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GEOLOGICAL STRUCTURE AND SOME WATER CHARACTERISTICS OF THE EAST CHINA SEA AND THE YELLOW SEA

By

K. O. Emery[1], Yoshikazu Hayashi[2], Thomas W. C. Hilde[3], Kazuo Kobayashi[2], Ja Hak Koo[4], C. Y. Meng[5], Hiroshi Niino[6], J. H. Osterhagen[3], L. M. Reynolds[3], John M. Wageman[3], C. S. Wang[7], and Sung Jin Yang[4].

ABSTRACT

A geophysical survey was conducted in the East China Sea and the Yellow Sea between 12 October and 29 November 1968 aboard R/V F. V. HUNT. Joint participation of scientists from the Republic of China, the Republic of Korea, and Japan with American scientists was provided through ECAFE (Committee for Co-Ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas). The survey covered a region that is about equal to the combined areas of Texas, Oklahoma, and New Mexico or of Southeast Asia (Vietnam, Laos, Cambodia, and Thailand).

During the cruise more than 12,000 line km of continuous seismic reflection profiles were run with a 30,000-joule sparker. A continuous geomagnetic profile was made simultaneously. At two-hour intervals the following oceanographic data were measured for surface waters: color, transparency, quantity of suspended sediment, temperature, salinity, direction and size of waves, direction and speed of surface winds. Some of the oceanographic observations were, of course, restricted to daylight hours, and some (suspended sediment and salinity) required later laboratory analyses. Preliminary analyses of data were made aboard ship, and charts of each kind of measurement were kept up-to-date in order to guide the planning. Final analyses, compilations, and illustrations were completed ashore in the United States.

Most important for offshore mineral (oil and gas) exploration are the geophysical results. These show that the region is underlain by a series of nearly parallel ridges, each of which has served as a dam to trap sediments that have been derived mostly from the large area of China that is drained by the Yellow and the Yangtze rivers. The northermost ridge consists of Precambrian igneous and metamorphic rocks that crop out along the Shantung Peninsula. Sediments from the Yellow River have been trapped in the Gulf of Pohai by this ridge. The next ridge consists of Mesozoic-to-Precambrian rocks that were uplifted during the Mesozoic as the Fukien-Reinan Massif that crosses the mouth of the present Yellow Sea. Within the Yellow Sea the massif trapped a volume of at least 200,000 cu. km

1) Woods Hole Oceanographic Institution, Woods Hole, Mass., U.S.A., Contribution No. 2300.
2) Japan Petroleum Development Corporation, Tokyo, Japan
3) Pacific Support Group, U.S. Naval Oceanographic Office, San Diego, California, U.S.A.
4) Geological Survey of Korea, Republic of Korea (South Korea).
5) Chinese Petroleum Corporation, Taipei, Republic of China (Taiwan).
6) Tokyo University of Fisheries, Tokyo, Japan
7) National Taiwan University, Taipei, Republic of China (Taiwan).

of sediments mostly of Neogene age. Next seaward is a ridge of igneous and folded sedimentary rock that is located near the edge of the continental shelf between Japan and Taiwan. This is the Taiwan-Sinzi Folded Zone. Landward of it are perhaps 1 million cu. km of sediments believed to be mostly Neogene in age, on the basis of seismic characteristics, outcrops and wells on land, and dredgings from the sea floor. Beyond the continental shelf the Ryukyu Ridge, composed of volcanic rocks and folded Neogene and older sedimentary strata, has dammed a belt of sediment in the Okinawa Trough. A smaller ridge probably of similar composition and origin half way down the eastern slope of the Ryukyu Ridge has trapped a similar belt of sediment whose surface is a broad terrace at depths of several thousand meters. A portion of this feature off Japan is known as the Tosa Terrace. Lastly, at the base of the slope from the Ryukyu Ridge is the Ryukyu Trench that contains zero to only a few hundred meters of sediment.

Sediments beneath the continental shelf and in the Yellow Sea are believed to have great potential as oil and gas reservoirs. An area several times larger than Taiwan lies north of that island with sediment thicknesses exceeding 2 km, and perhaps reaching the 9 km thickness that underlies Taiwan. Most of these sediments are believed to be Neogene in age, the same as the oil-producing strata on the island. Anticlines, faults, and unconformities were encountered in these strata during the survey, and the character of the seismic reflections indicate that both shales and sandstones are included. Neogene sediments in two large basins beneath the Yellow Sea are less than 2 km thick, but the shales probably have a higher content of organic matter than do those of the continental shelf owing to the high organic productivity that is permitted by the nutrients in the rivers that debouch into the sea.

The shallow sea floor between Japan and Taiwan appears to have great promise as a future oil province of the world, but detailed seismic studies are now required. Afterward, the final test must be made by offshore drilling.

황해와 동지나해의 지질구조및 해수특성

케이. 오. 에머리(1), 요시가즈 하야시(2), 토마스 다부류. 시. 힐드 (3),
사스오 고바야시 (2), 구자학 (4), 시. 와이. 멩(5), 히토시 니노(6),
재이. 에취. 오스터하겐(3), 엘. 엠. 레이놀드 (3), 죤 엠. 왝그만(3),
시. 에스. 왕 (7), 양승진(4)

요 약

동지나해와 황해에 대한 물리탐사가 1968년 10월 12일부터 11월 29일까지 조사선 "알 부이 에푸 부이 헌트"에 의하여 실시되었다.

에카페 (아시아 지역 천해저광물자원 공동탐사 조정위원회)를 통해서 한국 중국 미국 일본의 과학자들이 조사에 공동 참여 하였다.
조사면적은 텍사스 오크라호마 뉴멕시코를 합한 면적또는 동남아시아 (월남 라오스 캄보디아 타이랜드) 의 면적에 상당한다.
12,000 킬로메타 이상의 조사항해를 하는 동안 연속 탄성파반사법이 30,000 줄의 스파카로서 행해졌고 동시에 지자기 연속측정이 행해졌다. 그리고, 해양학적 자료로서 해수의 색 투명도 부유물의 양 해수온도, 염도 파도의 방향과 크기 풍향과 풍속몽이 두시간마다 해수면에서 측정되었다.
해양학적 관측 중 몇가지는 낮에만 행해졌고 몇가지 (부유물과 염도)는 차후 실험실 분석이 요망된다.

자료의 일차적인 해석은 비에서 행해졌고 각종 측정도면은 계획을 세우기 위해서 지금까지 보관되었다.
최종적인 해석과 편집및 설명은 미국에서 완성되었다. 천해저광물(석유및 까스) 탐사를 위하여 가장 중요한 것은 지구 물리학적 결과이다.
이 물탐결과에 의하면 조사해역에는 몇줄기의 평행한 구능이 분포하는바, 이 구능들은 황와와 양자강에 의하여 중국의 광범한 지역으로부터 운반된 퇴적물을 집적하는 뗌의 역활을 한다.
북쪽 구능은 상동반도에 연하여 노출한 선캠부리아기의 화성암및 변성암으로 되어있다. 황하로 부터의 퇴적물은 이 구능에 의하여 포하이만에 퇴적되었다. 다음구능은 황해입구를 횡단하는 복강— 영남 저반대로 중생대에 상승한 중생대및 선캠부리아기에 걸친 암석으로 되어있다.
황해해역내에서 이 저반대는 적어도 200,000 입방 킬로메타의 신제3기 퇴적물을 집적하였다. 다음 바다쪽으로 일본과 대만사이의 대륙붕의 끝 부근에 위치한 화성암및 습곡퇴적암으로된 구능이 있다.
이것이 타이완— 신지 습곡대이다. 여기서 육지쪽으로는 탄성파 특성과 육지에서의 노두및 시추공과 해저시료채취 결과에 근거하면 신제3기라 믿어지는 퇴적물이 1백만 입방킬로메타 가량존재한다.
대륙붕바깥쪽으로 떨어진 곳에는 화산암및 습곡된 제3기 및 그기의 퇴적암층으로 되어있는 류구 구능이 있어 오끼나와 해구에 퇴적암대를 집적케 하고 있다.

류규 구능의 동쪽사면 중간쯤에는 흡사한 성분과 근원으로 보이는 더 작은 구능이 유사한 퇴적암대를 집적케하고 있는바 이 퇴적암의 표면은 수천메타의 깊이에서 광범한 테러스로 되어있다.
일본 근해에서 이런 구조의 일부는 도사 테러스라고 알려져있다.
마지막으로 류규 구능의 경사의 저부는 류규 해구로서 0내지 수백메타의 퇴적물을 포함하고 있다.
대륙붕 하부와 황해에 있어서의 퇴적물은 석유및 까스 보유암으로서의 유망성을 많이 갖었다고 믿어진다.
대만 북쪽에는 2킬로메타 이상의 퇴적암 두께를 갖인 지역이 대만의 수배되는 면적에 걸쳐 분포하며 대만 하부에서는 퇴적암 두께가 9 킬로메타에 달할 것이다. 이 퇴적물의 대부분은 육지의 함유층과 같은 신제3기층이라 생각된다. 배사구조 단층및 부정합이 이번조사에서 확인되었으며 탄성파반사파의 특성은 이들 퇴적층이 세일뿐 아니라 사암도 포함하고 있다는 것을 보여준다. 황해 해저의 두개의 커다란 분지의 퇴적물의 두께는 2킬로메타 이하이나 그 중 세일은 바다로 유입되는 강물내의 영양분에 의한 유기물 생성능력때문에 대륙붕의 세일보다 더 많은 유기물을 함유하고 있다.
일본 대만 사이의 얕은 해저는 미래의 세계유전으로서의 전망을 갖었으나 더 세밀한 탄성파적 연구가 요망된다. 차후에 최종적인 탐사는 해상 시추에 의하여 행해져야 한다.

