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A Geochemical Method of Finding Leaks in Submarine Pipelines

by R.G. Aldridge, Robert G. Aldridge & Assocs. Inc., and V.T. Jones III,
Exploration Technologies Inc.

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ABSTRACT

A direct method of detecting leaks in submarine pipelines using established geochemical technology is discussed, including the theoretical basis and available equipment. An operational plan for location and pinpointing of a leak is outlined. This technology offers a superior solution for environmental monitoring for potential leakage, and a systematic means of locating the leaks that actually occur before any significant environmental damage is done.

INTRODUCTION

The purpose of this report is to present the technical aspects of adapting existing technology from the field of exploration geochemistry to detection and pinpointing the location of leaks in submarine pipelines.

A small leak in a pipeline can be difficult and costly to locate. However, in the case where hydrocarbons are involved, it is imperative that it be located and repaired as soon as possible to avoid losses of product and damage to the environment. If the pipeline is under water or ice, the problem is greatly magnified.

Ordinarily, leaks in underwater pipelines are found by visually searching for escaping liquids or gas. Sometimes this search is aided by dyes or sonic devices. In many cases a diver must "walk" the line to find the leak. This visual technique is time consuming, and so inherently difficult, that it is probable many small leaks go undetected, hydrostatic test notwithstanding. Deep water, poor visibility, waves and currents, depth of burial, and ice cover all tend to seriously aggravate the problem.

— References and Illustrations at end of paper

Over the past twenty years there have been extraordinary advances in the science of geochemistry (Jones, 1979, Mousseau and Williams, 1979, and Weismann, 1980). This field of science involves the detection of minute quantities of hydrocarbons seeping from the earth's surface. The principle driving force behind this advancement has been the search for petroleum (Jones and Drozd, 1983). Geochemical technology, while applicable to both the onshore and offshore provinces, is particularly effective offshore because of the special sampling techniques that have been devised (Williams and Mousseau, 1981). Specifically, this technique provides for continual sampling of water close to the sea bottom and virtually continuous chemical analysis of the dissolved gas contained in the bottom water samples.

A study of the techniques and equipment used in geochemistry for petroleum exploration reveals that the technology is directly applicable to finding leaks in pipelines--both onshore and offshore. The technology is particularly applicable in environmentally sensitive areas of the offshore and the Arctic regions.

Also, it is an important fact that all the equipment needed is state-of-the-art, with no further research and development required. All components of the system have been tried and proven in actual practice. The only special activity required will be careful planning to adapt the concepts to be used to the specific program envisioned.

THEORETICAL BASIS

The science of geochemistry, as applied to offshore detection of hydrocarbons, combines the technical disciplines of chemistry, marine geology, physics and oceanography. To adapt geochemistry to a workable system for the location of pipeline leakage, the disciplines of marine pipeline engineering and ocean engineering are also required.

In geochemical prospecting for oil, the methods employed involve establishment of the presence of dispersed oil components in the form of hydrocarbon gases or bitumens in the water, soils and rocks in the vicinity of oil and gas accumulations. In recent years geochemists have developed means of detecting extremely small hydrocarbon seeps (Weismann, 1981), (Jones and Drozd, 1983). So small,in fact, that these microseeps are not visible to the naked eye. Leakage from a pipeline, even though it may not be visible to the naked eye, is very large in comparison to these natural ambient levels, as shown in Figure 1, which is a geochemical profile of an actual leak from a natural gas pipeline. Note that both the methane and propane anomalies are over 30 times larger than the adjacent background. Previous experience by Jones (1983) has shown this to be a typical example. Thus, there is virtually no chance that such seeps would be missed using state-of-the-art geochemical techniques. In fact, the methods are so accurate that almost any level of contamination above the norm found in nature can be detected. An interesting example of this accuracy is found in an actual case illustrated in Figure 2 in which differences are shown between contamination from a production platform versus natural microseeps. The upper portion of this Figure exhibits the contamination from a producing area in the Gulf of Mexico. At the bottom of the Figure can be seen three seeps emitted from the bottom. These are the sharp spikes which are termed localized anomalies. As shown, they obviously originate from the bottom and bear no relationship to the surface contamination.

