Voyage of the E.W.SCRIPPS to the Gulf of California,
October-December, 1940

Account of the Expedition
C.A. Anderson, Roger Revelle, and F.P.Shepard

Introduction

During the fall of 1940, the auxiliary research schooner "E.W.Scripps" made a scientific cruise to the Gulf of California ~~sponsored~~ supported jointly by the Geological Society of America and the Scripps Institution of Oceanography of the University of California. The voyage lasted 78 days, from October 5 to December 22. A total distance of 6400 nautical miles was travelled; 4600 miles were logged during the 65 days that the vessel was in the Gulf itself, and the remaining 1800 miles were covered enroute to and from the area.

The ship was under the command of Captain E.D.Hammond. Assiting him in the handling of the vessel was a crew of six, including two engineers, two deckhands, a cook and a cabin boy. Seven men made up the personnel of the scientific party on board. The work at sea was under the joint supervision of Roger Revelle and Francis P. Shepard. Sydney C. Rittenberg was in charge of the chemical and bacteriological studies made on the Gulf waters and on sediment samples collected from the bottom; ~~while~~ and Kenneth O. Emery and Robert S. Dietz, assisted in all the operations at sea and were particularly responsible for the taking of cores and other samples of bottom sediments. The geology of the island and land areas in and surrounding the Gulf was studied by Charles A. Anderson. He was

assisted in the field by J. Wyatt Durham. Durham, who joined the ship after her arrival in Guaymas, also acted as paleontologist.

C. Francisco Diaz Salcido of the Mexican Departmento de Marina accompanied the expedition as representative of the Mexican Government. In addition to his official duties, Senor Diaz kindly acted as interpreter and as contact man with public officials, merchants and others. His services were invaluable, particularly to the geologists ashore. It is appropriate here also to acknowledge the gratitude felt by all the members of the expedition for the unfailing cooperation and courtesy extended to them by the representatives of the Mexican Government in San Diego, Guaymas, and other ports visited. Everything possible was done by these authorities to aid in the successful carrying out of the enterprise.

When the expedition was being organized, it was planned that Dr. W.S.W.Kew should be one of the members of the scientific party. Kew's previous geological work on the peninsula of Baja California and his extensive experience in reconnaissance geology and stratigraphy would have been of the greatest value to the enterprise, but unfortunately certain unforeseen developments prevented his participation, much to the regret of all concerned.

Considerable scientific exploration of the peninsula of Baja California has been carried out in the past, and many biological collecting expeditions have visited the islands and waters of the Gulf, but until 1939 there was virtually no information concerning either the geology of the Gulf Islands and sea floor or the physical and chemical oceanography of its waters. In 1939 the "E.W.Scripps" made a reconnaissance expedition to the entire Gulf, which was participated in by Revelle. From the soundings and cores of bottom sediments and the brief glimpses of land geology obtained then,

it seemed likely that in the Gulf of California at the present time are reproduced many of the conditions which characterized in the past, certain land areas of great geologic interest. It therefore became the purpose of the 1940 expedition to study the geologic processes which are or have been active in the Gulf, through coordinated investigation of the recent geologic history of the land, of the bottom topography and sediments, and of the nature of the marine environment. In its unity of purpose, which was constantly kept in mind both in planning the work and in discussing results, it is believed that the expedition differed from most of its predecessors.

On the 1939 expedition, soundings, cores and hydrographic data were obtained on a series of cross sections at more or less regular intervals between the entrance to the Gulf and a point about 30 miles below the mouth of the Colorado. Accordingly it was felt that maximum results could be obtained by concentrating the work in 1940 on certain relatively small areas of diverse character. Four such areas were selected:

(1) The region around Guaymas, with a relatively broad shallow shelf in the southern portion at the mouths of the Yaqui and Mayo rivers, and a mountainous coast north of the city, was chosen as representative of the range of conditions to be found on the eastern side of the Gulf.

in the western gulf

(2) The Carmen Island area, a region of complex submarine topography, and of many islands on which extensive exposures of fossiliferous marine Tertiary rocks occur, ~~was one of two regions selected from the western side of the Gulf, the other being~~

also in the western gulf

(3) The Concepcion Bay area, of less complex bottom topography but with a variety of sedimentational environments and extensive Pliocene and Pleistocene deposits.

