UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY . [Reports - Open file series]



# Facts Relating to Well No. 5, Lease OCS-P 0234, Pitas Point Unit Area, and the Earthquake of August 13, 1978, Santa Barbara Channel, California



By

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Open-File Report 78-906

1978

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## I. SUMMARY OF CONCLUSIONS

The conclusions of the task group are summarized here under the following four charges given to the group by the Director, U.S. Geological Survey, in his memorandum of August 14, 1978 (Enclosure 1):

A. Develop a better understanding of the subsurface geology in the vicinity of the well.

1. The uppermost 750 feet consists of unconsolidated to semiconsolidated silt, clay, and mud. Siltstone and mudstone predominate from 750 feet to about 2,500 feet depth, below which interbedded sandstone and siltstone occur in nearly equal amounts (see V and VII. A. 1). Above 5,100 feet, porosities and permeabilities are high (see VII. A. 3 and Fig. 6).

2. The Pitas Point geologic structure is a relatively gently folded anticline compared to the Rincon structure on the north. It is bounded by major east-west fault zones on its north and south flanks. Internal faults in the structure are minor (see V and VII. A. 2, 4, 5, and 6).

3. The major fault zones bounding the Pitas Point structure are considered to be barriers rather than conduits. Natural fractures and joints in the structure above 5,000 feet depth are considered unlikely because of the semiconsolidated nature and plasticity of the beds (see VII. A. 5 and 6).

B. Analyze the potential effects of gas pressures in the plugged well on all formations in the field.

1. Several observers conclude that no oil slicks or gas bubbles have emanated from the Pitas Point geologic structure as a result of down-hole problems with Well No. 5 (see VII. B. 1).

2. The likelihood that any of the cased-off formations have become excessively pressurized is judged to be near zero (see VII. B. 3).

3. Gas from deeper formations is believed to have entered the bore hole as a result of pumping, fishing, circulating, and other extraordinary operations utilized in attempts to recover drill pipe. It is possible that the deepest cement plug was mud-cut or cement-cut. High casing pressure (2,150 psi) was observed August 13 after the operator was forced to shut-in the well to repair a mud leak on the degasser line. About a minute after reaching this pressure at the annulus, an abrupt pressure drop of about 150 psi was registered on both the drill pipe gauge and the casing annulus gauge, indicating formation breakdown in the well bore below the casing shoe at 3,581 feet depth (see VI. C. and VII. B).

4. The full pressure of the gas from deeper formations will not be communicated without loss to the rocks at the casing shoe because: (a) the cement plugs are fairly effective barriers to free movement of deep gas despite temporary leakage around them; (b) the long string of lost drill pipe and collars probably substantially blocks much of the uncased lower portion of the hole; (c) spontaneous blocking of the uncased well bore by caving and sloughing is probable; (d) the part of the hole between the casing shoe and 4,219 feet is now thoroughly plugged with cement; and

(e) the pressurized fluids will spend their energy through work done in entering the numerous water-bearing sands below 5,983 feet depth, and pressure build-up in them would almost certainly not be so intensive as to approach the fracture gradient (see VII. B. 11).

5. In any case, formation breakdown that might establish ruptures that could propagate themselves upward by sequential migration and pressurization is considered not a likely or imminent danger (see VII. B. 12).

C. Determine if a relief well as currently planned is the most effective remedial procedure to reduce the possibility of fracturing the formations.

1. Re-entry of Well No. 5 would be possible but not useful to shallow depths. It would not be feasible below the top of the drill pipe fish at 2,968 feet (see VII. C. 1).

2. Drilling a relief well to intercept Well No. 5 above the lower Pico-Repetto gas sands will (a) enhance confidence that upward migration of high-pressure gas through the well bore into shallow, lower-pressured sands is precluded, (b) conserve recoverable gas reserves, and (c) provide additional geological and engineering data which will increase the safety and effectiveness of future drilling elsewhere in the Pitas Point unit area (see VII. C. 2).

3. On August 18, Texaco, with the approval of its partners in the unit, filed an application to drill Well No. 6, a combination relief and investigative well, to intercept Well No. 5 above the lower Pico gas sands. This well was approved by the Oil and Gas Supervisor, Geological Survey, under authority of the emergency provision of Title 30, CFR Part 250.34-1(h), with the concurrence of the task group. It was drilling at 2,900 feet depth on August 30 (see VII. C. 2).

D. Determine if there is any evidence of a relationship between the well-control problem and the earthquake of August 13.

1. The distance from the bottom of Well No. 5 to the hypocenter of the main shock is approximately 9 miles.

2. Problems with cement plugs in the well or the gas flow seem unlikely to have been caused by any earthquake.

3. Given that this region is naturally seismically active, and the great improbability that any pore pressure could have been transmitted over the 9 miles to the earthquake's focus, it is concluded that the occurrence of this earthquake is causally unrelated to the difficulties at Well No. 5 (see IV and VII. D).

## II. INTRODUCTION

A build-up of pressures developed in an exploratory well being drilled in the Santa Barbara Channel during the period August 9 to 15, 1978. Nearly coincidentally, a sharp earthquake occurred 2 miles south of the city of Santa Barbara at 3:55 p.m. PDT on August 13, 1978. A task group was formed by the Director, Geological Survey, on August 14, mainly because of concern over the high down-hole pressures in the well. The charge to the task group was to study the situation fully in order that appropriate and immediate measures could be directed to protect against a fracturing of rock formations in the vicinity of the hole that might permit the escape of gas or oil to the surface. The task group was also asked to look into the possibility of any relationship between the well problems and the earthquake.

The composition of the Geological Survey task group and their individual major contributions to this group report were as follows:

A. Dewey Acuff, petroleum engineer and Regional Conservation Manager, Metairie, Louisiana: VI. C; VII. B. 3 through 6; VII. B. 8; VII. B. 13; and VII. C. 1 through 5.

Thane M. McCulloh, research geologist, Seattle, Washington: VII. B. 2; VII. B. 7; VII. B. 9 through 12; and VII. C. 6.

C. Barry Raleigh, geophysicist, Menlo Park, California: IV; and VII. D. 1 through 4.

John G. Vedder, marine geologist, Menlo Park, California: III; and VII. A. 1 through 6 (with Yenne).

Keith A. Yenne, district geologist, Los Angeles, California: V; VI. A. and B; VII. A. 1 through 6 (with Vedder); and VII. A. 7 and 8.

Russell G. Wayland, task group leader, USGS National Center, Reston, Virginia: I; II; and VII. B. 1.

All task group members contributed to the entire report. Credit and thanks are also due to Daniel J. Bourgeois and H. Glen Frizzell, petroleum engineers, and Donald M. Pert, well log analyst, Metairie, Louisiana; to Maurice V. Adams, petroleum engineer, Cyril V. Bird, geologist, and Ahmed A. Fouda, geophysicist, Los Angeles, California; to W. H. K. Lee, geophysicist, and R. F. Yerkes, geologist, Menlo Park, California; and to the Geological Survey support staff in Los Angeles, California. Consultations included Lt. Klaus Adie of the U.S. Coast Guard, Santa Barbara, California; Mike Wilson of the Remote Sensing Unit, University of California at Santa Barbara; and the following personnel of Texaco, Inc.: W. C. Lenz, Division Manager; W. E. Bauer, Assistant Division Manager, Exploration; A. L. Weismeyer, District Geologist; J. J. Mendoza, Assistant Division Petroleum Engineer; and D. D. Barman, Assistant Division Geophysicist.

## III. GENERAL GEOLOGY OF THE SANTA BARBARA CHANNEL REGION

The Santa Barbara Channel is part of the westernmost Transverse Ranges province, in which west-trending geomorphic and structural features transect the northwest-trending grain that is characteristic of the remainder of southern California. The channel is nearly 75 miles (120 km) long and about 30 (50 km) wide north of Santa Rosa Island; and the central part is as deep as 2,040 feet (625 km). It is bordered on the north by the Santa Ynez Mountains and on the south by the northern group of Channel Islands. Point Conception and the western shelf edge of San Miguel Island define the west end of the channel, but the structural basin beneath it may extend as far as the continental slope. Hueneme Canyon and the northeastern shelf edge of Anacapa form the east end of the channel.

The subsea geology of the eastern Santa Barbara Channel is similar to the onshore geology of the Ventura basin, a late Cenozoic structural and depositional depression that may contain more than 50,000 feet (15,000 m) of Cretaceous, Tertiary, and Quaternary strata. The mountain ranges and islands that bound the channel on the north and south consist of complexly folded and faulted sedimentary, igneous, and metamorphic rocks. In general, this thick sequence of rocks consists of clastic sedimentary strata that are chiefly marine in origin and that are typified by lateral facies changes, particularly in the younger part. Miocene volcanic rocks locally intrude and commonly are interlayered with clastic rocks of the same age along the southern and eastern edges of the channel.

A. Stratigraphy

Basement rocks similar to some of the Coast Range Franciscan rocks have been penetrated below a depth of about 7,000 feet in the Union Gherini No. 1 well on the east end of Santa Cruz Island, north of the Santa Cruz

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Note: Stratigraphic nomenclature in this report follows petroleum industry usage for the Santa Barbara Channel area.

Island fault, where greenstone was cored and dated at 152 ± 8 m.y. (Howell, McLean, and Vedder, 1976). Basement rocks are exposed south of this fault (Hill, 1976) but are deeply buried beneath the Santa Barbara Channel, where their age and composition are unknown.

The only reports of Cretaceous sedimentary rocks beneath the Santa Barbara Channel are from exploratory wells drilled near the middle of the channel (Vedder and others, 1969; Weaver, 1969). The Richfield Santa Cruz No. 1 well, located at the west end of Santa Cruz Island and north of the Santa Cruz Island fault, drilled 2,000 feet (610 m) of conglomerate, sandstone, and shale of Late Cretaceous age (Weaver, 1969: Howell, McLean, and Vedder, 1976). The Richfield Santa Cruz No. 2 well, located south of the fault, penetrated 2,260 feet (689 m) of sedimentary rocks of similar age and lithology. A recent exploratory well drilled by Mobil south of the median fault on Santa Rosa Island spudded in Eocene strata and presumably bottomed in Cretaceous rocks.

Paleogene rocks beneath the channel are believed to underlie most of the offshore region and to attain thicknesses of as much as 10,000 feet (3,048 m) or more nearshore (Curran, Hall, and Herron, 1971; Campbell and others, 1975). Marine sandstone and claystone beds form the bulk of the Paleocene and Eocene sequences and locally are interlayered with conglomerate. The Oligocene section grades westward from nonmarine to marine and is composed primarily of sandstone and siltstone (Curran, Hall, and Herron, 1971; Vedder and others, 1974).

Neogene strata in the Santa Barbara Channel region are composed of diverse sedimentary rock types and locally interlayered volcanics. In general, the lower Miocene section is composed of mudstone, sandstone, and conglomerate; the middle Miocene, siliceous and calcareous shale; and the upper Miocene, claystone and siltstone. Stratigraphic units of all ages, however, are typified by facies changes; and volcanic intrusives, flows, and pyroclastics interrupt the lower and middle Miocene sequences, particularly along the southern edge of the region (Dibblee, 1950, 1966; Weaver and others, 1969; Howell, McLean, and Vedder, 1976; McLean, Howell, and Vedder, 1976). Pliocene strata in the northeastern part of the channel include turbidite sequences of sandstone, mudstone and conglomerate that are as much as 12,500 feet (3,810 m) thick near Ventura and 6,000 feet (1,829 m) thick in mid-Channel south of Santa Barbara (Curran, Hall, and Herron, 1971). The Pliocene section thins westward and wedges out southward.

Quaternary sediments, which onshore grade westward from nonmarine to marine are more than 4,000 feet (1,219 m) thick directly offshore from Ventura (Campbell and others, 1975). These strata are composed chiefly of semiconsolidated sandstone and conglomerate together with minor amounts of siltstone. Well cores and logs show that these beds are increasingly compact at depth. Farther west and south beneath the channel, the overall grain size decreases and much of the section is mudstone.

B. Structure

Structurally, the Santa Barbara Channel is a tectonic trough bounded on the north by a regionally extensive, warped homocline in the Santa Ynez Mountains and on the south by the faulted and folded insular platform of the northern group of Channel Islands. Although basement rocks have not been reached by wells in the deep part of the depression, the structural relief across the region is estimated to exceed 60,000 feet (18,300 m).

Repeated tectonism throughout late Cenozoic time has left a complex imprint on older structures in the Santa Barbara Channel region. Most faults and folds are oriented east-west as they are in the onshore parts of the western Transverse Ranges province (Vedder, Wagner, and Schoellhamer, 1969; Campbell and others, 1975). Fold trends are well defined and many individuals anticlinal culminations are arranged en echelon. High-angle faults with apparent normal and reverse separations are interspersed with those that have strike-slip components of movement (Lee and Vedder, 1973; Ellsworth and others, 1973; U.S. Geological Survey, 1975; Greene, 1976). North of mid-Channel, north-dipping reverse faults with a left-lateral component are dominant (R. F. Yerkes and W. H. K. Lee, written commun., 1978). Some old structures may have controlled sediment dispersal as early as Eocene time, and many faults cut strata no younger than Miocene. On the other hand, domed late Pleistocene alluvium, tilted marine terrace platforms and faults that cut Holocene sea-floor sediments attest to the recency of tectonic activity, particularly along the mainland edge of the channel, where uplift rates of as much as 33 feet (10 m) per 1,000 years have been reported (K. R. Lajoie, oral commun., 1978).