(1) 우드 홀 해양연구소, 미국 마사츄세쓰주 우드 홀

(2) 일본 석유 개발회사, 일본 동경

(3) 미국 해군 해양연구소 태평양 지원반, 미국 캐리포니아주 산디아고

(4) 한국 국립 지질조사소, 대한민국 서울

(5) 중국 석유공사, 중화민국 대북

(6) 동경 수산대학교, 일본 동경

(7) 대만 국립대학교, 중화민국 대북시

東支那海海底の地質構造と，海水に見られるある種の特徴に就いて

摘　要

東支那海海底の地球物理学的調査は1968年10月12日より同年11月29日の間R/V F.V. HUNT により行なわれた．この調査にはE.C.A.F.E.の亜細亜海域沿岸海底鉱物資源協同調査委員会を経て中華民国・大韓民国・日本および北米合衆国の科学者が参加したがその調査海域は米国ならばテキサス・オクラホマ・ニューメキシコ州を併せたものか，亜細亜ならばベトナム・ラオス・カムボチャ・タイ国等を併せた広さに相当した．

航跡は12,000 km におよび30,000 Joule のスパーカーで反射記録が得られ，また地磁気の継続記録も得た．2時間間隔海洋表層の観測が行なわれた．水色，透明度，浮遊物質量，水温，塩分，波浪の強さと方向，海面風速および方向等であるがこのうちではもちろん昼間に限られる種類も後で研究室での調査が不可欠のものもある．予察的な調査要素の分析は調査進行の一指針として刻々船上で作られた．しかし完全な解析および実状は米国着後に示される予定である．沖合鉱物資源（主として石油および天然ガス）開発にとって地球物理学的調査の結果は重要である．今回の調査の結果この海底にはほとんど平行して発達した一連の海底隆起地形があって，そのそれぞれが，広大な支那大陸から揚子江・黄河等の流れにより運ばれてきた堆積物にとって堰堤の役割を演じて堆積が行なわれた如くである．

このうち最北の隆起は山東半島に沿う前カムブリア紀の変成岩と火成岩である．黄河によって渤海湾に運ばれたものはこの隆起部で捕捉された．次の隆起は黄海を通過する前カムブリア紀から中生代に至る地層で構成される地塊である．この地塊により少くとも 2,000,000 km³ の堆積物が捕捉されこれは主として新第三紀層に属する．次の海洋側の隆起は火成岩および褶曲している水成岩よりなり台湾と日本とを結ぶ大陸棚の縁辺に沿うものでいわゆる台湾一宍道褶曲帯に相当する．陸側にある堆積物は百万立方 km，これが新第三紀層に考えられるいわゆるスパーカーの連続記録による特徴，島嶼の露頭陸上および海底からの採取岩石の特徴によるものである．

大陸棚を離れると琉球隆起がある．琉球隆起は古生代，火成岩および褶曲した新第三紀の地層よりなり沖縄海淵中の堆積帯の堰堤を形成している．

琉球隆起の東側の斜面中途に琉球隆起に同一源の構成と考えられる小隆起があり，これによって一連の数千メートルの深さの広い深海段丘面を形成している堆積帯がある，この面は土佐深海段丘として知られているものの一部分と考えられる．最後に琉球隆起の斜面の基部は琉球海溝でありここには0～数百メートルの堆積物があるにすぎない．大陸棚下底と黄海下にある堆積物には石油および天然ガスが保留されている可能性が大きい．台湾島の広さに数倍する広い地域が台湾の北方に広がりそこでの堆積物の厚さは 2 km 以上に達していることが明らかであるが，恐らく台湾で知られている 9 km の厚さにも達するかも知れない．そしてこの堆積物は新第三紀層に属すると考えられている．台湾ではこの地層から石油を産出している．背斜軸，断層等が調査中にこの堆積層中で認められている．地球物理学的（地震反射波）の特徴から推してこの堆積物は頁岩ばかりでなく砂岩を包含している．

黄海海底の堆積物は 2 km 以内ではあるが，ここの頁岩は大陸棚のそれより高い有機物を含んでいるであろう．何故ならば河川が運んだ営養塩により有機質の高い生産があるからである．

台湾と日本との間に横たわる浅海底は将来一つの世界的な産油地域となるであろうと期待される．しかし更めて詳細な地震探査が必要である．最後に，沖合鑿井により最終的な試掘が望まれる．

黄海及中国東海地質構造及海水性質測勘

摘　　要

黄海及中國東海区之地球物理測勘擧行於亨特號 (R/V F. V. HUNT) 研究船上，自1968年十月十二日起至同年十一月廿九日止，共計49日。此行経聯合國亜経會聯合探勘亜洲海底礦産資源協委會方面供中華民國，大韓民國，日本處美國科学家共同参加此項海上探勘之工作，総計測勘面積，如以東南亜地区相比約相等越南東埔寨及泰國三國面積之徳和。

本次海上測勘総航程一万二千公里長度中，進行聯續不停之反射震測剖面記録，係以三万 Joule 能力之火花爆震測儀施測者。同時，另一聯續性地磁剖面記録工作亦在進行。有関海洋学方面之各項記録，如近海面水之顏色，透光度，飄懸物含量，水温，塩份，海浪之方向及大小，近海面風之方向及速度等，皆毎隔二小時観察一次， 其中若干項僅能於日間観察， 亦有若干項須戻抵岸後作試験， 其初步記録分析及解釋工作皆於航行中進行，盂対整計劃可有啓発及指導之作用。至於最後之詳細解釋，分析，編綴及製図等工作俟於不久将左美完成之。

海底礦産資源測勘（石油及天然気之探勘佔重要位置）最重要者即穫得地球物理測勘之結果。本次地探記録顯示最明者為本区内有数条幾相平行排列背梁之出現，毎一背梁均形成一攔覇，将大部份来自中國大陸黄河及楊子江所携来之沉積物存積其内。本区最北之一背梁為前寒武紀及変質岩所組成，沿山東半島露出，黄河携帯之泥砂即被本背梁所阻，積於渤海湾之内。次一背梁為前寒武紀至中生代之岩石所組成，於中生代末期熱山運動擁起為福建一越南地塊，在本区内乃横跨今日之黄海出口位置。此地塊所形成之背梁乃阻聚至少二十万立方公里体積数量之沉積物於黄海中，年代多半應属新第三紀以後者。

更向海方向歴数，又為一由火成岩及経褶皺之沉積岩所構成之背梁，其位置乃接近本区大陸棚之辺縁，而介於日本及台湾之間。其向陸方向， 或可有一百万立方公里体積之沉積物， 依震測記録之性質， 陸上所見之露頭，鑽井記録以及在海底所採獲之岩様等引証，其年代應當為新第三紀者。

大陸棚以外之琉球背梁， 係由火成岩及経褶皺之新第三紀地層組成， 応将其西北之沖縄海槽沉積物攔阻背内。另一小背梁或寛前者同一組成，位置於琉球背梁向東坡之中途，形成一寛廣面積，日入称此地形特徵為「土佐台地」(Tosa Terrace)，向海之最後特徴為琉球海槽，係位置於琉球背梁東坡之底，最深寛達7881公尺。該槽内，僅存留自零至数百公尺厚之之積物而已。

本区大陸棚下之沉積，経本次測勘認為儲集石油及天然気之可能性甚重，居台湾之東北方有面積較其本島達数倍之一處，沉積厚度在二千公尺以上，可能延至台湾達八，九千公尺者。該沉積大部份応属新第三紀，亦即台湾油気之生産地層。本次海上測勘期中曽見於地層剖面中有背斜，断層及不整合等対儲油有利之構造，且於震測反射記録中， 応可分辨非僅属頁岩， 砂岩更存在不少。 黄海海底之两大盆地内之沉積厚度似少於 二千公尺，但其頁岩中成可能含有机物質較大陸棚者為豊，因黄河及楊子江所携至海内之營養物較多，易使有机生産率増高也。

日本至台湾間之浅海底似可成為將来世界豊厚希望之產油区，但目前所急needs進行者，為進一歩之詳細震測工作及研究，從之必在海上鑽井，以試意究也。

INTRODUCTION

In 1966 the United Nations Economic Commission for Asia and the Far East (ECAFE) set up a Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas to aid in the reconnaissance exploration for potential mineral resources from the sea floor off eastern Asia. The initial members of this committee were Japan, the Republic of Korea, the Republic of China, and the Philippines. One of the first acts of the committee was to invite participation of representatives from the Federal Republic of Germany, France, United Kingdom, and the United States as members of a Technical Advisory Group. Meetings of the committee and of the Technical Advisory Group in Tokyo, Seoul, and Taipei indicated a great likelihood of stratigraphy and structure favorable for accumulations of oil and gas in the shallower parts of the East China Sea and vicinity. Evidence was based upon previous studies of about 330 sediment samples from the region (Niino and Emery, 1961), rock dredgings and extrapolation of structures known on land in Japan, Korea, and China (Emery and Niino, 1967), and preliminary results of an airborne geomagnetic survey made by the U.S. Naval Oceanographic Office's Project MAGNET in June 1968 as a United States' contribution to the ECAFE objectives.

