

Turner (1970) reported K/Ar age dates of 16.1±0.9 Ma on a sample probably from the upper part of the Devil's Peak Member, and 16.5±0.8 Ma on a sample probably from the middle of the Prisoners' Harbor Member (these and subsequent dates have been corrected to new IUGS constants). Crowe et al. (1976) reported dates of 16.0±0.7 Ma and 19.9±0.9 Ma on the same sample from a dike cutting the lower part of the Devil's Peak Member. The lower part of the sequence has not been dated. San Onofre Brecccia of probable Saucesian age was encountered beneath the volcanics in the Union Oil Gherini No. 1 well drilled at the east end of the island (Weaver and Meyer, 1969), which probably limits the onset of volcanism to less than 23-25 Ma (Crouch and Bukry, 1979).

Petrographic varieties include aphryc and porphyritic basalt, porphyritic pyroxene andesite (the most common rock type), aphyric to sparsely porphyritic pyroxene andesite, porphyritic pyroxene dacite and porphyritic hornblende dacite (Crowe et al., 1976).

Based on SiO_2 contents, the 35 analyzed samples of SCI Volcanics are 3% basalt, 69% andesite, 20% dacite and 9% rhyolite; these percentages are in agreement with those of Crowe et al. (1978) based on petrographic criteria. They state that mafic rocks predominate in the lower part of the sequence, and intermediate to silicic rocks predominate in the upper part.

These rocks are subalkalic on an alkali-silica diagram and predominantly calc-alkaline based on the AFM diagram. Most trace elements also show calc-alkaline characteristics. Rare-earth-element patterns are similar and exhibit moderate light REE enrichment and small Eu anomalies. Isotopic values are low: $^{87}Sr/^{86}Sr$ ranges from .7025 to .7036 and $d^{18}O$ ranges from 6.7 to 7.3 (Hurst, 1983; Johnson and O'Neill, 1984).

Only three samples of lava from Anacapa Island have been analyzed . They fall within the range of SCI Volcanics for all major elements and most trace elements. It's hard to tell whether small differences in some trace elements argue for different source areas or petrogenetic processes or for inadequate sampling. More significant differences exist between SCI Volcanics and Conejo Volcanics exposed in the Santa Monicas. Conejo rocks are generally lower in K_2O and TiO_2, and are significantly lower in most trace elements, including the REE.

BLANCA FORMATION

The Blanca Formation was first described by Rand (1931) and Bremner (1932). Fisher and Charlton (1976) described the deposits as consisting of epiclastic debris in a tuffaceous matrix, fallout tuff, massive pyroclastic flows and reworked pyroclastic debris. A few occurrences of basalt and andesite flows and dikes are found throughout the outcrop area.

Weaver et al. (1969) divided the Blanca Formation into three members on the basis of texture, color and percentage of volcanic clasts. The lower member consists of bluish-grey, thin- to thick-bedded cobble conglomerate interbedded with pebble lithic tuffaceous sandstone. Both this member and the underlying San Onofre Breccia contain blueschist clasts; the Blanca is marked by the first occurrence of dacite clasts. The lower contact contains layers of oyster, *Pecten* and barnacle fragments. The middle member consists of white to light gray massive tuff breccia interbedded with tuffaceous sandstone and conglomerate; blueschist fragments are absent. The upper member consists of tan, massive, thick-bedded tuff breccia, tuffaceous sandstone and pebble to cobble conglomerate and breccia. The uppermost contact is not exposed.

Fisher and Charlton (1976) found the environment of deposition of the Blanca difficult to interpret because 1) fossils are scare or absent, and 2) the rock sequence is not typical of any well-known depositional stratigraphic model. They envisioned the depositional area as a narrow and relatively shallow continental shelf adjacent to a steep coast. The formation resulted from rapid deposition of material derived from a nearby, active volcano. Minck (1982) concluded that the middle member was deposited in a fan-delta system located along an abrupt basin margin adjacent to an area of active pyroclastic volcanism. She divided the member into 1) a tuff-breccia lithofacies deposited near the volcanic source in the subaerial part of the system, and 2) a sandstone-conglomerate lithofacies deposited in more distal portions of the system.

Paleocurrent indicators are rare in the formation. Those measured by Howell and McClean (1976) and Minck (1982) range between south and west. When corrected for the 126° of post-depositional clockwise rotation indicated by paleomagnetic data (Kamerling and Luyendyk, 1985), the source area was generally to the west shedding material to the east.

A volcanic clast from the middle member was dated by K-Ar at 13.3± 0.8 Ma, and an andesite flow from the upper member was dated at 14.9±0.8 Ma (McClean et al., 1976b). This apparent discrepency is probably a result of sampling or dating problems.

Based on SiO_2 contents, the 44 analyzed Blanca clasts (Shelton, 1988; H. McLean and D. Howell, unpubl. data) are 0% basalt, 5% andesite, 9% dacite and 86% rhyolite. As a suite, they are subalkaline and calc-alkaline. Except for one major element, the three members are indistinguishable; the upper member has slightly higher TiO_2 contents. In a petrographic study of the Blanca clasts, McLean et al. (1976b) found about 60% dacite and 38% andesite distributed among the following rock types: porphyritic quartz-pyroxene-hornblende dacite, porphyritic quartz-hornblende dacite, augite-hypersthene dacite and porphyritic pyroxene andesite. In view of the geochemical data, most of this "dacite" is probably rhyolite; further work is needed to resolve this dilemma.