## IV. REGIONAL SEISMICITY

The Santa Barbara Channel region has experienced several strong earthquakes over the past 170 years, as is shown in figure 1. Since 1900, 14 earthquakes with magnitudes (or intensities) equivalent to the August 13 shock have occurred within 35 miles of Santa Barbara. Of these, three occurred in the earthquake swarm of 1902 and four in the destructive earthquake sequence of 1925.

More accurate locations of epicenters, since a seismic network was installed in 1969, show that for the period 1970 through 1975, two east-west trending zones of activity are evident. Figure 2 shows earthquake centers in the channel region from 1970 through 1973. The northerly zone lies just north of the Rincon trend along the coastline and the other lies about at mid-channel. The earthquake mechanisms indicate reverse faulting with the maximum compressive stress oriented about N. 20° E. (W. H. K. Lee, R. F. Yerkes, and M. Simirenko, written commun., 1978).

V. GENERALIZED STRATIGRAPHY AND STRUCTURE OF THE PITAS POINT UNIT AREA

The stratigraphic section penetrated by the seven wells drilled on the Pitas Point Unit anticline consists of a relatively thin sequence of south-dipping Pleistocene and Holocene sediments overlying gently folded Pliocene and Miocene strata (figs. 3 and 4). Well No. 3, the deepest well on Lease OCS-P 0234, was drilled to a total depth of 18,318 feet in the Santa Margarita Formation of late Miocene age. None of the wells reached the siliceous shale of the Monterey Formation.

Rock types making up the Pliocene section are alternating sandstone, siltstone, and claystone beds which have a sand-shale ratio of about 50/50. Well logs indicate that claystone beds, which make an excellent seal above prospective sandstone and siltstone reservoirs, compose the interval from the ocean floor to a depth of approximately 2,500 feet in the vicinity of Well No. 5 on Lease OCS-P 0234.

The Pitas Point structure is an east-west trending anticlinal culmination, approximately 10 miles long and 3 miles wide, centered in the north-central portion of Lease OCS-P 0234 but extending into Leases OCS-P 0235 and 0233 (fig. 4). Closure is estimated to be at least 700 feet. The axial plane of the anticline dips to the south, and Well No. 5 on Lease OCS-P 0234 was directionally drilled southward in an attempt to penetrate all formations near the crest of the fold. Quaternary beds truncate older strata above the crest of the anticline indicating that the structure developed during an interval between late Pliocene and late (?) Pleistocene time. A major fault zone, commonly called the Pitas Point fault, strikes east-west along the northern boundary of the unit area. At shallow depths in rocks of the middle Pico Formation, this north-dipping fault cuts the north flank of the anticline but at greater depth in upper Miocene rocks, the fault surface is much farther north and near the south edge of the Rincon structures.

Another major fault transects the southern edge of the Pitas Point Unit and may be the westward extension of the onshore Oak Ridge fault. This fault strikes nearly east-west, generally dips south, and shows reverse displacement in strata as young as late Quaternary (Ziony and others, 1974). However, some segments of the fault apparently cut more of the Quaternary section than others. On shore, the Oak Ridge fault shows larger offsets of rock units with increasing depth, indicating that it is a growth fault. It seems likely that the offshore segment is the same type.

## VI. LEASING, UNITIZATION, AND DRILLING HISTORY OF THE PITAS POINT UNIT AREA

Leases for the three tracts composing the Pitas Point Unit Area were awarded to high bidders in the Federal OCS Lease Sale held in Los Angeles on February 6, 1968. A group composed of Union, Gulf, Texaco and Mobil was high bidder for both tracts OCS-P 0233 and OCS-P 0234, bidding $4,038,000 and $56,378,000, respectively. Humble (Exxon) was high bidder ($45,262,080) for tract OCS-P 0235. The Pitas Point Unit was formed by the Texaco group and became effective on March 31, 1973.

A. Pre-lease core holes

Prior to the lease sale in the Santa Barbara Channel in 1968, many core holes were drilled in the southern California OCS. The total depths of the core holes varied greatly, with the majority of the holes less than 5,000 feet deep, but many were deeper. Two core holes were drilled in the area which now is included in the Pitas Point Unit area: Phillips' 1 OCS was drilled to a total depth of 6,942 feet and Standard Oil of California's 8R-27 was drilled to a total depth of 5,990 feet (fig. 4). These core holes, along with seven other core holes drilled nearby, have produced valuable information helpful in the location of the Pitas Point structure.

B. The first six lease wells drilled in the unit area

Humble drilled two dry holes on OCS-P 0235 in 1968, and in December of 1969 relinquished the lease. Texaco, the operator of Lease OCS-P 0234, drilled the No. 1 well in 1968, and on the basis of a test of the interval from 12,770 feet to 15,247 feet it was determined to be capable of producing oil in commercial quantities. Well No. 2 was drilled in 1969, Well No. 3 in 1976, Well No. 4 in 1977, and Well No. 5 was plugged and suspended in August 1978. Figure 4 shows the location of these wells and the old core holes drilled in the early 60's. Drill stem tests in Well No. 4 between the depths of 5,600 feet and 7,453 feet found what appears to be commercial gas in the middle Pico Formation.

The first six wells drilled in the Pitas Point Unit are summarized in table 1.

C. Drilling history of Well No. 5, Lease OCS-P 0234

Texaco Inc. submitted to the Santa Barbara District Engineer an application to drill Well No. 5 OCS-P 0234 on March 17, 1978. The well was proposed to be drilled to a total depth of 10,325 feet MD (9,552 feet TVD) from a surface location 6,500 feet east and 2,100 feet south of the NW corner of Lease OCS-P 0234 to a bottom-hole location south of the surface location. The well was to be located approximately 9 miles SSW of Carpinteria in a water depth of 288 feet in the Santa Barbara Channel. The APD was approved on June 6, 1978, and the drilling vessel Zapata Trader arrived on location at 9:30 a.m. on June 7, 1978. Well No. 5 OCS-P 0234 was spudded in at 2:00 p.m. on June 8, 1978. The initial* drilling plan proposed the following casing program:

| Casing Strings | Depth Below Ocean Floor (BOF) in Feet |
|---|---|
| 30-inch structural | 100 |
| 20-inch conductor | 300 |
| 13 3/8-inch surface | 1,000 |
| 9 5/8-inch intermediate | 2,750 |
| 7-inch production | 10,000 |

*For the final casing program see VII. C. 5 and Fig. 5.

The maximum mud weight anticipated by the operator was 85 pounds per cubic foot (pcf) to the proposed total depth of 10,325 feet measured depth (MD). In addition, Texaco proposed to use a remotely controlled BOP stack consisting of 2 annular-type preventers, 3 pipe rams, and 1 blind-shear ram all rated to 10,000 psi working pressure (WP).

On June 21, 1978, approval was granted to set 9 5/8-inch intermediate casing at 3,590 feet MD (3,250 feet BOF). There had been no drilling problems encountered at this time and the well was drilled with a maximum mud weight of 71 pcf to a depth of 1,370 feet.

On June 26, the 9 5/8-inch casing was set at a depth of 3,578 feet MD (3,238 feet BOF). The casing shoe was tested to 90 pcf equivalent with no bleed-off, indicating a successful casing cementing operation. Drilling operations were commenced on June 27 with the mud weight at 73 pcf.

On June 30, the drill pipe was stuck at 5,037 feet MD as the pipe was being run back in the hole following a bit change. Again on July 2, the drill pipe stuck at 5,451 feet MD.

On July 13, approval was granted to Texaco's plans to deepen Well No. 5 to a total depth of 11,925 feet MD (11,242 feet TVD) at a bottom-hole location south of the surface location.

At this time, Texaco also indicated plans to complete the well for production (depending on results of drill-stem testing) by installation of 7-inch casing to total depth and leaving the well in mechanical condition to allow reentry at a later date. All cement plugs would be set and a corrosion cap installed prior to moving the rig from the surface location.

On July 16, while drilling at 12,112 feet MD with mud weight of 81 pcf, the well began flowing. The well was killed and flow controlled by raising the mud weight to 86 pcf. Drilling continued with the mud log indicating 80 units of background gas.

On July 21, Texaco received approval to deepen the well to a total depth of 13,000 feet MD (12,387 feet TVD) at a bottom-hole location south of the surface location.

Well No. 5 was drilled to a total depth of 13,000 feet MD on July 23 without further incident and with a maximum mud weight of 89 pcf. After conditioning the hole and logging, a Schlumberger Repeat Formation Tester tool was run on July 26 and formation pressure readings were to be taken at 12,533 feet MD and 12,440 feet MD. The tool was stuck and lost in the open hole at 12,440 feet MD while taking pressure readings. In attempting to recover the fish, the drill pipe became stuck in the hole. In addition, the wireline parted and added to the junk in the hole. The mud weight was increased to 91 pcf and attempts were made to circulate the hole, free the stuck pipe, and recover the fish. On July 28, there was a brief gas flow on the drill pipe while attempting to recover the drill pipe fish. Texaco continued to attempt to salvage the hole and recover the drill pipe by various techniques, such as spotting slugs of diesel oil and "pipe free," running bumper sub and jars, sinker bars and spears, impression block, freepoint tool and junk basket. On August 7, a 397 cf 50-50 Pozzolan cement plug was displaced in and out of the drill pipe with the calculated top of the cement outside the drill pipe at 11,700 feet and the top of cement inside the drill pipe at 10,366 feet. It was then decided to spot a 225 cf Class G cement plug w/20 percent sand from 5,983 feet to 5,479 feet MD. The plug was displaced and the well was shut in at 6:15 p.m. w/85 pcf mud in hole. A second 225 cf cement plug w/20 percent sand was equalized and set from 4,585 feet to 4,189 feet MD at 8:50 p.m. on August 7. On August 9 after waiting on cement, Texaco ran open-ended drill pipe back into the 9 5/8-inch casing to 3,581 feet MD and circulated and conditioned the hole with 88 pcf mud. After polishing off the top of the open-hole cement plug from 4,209 feet to 4,219 feet MD and pulling 3 stands of drill pipe from the hole, the well began to flow slightly. The pipe rams were closed and there was no surface pressure recorded on either the drill pipe or casing annulus. The hole was circulated through the choke line while the mud weight was increased to 91 pcf.

On August 10 the stand-pipe pressure was recorded as 600 to 650 psi and the casing pressure was 800 to 1,250 psi while circulating and waiting for additional supplies of barite. The hole was displaced with 112 pcf mud and the pressures were recorded as: stand-pipe from 900 to 190 psi and casing from 1,400 to 1,200 psi.

After a 15-second shut-in at 2:30 p.m. on August 11, the pressures dropped to 80 psi and 900 psi, respectively. Mud weight was gradually increased to 117 pcf and the hole was circulated for 24 hours on August 12 with no mud volume loss to open hole.

On August 13, the circulation of the hole continued with the bleeding off of dry gas at the surface until the degasser overloaded and a manifold connection to the degasser line cut out, resulting in a loss of mud volume. The well was shut in at 6:40 p.m. PDT for repairs to the manifold, with 112 pcf mud in the drill pipe. At 6:44 p.m. there was an apparent formation breakdown as the drill pipe pressure fell from 500 to 360 psi and the casing pressure fell from 2,150 to 2,000 psi.

Apparent gas influx to the well bore continued, and on August 14 two barite plugs were displaced without success to shut off the well bore pressures which were recorded as: drill pipe - 500 psi and casing 2,000 psi. A 700 cf cement plug (131 pcf) was displaced through drill pipe and bit with 70 barrels of 110 pcf mud and the well was shut in at 3:45 p.m. on August 14.

On August 15, a temperature log was run and the top of the cement plug in the annulus was found at 3,358 feet, which is 223 feet above the shoe of the 9 5/8-inch casing. Casing pressure was bled to zero which is the first indication the down-hole gas pressure has been shut off from the surface. An additional cement plug of 500 cf was displaced through the drill pipe with the slurry being displaced to a depth of 3,300 feet inside the drill pipe and the bottom calculated to be at approximately 4,000 feet. A diver inspected the ocean bottom around the drilling vessel and BOP stack and there was no indication of gas bubbles.

On August 16, a 300 cf cement plug was spotted inside the 9 5/8-inch casing and the top of the plug was tagged at 2,445 feet.

On August 17 and 18, two additional shallow cement plugs were set inside the 9 5/8-inch casing, the top of one at 1,101 feet and the other calculated to extend from 650 feet to 450 feet. Also, on August 18, the BOP stack and marine riser were removed.

On August 19, divers were used to set the corrosion cap on Well No. 5 and cut the guidelines from the guide base on the ocean floor. The well has been classified as temporarily suspended and left in condition for possible reentry at a later date. The drilling vessel Zapata Trader was moved off location at 8:00 p.m. August 19, 1978.

VII. SUBJECT AREAS CONSIDERED BY THE TASK GROUP

A. <u>Subsurface geology, Lease OCS-P 0234</u>

1. <u>What are the rock types and degree of consolidation of the formations in Well No. 5?</u>

In Well No. 5, a section of approximately 750 feet of unconsolidated to semiconsolidated silt, clay, and mud of Holocene and Pleistocene age unconformably overlies lower Pleistocene and Pliocene rocks that are subdivided into the upper, middle, and lower Pico Formation and the Repetto Formation. These formations consist of differing amounts of interbedded shaly sandstones (with varying degrees of shaliness) and clayey rocks, in large part turbidite deposits, mostly in a thinly bedded repetitive sequence. Roughly 1,300 feet below the top of the middle Pico (about 2,500 feet deep in the No. 5 Well), sandstone and siltstone occur in nearly equal amounts to the basal part of the lower Pico. Siltstone and mudstone predominate above 2,500 feet in Well No. 5.