Large sub-bottom seeps are often associated with geophysical anomaly which is referred to as a bright spot as shown in Figure 3. A series of bright spots marching down a fault might indicate a gas migrated from a potential reservoir, along a fault or fracture, to a near-surface horizon where it then forms a micro-reservoir in the near-surface environment. It is this near-surface micro-reservoir which is the source of the surface geochemical anomaly. Such seismic bright spots are the result of the larger scale tectonic features and their associated macroseeps. Geochemistry is, however, capable of detecting much smaller hydrocarbon leaks, seeping along micro-fractures, which are not detectable by geophysics.

In addition, the geochemical analysis can differentiate between oils, condensate, and gas (Williams and Mousseau, 1981, Jones and Bray, 1983), making it possible to identify and compare the leakage with a specific pipeline source, or to differentiate between natural and man-made sources.

Given this ability to detect minute concentrations (ten parts per billion or less) of hydrocarbons in seawater, and the ability to position the sampler at any desired depth, it follows that given good oceanographic information and an adequate navigational positioning system, then small pipeline leaks can be located and traced back to their source. This was originally accomplished (Dunlap, Bradley and Moore) in the early 1960's and in recent years has become a fairly routine practice for accurately locating petroleum seeps from the sea bed during geochemical exploration surveys.

In the following sections the equipment used will be described and its adaptation to pipeline leak location and confirmation will be discussed.

DESCRIPTION OF THE EQUIPMENT

The equipment required to locate seeps from the sea bed using the geochemical method consists of (1) a means to continually collect the water samples, (2) a means of analyzing the samples continuously, and (3) a means of establishing the location of the leak. This system is essentially the same as that which would be required for location of leaks for a submerged pipeline.

One of the first such systems was designed at Gulf Oil Research and Development in Pittsburgh during the mid 1960's. Figure 4 illustrates the general form and schematic layout of this system. A second system, called the C-Gas System, was originally built in England, and is shown in Figures 6-10. The main differences between the two systems are in the gas stripping devices and in the gas chromatographs employed. The Gulf system has more sensitive and reliable gas chromatographs, allowing the use of a more reliable positive pressure stripper system than the vacuum stripper used in the C-Gas System. Otherwise, the two systems are essentially compatible.

(1) Sampling

In either system, water samples are continuously pumped from a near hull surface inlet, and simultaneously from greater depth through a towed "fish". The fish, towed at depth, contains an instrument package for monitoring temperature, salinity, and depth and has a water inlet connected to a submersible pump. This equipment is illustrated in Figures 4-7. The fish is deployed from a suitable vessel by means of a faired umbilical cable at the desired water depth. Sea water from the bottom is continually taken in by the fish and pumped through the umbilical to the vessel where the samples are analyzed in the onboard laboratory, shown in Figures 8-10. The present maximum depth capability available today is approximately 1,200 feet. Smaller more portable winch systems are also available for shallower depth surveys.

(2) Analysis

Aboard the boat the dissolved gases are continuously stripped from the sea water by a special "stripper" unit and then analyzed chemically in a specially designed computer based flame ionization detection gas chromatograph. When appropriate, as when special tracer gases are employed, a helium mass spectrometer and/or carbon dioxide analyzer can also be included as part of the analysis equipment as shown in Figure 8.

The dissolved gas data can be displayed in both analog and digital form on a CRT screen and stored on cassette tape. Both raw and processed data are stored, allowing full retrieval of all original data. Hard copies can be printed on line. In addition, the data can be statistically processed and displayed in both profile and map form aboard ship.

(3) Location

Establishment of the location of a leak or seep is accomplished through the navigational positioning equipment installed on the boat. The positioning system is coupled with the computer based chromatograph to record data points by geographic coordinates at appropriate intervals on a real time basis. Lag time between the entry of sample water in the inlet port of the fish and the chromatograph is automatically compensated for by the computer.

