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REPORT C

GENERAL DATA ON BOTTOM SEDIMENTS
INCLUDING CONCENTRATION OF VARIOUS ELEMENTS
AND HYDROCARBONS IN THE PERSIAN GULF AND GULF OF OMAN

by

David A. Ross and Peter Stoffers

REPORT D

GENERAL DATA ON THE GEOPHYSICAL
NATURE OF THE PERSIAN GULF AND GULF OF OMAN

by

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TECHNICAL REPORT

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Report C

General Data on Bottom Sediments Including
Concentration of Various Elements and Hydrocarbons
in the Persian Gulf and Gulf of Oman

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ABSTRACT

This report is divided into two parts; the first concerns the sediments of the Persian Gulf/Gulf of Oman, the second the geophysics of the same area. Data are presented in the first part on sediment texture, mineral composition, pore-water chemistry and hydrocarbon content. In the second part data are given concerning the bathymetry, magnetic gravity and multi-channel seismics. Interpretation and significance of much of the data is discussed.

ATLANTIS II CRUISE 93

LEG 18

Introduction

This portion of the Persian Gulf and Gulf of Oman cruise had three principal objectives:

- 1) to study the general geology and geophysics of the area;
- 2) to collect and study some of the fauna and flora of the area; and
- 3) to make some general chemical oceanography and physical oceanography measurements.

The biological study (objective number 2) is presented as a separate report. The chemical and physical oceanography measurements (objective 3) were principally done under the direction of Drs. Harger and Tabatabaie who were employees of the Iranian Department of the Environment (DOE). Their data has not been received by us and therefore we cannot comment on it at this time. Some general salinity and temperature measurements, however, were made during this leg of the cruise and are included with the biological results. The geological and geophysical results are the subject of this report, which is divided into three sections. The first presents results on sediment studies, including texture, carbonate content, mineralogy, and stratigraphy. The second section concerns geochemistry results including measurements of hydrocarbons made by Drs. John Hunt and Jean Whelan of the Chemistry Department of the Woods Hole Oceanographic Institution. The third section of this report

will concern itself with the results of the geophysical investigation. It should be noted that our studies have been in progress for less than a year and that further results will be made available to the Department of the Environment as they are completed. This report is in fulfillment of our contractual agreement with the Department of the Environment.

The Persian Gulf, Strait of Hormuz and Gulf of Oman - A General Description

The Persian Gulf is the drainage basin for most of Arabia, all of Iraq and parts of Syria, Turkey and Iran. It is a long shallow sea trending northwest to southeast and separated from the Indian Ocean by the Strait of Hormuz (Figure 1). The area of the Gulf is $226,000 \text{ km}^2$ (slightly less than that of the Great Lakes) and its volume is about $7,800 \text{ km}^3$.

On the northeast, the Persian Gulf is bordered by the Zagros Mountains of Iran, on the southwest by the Arabian Shield. The Persian Gulf is asymmetrical in cross section with the deepest water (about 100 meters) being near the Iranian coast in contrast with water depths of less than 40 meters along the Arabian coast. A sill is not present at the Strait of Hormuz, where the water is as deep as 100 meters. Depths increase to 3,000 meters or more in the Gulf of Oman.

The Strait of Hormuz represents a major change in the direction of the structural fabric between the Persian Gulf and the Gulf of Oman (see Part III), a point that is substantiated by the change in the earthquake pattern in this area. The Straits, formed by the Oman Mountains, apparently results from the subduction of the Arabian plate along the Persian coast.

Figure 1 General bathymetry and other features of the Persian Gulf - Gulf of Oman area.

The Gulf of Oman is a broad basin separated by the narrow Murray Ridge from the Arabian Sea. It is bounded on the north by the Makran Mountains of Iran and western Pakistan and the Oman Mountains to the south and west.

The entire area bordering the Persian Gulf is extremely arid, and the only river discharge of any importance comes from the north, where the Shatt-al-Arab brings the discharge of the Tigris, Euphrates, and Karun rivers into the Gulf. These discharges do not compensate for the loss of water by evaporation in the Gulf, the balance being made up by a large net intake of water from the Indian Ocean via the Gulf of Oman at the Strait of Hormuz. The average rainfall into the Gulf is generally less than 7 cm/year, whereas the average evaporation rate is of the order of several (up to 5 or more) meters per year. The main river near the Gulf of Oman is the Indus Triver system over 250 miles to the east, but the sediments from this river are presently prevented from entering the Gulf by the Murray Ridge.

The structure of the Persian Gulf, Strait of Hormuz and Gulf of Oman area is intimately controlled by the present and past collision of the Arabian Plate with the Eurasian Plate and subsequent subduction along the Zagros thrust zone (see discussion in Part III).

The temperature-salinity characteristics of the area up to 1960 have been published in a National Oceanographic Data Center Report (Dubach, 1964). The report included the early data of

Schott (1908 and 1918); Shultz (1914); Blegvrad (1944); Emery (1956) and Dubach and Wehe (1959). These studies were followed by general hydrographic observations made from ships of opportunity or in passage by the French in 1961, the Germans in 1965, Russians in 1968, United Kingdom in 1958, 1962, 1963, 1967, 1968, United States in 1960, 1961, 1963 and 1965 (last two were Woods Hole cruises). Most of these observations were general in nature and the later ones were mainly in the Gulf of Oman and Arabian Sea area.

Surface salinities in the Persian Gulf average between 37-40‰ in the central portions and may reach as high as 70‰ in shallow embayments along the Trucial and Arabian coasts. Salinities can be as low as 30‰ depending on the season off the Shatt-al-Arab. Temperatures tend to be higher near the mouth of the Persian Gulf and decrease inward. Like salinity, extreme temperatures (up to 40°C) can occur in coastal areas. The thermocline is best developed in summer, with more vertical mixing due to surface cooling occurring in winter and autumn. The thermocline tends to rise from about 40 m near the Strait of Hormuz to near 20 m at the northwest end of the Persian Gulf (Seibold, 1970). The general hydrological regime of the Persian Gulf is that of surface waters moving in from the Gulf of Oman via the Indian Ocean towards the coasts, evaporating and sinking at the margins and leaving the Persian Gulf at depth (Sugden, 1963). Tides can be over 4 m which should have a distinct effect on mixing of the water in the relatively shallow Persian Gulf.

The Gulf of Oman is in open contact with the northern Indian Ocean (Arabian Sea) and thus is hydrographically similar. According to Schott (1935) some Persian Gulf water is present between 200 and 400 m in the Gulf of Oman and probably extends into the Indian Ocean. There have been reports of a zone of hydrogen sulfide accumulation in the oxygen minimum waters at about 500 to 1200 meters depth in the Gulf of Oman (Sewell, 1935; Bezrukov, 1961). This possibility does not appear to have been checked by detailed study nor by collection of sediments from where this layer intercepts the bottom. Organic carbon content of the bottom sediments range from less than 1% to 6% (Stewart et al., 1965) and appear to be higher where the hydrogen sulfide zone might intersect the bottom.

Sediments

The sediments of the coastal areas of the Persian Gulf have been the subject of numerous studies. These have emphasized the sabkha areas around the Trucial States and Saudi Arabia (Evans, Kendall and Skipwith, 1964; Evans, Kinsman and Shearman, 1964; Kinsman, 1964; Sugden, 1963a and b; Shinn, 1969; Evans et al., 1969) and other areas such as Kuwait Harbor (Dubach and Wehe, 1959) and Abu Dhabi (Kendall and Skipwith, 1969). The sabkhas are low coastal areas composed of unconsolidated carbonate and evaporitic minerals such as aragonite, dolomite, halite, gypsum and anhydrite. Actually, carbonates and evaporite minerals are the typical sediment type throughout the Persian Gulf area. Terrigenous

sedimentation from rivers is minor, however, about 1/3 of the Gulf sediments are wind-transported sand and dust mainly carried by the prevailing NW winds which cross up to 800 miles of desert before reaching the Gulf (Pilkey and Noble, 1966).

Sediment studies of the Persian Gulf generally have considered only the surface sediments. In 1964-1965, a German expedition aboard METEOR obtained numerous surface or near surface sediment samples and echo-sounding profiles mainly from the Iranian side of the Gulf (Seibold and Vollbrecht, 1969; Sarnthein, 1971). These studies (and the previously mentioned ones) and a latter volume edited by B.H. Purser (The Persian Gulf: Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea, Springer-Verlag, 1973) have adequately described the Persian Gulf surface sediments and bathymetry.

The sediments of the Gulf of Oman have been studied by Stewart et al. (1965), who examined 52 short gravity cores and Konta (1968) and Degens and Hunt (1968) who examined one piston core from the area. The first study showed that terrigenous sediments are dominant, the latter two showed occasional layers of carbonate at depth. A considerable sediment thickness of several kilometers exists in the eastern portion of the Gulf..

The Gulf of Oman is an area of high biological productivity; the assimilation rate of carbon is higher than 1 gram of carbon/m²/day (Ryther et al., 1966). This high productivity is generally not expressed in the bottom sediments perhaps because it has been recycled within the water column or consumed at the sediment surface by bottom living organisms.

Methods of Study

During Leg 18 we continuously collected bathymetric and gravity data while operating in the Persian Gulf and Gulf of Oman. Our cruise track is shown in Figures 2 and 3. When the seismic profiling operation was in progress we also collected magnetic data. During portions of the geophysical operation we were also able to make biological observations such as net and neuston tows. About 50 percent of our time was spent doing the geophysical work; the remainder of the expedition was spent sampling the sediment on the bottom and the water column. Numerous sediment cores were obtained (Table 1 and Figure 4). The coring stations yielded a good general coverage of this essentially previously uncored area. Suspended matter, Martek observations (made by scientists of the Department of the Environment) and occasional hydrographic measurements were also made at the various stations (Figure 5). Once the ATLANTIS II returned to Woods Hole (mid-1977) the study of the cores and the other data could begin. The cores were processed in our core locker where they were split, described and sampled. Most of the sediment analysis has been done in cooperation with Dr. Peter Stoffers.

Figure 2 ATLANTIS II Cruise 93 Leg 18 - Cruise track
in the Persian Gulf

Figure 3 ATLANTIS II Cruise 93 Leg 18, cruise track
in the Gulf of Oman

Table 1
Persian Gulf & Gulf of Oman Sediment Sample Locations
R/V ATLANTIS II
Cruise 93 Leg 18

Sta. #	Core #	Depth	Latitude (N°)	Longitude (E°)	General Location	Piston Core Length cm	Pilot Core Length cm
64	40GC	80	26° 06.44'	55° 43.17'	Straits of Hormuz/Persian Gulf		1
65	41GC	74	25° 58.18'	55° 12.99'	Straits of Hormuz/Persian Gulf		9
66	42GC	44.	25° 38.91'	54° 46.29'	Eastern Persian Gulf		81
67	43PC	46	25° 38.78'	54° 45.60'	Eastern Persian Gulf	-0-	-0-
68	44GC	43	28° 49.29'	49° 35.68'	Northwestern Persian Gulf		38
68		44	28° 49.29'	49° 35.68'	Northwestern Persian Gulf		
69	45PC	30	29° 20.22'	49° 45.32'	Northern Persian Gulf	531	105
70	46PC	46	29° 03.65'	50° 15.50'	Central Western Persian Gulf	396	86
71	47PC	53	28° 21.35'	50° 36.59'	Central Western Persian Gulf	448	28
72	48PC	61	27° 26.57'	50° 28.09'	South Western Persian Gulf	10	
72	48GC	61	27° 27.27'	50° 27.84'	South Western Persian Gulf		76
73	49GC	63	27° 04.65'	50° 56.35'	South Western Persian Gulf		71
74	50PC	51	26° 57.61'	52° 05.1'	Central Persian Gulf	510	-0-
74	51GC	51	26° 57.61'	52° 05.1'	Central Persian Gulf		107
75	52PC	78	26° 56.81'	52° 42.99'	Central Persian Gulf	306	67
76	53GC	48	25° 39.65'	53° 08.96'	Central Persian Gulf		90
76	54PC	48	25° 39.48'	53° 08.81'	Central Persian Gulf	30	8
77	55PC	29	25° 20.53'	54° 11.53'	Eastern Persian Gulf	217	-0-
78	56PC	84	26° 02.39'	54° 55.41'	Eastern Persian Gulf	403	36
79	57PC	72	26° 26.64'	56° 01.70'	Eastern Persian Gulf	363	52
80	58PC	103	25° 58.72'	56° 46.34'	Gulf of Oman Near Straits of Hormuz	260	89
81	59PC	311	25° 18.20'	57° 00.71'	Gulf of Oman	684	73
82	60PC	1590	24° 33.23'	57° 33.20	Gulf of Oman	661	65
83	61PC	2658	24° 24.59'N	57° 59.15'	Gulf of Oman	651	70
84	62PC	3314	23° 55.39'	59° 13.979'	Gulf of Oman, Abyssal Plain	926	127

Figure 4 Location of sample numbers in the Persian Gulf and Gulf of Oman (see Table 1 for more details).

Figure 5 Location of stations in the Persian Gulf and Gulf of Oman area (see Table 1 for more details).

PART I - Sediment Studies

Stratigraphy

The Persian Gulf and Gulf of Oman sediments can be divided into three general stratigraphic units (Figure 6). The uppermost unit is an olive gray color (7.5y 5/2) silty sediment with abundant shell fragments. Organic carbon content is generally $>0.3\%$. The second unit is light greenish gray (5GY 2/1) with organic carbon contents $<0.2\%$. Aragonite is the dominant constituent (Figure 7a). A lithified interval is found at the top of unit 2 at Station 79 as well as at Station 80 located in the Strait of Hormuz. These lithified intervals are probably related to periods of lower sea level. The third unit, which is the most prominent, is composed of grayish brown (2.5y 5/2) sediment with abundant sand intercalations. The most characteristic minerals are abundant calcite, dolomite, protodolomite and quartz clearly demonstrating the detrital source of the sediments (Figures 7b and 8). Organic carbon content is generally low, $<0.3\%$. These sediments were probably deposited under freshwater conditions during a period of lowered sea level when the mouth of the Shatt-al-Arab was east of the Strait of Hormuz.

Figure 6 The three general stratigraphic units from the Persian Gulf and Gulf of Oman.

Figure 7a UNIT 2 - light greenish gray - Aragonite mud
PG 45 ~ 60 cm

Figure 7b UNIT 3 - grayish brown detrital - some aragonite
needles are still present. Typical for this unit
are the abundant dolomite rhombs.
PG 45 ~ 500 cm

Figure 8a UNIT 3 - grayish brown (2.5y 5/2) detrital
material abundant dolomite rhombs

PC 46 107-111

Figure 8b UNIT 3 - as above

Sediment Texture - Persian Gulf

These sediments have a relatively high silt content generally being more than 50 percent, and exceeding 80% silt at Station 66 (core 52 GC) and Station 79 (core 57 PC) - see Figure 9. Percentage of sand-silt-clay values are shown in Table 2 with bulk mineralogy. Sand was relatively abundant at Stations 68 and 70 (Grab #44 and core 46). In the upper parts of the core sections the sand is mainly of biogenic origin whereas it is of terrigenous origin in the lower parts of the cores. The clay content ($< 2\mu$) varies between 7 and 59% with values $> 30\%$ present at Stations 69, 74 and 75. At Station 69 an increase in the clay fraction and a corresponding decrease in the sand portion with increasing core depth can be observed, otherwise the grain size remains rather uniform with core depth. The areal distribution of grain size shows generally higher contents of sand-sized material along the southern and central portions of the Persian Gulf as compared to the Iranian side (see also Hartmann et al., 1971; Peery 1965; and Houbolt, 1957). The grain-size increase in large part follows water depth with an increase in grain size with depth.

Sediment Texture - Gulf of Oman

The sediments studied from the Gulf of Oman cores are predominantly clayey silts (Figures 10a, b, c, d,). Silt content varies between 44 and 91% whereas the amount of clay

Figure 9 Sand-silt-clay content for some Persian Gulf cores.