The degree of consolidation of the rocks penetrated by Well No. 5 ranges from unconsolidated at shallow depths to compact and well lithified at total depth. A quantitative measure of the degree of consolidation is provided by estimates of averaged bulk rock density and porosity derived from the Formation Density Log of the well. Figure 6 illustrates the gradational depth dependence of the bulk density and porosity.

2. Does any fault intersect Well No. 5?

Our interpretations of well-log data indicate that at least one south-dipping, high-angle reverse fault cuts Well No. 5 about 3,100 feet below the ocean floor and apparently repeats 70 feet of middle Pico section. This fault extends westward into relinquished Lease OCS-P 0235 and possibly eastward into Lease OCS-P 0233 (fig. 4). Discontinuous reflectors on acoustic-reflection profiles suggest that smaller faults of unknown displacement may be present in the well along the crest of the anticline.

3. What are the depth intervals and sand counts of the most permeable sands encountered in the uncased portion of Well No. 5?

To a depth of about 2,500 feet, fine-grained shaly beds predominate; below this depth, sand and shale occur in about equal amounts. As indicated by the curve shown in figure 6, porosities and permeabilities are high at depths of less than 5,100 feet in Well No. 5.

4. At their highest on the structure, how far are these sands above their intersection with Well No. 5?

The most permeable sands in the uncased part of the well rise approximately 110 feet to the crest of the structure in the middle Pico, and 50 to 100 feet in the lower Pico and Repetto Formations. It is noteworthy that the middle Pico sands in Well No. 4, which is high on structure, are gas bearing and possibly capable of commercial production but that equivalent sands tested wet in Well No. 1, which is down structure.

5. What faults occur elsewhere in or bounding the unit area? What is the nature of each, and are they likely conduits?

Major faults lie close to the north and south boundaries of the unit. The Pitas Point fault zone, which trends nearly east-west, is about 2,500 feet north of the surface position of Well No. 5, is about 750 feet wide and dips north approximately 80° near the surface (fig. 4). Reverse slip with a left-slip component is inferred for the Pitas Point fault zone, but the exact amount of stratigraphic separation is unknown because of the lack of correlatable marker beds in the Pliocene sections on opposite sides. According to Ziony and others (1974), the offshore segment of the Pitas Point fault zone cuts upper Quaternary sediments. A high-resolution acoustic-reflection profile with penetration of about 300 feet across the zone shows slightly deformed reflectors to within 50 feet of the sea floor on a north-south track about 1 mile east of Well No. 5. A similar record about 1 mile west shows no detectable deformation. To the south, a large east-trending reverse fault that may be the offshore extension of the Oak Ridge fault lies beneath the south edge of the unit. This fault is nearly vertical and/or steeply south dipping. Ziony and others (1974) assigned a Quaternary age to this fault. A north-trending barrier occurs in the western part of the unit, but its nature is unknown.

Small faults typically are present along the crests of anticlines, and a few discontinuous reflectors in the Pliocene section suggest the presence of such faults within the unit area. Because of the north-south compression and crustal shortening in the area, the faults presumably are barriers rather than conduits.

6. What fracture or joint patterns are likely to exist in the unit area?

Fractures and joints are unlikely in the post-Miocene strata of the unit area because the degree of consolidation (see VII A.1 and fig. 6) and plasticity of the beds above about 5,000 feet is such that brittle fracturing is unlikely.

7. Are there any indications of shallow geologic drilling hazards in the vicinity of Wells No. 5 and No. 6?

Two Fairfield Industries' high-resolution surveys of the unit area indicated potential shallow gas sands. USGS analyses of the same data also indicated possibilities of shallow gasification of sediments. The seven wells drilled in the unit area, however, have had no shallow drilling problems.

8. What is the likely field potential?

Tests of wells drilled on lease OCS-P 0234 indicate that oil and gas probably occur in sufficient quantities to warrant their development.

B. Effects of gas pressures on all formations

1. Have oil slicks or gas bubbles at or near Well No. 5 been observed during recent or current monitoring?

Statements covering recent monitoring are attached as Enclosures Nos. 3, 4, and 5. Enclosure No. 3 summarizes U.S. Coast Guard observations from August 14 to August 25, when daily flights replaced the usual twice-weekly surveillance flights. Lt. Klaus Adie, the Commanding Officer of the Group Santa Barbara Detachment, served as observer on all days but one. His conclusions are that no new seep areas were discovered during the observation period, and that while increased seep activity was noted after the earthquake, tides and currents may have been the larger factors in its cause.

Air photography contracted by the Geological Survey with Pacific Western Aerial Surveys for the period August 18 through 25 was available for interpretation through August 22 as this report was written. Enclosure No. 4 is a preliminary statement by Mike Wilson of the Remote Sensing Unit, Department of Geography, University of California at Santa Barbara. No new seeps could be identified from imagery flown August 18 through 20. Although large continuous iridescent to silver slicks were observed around the drilling ship at Lease OCS-P 0234, he felt that the point of origin was elsewhere. On August 22 the lease area was free of oil sheen.

A diver inspected the ocean floor around Well No. 5 on August 15 and found no indication of gas bubbles.

Enclosure No. 5 is a copy of a USGS routine pollution surveillance flight report made August 14 which classifies the conditions around known seeps as "light."

From the foregoing reports, and from the absence of Texaco or USGS drill ship inspection reports to the contrary, it is concluded that no oil slicks or gas bubbles have emanated from the area of Lease OCS-P 0234 as a result of down-hole problems with Well No. 5.

2. What was the maximum pressure at the intermediate casing shoe prior to placing cement plugs above 4,189 feet?

The maximum pressure at the intermediate casing shoe (3,581 feet) occurred on August 13, 1978, when formation breakdown occurred and the casing pressure was observed to be 2,150 psi, and drill pipe pressure was observed to be 500 psi, with 112 pcf mud in the drill pipe. The calculated pressure at the casing shoe under these conditions was 3,378 psi (gradient of 0.943 psi/ft. from KB).

3. What is the likelihood that cased-off formations are abnormally pressured?

The likelihood that any of the cased-off formations have become excessively pressurized is judged to be near zero. Abnormally pressured formations would have resulted only if large volumes of gas from the deeper part of the well had migrated upward between the cement around the 9 5/8-inch intermediate casing and the wall of the drilled hole and thereby entered formations above 3,581 feet. The high fracture gradient evidenced for the rocks at the casing shoe indicates that such migration should be considered unlikely. The absence of gas seepage around the ocean-floor installation strengthens this conviction, as does the fact that the cement job and the rocks below the casing shoe withstood a pressure bleed-off test at 2,238 psi.

4. What is the significance of the slight well flow of August 9, 1978?

The gas flow is thought to have occurred as a result of polishing off (drilling) the cement plug from 4,209 feet to 4,219 feet (in preparation to sidetrack the hole at this point), allowing gas from deeper formations to move through or around the cement plug. The gas from deeper formations is believed to have entered the bore hole as a result of the lengthy period of previous pumping, fishing, circulating, and other extraordinary operations utilized in attempts to recover the original drill pipe fish. It is possible also that the deepest cement plug was deficient because of mud-cut or gas-cut cement from the outset.

5. <u>What is the significance of the increase in "background gas units" on August 10?</u>

The increase is considered to be due to the slight gas flow through or around the cement plug at 4,219 (as noted in No. 4 above), while circulating and building mud weight to control the flow of gas. The flow through or around the cement plug indicates communication with gas formations down hole at that time. Possibly this communication existed for a short time only, since formations of the type exposed in the open hole contain materials that normally tend to swell or slough within a short time and so the uncased hole spontaneously becomes bridged or sealed, and further gas flow is prevented.

6. <u>What is the reason for the 2,150 psi casing pressure observed on August 13?</u>

This high pressure was caused by the segregation of gas entrained in the mud accompanied by upward migration, accumulation, and expansion of the gas near the top of the casing annulus after the operator was forced to shut in the well to repair a mud leak in the manifold to the degasser line.

7. <u>What is the significance of the apparent breakdown of the formations (150 psi loss) during the shut-in of August 13?</u>

On August 13, while circulating with 112 pcf mud, it became necessary to shut the well in for 1-1/2 hours to repair a leaking pipe connection between the surface manifold and the degasser. Pressure built gradually to 500 psi in the drill pipe and to 2,150 psi in the casing annulus as the well stood shut in. About a minute after reaching these highest pressures, an abrupt pressure drop occurred simultaneously at both the drill pipe gauge and the casing annulus gauge. Both gauges registered a pressure loss of about 150 psi (to 2,000 psi for the annulus and 360 psi for the drill pipe).

Such an abrupt simultaneous pressure decline is a characteristic response to formation breakdown in a well bore. Presumably the pressure exerted by the drilling fluid in the uncased bore hole below the casing shoe at 3,581 feet and above the top of the highest cement plug then in place at 4,219 feet was sufficient to cause fluid entry into the rock. As such, it is the best available indication of the pressure gradient required for formation breakdown at moderate depths in the Pitas Point Unit area. Calculations based upon the gauge pressures recorded and the density of the drilling mud circulating in the well at the moment of shut-in indicate that the rupturing pressure gradient at the casing shoe almost certainly was approximately 0.943 psi per foot of depth.

Only if the drilling fluid in the drill pipe was significantly gas cut could the fracture gradient have been substantially below the range of values calculated. This seems highly unlikely physically because the mud being pumped in had been completely degassed. The high gradient is not completely consistent with independent calculations using the "formation density" log (FDC gamma gamma log) of the well to estimate overburden pressure. These standard calculations yield values lower (0.7 to 0.8 psi/ft.) than the empirical test result.

The significance of this inadvertent experimental demonstration is that it sets a limit of sorts on the pressure gradient that would be required for rupturing to occur if pressure buildup were to result from migration of deep high-pressure gas into the higher part of the borehole below the casing shoe or even below the lowest plug. The drilling fluid would penetrate such rocks with greater difficulty than gas, and the fracture gradient for gas would be lower than the 0.943 psi per foot of depth observed for the 112 pcf mud.

8. Is the cement plug across the 9 5/8-inch casing shoe likely to hold?

This cement job is expected to hold, the displacing pressure (1,850 psi), the final pressure (900 psi), and the resulting successful cement plugging operation (on August 16, 1978) indicate good integrity of both the casing and cement jobs.

9. What were the virgin formation pressures in the well bore?

Information about virgin fluid pressures encountered in rocks penetrated by the Well No. 5 derives from 22 successful drill stem tests conducted in Pitas Point exploratory wells Nos. 1, 2, 3, and 4, and from three successful wireline formation tests conducted in Well No. 5, augmented by consideration of mud weights required for drilling Well No. 5. Drill-stem and formation tests range in depth (mid-point of tested interval) between 4,931 feet and 17,755 feet. The fluid pressure gradients indicated by these measurements are about 0.444 psi per foot in shallow rocks (down to about 7,000 feet) and then become gradually more and more elevated above "normal hydrostatic" as greater depths are penetrated. At 13,000 feet the pressure gradient indicated by test data is about 0.76 psi/ft. Pressures recorded by the wireline tester near 12,000 feet (MD) in Well No. 5 yield gradients of about 0.6 psi/ft., consistent with the gradient of 0.621 psi/ft. calculated from the mud density required in drilling the deepest portion of the hole.

10. <u>What is the most likely source of gas in the well bore?</u>

Clues about the most likely source of gas that leaked past the plugged portion of the well bore are gained from study of the mud logging records acquired during drilling and from comparison of the compositions of gases recovered from the leaking well, from drill-stem tests in the Pitas Point Well No. 1, and from tests of Well No. 4. Gas chromatographic analyses of these several gases suggest that the reservoir unit just below 12,112 feet (MD) in Well No. 5 is a possible source of the nearly pure methane which leaked past the cement plugs at 4, 219 feet, but that other possible sources might be present within the middle Pico section. The record of gas shows recorded during mud logging of the well implies that there are probably no significant gas-bearing rocks between the 9 5/8-inch casing shoe and a depth of 5,870 feet or more in Well No. 5, and that the first really conspicuous shows occur below 12,070 feet (MD).

11. <u>Given the observed pressure gradient to 12,112 feet KB, (the July 16 flow depth) and open hole below 3,581 feet KB, what can the pressure in the well bore build up to if ± 12,112 feet is the source of the gas?</u>

The bottom hole pressure at 12,112 feet is the highest pressure that could occur anywhere in the open hole. From the mud weight required to control the well kick which occurred at that depth, this maximum possible pressure is estimated to be 6,690 psi.

12. Given the observed pressure gradient to 12,112 feet KB (the July 16 flow depth) and open hole below 3,851 feet KB, where might this result in formation breakdown?

The fluid pressure gradient indicated for the upper part of the reservoir encountered at 12,112 feet is probably about 0.57 psi/foot and certainly not more than 0.6 psi/foot. If the full pressure (6,485-6,875 psi) of the gas in that reservoir could be communicated without loss to the rocks at the casing shoe, the rupturing pressure there of about 3,275 psi would be greatly exceeded and formation breakdown would result. This is not now possible for several reasons. First, the cement plugs are fairly effective barriers to free movement of deep gas through the upper part of the bore hole even though temporary leakage of some gas past them indicates that they are imperfect. Second, the long string of lost drill pipe and collars probably substantially blocks much of the uncased lower portion of the hole. Third, spontaneous blocking of the well bore by caving and sloughing formations is probable. Fourth, the part of the hole between the casing shoe and 4,219 feet is now thoroughly plugged with cement also, a further impediment to free migration high in the well bore. Fifth, evidence from the mud log indicates that probably no substantial gas or oil reservoirs are present in the portion of the hole below the casing shoe and above 12,112 feet, even though the geophysical logs indicate that a high percentage of the gross interval is sandstone of reservoir quality (high permeability and porosity).