Based on general age and petrographic similarities, the volcanic clasts of the Blanca were thought to have been derived from the SCI Volcanics located across the SCI fault by Weaver et al. (1969), but later petrographic and geochemical studies argue against this (McLean et al., 1976b; Weigand, 1988). Fisher and Charlton (1976) suggested the Conejo Volcanics in the western

Santa Monicas or the Tranquillon Volcanics in the western Santa Ynez Mountains as possible source areas.

The major distinction between the two volcanic units on Santa Cruz is the preponderance of silicic compositions in the Blanca clasts. Additinally, the Blanca rocks exhibit significant differences in several major and trace elements compared to felsic samples from the SCI Volcanics. These observations agree with the suggestion by McLean et al. (1976b) based on petrographic evidence that the Blanca was not derived from the SCI Volcanics. There are also significant geochemical differences between the Blanca clasts and 1) the Conejo Volcanics, 2) the Zuma Volcanics, and 3) the Tranquillon Volcanics. The search for the Blanca volcano continues.

DISCUSSION

The volcanic rocks from Santa Cruz and Anacapa Islands share gross age and compositional similarities with other volcanic rocks in the Los Angeles and southern California Borderland, including those from Santa Catalina and San Clemente Islands, Zuma, Glendora, El Modeno, Palos Verdes and Laguna Beach. These rocks are characterized by low Sr and O isotopic values and by being calc-alkaline, a combination conventionally interpreted as resulting from subduction-related processes.

The coastal volcanics could not have been produced by subduction of the Juan de Fuca plate, because the Mendocino triple junction was in the Los Angeles area about 25 Ma ago, and had migrated 400-500 km to the northwest by the time most of the coastal volcanism was occurring (Atwater and Molnar, 1973; Engebretson et al., 1985). The alternative is that the coastal volcanics were produced by subduction of the Cocos plate, yet several reconstruction models place the location of the Rivera triple junction far south of the Los Angeles area by 16-14 Ma ago (Atwater and Molnar, 1973; Engebretson et al., 1985).

All of the coastal volcanic rocks are located on the Baja-Borderland allochthon (Blake et al., 1982). Although the uncertainties are large, this allochthon may have been about 2.5° farther south relative to the North American craton and the Santa Lucia-Orocopia allochthon (Howell et al., 1987). Paleomagnetic evidence from the coastal volcanic rocks is consistent with the interpretation that since their eruption, the Conejo and northern Channel Island volcanic rocks experience northward translation relative to the North American craton, perhaps up to 8° or ~860km (Kamerling and Luyendyk, 1985; see also Champion et al., 1986).

Thus, several lines of compositional evidence indicate that these rocks were produced from a mantle source in a subduction environment. Volcanism occurred above the subducting Cocos plate onto the Baja-Borderland allochthon south of the Rivera triple junction; this allochthon then underwent northwestward translation subsequent to the wind-down of volcanic activity about 14 Ma ago.

CHRISTY ANTICLINE AREA

The Christy Anticline area is located at the southwest corner of Santa Cruz Island. It exposes a thick sequence of Tertiary rocks from the Paleocene through the Miocene along its westen limb, in Alegria, Well and Pozo Canyons, and Near Point.

The Pozo Formation is exposed in Well Canyon just east of Alegria Canyon, and is the oldest exposed sedimentary sequence on the island, although an exploratory oil well drilled by Richfield Oil Corp. penetrated 689 meters of marine sediment and bottomed in Upper Cretaceous sandstones and conglomerates. The Pozo Formation is a fine-grained, thin-bedded, well-sorted, calcite-cemented, arkosic sandstone and siltstone. It contains large *Turritella pachecoensis* fossils and some shallow water foraminifera, mainly *Cibicides,* and *Eponides.* The Pozo formation has been dated as Paleocene based on the presence of *Turritella pachecoensis* (Weaver et al., 1969).

The Cañada Formation is about 427 meters thick, and is composed of shale and thin-bedded siltstone with scattered limestone beds. It is rich in foraminifera and contains occasional mollusks. Doerner (1969) delineated four foraminifera zonules based on the assemblages found in the Cañada Formation. According to Doerner (1969), the Cañada Formation was deposited in a bay to inner shelf environment. The basin subsided during deposition, and the top of the formation was deposited in a bathyal, cold water environment.

The Jolla Vieja Formation is a medium-grained, structureless to thick-bedded, well-sorted arkosic sandstone that varies laterally in thickness and grain size. The exposure in Alegria Canyon is not completely representative (Weaver et al., 1969) and is only 26 meters thick. It is reported to be 255 meters thick (Rand, 1933) northeast of Kinton Point. Doerner (1969) reports that no microfossils were obtained from this unit, but Rand (1933) has recorded both foraminifera and molluscs from localities that may be within this formation.

The Cozy Dell Formation has a maximum thickness of 279 meters, is composed predominantly of shale, and is rich in foraminifera. Doerner (1969) delineates one zonule within the unit and describes it as lower bathyal and possibly anoxic. An angular unconformity exists between the cozy Dell Formation and the overlying Vaqueros Formation (Weaver et al., 1969).