The accumulated information indicated that thick Neogene strata, possibly oil-bearing, underlies the Ryukyu Ridge, the outer margin of the continental shelf between Japan and Taiwan, the central part of the Yellow Sea, and the Gulf of Pohai. Geophysical measurements were needed in order to estimate the thickness and attitude of the Neogene sediments and to infer the nature of underlying rocks. Although the airborne geomagnetic profiles provided some information, seismic data were considered more definitive. Several possible sources of ships and equipment were investigated; the most practical source was an offer for joint participation of ECAFE personnel in a study planned by the Pacific Support Group of the U.S. Naval Oceanographic Office to investigate the East China Sea using shipboard reflection seismic and geomagnetic methods. The ship was R/V F. V. HUNT, operated by the Marine Acoustical Services of Miami, Florida, under contract to the Navy's Military Sea Transportation Service and directed by the U.S. Naval Oceanographic Office. She is a 850-ton, 55-meter, dieselelectric converted cable-laying vessel (Fig. 1). The ample laboratory space in the original cable tank and her good sea-keeping ability are ideal for marine geophysical investigations.

Work in the East China Sea occurred during three separate cruise legs: Sasebo (Japan) to Sasebo—12 to 21 October; Sasebo to Chilung (Taiwan)—25 October to 11 November; and Chilung to Sasebo—16 to 29 November 1968. The total distance run was 12,200 km. During all three legs John M. Wageman was chief scientist, assisted by Thomas W. C. Hilde, L. M. Reynolds, and John H. Osterhagen. K. O. Emery served as ECAFE liason scientist. During each of the three legs two or three Asian scientists participated in the work: C. Y. Meng and C. S. Wang from China; Yoshikazu Hayashi, Kazuo Kobayashi, and Hiroshi Niino from Japan, and Ja Hak Koo and Sung Jin Yang from Korea. All contributed heavily to the success of the cruise and are listed in simple alphabetical order as authors of this report.

Appreciation is due Captain Samuel W. Shores and his officers and crew whose ability, good humor, and willingness to work insured the success of the cruise. Special thanks are due Ronald G. Roy, John A. Frank, and Edwin O. Danford for their contributions as electronics technicians and as watch standers. Measurements of chlorinity were made at Nagasaki University, Faculty of Fisheries.

METHODS

Several kinds of geophysical and oceanographic measurements were obtained during the cruise, with geophysical measurements recorded continuously and automatically, and oceanographic data collected at two-hour intervals.

Simplest of the geophysical measurements was bathymetry, measured from a crystal transducer that was towed alongside the ship and that acted as both transmitter and receiver. Echoes from the bottom are filtered (12 kHz), amplified, and recorded with a Gifft recorder on wet paper 49 cm wide. In some areas of acoustically transparent sediment the records revealed subbottom reflections.

A Varian proton precession magnetometer was towed about 200 meters astern in order to be free of the magnetic effects of the steelhulled ship. Results were recorded by ink pen on paper having a 25.5-cm width for 1000 gammas.

Continuous seismic reflection profiles were made with a Geotech (a Teledyne company) system. A condenser bank at 14 kv was discharged at 4-second intervals to release 30,000 joules between electrodes about 50 cm apart that were trailed 50 meters astern of the ship. The hydrophone receiver was a single streamer 50 meters long, containing 100 crystal detectors, and towed with its leading end 135 meters astern; thus the center of the receiving streamer was about 110 meters from the spark sound source. The echoes from bottom and subbottom reflectors were fed through band pass filters between 20 and 100 Hz, amplified, and recorded on a Raytheon unit having a 4-second sweep rate on spark-sensitive dry paper 49 cm wide. The results obtained at the standard cruising speed of 10 knots (18 km/hour) were excellent and far better than those at lower ship speeds.

Oceanographic observations consisted mainly of surface or nearsurface water characteristics. Surface water obtained in a plastic bucket provided temperature, a 100-m*l* sample for chlorinity and a 1000-m*l* sample for suspended sediment. The 1000-m*l* sample was filtered aboard ship through tared 0.45-micron millipore filters. Later, on shore, the filters were dried, weighed, and the concentrations of suspended sediment were calculated. For comparison with the concentration of suspended sediments, the color of the sea was measured during the daytime with standard Forel color vials, and the transparency was measured by Secchi disk at daytime stations where the ship lay stopped. At two-hour intervals the Beaufort wind force, the wind direction, and the height, length, and direction of the two or three distinct wave trains also was obtained visually.

Navigation was based upon RADAR when the ship was within range of the many steep islands off Korea, Japan, and along the Ryukyu Ridge. Positions farther from shore were controlled by LORAN A and star fixes. Positions are considered accurate within 3 km except in the northern part of the Yellow Sea and in Taiwan Strait where some of them may be as much as 6 km in error.

Running plots were kept on ship for all geophysical measurements and for oceanographic observations of the surface waters. These served as the bases for the drawings that accompany this report.

REGIONAL SETTING

This study covers a range of environments that have distinct differences in structure, rocks types, sediments, topography and water properties. The main objective was to discover and describe the structure; however, a brief description of the region in terms of its other characteristics is desirable. For convenience, the region can be divided into three main topographic units that are nearly equal in area: the Yellow Sea, the continental shelf, and the trough, ridge, and trench province.

YELLOW SEA

The northernmost topographic unit of the region is the Yellow Sea and its adjacent Gulf of Pohai. The area of this unit northwest of a line between southeastern Korea, southeastern Cheju Island, and the south side of the Yangtze River (Fig. 2) is about 0.50 million sq. km. It is a flat region with depths that average about 55 meters and nowhere exceed 125 meters. The western side is bordered by the combined deltas of the Yellow and the Yangtze rivers plus the hilly projection of the Shantung Peninsula that separates the lowland areas through which the Yellow River has alternately debouched in historical time and earlier. The eastern side of the Yellow Sea is hilly and fringed by hundreds of small rocky islands, but lowlands border the mouths of the Han River of South Korea, the Yalu River of North Korea, and the Liao River of China (in the Gulf of Pohai).

Influence of the Yellow and Yangtze rivers extends far beyond the shorelines, so that a smooth gentle slope from the west (1:26,000) meets the steeper and less regular slope from the east (1:6,000) in an axial valley that borders the eastern third of the sea. Sediments as well as topography reflect the work of the rivers, for the eastern third of the Yellow Sea is floored by sands derived from the mountains of Korea, whereas the western two thirds has silt and clay brought by the Yellow and Yangtze rivers (Fig. 3). Echograms made during the survey show that the upper layers of sediment in many parts of the sea are transparent to sound from ordinary echo sounding at 12 kHz, as is typical of fine-grained sediments deposited in low energy environments. In several places along the eastern side large sand waves were discovered, and their steeper slopes suggest a general northward flow of bottom water.

Properties of the water in the Yellow Sea provide information about the sediment sources and the current systems. Temperature and chlorinity of the surface waters, measured during the survey, show that a tongue of warm high-chlorinity water flows northward along the eastern side of the Yellow Sea. It eventually turns southward and returns along the western side much diluted by river effluent as a cool lower-chlorinity current (Figs. 4, 5). Similar results have been found by other workers in other years (Ichiye, 1960; Asaoka and Moriyasu, 1966).

The Yellow River (*Hwang Ho*) takes its name from its load of reworked loess derived from northwestern China. This load plus that of the Yangtze River is distributed throughout the western half of the sea, imparting the color that is the origin of the name for the Yellow Sea (*Hwang Hai*). In terms of Forel standard colors, the water in the western half of the sea contains more than 30 per cent yellow. In contrast, the warm saline water that flows northward in the eastern half contains less than 20 per cent yellow except in shallow depths near shore (Fig. 6). The same concentrations of sediment that produce yellow color also reduce the transparency of the water in the western half to less than 10 meters for the Secchi disk, whereas the transparency in the eastern half is more than 10 meters (Fig. 7) except near shore. The results are similar to those obtained by Nishizawa and Inoue (1958), who used transparency meters in the southern part of the Yellow Sea.

Suspended sediment concentrations are more direct indicators of the influence of the

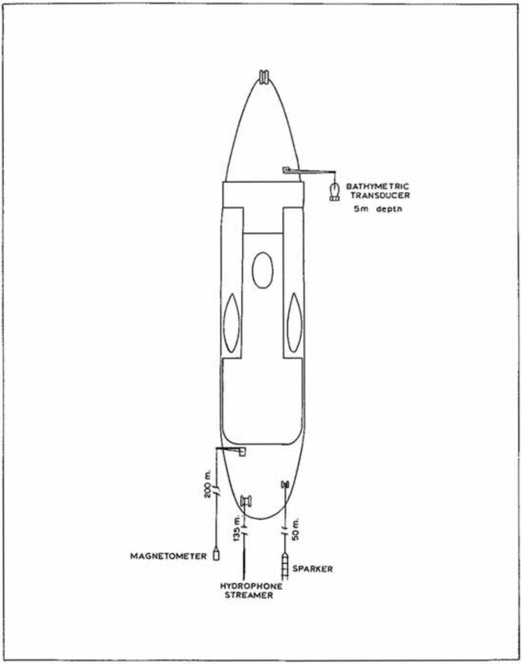

Figure 1. Sketch of R/V F. V. HUNT showing positions of towed sounding fish, spark electrodes, hydrophone streamer, and magnetometer.

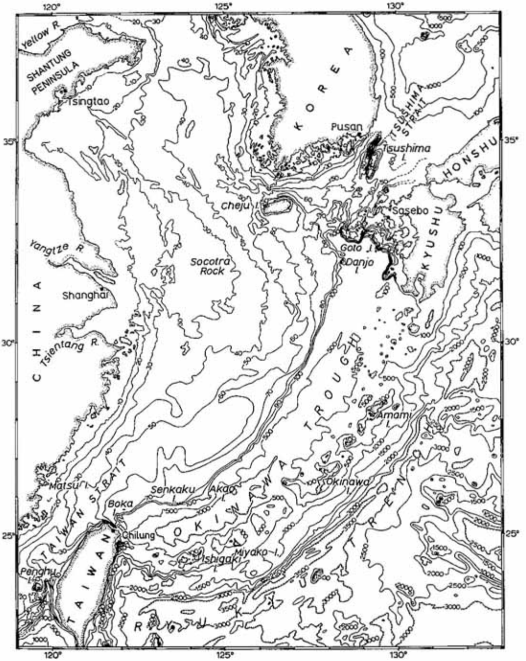

Figure 2. Topography of the region. The contours inshore of the Ryukyu Ridge are from a recent compilation by the U.S. Naval Oceanographic Office, and those seaward of the Ryukyu Ridge are from Scripps Institution of Oceanography. Note that the contours are in fathoms, whereas meters are used throughout the rest of this report.