(4) The Tiburon area, a region of special interest not only because it forms a constricted transition zone between the deep southern portion of the Gulf and the relatively shallow, gently sloping northern third, but because it contains the long, straight and deep fault trough of the ~~Ballenas~~ Salsipuedes Basin, between Angel de la Guardia Island and the peninsula, was the fourth area chosen.

In addition to these four areas, surveys of bottom topography in two submarine canyons were made while enroute to Guaymas, and the course of the vessel was so laid at other times that soundings could be taken in regions of topographic interest.

Reports on the geology of certain of the islands and of a portion of the coast are included in the present volume, in papers by Anderson, Durham and M. L. Natland. A discussion of the submarine topography is given by Shepard, together with a series of charts and a glossary of place names. Results in marine sedimentation and in physical, chemical and biological oceanography are not yet in final form but a brief survey of the field observations is given below.

Sedimentation.

Descriptions of sediments collected.

The cores obtained with the Emery-Dietz coring device were at the time the longest on record from the open sea (table 1). It is believed that the unusual lengths of the cores resulted from the relatively soft character of some of the bottom muds, and also from the use of core barrels 20 feet in length and 2 1/2 inches in diameter, equipped with liners of thin flexible celluloid in place of the metal or glass previously used.

Table 1.

Summary of coring operations

Type of sediment	No. of cores collected	Average length inches	Range in length inches
Laminated diatomaceous mud	32	156	48-201
Green or gray silty and clayey muds	20	86	49-180
Sandy or shelly muds	14	64	14- 91
Gravel, sand and shell	19	22	2- 65
Hard gray clay	9	15	4- 42
Total no. of cores collected	94		
Total no. of trials	119 (5 from rocky areas)		

Several of the cores collected in the Guaymas area were over 15 feet long, and one was nearly 17 feet in length. Approximately 50 cores and about 10 surface snapper samples were taken in this region. The coring was done systematically, along six lines at right angles to the coast, extending from the inner continental shelf to depths of 400 to 1000 fathoms 20 to 30 miles from shore. In the northern part of the area, the deeper cores were usually finely laminated diatomaceous muds stinking of H_2S from top to bottom, and apparently high in organic matter. On drying, the laminations were clearly seen as alternating white and green bands about .2 to 1 mm thick, which became more closely spaced as the bottom of the core was approached, probably owing to compaction. A count of the number of laminations in a section of one core 7 inches long showed about 200 white bands. If these represent annual layers corresponding to seasonal fluctuations in the production of plankton diatoms in the overlying waters, the rate of deposition of these relatively loose muds may be calculated as about 1 foot in 350 years. The rate of accumulation of the compacted sediments is probably considerably smaller, however.

Appreciable amounts of an inflammable gas, possibly methane, were present in the lower parts of several cores of diatomaceous mud. Yellowish layers, often up to an inch in thickness, which may be bentonite, occur in many of the diatomaceous muds of the middle third of the Gulf. These may represent one of the episodes of recent vulcanism which are known to have occurred in this region and suggest that volcanic activity has supplied some of the silica utilized by diatoms and removed when their skeletons were deposited.

In the southern part of the Guaymas area, the laminated diatomaceous muds are intercalated with gray sand, silt and clay layers ranging from 1 mm to 4 or more cm in thickness. These may represent flood materials carried

by the Yaqui or Mayo rivers, and agree in appearance with the gray to chocolate brown stratified deposits on the shallow shelf between Guaymas and Isla Lobos at the mouth of the Yaqui river. In general the relatively gentle bottom topography of much of the area and the evidence of recent subsidence, given by both the shore geology and the presence of submarine terrace levels at depth, indicate that the Guaymas area is one of considerable sediment accumulation. On the other hand the presence of several steep slopes, some of which are apparently bare of recent deposits and of two steep sided ridges suggests that this accumulation is ~~probably~~ extremely variable in thickness, depending on the bottom topography and the distribution of bottom currents. It is quite likely that continuing diastrophic activity accompanies and frequently interrupts the sedimentation.