TABLE 2
BULK MINERALOGY AND GRAIN SIZE DISTRIBUTION
PERSIAN GULF

	CARBON- ATE CONTENT%	CC %	MgC %	d %	ar %	qu %	feldsp%	layer silicat- es %	SAND %	SILT %	CLAY %
ST66 42GC											
0 - 5 cm	85	12	21	3	49	2	tr	13	10	82	8
5 - 10 cm	85	14	20	3	48	2	tr	13	13	79	8
14 - 16 cm	85	13	21	2	49	2	tr	13	6	85	9
25 - 30 cm	86	13	18	6	49	2	tr	12	11	83	6
45 - 50 cm	85	13	18	3	51	2	-	13	6	87	7
67 - 71 cm	86	12	19	4	51	2	tr	12	6	87	7
75 - 80 cm	86	11	22	2	51	2	tr	12	7	82	11
ST67 GRAB											
0 - 1 cm	72	12	11	10	39	5	2	21	65	22	13
1 - 2 cm	71	21	9	2	40	5	2	22	64	23	13
2 - 3 cm	72	12	9	2	49	5	2	21	66	20	14
4 - 5 cm	72	14	8	5	45	5	3	20	61	28	11
8 - 9 cm	69	16	11	4	38	5	3	22	63	23	14
ST69 45GC											
0 - 1 cm	52	26	8	5	13	8	3	36	14	54	32
1 - 3 cm	66	26	6	18	16	10	2	22	12	56	32
3 - 5 cm	52	24	6	7	15	8	1	38	12	56	32
8 - 10 cm	54	26	7	4	17	11	2	33	17	53	30
18 - 20 cm	57	25	8	6	18	7	2	34	18	50	32
38 - 40 cm	57	25	7	5	19	7	3	33	14	54	32
64 - 66 cm	58	25	7	6	20	9	2	31	17	52	31
84 - 86 cm	53	24	5	7	17	8	2	37	6	57	37
108 - 111 cm	53	20	7	5	21	8	2	37	15	53	32
PC45											
67 - 72 cm	57	32	-	6	19	6	2	35	7	45	48
218 - 221 cm	52	33	-	9	10	8	1	39	-	58	42
370 - 374 cm	53	32	-	6	15	8	2	37	8	57	35
510 - 515 cm	55	30	-	5	20	7	2	36	3	54	43
core catcher	54	28	-	14	12	8	2	36			
ST70 PC46											
107 - 111 cm	52	38	-	14	-	11	5	32	51	33	16
236 - 241 cm	67	27	-	8	32	6	tr	26	38	32	30
241 - 245 cm	67	-	-	-	-	7	1	25	41	32	26
371 - 376 cm	67	29	-	13	25	7	1	25	34	36	30
ST74 PC50											
41 - 45 cm	61	14	-	4	43	3	1	35	-	41	59
195 - 198 cm	54	23	-	11	20	7	1	38	1	59	40
345 - 348 cm	49	22	-	10	17	7	1	43	1	61	38
490 - 493 cm	51	21	-	12	18	7	1	41	12	55	33
ST75											
0 - 3 cm	43	25	-	5	13	6	tr	51	6	51	43
10 - 12 cm	44	24	6	4	10	6	tr	50	13	50	37
35 - 37 cm	47	24	6	5	12	5	tr	48	4	47	49
65 - 67 cm	47	22	7	5	13	6	tr	47	4	48	48
95 - 97 cm	44	21	-	11	12	6	1	49	9	46	45
PC 3 - 6 cm	43	22	6	4	11	6	tr	50	1	55	44
140 - 146 cm	55	45	-	10	-	9	1	35	1	61	38
146 - 150 cm	36	27	-	8	-	16	3	55	2	58	40
* 292 - 295 cm	52	19	-	8	25	7	1	50	9	43	48
ST79 PC57											
35 - 37 Pilot	54	17	9	5	23	4	tr	42	1	75	24
105 - 111 cm	67	14	-	5	48	3	1	29	1	89	10
358 - 363 cm	58	26	6	8	18	11	2	29	26	58	16
ST80 PC58											
0 - 5 Pilot TOP	58	16	12	5	25	4	2	46	7	71	22
80 - 84 cm Pilot co	69	16	11	2	40	2	2	27	40	41	19
105 - 111	39	30	-	-	9	9	4	48	3	76	21
245 - 250 oo	41	25	-	8	8	11	3	45	2	62	37

* flown in

cc = calcium carbonate; MgC = magnesium carbonate; d = dolomite; ar = aragonite;
qu = quartz; feldsp = feldspar

Figure 10a Sand-silt-clay diagram for cores from the Gulf of Oman.

Figure 10b

Figure 10d

ranges from 8 to 54%. Sand content is generally low (<5%) and decreases with increasing water depth. The highest silt content is found at Station 84 (core 62) located in the deepest part of the Gulf which reflects the abundant turbidities present in this core. Percentage sand-silt-clay values are shown in Table 6 with the bulk mineralogy. Sediments in the Gulf of Oman are considerably finer-grained than those of the Persian Gulf.

The water content and sediment texture of piston core and trip gravity core no. 62 were studied in detail (Figure 11). Sand is generally rare throughout the core except for some near 250 cm depth. There is a general increase in clay content with depth down the core. Water content shows a slow decrease with depth.

Bulk Mineralogy - Persian Gulf

Bulk samples of the silt and clay fraction were studied by x-ray diffraction. Calcite, dolomite, quartz, feldspar and clay minerals were detected in all samples (see Table 2). The amount of quartz (2-16%) and feldspar (trace-5%) is generally small. Only a few samples contain more than 10% quartz. Aragonite is present in nearly every sample with the exception of the lower portion of cores 46 and 52 PC, and is the dominant carbonate mineral at Stations 66, 68 and in the upper sediment sequence of Stations 74 and 79. The highest amount of aragonite (~50%) was found at Station 66 which also contains the highest percentage of high magnesium calcite (~20%). High magnesium

Figure 11 Water content and grain size distribution of PG and PC 62 taken in the Gulf of Oman.

calcite generally occurs only in the upper meter or so of the sediments and no high magnesium calcite was found in the deeper parts of the cores. Calcite is present in quantities varying between 11 and 45% with higher amounts present in the lower sections of the cores. Dolomite is generally found only in small quantities ($\sim 5\%$), but some higher values ($\sim 10\%$) occur in the lower part of some cores, where sometimes, in addition to stoichiometric dolomite, protodolomite is also present.

The carbonate mineralogy of the silt and clay fractions shows some distinct differences. High magnesium calcite and calcite, as well as dolomite, are enriched in the silt fraction whereas aragonite is more common in the clay fraction. X-ray mineralogy of three dust samples collected in the northwestern, central and northeastern part show the same kind of pattern with calcite, dolomite, quartz, traces of feldspar and clay minerals (Figure 12).

The surface concentration of calcium carbonate minerals is generally always over 50 percent of the sediment with the exception of some areas along the Iranian coast. Values can be as high as 80 percent off Saudi Arabia. A comparison of carbonate content with grain size generally shows that they both increase or decrease together (see also Seibold, et al, 1973). These authors interpret this as indicating that, in addition to local terrigenous sources of carbonate, that organisms are the prime contributors to the carbonates.

Figure 12 (a) SEM Dust - Persian Gulf

(b) SEM Dust - Persian Gulf - dolomite - rhomb

In the sand fraction the principal constituents are faecal pellets, terrigenous components, relic fractions and mainly biogenetic material (detailed studies have been made by Sarnthein, 1971).

The variation in bulk mineralogy with depth for some cores are shown in Figures 13 through 15. Core 45 taken in the northwestern part of the Persian Gulf near the Shatt-al-Arab shows generally uniform amounts of carbonate with depth, values are generally higher than 50% (Figure 13). Clay content and quartz plus feldspar content likewise stays generally constant with depth. The upper part of the section studied from the trip gravity core and a nearby gravity core generally shows similar values although some smaller irregularities are evident.

PC 46 also taken in the northwestern portion of the Persian Gulf somewhat to the southeast of core 45 likewise showed a relatively uniform content of carbonates with depth although there were slightly higher values of quartz-feldspar content (Figure 14). Among the carbonates, aragonite content dropped to zero relatively quickly within the top 20 cm of the core. GC 42 taken at the southern end of the Persian Gulf showed considerably higher contents of calcium carbonate with aragonite dominating the carbonate fraction (Figure 14). A grab core taken at Station 67, which was essentially the same location as for core 42, obtained a higher amount of surface sediments and showed a similar distribution of minerals.

Figure 13

Bulk mineralogy of core 45 as determined by x-ray techniques.

Figure 14 Bulk mineralogy and carbonate mineralogy of cores GC 42, PC 46 and Grab 67.

Figure 15 Bulk mineralogy and carbonate mineralogy of core 52.

GC and PC 52 taken in the middle portion of the Persian Gulf near the Iranian coast, showed generally lesser amounts of carbonates than the previously described cores and the total carbonate content tended to be less than 50%.

Clay and quartz-feldspar content tended to be generally constant with depth. The carbonate mineralogy was dominated at this station by calcite with lesser amounts of magnesium, calcite, aragonite and dolomite. In PC 52, aragonite content disappeared by about 50 cm. It was present at deeper depths in the gravity core but this may just be an artifact of the coring procedures since it is well known that piston cores generally miss some of the upper parts of the sediment section.

A detailed analysis was made of the carbonate mineralogy of the different size fractions from PC, GC and PG 45 (Figure 16). Carbonate content for this core generally was higher in the >63 microns (μ) fraction and calcite tended to be the major constituent. In the surface and near-surface portions of these cores, aragonite was present; especially in the smaller size fractions. It was often missing from the coarser fractions with depth.

Analyses of the mineral composition of the silt fraction and clay fraction are shown in Tables 3 and 4. These confirm the previously mentioned statements that carbonate content generally tends to be less in the finer-grained portions and aragonite tends to be relatively high. Quartz content generally is higher although not significantly so in the silt fraction.

Figure 16 Carbonate mineralogy of the different size fractions of core 45 (GC, PG and PC).

TABLE 3

MINERALOGY OF THE SILT-FRACTION OF THE PERSIAN GULF SEDIMENTS

	*1 CARBONATE CONTENT%	*2 CARBONATE CONTENT%	CC %	MgC %	d %	ar %	qu %	feldsp %	layer silicates%
ST66 42GC									
0 - 5 cm	85	88	13	21	2	52	1	1	10
5 - 10 cm	85	89	12	19	2	56	2	-	9
14 - 16 cm	84	89	17	18	2	51	1	-	10
25 - 30 cm	83	86	12	20	2	52	1	tr	13
45 - 50 cm	84	89	12	20	1	55	1	-	11
67 - 71 cm	83	88	12	19	2	55	1	-	11
75 - 80 cm	84	88	11	26	3	48	2	tr	10
ST67 GRAB									
0 - 1 cm	48	56	22	12	5	16	12	2	30
1 - 2 cm	46	53	22	10	7	14	13	8	26
2 - 3 cm	47	54	22	10	6	15	14	6	33
4 - 5 cm	46	50	20	9	5	15	17	6	31
8 - 9 cm	44	51	22	10	7	11	16	4	36
ST69 45GC									
0 - 1 cm	52	60	30	6	15	9	13	6	21
1 - 3 cm	48	56	25	5	17	9	17	4	23
3 - 5 cm	49	57	33	5	11	8	11	2	30
8 - 10 cm	52	56	30	5	11	9	14	4	26
18 - 20 cm	49	57	30	6	10	11	8	2	33
38 - 40 cm	51	57	30	6	13	8	12	6	25
64 - 66 cm	49	57	26	5	18	8	13	4	26
84 - 86 cm	49	59	34	3	15	7	14	2	25
108 - 111 cm	50	57	27	5	15	10	16	2	25
PC45									
67 - 72 cm	54	65	51	-	-	14	8	1	26
218 - 221 cm	49	60	46	-	-	14	10	1	29
370 - 374 cm	51	61	48	-	-	13	7	3	29
* 510 - 515 cm	49	63	46	-	-	17	8	3	26
* core catcher	50	61	44	-	-	17	9	2	28
ST70 PC46									
107 - 111 cm	55	62	43	-	15	4	8	1	29
* 236 - 241 cm	54	65	40	-	17	8	9	1	25
* 241 - 245 cm	56	64	39	-	15	10	8	1	27
* 371 - 376 cm	55	63	41	-	14	8	13	2	22
ST74 PC50									
41 - 45 cm	55	67	37	-	10	20	14	2	17
195 - 198 cm	51	63	44	-	14	5	10	4	23
* 345 - 348 cm	51	63	48	-	15	-	11	2	24
* 490 - 493 cm	50	65	45	-	14	6	11	2	18
ST75									
0 - 3 cm	47	57	30	7	9	11	8	1	34
10 - 12 cm	47	56	34	6	6	9	7	1	36
35 - 37 cm	49	61	37	7	9	8	10	2	27
65 - 67 cm	52	60	36	5	9	10	9	1	30
95 - 97 cm	52	61	36	5	8	11	8	2	29
PC 3 - 6 cm	51	57	35	5	8	9	8	2	33
140 - 146 cm	42	52	40	-	12	-	10	2	36
146 - 150 cm	43	50	42	-	8	-	15	4	31
* 292 - 295 cm	55	65	37	4	12	12	10	2	23
ST79 PC57									
35 - 37 Pilot	59	63	17	11	4	31	5	1	31
105 - 111 cm	62	72	18	-	8	46	4	1	23
358 - 363 cm	40	57	37	-	14	5	8	2	33
ST80 PC58									
0 - 5 Pilot TOP	61	67	16	12	3	36	5	1	27
80 - 84 cm Pilot cc	63	69	19	16	2	32	4	1	26
105 - 110 cm	33	45	35	-	10	-	13	4	38
245 - 250 cm	37	50	35	-	15	-	14	3	33

*1 Prompt reading

*2 Reading after 15 minutes

*flowed in

TABLE 4

MINERALOGY OF THE CLAY-FRACTION OF THE PERSIAN GULF SEDIMENTS

				CARBONATE CONTENT %	CC %	MgC %	d %	ar %	qu %	feldsp %	layer * silicates%
ST66	42GC	0 - 5cm		50	17	-	1	32	1	-	49
		5 - 10cm		50	14	4	-	32	1	-	49
		14 - 16cm		50	18	-	-	32	1	-	49
		25 - 30cm		60	16	6	-	38	1	tr	39
		45 - 50cm		55	20	3	-	32	1	-	44
		67 - 71cm		55	18	3	-	34	1	-	44
		75 - 80cm		65	17	8	-	40	1	-	34
ST67	GRAB	0 - 1cm		23	11	-	-	12	2	tr	75
		1 - 2cm		33	11	-	-	-	2	-	65
		2 - 3cm		30	14	-	-	16	2	tr	68
		4 - 5cm		33	16	3	-	14	2	tr	65
		8 - 9cm		34	16	3	-	15	2	tr	64
ST69	45GC	0 - 1cm		24	8	1	-	15	2	tr	74
		1 - 3cm		40	16	3	-	21	2	tr	58
		3 - 5cm		36	13	1	-	22	2	tr	62
		8 - 10cm		40	13	1	-	26	2	-	58
		18 - 20cm		42	15	3	-	24	2	tr	56
		38 - 40cm		41	13	3	-	25	2	-	57
		64 - 66cm		41	12	3	-	26	2	tr	57
		84 - 86cm		42	12	2	-	26	2	tr	56
		108 - 111cm		42	14	-	-	28	2	tr	56
PC45		67 - 72cm		44	17	-	1	26	2	tr	54
		218 - 221cm		38	15	-	1	22	3	tr	59
		370 - 374cm		31					3	tr	66
		510 - 515cm		43	14	-	1	28	3	tr	56
	core catcher			41	14	-	1	26	3	tr	56
ST70	PC46	107 - 111cm		25	16	-	5	4	4	1	
		* 236 - 241cm		51	10	-	1	40	2	-	47
		* 241 - 245cm		49	9	-	2	38	2	tr	49
		* 371 - 376cm		43	10	-	1	32	2	tr	55
ST74	PC50	41 - 45cm		61	4	1	1	55	1	-	38
		195 - 198cm		40	8	-	2	30	1	tr	59
		* 345 - 348cm		36	6	-	1	29	1	tr	63
		* 490 - 493cm		40	7	-	1	32	2	tr	38
ST75		0 - 3cm		27	16	2	1	8	2	tr	71
		10 - 12cm		33	18	5	1	10	2	tr	65
		35 - 37cm		31	17	3	1	10	1	tr	68
		65 - 67cm		38	17	3	1	17	1	-	61
		95 - 97cm		31	16	2	-	13	2	tr	67
PC		3 - 6cm		29	15	4	-	10	2	tr	69
		140 - 146cm		17	16	-	1	-	3	tr	80
		146 - 150cm		19	18	-	1	-	3	tr	78
		292 - 295cm		45	11	2	-	32	1	-	54
ST79	PC57	35 - 37 Pilot		30	15	3	-	12	2	tr	68
		105 - 111cm		36	4	-	-	31	2	tr	62
		358 - 363cm		29	8	-	2	19	2	tr	69
ST80	PC58	0 - 5 Pilot		23	9	1	1	12	4	tr	73
		80 - 84cm Pilot									
		co		28	10	1	1	16	2	tr	70
		105 - 110		9	9	-	-	-	3	tr	88
		245 - 250cc		20	7	-	1	12	2	-	78

* Including Palygorskite

Feldspars and quartz content are considerably lower in the clay-size fraction.

Clay Minerals - Persian Gulf

The distribution of clay minerals is shown in Table 5. The major minerals detected were illite, chlorite, kaolinite, smectite and palygorskite. Illite generally was the most abundant clay mineral followed by chlorite and palygorskite. Palygorskite was most common at Stations 70 and 75 (cores 46 and 52); both these stations are near the Iranian coast suggesting a local detrital origin for the material. Smectite was more abundant at Stations 68 and 69 (cores 44 and 45) situated in the northern portion of the Gulf, and perhaps the smectite was derived from the Shatt-al-Arab. Kaolinite was generally common in lesser quantities with no major areal distribution. Dust samples showed illite, chlorite and palygorskite.

The illite/chlorite ratio generally was near 1 for the entire range of samples examined and the illite/palygorskite ratio averaged slightly above 1. The chlorite/palygorskite ratio likewise varied around 1 although some values as high as 2 were observed.