For all of these reasons, if migration of gas from the 12,112-foot reservoir does occur through any open portion of the lower part of the hole, the high pressure of the entering fluid can be counted upon to be wholly or largely spent through work done in transmitting gas to those many separate water-bearing sands presumably open to the uncased well bore below 5,983 feet. Although quantitative information does not permit accurate material balance calculations, consideration of the volumetric relations involved and of the likely rates of fluid flow indicates that it is not possible for the 12,112-foot reservoir pressure to be transmitted unmodified to any of the higher permeable units. Pressure buildup in any of the sandstones permeable to gas entry that might be open to the uncemented portion of the bore hole above the 12,112-foot source almost certainly would not be so intensive as to approach the formation fracture gradient.

Thus, formation breakdown due to pressurization of shallower beds by migrating high-pressure gas now appears ruled out for any rocks above 5,479 feet, and breakdown at deeper levels is considered to be so unlikely as to be virtually not possible. In any case, breakdown that might establish ruptures that could propagate themselves upward by sequential migration and pressurization is considered not a likely or imminent danger.

13. What, if any, significance to the Well No. 5 problem does the Well No. 3 leak experience have?

On October 6, 1976, while drilling Pitas Point Well No. 3 at about 15,882 feet, gas bubbles (yielding an oil sheen) were detected coming from the ocean floor near the well conductor. This low-volume ocean-floor leakage continued at closely monitored variable rates. The well was drilled to its planned total depth of 18,318 feet on November 7, 1976, and then was tested and plugged back to 4,850 feet on November 27. On December 2 the casing was perforated between 2,929 and 2,933 feet, and mud followed by cement was squeezed into the formation. The surface seepage immediately subsided and died (on December 10). Prior to abandonment of the well, the casing was perforated from 4,926 to 4,936 feet and the interval tested. Gas was produced on a short test of the interval at rates comparable to the former seepage rates.

This history indicates conclusively that the sea-floor seepage gas came from deeper than the squeeze-cemented interval, probably from the interval tested. Possible causes were considered, but any conclusions are speculative.

There seems to be no connection of any sort between the Well No. 3 event late in 1976 and the Well No. 5 problem of mid-1978. No surface seepage resulted from the events connected with Well No. 5 where a deep zone is the most likely source of the problems. Conversely, no difficulties with any deep zones were encountered in Well No. 3, and the problem due to shallow gas was efficiently and completely ameliorated by squeeze cementing at shallow depth. The two wells are separated by about 2 miles, and the problems occurred about 1 1/2 years apart.

C. Remedial plans to reduce possible fracturing

1. If feasible, what could be gained by re-entry of Well No. 5?

There is an 850-foot drill pipe and bit fish which is cemented in the hole from 2,968 feet to 3,818 feet. This fish extends 613 feet above and 237 feet below the 9 5/8-inch casing shoe set at 3,581 feet. There are three cement plugs above the fish. The top of the uppermost plug is at 450 feet. While reentry of the well to shallow depths by drilling out the cement plugs would be possible, it would not be practically feasible to attempt redrilling below the top of the drill pipe fish at 2,968 feet. Furthermore, since the initial cement plug (set after the migration of gas above the cement plug at 4,219 feet) was successful in confining the gas to the lower portion of the hole, whatever useful purpose would be served by reentering or establishing communication in the upper portion of the hole would be offset by the operational difficulties and time requirements.

2. Should a relief well be drilled, and, if so, to what specific objective and for what purpose?

Texaco filed on August 18 an application to drill Well No. 6, which may be considered as a combination relief and twin well. Approval was granted on August 18 and drilling commenced on August 20. The well is being drilled with the Zapata Trader, the same drill ship which drilled Well No. 5. The surface location of the well is 2,310 feet south and 289 feet east of Well No. 5.

The plan is to drill vertically to approximately 9,000 feet, then to deviate and directionally drill the hole following closely the course of the Well No. 5 bore hole to a measured depth of 10,470 feet in Well No. 5 where interception is expected. The 9 5/8-inch protective casing will be set at about 9,755 feet MD, about 200 feet above the interception point.

The point of interception is immediately above the top of the lower Pico-Repetto gas sands believed to be the source of the gas that leaked past the cement plug at 4,219 feet. If communication is established between the two holes at the point of interception, a cement plug will be placed in Well No. 5 to prevent the migration of fluids to overlying formations with lower pressures. If operations are successful, a 7-inch casing liner will be run and cemented to the proposed total depth of 13,000 feet to permit the testing of Repetto sands which was interrupted in Well No. 5.

Drilling the relief well will accomplish three objectives:

First, from a safety standpoint, enhance confidence that upward migration of high-pressure gas from the lower Pico and upper Repetto formations through the Well No. 5 bore hole into shallow, lower-pressured sands is precluded. Drilling this well will provide an opportunity to observe any excessive pressures in formations possibly pressurized by Well No. 5. However, it is concluded that pressure build-up in the upper sands would not be sufficient to cause formation fractures, including fractures leading to the ocean floor.

Second, from an economic and energy conservation standpoint, provide added assurance that substantial gas reserves in the lower Pico and Repetto sands will not be lost. Such a loss could occur if gas migrated to shallower, lower-pressured wet sands where it could not be recovered. Economic recovery could not be anticipated because the large overall reservoir volume of the numerous porous and permeable middle Pico sands encountered in Well No. 5 would be subject to water entry from below before fill-up with gas. It is reasonable to assume that the upward migration of any substantial quantity of gas is unlikely. The probability is high that the hole has spontaneously bridged, or will bridge (plug itself), above the lower gas sands through obstruction of the presumably small opening between the drill pipe fish and the open bore hole (8 1/2-inch drilled hole with 5-inch drill pipe and 6 1/4-inch drill collars) by debris from the softer formations. A relief well will further increase confidence that this is so.

Third, provide additional geological and engineering data which will increase the efficiency, effectiveness, and safety of future exploration, development, and production activities in the Pitas Point unit area.

3. <u>Should a twin well be drilled to observe and relieve excessive pressures in formations possibly pressurized by Well No. 5?</u>

The drilling of Well No. 6 was commenced on August 20. This well is considered to be a combination relief and twin well which, if successful, will accomplish the desired objectives.

4. <u>What are the permitting and drilling time requirements for a relief or twin well?</u>

Well No. 6, considered to be a combination relief and twin well, is currently being drilled. Approval was granted on August 18, the same day that the application to drill was filed, under the emergency provisions of 30 CFR 250.34, with respect to the environmental procedures required by those regulations.

Drilling and abandonment time for Well No. 5 was about 2 1/2 months (June 8 to August 19). Drilling and abandonment time for relief Well No. 6 is estimated to be about 2 months.

5. <u>What was the final casing program for Well No. 5, and what should the casing program be for a relief or twin well, if drilled?</u>

Figure 5 depicts for Well No. 5 the final casing program, which complied with the provisions of OCS Order No. 2 governing drilling operations in the Pacific Area. Well No. 5 casing, cementing, and testing details are:

| Casing Size (inches) | Depth (MD) KB (feet) | Depth (MD) Ocean Floor (feet) | Cement (CF) | Casing Test (PSI) | Casing Shoe Test |
|---|---|---|---|---|---|
| Structural -30 | 435 | 95 | 575 | NA | NA |
| Conductor -20 | 642 | 302 | 720 | 200 | NA |
| Surface -13 3/8 | 1,328 | 988 | 1,040 | None | NA |
| Intermediate -9 5/8 | 3,581 | 3,241 | 1,190 | 1,500 | Tested to 90 pcf equivalent - no bleed off |

The approved casing program for relief Well No. 6 is:

| Casing Size (inches) | Depth (MD) KB (feet) | Depth (MD) Ocean Floor (feet) | Cement (CF) |
|---|---|---|---|
| Structural-Conductor -30 | 649 | 300 | |
| Surface -20 | 1,349 | 1,000 | 2,200 |
| Intermediate -16 | 2,849 - 3,349 | 2,500 - 3,000 | 5,600 |
| Protective -13 3/8 | 4,849 - 6,349 | 4,500 - 6,000 | 4,500 |
| Protective -9 5/8 | 9,755 | 9,406 | 3,850 |
| Liner -7 | 13,000 | 12,651 | |

The above casing program was proposed by Texaco and approved by the District Engineer after consultation with the Area Supervisor, his staff, and Task Group members. A combined string of 30-inch structural-conductor casing was run to 300 feet below the ocean floor. Because shale is predominant to a depth of 2,500 feet at this location, no well-control problems to that depth are expected. Running the larger-diameter, 30-inch pipe (normally 20-inch) to the 300-foot depth permits a larger number of relatively larger-diameter pipe strings to be set down the hole. The additional strings enhance the ability to confine formation fluids and pressures and maintain well control. Also, the larger-diameter pipe helps to avoid and control down-hole operational problems often encountered in small-diameter pipe.

OCS Order No. 2 for the Pacific Area requires that both structural and conductor casing strings be run. Thus, combining these strings into one string constitutes a minor departure from the requirements of the Order. The Area Supervisor's approval of this departure was in accordance with the regulations in 30 CFR 250.12(b) because it will improve the safety of operations during the drilling of Well No. 6.

6. Should no further remedial action be undertaken?

Well No. 5 is plugged and there is no evidence of gas or other formation fluids leaking at the surface. Therefore, no further remedial operations on Well No. 5 are needed except those which are planned by the drilling of the relief-twin Well No. 6 discussed under question No. 2 above.

D. Evidence of relationship with August 13 (3:55 p.m. PDT) earthquake

1. What are the spatial and geological structural relations between the well and the earthquake?

The earthquake of August 13, 1978, had its epicenter at 34° 22.2' N., 119° 43.0' W. and a focal depth of about 7.8 miles. This placed it about 2 miles offshore, just south of Santa Barbara. Figure 7 shows the seismograph stations used in calculating the hypocentral locations of the main shock and some 70 aftershocks. The main shock was preceded 4 hours by a small earthquake of Richter magnitude of 2 to 3, shown at the lower right corner of figure 8.

A cross-section A-A' perpendicular to the trend of the epicenters of the aftershocks shows the focal depths in relation to the surface of the mapped faults (fig. 9). The active fault trace is projected through the focal region at the dip angle determined from the focal mechanism of the main shock (fig. 10). The fault appears to have ruptured in a reverse or thrust faulting mode in the main shock, with the rupture surface being defined by the zone of aftershocks.

The distance from the bottom of Well No. 5 to the hypocenter of the main shock is about 9 miles, and the distance from the well southeastward to the epicenter of the small earthquake is about 6 miles (fig. 8).

(Preceding data for question 1 taken from information furnished by W. H. K. Lee, C. E. Johnson, T. L. Henyey, and R. F. Yerkes, (written commun., 1978).)

2. Was the earthquake 5.1 or 5.5 on the Richter scale?

Differences in magnitude estimates of $M = \pm 0.5$ are common and have to do with complexities in the relation between the source and the receiver and the paths traveled by the seismic rays. The difference in estimates reported by different centers for earthquake study immediately after the earthquake is therefore not a significant one. The agreed figure for this earthquake is 5.1.

3. Could smaller earthquakes prior to the main shock at 3:55 PDT have:

a. Disturbed the cement plugs in Well No. 5 on August 8?

b. Caused the gas flow at Well No. 5 on August 9?

During the period August 8 through August 9 no earthquakes occurred which were large enough to be felt in the area. Neither effect seems likely to have been caused by earthquakes.

The small earthquake that occurred 6 miles southeast of Well No. 5 on August 13 is considered to be unrelated to the formation breakdown in Well No. 5, which occurred later that day at 6:44 p.m. PDT and was caused by operational difficulties.

4. Could pressurizing the formations at Well No. 5 have triggered the earthquake?

In order for the faulting responsible for the earthquake to be triggered artificially, a fluid pressure increase at the point where failure occurred would be required. Triggering of earthquakes by fluid pressure increases has been documented in at least three cases. In all of these, fluid pressures were raised by injection at several hundred psi above the ambient pore pressure in the fractured rocks. However, triggering of earthquakes by filling of surface reservoirs has been demonstrated where the subsurface fluid pressures may have been raised by no more than 60 psi.

If there was significant pressurization of the upper sands below the casing shoe at 3,581 feet in Well No. 5, it nevertheless is extremely unlikely that a perceptible rise in pressure would have been recorded at the epicentral distance of 9 miles from the well. Even if a rise in pressure were experienced in the Pico Formation sands near the epicenter, there remains the difficulty of transmitting such a pressure increase to depths near the earthquake focus. If the 7.8 mile thick column of rock above the hypocenter was highly permeable throughout, the pressure differential would be transmitted to the fault surface. However, if any layers of low permeability intervened, which is virtually certain to be the case, a rise in pore pressure would not occur at the earthquake focus. In our judgment, given that this region is naturally seismically active, and the great improbability that any pore pressure increase could have been transmitted over the 9 miles to the earthquake's focus, the occurrence of this earthquake is causally unrelated to the difficulties at Well No. 5.