The Vaqueros Formation is the youngest unit to crop out in Alegria Canyon. It has a maximum thickness of 240 meters and is composed of a lower conglomeratic unit and an upper volcanic arenite. Large cross beds and rare imbrication are exposed in Alegria Canyon. It contains abundant megafossils including pelecypods, gastropods, crustacea and shark teeth and has been dates as Oligocene based on the *Pectin-Ostrea* fanule. This fanule also indicates a relatively shallow depth, probably inner shelf (Weaver et al., 1969). No microfossils have been reported. The upper contact is conformable with the Rincon Formation.

The Rincon Formation crops out southeast of Alegria Canyon between Near Point and the mouth of Pozo Canyon. It is 76 meters thick and consists primarily of gray to brown calcareous shale and mudstone. Two zonules based on foraminifera have been delineated by Bereskin and Edwards (1969), the *Globigerina* zonule and the *Valvulineria* zonule, and interpreted to be deposited in an anoxic basin much like the present Santa Barbara Basin. The upper contact is conformable with the overlying San Onofre Breccia.

The San Onofre Breccia is 99 meters thick and consist of conglomerate, sandstone and mudstone that contain clasts of dacite porphyry, quartzite, and glaoucophane schist. Deposition was probably in an inner shelf environment based on sparse assemblages of *Ostrea englekyi*, *Lyropecten crassicardo* and *Trachycardium vaquerosynsis* (Keen, 1963; Hall 1960).

The Monterey Formation, Beechers Bay Member is 177 meters thick and consists of thinly bedded siltstone, sandstone and conglomerate. Based on four foraminifera zonules, deposition of the Beechers Bay Member was in a shelf environment that deepened to outer shelf or upper slope (Weaver et al., 1969).

SUMMARY OF PALEOENVIRONMENT

MONTEREY FORMATION BEECHERS BAY MEMBER		Shelf
SAN ONOFRE BRECCIA		Inner shelf
RINCON FORMATION		Shallow anoxic basin
VAQUEROS FORMATION		Inner shelf
	angular unconformity	
COZY DELL FORMATION		Lower bathyal possibly anoxic
JOLLA VIEJA FORMATION-?-		
		Bathyal, cold water
		Upper to lower bathyal
		Outer shelf, upper bathyal
CAÑADA FORMATION		Bay, inner shelf, to neritic
	parallel unconformity	
POZO FORMATION		Shallow inner shelf

ROADLOG FOR SANTA CRUZ ISLAND

Unlike most geological field areas, Santa Cruz has no logically throughgoing route that demonstrates the interesting geological features of the island. The localities below are arranged roughly in the order we'll see them, but could be viewed in a variety of sequences. They are keyed to the topographic maps (see Fig. 7). Our tentative sequence is:

Day 1: Arrive by Navy boat at Prisoners' Harbor. Transfer to the UC Santa Cruz Island Reserve research station, get gear and food squared away and eat lunch. Explore Willows Canyon.

Day 2: Explore Laguna Canyon - climb Sierra Blanca.

Day 3: Explore Cañada Pozo - hike around Near Point and up Alegria Canyon.

Day 4: Climb Devil's Peak - clamber up Cascadia.

Day 5: Unstructured morning - pack up, clean premises, transfer to Prisoners' Harbor and return to Port Hueneme.

Location 1. Prisoners' Harbor. This pier is maintained by the Navy, which supports a communication facility on a high hill to the SE and provides transportation by surface craft from Port Hueneme on Mondays and Fridays.

The road from here to #2 follows Cañada del Puerto through the Prisoners' Harbor and Stanton Ranch Members of the SCI Volcanics. We will look at these volcanic rocks at Cascadia (#17). The eucalyptus trees in the groves south of the harbor and west of the research station were planted by early ranchers.

Location 2. Stanton Ranch, home of former island owner Carey Stanton, and the UC field station, the research facility of the SCI Reserve. The station was founded in 1966 by the UCSB Geology Department and the UC Natural Reserve System, and is used to lodge researchers and students.

Location 3. Near the beginning of the ridge route notice a change in the color of the soil from white to red. This marks the trace of the southern branch of the SCI fault which separates the lower member of the Blanca Formation from the SCI Schist.

Location 4. Good view of the SCI fault, Stanton Ranch, the eastern end of the island (light Monterey Formation over dark SCI Volcanics), and, if clear, the Santa Ynez Mountains.

Location 5. Willows Canyon. The following are found in this canyon: north and south branches of the Valley Anchorage fault, Willows fault, SCI Schist, Willows Diorite, San Onofre Breccia, and middle and upper members of the Blanca Formation. The North Valley Anchorage fault is well exposed on the eastern valley slopes where the two main drainages intersect. We will drive through the canyon, arms waving, and mostly poke around at the beach.

Location 6. Overview of Sierra Blanca (464m-1523') to the SW, Santa Rosa Island to the west and Devil's Peak (>747m-2450') to the north. The light-brown, upper member of the Blanca Formation is easily seen capping Sierra Blanca, and is downdropped to the north where it caps Ragged Mountain. The North Valley

Anchorage fault is well exposed on the western slopes seen from the road down the spur.