In contrast to the east side of the Gulf, where a relatively large amount of detritus is carried to the sea during floods by intermittent streams of Sonora and Sinaloa, little clastic debris of sand size occurs in the sediments of the west side. On the 1939 expedition it was found that calcareous sands and gravels are present on many of the beaches and in shallow water areas near shore on the west side of the gulf, while glauconitic and foraminiferal muddy sands cover some of the off-lying ridges. In order to study the distribution of these calcareous deposits, several lines of closely spaced snapper samples were run out from shore during the 1940 expedition in both the Carmen Island and Concepcion Bay areas. It was found that nearly pure calcareous sands and gravel occur only in depths less than about 30 fathoms on the open shelf, and that beyond the shelf or in deeper water there is a relatively abrupt transition through foraminiferal muddy sands to muds containing little carbonate. In protected embayments such as Concepcion Bay, there are

~~occur~~ gray muds, of low carbonate content, but with abundant shells, while off the occasional flood plains, detrital sands and muds predominate. It is noteworthy that many of the late Pliocene and Pleistocene deposits of the islands and the Peninsula closely resemble lithologically the calcareous deposits found on the shallower parts of the open shelf and therefore were probably deposited under the same conditions. Systematic coring lines were run out from shore in both the Carmen Island and Concepcion Bay areas although delays due to bad weather and other causes prevented the taking of as many cores as would have been desirable. Laminated diatomaceous muds and green non-laminated muds were found. Some of the cores contain sandy or silty layers, made up of glauconite grains and foraminiferal tests.

In the channel between Tiburon and Angel de la Guarda Islands an area of relatively complex bottom topography was found. The characteristic deposit at this point is an extremely compact gray or greenish clay overlain by muddy sands and gravels, the latter often containing subangular pebbles up to several centimeters in diameter. Sands and gravels are widespread at depths as great as 220 fathoms, although in the small basins which occur in this channel, fine-grained green muds are found. In the deep ~~Ballenas~~ Salsipuedes basin, to the west of Angel de la Guarda Island, a core several feet thick of relatively well sorted muddy sand was collected, and at another point, 600 fathoms deep, a coarse shell gravel was found. In the deepest part of the basin, fine-grained muds occur. These results make credible the finding by Natland of widespread gravelly sands containing relatively deep-water forams in the Pliocene of the Ventura basin of Southern California.

In the deep, broad basin to the south of the Tiburon area, laminated diatomaceous muds occur ~~which, however,~~ These differ from those found near Guaymas in their firm, relatively stiff character, suggesting the action

of diagenetic processes, perhaps a change in the nature of the colloidal silica.

Chemical and bacteriological studies of sediments.

Various types of investigations were carried out on freshly collected cores in order to study the chemical and biological conditions under which diagenetic processes are occurring in the muds.

Table 2

Statistical summary of analyses of sediments

Type of measurement	No. of cores studied	No. of individual portions of cores examined
Hydrogen ion concentration (pH)	95	1200
Oxidation reduction potential	8	70
Amount of decomposable organic matter	27	105
Presence of sulphate-reducing bacteria	32	100
Sulphide content	8	40
Quantitative measurements of bacterial distribution	9	60
Qualitative tests for presence of viable bacteria	26	50

Quantitative bacterial counts were made on the mud from nine cores, representing most of the types of sediments found. The aerobic and anaerobic populations were determined from the top to the bottom of the mud column, an average of seven levels per core being sampled. The bottom layers of 26 other cores, from 6 to 16 feet in length, were also tested for both aerobic and anaerobic bacteria by enrichment culture techniques. Although microorganisms are abundant in the top layers of the sediments, they are absent or very scarce near the bottoms. Geologically this may mean that the role of bacteria in diagenesis is confined to the topmost

~~mean that the role of bacteria in diagenesis is confined to the topmost~~ layers of sediment.