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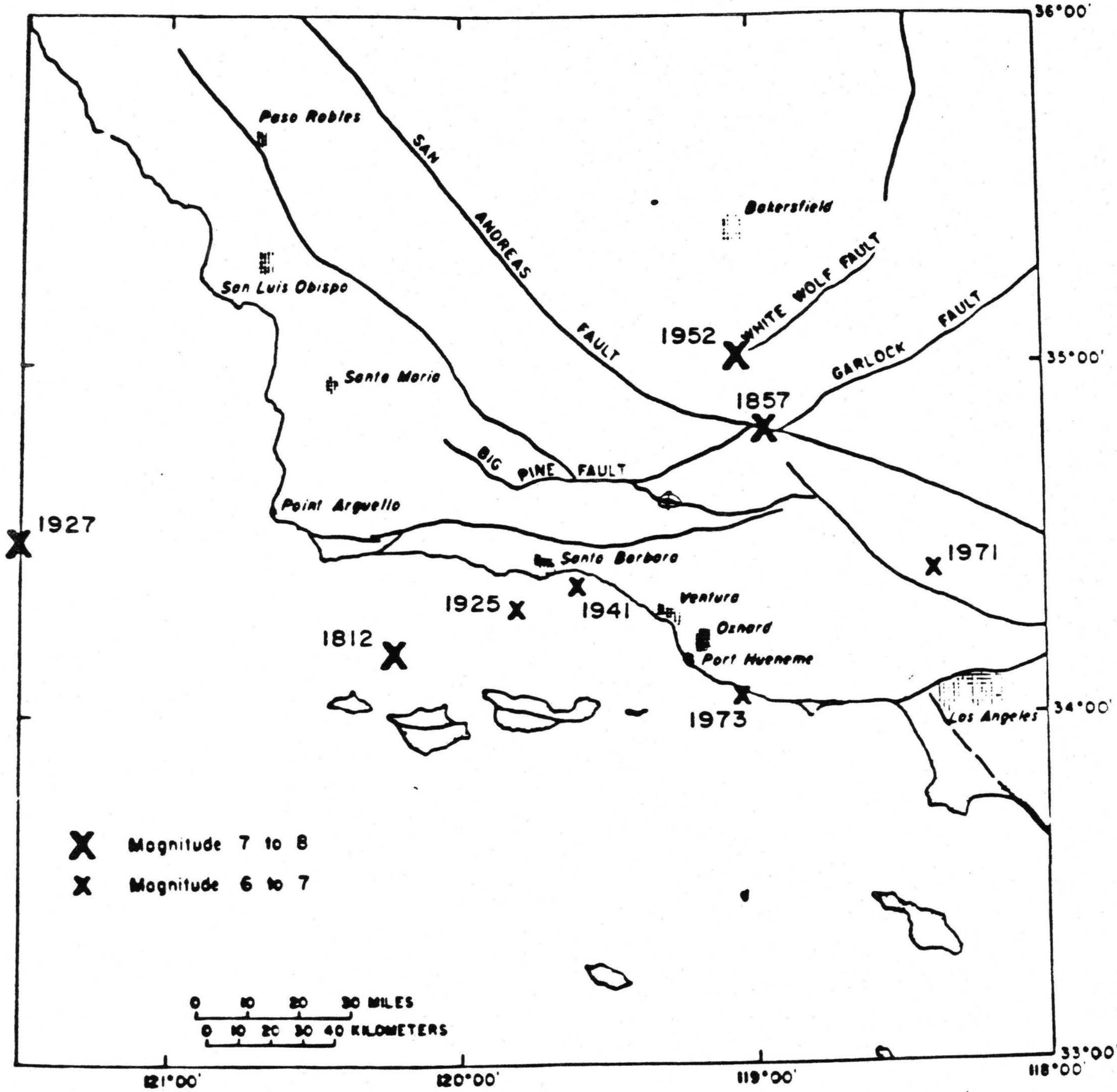



Figure 1.--Approximate epicenters of selected strong earthquakes that have affected the Santa Barbara Channel region. Not all strong earthquakes in the area are shown.

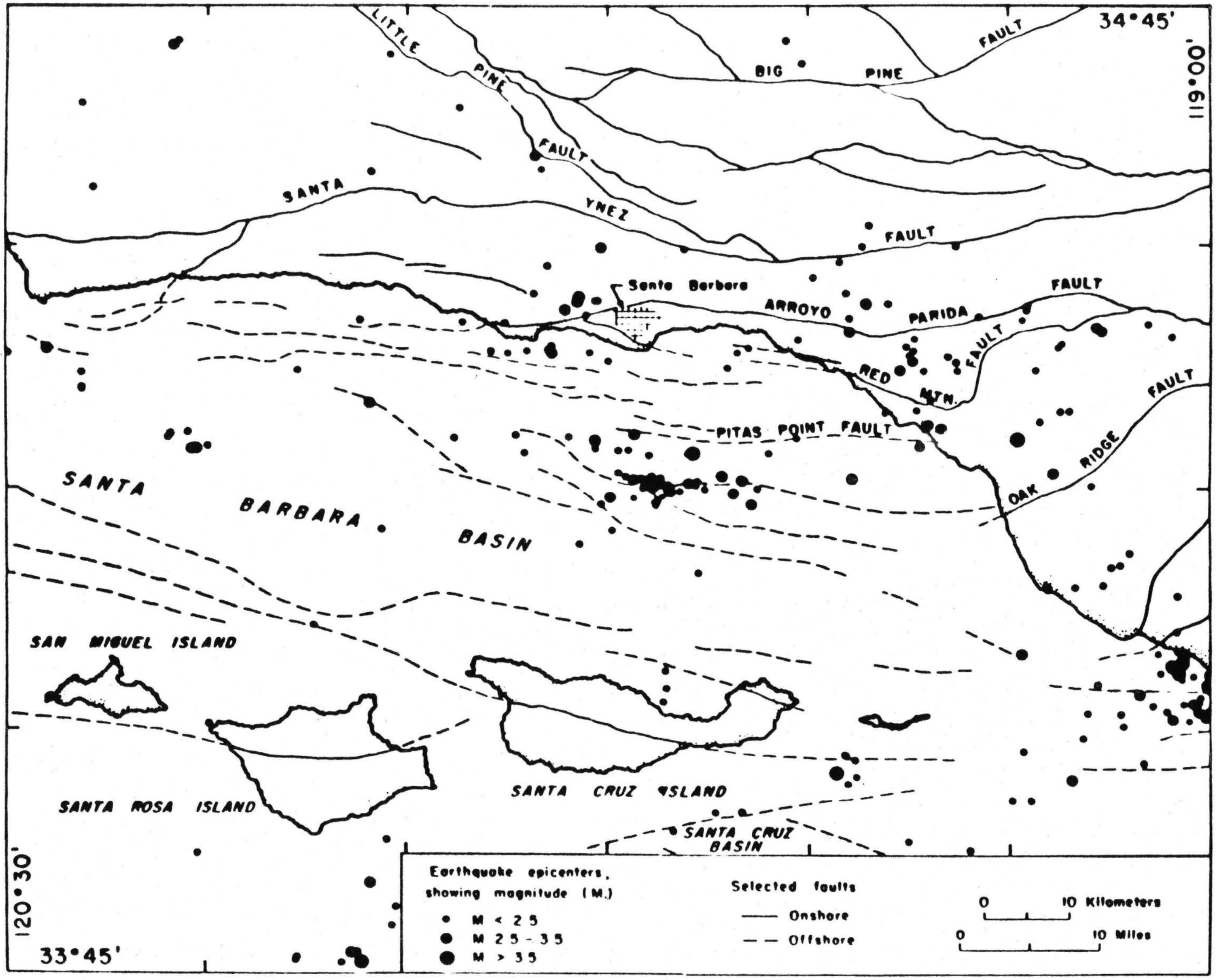



Figure 2.--Earthquake epicenters in the Santa Barbara Channel region from 1970 through 1975, as determined by the U.S. Geological Survey.

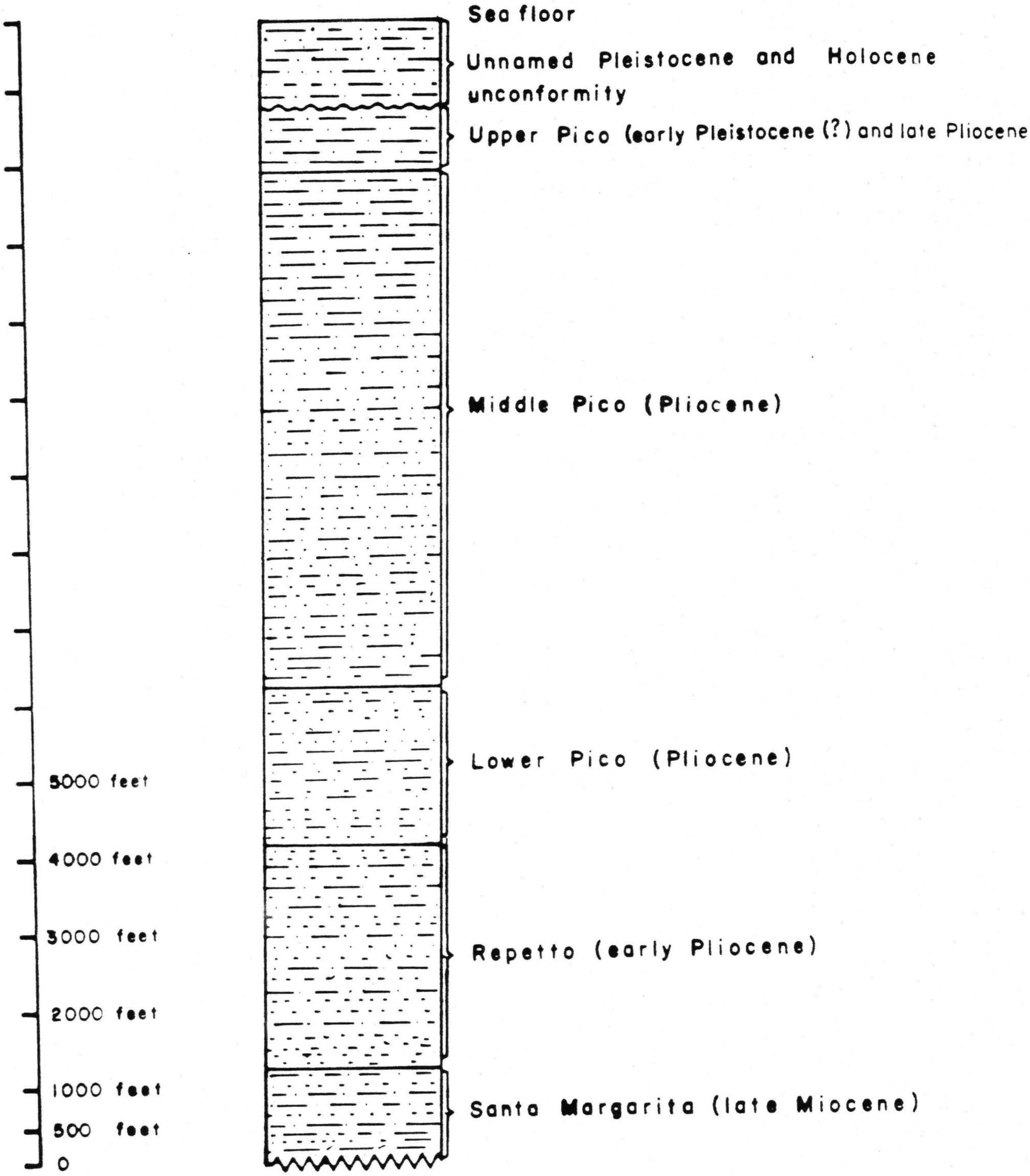
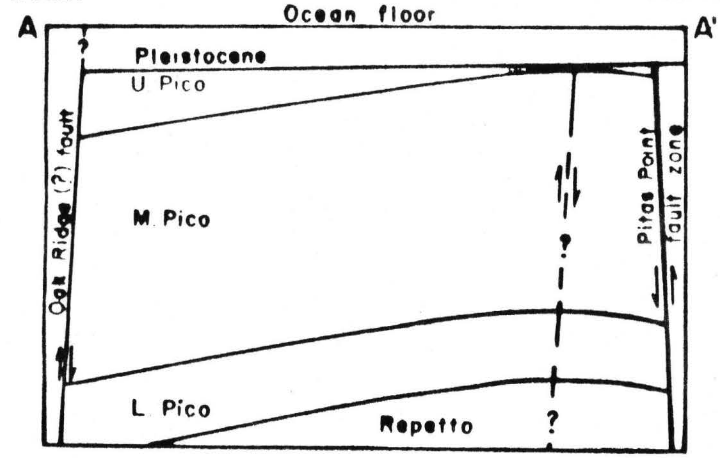



Figure 3.--Generalized stratigraphic column for Pitas Point Unit based on thicknesses drilled in OCS-P 0234 Well No. 1.




