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Landsat Goes to Sea

Landsat MSS film imagery was used to evaluate and revise the positions of islands, banks, and reefs on the nautical chart of the Chagos Archipelago in the Indian Ocean.

Abstract: *Current and proposed technological advances in navigation technology and the remote sensing of oceanic parameters will require nautical charts more accurate than many of the charts that are in use today. This is of serious concern to the international hydrographic community since existing hydrographic survey resources are too limited to perform the detailed surveys required to produce the type and volume of charts that will be required in the 1980's. The Defense Mapping Agency, which has a statutory responsibility to provide charts for civil maritime use in addition to its defense obligations, has been investigating a new charting tool that may provide a partial solution to this dilemma. NASA's Landsat returns data from its Multispectral Scanner (MSS) that can be used to evaluate and update medium- and small-scale nautical charts. The MSS green band data can be used to probe clear oceanic waters to those depths required for safe navigation by most ships. The data also may be used to plan hydrographic surveys of reef and shoal areas so that limited survey resources can be exploited to their fullest. Existing charts can be evaluated for accuracy and currency of hazardous, near surface features, thus permitting the hydrographic survey resources that are now stretched thin to be most effectively used where they are most needed: to define the safe shipping routes. A recent test project, performed at the Defense Mapping Agency Hydrographic Center, has demonstrated the feasibility of using MSS film imagery to evaluate and revise the positions of islands, banks, and reefs on a nautical chart. Additional research is being funded to investigate the practicality of using, and to optimize the digital water depth determination capabilities of, the MSS data as demonstrated in the 1975 joint NASA/Cousteau Ocean Bathymetry Experiment. Such techniques then could be more effectively applied to the chart production.*

Introduction

Biologists tell us that man's ancestors emerged from the sea. Economists tell us that man must now turn again to the sea. The world's economy is becoming more and more dependent on the oceans; for food, for minerals, for energy, and for transportation. Yet, at a time when cameras and sensors aboard National Aeronautics and Space Administration's (NASA) interplantetary probes have mapped the surface features of the moon and several planets, fully 70 percent of the earth's surface remains shrouded in mystery beneath the oceans. Major technology development efforts are being oriented towards exploring and exploiting the earth's last frontier. In the United States these marine studies are supported by the Marine Resources and Engineering Development Act of 1966 (Public Law 89-454, June 17, 1966). The policy of the United States as stated herein is "to develop, encourage, and

maintain a coordinated, comprehensive, and long range national program in marine science for the benefit of mankind to assist in protection of health and property, enhancement of commerce, transportation, and national security, rehabilitation of our commercial fisheries, and increase utilization of these and other resources."

Hydrographic Surveying History

Although man has been venturing over the oceans for thousands of years, it was only within the last 50 years that advances in technology enabled him to make more detailed observation of features hidden in the depths beyond the limits of his natural senses. Until the invention of the echo sounder, knowledge of the sea bottom topography was primarily limited to that information which could be gleaned by lowering a rod or a weighted line over the side of a boat until it touched bottom, or until it reached its length. In the latter case, a no bottom sounding was recorded in the survey data. Such sounding methods have been documented as early as 1422 B.C. when they were depicted on the wall of the tomb of Menna, an Egyptian scribe[1]. Actually, this simple procedure could be said to be the first form of remote sensing. The sounding line continued to be used to determine depth during the extensive worldwide surveys undertaken by the major sea powers during the nineteenth and early twentieth centuries. Despite the phenomonal efforts of these early hydrographers, they were able to examine in detail only a fraction of the oceans' 360 million square kilometers. The majority of these surveys were dedicated to ensuring safe passage for vessels with less than ten meters draft. The relative accuracies of many of these early surveys in areas near land features was often astounding, especially considering that their primary tools were leadline, sextant, and chronometer. On the other hand, the absolute accuracy of these surveys and the relative accuracy of any surveys made out of sight of land were limited by the ability of the hydrographer to obtain adequate celestial fixes which at best could only define his position to within several kilometers. The fact that they were often unaware of currents that carried them off course also degraded the results.