If gas bubbles are associated with the leak then they can be vividly displayed on the color imaging sonar system and photographically recorded, as shown in Figures 11-13. This provides visible confirmation of the location of the leak.

OPERATIONS - UNDERWATER LEAK SEARCH

A search for an underwater pipeline leak using the geochemical technique is a planned scientific exercise in contrast to the present approach, which is frequently filled with uncertainties, and many times conducted in a haphazard and costly manner.

Hydrocarbon leakage plumes have been detected as far away from the source as six miles (Dunlap, Bradley and Moore) since the diffused upper part of the plume covers a fairly wide area, it is apparent that a properly executed search pattern can easily locate the upper part of the plume geographically. After the plume is located, with proper technique, it can be tracked to its source on the sea bed. The actual location of the source can be pinpointed within the normal limits of accuracy of the positioning system used. The final analysis is conducted with the fish hanging vertically behind the stationary vessel which is positioned as directly as possible over the leaking pipeline. A sea buoy can then be anchored to the bottom at this location in order to expedite remedial action. A summary of the activities required to implement a proper pipeline leakage assessment is as follows:

(a) Pre-planning
(b) Mobilization of special equipment
(c) Field verification of pipe location and oceanographic information

(d) Establishment of the ambient hydrocarbon levels
(e) A systematic search, and
(f) Location and verification of a leak

A discussion on each of these activities follows:

(a) Pre-Planning

Preliminary to any field activity all information available regarding the pipeline to be surveyed should be examined. The location of the pipeline should be determined and plotted on navigation charts. Meteorological and oceanographic data should be studied and the anticipated current velocities determined. If possible a sample of the pipeline fluid should be obtained and compositionally analyzed.

Based on the plotted location of the pipeline, the estimated current velocities, and other information, a search pattern can be devised and pre-plotted on the charts.

(b) Mobilization

The boat selected is based on the location of the work, the duration of the assignment, and the personnel required. Normally, a 100 to 135 foot boat is adequate for a deep water operation. A positioning system is set up on the boat along with current meters and pipe location equipment. The geochemical sampling and analysis equipment are containerized and can be shipped to a convenient port for mobilizing on the vessel of choice.

Personnel consisting of a program manager, chief technician, positioning system operator, and instrument technician, are then mobilized on the appropriate vessel.

(c) Verification of Pipeline Location

On reaching the job site, the pipe is then located in enough spots to confirm the pre-plotted position using a magnetometer. If necessary, corrections are made in the location of the line, and the pre-plotted search pattern modified accordingly. At this time, actual current and temperature measurements can be made and taken into consideration. The survey is then ready to commence.

(d) Establishing the Ambient Hydrocarbon Levels

During this preliminary location survey, the seep detector will be used to establish background hydrocarbon levels and to look for major seep anomalies associated with the pipeline.

(e) Planned Search

Based on experience and knowledge gained in the search for seabed seeps, the planned search is devised to first locate the diffused leakage plume in the water column. Therefore, initially, the fish would be towed adjacent to the full length of the pipeline in a pre-plotted search pattern at an intermediate depth and at a fairly rapid speed of five or six knots, taking into consideration the prevailing ocean and meteorological conditions. This activity would quickly identify the approximate positions of leakage anomalies in the area near the pipeline. Next, the vessel would be returned to each anomaly with the fish towed at a slower speed. Using a navigational technique, the center of the plume is tracked at increasing depth until the source is located. Each anomaly is chromatographically "finger-printed" and compared to the "finger-print" of the fluid in the pipeline being surveyed.

(f) Location and Verification

When a hydrocarbon plume has been tracked to the sea bed the location can be pinpointed within the accuracy of the positioning system used. It can be verified and differentiated from a natural seep in the following ways:

(1) Through experience it is known that natural seepage, though localized, generally escapes from the ground in a much wider geographical area than does leakage from a pipeline, even when the pipeline is buried. Consequently, an experienced operator can distinguish between the two.