Location 7. Laguna Canyon. We will look at SCI Schist in the stream bed and an outcrop of Willows Diorite. Those who wish may hike to the top of Sierra Blanca (because it is there!). Numerous EW and NS dip-skip faults are clearly seen from the top of the spur just before the final ascent of the peak. The hike is rigorous and should only be attempted by those in good physical shape. After the hike, we'll explore the beach area, where a boulder conglomerate of the upper member of the Blanca Formation is well exposed.

Location 8. Valley road crosses the SCI fault, which separates reddish SCI Schist on the south from the purplish-gray SCI Volcanics on the north.

Location 9. Centinela Gate; ridge route to the south, road to Devil's Peak on the north. SCI fault again indicated by soil color change - reddish schist against purplish volcanics.

Location 10. Stream bed cut through marine terraces west of Christy Ranch exposes Blanca Formation. What member is this?

Location 11. Note incised meanders. Streams in both Cañada Cervada and Cañada de los Sauces are incised. Is this caused by climate changes, tectonic movements, or normal depositional/erosional processes?

Location 12. Richfield #2 well site drilled by Arco in 1955 on the axis of Christy Anticline to a depth of 700 m. The Pozo Formation exposed here represents the oldest Tertiary sedimentary rocks exposed on the island. The well bottomed in the upper Cretaceous Jalama Formation beneath the Pozo. Just down the hill, look for the base of the overlying Cañada Formation marked by a conglomeratic bed.

Location 13. Driving down Cañada Pozo, we will pass through Jolla Vieja and Cozy Dell Formations, and stop in Vaqueros Formation at the beach. We will examine the sedimentology and paleontology of the Vaqueros, Rincon and San Onofre Formations, and the Beechers Bay Member of the Monterey at Near Point.

Location 14. We will hike up Alegria Canyon and look at the sedimentology of the Vaqueros, Cozy Dell and Jolla Vieja Formations.

Location 15. To the north across Cañada Cervada, note the offset drainages indicating moderately recent left-lateral movement. Tectonic models postulate right-lateral motion on the SCI fault.

Location 16. Short hike to Devil's Peak. This is in the Devil's Peak Member (what else?) of the SCI Volcanics. The major focus of igneous activity is thought to have been located in the geologically complex area just to the east. A private communications antenna caps the peak. There are spectacular views of Santa Cruz, Santa Rosa and the mainland from here.

Location 17. On our scramble up Cascadia, where the stream is deflected away from the trace of the SCI fault, possibly by a mafic intrusion, we will look at various flow and pyroclastic features in the Griffith Canyon Member of the SCI Volcanics.

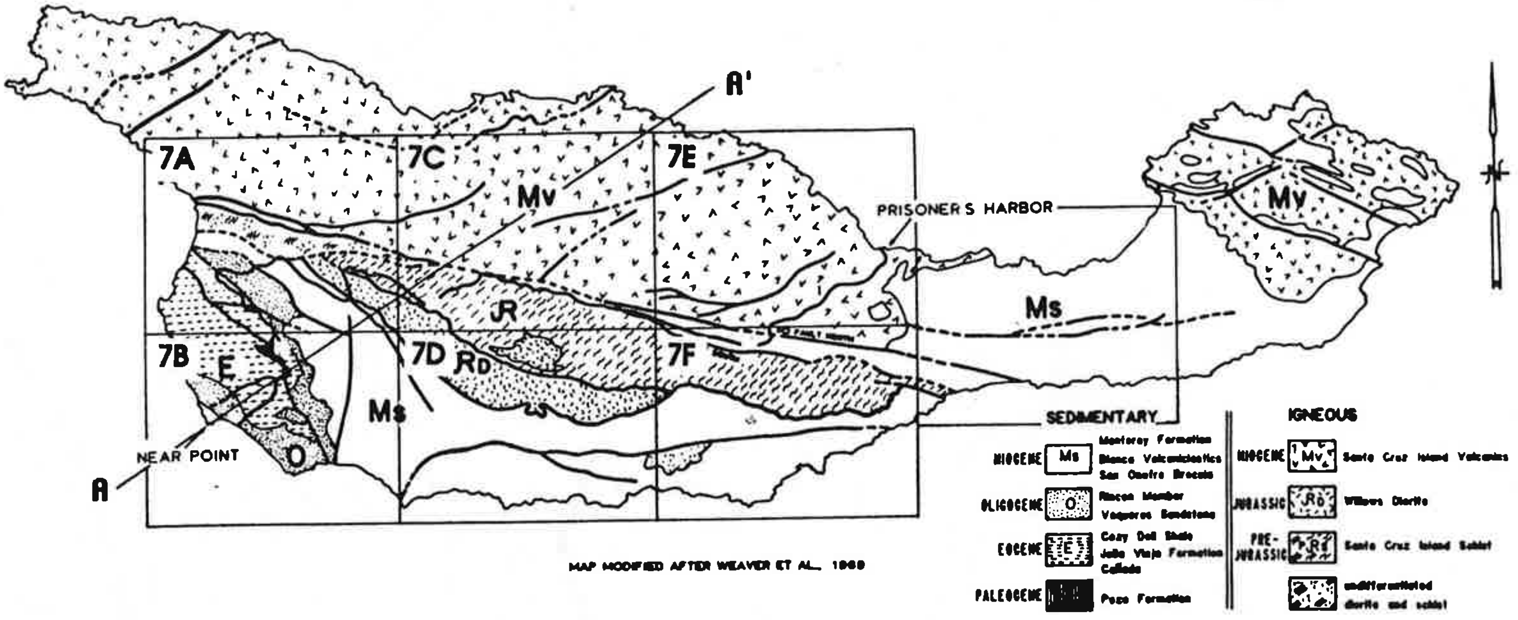

Figure 6A. Index map showing location of geologic cross-section (**A-A'**, Fig.4) and topographic coverage shown in Figs. **7A - 7G**.