Data Shortfalls

Since the widespread use of precision sonar equipment in the early 1950's, more information about sea bottom topography has been collected than during the rest of man's recorded history. However, a recent appraisal by the International Hydrographic Bureau estimates that only about 16 percent of the oceans has sufficiently adequate soundings to determine sea floor topography. Another 22 percent of the oceans has data sufficient only for the determination of the major sea floor features and the remaining 62 percent of the ocean area has data that is too sparse for determining sea floor topography[2]. In fact, one French expert, Captain L. Oudet, Ret., has stated "that any chart based on surveys before 1970 carries with it a risk that the surveyors may have missed some dangerous wreck or other obstacle to navigation"[3].

Changing Requirements

Until recently, in spite of the limitations of the survey data, most charts available have been satisfactory for conventional ships in areas where safe routes have been established. Unfortunately, however, these sea lanes do not always follow the most direct routes[3]. Additionally, some conventional passages such as the Strait of Malacca are too shallow for the new deep draft vessels (some of which require clearances of nearly 30 meters). Consequently, they must seek out longer, less well surveyed, but deeper routes to their destinations. A number of other factors are contributing to the opening of new trade routes for vessels of all sizes. The increasing production and export of natural resources from the developing nations, particularly those in the southern hemisphere, is resulting in increased shipping through areas with outdated or inadequate surveys. A large majority of these developing nations have not yet established hydrographic services[2]. Present technology trends will result in even more drastic changes to shipping patterns during the 1980's. The proposed NAVSTAR Global Positioning System will provide mariners with continuous, precise positional information anywhere in the world. Environmental monitoring satellites will be providing worldwide weather conditions, ice patterns, sea state, and ocean current data. Maritime communication satellites will make this type of information available to the mariner in near real time. With the inflated fuel costs projected for the next decade, more navigators will plot their course to minimize distance traveled while taking advantage of all favorable winds and currents.

National and International Priorities

Thus, the requirement to acquire accurate and adequate hydrographic surveys over large areas of the world's oceans demands immediate attention. However, hydrographic survey resources are quite limited and tend to be expensive. Both national and international interest is being taken in this problem. In April 1970, the President's message to the Congress[4], prepared by the National Council on Marine Resources and Engineering Development, stated:

> "More efficient sea transportation vitally depends upon portfolios of accurate nautical charts and publications for the open ocean as well as coastal ports and waterways . . . International, oceanic, legal, and political questions often require facts available only from precise maps and accurate marine data if they are to be answered."—Chapter IX, Page 115;
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> "The seemingly simple activities of charting the ocean and predicting its future actions are in fact the most massive and intractable problems which now face marine scientists. At our present rate of progress, mapping the topography of the ocean bottom will involve hundreds of ship-years of work . . . Faced with tasks of this magnitude, the United States clearly must take two steps: First, delineate what parts of the sea are the prime interest and therefore to be given priority attention; and second, increase the speed and efficiency of survey operations."—Chapter IX, Page 127-8.

Internationally, 47 nations are cooperating in hydrographic surveying and charting under the authority of the International Hydrographic Organization (IHO) which was established in 1921 as the International Hydrographic Bureau. By means of conferences, publications, and correspondence, the IHO has developed international accuracy standards for hydrographic surveys[5] and an international series of small-scale charts, and is encouraging the exchange of hydrographic data among nations as well as coordinating joint multinational surveying efforts. In spite of international cooperation and even allowing increased survey efficiency from improved technology, much of the ocean will still lack adequate hydrographic surveys during the 1980's. (As a basic example, a recent British Hydrographic Study Group concluded that 284 ship-years of work will be required to bring their territorial waters up to modern standards and that their foreign areas of responsibility would require an additional 300 ship-years of effort[6].)