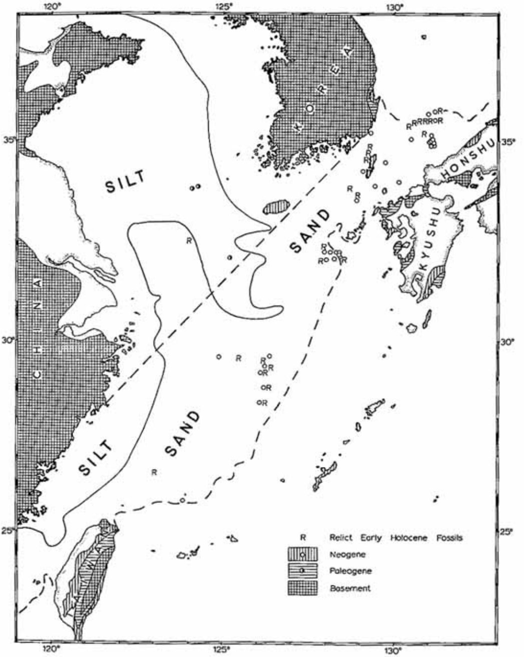

Figure 3. Generalized pattern of unconsolidated sediments (Niino and Emery, 1961; Wang, 1961), and positions of samples containing rock fragments identified by fossils or lithology as belonging to Paleogene or Neogene strata (Emery and Niino, 1967; Niino, 1968). Outcrops on land also are shown (Chinchang and Chang, 1953; Geol. Survey of Korea and Geol. Soc. of Korea, 1956; Geol. Soc. of Japan, 1964). Basement is shown in a rather generalized way to include areas having many small outcrops and presumbly only thinly overlain by Mesozoic and Cenozoic sediments.

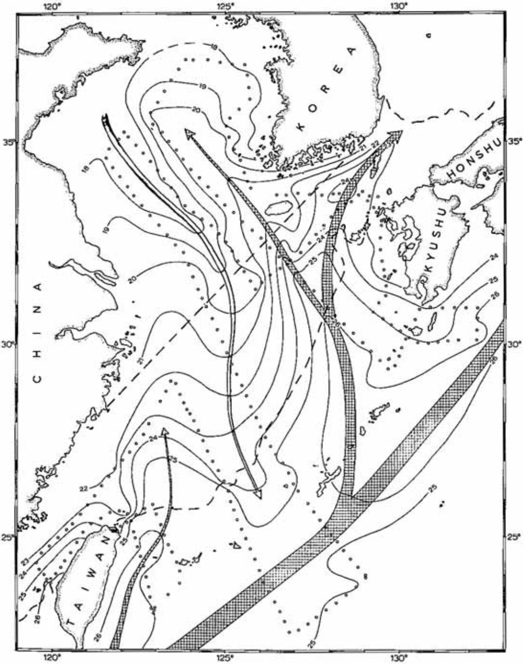

Figure 4. Temperature of surface water in the region, 12 October to 11 November 1968 in degrees Celsius. Temperatures between 16 and 29 November were about 2 degrees lower, but they exhibited the same areal pattern, in accordance with the trends described by Koizumi (1962). The cross-hatched arrows show the axes of flow of warm water brought into the area by the Kuroshio; the solid arrow shows the flow of cold water from the northern Yellow Sea.

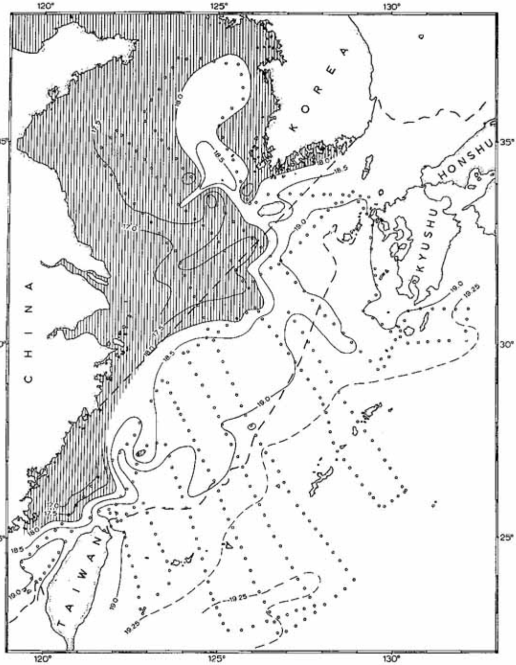

Figure 5. Chlorinity of surface water in the region, 12 October to 27 November 1968. Titrations were made by the Faculty of Fisheries, Nagasaki University, under the guidance of Haruhiko Irié.

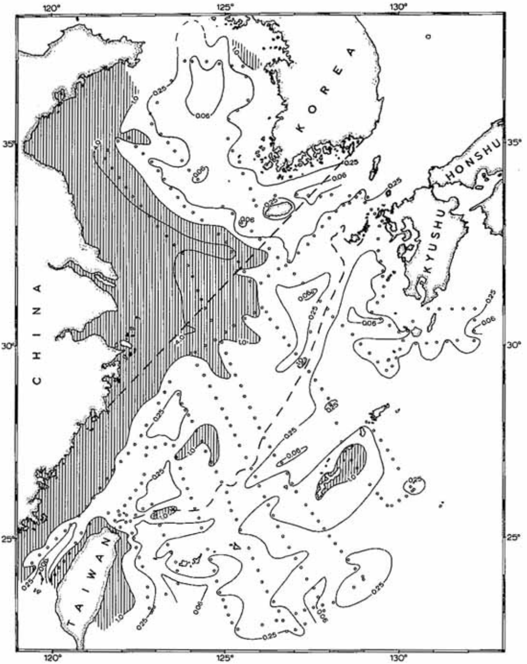

Figure 6. Color of surface water in the region in terms of percentage yellow by the Forel standard color vials, 12 October to 28 November 1968.

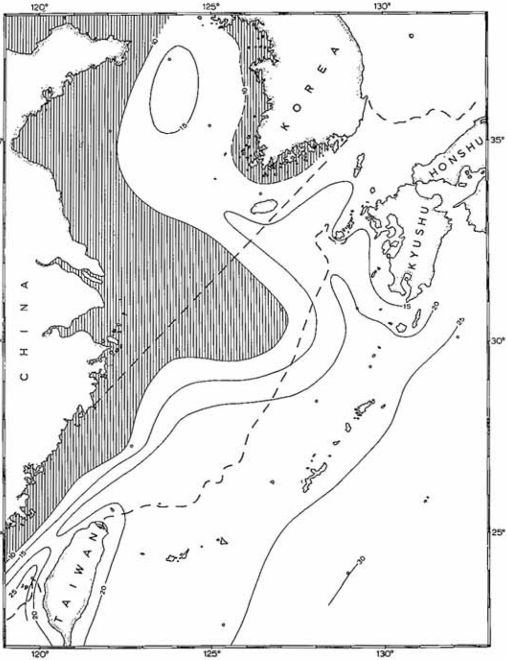

Figure 7. Transparency of the water in meters (depth at which a 30-cm Secchi disk is just visible), 12 October to 28 November 1968.

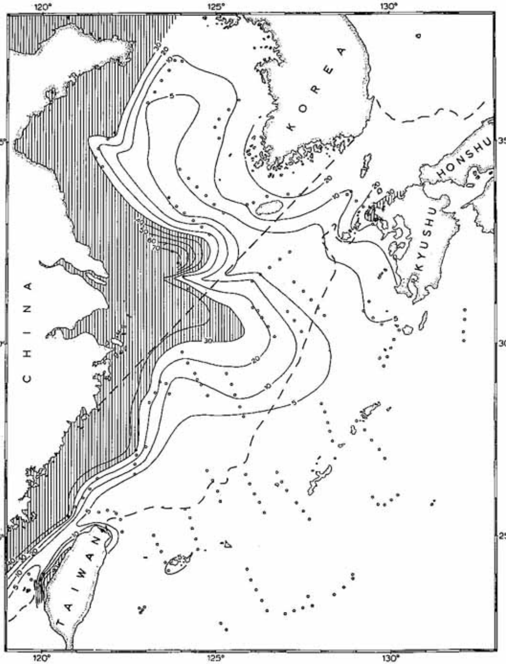

Figure 8. Concentrations of total suspended sediment (mg/l) in surface waters of the region, 12 October to 26 November 1968.