Bulk Mineralogy - Gulf of Oman

The bulk mineralogy and grain size distribution of the Gulf of Oman sediments are shown in Table 6. In general, the carbonate content of the Gulf of Oman sediments is lower than

TABLE 5

CLAY MINERALOGY OF PERSIAN GULF SAMPLES

Illite Chlorite Koalinite Smectite Palygorskite Illite
Chlorite Illite
Palygorskite Chlorite
Palygorskite

ST69 GRAB								
0- 1cm	xx	xxx	x	xx	xx	0.8	1.5	2.0
4- 5cm	xxx	xxx	tr	xx	xx	0.9	1.8	2.1
8- 9cm	xxx	xxx		xx	xx	0.9	1.7	1.9
ST6945GC								
0- 1cm	xxx	xxx	x	xx	xx	0.9	1.3	1.7
1- 3cm	xxx	xxx	x	xx	xx	0.8	1.8	2.2
3- 5cm	xxx	xxx	x	xx	xx	0.9	1.1	1.2
18- 20cm	xxx	xx	xx	xx	xx	1.1	1.3	1.2
38- 40cm	xxx	xx	xx	xx	xx	1.0	1.6	0.9
64- 66cm	xxx	xx	xx	x	xx	0.7	0.9	1.2
84- 86cm	xxx	xx	xx	x	xx	1.4	2.4	1.7
108-111cm	xxx	xx	xx	x	xx	0.8	1.2	1.5
67- 72 cm PC	xxx	xx	x	x	xx	1.4	1.3	0.9
218-221cm	xxx	xx	x	x	xx	1.2	1.2	1.0
370-374cm	xxx	xx	x	x	xx	1.0	0.9	0.9
510-515cm	xxx	xx	x	tr	xxx	1.1	1.1	1.0
CC	xxx	xx	x	x	xxx	1.0	1.1	1.0
ST70PC								
* 236-241cm	xxx	xx	x	tr	xxx	1.2	1.3	1.1
* 241-245cm	xxx	xx	x	x	xxx	1.1	1.2	0.7
* 371-376cm	xxx	xx	x	x	xxx	1.1	1.2	1.0
ST74								
41- 45cm	xxx	xx	x	x	xxx	1.1	1.1	1.0
195-198cm	xxx	xx	x	x	xxx	1.2	0.9	0.7
* 345-348cm	xxx	xx	x	x	xxx	1.0	0.8	0.8
* 490-493cm	xxx	xx	x	x	xxx	1.1	0.7	0.7

Illite Chlorite Koalinite Smectite Palygorskite Illite
Chlorite Illite
Palygorskite Chlorite
Palygorskite

ST75GC52								
0- 3cm	xxx	xx	tr	x	xxx	0.8	0.9	1.1
10- 12cm	xxx	xx	x	x	xxx	0.9	0.5	0.6
35- 37cm	xxx	xx	x	x	xxx	0.9	0.7	0.8
65- 67cm	xxx	xx	x	x	xxx	0.8	0.6	0.8
140-146cm PC	xxx	xx	x	xx	xx	0.8	1.3	1.6
146-150cm	xxx	xx	x	x	xx	0.7	1.1	1.6
* 292-295cm	xxx	xx	x	x	xxx	0.9	0.9	1.1
ST79PC57								
105-111cm	xxx	xx	x	x	xx	1.1	1.3	1.1
358-363cm	xxx	xx	tr	x	xx	1.6	1.4	0.8
ST80PC58								
0- 5cm Pilot	xxx	xx	tr	x	xx	0.7	1.4	1.9
80- 84cm Pilot	xxx	xx		x	xx	1.0	1.2	1.2
105-110cm	xxx	xx	tr	xx	xx	1.5	1.4	1.0
245-250cm CC	xxx	xx	x	x	xx	1.2	1.4	1.2

xxx DOMINANT
XX ABUNDANT
x RARE
tr TRACE

TABLE 6

BULK MINERALOGY AND GRAIN SIZE OF SEDIMENTS FROM GULF OF OMAN

		CARBON- ATE CONTENT%	CC %	MgC %	d %	ar %	qu %	feldsp%	layer silicat- es %	SAND	SILT	CLAY
ST81 PC59												
0 -	2 cm	47	16	6	6	19	7	2	44	3	73	24
55 -	59 cm Pilot cc	48	17	7	4	20	7	2	43	2	64	34
91 -	95 cm	46	17	6	3	19	6	1	47	4	65	31
234 -	238 cm	48	16	7	3	22	7	1	44	3	61	36
377 -	382 cm	43	15	6	4	18	6	1	50	3	66	31
527 -	531 cm	45	15	7	3	20	6	2	47	3	65	32
656 -	661 cm	46	17	6	4	19	8	1	45	3	66	31
ST82 PC60												
54 -	59 cm Pilot cc	25	23	-	2	-	11	2	62	1	51	48
42 -	47 cm	31	19	-	2	10	10	1	58	2	44	54
196 -	200 cm	41	22	-	5	14	12	2	45	5	62	33
350 -	355 cm	36	29	-	7	-	14	4	46	4	72	24
504 -	509 cm	35	20	-	15	-	15	4	46	3	67	30
648 -	653 cm cc	34	28	-	6	-	12	4	50	4	73	23
ST83 PC61												
0 -	1 cm Pilot	14	14	-	-	-	11	3	72	2	59	39
1 -	3 cm "	16	16	-	tr	-	12	3	69	tr	57	43
3 -	5 cm "	15	9	-	6	-	14	3	68	-	57	43
5 -	7 cm "	19	19	-	tr	-	11	3	67	-	53	47
7 -	9 cm "	17	16	-	1	-	12	3	68	-	55	45
9 -	11 cm "	17	16	-	1	-	12	2	69	1	51	48
11 -	13 cm "	15	13	-	2	-	12	3	70	-	54	46
65 -	67 cm PC	22	20	-	2	-	12	3	63	1	54	45
115 -	120 cm "	29	24	-	5	-	18	4	49	tr	65	35
191 -	195 cm "	30	26	-	4	-	15	5	50	2	66	33
340 -	345 cm "	26	23	-	3	-	12	3	59	-	70	30
493 -	496 cm "	38	20	-	3	15	12	2	48	-	56	44
636 -	640 cm co	39	17	-	3	19	10	2	49	-	54	46
ST84 PC62												
112 -	117 Pilot	14	12	-	2	-	17	5	64	tr	62	38
PC 17 -	22 cm	15	12	-	3	-	32	8	45	1	91	8
160 -	164 cm	14	12	-	2	-	19	3	64	tr	68	32
305 -	309 cm	24	18	-	6	-	32	7	37	tr	85	15
450 -	454 cm	17	14	-	3	-	29	6	48	tr	87	13
595 -	600 cm	19	18	-	1	-	16	4	61	tr	70	30
761 -	766 cm	18	17	-	1	-	14	3	65	tr	51	49
905 -	908 cm	14	13	-	1	-	16	3	67	tr	59	41

those from the Persian Gulf. Carbonate contents never exceed 50% and decrease rather dramatically with water depth. Highest values are about 50% near the Strait of Hormuz (core PG 58) and decrease to 10-20% by PC 62 (Figures 17 and 18). Carbonate content generally stays fairly constant within individual cores although a decrease is observed in PC 58, where the decreasing carbonate content is replaced by increasing amounts of clay minerals (Figure 17). In deeper water, in particular PC 62, considerable variations exist in the relative amounts of clay content and quartz + feldspar content (Figure 18). This may be due to some terrigenous input perhaps via turbidity currents. The carbonate mineralogy of PC 58 and 60 are shown in Figure 19. In general, aragonite content decreases and eventually disappears with depth. In the upper parts of PG 60 the carbonate fraction is dominated by calcite with only small amounts of dolomite being present. This situation also exists at depth with PC 60 below 300 cm.

A comparison of carbonate contents of the silt and clay fraction (Tables 7 and 8) shows higher values of carbonate in the silt fraction than in the clay fraction. Likewise, quartz and feldspar is also higher in the silt fraction than in the clay fraction. The clay fraction, as expected, is dominated by layered silicates which are described and discussed in the next section. In some cores the clay fraction is devoid of carbonates. In general, calcite, dolomite, quartz, feldspar and layered silicates were found in most samples. Aragonite and high magnesium calcite were only found in the shallow water core from Station 81.

Figure 17 Bulk mineralogy of cores 58 and 60 from the Strait of Hormuz and Gulf of Oman area.

Figure 18 Bulk mineralogy of cores 61 and 62 from the Gulf of Oman area.

Figure 19 Carbonate mineralogy of cores 58 and 60.

TABLE 7
MINERALOGY OF THE SILT FRACTION
OF THE SEDIMENTS FROM THE GULF OF OMAN

	*1 CARBONATE CONTENT%	*2 CARBONATE CONTENT%	CC %	MgC %	d %	ar %	qu %	feldsp %	layer silicates
ST81 PC59									
0 - 2 Pilot	42	51	17	7	6	21	10	2	37
55 - 59 cm Pilot cc.	46	55	20	13	4	18	9	2	34
91 - 95 cm	46	53	19	6	7	21	10	2	35
234 - 238 cm	50	56	20	12	4	20	10	2	32
377 - 382 cm	51	56	20	8	4	23	9	2	33
527 - 531 cm	51	57	20	10	4	22	9	2	32
656 - 661 cm	52	55	22	8	4	20	10	2	33
ST82 PC60									
54 - 59 cm Pilot cc	26	28	24	-	4	-	15	3	54
42 - 47 cm	30	32	29	-	3	-	15	3	50
196 - 200 cm	39	44	32	-	6	6	13	4	39
350 - 355 cm	38	45	36	-	9	-	16	4	35
504 - 509 cm	39	44	35	-	9	-	17	6	33
648 - 653 cm cc	32	39	33	-	6	-	14	6	31
ST83 PC61									
0 - 1 cm Pilot	8	13	11	-	2	-	14	3	70
1 - 3 cm "	10	13	11	-	2	-	22	5	60
3 - 5 cm "		13	11	-	2	-	23	4	60
5 - 7 cm "		15	13	-	2	-	22	3	60
7 - 9 cm "		15	13	-	2	-	23	3	59
9 - 11 cm "		16	14	-	2	-	24	4	56
11 - 13 cm "		15	13	-	2	-	22	4	59
65 - 67 cm PC	20	25	20	-	5	-	25	4	46
115 - 120 cm "	34	38	33	-	5	-	19	5	38
191 - 195 cm "	28	30	26	-	4	-	22	5	43
340 - 345 cm "	25	29	24	-	5	-			
493 - 496 cm "	36	40	34	-	6	-	16	3	41
636 - 640 cm "	37	43	38	-	5	-	17	3	37
ST84 PC62									
112 - 117 Pilot	12	15	14	-	1	-	25	3	57
PC 17 - 22 cm	15	16	15	-	1	-	35	8	41
160 - 164 cm	14	16	15	-	1	-	37	4	43
305 - 309 cm	13	16	14	-	2	-	32	7	45
450 - 454 cm	18	21	16	-	5	-	31	6	42
595 - 600 cm	18	24	20	-	4	-	26	2	48
761 - 766 cm	21	25	22	-	3	-	20	2	53
905 - 908 cm	11	16	14	-	2	-	24	2	58

TABLE 8

MINERALOGY OF THE CLAY FRACTION
OF THE SEDIMENTS FROM THE GULF OF OMAN

	CARBONATE CONTENT %	CC %	MgC %	d %	ar %	qu %	feldsp %	layer * silicates%
ST81 PC59								
0 - 2 cm	23	9	-	-	14	3	1	73
55 - 59 cm Pilot co	24	8	2	-	14	2	tr	74
91 - 95 cm	24	9	-	-	15	3	tr	73
234 - 238 cm	23	9	-	-	14	2	tr	75
377 - 382 cm	23	10	-	-	13	3	tr	74
527 - 531 cm	22	9	-	-	13	3	tr	75
656 - 661 cm	23	11	-	-	12	2	tr	75
ST82 PC60								
54 - 59 Pilot	17	13	-	-	4	4	1	78
42 - 47 cm	24	13	-	-	11	4	tr	76
196 - 200 cm	34	13	-	-	21	3	tr	63
350 - 355 cm	17	11	-	1	5	3	tr	80
504 - 509 cm	23	17	-	-	-	3	tr	74
648 - 653 cm	17	16	-	1	-	4	1	78
ST83 PC61								
0 - 1 cm Pilot	8	8	-	-	-	6	1	85
1 - 3 cm "	11	11	-	-	-	6	1	82
3 - 5 cm "	12	-	-	-	-	5	1	82
5 - 7 cm "	9	-	-	-	-	5	1	85
7 - 9 cm "	5	3	-	1	-	6	1	88
9 - 11 cm "	11	-	-	-	-	6	1	82
11 - 13 cm "	< 2	-	-	-	-	5	1	93
65 - 67 cm PC	< 2	-	-	-	-	4	1	94
115 - 120 cm "	15	-	-	-	-	3	tr	82
191 - 195 cm "	14	-	-	-	-	5	1	80
340 - 345 cm "	13	-	-	-	-	3	tr	84
493 - 496 cm "	28	7	-	-	21	2	tr	70
636 - 640 cm cc	30	6	-	-	24	2	tr	68
ST84 PC62								
112 - 117 Pilot	-	-	-	-	-	7	1	92
PC 17 - 22 cm	-	-	-	-	-	6	1	93
160 - 164 cm	4	4	-	-	-	5	tr	91
305 - 309 cm	-	-	-	-	-	7	1	92
450 - 454 cm	4	4	-	-	-	8	1	87
595 - 600 cm	12	12	-	-	-	5	1	82
761 - 766 cm	11	11	-	-	-	5	tr	84
905 - 908 cm	6	6	-	-	-	7	1	86

*Including Palygorskite

At Stations 82 and 83 aragonite is present at distinct intervals within the clay fraction. Calcite is, in general, the most abundant carbonate mineral. Dolomite occurs only in smaller amounts, and averages $\leq 5\%$.

X-ray mineralogy of the clay and silt fraction generally shows enrichment of aragonite in the clay fraction whereas all other carbonate minerals are more concentrated in the silt fraction.

Quartz content is of the order of 10 to 15% reaching higher levels in the possible turbidite sediments of Station 84. In these intervals feldspars get up to 8%, elsewhere they are normally in the range of 2-4%. A dust sample collected from the Gulf of Oman shows calcite, quartz, traces of dolomite and clay minerals.

Clay Minerals - Gulf of Oman

Illite, chlorite, palygorskite, small amounts of smectite and traces of kaolinite were detected in the clay fraction of the sediments from the Gulf of Oman (Table 9). The amount of kaolinite, smectite and palygorskite generally decreases with increasing water depth. By Station 84 only illite and chlorite with small amounts of palygorskite are present. Illite, chlorite and palygorskite were detected in the dust sample thus clearly indicating their terrigenous origin.