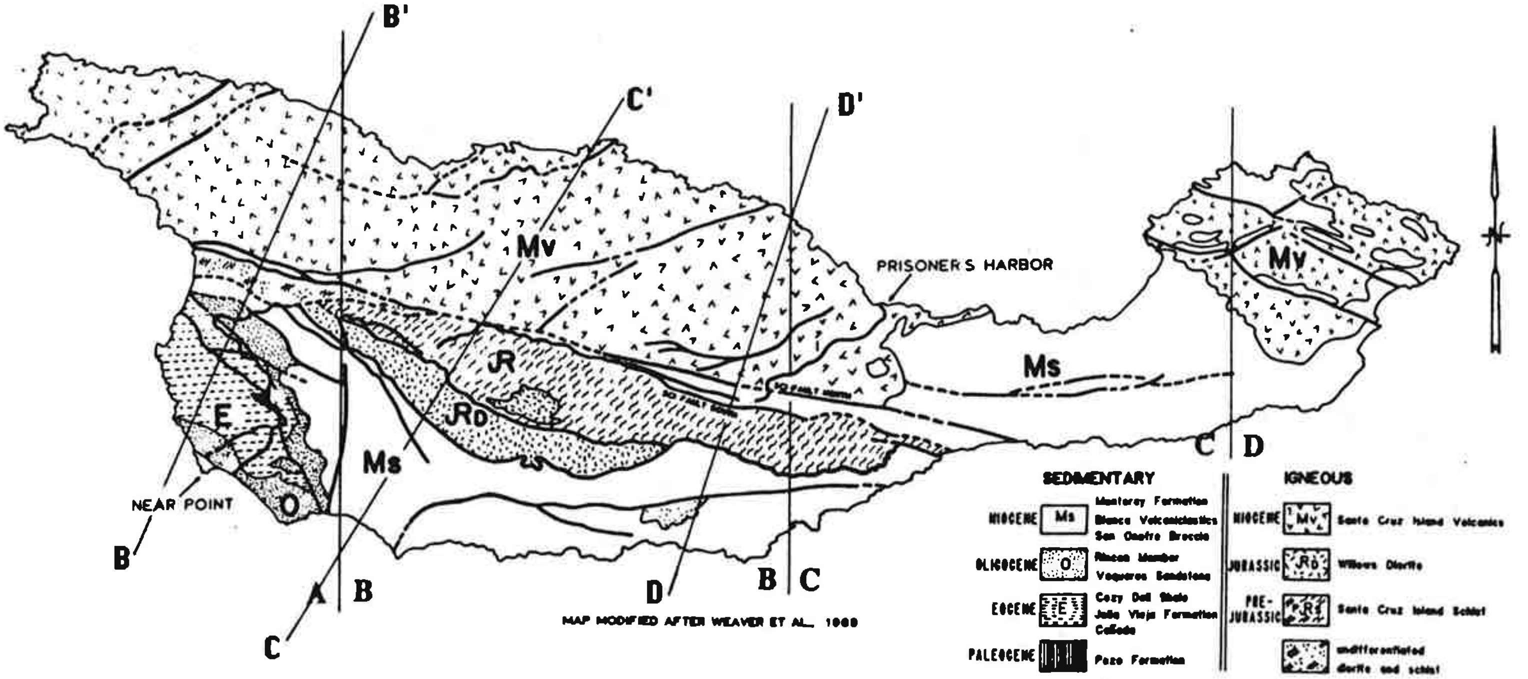

Figure 6B. Index map showing locations of topographic profiles (**B-B'**, **C-C'** and **D-D'**, Fig. 5) and Santa Cruz Island Quadrangle sheets (**A-D**).