NASA/Cousteau Ocean Bathymetry Experiment

With such inadequacies in surveying resources in mind, NASA and the Cousteau Society conducted a joint Ocean Bathymetry Experiment during August and September, 1975. The goal of the experiment was to determine the capability and feasibility of determining water depths from special high-gain data collected by the Multispectral Scanners (MSS) aboard the two Landsat (formerly ERTS) satellites currently in orbit. Previous studies with both aircraft and standard MSS data from Landsat-1 had demonstrated the general techniques of remote bathymetry from multispectral scanner data.[7,8] The NASA/Cousteau Ocean Bathymetry Experiment did prove the feasibility of satellite bathymetry. In the Berry Island test area, depths as deep as 22 meters (10% rms accuracy) were measured from the satellite data and verified by the ground truth team on the *Calypso*[9]. Landsat also revealed shoals that were later determined by the *Calypso* to be at a depth of 40 meters. In the less clear waters off the Florida coast, Landsat data were used to map shoals as deep as 10 meters[9]. Additional research and comparison of Landsat high-gain data with aircraft acquired data and recent charts indicated that depths could be deduced without knowledge of the measured optical properties of the waters in the area investigated[10]. This capability could be very important when studying remote areas.

DMAHC Evaluation

Within the United States, the Defense Mapping Agency (DMA) through its Hydrographic Center (DMAHC) carries out statutory responsibilities to provide "accurate and inexpensive nautical charts" and other marine navigation data "for the use of all vessels of the United States and of navigators generally" for all areas outside U.S. territorial waters[11]. Following the presentation of the initial results of the NASA/Cousteau experiment, a comparison was made between worldwide Secchi disc data[12] and the areas most deficient in adequate bathymetry[13]. It was found that many of those areas lacking adequate survey data have water as clear as or clearer than that in the Berry Islands test area. Thus, in February 1976 the Defense Mapping Agency requested NASA to provide special Landsat high-gain MSS data over three tests areas where forthcoming survey efforts would be able to provide ground/sea truth for evalua-

tions. The goal was to test the practicality of using Landsat MSS data for chart evaluation and preparation as well as to appraise their use as a survey planning tool. Pending receipt of data from the special tasking, a research contract was initiated with the Environmental Research Institute of Michigan to convert digital MSS data from two previously acquired high-gain images of the Bahamas to a form that could be used in chart production or survey planning. The results of this endeavor will be available later this year.

Chart Revision

At the conclusion of the data acquisition period, only partially cloud-free imagery had been received over the Bahamas test area; the Virgin Island test site had been completely cloud covered; but 80 percent cloud-free imagery had been obtained over the third test area, the Chagos Archipelago in the Indian Ocean. It was the initial evaluation of the Chagos imagery acquired in March and April that resulted in a profitable side application beyond the original test design. The film imagery acquired on March 29, 1976 revealed a major reef 8 kilometers long as well as a number of other variations that were not portrayed on the existing chart of the Archipelago. (U.S. Chart No. 61610, Second Ed., February 21, 1976, 1:363,230). This discovery resulted in an application of the proven cartographic capabilities of the Landsat film imagery[14, 15, 16] to the evaluation and the correction of the horizontal positions of features on a medium-scale nautical chart. Film images at 1:1,000,000 scale were obtained for the Chagos scenes and the chart of the area was reduced to the same scale in order to compare features.