Schematic North-South Section Through Lease OCS P-0234

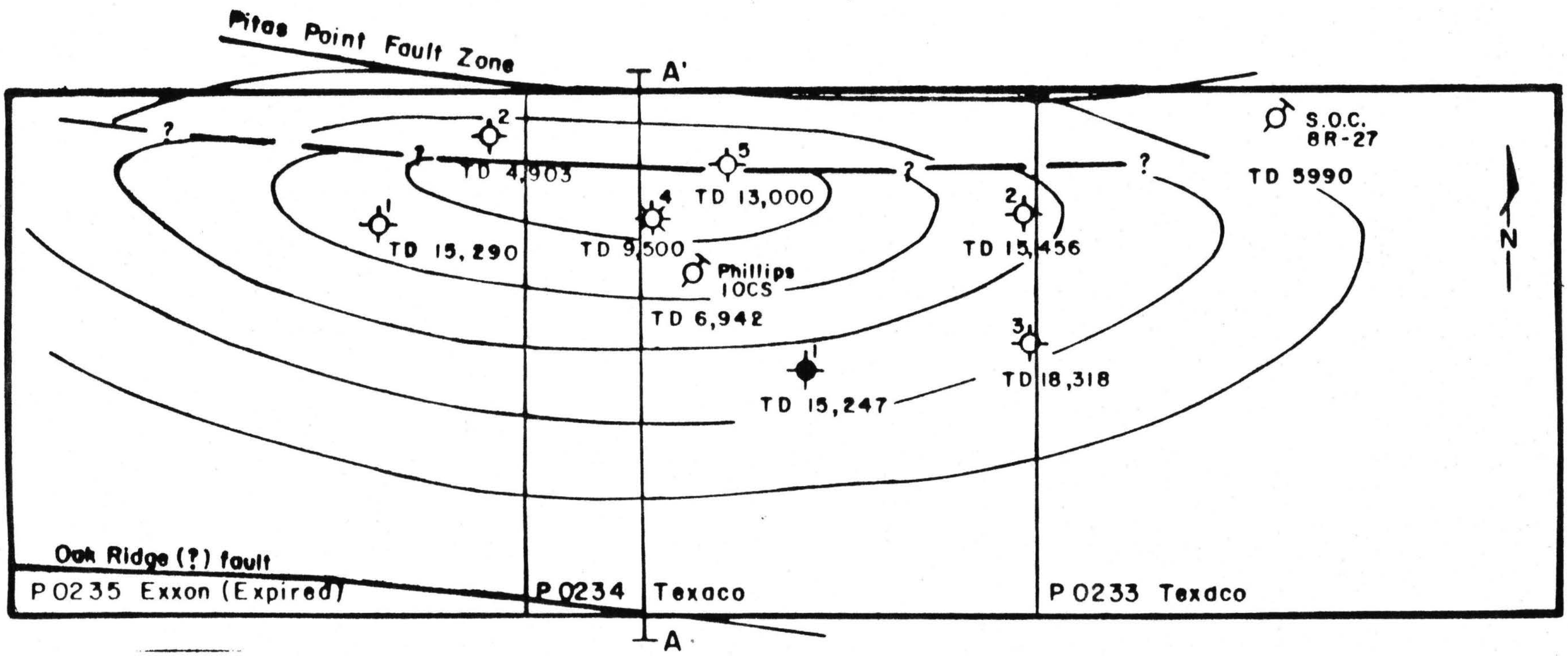



Figure 4.--Schematic structure contour map of a middle Pico Formation horizon in the Pitas Point Unit area.

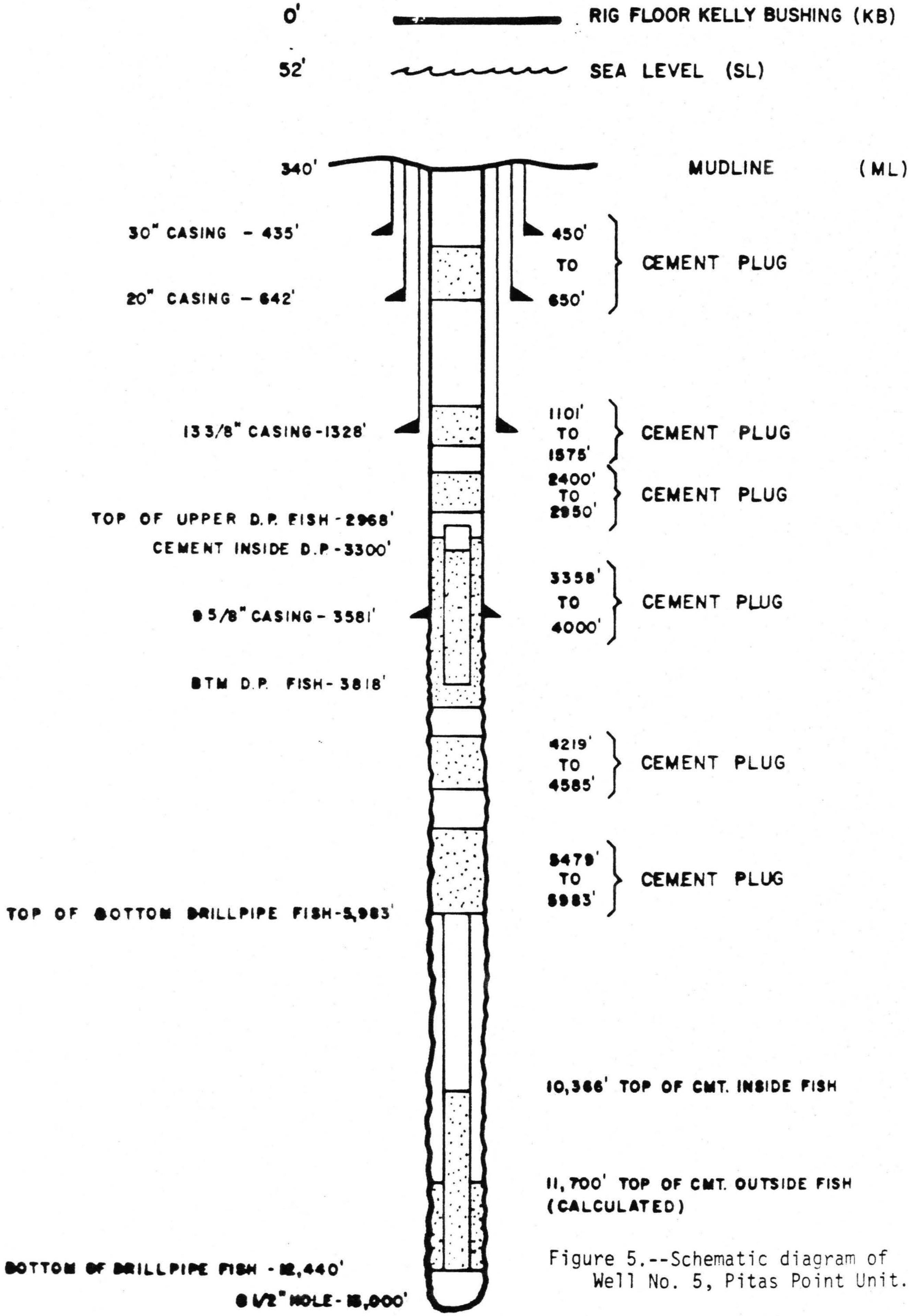



Figure 5.--Schematic diagram of Well No. 5, Pitas Point Unit.

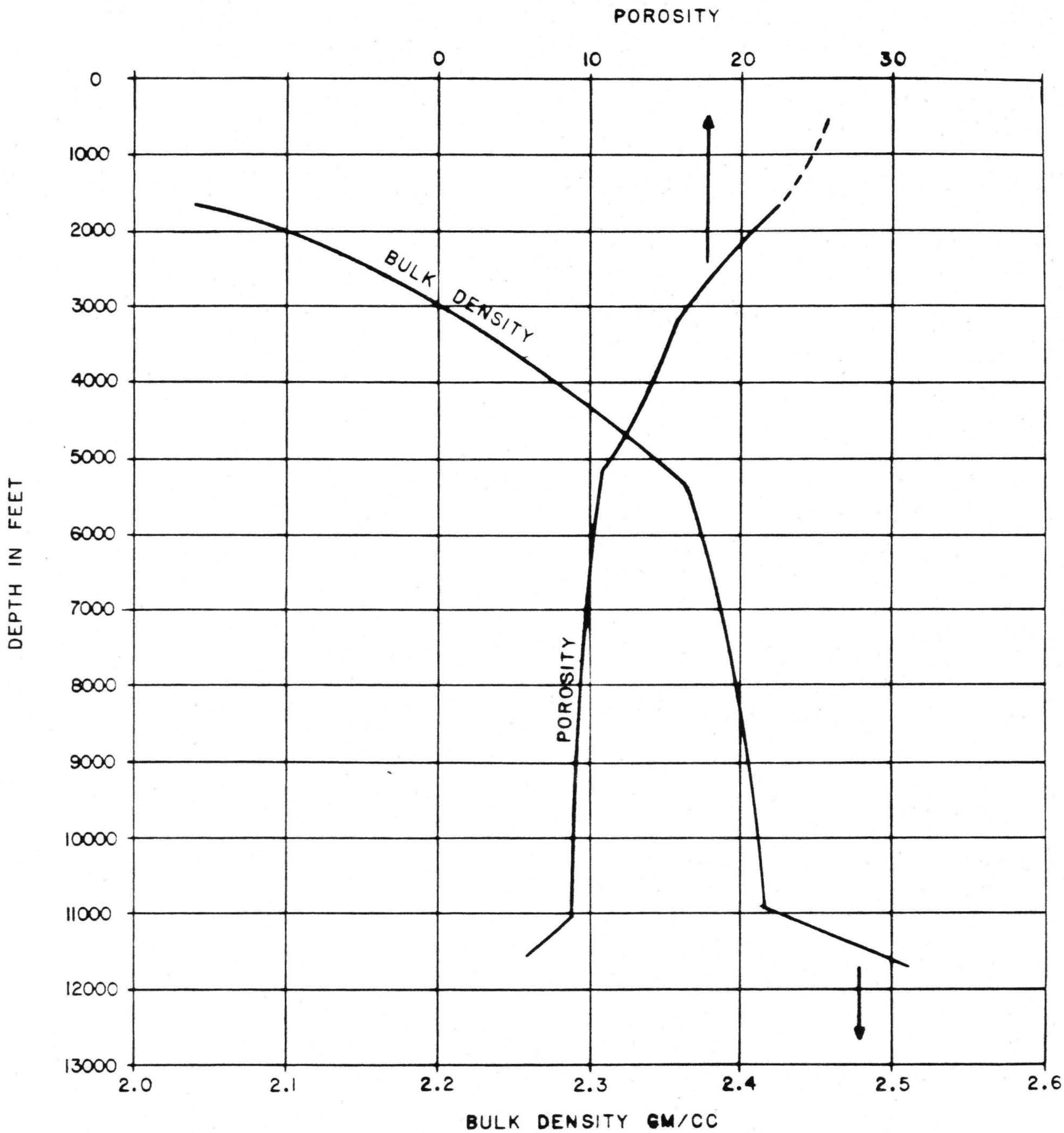



Figure 6.--Averaged bulk rock density and porosity as a quantitative measure of consolidation. Curves derived from interpretations of the formation density log of Well No. 5.

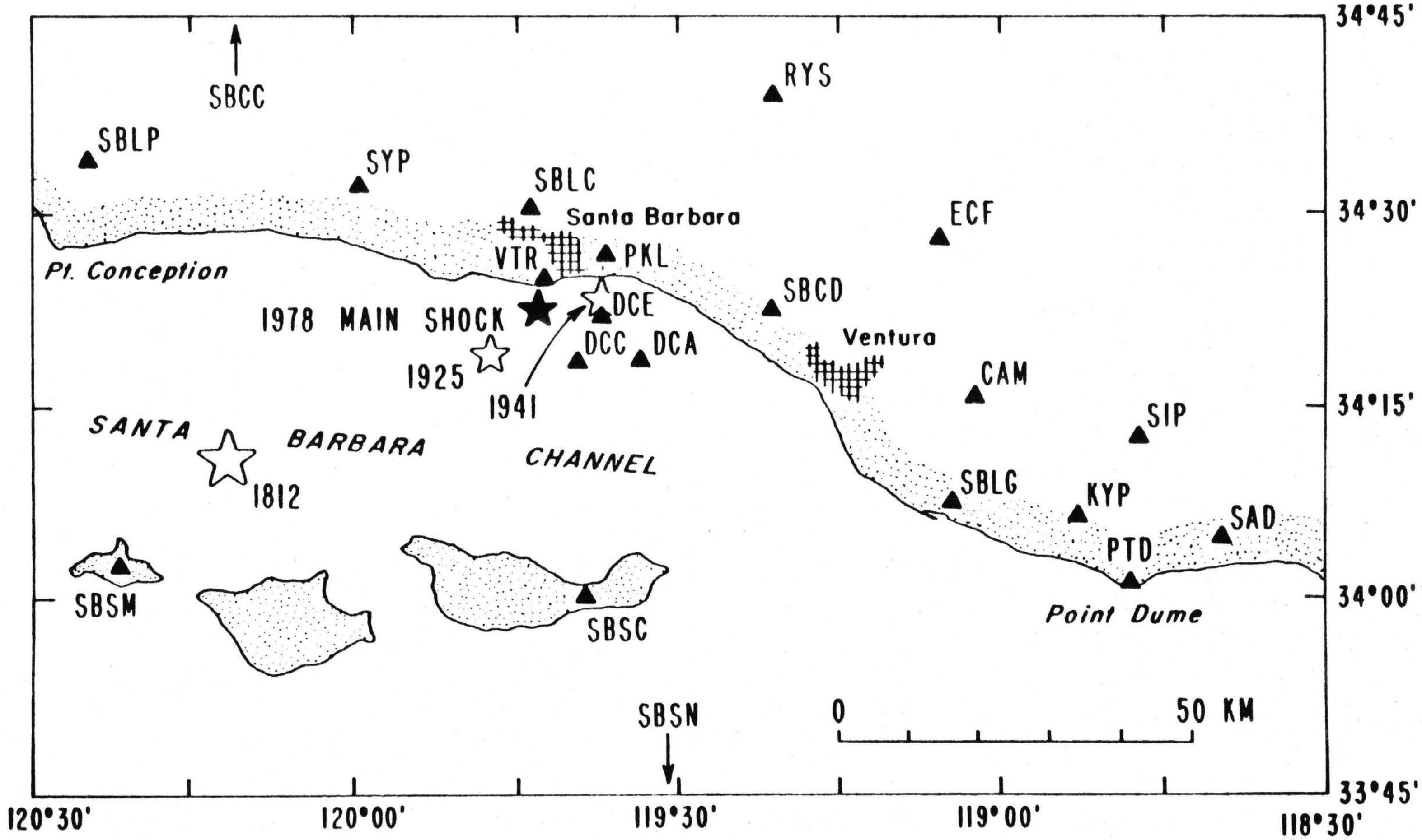



Figure 7.--Seismic stations used in location of August 13, 1978, main shock and aftershocks (solid star). Approximate epicenters of earlier strong earthquakes shown by open stars.