(2) Normally, the location of a pipeline would be checked using a magnetometer or acoustic instruments prior to beginning the search. If the plume is traced to the location of the pipeline, it is a good indication the source is the pipeline.

(3) If a sample of the contents of a pipeline being checked is available then matching its' chromatographic analysis to that of the plume can confirm the pipeline as the source.

(4) Large pipeline leaks can be further confirmed by the color sonar system. An experienced operator can distinguish between natural seeps and leakage anomalies in most cases.

(5) If a pipeline has not yet been put into service, an inert tracer gas such as helium or sulfur hexafloride can be introduced into the hydrostatic test water. If the pressure test fails because of a leak, then the leak can be located by tracking the plume of the injected tracer in the same manner as for hydrocarbons.

The underwater search described is applicable to either buried or exposed pipelines. A leakage plume from a pipeline buried with normal cover will ascend nearly vertically through relatively homogeneous material and exit the sea bed directly over and along the trace of the pipeline. The diffused seepage plume is not expected to be more than a few meters in diameter at the sea bed. For pipelines buried more deeply a more precise location is possible by chromatographic analysis of sediment-gas samples taken from the sea bottom. If this is done, a profile of the magnitude of hydrocarbon concentrations along the pipeline can be constructed. The leak will generally be found in close proximity to the highest concentration level indicated on the profile.

SUMMARY

Geochemistry, as it is practiced today, is a well established technology. It is used successfully today in the search for petroleum by locating seeps from the earth that are undetectable by any other means. The techniques of analysis are so refined that gas versus oil can be easily differentiated from one another, and from natural seepage occurrences. Oil industry geochemists have been successfully locating and analyzing natural seeps issuing from the sea bed for many years.

It is a relatively simple matter to adopt these marine seep detection systems to a marine pipeline leak detection system. The major difference being in the planning of a program and execution of the search pattern. The search patterns are devised to allow tracing of the leakage plume to its source at the pipeline rather than attempting to execute the difficult task of tracking the exact routes of the pipeline. However, it is noted that recent advancements in ROV mounted magnetometers indicate there is potential for a second generation system that would allow close tracking and simultaneous sampling along the pipeline.

After finding and tracing a leak to its source, the location can be pinpointed by hovering over the source and recording its geographic coordinates. The leak can also, be confirmed at that time by the color sonic device and its hydrocarbon finger-print.

CONCLUSION

It is concluded that marine geochemical technology provides a viable tool for the location of leaks in submarine pipelines. Conversely, if no leakage is present in a pipeline, this fact can be conclusively confirmed. The significance of this concept is that the geochemical method has the potential for minimizing environmental damage caused by leakage from existing facilities and could assist in the removal of environmental objections to the installations of new facilities in environmentally sensitive areas.

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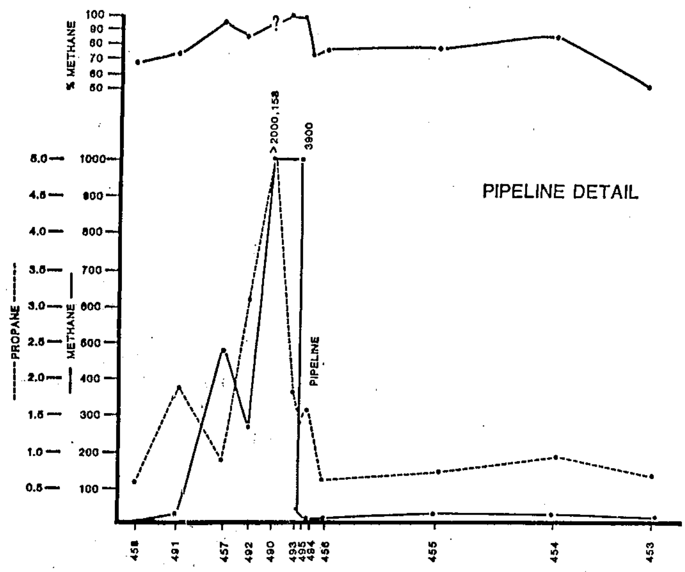

Fig. 1—Geochemical profile of natural gas pipeline leak.