When the imaged island features were registered to the charted island features, significant variations were immediately apparent. There was a major reef or bank where the chart showed safe, deep water and some banks appeared to be out of position by more than 15 kilometers relative to the nearest land. Next, the existence and permanency of the features imaged on Landsat was confirmed by cross comparison of scenes acquired on two different days. At this point, priority evaluation was switched to the Chagos area from the Bahamas. The Director of the DMA Hydrographic Center directed that radio warnings be sent to mariners and that a new chart edition be prepared by the first of September 1976 by using the Landsat images to adjust the horizontal positions of the islands, banks, and reefs. Geodetic control was plotted and a new mosaic of the Landsat photography was prepared at the original chart scale. An initial determination of the positions of the most hazardous uncharted reef edges was made and on June 18, 1976, a radio warning was broadcast to ships

NAVAL MESSAGE

OPNAV FORM 2110-28 (REV. 3-69) S/N 0107-701-4001

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DATE: 18 JUNE 1976	TOR/TOD:	ROUTED BY:	CHECKED BY:	

MESSAGE NR	DATE/TIME GROUP	PRECEDENCE	FLASH	IMMEDIATE	PRIORITY	ROUTINE
3159 3160	181809Z JUN 76	ACTION			P	
		INFO				

FM DMAHC WASHINGTON DC

TO AIG 9280

MIDEASTFOR-RHCFMKK

UNCLAS

HYDROPAC 1175 /76(61). INDIAN OCEAN, CHAGOS ARCHIPELAGO.

CHART 61610.

1. DANGEROUS SHOAL EXTENDS BETWEEN 04-51S 04-56S AND 72-36E 72-38E.

2. GANGES BANK IS LOCATED 8 MILES WESTWARD OF CHARTED POSITION 07-22S 71-06E.

3. PITT BANK 07-00S 71-14E EXTENDS 4 MILES FURTHER NORTHWESTWARD AND 6 MILES FURTHER SOUTHEASTWARD THAN CHARTED.

FIG. 1. Radio message to mariners warning of hazards revealed by Landsat.

at sea (HYDROPAC 1175/76(61), Figure 1). These same data were included in Notice to Mariners #28, dated July 10, 1976. Additional refinements were made to the data and Notice to Mariners #29, dated July 17, 1976, carried a more detailed description of the dangerous new reef and corrected reef positions. Work was completed on the third edition of Chart 61610 and it went to press on August 28, 1976. The horizontal positions of islands, banks, and reefs portrayed on the new edition were derived from the Landsat MSS imagery acquired in March and April and which had been adjusted to geodetic control. The present effort used only film imagery to derive the positioning data for subsurface as well as surface features. Even though water depths for the newly discovered reefs could not be determined from the film, the fact that they could be seen on the film indicated that they represented a navigational hazard.

Such an approach leaves a major problem to be resolved: namely, how to use the old sounding data in areas where the imagery showed changes in the alignment or positions of reef features. The only detailed survey of the entire archipelago had been conducted by the Indian Navy in 1837. Typically, survey accuracy in this time period was limited by navigational capabilities. The data were reasonably accurate in and around islands (as confirmed in several places in Chagos area by the Landsat imagery). However, in the more remote areas, out of sight of land, there were problems in obtaining a good navigational fix as well as with omissions in the sounding data, as when the track lines pass on either side of a reef. (These cases were demonstrated by the Landsat imagery revealing positioning errors of up to 18 kilometers and by the discovery of new shoals or reefs as shown in Figures 2 and 3.) For the present chart revision, a number of soundings were removed (Figures 4-7). However in the future, digital depth analysis of the MSS data as in the joint NASA/ Cousteau experiment should permit correlation and adjustment of old soundings to their true positions. In this present work, however, many soundings had to be deleted for the sake of safety.