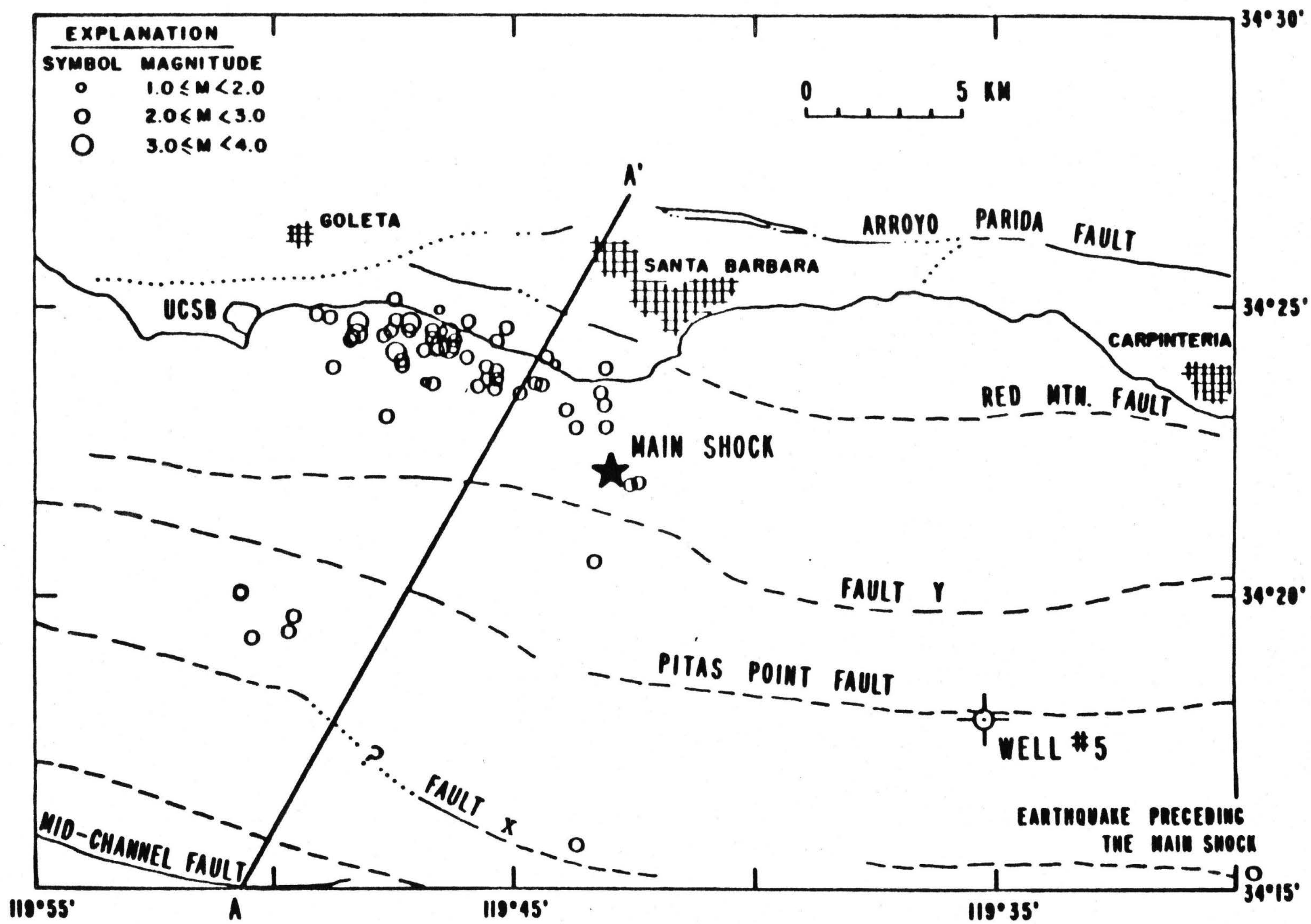



Figure 8.--Epicenters of the Santa Barbara earthquake of August 13, 1978, and its major aftershocks.

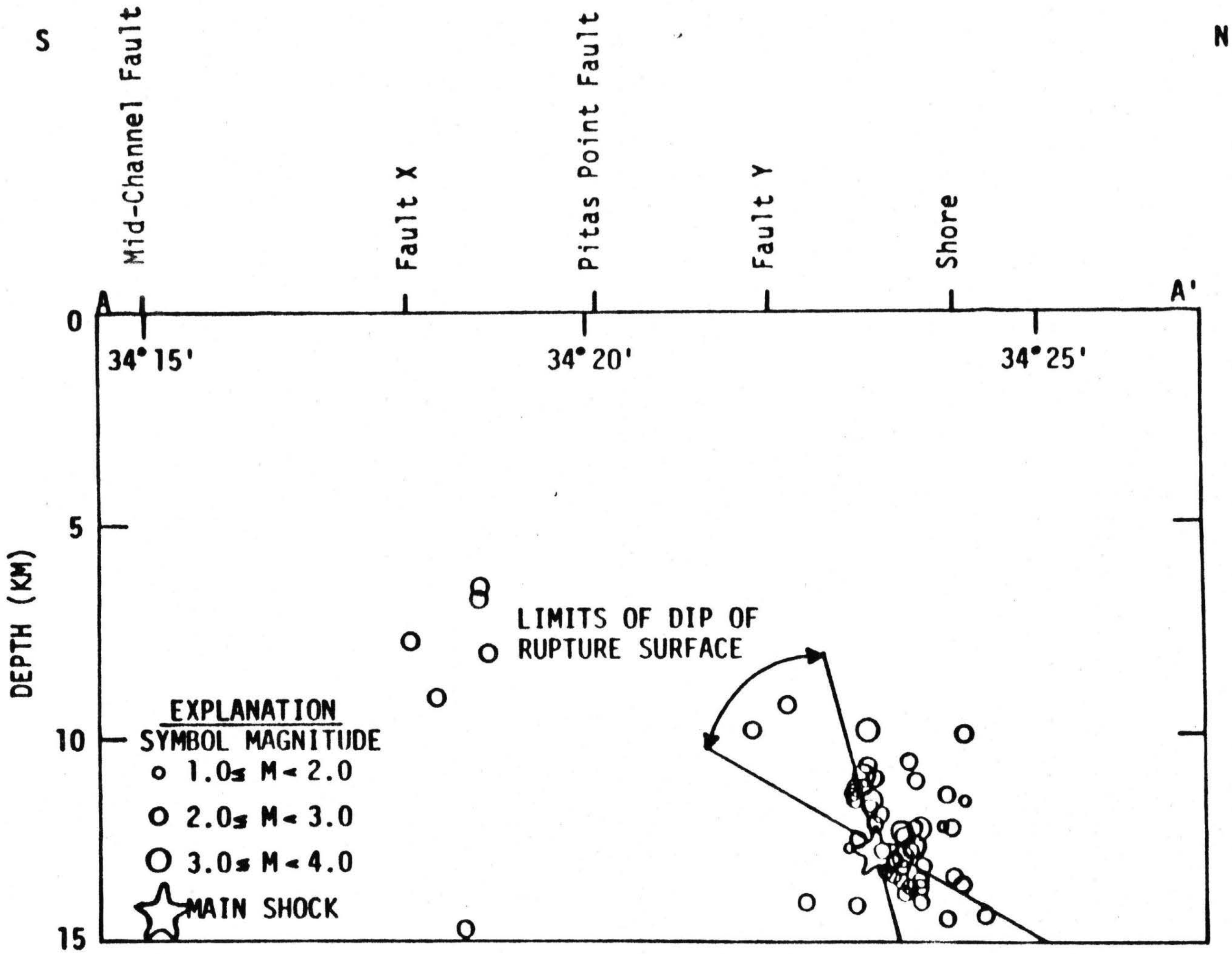



Figure 9.--Cross section A-A' through hypocenters of the August 13, 1978, earthquake.

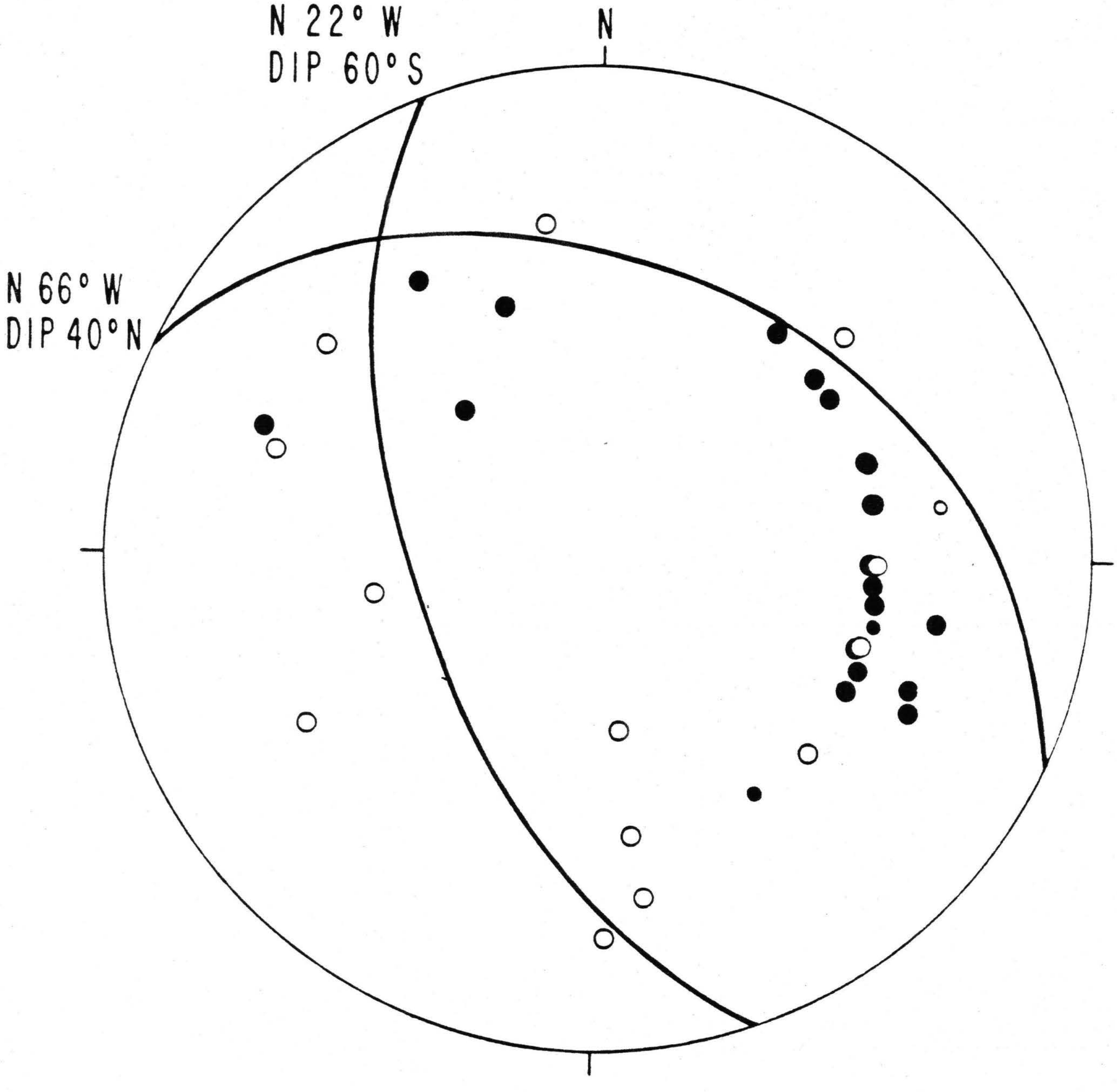



Figure 10.--Fault-plane solution of the Santa Barbara earthquake of August 13, 1978 (22:54 GMT), plotted on an equal-area, lower hemisphere projection. Compressions, solid dots; dilatations, open circles. The N. 66° W., 40° N. nodal plane is most likely to be the fault plane.

Table 1--Summary data for the first six lease wells drilled in the Pitas Point Unit area

| COMPLETION DATE | TOTAL DEPTH IN FEET | CASING SIZE | DEPTH, FEET BELOW OCEAN FLOOR | REMARKS |
|---|---|---|---|---|
| **Well 0234 No. 1** | | | | |
| 6/15/78 | 15,247 | 20" | 347 | Oil discovery |
| | | 13 3/8" | 2,530 | |
| | | 9 5/8" | 10,229 | |
| **Well 0234 No. 2** | | | | |
| 2/11/69 | 15,546 | 20" | 308 | Dry hole |
| | | 13 3/8" | 2,549 | |
| | | 9 5/8" | 10,013 | |
| | | 7" | 14,092 | |
| **Well 0234 No. 3** | | | | |
| 11/7/76 | 18,318 | 30" | 104 | Dry hole |
| | | 20" | 545 | |
| | | 16" | 1,540 | |
| | | 13 3/8" | 4,508 | |
| | | 9 5/8" | 14,904 | |
| **Well 0234 No. 4** | | | | |
| 1/15/78 | 9,500 | 30" | 105 | Gas in middle Pico |
| | | 20" | 303 | |
| | | 13 3/8" | 1,018 | |
| | | 9 5/8" | 2,248 | |
| | | 7" | 7,217 | |
| **Well 0235 No. 1** | | | | |
| 8/16/68 | 15,290 | 30" | 142 | Dry hole |
| | | 20" | 469 | |
| | | 13 3/8" | 2,855 | |
| | | 9 5/8" | 11,542 | |
| **Well 0235 No. 2** | | | | |
| 11/24/68 | 4,903 | 30" | 96 | Dry hole |
| | | 16" | 510 | |
| | | 10 3/4" | 4,490 | |

# United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

In Reply Refer To:
Mail Stop 905

AUG 14 1978

Memorandum

To: Russell G. Wayland

From: Director, Geological Survey

Subject: Santa Barbara Task Group

Confirming our discussion this morning, you are to proceed immediately to our Los Angeles office where you will head a Task Group to study a problem which Texaco is having in controlling an exploratory well on Santa Barbara Channel lease P-0234.