The source and fate of the hydrogen sulphide found in many cores was investigated. If the sulphide results from the reduction of sulphate ion in sea water, sulphate-reducing bacteria should be present, and accordingly 32 cores were tested for sulphate reducers at three or more levels from the surface to the bottom. Sulphate-reducing bacteria were found only near the surface. Chemical examination, both qualitative and quantitative, showed that in the green muds little or no H_2S occurs in the surface layers, where sulphate-reducing bacteria are found, but that the H_2S content rises to a maximum several feet below the surface, and then frequently decreases with depth. No acid-soluble iron sulphide is present in the green muds, even those containing more than 100 milligrams of hydrogen sulphide per liter of interstitial water. On the other hand gray muds from Guaymas harbor, and black muds from the Carmen Island salt lagoon, contain considerable acid-soluble sulphide and little if any hydrogen sulphide. Evidently, in these sediments, H_2S is precipitated as iron sulphide as fast as it is formed. The failure of iron sulphide to form in the green muds suggests that the iron in these muds is present in highly insoluble compounds.

The hydrogen ion concentration (pH) of the interstitial mud waters was determined at all depths in most of the cores collected. Each general type of sediment seems to have its characteristic pH. The values found range from 7.40 to 9.50. In cores of uniform composition there is a tendency for the pH to increase with depth, that is for the interstitial water to become more alkaline. The pH also tends to increase with increasing particle size.

The amount of organic matter available for oxidation by microorganisms was determined in 27 cores, by measuring the amount of oxygen consumed in stored water samples containing some of the mud in suspension. The results indicate that an appreciable fraction of the total organic matter in the sediments is readily decomposable.

Physical and Chemical Oceanography

Current measurements.

There can be little doubt that the coarse sands and gravels found on the bottom in the Tiburon area have been deposited under nearly the conditions of the present day, but the mechanism of transportation of the sand grains and pebbles is difficult to understand. Strong tidal currents are known to occur in this area, however, and it was thought possible that under extreme spring tide conditions the bottom currents might be competent to transport coarse sand and pebbles. In order to test the above possibility, bottom current measurements were made during a twelve hour period at a depth of about 220 fathoms in the channel between Tiburon and Angel de la Guarda Islands. Later the vessel was anchored, for thirteen hours, at a depth of 700 fathoms in the ~~Ballenas~~ Salsi Puedes basin, while currents at various depths from the surface to the bottom were measured. In both instances appreciable bottom currents were observed with velocities up to a third of a knot. The period of observation was one of rather small tides, but it is noteworthy that the currents at the bottom were about half as strong as the observed surface currents. The latter are known to reach velocities of several knots, so that the maximum bottom currents may be expected to be at least one or two knots. ~~Given the aid of~~ a small ~~downhill~~ slope (storm), such currents may be able to move small pebbles. The facts that relatively high velocities were observed several hundred fathoms below the sill in the ~~Ballenas~~ Salsi Puedes basin, and that the velocity at the bottom was in general opposite

in direction to that at the surface, indicate that the currents in this area are associated with an internal wave and are not true tidal currents, since the latter are constant in direction from top to bottom, and cannot exist in a basin below sill depth.

Bottom current measurements with a tripod were made at depths of about 1000 fathoms during two nights while the ship was drifting in the basins east of the Carmen Island and Concepcion Bay areas. The observed currents were of very small magnitude, usually less than a few hundredths of a knot. It should be noted that the cores collected in these localities were uniformly fine-grained laminated diatomaceous muds.

On two occasions the ship was anchored in the southwestern part of the Guaymas area, where the bottom sediments were found to consist of alternating clay, silt, or sand layers and diatomaceous muds. At the first anchor station, measurements were continued for 24 hours, while on the second, the vessel lay at anchor in about 700 fathoms for 5 days.