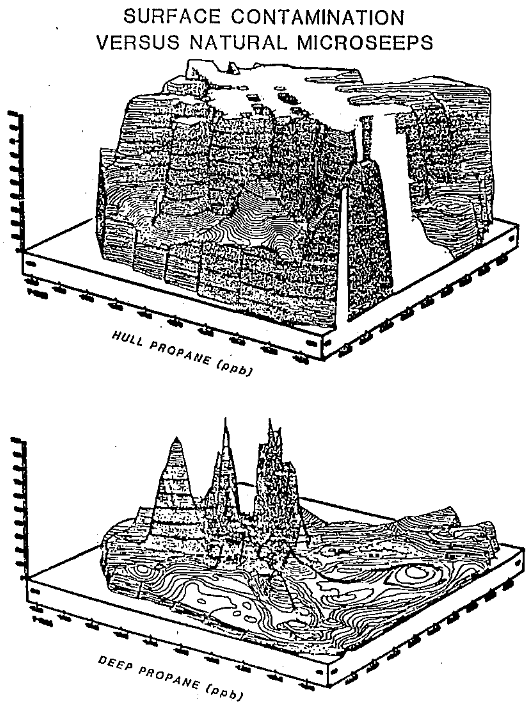

Fig. 2—Contour maps of propane concentration in surface contamination from production platform (top) and from natural seeps (bottom).

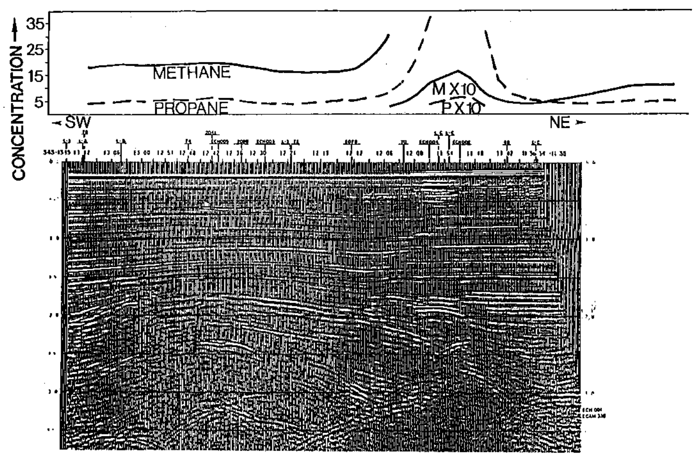

Fig. 3—Marine seep over bright spot.