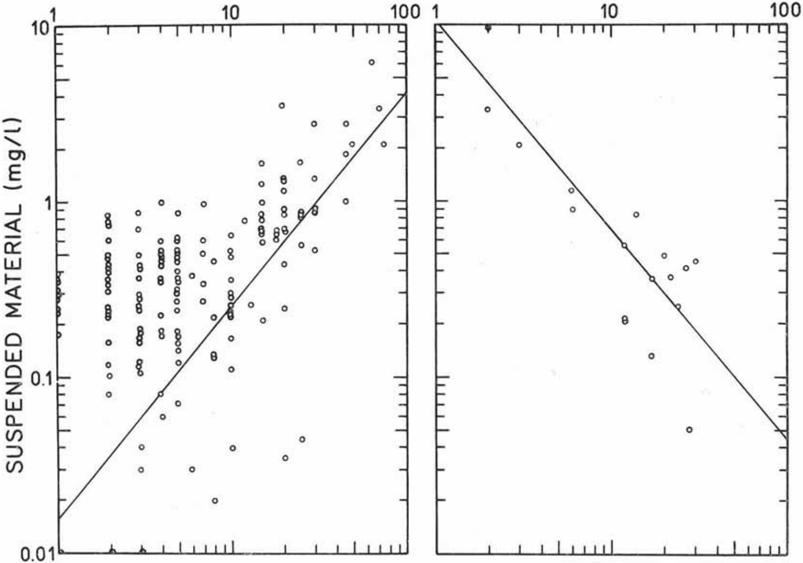

Figure 9. Relationships between concentration of suspended sediment and the color and transparency of the sea water. The diagonal lines in both graphs show correlations obtained for about 200 sets of similar measurements off the Atlantic coast of the United States (Manheim, Meade, and Bond, submitted for publication); the relationships are almost identical in the two areas.

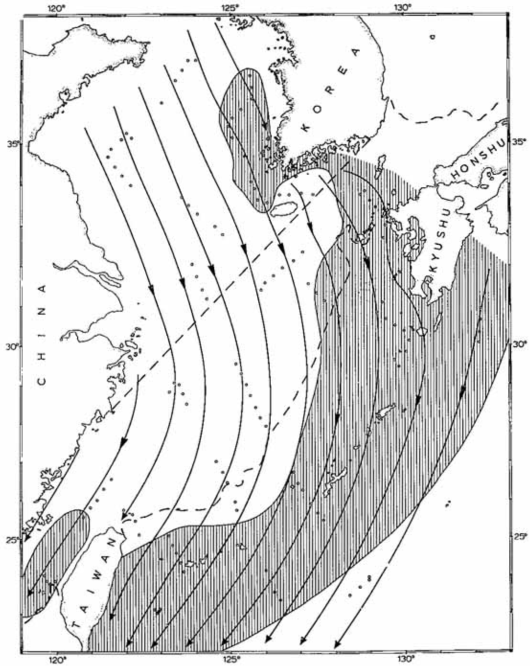

Figure 10. Wind streamlines and Beaufort wind forces observed 12 October to 11 November 1968. Effects of Typhoon Gloria are omitted. Winds between 15 and 29 November were more easterly. Areas of wind force more than 4 are cross-hatched.

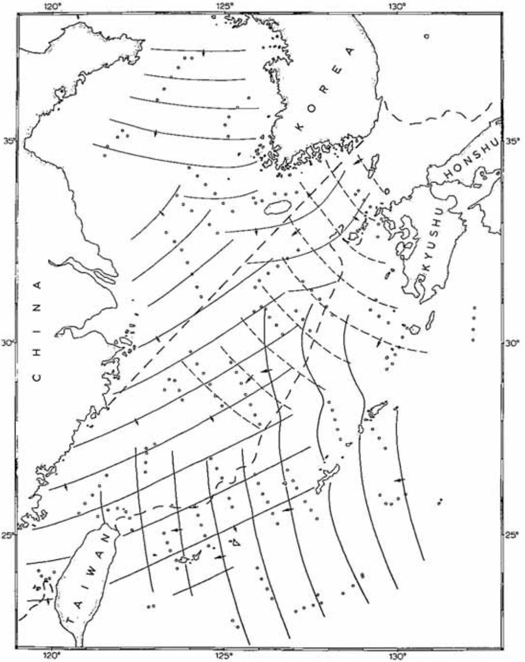

Figure 11 Generalized pattern of swells produced mainly in the northern Yellow Sea and Gulf of Pohai, in the Japan Sea, and in the open Pacific Ocean south of Japan, as observed between 12 October and 26 November 1968. Effects of Typhoon Gloria are omitted. Arrows show direction of movement of swells.

rivers, with more than 1 mg/*l* along the western half, and less than 0.1 mg/*l* for most of the eastern half (Figs. 8, 9). In comparison, the average concentration of suspended sediment in the Yangtze River is 0.8 gm/*l* and in the Yellow River, 45 gm/*l* (Holeman, 1968). Probably about 50 per cent of the suspended sediment in the Yellow Sea is detrital clay and silt; the rest is organic material derived from land areas or produced in the sea from nutrients contributed by the rivers. Such ratios are typical of waters off the Atlantic and Gulf coasts of the United States (Manheim and others, 1966; submitted for publication).

The general counterclockwise circulation of water in the Yellow Sea has long been known on the basis of the distribution of temperature and salinity, and it recently has been confirmed from the distribution of diatoms as well (Asaoka and Moriyasu, 1966). Winds over the Yellow Sea are of a general monsoon type, landward during the summer and seaward during the winter (McDonald, 1938; Tregear, 1965, pp. 15–17). The pattern during the cruise was typical of winter except during a few days (21 to 26 October) when the fringes of Typhoon Gloria intruded the area. Streamlines and Beaufort wind forces observed during daytimes of the rest of the cruise are shown by Figure 10. These winds produced waves and swells that moved throughout the sea (Fig. 11).

Rocks from outcrops that project through the sediments are not known from the central part of the Yellow Sea. Moreover, wells drilled to 960 meters depth in the Yellow River floodplain north of the Shantung Peninsula encountered only shallow-water deltaic sediments to their maximum depths (Niino and Emery, 1961; Tregear, 1965, p. 37). In contrast, notations of rocky bottom are shown on navigational charts in the nearshore regions of Korea, just south of Shantung Peninsula, and along the eastward projection of the peninsula. Rock outcrops also occur at the entrance of the Yellow Sea between Korea and the mouth of the Yangtze River. Several of the rocky areas rise above the ocean (Cheju Island) and others form shoals (Socotra Rock) of Tertiary volcanic rocks; other islands off the Yangtze River consist of Mesozoic volcanic rocks (Director Geol. Survey of India, 1959).

Continental Shelf

The second topographic unit of the region is the continental shelf. At the north the shelf takes the form of Tsushima Strait between Korea and Japan, a width of about 150 km (Fig. 2). The middle part of the shelf fronts the Yellow Sea, and the southern part borders the China mainland from the mouth of the Yangtze River to beyond the strait between Taiwan and the mainland. The outer edge of the shelf coincides approximately with the 120-meter contour. The maximum width of the shelf is off the Yangtze River where it reaches 450 km; farther soutwest the shelf narrows to about 125 km west of Taiwan. Within Figure 2 the area of the shelf is about 0.41 million sq. km.

Sediments of the continental shelf exhibit a simple pattern of silt and clay on the nearshore half and sand on the outer half (Fig. 3). The silt and clay forms a continuous belt that extends southwestward from the western part of the Yellow Sea; it clearly is a modern deposit carried from the Yangtze River and probably also the Yellow River by the inshore southwesterly-flowing current. Sands on the outer half of the shelf are calcareous (averaging about 30 per cent calcium carbonate) and they are iron stained, typical of relict sediments that have remained unburied on most continental shelves of the world since Pleistocene times of glacially lowered sea levels (Emery, 1968). Confirmation of the relict origin is provided by 27 bottom samples that contain the remains of land mammals, brackish-water mollusks, and shallow marine mollusks (Emery, Niino, and Marsters, in preparation). Radiocarbon dates for several samples range from 4,000 to 30,000 years.

Properties of the surface water are closely related to those of the two types of bottom sediment. The low temperature, low chlorinity, low transparency, and high percentage of yellow color and of suspended sediment (Figs. 4, 5, 6, 7, 8) denote the southwestward-flowing nearshore current. The northeastward-flowing warm saline clear water atop the outer part of the shelf marks the Kuroshio Current that continues out of the region and south of Japan, with a small branch extending through Tsushima Strait into the Japan Sea and another into the Yellow Sea. The high temperature, chlorinity, and transparency of the Kuroshio water favors the deposition of the calcareous shell and algal debris that is absent to rare below the nearshore current.

Rock projects above the sediments in the many islands near Japan and in a few others near the shelf edge farther southwest. Most of the islands consist of Tertiary and Pleistocene volcanic rocks that bury or are interbedded with mainly Neogene sedimentary strata. Dredgings from the continental shelf have recovered 34 samples consisting of Neogene sandstones and shales (Fig. 3). Fossils in most rocks from Tsushima Strait are shallow-water forms, whereas those from farther southwest indicate moderate depths of original accumulation. Additional geological data comes from coal mining operations at Nagasaki where seaward-dipping Paleogene coal beds have been mined to 5 km seaward of the shore (Yamamoto and others, 1967), and from deep oil borings at Taiwan that have penetrated more than 5,000 meters of Neogene strata (Schreiber, 1965; Meng, 1967, 1968) The pattern of stratigraphy and structure suggests that the seaward edge of the shelf may follow a belt of folded thick Neogene strata that extends from Japan to Taiwan, the Taiwan-Sinzi Folded Zone (Emery and Niino, 1967).

Trough, Ridge, and Trench Province

The third unit of the region includes the Okinawa Trough, the Ryukyu Ridge, and the Ryukyu Trench; these features also are known as the Nansei Shoto Trough, Ridge, and Trench. All of them extend in a seaward curving arc from Japan to Taiwan (Fig. 2), and their topography has been mapped and described by Hess (1948), Tayama (1952), Dietz (1954), Udintsev and others (1963), and Menard (1964). Their combined area within Figure 2 totals about 0.40 million sq. km.