TABLE 9

CLAY MINERALOGY - GULF OF OMAN SEDIMENTS

	ILLITE	CHLORITE	KAOLINITE	SMECTITE	PALYGORS- KITE	ILLITE/ CHLORITE	ILLITE/ PALYGORS- KITE	CHLORITE/ PALYGORS- KITE
ST81 PC59								
0 - 2 cm Pilot	xxx	xxx	tr	x	xx	0.9	1.4	1.4
55 - 59 cm Pilot cc	xxx	xxx	tr	tr	xx	0.9	1.6	1.8
91 - 95 cm	xxx	xxx	-	x	xx	0.9	2.0	2.3
231 - 238 cm	xxx	xxx	tr	tr	x	0.8	1.8	2.2
377 - 382 cm	xxx	xxx	tr	tr	xx	0.9	1.6	1.7
527 - 531 cm	xxx	xxx	tr	tr	xx	0.9	1.7	1.8
656 - 661 cm	xxx	xxx	tr	x	xx	1.2	1.3	1.1
ST82 PC60								
54 - 59 cm Pilot	xxx	xxx	-	x	tr	1.2	-	-
42 - 47 cm	xxx	xxx	-	tr	tr	1.0	-	-
196 - 200 cm	xxx	xxx	tr	x	xx	1.2	1.9	1.7
350 - 355 cm	xxx	xxx	-	tr	xx	1.1	1.4	1.3
504 - 509 cm	xxx	xxx	-	x	xx	1.5	1.6	1.1
648 - 653 cm	xxx	xxx	-	tr	xx	1.3	2.0	1.5
ST83 PC61								
0 - 1 cm Pilot	xxx	xxx	-	tr	x	1.1	2.8	2.5
1 - 3 cm "	xxx	xxx	-	tr	x	1.2	2.3	1.9
3 - 5 cm "	xxx	xxx	-	tr	tr	1.2	-	-
5 - 7 cm "	xxx	xxx	-	tr	x	1.2	2.3	1.9
7 - 9 cm "	xxx	xxx	-	tr	x	1.3	2.1	1.6
9 - 11 cm "	xxx	xxx	-	tr	tr	1.0	-	-
11 - 13 cm "	xxx	xxx	-	tr	tr	1.4	-	-
65 - 67 cm Pilot cc	xxx	xxx	-	-	tr	1.1	-	-
65 - 67	xxx	xxx	-	x	xx	1.0	1.7	1.7
115 - 120 cm	xxx	xxx	-	x	xx	1.4	1.5	1.1
191 - 195 cm	xxx	xxx	-	xx	xx	1.5	1.7	1.1
340 - 345 cm	xxx	xxx	-	x	xx	0.9	1.7	1.8
493 - 496 cm	xxx	xxx	-	x	xx	1.0	1.7	1.7
636 - 640 cm	xxx	xxx	-	x	x	1.0	1.9	1.9
ST84 PC62								
112 - 117 cm Pilot	xxx	xxx	-	-	x	-	-	-
17 - 22 cm	xxx	xxx	-	-	x	1.5	2.5	1.7
160 - 164 cm	xxx	xxx	-	-	-	1.4	-	-
305 - 309 cm	xxx	xxx	-	-	-	1.8	-	-
450 - 454 cm	xxx	xxx	-	-	-	1.6	-	-
595 - 600 cm	xxx	xxx	-	-	-	1.2	-	-
761 - 766 cm	xxx	xxx	-	-	-	1.4	-	-
905 - 908 cm	xxx	xxx	-	-	-	1.3	-	-

Part II - Geochemistry Studies

Geochemistry of Persian Gulf Sediments

Persian Gulf sediments were analyzed for iron, manganese, zinc, copper, chromium, nickel, titanium oxide, aluminum, vanadium, calcium, magnesium, potassium, strontium, lithium and percent organic matter. The results of these analyses are reported in Table 10. In general, the geochemistry of the sediments is strongly related to the amounts of biogenous and detrital constituents. This is shown by the higher quantities of iron, nickel, titanium oxide, aluminum, and vanadium in the more terrigenous sediments found in the lower sections of many of the cores. The influence of the different carbonate materials is seen in their higher strontium, calcium and magnesium content. In general, organic carbon content is low ranging from 0.12 to 1.76% with an average value of about 0.3%. Nitrogen was only measured in the samples of Station 69 and the values were all below 0.2%. In general, iron ranges from between 1% to 3% and with the higher values found at Stations 80 and 75. Manganese ranges from about 80 to 500 ppm with average values of about 300. Zinc is generally found in smaller amounts although a maximum value of 137 was found in PC 45. Copper was considerably lower than zinc and a maximum value of 42 ppm was found at Stations 69 and 74. Chromium was similar to copper in its content and a maximum value of 108 was found at Station 75; average values were closer to 60-70. Nickel had a maximum value of 198 ppm

TABLE 10

GEOCHEMISTRY OF BULK PERSIAN GULF SEDIMENTS

	Fe %	Mn ppm	Zn ppm	Cu ppm	Cr ppm	Ni ppm	TiO ₂ %	Al %	V ppm	Ca %	Mg %	K %	Sr ppm	Li ppm	Corr %
ST66 42GC															
0 - 5	0.36	80	18	17	27	52	0.08	0.8	14.4	33.5	1.35	0.15	2600	7	0.53
5 - 10	1.08	120	12	18	26	56	0.12	0.8	34.3	32.0	1.4	0.19	2720	8	0.75
14 - 16	0.5	100	14	14	24	56	0.09	0.8	14	29.5	1.4	0.19	2640	9	0.65
25 - 30	0.38	96	12	14	22	56	0.13	0.8	8.8	36	1.35	0.18	2800	9	0.65
45 - 50	0.3	96	15	14	32	50	0.08	0.8	8	37.5		0.175	2640	7	0.48
67 - 71	1.08	90	18	8	30	64	0.10	0.8	14.8	30.0	1.52	0.18	2840	10	0.58
75 - 80	0.42	96	18	12	32	56	0.11	0.9	12.8	37.5	1.42	0.18	2640	9	0.62
ST67 GRAB															
0 - 1	1.2	210	30	18	34	74	0.14	1.6	51.4	36.8	1.6	0.3	2700	12	0.22
1 - 2	1.3	230	30	18	30	74	0.23	1.8	25.1	25.5	1.62	0.3	2600	12	0.29
2 - 3	1.2	220	20	22	48	74	0.21	1.5	21.7	26.8	1.43	0.3	2600	12	0.14
4 - 5	1.2	230	22	18	22	76	0.23	1.8	21.7	24.3	1.58	0.3	2700	12	0.31
8 - 9	1.2	230	22	18	32	76	0.23	1.6	24	23.5	1.6	0.3	2700	14	0.28
ST69 45GC															
0 - 1	1.9	400	42	26	32	98	0.43	3	45.71	17.8	2.52	0.635	1280	20	0.31
1 - 3	1.8	390	42	22	32	100	0.45	3.0	54.28	19.2	2.6	0.635	1280	22	0.33
3 - 5	1.7	390	38	18	72	94	0.33	3.2	40.8	17.4	2.56	0.84	1100	25	0.41
8 - 10	1.8	390	100	26	82	98	0.33	3.0	51.42	19.2	2.58	0.635	1240	26	0.38
18 - 20	1.7	360	42	18	32	95	0.33	2.8	45.71	18.2	2.58	0.635	1240	20	0.29
38 - 40	1.8	380	42	18	82	97	0.28	3.0	45.71	19.4	2.6	0.635	1300	23	0.43
64 - 66	2.1	380	44	42	32	96	0.31	2.9	51.42	19.2	2.6	0.635	1300	20	0.43
84 - 86	2.1	380	46	18	60	102	0.38	3.1	54.28	19.2	2.6	0.635	1460	23	0.33
108 - 111	1.7	280	40	26	20	97	0.28	2.4	48.57	21.0	2.1	0.6	3600	19	0.36
PC45															
67 - 72	2.2	400	137	30	46	108	0.40	3.7	65.71	18.2	2.65	0.895	1200	28	0.31
218 - 221	1.9	380	50	22	32	105	0.30	3.3	30.3	17.8	2.55	0.96	860	23	0.24
370 - 374	2.3	370	50	22	40	116	0.38	3.6	46.8	17.8	2.65	1.02	940	25	0.28
510 - 515	2.8	380	52	22	32	110	0.41	3.7	65.71	17.8	2.69	0.895	1200	25	0.14
CC	2.2	360	54	26	20	107	0.38	3.4	46.8	17.5	2.65	1.02	920	23	0.24
ST70 PC46															
107 - 111	1.4	350	46	14	48	76	0.33	2.4	44	18.4	2.6	0.6	480	14	0.14
*236 - 241	1.26	300	37	14	43	80	0.24	2.3	24	21.5	2.08	0.52	1900	16	0.28
*241 - 245	1.2	330	32	18	30	80	0.22	2.2	27.2	22	2.08	0.6	1800	18	0.36
*371 - 376	1.3	300	37	20	27	82	0.26	2.4	36	24.0	2.23	0.6	1620	17	0.12
ST74 PC50															
41 - 45	2.4	420	60	42	70	132	0.34	4.0	45.7	19.6	3.05	1.02	900	30	0.19
195 - 198	1.9	380	50	18	46	115	0.36	3.6	47.7	17.5	3.05	0.94	1400	24	0.26
*345 - 348	2.1	360	50	22	46	115	0.27	3.6	36.8	17.3	3.0	0.89	1300	24	0.19
*490 - 493	2.4	380	50	26	70	105	0.36	3.3	42.3	17.8	2.9	0.89	1300	24	0.29
ST75 GC52A															
0 - 3	2.26	410	58	26	82	120	0.31	4.1	44.8	16.6	3.05	1.12	940	33	1.12
10 - 12	2.4	430	55	26	108	124	0.36	4	65.72	15.6	3.3	1.02	900	29	0.74
35 - 37	1.96	465	55	30	65	120	0.34	4.0	46	15.9	3.11	1.13	1140	30	0.95
65 - 67	2.4	464	58	34	108	132	0.34	4	71.43	15.6	3.18	0.87	800	29	0.98
95 - 97	2.3	442	55	30	60	128	0.32	3.6	57.14	17.2	2.85	0.87	600	28	0.83
PC5															
3 - 6	1.7	370	43	18	46	104	0.36	3.3	36.6	17.8	2.55	0.75	1260	20	1.16
140 - 146	3.0	570	68	26	92	168	0.48	5.1	76.6	12.3	2.62	1.32	350	25	0.14
146 - 150	3.2	600	75	22	82	198	0.5	4.6	80	13.3	2.62	1.18	420	26	0.36
*292 - 295	2.1	330	50	26	32	116	0.36	3.4	44.6	18.2	2.7	0.9	1700	28	0.21
ST79 PC57															
35 - 37 Pilot CC	1.7	290	42	24	79	100	0.29	3.3	32.8	17.2	2.63	0.9	1460	24	1.76
105 - 111	1.7	310	84	16	46	96	0.26	2.7	45.71	21.5	3.48	0.59	3400	16	0.53
358 - 363	1.54	320	39	14	70	88	0.31	3.1	41.1	19	2.6	0.68	1600	18	0.22
ST80 PC58															
0 - 5 Pilot Top	1.9	280	44	22	46	96	0.34	3.2	44.6	19.5	2.32	0.745	1800	23	1.34
80 - 84 Pilot CC	1.3	300	34	18	20	86	0.57	2.6	29.6	26.8	1.8	0.6	2600	18	0.88
105 - 110	3.2	536	64	30	32	136	0.32	4.8	80	11.7	3.85	1.16	440	28	
245 - 250	3.1	570	57	26	43	134	0.42	5	74	14.7	3.76	1.43	700	30	

* flown in

at Station 75, and in general, nickel contents from this station were high probably reflecting local input from the adjacent Iranian coast. Titanium oxide was generally less than 1% and averaged about 0.2 to 0.3%. Aluminum was variable in content reaching a maximum of 5% at Station 80 and was extremely low at Station 42 where it did not get above 1%. Vanadium had a maximum value of 80 ppm at Station 75, but generally was in the range of about 40 ppm. Calcium had maximum values of about 37% at Station 66 but generally averaged around 20%. Magnesium ranged between 1-3% in content with a maximum value found at Station 80. Potassium was generally less than 1% although cores from Stations 69, 75 and 80 had higher values. Strontium generally ranged from about 3000 ppm to values as low as 400 ppm; and generally had a direct relation to the calcium content. Lithium was low and had a maximum value of 33 ppm at Station 75. Organic carbon had a maximum value of 1.76 at Station 79.

Geochemistry of Gulf of Oman Sediments

The sediments from the Gulf of Oman were analyzed for iron, manganese, zinc, copper, chromium, nickel, titanium oxide, aluminum, vanadium, calcium, magnesium, potassium, strontium, lithium, PO_4 and organic matter (Table 11). In general, the geochemistry of this material reflects the dominance of terrigenous material in the sediments of the Gulf of Oman. This is shown by the high concentrations of iron, chromium, nickel, titanium oxide, aluminum, vanadium and potassium. The high

TABLE 11

GEOCHEMISTRY OF BULK GULF OF OMAN SEDIMENTS

	Fe %	Mn ppm	Zn ppm	Cu ppm	Cr ppm	Ni ppm	TiO ₂ %	Al %	V ppm	Ca %	Mg %	K %	Sr ppm	Li ppm	PO ₄ %	Corg %
T81 PC59																
0-2 Pilot Top	2.4	390	60	22	108	124	0.39	4.3	34.3	15.2	2.8	1.16	1350	31	0.33	2.0
5-59 Pilot CC	2.4	380	60	22	108	134	0.39	4.3	34.3	15.2	2.83	1.16	1260	31	0.31	1.4
91-95	2.3	380	60	26	82	134	0.38	4.3	37.5	15.0	2.83	1.16	1340	30	0.31	1.5
54-238	2.4	380	60	18	122	134	0.43	4.5	32.3	15.2	2.9	1.16	1350	30	0.34	1.4
77-382	2.3	380	60	26	70	135	0.37	4.5	27.8	15.2	2.78	1.16	1350	30	0.32	1.5
27-531	2.4	380	52	22	92	128	0.35	4.4	35.5	15	2.79	1.16	1350	28	0.30	1.4
56-661	2.4	380	55	22	132	134	0.41	4.5	40.9	15.2	2.8	1.18	1320	30	0.32	1.4
T82 PC60																
54-59 Pilot CC	4.3	630	104	38	92	198	0.59	6.3	54.5	8.7	2.9	1.8	600	40	0.28	1.6
42-47	3.9	490	92	30	108	170	0.49	6.3	65	10.0	2.95	1.8	800	40	0.24	0.75
96-200	2.66	440	61	22	70	132	0.4	4.8	36	13.8	2.55	1.24	1000	26	0.19	0.39
50-355	2.4	350	64	26	82	122	0.46	4.9	46.4	12.4	2.8	1.5	600	32	0.19	0.76
04-509	2.8	350	68	26	146	152	0.47	4.9	50.4	12.3	2.85	1.5	600	32	0.19	0.54
48-653 CC	2.8	370	74	26	108	126	0.45	5	58.4	10.9	2.6	1.5	580	32	0.22	1.1
T83 PC61																
0-1 Pilot	4.8	1600	113	54	143	175	0.51	7.2	122	5.0	2.96	2.06	350	45	0.30	2.0
1-3 "	4.8	640	114	57	94	170	0.63	7.2	130	5.0	2.95	2.12	370	42	0.29	1.9
3-5 "	4.9	590	116	53	124	170	0.51	7.4	130	5.1	2.95	2.26	370	47	0.29	1.9
5-7 "	4.5	570	120	53	94	172	0.51	7.2	134	5.1	2.95	2.26	360	45	0.30	1.9
7-9 "	4.8	680	120	88	62	168	0.53	7.2	136	5.3	2.88	2.12	350	45	0.29	2.0
9-11 "	4.5	590	120	57	76	172	0.59	7.2	128	5.3	2.95	2.07	350	44	0.29	2.0
11-13 "	5.0	700	120	53	85	180	0.52	7.5	134	5.2	3.0	2.12	370	44	0.29	1.9
65-67	4.5	596	108	53	112	160	0.48	7.0	132	6.6	2.98	2.12	400	47	0.27	1.2
115-120	3.6	520	67	26	64	114	0.51	5.3	90	10.2	2.82	1.49	450	31	0.21	0.80
191-195	3.9	610	75	34	84	122	0.42	5.6	107	10.0	2.51	1.71	400	35	0.20	0.72
340-345	3.9	530	82	42	64	120	0.37	5.8	92	9.1	2.8	1.73	450	37	0.22	0.56
493-496	2.8	502	65	30	67	112	0.44	5.2	86	13.4	2.51	1.46	1250	32	0.20	1.0
536-640 CC	3.0	430	61	30	43	116	0.45	4.7	78	14.2	2.6	1.22	1500	32	0.22	0.64
ST84 PC62																
17-22	2.66	460	104	18	92	90	0.53	7.2	53.6	5	1.4	1.23	220	33	0.25	0.50
112-117 Pilot	3.4	550	92	22	122	129	0.65	8.0	64.8	3.9	2.11	2.43	220	50	0.25	0.27
160-164	4.5	560	88	24	42	114	0.63	7.8	118	4.3	2.0	2.07	250	48	0.25	0.51
305-309	3.3	620	64	20	30	84	0.63	5.8	92	6.2	1.62	1.42	300	32	0.24	0.26
450-454	4.1	680	70	18	37	90	0.66	6.2	68.8	5.6	1.69	1.5	200	38	0.24	0.27
595-600	5.3	700	96	38	32	130	0.59	8.0	150	5.6	2.38	2.27	350	47	0.24	0.62
761-766	5.46	680	100	42	127	140	0.5	7.8	160	5.4	2.27	2.38	300	48	0.23	0.56
905-908	5.26	650	96	34	70	132	0.58	8.2	150	4.1	1.9	2.38	200	49	0.23	0.36

strontium content found in some intervals is probably related to the aragonite content in these sediments. Organic matter varies from between 0.1 to 3%.

In the Gulf of Oman sediments several small intervals of material having dark olive content were sampled. These were found to have organic contents of about 3%. It is possible that these sediments could be classified as a sapropel or protosapropel. Nitrogen content ranges between 0.02 and 0.39% with the highest contents occurring in the sapropels.

Iron contents in general ranged from 3-4% which was 1-2% higher than the Persian Gulf material. Manganese also was higher in the Gulf of Oman than the Persian Gulf as were zinc and copper values. Zinc contents of above 100 ppm were found in the upper parts of Stations 82, 83 and 84. Chromium contents were variable but did reach a maximum of 146 ppm. These values again were slightly higher than those in the Persian Gulf. Nickel values, although not having a maximum as high as the Persian Gulf, tended to average about 120-130 ppm; a value somewhat higher than that in the shallower area of the Persian Gulf. Titanium oxide content is about similar, although aluminum is considerably higher in the Gulf of Oman than the Persian Gulf with the deeper water samples having values of between 7-8%. This, in all likelihood, reflects the higher amounts of clay minerals. Vanadium content is also slightly higher in the Gulf of Oman area. Calcium, on the other hand, tends to be lower.

This and most of the previously mentioned observations, of course, reflect the increasing terrigenous/biogenous ratio in the Gulf of Oman as compared to the Persian Gulf. Magnesium content was a little bit higher in the Gulf of Oman sediments as were the potassium values. Strontium, however, (generally had a trend similar to calcium) is lower in the Gulf of Oman than the Persian Gulf. Lithium is slightly higher in the Gulf of Oman but somewhat surprising is the fact that the organic carbon content appears higher in the Gulf of Oman than in the Persian Gulf.