The Task Group is charged as follows:

- o Develop a better understanding of the subsurface geology in the vicinity of the well.
- o Analyze the potential effects of gas pressures in the plugged well on all formations in the field.
- o Determine if there is any evidence of a relationship between the well-control problem and the earthquake of August 13.
- o Determine if a relief well as currently planned is the most effective remedial procedure to reduce the possibility of fracturing the formations.

The following persons will be members of your Task Group:

A. Dewey Acuff, Petroleum Engineer

Thane McCullough, Geologist

C. Barry Raleigh, Geophysicist

John G. Vedder, Marine Geologist

Keith A. Yenne, Geologist

Enclosure 1

The Los Angeles office of the Conservation Division will provide you with suitable office space and whatever administrative support you may require on the highest priority basis. The Oil and Gas Supervisor and the Area Geologist are hereby charged to provide you with whatever information you may need. Please submit any significant findings to this office as soon as they are determined. An interim report should be provided by August 31 with a final report following shortly thereafter.

W. A. Radlinski

Acting Director

**DEPARTMENT of the INTERIOR**

GEOLOGICAL SURVEY

news release

For Release August 16, 1978

Frank Forrester (703) 860-7444

PROBE SANTA BARBARA OFFSHORE GAS WELL PROBLEM

A special task group from the U.S. Geological Survey, Department of the Interior, has been formed to investigate a gas well problem that developed August 9, 1978, in an exploratory drill hole in the Santa Barbara Channel off the California coast.

The gas problem developed in an exploration well being drilled from the drill ship Zapata Trader operated for Texaco while drill pipe was being removed from the hole. The ship is located in about 280 feet of water about four miles south of Pitas Point, and about 12 miles southeast of Santa Barbara in the Channel.

The USGS group will focus its attention on the potential effects of high pressures that might build up in the plugged well and in rock formations in the area. Such pressures could lead to the fracturing of rock and the escape of gas to the surface. The group will try to obtain a better understanding of the subsurface geology in the vicinity of the well, and also will try to determine if a relief well is the most effective procedure to reduce the possibility of rock fracturing because of the excessive pressures.

Dr. H. William Menard, USGS Director, said the task group was formed, mainly, because of concern over high downhole pressures that have been encountered in the exploration well on the drill ship. "We want to make sure," he said, "that we have a full understanding of the situation in order to take appropriate and immediate remedial measures to protect against a fracturing of any unconsolidated rock formations in the vicinity of the hole that would permit the escape of gas or oil to the surface."

Menard said the group is also being asked to look into the significance of the sharp earthquake that occurred south of Santa Barbara on August 13, 1978.

The damaging tremor of August 13, felt over a three-county area of southern California, registered about 5.1 on the Richter Scale. A preliminary determination indicates that it was centered in the Santa Barbara Channel about eight miles west-northwest of the drill ship. The precise epicenter is currently being determined.

The task group, headed by Russell G. Wayland, Research Physical Scientist at the USGS National Center, Reston, Va., includes:

* Dewey Acuff, Petroleum Engineer, Metairie, La.
* Barry Raleigh, Geophysicist, Menlo Park, Calif.
* John G. Vedder, Marine Geologist, Menlo Park, Calif.
* Keith Yenne, Geologist, Los Angeles, Calif.
* Thane McCulloh, Geologist, Seattle, Wash.

The study team will be headquartered at the Geological Survey's Los Angeles office. They will submit an interim report by August 31.

Enclosure 2

x x x

POST-SANTA BARBARA EARTHQUAKE NATURAL SEEP SURVEILLANCE

Observations of Lt. Klaus Adie, Group Commander,

U.S. Coast Guard, Santa Barbara

August 25, 1978

The Coast Guard routinely conducts multi-mission helicopter patrols of the Santa Barbara Channel twice weekly throughout the year. Oil pollution surveillance is one of the missions of these patrols. The natural seeps at Rincon, Platform A, La Mesa, Platform Holly, Coal Oil Point and Platform Herman are routinely noted on these flights. Additional oil noted in the Channel is also reported. These reports are disseminated to the Eleventh Coast Guard District Office in Long Beach and Group Santa Barbara for action as the situation reported warrants.

Subsequent to the Santa Barbara Earthquake of 13 August 1978, the Coast Guard increased the frequency of these patrols to monitor pollution in the Channel area that may have resulted from the quake. From 14 to 25 August, four helicopter and two fixed-wing overflights were conducted, with Lt. Adie as an observer. Lt. Adie has overflown the Channel on approximately 15 occasions in the past 15 months and has reviewed all patrol reports made during that period.

Subsequent to the earthquake, the following observations were made:

- 14 August - Increased activity from the Coal Oil Point/Platform Holly area, Platform Herman and Platform A. Weather this date was generally light (>5 knots) westerly winds, overcast with light fog through early afternoon. Tidal range was 6 feet.

Enclosure 3

Some additional oil seep activity was noted in the Carpinteria seep area in the vicinity of the Chevron facility. It was minor in comparison with other seeps.

- Surveillance over the next 7 days revealed little change in the observed seep activity. However, due to the lack of appreciable wind and the general overcast weather, little dissipation was occurring allowing numerous bands of brownish oil to form. These bands were noted on 21 August to extend from Cojo Bay to Rincon Island, from shore to as much as 5 miles offshore in the Santa Barbara Mesa area. Offshore fog prevented surveillance activity beyond 5 miles offshore. Tidal ranges increased from 6.9 feet on the 15th to 7.8 feet on the 17th and 18th and decreased to 5.1 feet on the 21st.
- The 23 August overflight revealed that activity had lessened, and increased wind and no overcast had dissipated the oil into scattered sheens. Light silvery sheens with minor iridescence were noted up to 15 miles offshore from a point due south of Goleta to 10 miles offshore due south of Pitas Point. The only brown oil noted was a band with a maximum width of 20 feet stretching approximately 3 miles, 1 mile off Carpinteria, paralleling the shore.
- The 24 August overflight (Lt. Adie not on board) reported that all seeps appeared to be back to normal activity. By this date the tidal range had decreased to 3.5 feet.

No seep areas previously not reported were discovered during the observation period. Although increased seep activity was noted after the quake, the weather, tide and currents experienced during the observation period may have been the larger factors in the amount of oil and area of coverage noted.

Tides (feet) for August 13 to 25, 1978

| Date | High | Low | Range |
|---|---|---|---|
| August 13 | 5.6 | .8 | 4.8 |
| 14 | 6.1 | .1 | 6.0 |
| 15 | 6.5 | (-).4 | 6.9 |
| 16 | 6.8 | (-).8 | 7.6 |
| 17 | 6.8 | (-)1.0 | 7.8 |
| 18 | 6.8 | (-)1.0 | 7.8 |
| 19 | 6.2 | (-).8 | 7.0 |
| 20 | 5.6 | (-).4 | 6.0 |
| 21 | 5.3 | .2 | 5.1 |
| 22 | 5.2 | .8 | 4.4 |
| 23 | 5.0 | 1.4 | 3.6 |
| 24 | 4.9 | 1.4 | 3.5 |
| 25 | 4.8 | 1.2 | 3.6 |

UNIVERSITY OF CALIFORNIA
SANTA BARBARA DEPARTMENT OF GEOLOGY
REMOTE SENSING UNIT

Statement by Mike Wilson
August 25, 1978

Our group was contacted by the Geological Survey to provide background material and analysis of new (post-earthquake) aero color negative imagery of brown oil seeps in the Santa Barbara Channel. The imagery was flown at 7,300 feet with a focal length of 6 inches yielding a scale of 1 to 14,600. Flying days were August 18 through August 25. A 20-percent overlap was utilized for the first 6 days and a 60-percent overlap was utilized for the last 2 days. Images inspected were in transparency form and overlap was end lap versus side lap. Resolution was excellent but due to the high moisture content of the intervening atmosphere, contrast in the image outside the limited area of sun glint was variable from poor to moderate.

Three separate flight lines were utilized. Number 1 was an east-west line extending 2 miles on either side of the drill ship off Pitas Point. Number 2 was an east-west line beginning at State oil Platform Heidi and extending westward to include all Federal platforms out to Platform C. This flight line (No. 2) extended 6 miles further on the same heading to cover what was originally thought to be the earthquake epicenter. Lastly, flight line No. 3 was a southeast-trending line commencing at Coal Oil Point, including Platform Holly and some of the major oil seeps in its vicinity and extending to a point 2 miles beyond.

Although image quality was limited by low clouds and haze, several things were notable. On imagery for the 18th, 19th, and 20th of August, oil was prevalent in moderate to high concentrations in virtually all frames. However, due to the limited areas of sun glint from which interpretation could be made, no accurate areal map of oil coverage could be generated. Points of origin could be traced to the well-known seeps east of and at Platform Holly, (flight line No. 3), as well as those at Platform A (flight line No. 2). No new seeps could be identified from the imagery. Although large continuous iridescent to silver slicks were observed around the drilling ship (flight line No. 1) on the 18th through the 20th of August, it is felt the point of origin was elsewhere. Evidence for this conclusion lies in the weather conditions during this period and in the fact that no distinct point of origin could be discerned.

It should be noted that weather conditions during the first few days of observation, though poor for aerial coverage, were unsurpassed for generation and maintenance of oil slicks. Winds were light and variable, causing random drifts and generally indiscriminate movements. Tidal fluctuation was at its peak, causing wide changes in pressure at the seeps. And skies were mostly overcast, limiting evaporation of oil slick volatiles.

In general, though the flight lines chosen did not optimize coverage of known seeps, the trend observed was an increasingly heavy coverage of oil through the 20th. Imagery for the 22d of August showed a diminished area of coverage in areas not normally blessed with oil slicks. The area around the drill ship along flight line No. 1 was observed to be free of oil. Activity at the known seeps was observed to be continuing, and silvery sheen to iridescent slicks in their vicinity continued to exist. Weather for this period showed an increasing trend to windy sunny afternoons which could account for the slick dissipation.

Memorandum

To: Files

From: Dee Adams

Subject: Pollution Surveillance Flight

Date and Time of Departure: 8-14-78 0820

Name & Location of Contractor: Condor Starting/Ending Location: Oxnard

No. Passengers: 1 Pay Load: Cargo: Type Aircraft:

Rate: Period of Use: Total Cost:

Fuel furnished by: Condor

Flight Course: Platform "C" to Santa Barbara - sewage outfall continued up the ~~beach to Coal Oil Point - to Hondo on to Santa Barbara Airport for fuel - Continued down the beach to Union Oil Pipeline then to Platform Hillhouse~~

Stops:

Observations:

| Area: | Sea State | Sheen | Light | Normal | Heavy | Did Not Observe |
|---|---|---|---|---|---|---|
| Coal Oil Pt. Seeps | Calm | | X | | | |
| Gas Boil 1/2 mi. SE Holly | | | X | | | |
| Oil Seep 1 mi. NW Holly | | | X | | | |
| Oil Seep 2 1/2 mi. off Hendry's Beach | | | X | | | |
| Oil Seep 300' W of "A" | | | X | | | |
| Oil Seep 500' E of "A" | | | X | | | |
| Gas Seeps between Houchin & Rincon Is. | | | X | | | |
| Gas Seeps 50' E of Heidi | | | X | | | |
| Oil Seeps off Summerland Beach | | | X | | | |
| Santa Barbara Sewage Outfall | | | | | | X |

OGICAL SURVEY
RECEIVED
AUG 17 1978
LOS ANGELES

Phillips - La Conchita Pipelines Normal

Union - Mobil Plant Pipelines Normal

Beach Condition: clean

Remarks: Oil seeps around Holly & Coal Oil Point were large possibly due to the flat sea state and zero wind.

Around noon west of Platform "A" gas bubbles and oil appeared and continued for approximately 1 hour

Orig: Flight Book
cc: L. A. Area ← THIS COPY FOR

The Earthquake which occured 8-13-78 @ 4:00P.M. didn't create any visible damage in the area

Enclosure 5

RAU

R. Dee Adams

## Glossary of Abbreviated Terms

| | |
|---|---|
| psi | - pounds per square inch |
| pcf | - pounds per cubic foot |
| KB | - kelly bushing |
| VD | - vertical depth |
| SX | - sacks |
| $\pm$ | - plus or minus |
| MD | - measured depth |
| CF or cf | - cubic feet |
| TVD | - true vertical depth |
| NW | - northwest |
| SSW | - south-southwest |
| APD | - application for permit to drill |
| BOP | - blowout preventer |
| WP | - working pressure |
| BOF | - below ocean floor |
| km | - kilometer |
| PDT | - Pacific daylight time |
| GMT | - Greenwich mean time |