The Okinawa Trough borders the continental shelf, and its western side is the continental slope. The deepest part, near Taiwan reaches 2270 meters, and its floor shoals northeastward toward Japan. Clearly, the trough is an area of deposition dammed by the Ryukyu Ridge in much the same manner that the Fukien-Reinan Massif dams the Yellow Sea basin, and the Taiwan-Sinzi Folded Zone may dam an elongate basin beneath the continental shelf.

The Ryukyu Ridge is an elongate island arc atop which rise many islands including Okinawa. Islands along the inner part of the arc mainly consist of volcanic rocks, but those on the outer part contain outcrops of Neogene, Paleogene, Mesozoic, and even Paleozoic sedimentary strata intruded by granitic or gabbroic masses (Konishi, 1964). Intense folding along the ridge identifies it as the Ryukyu Folded Zone that connects folds of southern Japan with the complicated alpine structure of Taiwan.

Seaward of the Ryukyu Ridge is one of the deepest parts of the ocean, the Ryukyu Trench. The axis of the trench between Japan and Taiwan is mostly deeper than 6,500 meters and near the midpoint is a sounding of 7,881 meters. The trench floor is flat over much of its length due to a thin undeformed sediment layer. The inshore slope is steep up to an extensive terrace at 2,000 to 3,000 meters (Yabe and Tayama, 1934), and it probably consists of both thick sediments and exposed igneous rock. The seaward slope has exposed igneous rock (Murauchi and others, 1968). At its north end the Ryukyu Trench is terminated both topographically and structurally by the intersection with the continental slope of several subparallel ridges from the southeast. These are the Kyushu-Palau Ridge (the longest one) and the Daito and Oki-Daito ridges. A trench structure, the Nankai Trough (Hilde, Wageman, and Hammond, 1969) continues northeast of this intersection; however, it displays more gentle topography and a thick sediment layer that continues from the Philippine Basin into the trench. The difference in these trenches, the intersecting ridges, and the possible offsets in the Ryukyu Island Arc suggested by Konishi (1965) probably relate to differential movement of the oceanic crustal plate toward the continent (Le Pichon, 1968; Morgan, 1968; Isacks, Oliver, and Sykes, 1968). To the southwest the Ryukyu Trench terminates against the north-south folded structures of Taiwan.

Water above the Trough-Ridge-Trench Province is typical western oceanic water—deep blue (less than 5 per cent yellow) highly transparent (more than 25-meter depth of Secchi disk), very little suspended sediment (mostly less than 0.5 mg/*l*), warm (more than 25°C.) and saline (more than 19 parts per thousand chlorinity), as shown by Figures 4 to 8. Winds in the open ocean east of the Ryukyu Islands were northeasterly, and they merged into the northerly winds from the Yellow Sea (Fig. 10). Swells east of the Ryukyu Islands were from the open Pacific Ocean, in contrast with the more locally derived ones of the Yellow Sea and the continental shelf (Fig. 11). Essentially all of the area east of the Ryukyu Islands was occupied by the Kuroshio (Black Current) that moves northward past Taiwan to divide and flow on either side of Japan, predominantly on the southeastern side.

STRUCTURE

Compilation Procedure

Bathymetry was plotted from soundings at 5-minute intervals during the cruise on a horizontal scale of 1:1,000,000. A vertical exaggeration of 22.5 was selected as most convenient for the regional topography. The total-field magnetic profile was plotted at the same horizontal scale from readings of the magnetometer at 15-minute intervals plus intervening high and low points. Continuous seismic reflection profiles were studied at intervals of several days when the record rolls were removed from the recorder. Interpretations were drawn with grease pencil on sheets of transparent plastic laid atop the recordings. All reflecting horizons deemed significant were traced, including the profile of the sea floor. These grease-pencil lines were then transferred by hand to the bathymetric profile using half-hourly time marks as guides for the horizontal scale. An assumed sound velocity in the sediment of 2,000 m/sec provided the vertical scale.

Three general kinds of materials were considered as mappable facies in the region. The bottomoost and oldest facies is opaque to sound, and the recordings of it exhibit many hyperbolic reflections presumably produced by irregular surfaces. Overlying strata wedge out against the opaque facies or arch over it with the appearance of differential compaction. Where the opaque facies is shallow, the geomagnetic profiles are very irregular—indicating large variations in the magnetic susceptability of the material. In all respects the facies acts as an acoustic basement and it has an appearance on the record like that of intrusive igneous and metamorphic rocks that have been profiled by reflection seismic methods elsewhere in the world. However, in the absence of rock samples or of detailed seismic velocities, one cannot be certain that ancient sedimentary strata or thick lava flows are not also included in this facies.

Both the second and third facies are transparent to acoustic energy, but they differ in their structural attitudes. The second facies underlies the third one, and it generally exhibits evidence of structural deformation followed by erosion. Thus the second and third facies are commonly separated by an unconformity. In some parts of the region the second facies was identified only on the basis of an exceptionally good reflector that appeared to be continuous with a nearby unconformity, perhaps the result of orientation of the profile along the strike rather than at an angle to the strike of dipping beds. We term the age of the second facies as pre-deformation and that of the third one as post-deformation.

For convenience in presentation, the final plots of bathymetry, subbottom reflectors, and total field geomagnetics were grouped into the same three topographic units of the region that were discussed in the preceding section of this report.

YELLOW SEA

Four profiles were made in the Yellow Sea northwest of a line between southeastern Korea and the mainland of China south of the mouth of the Yangtze River (Fig. 12). The total length of these profiles is 2,500 km. The basement facies is present along most of the lengths of all profiles, especially profile 1, which is nearest the Korean coast. Its top may be exposed on the sea floor only for a small part of profile 1, and it deepens in the other profiles so that it mostly lies deeper than 1 km in profile 4. Exammation shows that the magnetic profiles are highly irregular where the basement is near the surface, as in profile 1 and part of profile 2. Where the basement is deep, the magnetic profiles are only broadly undulating. The shoaling of the acoustic basement toward the Shantung Pensula, Korea, Cheju Island, and the China mainland south of the Yangtze River indicates that it consists mainly of the same Mesozoic and earlier igneous and metamorphic rocks that crop out in these land areas. More than 1,200 meters of Mesozoic continental sediments underlie western Korea, and the rise of acoustic basement toward this area indicates that these strata also act as acoustic basement, perhaps because of their included thick sandstone members. The ridge of acoustic basement across the entrance of the Yellow Sea probably is a continuation of the Fukien-Reinan Massif (Kobayashi, 1952) that crops out in southern Korea and south of the Yangtze River mouth (Fig. 3). Rocks of the same kind and age and with parallel structural trends occur in both areas. A second submerged ridge of igneous and metamorphic rock appears to prolong the Shantung Peninsula and limit the Yellow Sea basin at the northwest.

Strata of the second facies (pre-deformation sediments) are progressively more abundant to the southwest (Fig. 12). On profiles 1, 2, and 3 they lie below an unconformity that commonly also truncates adjacent areas of the basement. As shown by all profiles, the unconformity is broadly undulating, from less than 100 meters depth to about 1,600 meters. The wave length of the undulations is about 300 km. The fact that the unconformity commonly bevels basement as well as the pre-deformation sedimentary strata means that the unconformity is a major one. Considerations of general regional geology support the concept that the unconformity followed the widespread mid-Tertiary orogeny. Such an assumption means that the pre-deformation sedimentary strata are Paleogene or earlier, perhaps including some Late Cretaceous shales, but excluding igneous and metamorphic rock and sandstones that have acoustic properties similar to those of the basement complex. Support for this conclusion is provided by the three samples of Paleogene rocks that were dredged near the entrance of the Yellow Sea (Fig. 3) where overlying strata are thin enough to permit local projections of Paleogene strata above the sea floor.

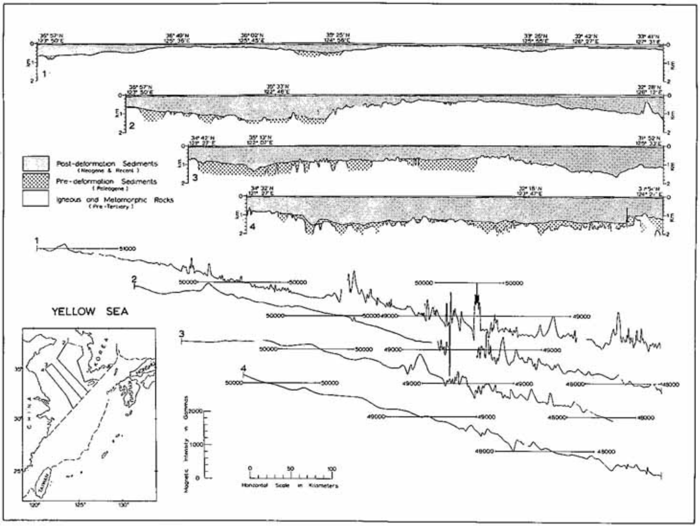

Figure 12. Continuous seismic reflection profiles and geomagnetic profiles of the Yellow Sea.