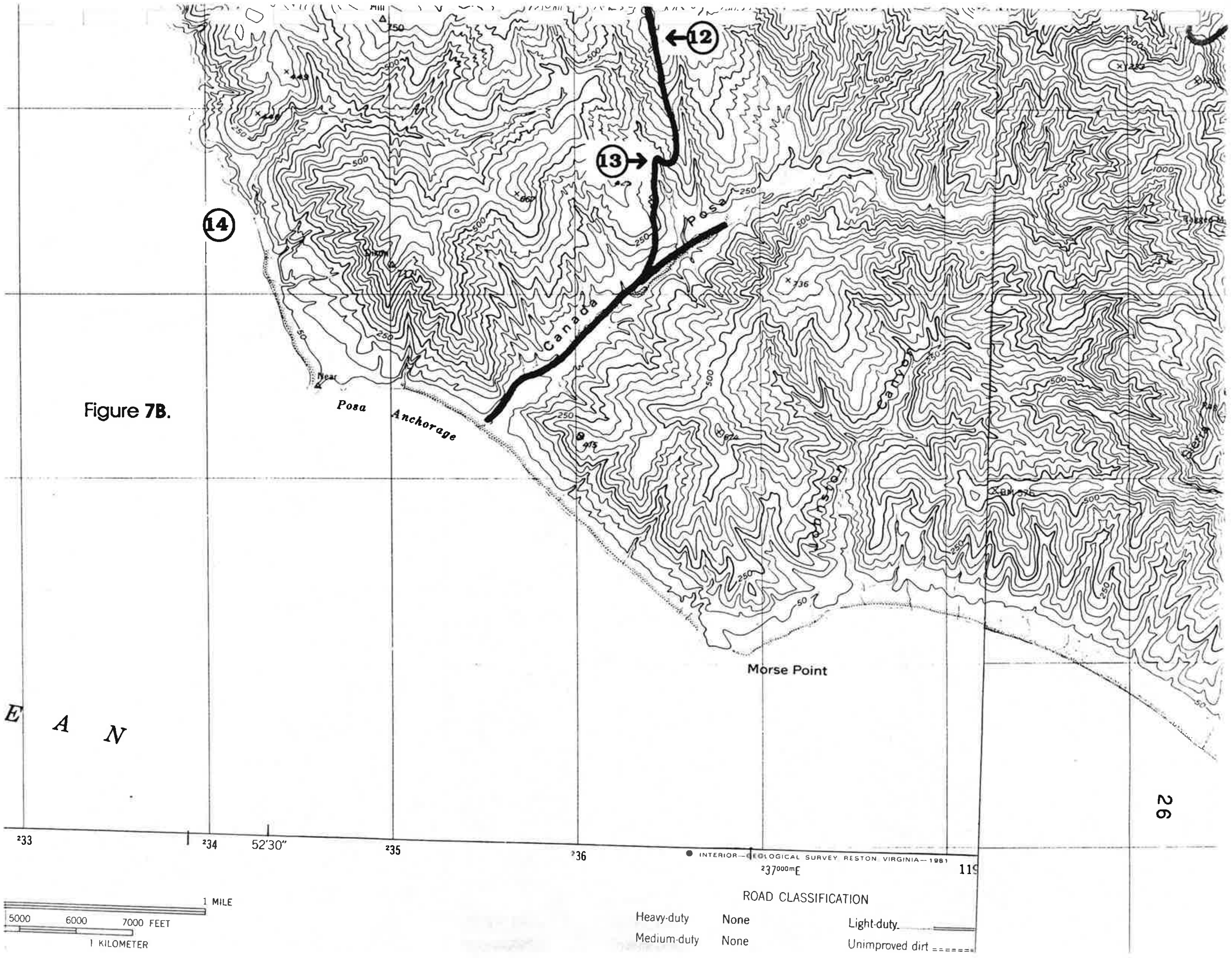

Figure 7B.

⑫
⑬
⑭
Posa Anchorage
Canada Posa
Johnston Canyon
Morse Point
Sierra
E A N
Near
250
500
1000
50
736
²33
²34
52'30"
²35
²36
²37000mE
119
INTERIOR—GEOLOGICAL SURVEY RESTON VIRGINIA—1981
1 MILE
5000 6000 7000 FEET
1 KILOMETER
ROAD CLASSIFICATION
Heavy-duty None
Medium-duty None
Light-duty
Unimproved dirt