Pore Water Chemistry - Persian Gulf

Pore waters collected from the Persian Gulf sediments were analyzed immediately after collection for pH, Eh and salinity while the other analyses were generally made later in the laboratory. The data are presented in Table 12 and plotted in Figures 20 and 21. In general, there was an increase in pore water salinity with increasing core depth which suggests a deep lying evaporitic sediment, a point that seems consistent with other geophysical and general stratigraphic knowledge of the region. The highest salinity value was 55.5‰ from Station 75. In general, as salinity increased there was an increase in calcium, magnesium and strontium content. SO_4 and Cl generally also increased with depth reflecting salinity changes. Salinity is generally higher than that of the overlying water and as previously mentioned, increases with depth. Sediment pH generally was about 7.4 to

TABLE 12

PORE WATER ANALYSES OF PERSIAN GULF SEDIMENTS

	pH	Eh(mV)	Salinity	NH ₄	HCO ₃	SO ₄	Cl	Ca	Mg	Na	K	Sr	Li	B	SiO ₂	Mn
			o/oo	mg/l	mg/l	mg/l	g/l	mg/l	mg/l	g/l	mg/l	mg/l	mg/l	mg/l	mg/l	ppb
ST6642GC																
0- 5cm	7.55	- 29	41.0	2	166.46	2450	23.77	480	1540	12.88	480	8.0	0.18	5.47	9.5	83
5- 10cm	7.65	-165	41.5	6	158.39	2900	23.32	475	1540	12.83	460	8.0	0.18	5.34	8.0	36
14- 16cm	7.65	-165	41.5	4	156.63	2950	23.10	485	1540	12.69	470	8.5	0.18	5.65	7.5	36
25- 30cm	7.75	-194	41.5	4	175.54	3020	23.43	470	1540	12.97	450	8.0	0.19	5.27	6.5	30
45- 50cm	7.75	-200	42.0	4	168.22	2900	23.63	470	1540	13.04	450	8.0	0.19	5.40	5.5	30
75- 80cm	7.80	-238	40.5	4	130.40	2950	23.52	470	1510	13.04	450	7.5	0.18	4.50	6.0	30
ST68 surface water	8.05					2900	23.32	475	1510	12.82	460	9.0	0.19			
0- 1cm Grab	7.55	+331	42.0		158.60	2820	23.37	485	1540	12.79	480	9.0	0.19	5.78	10.0	80
2- 2cm	7.45	+207	42.0	6	136.43	2900	23.49	480	1540	12.91	490	9.0	0.19	6.25	8.0	107
2- 3cm	7.45	+177	42.0	6	133.99	2900	23.60	480	1570	12.92	490	9.0	0.18	6.09	7.5	107
4- 5cm	7.45	+159	42.0	4	149.92	3150	24.20	515	1540	13.42	520	9.5			11.0	226
8- 9cm	7.45	+136	42.0	4	149.92	3020	23.40	480	1540	12.90	510	9.0			12.5	286
ST6945GC																
0- 1cm	7.85	+189	41.5	4	134.06	3100	23.74	495	1510	13.19	515	9.0	0.17	5.60	7.5	155
1- 3cm	7.60	+104	41.5	4	156.63	3100	23.32	490	1540	12.87	510	9.0	0.19	5.73	9.5	173
3- 5cm	7.65	+ 39	41.5	4	139.55	3120	23.15	480	1510	12.85	480	9.0	0.17	5.65	9.5	137
8- 10cm	7.55	+ 30	41.5	12	113.66	3070	22.95	475	1570	12.60	470	8.5	0.18	5.27	9.5	113
18- 20cm	7.85	-227	41.5	14	106.88	3050	23.43	480	1540	12.95	475	8.5	0.18	5.32	8.0	95
38- 40cm	7.75	-274	41.5	10	112.51	3020	23.10	480	1540	12.73	460	8.5	0.16	5.45	10.0	54
64- 66cm	7.75	-268	41.5	10	112.51	3170	34.34	485	1540	12.95	460	9.0	0.19	5.09	9.5	60
84- 86cm	7.70	-185	41.5	12	110.00	3160	23.15	475	1540	12.81	450	9.0	0.19	5.22	10.5	48
108-111cm	7.70	-159	41.0	12	78.28	3150	23.32	460	1540	12.92	500	9.0	0.19	4.37	8.0	49
67- 72cm PC	7.45	-126	45.5	14	83.09	3400	25.45	650	1540	14.23	460	27.0	0.20	5.45	13.5	37
218-221cm	7.45	-135	49.5	16	79.36	3700	27.55	750	1610	15.48	470	35.5	0.22	5.14	13.5	73
370-374cm	7.70	- 2	52.0	20	52.39	3650	29.00	855	1650	16.19	470	38.5	0.24	5.29	13.5	49
410-515cm	7.55	+ 0.5	52.5	20	53.61	3700	29.00	845	1640	16.26	450	38.5	0.24	6.17	14.0	55
ST70PC46																
69- 74cm Pilot	7.50	- 62	41.5			3400	23.26	490	1540	12.78	490	12.5	0.19	3.88		61
107-111cm	7.45	-227	47.0	10		3320	26.58	620	1600	14.91	510	20.5	0.25			154
*236-241cm	7.45	-156	43.5	10		3300	24.03	500	1560	13.31	520	10.0	0.23	3.83		37
*241-245cm	7.45	0	42.0	6		3350	23.83	535	1560	13.17	510	12.5	0.23	3.83		61
*371-376cm	7.50	-115	42.0	10		3300	23.80	515	1540	13.17	535	11.5	0.19	3.93		49
ST74PC50																
H ₂ O in 50m	8.15	+343				2800	22.61	470	1510	12.31	470	8.5	0.17	4.38		< 10
41- 45cm	7.50	-312	44.5	12.0	133.79	3220	25.05	545	1600	13.89	490	15.0	0.18	5.88	18.0	45
195-198cm			47.5	10.0	107.63	3400	26.92	600	1650	14.99	535	22	0.20	6.63	19.0	38
*345-348cm			49.5	20.0	87.77	3450	28.23	650	1710	15.69	545	24	0.19	6.68	19.5	45
*490-493cm	7.45	-206	49.5	14.0	105.66	3470	28.23	680	1710	15.67	535	25	0.20	6.68	19.0	40
ST75GC52																
0- 3cm	7.65	- 64	40.5	6.0	135.21	3050	22.81	485	1540	12.52	510	9.0	0.17	5.13	14.5	475
10- 12cm	7.75	-126	40.5	6.0	133.99	3150	23.06	475	1540	12.75	500	8.5	0.17	5.13	9.0	220
35- 37cm	7.60	-194	41.0	6.0	135.21	3150	23.06	480	1540	12.74	510	9.0	0.17	5.50	8.5	130
65- 67cm	7.70	-176	41.5	6.0	130.33	3170	23.26	495	1560	12.82	510	9.0	0.19	5.43	8.5	100
95- 97cm	7.75	-176	41.5	8.0	118.06	3150	23.63	485	1540	13.08	520	9.0	0.19	5.38	8.5	110
3- 6cm PC	7.90	-224	41.0	6.0	140.70	3150	23.46	485	1600	12.88	510	8.5	0.17	5.13	8.5	100
140-146cm			55.5	8.0	138.80	3550	31.05	980	1990	16.95	560	20.0	0.25		17.0	
146-150cm			55.5													
*292-295cm	7.55	-192	43.5	6.0	130.33	3320	24.71	415	1650	13.76	500	11.0	0.20	5.63	10.0	80
ST79PC57																
35- 37cm Pilot	7.25	-197	40.0	8.0	205.29	3050	22.52	460	1540	12.40	490	8.0	0.17	5.13	9.0	160
105-111cm	7.45	-218	41.0	14.0	113.59	2970	23.23	470	1490	12.89	480	10.0	0.18	5.63	11.0	50
358-363cm	7.50	-108	42.0	16.0	45.20	3000	23.52	495	1490	13.51	545	10.5	0.19	4.13	8.0	40
ST80PC58																
H ₂ O bottom	8.15			8.0		3050	21.21	490	1510	11.5	470	8.0	0.18			< 10
0- 5cm Pilot TOP	7.55	-106	41.5	6.0	148.02	3150	23.03	490	1510	12.76	520	8.0	0.18	5.83	8.5	270

*flown in

PORE WATER MAJOR ELEMENTS

PILOT

PISTON

- GC, PC 45
- * PG, PC 46
- PC 50
- GC, PC 51
- PC 57

Figure 20 Pore water analyses of major elements from Persian Gulf cores.

PORE WATER MINOR ELEMENTS

PILOT

PISTON

- GC, PC 45
- * PG, PC 46
- PC, 50
- GC, PC 51
- PC, 57

Figure 21 Pore water analyses of minor elements from Persian Gulf cores.

7.8 and in most instances the Eh was negative. NH_4 content tended to increase with depth reaching a maximum value of about 20 mg/l. HCO_3 decreased with depth. Calcium and magnesium, although usually fairly constant, showed some relatively high calcium values at depth from Station 69. This station also has relatively high values of sodium and may be reflecting river input from the Shatt-al-Arab. Strontium values are also relatively high in this locality. The plot of the distribution of the different elements (Figures 20 and 21) shows some trends although they generally are poorly defined in the shorter cores. Lithium, strontium, magnesium, calcium, potassium, chlorine, SO_4 and perhaps NH_4 show increases with depth. Manganese, barium, SiO_2 appear to decrease with depth. The water content generally shows a decrease with depth although one core, PC 45, studied in detail, had gradual change (Figure 22).

Pore Water Studies - Gulf of Oman

The same analyses made of the Persian Gulf pore waters have been made on pore waters from the Gulf of Oman (Table 13). In general, there is a salinity decrease in the near surface pore waters with increasing water depth from about 38.5‰ to 34‰ at Station 84. This probably is a direct reflection of the outflowing, higher salinity Persian Gulf waters. With depth in the cores, salinity tends to stay more or less constant (Figures 23 and 24). In general, pH tends to be a little less than that for the Persian Gulf waters. Salinity does not show

TABLE 13

PORE WATER ANALYSES OF GULF OF OMAN SEDIMENTS

	pH	Eh(mV)	Salinity	NH ₄	HCO ₃	SO ₄	Cl	Ca	Mg	Na	K	Sr	Li	B	SiO ₂	Mn
			o/oo	mg/l	mg/l	mg/l	g/l	mg/l	mg/l	g/l	mg/l	mg/l	mg/l	mg/l	mg/l	ppb
ST81PC59																
0- 2cm Pilot	7.55	- 70	38.5	14	206.31	2650	21.56	450	1450	11.78	485	7.5	0.16		25	1685
55- 59cm Pilot	7.60	-227	37.5	40	927.06	950	21.44	165	1380	11.66	470	4.0	0.15	6.25	16	90
91- 95cm PC	7.55	-224	36.5	80	928.14	170	21.70	75	1240	11.86	505	2.5	0.14	5.88	12	40
234-238cm	7.35	-280	36.0	80	983.04	260	21.21	90	1200	11.68	480	3.0	0.14		12	30
377-382cm	7.95 ⁺⁺	-209	36.0	88	1146.25	120	21.13	70	1200	11.65	490	2.5	0.14		12	30
527-531cm	7.65 ⁺⁺	-247	36.0	88	1008.39	65	20.90	70	1200	11.42	490	2.5	0.14		11	50
656-661cm	7.30	-277	35.5	80	911.67	270	21.10	90	1200	11.60	460	3.0	0.14	7.18	15	90
ST82PC60																
54- 59cm Pilot	7.80	-203	34.5	16	180.01	2450	19.82	370	1260	10.99	500	7.0	0.15	7.13	17	1695
42- 47cm PC	7.55	- 5.4	35.5	14	213.63	2400	19.94	335	1260	11.09	510	7.0	0.14	7.13	15	860
196-200cm	7.65	- 8.4	35.5	20	252.47	2100	20.14	250	1230	11.24	535	7.0	0.13	7.08	14	230
350-355cm	7.55	- 12	35.5	28	357.73	1720	20.07	200	1150	11.27	535	7.0	0.12	7.93	14	50
504-509cm	7.50	-230	35.5	20	451.94	1350	19.82	140	1140	11.05	535	7.0	0.11	6.25	24	30
648-653cm	7.60	-138	34.0	16	419.13	1150	19.88	125	1080	11.10	540	6.5	0.10	6.60	17	40
ST82PC61																
H ₂ O bottom	8.0			14		2650	20.42	435	1380	11.13	420	7.5	0.18	5.08		210
0- 1cm Pilot	7.45	+177	36.5	10	120.44	2500	20.11	435	1330	10.98	480	7.5	0.22	5.33	29.0	410
1- 3cm "	7.55		36.0	10	133.86	2700	19.94	415	1280	11.08	500	7.0	0.18	5.50	31.5	3200
3- 5cm "	7.55		36.0	8	140.63	2750	20.56	430	1280	11.47	530	7.0	0.18	6.00	26.5	4370
5- 7cm "	7.50		35.5	8	135.75	2720	20.22	420	1250	11.30	520	7.0	0.17	5.88	29.5	4200
7- 9cm "	7.55		35.5	8	141.85	2720	20.33	430	1230	11.41	510	7.0	0.17	5.88	32.0	3620
9- 11cm "	7.75		35.5	8	127.21	2720	20.22	420	1290	11.21	550	8.0	0.19	5.75	30.5	3520
11- 13cm "	7.70		35.5	10	135.08	2600	20.02	400	1280	11.07	545	7.0	0.18	6.08	29.6	3260
65- 67cm "	7.55	-150	35.5	12	96.58	2620	20.16	390	1270	11.17	575	7.0	0.18	4.18	20.0	2020
115-120cm PC	7.45	-270	35.5	10	175.95	2600	19.77	355	1230	11.05	580	7.0	0.15	4.88	27.0	410
191-195cm	7.45	-230	35.5	10	188.76	2400	19.88	340	1250	10.99	610	7.0	0.14	4.83	24.0	180
340-345cm	7.45	-265	35.5	6	234.03	2600	20.31	350	1250	11.38	590	7.5	0.14	5.33	34.0	130
493-496cm	7.35	-270	35.5	8	204.68	2370	20.05	335	1230	11.18	530	8.0	0.13	5.33	32.0	170
636-640cm	7.30	-282	35.5	8	244.94	2320	19.94	330	1230	11.11	535	8.0	0.13	5.0	33.0	220
ST84PC62																
H ₂ O bottom				8		3000	20.83	440	1400	11.50	460	7.5	0.16	5.18		430
112-117cm Pilot	7.35	-207	34.0	14	830.34	900	19.97	195	1150	10.98	535	5.0	0.14	6.83	21	620
17- 22cm PC	7.20	-191	34.5	14	661.37	1350	20.16	295	1230	11.01	500	6.0	0.14	5.93	18	120
160-164cm	7.25	-180	34.0	16	547.23	1050	19.82	330	1240	10.52	535	6.5	0.15	7.33	20	1700
305-309cm	7.30	-207	34.0	24	986.16	25	19.77	160	1110	10.65	475	5.0	0.11			1380
450-454cm	7.45	-253	33.5	20	1201.63	40	19.71	115	1090	10.78	480	5.0	0.08	6.25	20	2020
595-600cm	7.45	-233	33.5	36	1184.62	25	20.16	95	1060	11.15	500	4.5	0.08	7.63	18	470
761-766cm	7.45	-230	34.0	48	859.08	35	19.78	70	2020	20.88	540	3.0	0.08	7.25	12	200
905-908cm	7.45	-162	34.0	40	971.59	140	20.36	75	1060	11.24	580	3.0	0.09	7.18	13	120

⁺⁺ after 10h

PORE WATER MAJOR ELEMENTS

PILOT

PISTON

- PG, PC 58
- * PG 59
- PG, PC 60
- PG, PC 61
- PG, PC 62

Figure 23 Pore water analyses of major elements from the Gulf of Oman cores

PORE WATER MINOR ELEMENTS
PILOT

PISTON

- PG, PC 58
- * PG 59
- PG, PC 60
- PG, PC 61
- PG, PC 62

Figure 24 Pore water analyses of minor elements from the Gulf of Oman cores

the same increase with depth suggesting that if evaporitic layers are present in the Gulf of Oman they are not as evident as under the Persian Gulf sediments. This, of course, does not prove that they are not present but rather that they may be at a greater depth or that diffusion has not occurred at the same rate. In general, there tends to be an increase in potassium and HCO_3 and perhaps SiO_2 and NH_4 with depth in the cores, whereas lithium, magnesium, calcium and SO_4 decrease with depth. There are relatively high amounts of manganese at depth in core 62 which may reflect strong, reducing conditions.

Organic Geochemistry Studies

During Leg 17 of ATLANTIS II Cruise 93 (Peter Brewer, Chief Scientist) Dr. John M. Hunt, Department of Chemistry, Woods Hole Oceanographic Institution, collected several samples from the Persian Gulf and Gulf of Oman area which he, with Dr. Jean Whelan, subsequently analyzed for their organic matter content. The location and general characteristics and other details of the samples collected are described in Table 14. The results of their analyses are given in Table 15.