By means of instruments specially constructed by C.I.Johnson of the Scripps Institution, which were so designed that they could all be suspended on the wire at the same time, current measurements were made simultaneously at the surface, 200, 500 and 800 meters, and at the bottom. At intervals between current observations, the vertical distribution of temperature, salinity and oxygen from the surface to 1000 meters was obtained. Velocities up to more than 1 knot were found at all depths above the bottom, while even at the bottom very appreciable currents were observed, in spite of the marked frictional drag on water movements which must be exerted by the uneven sea floor. It seems certain that part of the current motion was tidal in origin and the existence of an internal wave of tidal or longer period is suggested by the general tendency for the current at the surface and the bottom to flow in

opposite directions.

Rate of deposition of organic remains.

The occurrence of laminated diatomaceous muds on the Gulf floor raises three important questions: (1) Are the laminations seasonal, perhaps representing seasonal rhythms in the rate of diatom production in the subsurface waters of the Gulf?; (2) What peculiar conditions in the water allow the deposition of the diatom frustules on the bottom, to form a deposit which is perhaps unique on the present sea floor?; (3) What is the origin of the silica continually extracted from the sea water by the diatoms and permanently removed by the deposition of their frustules on the bottom? In an attempt to partially answer these questions investigations of various types were carried out on the Gulf waters. These are summarized in Table 3.

Table 3

Summary of hydrographic work accomplished

Type of observation	No. of stations	No. of Series	No. of observations
Water temperature	13	29	334
Water samples for chlorinity	13	29	269
Dissolved oxygen content	13	28	265
Dissolved phosphate content	9	16	172
Dissolved silica content	10	16	172
Phytoplankton distribution	13	17	104
Rate of photosynthesis	4	6	25
Content of decomposable dissolved organic matter	5	5	49
Bacterial distribution	9		18
Amount of suspended matter in deep water	9	13	47
Current measurements	6		463

The seasonal character of phytoplankton production in the Gulf is demonstrated by means of information obtained on the two "E.W.Scripps" expeditions. On the 1939 cruise, which took place in February and March, the Gulf lived up to the name given it by Cortez; "The Vermilion Sea", for the waters over large areas were reddened and opaque, so great was

the phytoplankton population. When the 1940 expedition first reached the Gulf, the amount of phytoplankton as shown by quantitative sampling was very small and the waters were correspondingly blue and clear. Silica and phosphate, both essential substances for the growth of diatoms, were found to be present in very low concentrations in the waters near the surface. There was little possibility of a supply being brought from below, for the warm temperature of the surface waters, built up during the summer and fall seasons of generally weak southeasterly winds, caused the existence of an effective density stratification, which prevented mixing. With the development of northwesterly winds of gale force, beginning in November, repeated measurements of the vertical distribution of temperature, salinity and oxygen showed that the warm surface waters were being blown southward, while upwelling of cold water of low oxygen content from moderate depths, and mixing of surface and subsurface waters, was taking place. Simultaneous measurements of the amount of dissolved phosphate and silica showed a marked increase in the surface layers, which was followed by a decrease as growing diatoms and other phytoplankton utilized these substances. The relatively rapid rate of phytoplankton growth was measured directly by determining the amount of oxygen produced in situ at depths between the surface and 40 meters. Amounts of oxygen were liberated in one day equivalent to about 2 milligrams of dry organic matter production per square centimeter of sea surface, or about 100 pounds of diatoms per acre, per day. At the same time quantitative photoplankton samples showed a marked increase, and small patches of red water were seen in December.

Large scale phytoplankton growth and huge diatom populations occur elsewhere, notably off the American west coast, yet the bottom deposits are not notably diatomaceous, because the frustules settling into deep water

become dispersed and dissolved. In contrast to these open sea areas, the deep waters of the Gulf were found by quantitative samples of the suspended water to contain an abundance of diatom frustules, and determinations of dissolved silica indicated that the deep waters have about 30% more silica in solution than do those of the open sea. The amount of silica in the deep water increases from the mouth of the Gulf to the region west of Guaymas, indicating that the deep waters of the latter region are perhaps nearer to saturation and thus allow diatom frustules to settle without dissolving. Furthermore, this difference in silica content of the deep water can be interpreted as meaning that there is a constant supply of silica to the Gulf from the open sea, which is removed by deposition on the bottom. That is, silica-rich water flows into the Gulf at depth, and silica-poor water is replaced near the surface.