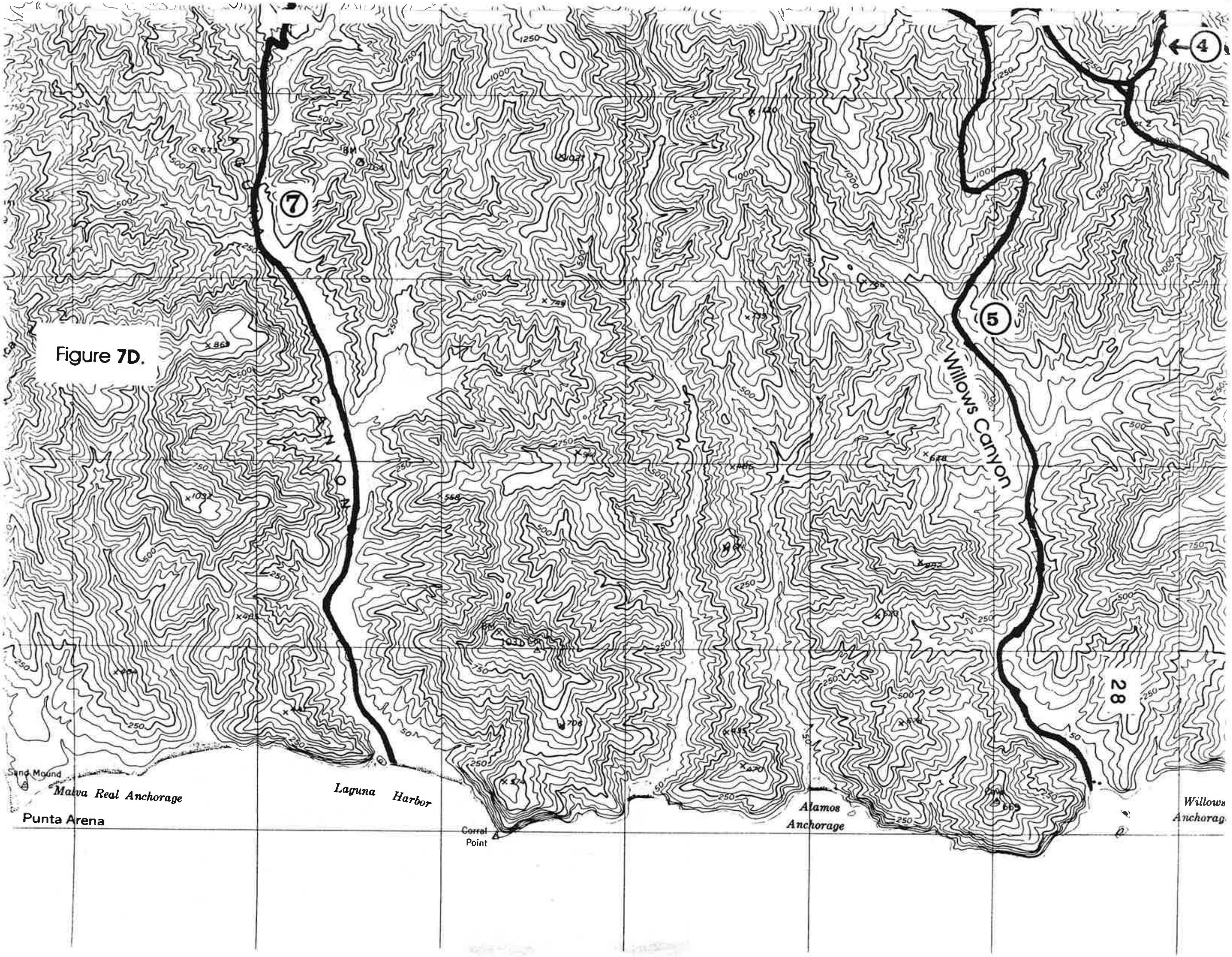
④
⑤
⑦
Willows Canyon
CANYON
28
Sand Mound
Malva Real Anchorage
Punta Arena
Laguna Harbor
Corral Point
Alamos Anchorage
Willows Anchorag
BM
1250
1000
750
500
250
50
×673
×863
×1032
×483
×704
×1027
×749
×568
×506
×733
×486
×678
×552
×533
×435
×470
×574
×706
669

Figure 7D.

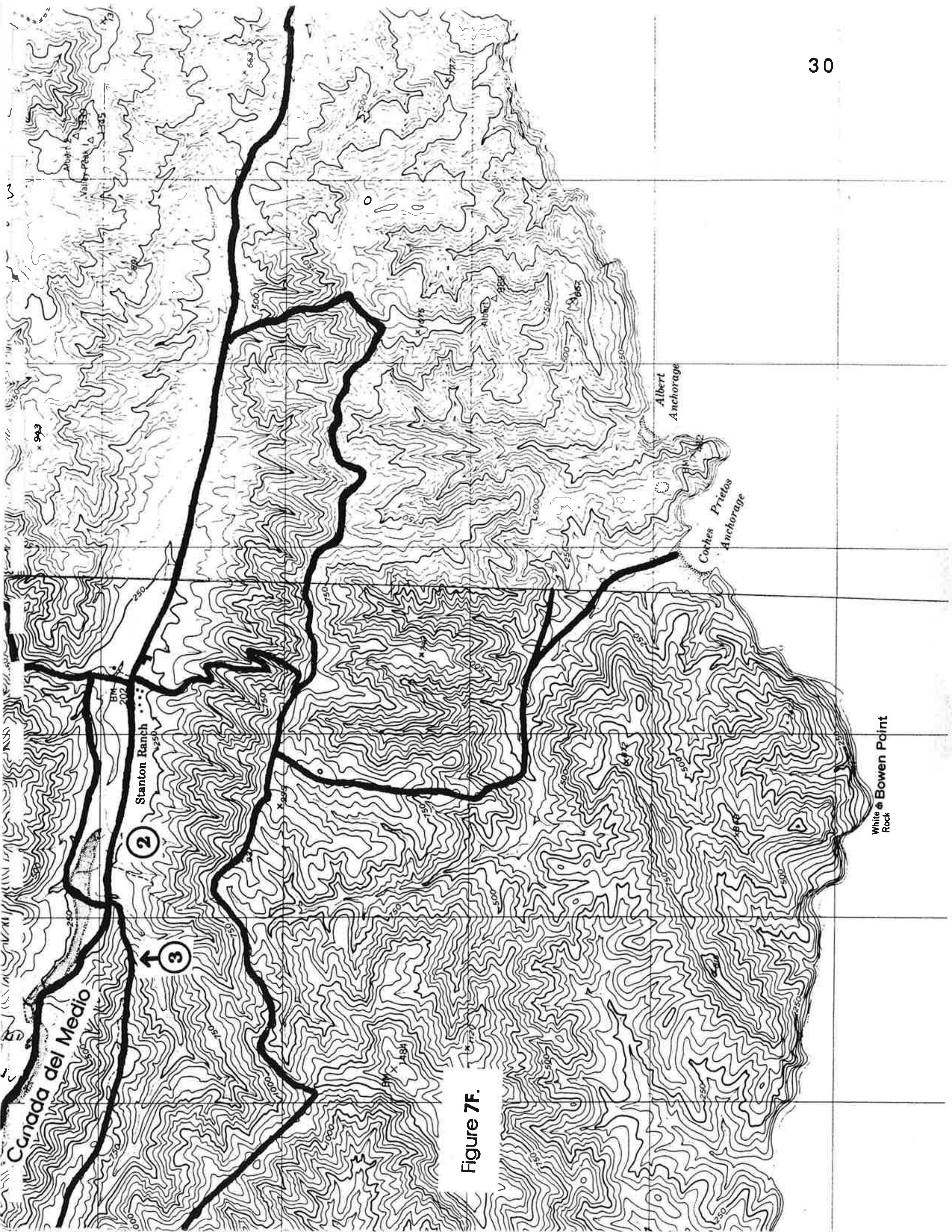
Canada del Medio
Stanton Ranch
BM 202
②
③
Valley Peak
Albert Anchorage
Coches Prietos Anchorage
Bowen Point
White Rock
250
500
750
1000