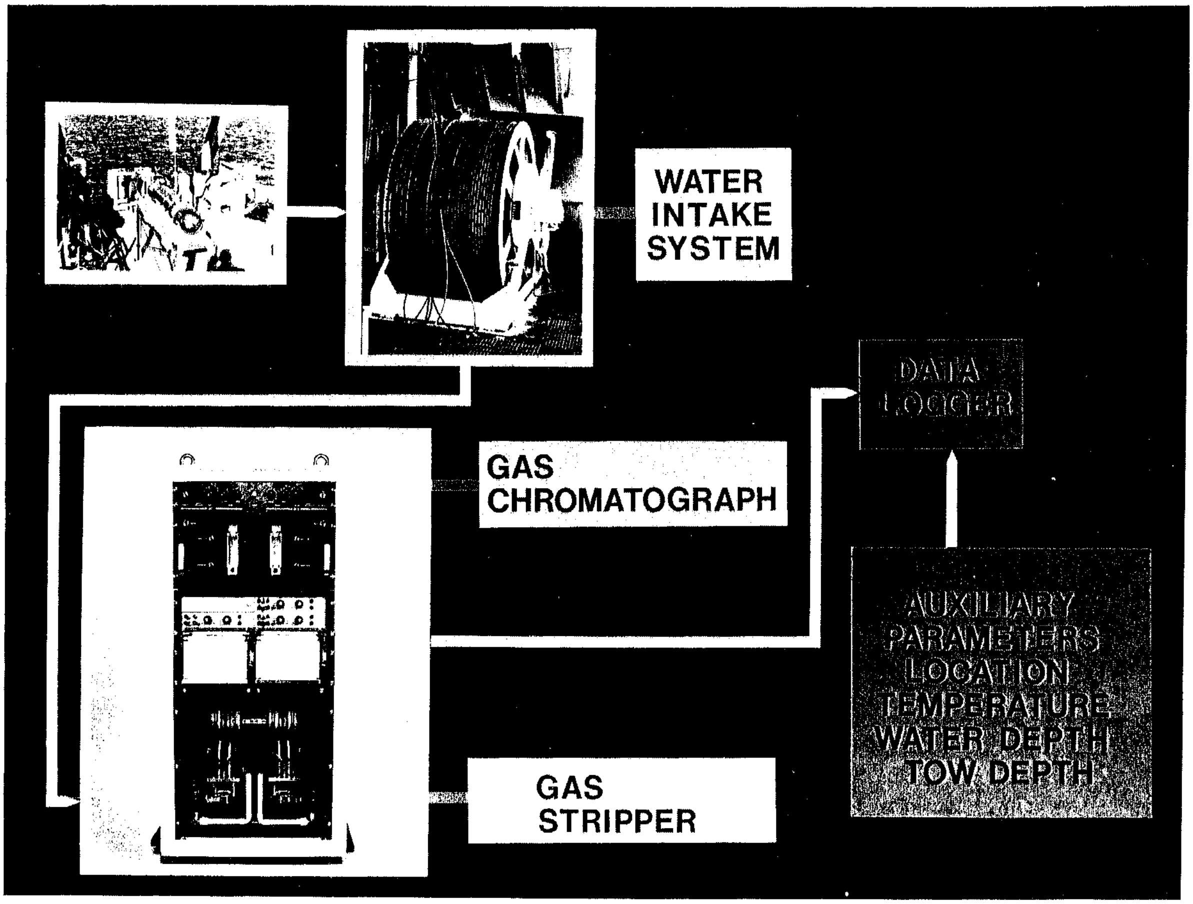

Fig. 4—Diagram of marine hydrocarbon detection system.

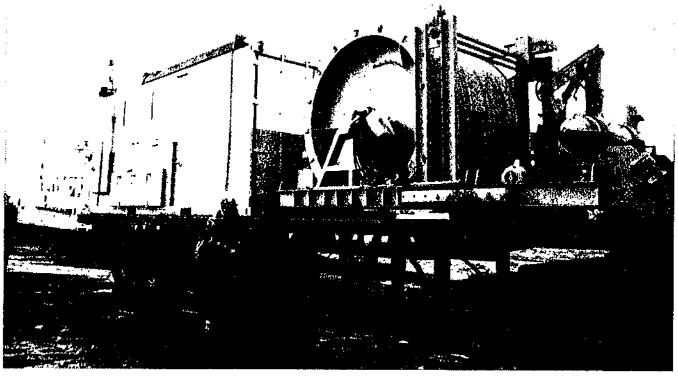

Fig. 5—C-gas system loaded on truck for mobilization.

Fig. 6—Rigging the C-gas system aboard workboat.

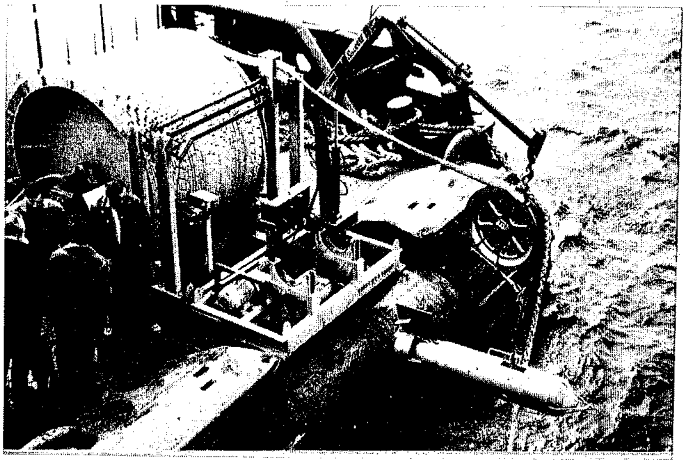

Fig. 7—Tow body being deployed at sea.