Summary

National and international concern is being expressed over the growing need to improve the quantity, currency, and accuracy of worldwide hydrographic survey data to assure navigational safety. Thousands of ship-years will be required to acquire adequate worldwide hydrographic survey data. The use of Landsat high-gain MSS imagery for bathymetric application was tested in the joint NASA/Cousteau Ocean Bathymetry Experiment. This joint venture proved the feasibility of detecting and mapping shoals in clear water to depths equal to or greater than those required for most surface shipping. Although its limited resolution cannot identify small navigational hazards, in many areas it can provide data that are, in some cases, orders of magnitude better than the existing surveys. With this upgraded information, adequate ship surveys need be planned only for those expanses that offer a potentially safe route for shipping. This will result in optimal use of the limited and expensive hydrographic surveying resources. Even though several years of research and development will probably be required before satisfactory algorithms can be developed that will permit operational bathymetric analysis of the MSS digital data, the revision of the Chagos Archipelago chart demonstrated a valuable use of the film imagery: shoal features can be found and positioned with respect to known surface features. The very fact that a shoal or reef appears on the images indicates that it presents a hazard to navigation. Thus, the Landsat high-gain imagery currently represents a useful tool that can be used to provide improved realtive horizontal information about remote islands and reefs. It also exhibits a great potential in the digital mode for supporting international hydrographic surveying and charting efforts, thereby increasing the efficiency of limited hydrographic surveying resources and making the seas safer for the international maritime community.

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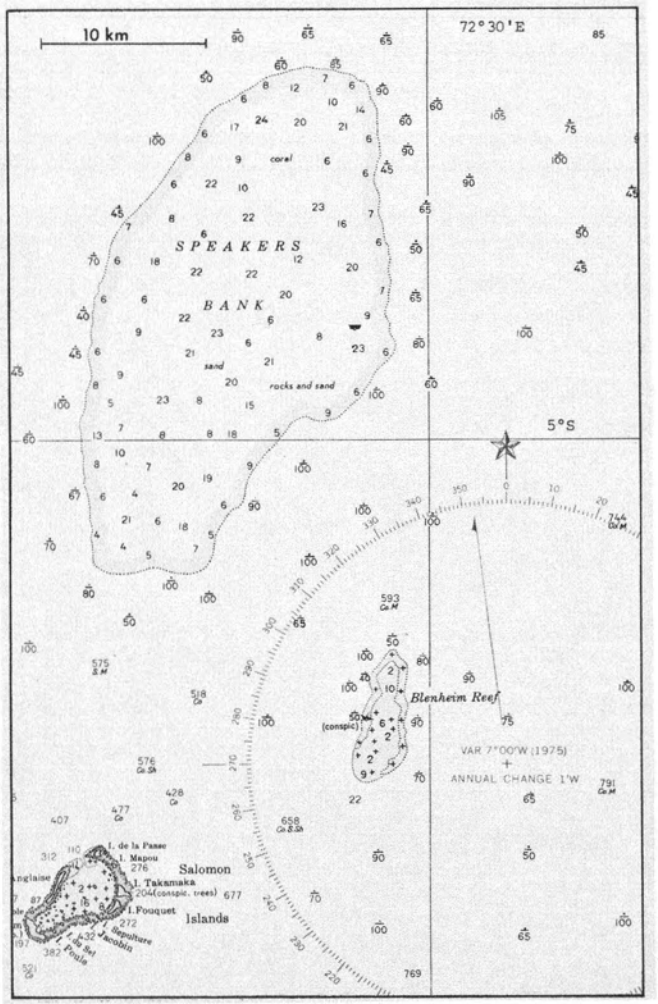

FIG. 2. Portion of Chart 61610, 2nd ed., February 21, 1976, showing Speakers Bank and no bottom soundings to the east (⊥over sounding indicates that no bottom was found at that depth).