The analyses for C1-C7 hydrocarbons and non-hydrocarbons was carried out on fifty-seven samples (Table 15); some taken at various depths on the longer cores. The results can be summarized as follows:

1. There is an inverse correlation between organic carbon (C_o) content and carbonate carbon. The C_o ranged up to 12% in low carbonate samples and down to 0.5% in high carbonate samples.

TABLE 14

SAMPLES COLLECTED BY DR. JOHN HUNT
AND ANALYZED FOR ORGANIC MATTER

<u>Date</u>	<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Depth(M)</u>	<u>Comments</u>
8/2	2358	18.24N	64.38E	3475	35cm core w/ 3 wts. 70m/min.
10/2	Dredge A-1	16 34N	59 55E	3176	2 bag samples
10/2	A-2	16 37N	59 55E	2300	3 bag samples
10/2	A-3	16 40N	59 54E	2700	1 bag
11/2	2359	17 52N	60 46E	3853	100cm core/ 3 wts. 100m/min.
11/2	B-1	18 55N	60 37E	3200	1 bag
12/2	B-2 B-2	18 55N 18 56N	60 31E 60 34E	2724	1 bag 300 cm core
14/2	2362	22 47N	62 08E	2651	200 cm core
15/2	2363	23 30N	60 45E	3347	135 cm core
15/2	2364	24.15N	59 30E	3213	154 cm core
16/2	2365	25 03N	57 46E	1097	core#1 98cm core#2 140cm core#3 185cm
16/2	2366	25 30N	57 00E	150	40 cm
17/2	2368	26 05N	54 53E	83	58 cm
17/2	2370	26 10N	53 38E	78	165 cm
17/2	2371	26 14N	52 54E	70	two cores 105cm 119cm
18/2	2377	25 38N	53 48E	50	52 cm
19/2	East of 55 all hard coral reef rock. Two attempts showed no bottom mud.				
19/2	32	26 20N	54 14E	56	93 cm

<u>Date</u>	<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Depth(M)</u>	<u>Comments</u>
19/2	33	26 16N	53 48E	70	140 cm core Reef rock and mud core 2
20/2	34B	26 17N	53 20E	73	80 cm + bag
20/2	35	26 15N	52 42E	64	95 cm + bag
20/2	36	26 12N	52 32E	57	bag
20/2	2388 (39)	26 35N	52 00E	57	bag
20/2	2389 (40)	26 49N	52 11E	60	77 cm + cc bag
21/2	2390 (41)	27 05N	52 22E	73	161 cm + top bag + cc bag
21/2	43	27 24N	52 10E	70	206 cm 2 sections
21/2	44	27 25N	52 00E	70	core #1 - 38 cm core #2 - 184 cm
21/2	45	27 26N	51 47E	42	145 cm
21/2	46	27 32N	51 29E	30	188 cm + 10 cm in cc 2 sections + bag
21/2	47	28 02N	51 01E	65	80 cm
22/2	55	28°33'N	49°29'E	46	251 cm
22/2	56	28° 58'N	49°34'E	40	104 cm + CC
22/2	57	29°25'N	49°40'E	22	1 bag
22/2	58	29°45'N	49°30'E	15	71 cm
22/2	59	29°39'N	49°15'E	18	87 cm
23/2	60	29°32'N	49°02'E	18	120 cm + CC
24/2	63	27°25'N	49°50'E	37	184 cm + CC
25/2	66	27°09'N	51°09'E	64	71 cm

TABLE 15

ORGANIC GEOCHEMISTRY ANALYSES OF SEDIMENTS
FROM THE PERSIAN GULF, GULF OF OMAN AND INDIAN OCEAN
(Courtesy Drs. John Hunt and Jean Whelan)

(Amounts of Hydrocarbons are all given in ng of compound/g dry weight of sediment)

SAMPLE	B-2	B-2	2358-1	2358-4	2359	2362
Sed Depth (cm)	0-10	125-135	0-10	30-35	0-10	0-10
Water Depth (m)	2724	2724	3475	3475	3858	2651
Lithology	fine brn clay	olive ym clay	lt. brown clay	blk. brn clay	fine olive clay	gry brwn clay
Methane	11.4	4.69	0.81	4.76	5.2	0
Ethane	0.12	0.076		0.05	0.07	
Ethylene	0					
Propane	0.25			0.03	0.06	
i-Butane	0					
n-Butane	0			0.02	0.07	
neoPentane	0					
Me Butane or Pentene	0		0.41			
i-Pentane	0				0.009	
n-Pentane	trace	Pentene = 0.73	Pentene = 0.63	Pentene = 0.04	1-Pentene 0.69 methane 0.78	0.30
cycloPentane	0				Pentene 0.78 0.08(?)	
DMS or CS ₂		0.03				
2,2-DiMeButane	0.57					0.10
2,3-DiMeButane					1.37	
2-MePentane	trace				1.97	0.02
2-MeFuran					0.04	
3-MeFuran					1.54	
3-MePentane or 1-Hexene			0.01	0.04		
n(6 or 2-Hexene or MePentene		trace	0.06		0.23	0.02
3-MeButane		0.11			0.36	
2-MeButane or MePentene	trace				Me Butane 0.10	
MecycloPentane					0.10	0.02
2,2-DiMePentane	0.08	0.02			20.05 21.78	
Benzene	trace				0.80	0.055
2,4-DiMePentane	trace				0.05	
2,2,3-TiMeButane						
1-Mecyclopentene						
cyclohexane					0.14	
c+t3, 5DM cyclopentene						
3,3-DiMePentane						
cyclohexene					2.05	
1,1-DiMecycloPentane						
2-MeHexane					0.39	
2,5-DiMeFuran						
1-Trans-3-DiMecycloPentane						
2,3-DiMePentane					0.51	
3-MeHexane					0.46	0.10

TABLE 15 (CONTD.)

SAMPLE	B-2	B-2	2358-1	2358-4	2354	2362
Sed Depth (cm)	0-10	125-135	0-10	30-35	0-10	0-10
Water Depth (m)	2724	2724	3475	3475	3858	2651
1-Trans-2-DiMecycloPentane						
3-Ethyl Pentane						
1,3 DiMecycloPentene						
1,4 DiMecycloPentene						
3 Methyl Methylene cyclo-pentene						
n-Heptane					0.06	0.03
1,c-2-DiMecycloPentane						
MecycloHexane						0.06
1,1,3-TMCP						
2,2-DMH						
ECP						
2,5-DMH						
ECP						
2,5-DMH						
2,4-DMH						
1,2 DiMecycloPentene						
2 Methcophene					702	
Tol	trace				0.76	
3-Methcophene						
1C2T3TMCP						
Total C (%)	18.42	7.13 ± 0.25	2.91 ± 0.05		5.24 ± 0.07	4.99 ± 0.06
organic C (%)	1.85 ± 0	1.68 ± 0.03		0.27 ± 0.04	2.62 ± 0.87	0.67 ± 0.03
SATD ALKANES						
ΣC ₂ + C ₃ (ng/g)	0.37	0.076	0	0.08	0.13	0
ΣC ₄ + C ₅ (ng/g)	trace	0	0	0.02	0.08	0
ΣC ₆ + C ₇ (ng/g)	0.24	0	0.07	0.04	6.57	0.32
other compounds (ng/g)	0.6	0.9				
ngΣC ₂ + C ₃ /ng Co x 10 ⁷			Alkenes = 1.1	Alkenes = 0.04	Alkenes = 5.65 Others = 1.16	Alkenes = 0.08
ngΣC ₄ + C ₅ /ng Co x 10 ⁷						
ngΣC ₆ + C ₇ /ng Co x 10 ⁷						
ng other compounds/ng Co x 10 ⁷						

SAMPLE	2362	2363	2364	2365	2365	2366-1
Sed Depth (cm)	67-78	0-15	10-20	0-10	160-175	0-10
Water Depth (m)	2651	3347	3213	1097	1097	150
Lithology	olive clay	olive brn clay				Sandy
Methane	4.81	2.69	5.58	14.5(0.7)	24.6	23.1
Ethane			0.04	0.30	0.78	0.52
Ethylene						
Propane			~0.02	0.28	0.32	0.45
i-Butane						0.04
n-Butane			0.03	trace		0.26
neoPentane					0.10	
Me Butane or Pentene			1.15	38.9		
i-Pentane						0.13
n-Pentane			trace			0.02
cycloPentane						0.08
DMS or CS ₂	5.50				20.4	0.04
2,2-DiMeButane	0.22 + MePene 0.29			0.7	0.37	
2,3-DiMeButane				3.9	0.72	0.46
2-MePentane	0.14			0.2	0.49	0.49
2-MeFuran	?0.09					
3-MeFuran					0.15	
3-MePentane or 1-Hexene	0.03		~0.10	0.2	0.37	0.37
n(6 or 2-Hexene or MePentene)	0.08	2.03	~0.50	MPene 1.0	0.37	0.17
3-MeButane		MePene 0.04				0.47
2-MeButane or MePentene			0.06 ?0.41			0.116
Mecyclopentane		0.41		0.31	0.07	0.008
2,2-DiMePentane	MePentene 0.02	0.15		3.12	0.47	0.67
Benzene		?0.13			?0.10	0.10
2,4-DiMePentane	0.29					±1.26
2,2,3-TiMeButane		0.04			0.32	0.86
1-Mecyclopentene						
cyclohexane	MePene 0.10	0.07			?0.09	MePene 0.19
c+t3, 5DM cyclopentene						0.22
3,3-DiMePentane						0.55
cyclohexene	0.11	0.94		1.74	1.74	0.89
1,1-DiMecyclopentane	?0.08					
2-MeHexane	0.02	0.04				
2,5-DiMeFuran						
1-Trans-3-DiMecyclopentane	0.04	0.03				
2,3-DiMePentane	0.03	trace				
3-MeHexane	?0.07	0.04				

TABLE 15 (CONTD)

SAMPLE	2362	2363	2364	2365	2365	2366-1
Sed Depth (cm)	67-78	0-15	10-20	0-10	160-175	0-10
Water Depth (m)	2651	3347	3213	1097	1097	150
1-Trans-2-DiMecycloPentane						
3-Ethyl Pentane	0.03	trace				
1,3 DiMecycloPentene	0.02					
1,4 DiMecycloPentene	0.04					
3 Methyl Methylene cyclo- pentene	0.02					
n-Heptane						
1,c-2-DiMecycloPentane		0.06				
MecycloHexane	0.55					
1,1,3-TMCP						
2,2-DMH		0.08				
ECP						
2,5-DMH						
ECP						
2,5-DMH						
2,4-DMH						
1,2 DiMecycloPentene						
2 Methcophene						
Tol	0.12					
3-Methcophene	0.14					
1C2T3TMCP						
Total C (%)	4.98 ± 0.05	2.09	0.50 ± 0.11	6.21 ± 0.04	5.56 ± 0.06	9.70 ± 0.42
organic C (%)	0.94 ± 0.00	0.7	0.63 ± 0.00	6.38 ± 0.02	4.02 ± 0.01	0.28 ± 0.03
SATD ALKANES						
ΣC ₂ + C ₃ (ng/g)	0	0	0.06	0.58	1.16	0.97
ΣC ₄ + C ₅ (ng/g)	0	0	0.03	0	0.10	0.53
ΣC ₆ + C ₇ (ng/g)	1.67	0.84	0.6	7.73	2.77	1.8-3.9
other compounds (ng/g)			0.47	2.2	22.9	0.9-2.2
ngΣC ₂ + C ₃ /ng Co x 10 ⁷			Alkenes = 0.70 Others = 6.13	Alkenes = 3.2 50.8	Alkenes = 0.37	Alkenes = 0.8-1.4
ngΣC ₄ + C ₅ /ng Co x 10 ⁷						
ngΣC ₆ + C ₇ /ng Co x 10 ⁷						
ng other compounds/ng Co x 10 ⁷						

TABLE 15 (CONTD.)

SAMPLE	2366-4	2368-1	2368-6	46-1	47	55-2
Sed Depth (cm)	35-47	0-10	50-60	0-10	0-10	125-135
Water Depth (m)	150	83	83	30	65	46
Lithology	gray brn clay	brn clay	br-bn sand	olive gray clay	olive gray	gray clay
Methane	4.39	11.0	4.3	58.6	44.2	4.07
Ethane	0.05	0.34	0.12	0.7	1.0	0.12
Ethylene				7.64	9.0	
Propane	0.02	0.37	0.06	0.44	0.87	0.18
i-Butane		0.009		0.002		
n-Butane	0.003	0.06	trace	0.004	0.008	0.009
neoPentane						
Me Butane or Pentene		0.078	0.11			
i-Pentane				trace		
n-Pentane	Pentene = 0.02					
cycloPentane	0.05	0.47	0.08		0.2	0.10
DMS or CS ₂		0.13 0.30	0.06	3.0	12.6	7.44
2,2-DiMeButane					0.1	0.42
2,3-DiMeButane					1.2	0.02
2-MePentane		0.04	0.08	2.0	0.6	0.08
2-MeFuran		0.02		0.06	0.2	
3-MeFuran				0.12		
3-MePentane or 1-Hexene		0.06				0.05
n(6 or 2-Hexene or MePentene)	0.21	MePentene 1.28 Hexene = 0.21	0.05	0.04	0.10	Hexene = 0.21 0.10
3-MeButane				0.10		
2-MeButane or MePentene						0.02
MecycloPentane		0.34		0.17	0.09	0.02
2,2-DiMePentane		0.20			0.56	0.18
Benzene	0.07				0.02	0.15
2,4-DiMePentane				0.05		0.09
2,2,3-TiMeButane				0.27	0.08	0.04
1-Mecyclopentene						
cyclohexane		0.19		0.52		0.18
c+t3, 5DM cyclopentene				traces		
3,3-DiMePentane				0.75	0.11	
cyclohexene		0.14			0.16	1.0
1,1-DiMecycloPentane				0.05 0.34	0.11	
2-MeHexane					0.04	0.02
2,5-DiMeFuran						
1-Trans-3-DiMecycloPentane						
2,3 - DiMe Pentane					0.05	0.05
3- me Hexane					0.04	0.02

TABLE 15 (CONTD.)

SAMPLE	2346-4	2348-7	2348-6	46-1	47	55-2
Sed Depth (cm)	35-47	0-10	50-60	0-10	0-10	125-135
Water Depth (m)	150	83	83	30	65	46
1-Trans-2-DiMecycloPentane				0.78		
3-Ethyl Pentane		0.07		1.02		0.02
1,3 DiMecycloPentene				0.57		0.02
1,4 DiMecycloPentene				0.04		0.06
3 Methyl Methylene cyclo-pentene				0.35		0.07
n-Heptane		0.16				
1,c-2-DiMecycloPentane				0.04		
MecycloHexane				0.23		
1,1,3-TMCP						
2,2-DMH		0.14		0.08		
ECP						
2,5-DMH						
ECP						
2,5-DMH						
2,4-DMH						
1,2 DiMecycloPentene						
2 Methcophene						
Tol		0.64				0.73
3-Methcophene						
1C2T3TMCP						
Total C (%)		4.81 ± 0.36	7.96 ± 1.36	6.40	6.42	5.48 ± 0.16
organic C (%)	4.1 ± 0.05		5.09 ± 0.69	1.36	4.95	3.74
SATD ALKANES						
EC ₂ + C ₃ (ng/g)	0.07	0.71	0.18	1.15	1.87	0.30
EC ₄ + C ₅ (ng/g)	0.003	0.069	0.005	0.006	0.008	0.009
EC ₆ + C ₇ (ng/g)	0.37	2.0	0.13	4.81	2.88	1.90
other compounds (ng/g)		0.56	0.14	3.43		5.72
ngEC ₂ + C ₃ /ng Co x 10 ⁷		Alkenes = 2.51	Alkenes = 0.11	Alkenes = 8.60	Alkenes = 18.95	Alkenes = 1.44
ngEC ₄ + C ₅ /ng Co x 10 ⁷						
ngEC ₆ + C ₇ /ng Co x 10 ⁷						
ng other compounds/ng Co x 10 ⁷						

SAMPLE	56	58	59	60	63-1	63-cc
Sed Depth (cm)	0-10	0-10	0-10	0-10	0-10	184
Water Depth (m)	40	15	18	18	37	37
Lithology	olive gray Sand	tan gray fine Sand	gray-brn clay	olive brn sand	olive brn coarse	
Methane	11.2	10.5	3.96	13.2	8.89	4.43
Ethane	0.54	0.52	0.07	0.16	0.19	0.16
Ethylene						0.20
Propane	0.09	0.11		0.39	0.10	
i-Butane						
n-Butane				0.02	0.05	0.03
neoPentane	0.12	0.07				
Me Butane or Pentene			0.12		1.6	0.34
i-Pentane		0.02		0.06		
n-Pentane					0.009	
cycloPentane			0.05		0.91 0.11	
DMS or CS ₂		11.8	7.77		1.46	
2,2-DiMeButane	0.05		0.17		0.84	0.01
2,3-DiMeButane	0.05	0.29	0.04	trace		0.02
2-MePentane		0.10	0.02	0.058	2.62	0.06
2-MeFuran		0.08			0.20	
3-MeFuran	0.03					
3-MePentane or 1-Hexene	trace	0.12			0.42	0.05
n(6 or 2-Hexene or MePentene	0.04	0.39	0.02	0.30	0.17	1.24
3-MeButane						
2-MeButane or MePentene						
MecycloPentane	trace		0.02		0.84	0.15
2,2-DiMePentane	0.03	0.17	0.04		0.15	
Benzene		0.03	0.04	0.073	0.10	
2,4-DiMePentane	trace					
2,2,3-TiMeButane						
1-Mecyclopentene	0.16	0.16			1.6	
cyclohexane			trace		0.3	
c+t3, 5DM cyclopentene						
3,3-DiMePentane		0.03			0.3	
cyclohexene		0.06	0.32		0.1	
1,1-DiMecycloPentane						
2-MeHexane			trace	0.023	trace	
2,5-DiMeFuran						
1-Trans-3-DiMecycloPentane				0.018		
2,3-Di Me Pentane			trace	0.024	1.0	
3-Me Hexane			trace	0.022		

TABLE 15 (CONTD.)