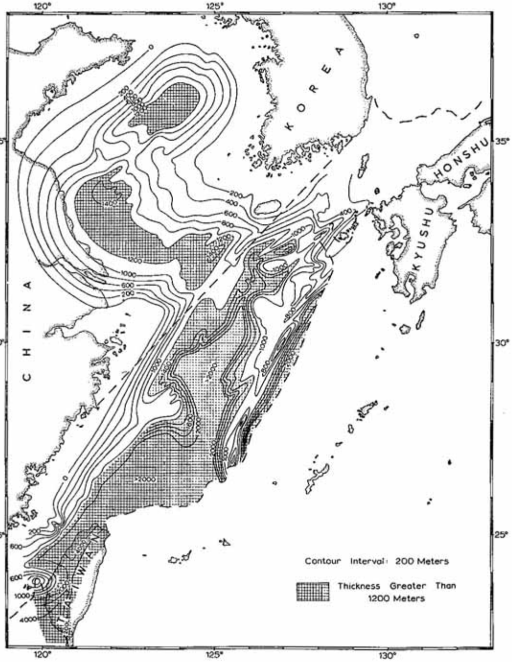

Figure 13. Isopach map of the third (post-deformational) facies in the Yellow Sea and the continental shelf. Contours are in meters. Because of the shallow water depths, this map also is essentially a structural contour map of the top of the second facies.

Atop the unconformity in the Yellow Sea is the most extensive facies, the post-deformation strata. Most reflecting horizons within it are so nearly horizontal as to not permit discrimination from the numerous multiple reflections of the flat sea floor. Only locally can subbottom reflections be identified in the third facies; mostly these are places where differential compaction atop basement hills has produced a dip, or where prominent discontinuities occur at such great depths as to be recorded after the bottom multiples have largely been attenuated. The third (post-deformational) facies was further investigated by plotting its thickness at half-hour intervals along the profiles to form an isopach map. This map (Fig. 13) clearly shows the presence of a large sedimentary basin which is dammed by a ridge between Korea and the Yangtze River mouth. The low point on the ridge appears to be about 1,100 meters below sea level. Within the Yellow Sea the basin contains three separate low areas. Two contain sediments that are 1,400 to 1,500 meters thick (or deep below sea level) and one has perhaps 100 meters less sediment. The shallowest one is just south of the tip of the Shantung Peninsula; the other two lie immediately off the Yangtze River delta. Outcrops of basement rocks on land in the Shantung Peninsula and near Shanghai (Director Geol. Survey of India, 1959; Roe, 1962) limit the westernmost margin of the basins to the vicinity of the delta front.

If the widespread unconformity in the Yellow Sea is mid-Tertiary in age, the post-deformation strata must be Neogene to Recent. A Neogene age is supported by the absence of known appreciable deformation in the land areas surrounding the Yellow Sea during this time interval. Also the thinning of the strata around the margins of the basin (Fig. 13) corresponds with the absence of Neogene strata on land except on Cheju Island, where their thickness is less than 100 meters. Pleistocene and Recent strata must also be included in the postdeformation facies, because at least 960 meters of Quaternary deltaic sediments have been encountered in water wells north of the Shantung Peninsula (Niino and Emery, 1961; Tregear, 1965, p. 31). Moreover, the volume of sediment annually discharged from the Yellow and Yangtze rivers is very great, 2,080 and 550 million tons each year, respectively, according to Holeman (1968). The rivers are the first and the fourth largest contributors of sediment to the ocean in the entire world. The total volume of the third facies in the Yellow Sea is about 200,000 cu. km. At a specific gravity of 2.0, this volume corresponds to 4×10^{14} tons. Thus, the third facies could have been deposited in only 150,000 years if the entire river load had been deposited in it. However, a large percentage of the sediment was deposited in the Gulf of Pohai (Zenkovich, 1967, pp. 75, 115, 644, 651, 659), and much more escaped seaward from the Yellow Sea, thereby increasing the time span by an unknown but probably very large amount.

Continental Shelf

Profiles across the continental shelf total about 4,500 km and consist of ten transverse lines and a composite one that follows the length of the shelf. The results show the bottom to be underlain by two main ridges of acoustic basement. The first ridge is the Fukien-Reinan Massif, most of which is within the Yellow Sea where it separates the Yellow Sea basin from the continental shelf. The part of the massif that is beneath the continental shelf is deeper (more than 1,000 meters below sea level) than the landward ends. Presumably the entire feature consists of Precambrian igneous and metamorphic rocks with some Mesozoic extrusives.

The second ridge lies near the edge of the continental shelf between Japan and Taiwan. Most of this one is buried beneath later sediments, and only near Japan does it rise above its

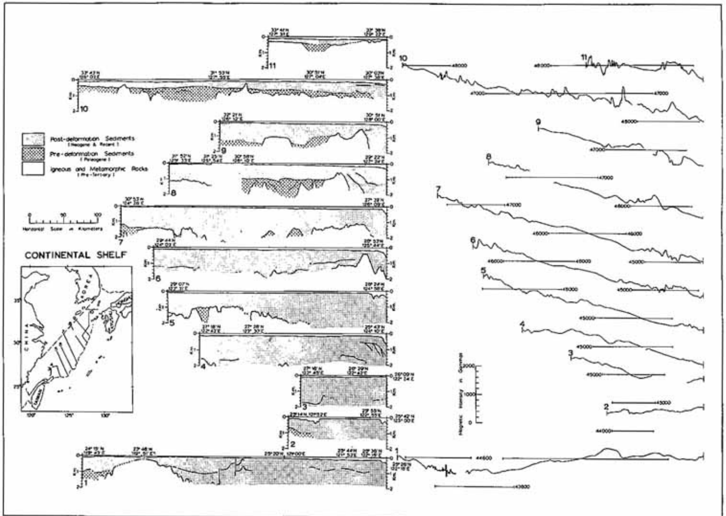

Figure 14. Continuous seismic reflection profiles and geomagnetic profiles of the continental shelf between Taiwan and Korea.

surroundings. Its greatest height occurs west of Kyushu in islands which contain folded sedimentary rocks and granodiorite, both of Tertiary age. Similar rocks occur farther northeast along the northwestern coast of Honshu, and thick folded Tertiary sediments are present in Taiwan as a southwestward extension of the ridge. Thus, the feature is termed the Taiwan-Sinzi Folded Zone, having its main deformation during Neogene times, but probably beginning during the Paleogene. The continuous seismic reflection profiles (Fig. 14) and the isopach map of Neogene sediments (essentially a structural contour map of the base of the Neogene sequence (Fig. 13) show that the ridge lies at the outer edge of the continental shelf between Japan and Latitude 26°30′. Between that latitude and Taiwan, about 400 km farther southwest, the ridge bows seaward and underlies the upper part of the continental slope. Two seismic refraction stations were made by Murauchi and others (1968) at the outer edge of the continental shelf and spanning our profiles 4, 5, and 6 (Fig. 14). They show that beneath 140 meters of water and 800 meters of sediments (seismic velocity of 2.0 km/sec) are 750 meters of material having a seismic velocity of about 3.4 km/sec. At greater depth is material of about 6.0 km/sec velocity. The intermediate seismic velocities of 3 to 5 km/sec support the concept that the Taiwan-Sinzi Folded Zone consists of sedimentary strata and acidic igneous rocks.

The magnetic profiles made during the cruise (Figs. 12, 14) reveal numerous anomalies where the profiles cross the Fukien-Reinan Massif and the Taiwan-Sinzi Folded Zone, attesting the presence of magnetic rocks, probably igneous intrusives and extrusives. Similarly, the isogams of the aeromagnetic survey by Project MAGNET (Fig. 15) exhibits a clear trend of positive anomalies that corresponds with the Taiwan-Sinzi Folded Zone, a less obvious one for the Fukien-Reinan Massif, and an intervening area of mostly negative anomalies that corresponds with the broad trough between the ridges. The anomalies rise to the south, even in the trough, so that almost the entire area just south of Taiwan has positive anomalies. At the north near Tsushima Strait the seismic and magnetic records of Figure 14 indicate that the trough shoals and divides into several secondary ridges that lie between and parallel to the two main ones.

Sediments above the acoustic basement are of two facies, as in the Yellow Sea: pre-deformation and post-deformation. The pre-deformation sediments are recognizable through their discordant dip beneath an unconformity that generally is 500 to 1,500 meters below sea level. On many profiles an unconformity is not evident, because it lies at great depth and is obscured by multiple reflections of the sea floor, or because the profiles are parallel to the strike of the dipping pre-deformation strata. Detailed laboratory comparison of all profiles from the continental shelf may permit mapping of the pre-deformation strata beyond the limits imposed by field examination of the records. For the present, the strata atop basement are best considered as a single unit, with the assumption that most of them are Neogene in age. The age of at least the upper strata is indicated by the presence of Neogene rocks, generally folded, on islands of the Goto Group near Kyushu, on Senkaku Island, and on Taiwan. In addition, 27 dredge samples of the continental shelf between Japan and Taiwan contain fossils or rock types of Neogene age. Evidently, Neogene strata forms a thick blanket beneath the continental shelf of the East China Sea.

The thickness of the Neogene (and of some Paleogene) strata is shown by the continuous seismic reflection profiles of Figure 14 and the isopach map of Figure 13. The strata are less than 200 meters thick in Tsushima Strait and they thicken southwestward to Taiwan, where the acoustic records show the presence of more than 2 km and where well borings have penetrated 5 km of Neogene beds. The linear trough fill is interrupted at only two places, at each of which shallow basement projects eastward into the trough. One place is beneath

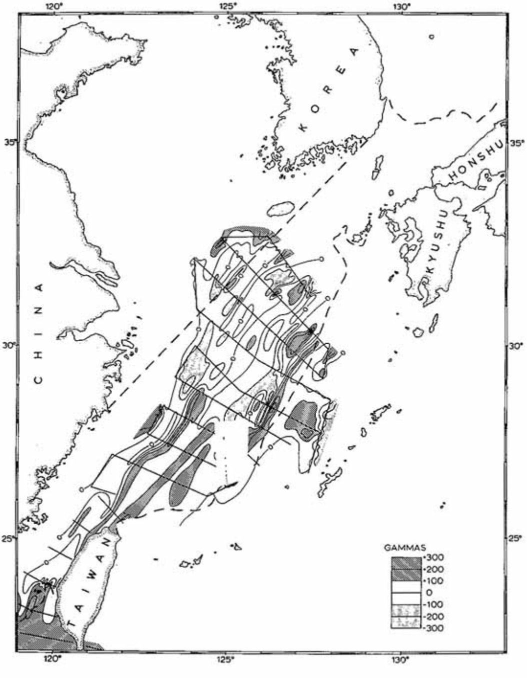

Figure 15. Geomagnetic anomalies of much of the continental shelf between Taiwan and Korea. Drawn from geomagnetic profiles of Project MAGNET supplied by Henry P. Stockard (Magnetics Division, U.S. Naval Oceanographic Office). Anomalies were obtained by subtracting from the total field measurements Cain's regional values plus 100 gammas.

the Penghu Islands and the other is at Latitude 28°. The first one is well known from exploration on land (Meng, 1968), and it must have existed during the filling of the trough because the fill south of it is much finer grained than the fill north of it (Stach, 1958).