Figure 7F.

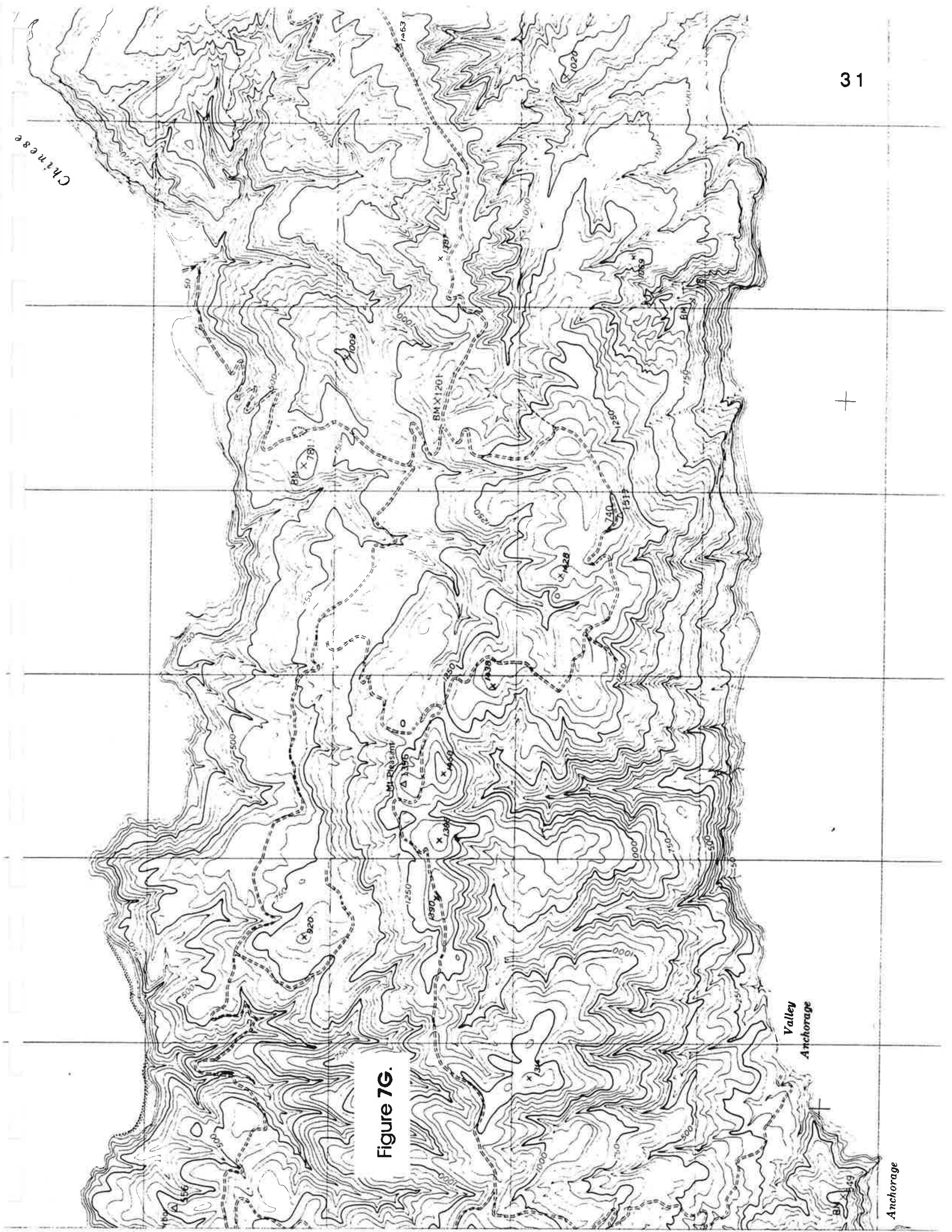
Figure 7G.
Chinese
Mt Pleasant
Valley Anchorage
Anchorage
BM
1396
1408
1438
1428
1512
1740
1201
1009
781
1059
1463
1020
1368
1390
920
1314
456
1000
1250
750
500
250
50

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There once were some geologists from C-SUN,
Who went over to Santa Cruz for some fun.
They looked at some rocks,
And the cute island fox,
And regretted when the trip was all done.

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