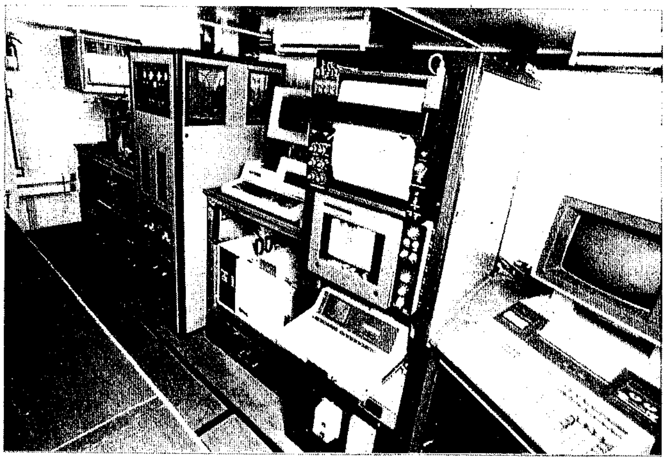

Fig. 8—Arrangement of geochem laboratory equipment inside portable container.

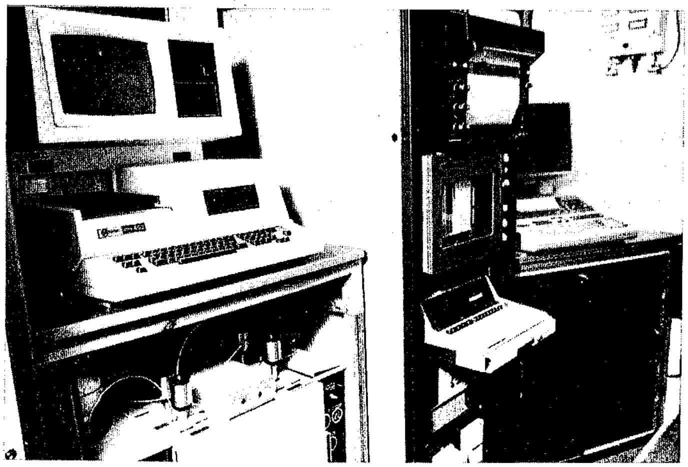

Fig. 9—Computer-based gas chromatograph.

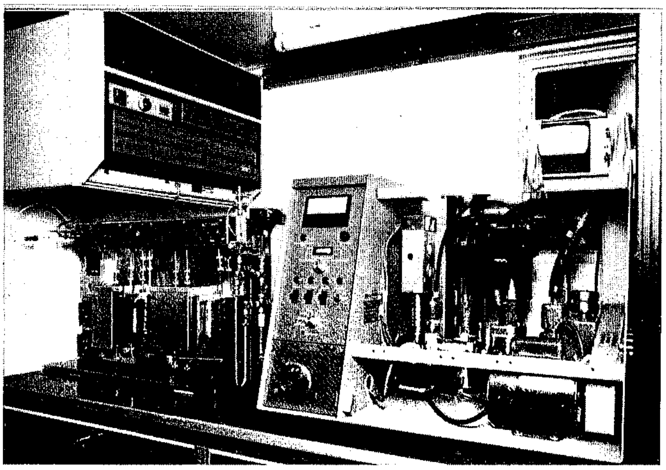

Fig. 10—Helium unit (right) and carbon isotope unit (left).