SAMPLE	56	58	59	60	63-1	63-CC
Sed Depth (cm)	0-10	0-10	0-10	0-10	0-10	184
Water Depth (m)	40	15	18	18	37	37
1-Trans-2-DiMecycloPentane				0.022		
3-Ethyl Pentane				0.037		
1,3 DiMecycloPentene			0.62			
1,4 DiMecycloPentene				0.42		
3 Methyl Methylene cyclo-pentene						
n-Heptane			0.02			
1,c-2-DiMecycloPentane				0.037		
MecycloHexane				0.023		
1,1,3-TMCP						
2,2-DMH						
ECP						
2,5-DMH						
ECP						
2,5-DMH						
2,4-DMH						
1,2 DiMecycloPentene			0.34			
2 Methcophene						
Tol		0.17	0.34	0.36		
3-Methcophene		0.23				
1C2T3TMCP						
Total C (%)	8.82 [±] 0.57	7.37 [±] 0.18	6.84 [±] 0.14	6.88 [±] 0.05	10.60 [±] 0.01	
organic C (%)	6.39 [±] 0.07	0.72	0.78 [±] 0.02	0.63 [±] 0.02	8.73 [±] 0.05	1.48 [±] 0.32
SATD ALKANES						
ΣC ₂ + C ₃ (ng/g)	0.63	0.62	0.07	0.55	0.29	0.36
ΣC ₄ + C ₅ (ng/g)	0.12	0.07	0	0.08	0.059	0.05
ΣC ₆ + C ₇ (ng/g)	0.17	1.03	0.9	1.04	5.28	1.50
other compounds (ng/g)	0.03	12.42	7.77	0.035	3.17	
ngΣC ₂ + C ₃ /ng Co x 10 ⁷	Alkenes = 0.03	Alkenes = 4.82	Alkene = 1.55	Alkene = 13.7	Alkene = 194	Alkene = 0.39
ngΣC ₄ + C ₅ /ng Co x 10 ⁷						
ngΣC ₆ + C ₇ /ng Co x 10 ⁷						
ng other compounds/ng Co x 10 ⁷						

SAMPLE	66-1	2371	2377-1	2377-2	2377-6	2389
Sed Depth (cm)	0-12	0-15	0-10	10-20	50-55	0-10
Water Depth (m)	64	70	50	50	50	60
Lithology	olive gray clay	olive gray	Librown silty silt	brn. sand, silty	dark brn silty	olive clay
Methane	0.95	14.0	5.20	4.15	3.86	44.0
Ethane	0.02	0.11	0.07	0.10	0.09	0.80
Ethylene	2.85					
Propane	0.01	0.05	0.08	0.06	0.05	0.23
i-Butane				trace		
n-Butane	0.002		0.007	0.01	0.009	0.11
neoPentane						
Me Butane or Pentene			0.14	0.38		
i-Pentane						
n-Pentane			0.008			84.8
cycloPentane		0.15	0.06	0.03	0.60	0.19
DMS or CS ₂	13.2	6.13		0.23		
2,2-DiMeButane	0.04	0.56				10.4
2,3-DiMeButane	0.38	0.04				6.99
2-MePentane	0.118	0.12	0.06	0.03	0.05	
2-MeFuran			0.097	0.04		
3-MeFuran	0.02					6.37
3-MePentane or 1-Hexene		0.08				6.04
n(6 or 2-Hexene or MePentene	0.02	0.17	0.036	0.18		0.06
3-MeButane						0.85
2-MeButane or MePentene					0.07	0.83
MecycloPentane		0.04		0.11		0.31
2,2-DiMePentane		0.20		0.24		1.86
Benzene	0.24	0.22				
2,4-DiMePentane						
2,2,3-TiMeButane						
1-Mecyclopentene				0.60		
cyclohexane	0.27	trace				0.58
c+t3, 5DM cyclopentene						
3,3-DiMePentane						
cyclohexene	0.27					
1,1-DiMecycloPentane	0.16					
2-MeHexane		0.04				
2,5-DiMeFuran	0.02					
1-Trans-3-DiMecycloPentane		trace				
2,3-DiMePentane		0.09				
3-MeHexane	0.06	0.20				

TABLE 15 (CONTD.)

SAMPLE	66-1	2371	2372-1	2372-2	2372-6	2389
Sed Depth (cm)	0-13	0-15	0-10	10-20	50-55	0-10
Water Depth (m)	64	70	50	50	50	60
1-Trans-2-DiMecycloPentane	0.035					
3-Ethyl Pentane		0.03				
1,3 DiMecycloPentene		0.01				0.53
1,4 DiMecycloPentene		0.09				
3 Methyl Methylene cyclo-pentene		0.63				
n-Heptane		0.10				
1,c-2-DiMecycloPentane						trace
MecycloHexane						
1,1,3-TMCP						
2,2-DMH		0.3				
ECP						
2,5-DMH						
ECP						
2,5-DMH						
2,4-DMH						
1,2 DiMecycloPentene						
2 Methcophene		0.20				
Tol						
3-Methcophene		0.50				
1C2T3TMCP						
Total C (%)	8.64 ± 0.39	7.97 ± 0.08	11.27 ± 0.15	11.03 ± 0.24	11.57 ± 0.20	8.09
organic C (%)	5.08 ± 0.06	3.51 ± 0.03	0.61 ± 0.02	0.60 ± 0.01	0.25 ± 0.00	3.86
SATD ALKANES						
ΣC ₂ + C ₃ (ng/g)	0.03	0.16	0.15	0.16	0.14	1.22
ΣC ₄ + C ₅ (ng/g)	2.85	0	0.015	0.01	0.009	0.12
ΣC ₆ + C ₇ (ng/g)	1.10	1.7	0.10	0.56	0	29.4
other compounds (ng/g)	13.28	7.18	0.18	0.27	0.39	3.65
ngΣC ₂ + C ₃ /ng Co x 10 ⁷	Alkene = 0.98	Alkene = 1.08	Alkene = 0.118	Alkene = 1.02	Alkene = 0.165	Alkene = 6.19
ngΣC ₄ + C ₅ /ng Co x 10 ⁷						
ngΣC ₆ + C ₇ /ng Co x 10 ⁷						
ng other compounds/ng Co x 10 ⁷						

SAMPLE	2390	33-1	35	43-2	44
Sed Depth (cm)	0-10	0-15	1-10	~100-110	0-10
Water Depth (m)	73	70	64	70	70
Lithology	olive brn clay	olive brn clay	olive brn clay	gray clay	
Methane	21.8	24.2	57.8	22.6	8.97
Ethane	0.68	0.54	1.18	0.44	0.11
Ethylene				~0.30	0.52
Propane	0.54	1.15	1.00	~0.20	
i-Butane				0.002	
n-Butane	0.13	0.13	0.15	0.006	0.03
neoPentane					
Me Butane or Pentene			1.0	0.22	
i-Pentane					
n-Pentane	0.02	0.11	0.06		0.006
cycloPentane	0.14	0.12			
DMS or CS ₂	2.63	22.9		12.7	
2,2-DiMeButane	14.4		0.02		traces
2,3-DiMeButane		0.15		0.01	
2-MePentane	0.04	0.10	0.13	0.09	
2-MeFuran	0.10		0.36	0.02	
3-MeFuran	1.08				
3-MePentane or 1-Hexene	trace	0.118	0.03	0.06	
n(6 or 2-Hexene or MePentene	1.61	2.69	0.12	0.40	
3-MeButane			0.07	0.08	
2-MeButane or MePentene					
MecycloPentane	18.6	0.38	0.06	0.08	
2,2-DiMePentane	0.05	0.11		0.08	
Benzene	5.92	0.27	0.10	0.02	
2,4-DiMePentane				0.29	
2,2,3-TiMeButane				0.04	
1-Mecyclopentene		0.118		0.04	
cyclohexane	trace			0.14	
c+t3, 5DM cyclopentene	0.03 _{eq}				
3,3-DiMePentane				0.06	
cyclohexene	0.13	0.10		0.07	
1,1-DiMecycloPentane	0.03	0.11		0.06	
2-MeHexane		0.07		0.09	
2,5-DiMeFuran					
1-Trans-3-DiMecycloPentane		0.06		0.05	
2,3-DiMePentane	0.05 0.41	0.08		0.15 0.17	
2-MeHexane					

TABLE 15 (CONTD.)

SAMPLE	2340	33-1	35	43-2	44	
Sed Depth (cm)	0-10	0-15	1-10	~10070	0-10	
Water Depth (m)	73	70	64	70	70	
1-Trans-2-DiMecycloPentane		trace		0.12		
3-Ethyl Pentane		trace		0.15		
1,3 DiMecycloPentene						
1,4 DiMecycloPentene		0.154				
3 Methyl Methylene cyclo- pentene				0.02		
n-Heptane		0.11		0.13		
1,c-2-DiMecycloPentane	0.26			0.08		
MecycloHexane		0.78		1.00		
1,1,3-TMCP				0.05		
2,2-DMH				0.06		
ECP	0.30			0.02		
2,5-DMH				0.054		
ECP				0.		
2,5-DMH						
2,4-DMH				0.08		
1,2 DiMecycloPentene				0.04		
2 Methcophene				5		
Tol	trace	0.85		1.47		
3-Methcophene				0.12		
1C2T3TMCP						
Total C (%)	8.09	8.53 ± 0.07	6.07 ± 0.11	8.24 ± 0.13	9.85 ± 0.16	
organic C (%)	3.86	4.57 ± 0.02	1.74 ± 0.18	1.94 ± 0.01	2.90 ± 0.	
SATD ALKANES						
ΣC ₂ + C ₃ (ng/g)	1.22	1.69	2.18	0.64	0.63	
ΣC ₄ + C ₅ (ng/g)	0.12	0.24	0.16	0.008	0.036	
ΣC ₆ + C ₇ (ng/g)	39.4	5.94	0.32	4.60	0	
other compounds (ng/g)	3.65	0.29		12.95	traces	
ngΣC ₂ + C ₃ /ng Co x 10 ⁷	Alkene = 649	Alkene = 1.0		Alkenes = 0.81	traces	
ngΣC ₄ + C ₅ /ng Co x 10 ⁷						
ngΣC ₆ + C ₇ /ng Co x 10 ⁷						
ng other compounds/ng Co x 10 ⁷						

2. Hydrocarbon concentrations showed a rabbit ears distribution with a few compounds dominant on the GC. The origin and accumulation processes at the surface are very specific. Many samples contained either no branched paraffins or a few specific ones. For example: 85% of samples with C_4 hydrocarbons contained only normal butane; 59% with C_5 hydrocarbons contained only normal pentane, 23% contained only neopentane, and 9% contained only isopentane; 83% of samples with aromatic hydrocarbons contained only benzene on the GC.

3. The gem-dimethyl hydrocarbons (neopentane, neohexane, and neoheptane) were dominant among the branched hydrocarbons. These are believed to have a terpene source. Among the C_6 branched alkanes, 2,2-dimethylbutane (neohexane) was in highest concentration in 59% of the samples, and among the C_7 , 2,2-dimethylpentane was highest in 38% of the samples.

4. Olefins were present in most of the surface samples. We identified by GC-MS - ethylene, propylene, pentenes, hexenes, cyclohexene, methylpentenes and dimethylcyclopentenes.

5. Several furans were identified, notably, 2-methylefuran, 3-methylfuran and 2,5-dimethylfuran. The 3-methyl is particularly interesting because it is very difficult to synthesize compared to the 2-methyl.

6. Sulfides such as dimethylsulfide, thiophene, 2-methylthiophene 3-methylthiophene and ethylthiophene were present in appreciable amounts. The concentration of dimethylsulfide seemed to be related to the reducing conditions of the sediment.

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Report D

General Data on the Geophysical Nature
of the Persian Gulf and Gulf of Oman

by

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Part III - Geophysical Studies

Cruise tracks for the geophysical studies are shown in Figures 25 and 26. Along these tracks we took echo-sounding, gravity, magnetic and seismic profiling data. The data, which is voluminous, will be of most use for those interested in specific areas. For this reason we have included copies of all the data and limit our discussion to a few generalities. The seismic profiles are included as a separate part of this report and contain five major components:

1. Cruise track - general
2. Actual navigation plots
3. On board, analog, single-channel, 5-second sweep, graphic recordings using hydrophone number 1 of the streamer. The digitally recorded data are presented immediately following the shipboard recordings.
4. Deconvolved, single channel (generally hydrophone number 1 of streamer) digitally recorded seismic reflection profile using four air guns fired synchronously (300, 120, 80 and 40 cubic inch chambers)
5. Common depth point stacks using 6 channels

Tables 16 and 17 show the materials listed on the digital tape logs and the parameters cited at the margin of each heading.

Some words about the seismic system we use are appropriate for those who may wish to use the data. The following has been prepared by Daniel R. Shaughnessy III:

Figure 25 Location of seismic profiles in Persian Gulf

Figure 26 Location of seismic profiles in Gulf of Oman

TABLE 16

EXPLANATION OF HEADINGS ON DIGITAL TAPE LOGS

DATE	day, month, year
HICUT) LOCUT)	filter pasband of the analog signal before digitizing
The data logging program normally makes an entry on the reel log sheet each fifteen minutes.	
SHOT	consecutive shot number on a line
FILE	file of shot on tape, one file per shot, typically 900 files per tape
SI	sampling interval in milliseconds, typically 4 ms
FIRE	source repetition rate in seconds
DI	delay in start of digitizing after shot instant in seconds, used to skip sound travel time in water column
HDC	ship's heading in degrees
SP	ship's speed through water in knots

TABLE 17

EXPLANATION OF PARAMETERS CITED IN THE HEADING ON THE LEFT
MARGIN OF EACH RECORDING.

There are six lines to the heading containing two to seven entries.

1. SHOT - consecutive shot number along line at start of reel
DELAY - the travel time between shot instant and start of digitization
in seconds
SAMPLE - digitizing rate in milliseconds, four milliseconds for all
these data
LENGTH - travel time interval digitized, five seconds for all these
data
2. FIRE - source repetition rate in seconds
SPEED - speed of the ship through water in knots at start of reel
HEADING - ship's course at start of reel
3. PRESSURE - air gun pressure in pounds per square inch
VOLUME - total chamber volume of air guns
- 4-5. Stacking parameters
NFOLD - number of channels used to form stack
LENGTH - number of seconds in stack
WINDOW - number of points in data window for each point in stack
COVERAGE - number of shots per half unit array spacing
LO-FR - lower limit of frequency pass band in Hertz
HI-FR - upper limit of frequency pass band in Hertz
DIP - slope of seafloor in degrees. Zero used for all these data
in less than 200m of water
PLOT SCALE - amplitude scale for traces on plot
6. Deconvolution parameters
NDCL - deconvolution operator length (no. of points)
NDCS - operator sampling relative to data sampling
NDCS - number of channel used for single-channel playback (deconvolved
recordings only)
ISTK - horizontal stacking running average coefficient for single
channel recordings
TVGE -)
TVGL -) operator parameters pertaining to automatic gain
CNTRST -) normalization subroutine of recording

The date stamped above the heading is the date of processing.

The spurious characters appearing in the label block are due to the Varian
Model 4000 recorder not being adequately warmed up.

Data Acquisition

Multi-channel processing relies heavily on the quality of the data acquired. This means not only the hardware, but also the physical environment of data acquisition. Data acquisition consists of several components: source, receiver, and acquisition system. The control and care used in combining these factors will greatly dictate the quality of the data and the ease with which processing can be accomplished. Extensive processing is not beneficial on data with a very low signal to noise ratio.

At Woods Hole Oceanographic Institution the Bolt air gun has become the dominant source used for seismics, although several other types of seismic sources are available. Air guns have become dominant because they are a realistic compromise between available energy, efficiency, reliability, cost, and potential hazard. With the application of tuned air gun arrays, the air gun signal has been modified to reduce some of its less desirable features. We have been successful at increasing the energy output and decreasing the length of the bubble pulse by use of a four or five gun array. The control of the array has been accomplished by an electronic package that generates time delays for each gun. Each gun is monitored by a separate

accelerometer, so that initial shot instant can be determined for each air gun. The depth of the air gun array is also important to the initial signal, $1/4$ wave length of the primary frequency being ideal.