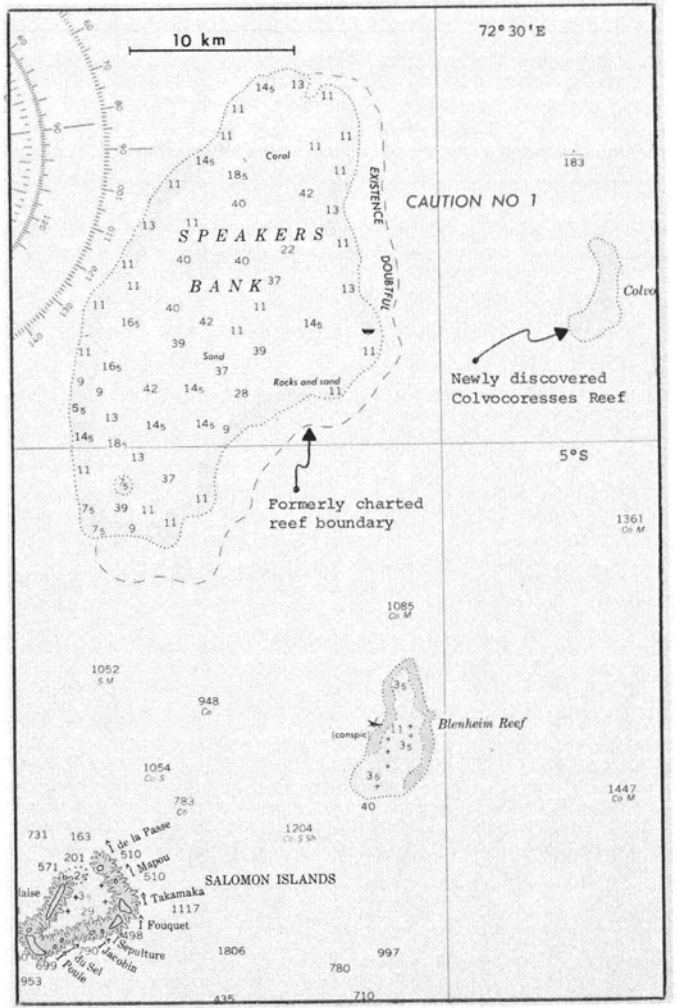

FIG. 3. Portion of Chart 61610, 3rd ed., August 28, 1976, showing adjusted position of Speakers Bank and new reef revealed by Landsat.

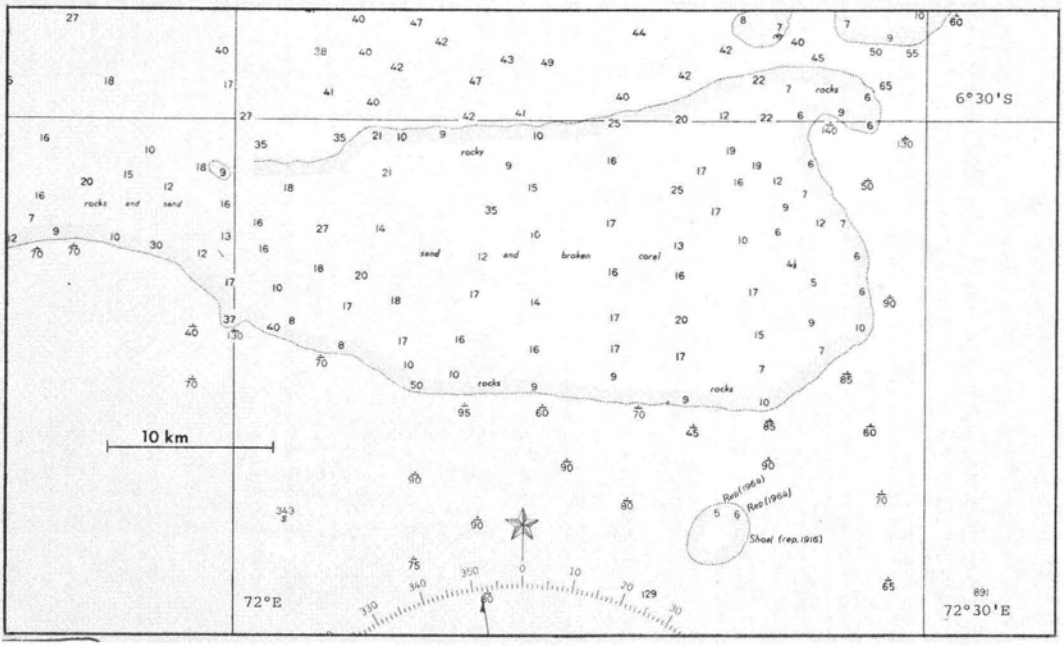

FIG. 4. Portion of Chart 61610, 2nd ed., February 21, 1976, showing southeast portion of Great Chagos Bank.