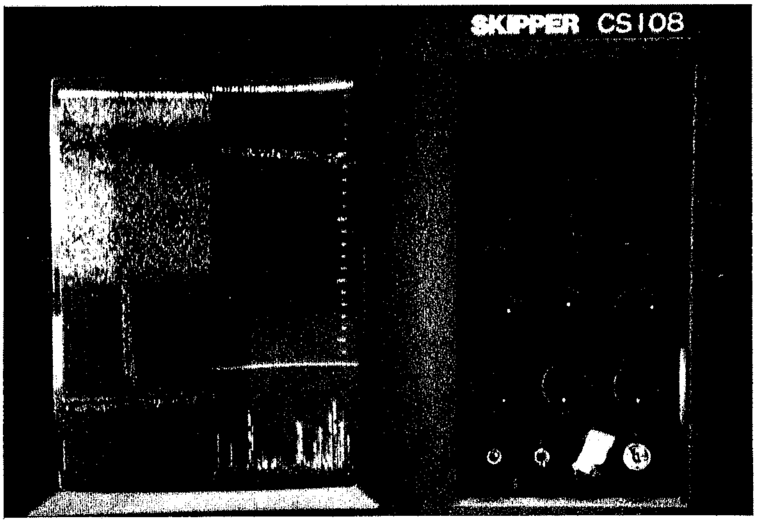

Fig. 11—Black and white photo of color imaging sonar system.

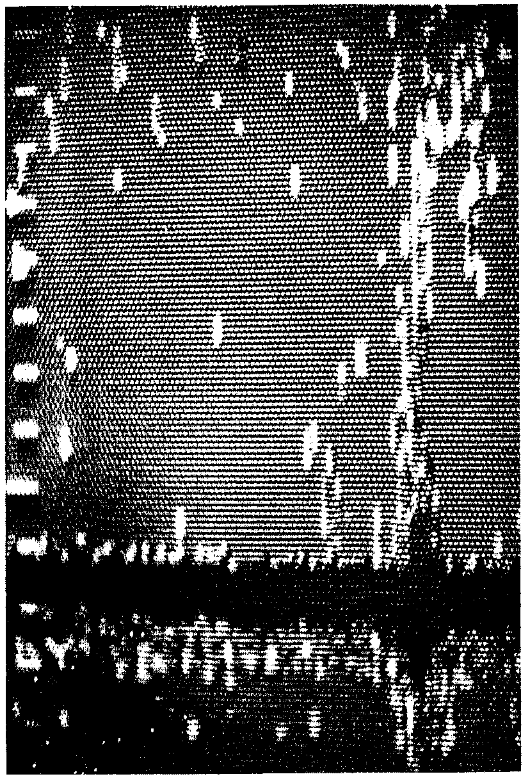

Fig. 12—Black and white photo of color image of a leak in a submarine pipeline.

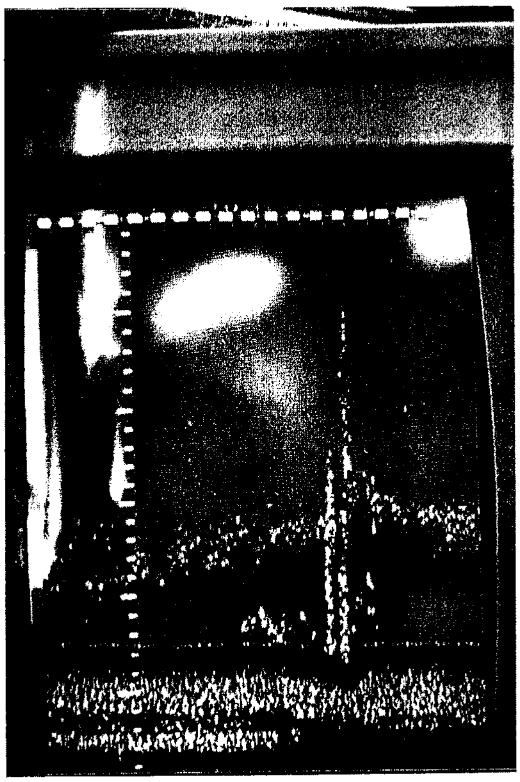

Fig. 13—Black and white photo of color image of a marine hydrocarbon seep.