The hydrophone array's characteristics are generally fixed at the time of construction. The operator selects an array which has specifications that suit his purposes. The operation of the hydrophone array will modify the data quality. The depth of the hydrophone array is important, again $1/4$ wave length of the primary frequency being best. This produces both a quality signal and minimizes sea noise. Tow noise is a function of the array and the speed at which the array is towed. Maximum speed for the 12-channel array should be six knots, with 4.5 knots being ideal. The operator should keep in mind that as noise goes up, penetration and resolution go down. Finally the array should be towed in a straight line. This is important to the processing programs that do common depth point stacking and deep water multiple removal.

The acquisition system is a computer-controlled system allowing for more flexibility. The incoming signal passes through several phases: filters, gain-ranging amplifiers, digitizer, computer and magnetic tape. Gain information is

preserved throughout this process so that real amplitude records can be produced, if desired. This gain information is used to normalize the signal to hydrophone output in volts. Computer control allows our field tapes to be written in a time demultiplexed and gain-normalized format. This eliminates the common first step of processing, demultiplexing of field tapes.

The delay changes that are used to window out the water column are controlled by the watchstanders. The improper handling of delay changes can complicate the later processing and the final interpretations. Delay changes should be handled in reasonable increments, such as .5 seconds rather than 0.1 or 0.2 seconds. It takes twelve shots to make a single common depth point stack; if the delay is changed on the 11th shot, the gather will involve two different delays. This, of course, complicates the processing and dictates the use of more computer time.

The term, common depth point gather, has certain implications regarding the navigation of the vessel conducting the seismic survey. Ideally, the vessel's navigation should be such that the mid-point on the sea floor, between the source and receiver, is occupied twelve consecutive times. That is, once for each channel. Navigation is not that exact a science. What is needed for good common depth point data is a straight line with little or no crabbing from the designated course. The second factor that enters into the navigational problems is knowing when to shoot. The operator must know when the next shot point is occupied.

This is done by one of two ways; either over the ground navigation, which is very expensive, used extensively by the oil companies. The other is done through the use of ship speed, assuming a constant rate over the ground in conjunction with a fixed source repetition rate, the method being used at W.H.O.I. now. Treatment of these navigational considerations in a light manner will decrease the effectiveness of stacking and complicate the velocity analysis portion of processing.

Introduction to Processing

Multi-channel seismic processing consists of several dependent sequential processing steps. At Woods Hole there are three basic steps, (1) single-channel processing, (2) velocity analysis, and (3) common depth point stacking. This type of processing is very time intensive because of the large amounts of data involved. On future cruises there will be twelve channels with a possible data length of ten seconds. A one-second data window is represented by 250 floating point values per channel. A floating point value is equal to two computer words. Therefore, a single 10-second shot is represented by 60,000 computer words; (250 floating point values x 2 computer words x 10 seconds of data x 12 channels). Normally, a shot takes place every thirty seconds during acquisition. This equals 7.2 million words per hour and 172.8 million words of data per day. Of course, not all ten seconds of data length will always be used.

The computer times for processing reflect the length of data and the number of channels. In the following discussion, a data length of five seconds and twelve channels of data is assumed. These times do not reflect the time that needs to go into program modification for twelve channels, estimated to be two man-months. Additionally, the time of the geologist is not considered in the report; Figure 27 shows his position in the processing flow. Table 18 is a tabular form of the times of processing for computer and operator.

Single-Channel Processing

The first phase of the processing sequence is to produce a single-channel record. The main single-channel program is DCOND. This program provides for a wide variety of options: predictive deconvolution of shallow-water reverberations, vertical stacking, filtering, correction of source receiver separation, and a variety of different graphical representations.

Figure 27

Flow diagram for seismic processing system.

TABLE 18

(Times for Computer and Operator)*

<u>PROGRAM **</u>	<u>OPERATOR</u> (Minutes)	<u>COMPUTER</u> (Minutes)
DCOND	20	60
TRACV	5	5
NMOV	30	30
VSET	20	60
VSCAM	10	640
VSCN2	10	65
VSCN3	5	10
NMOV	120	180
XDCDP	45	540
CDPQ	10	30
TRACV	<u>5</u>	<u>5</u>
Total:	4.67 hours	27.08 hours
Per Line Kil.	.114 hours	.66 hours

*The times expressed in this Table represent six hundred shots, each consisting of 5.0 seconds of data and 12 channels. These times also indicate a reel having no data problems. Therefore it is the minimum time that can be expected.

**Refer to flow diagram for program responsibilities.

The records that result from this program are used for preliminary geological interpretations and to select locations for velocity scanning. These locations are chosen with several criteria in mind: simplified geological structure, good-quality data, and consistent acquisition parameters. The spacing of these locations is determined by the geology of the area. The more complex the geology, the more locations needed. In simple flat-lying areas, a location every 4.5 kilometers may suffice, but this should not be regarded as a rule (most of the oil industry do velocity analysis every 1 to 2 kilometers; for them this is an upper limit. In some cases they will analyze every shot). The single-channel processing also indicates if there are any problems with the data tapes (see Figure 27). The time for executing the program depends on the options selected. A data set of 600 shots (41.6 kilometers) of five-second duration, with filtering, takes 40 minutes of computer time. The same data with deconvolution requires approximately one hour, depending on the length of the deconvolution operator.

Velocity Analysis

Phase two of the processing sequence, velocity analysis, has several steps. Initially, a pattern of velocities is selected and normal move out corrections are made for each channel at each velocity. These corrections are then stored in a disc file for use with the velocity scanning program VSCAM. These normal move out corrections need only be calculated once. The

initial velocity spacing is usually satisfactory for most data in a given area (with the stipulation that the geometry of the array is not changed during that time).

Normal move out corrections are time corrections. The corrections differ from channel to channel as a function of the geometry of the array and the layered medium the signal passes through. These corrections are applied to each channel so that the data string from each will be normalized in time, thus allowing for the different travel paths of each channel.

To lessen the need for tape changes and to make long nights runs possible, a secondary program (VSET) is used in conjunction with the program, VSCAM. VSET produces an intermediate magnetic tape that contains the necessary program parameters and only the data necessary to the velocity scanning. This program, VSET, allows thirty-one locations to be run at one time. VSCAM with 31 locations, takes approximately sixteen to eighteen hours. This is the most time consuming of the processing programs. The results are critical to the common depth point stacking. There are two other programs available for velocity analysis. One of these uses the Maximum Likelihood Method developed by Steve Leverette here at Woods Hole. The other program is the conventional velocity spectrum with coherency display. These programs are used to supplement the velocity scanning program, if its results are not decisive, but both programs are more time consuming than velocity scanning.

The results of the velocity analysis are then examined by the

geologist, who picks several velocity vs. two-way travel time points for each location. These picks are then used to determine the stacking velocities (Root Mean Square (RMS) velocities). The stacking velocities are used to construct a set of normal move out corrections through the use of program NMOV. This is done for each location and the corrections are arranged in an index file for use with the stacking program.

Common Depth Point Stacking

Stacking multi-channel data emphasizes the acoustic horizons, while destroying the multiples, if the stacking velocities are accurate. This is why velocity analysis is the key to good stacks. If the velocity analysis is poor, it is possible to stack multiples unknowingly, thus producing erroneous geological interpretations. XDCCDP uses the index file produced by NMOV to stack the multi-channel data. The stacking program, XDCCDP, has several options to further enhance the end product. The muting of the extreme channels (4, 5, and 6) in shallow water is often desirable. Linear interpolation between picks to preserve continuity of the record is another commonly used option. Deconvolution is an option that is used extensively in shallow water. These options are combined with filtering, gain normalization and geological knowledge to produce the optimum stack. (Please refer to Table 18 for times concerning stacking.)

This sequence of processing events is further complicated by the following prejudices: slope, deep water and complex

geological structure. The processing programs are presently set up to handle deep water situations, and changes in delay to a maximum of twelve seconds of data (data being the water delay plus the actual seismic data). This twelve-second limit is also in effect for the use of NMOV for VSCAMS. A deep-water multiple removal program is useful, but still experimental. Slope is regularly corrected for in simple geological areas. In complex geological areas, the migration technique is needed for stacking.

Work may begin in early 1978 on development of migration-type programs. Migration is generally used in areas of complex structures: dipping layers, curved layers, and faults. These structures cause the reflection points to migrate from their assumed mid-point locations. Curvature of reflectors, not dip, is the dominant factor in the migration of reflector points. Therefore, even flat lying reflectors which have curvature may benefit from migration. Migration is an operation which positions all data on a section to their true reflection points. There are basically two methods for migration: circular arc (Hagedoorn, 1954), and wave equation (Claerbout, 1969, 1970). Velocity inhomogeneity can be handled more satisfactorily by wave equation than by ray tracing. Both methods will be explored during early 1978.

All of these complicating factors are extremely time intensive, both for operators and computer. These time considerations may be extensively altered by modification of the existing computer system used for processing.

Bathymetry, Magnetism and Gravity

Bathymetric magnetic data, collected by using a towed magnetometer, and gravity information was collected along the seismic track and usually during travel between coring or water sampling stations. The data, like that of the seismics, are presented plotted against time (Table 19). This information is best evaluated by comparison to the seismic plots accompanying this report. Shown in the table is bathymetry in meters, magnetic anomaly in gammas, and the Free Air and Bouguer anomaly (plotted in darker print) in milligals. In general, the changes in magnetic and gravity values are subtle and appear correlatable although not very much so with that of the general structure of the region. In the Persian Gulf the structure is that of flat lying beds whereas that of the Gulf of Oman is of tight folds. Interpretation of these data is not complete at this time but will be available in the near future.

General Structure of the Persian Gulf/Gulf of Oman Area

Surprisingly little information is available in the scientific literature about the structure of the Persian Gulf. The western boundary of the Gulf is the Precambrian Arabian Shield or Platform covered by Mesozoic and more recent sediments. At the southern part of the Gulf, the Oman Mountains strike north towards Iran and constrict the opening of the Gulf (Figure 28). The Iranian coast on the Persian Gulf is the Zagros Fold Belt,

FREE AIR AIRY BOUGUER ANOMALY

MAGNETIC ANOMALY

PLotted in LONGITUDE PROFILES PRINTOUT

Bathymetry, magnetic and gravity data plotted against time from the Persian Gulf and Gulf of Oman.

06 03 77 0400

TABLE 19 (contd.)

TABLE 19 (contd.)

TABLE 19 (contd.)

TABLE 19 (contd.)

TABLE 19 (contd.)

TABLE 19 (contd.)

Figure 28

Main structural features of the Persian Gulf, Strait of Hormuz, Gulf of Oman area. Note that the suture zone in the Gulf of Oman is speculative.

with folds striking generally parallel to the NW trend of the Gulf. More inland is the intensely folded Zagros thrust zone and Zagros Mountains. Movement in this area probably began in Cretaceous but the main structures have resulted from Miocene to Recent folding (Lees, 1953). The Iranian coast is presently tectonically active. Thus the Persian Gulf lies between two distinct tectonic zones; the stable Arabian Shield and the unstable fold belts of Iran. The structure of the Persian Gulf, Strait of Hormuz and Gulf of Oman area is intimately controlled by the present and past collision of the Arabian Plate with the Eurasian Plate and subsequent subduction along the Zagros thrust zone (Figure 29). The structure of the Persian Gulf is generally thought to be one of gentle folding mainly from Miocene to Recent movements. A series of shallow sparker lines (penetration less than 30 m) made by Shell along the Arabian coast show a recent fault and fracture system affecting Miocene and perhaps Pliocene rocks (Kassler, 1973). Salt tectonics was also common during this time, both in the Persian Gulf and in Iran. In the Gulf the salt domes have formed islands, like Hormuz, or submerged bulges. The deepening of the Persian Gulf bathymetry near the Iranian coast is probably due to the tectonic activity and subduction (Figure 30).

The overall structural picture of the area is intimately related to plate movements (see for example Stocklin, 1974, and Stoneley, 1974). The collision of the Arabian and Eurasian plates and subsequent subduction of the Arabian plate began in the Mid-

Figure 29

The major plates and structural features of the Persian Gulf/Gulf of Oman area.

Figure 30 Schematic model of development of Zagros fold belt, suture zone and Persian Gulf (adapted from Haynes and McQuillion, 1974).

Cretaceous (Figure 30). This motion, which continues until today, has formed most of the present structure of southern Iran and the Persian Gulf. The present active suture zone between the Eurasian and Arabian plates is the Zagros Mountains range area (Haynes and McQuillan, 1974). The present limit of ocean crust may extend under southern Iran. Subduction has been detected by a recent British expedition using seismic reflection techniques in the far end of the Gulf of Oman east of 60°E. (Dan McKenzie, personal communication, 1975), but no surveys have been published from the main part of the Gulf of Oman or the Persian Gulf.

The Gulf of Oman is unique in that it is the only deep ocean area (>3000 meters) that lies between two closely juxtaposed continental plates that are presently converging (Arabian and Eurasian Plates). The northern shore of the Gulf of Oman consists of the Makran Mountain region, a Neogene flysch deposit nearly 5.5 km thick (Stoneley, 1974). These flysch deposits lie on an Upper Cretaceous melange containing ophiolites derived from the Tethyan ocean. The Neogene deposits prograde southward and are affected by southward-directed thrusting. Considerable shortening has taken place and the disposition of the sediments and faults suggest a northward-directed subduction of the material that forms the deeper parts of the Gulf of Oman (Stoneley, 1974). Andesitic volcanoes to the north beyond the Jaz Murian depression are reported to have had historic eruptions and complement the northward polarity of the subduction zone (Stoneley, 1974). Earthquake epicenters along the Makran coastal region have been related to

the present day subduction along the coast line (Nowroozi, 1972). Consumption of the lithosphere underlying the Gulf of Oman is now actively taking place along a presumably north-dipping subduction zone along the Makran Coast. Seismic profiles from a small area in the deepest parts of the Gulf of Oman reveal 4-8 km of sediments overlying a high velocity basement (6.3 km/sec; Bungenstock, 1966). It is not known if this high velocity layer represents older continental crust, newly-formed oceanic lithosphere, or fragments of the ancient Tethyan oceanic crust. The eastern boundary of the Gulf of Oman is marked by the Owen-Murray fracture zone, a large-scale transform fault separating the Indian plate from the Arabian Plate and Gulf of Oman (Stoneley, 1974). The southern boundary of the Gulf is marked by the Oman continental margin that has a gentle northward slope into the Gulf north of Muscat. Here Tertiary flysch sediments approximately 5 km thick rest unconformably on the Hawasina pelagic sediments (Permian to Lower Cretaceous) that formed in the ancient Tethyan Sea. South of Muscat on the Oman margin, the shelf is very steep with apparently little or no Tertiary sediments. On shore, in northern Oman, the Semail ophiolites representing Tethyan oceanic crust have been obducted on top of the Hawasina sediments during late Cretaceous and presumably were derived from the area which is now the Gulf of Oman depression (Glennie et al., 1973). To the west, the Gulf of Oman constricts to form the Strait of Hormuz where water depths become very shallow and presumably the thickness of the bottom sediments increases. Here the Musandam Peninsula, which constricts the Persian Gulf forming the Strait of Hormuz, is a drowned area of north-striking Permian autochthonous shelf

sediments apparently moving towards the Zagros fold belt where a continent-continent collision is now taking place.

The processed six-channel seismic reflection profiles taken in the Persian Gulf have gone through a preliminary interpretation. These seismic recordings, displaying from 2 to as much as 4 seconds of penetration, document the sedimentary history of the Gulf from Late Mesozoic to the present. Using well data from the region we have been able to identify two major unconformities, one of Late Cretaceous age and another of Eocene age. The recordings also indicate that diapiric structures associated with Hormuz salt are restricted to southeast of the Qatar line, a north-south trending structural high that divides the Gulf in two. This positive element appears to have influenced deposition in the region to recent geologic time. Future plans call for us to prepare geologic cross-sections and isopach and structure maps from the seismic profiles and from these reconstruct the Tertiary geologic history of the Gulf, a transitional zone between the Anatolian-Iranian ranges to the northeast and the Arabian shield to the southwest.

The Strait of Hormuz area is distinguished by considerable salt diapirs and faulting (Figure 31). Seismic profiles across the Gulf of Oman clearly show the effects of compression between the Arabian and Eurasian plate (Figures 32-34). The compression in the northwesterly direction has been sufficient to almost completely obscure the abyssal plains portion of the Gulf (Profile 17, Figure 32 and Profile 18, Figure 33). Whereas further to the southeast the two continental blocks have not yet met and some of the abyssal plain remains (Profile 19, Figure 34).

Figure 31

Location of profiles in the Gulf of Oman area and major structural features of the Strait of Hormuz region. Profiles 20, 21, 22 and 23 were made from the RRS Shackleton and were not a part of this expedition.

LINE 18

Figure 33 Seismic profile 18 taken in the near central portion of the Gulf of Oman. Note the lesser degree of folding on the Iranian side of the Gulf. See Figure 31 for location of profile.

NORTH

SOUTH

DISTANCE (kms.)

LINE 19

Figure 34 Seismic profile 19 taken in the central part of the Gulf of Oman. Note the presence of an abyssal plain. See Figure 31 for location of the profile.

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