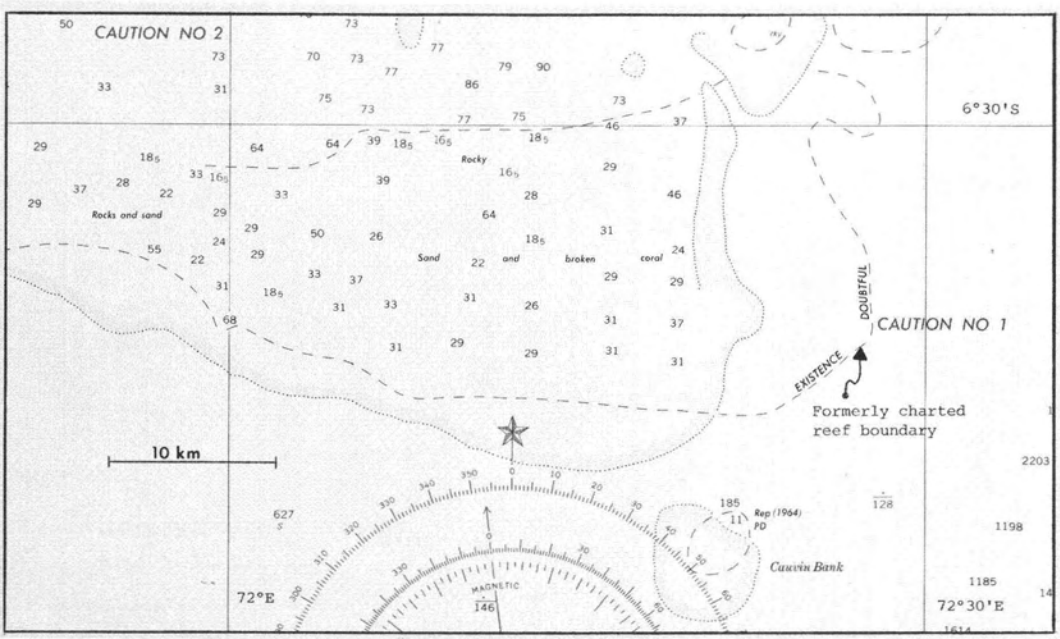

FIG. 5. Portion of Chart 61610, 3rd ed., August 28, 1976, showing revised reef boundaries. Many soundings have been deleted and Caution No. 2 warns against trusting validity of soundings within this reef.

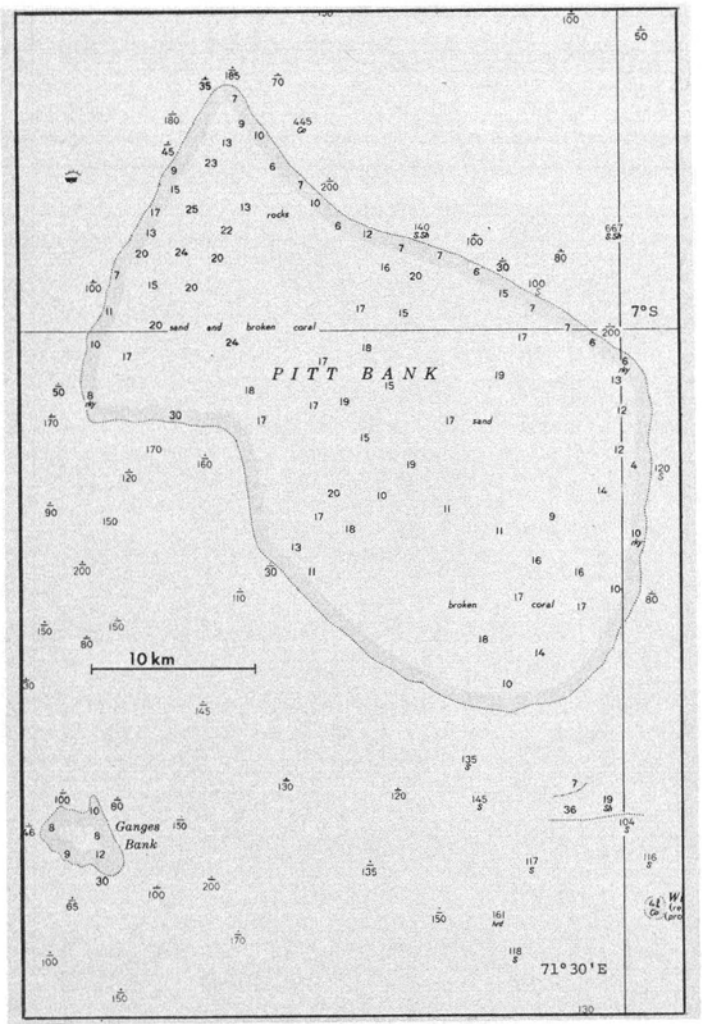

FIG. 6. Portion of Chart 61610, 2nd ed., February 21, 1976, showing Pitt and Ganges Banks.

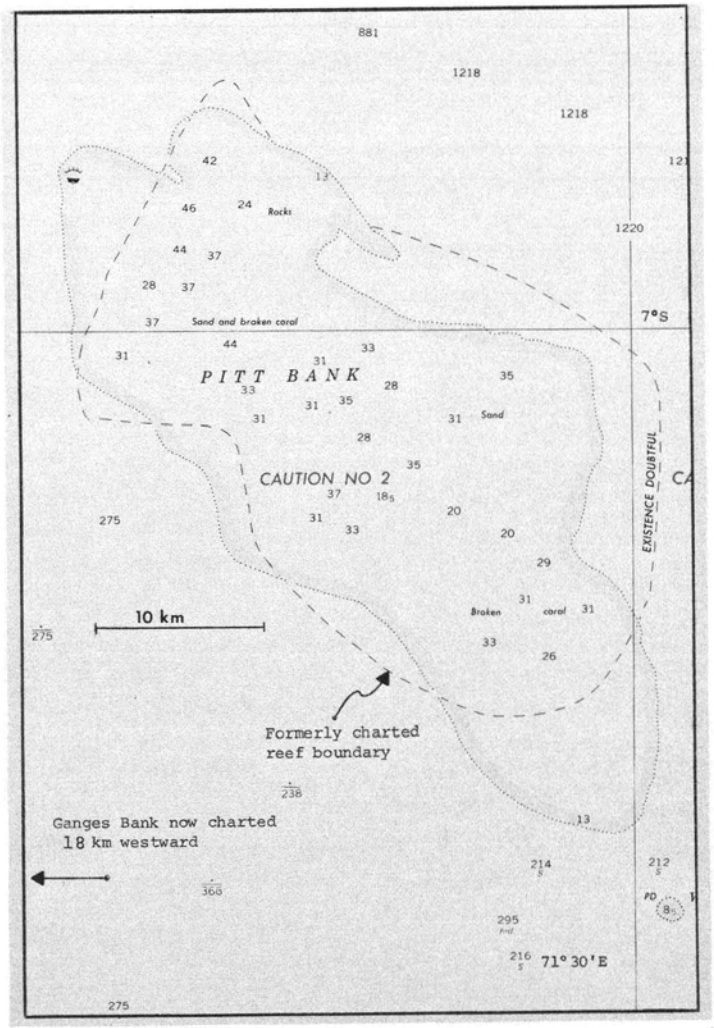

FIG. 7. Portion of Chart 61610, 3rd ed., August 28, 1976, showing revisions resulting from Landsat imagery.

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