The eastern side of the sediment-filled trough is the Taiwan-Sinzi Folded Zone that served as a dam from Japan to near Taiwan. Sediments have filled the trough and then surmounted the dam along most of its length. The main point of their escape is near Taiwan. In this area both the floor of the trough and the top of the dam are deeper than farther north. The total depth of fill in the trough from half way along the west side of Taiwan to a point about 200 km northeastward is too great to be measured with a 30,000-joule sparker and without electronic removal of the interfering multiple reflections of the sea floor. However, the seismic profiles reveal unconformities or tilted strata down to depths of 2,000 meters, so the thickness of sediments atop basement is at least that great. The area of sediments thicker than 2 km on the continental shelf is about 200,000 sq. km, indicating that the volume of sediments in this area alone is more than 400,000 cu. km and may approximate 700,000 cu. km. A reasonable estimate of the total volume of sediments atop basement throughout the entire continental shelf is 1 million cu. km. If deposited throughout the Cenozoic era, the average rate of deposition is about 4 cm 1,000 years. This is about five times the rate for the Atlantic continental shelf of the United States. Probably the greater rate off Asia is due to the huge drainage areas and sediment loads of the Yellow and Yangtze rivers.

Trough, Ridge, Trench Province

Ten transverse crossings of the sea floor beyond the continental shelf produced a total of 5,200 km of bathymetric, seismic, and magnetic records (Fig. 16). A system of alternating rocky ridges and sediment-filled trenches was defined. These features connect relatively well mapped zones in Japan and Taiwan that provide information about composition and age to supplement the geophysical measurements of this cruise and of previous cruises by other workers.

The first geological feature seaward of the continental shelf is the continental slope that has an average declivity of about 10 degrees for the steepest 200-meter section of each profile. The continental slope is also the western side slope of the adjacent Okinawa Trough. For the most part, both side slopes of the trough consist of sediments, with little exposed basement rock. The floor of the trough is generally flat in cross-section, but is incised by a narrow valley that probably owes its origin to turbidity currents that flowed along the axis of the trough. Sediment fill in the trough exceeds 1.2 km along all profiles, and it contains many subbottom reflectors that may be turbidite sand layers. The deepest part of the trough floor is opposite the gap in the Taiwan-Sinzi Folded Zone, as though tectonic activity had depressed both features. In this area the bottom depth is 2,200 meters. Nearer Taiwan the bottom shoals to less than 1,400 meters and the nature of its termination is not evident from existing soundings. At its northeastern end the trough shoals progressively until it reaches Japan, where it appears to be a direct continuation of the Amakusa Folded Zone. This folded zone underlies the Inland Sea of Japan still farther northeastward. Folding began during the Paleogene, earlier than in the Taiwan-Sinzi Folded Zone.

The next feature of the province is the Ryukyu Ridge above which rise many islands. This and the parallel Ryukyu Trench are the most prominent parts of the island arc. Both the continuous seismic reflection profiles and the geomagnetic profiles indicate the presence of volcanic rocks, which also are dominant on the islands. Also present on the islands of the arc, in southern Japan, and indicated by the profiler records are folded sediments. Where

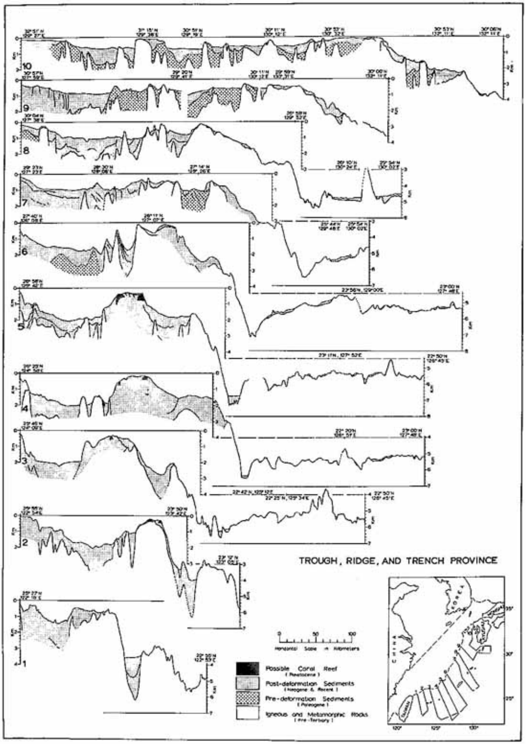

Figure 16. Trough, Ridge, and Trench Province:
a. Continuous seismic reflection profiles.

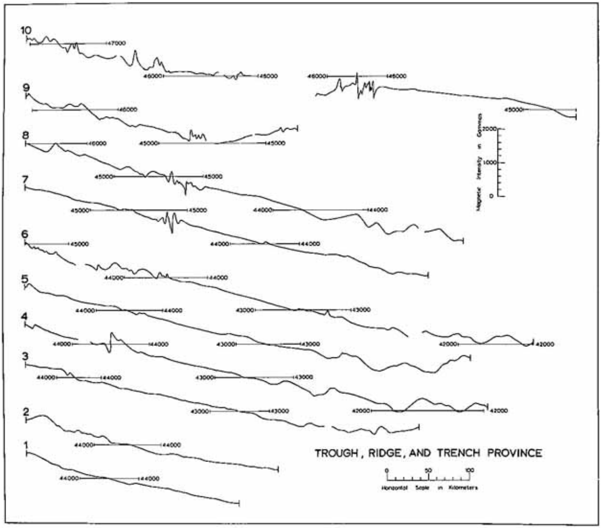

Figure 16. Trough, Ridge, and Trench Province:
b. geomagnetic profiles.

known on land, these are Neogene in age and they contain fossils that are characteristic of moderately deep water; thus the Ryukyu Folded Zone is at least largely Neogene in development. Several of the profiles reveal complex masses of low acoustic transparency near the edges of the flat top of the Ryukyu Ridge. The nature of the acoustic reflections and their depth (100 to 300 meters, about the same as the depth of the edge of the nearby continental shelf) are strongly suggestive of submerged coral reefs, probably Pleistocene in age. Living reefs fringe some of the southern islands of the arc; evidently reefs were somewhat more widespread during part of the Pleistocene Epoch than at present.

East of the Ryukyu Ridge the sea floor slopes downward at about 10 degrees to a terrace that was formed by ponding of sediments behind a dam presumably of fault origin and consisting of volcanic or consolidated sedimentary rock. The terrace fill and its confining dam can be traced nearly continuously from Taiwan to southern Japan, where part of it has been named and described as the Tosa Terrace (Tayama, 1952; Hilde, Wageman, and Hammond, 1969). The depth of the broadly concave surface of the terrace on the several crossings is somewhat irregular, in accordance with an irregular depth of the crest of the confining fault-block dam. Depths range from 1,800 to 4,000 meters, and thicknesses of sediment from "more than 600" to 2,700 meters.

Slopes continue beyond the terrace down to the floor of the Ryukyu Trench. These slopes and the ones on the seaward side of the trench are the steepest of the region, averaging about 13 degrees for the steepest 200-meter section of each sounding profile. Because the soundings were obtained with wide-angle equipment, the true slopes are steeper than the apparent ones. Seismic profiles show only little sediment mantling rock on either side of the trench, unlike the findings in the asymmetrical Japan Trench by Ludwig and others (1966). Due to lack of penetration beneath the western slope of the trench, we have indicated igneous rock there (Fig. 16a); however, the low (2.8 to 3.0 km/sec) seismic velocities obtained by Murauchi and others (1968) are indicative of sedimentary rock. Their seismic refraction stations reveal that material having seismic velocities less than 5 km/sec below the western slope of the trench continue westward beneath the terrace, the Ryukyu Ridge, the Okinawa Trough, and the continental shelf. Under this layer is another one having seismic velocities of about 6 km/sec; this layer continues eastward beneath the Ryukyu Trench to form the surface rock east of the trench. The floor of the trench deepens northeasterly from 5,600 meters near Taiwan to at least 6,800 meters near Okinawa. It shoals and disappears at the northeast, and just south of Japan it reappears as the Nankai Trough at 4,800 meters. Our seismic reflection profiles show the floor of the trench to be underlain by zero to 600 meters of sediment having several subbottom reflectors presumably of turbidite origin.

The deep-sea floor beyond the Ryukyu Trench is very irregular and mostly is impervious to acoustic energy at the level used in reflection profiling. It shoals irregularly eastward, where several ridges extending from a general southeasterly direction add to the roughness of the bottom. The bottom is underlain by material having a seismic velocity of 6 km/sec, presumably volcanic rock of layer 2 (Murauchi and others, 1968). Patches of sediment less than 200 meters thick are present in some of the depressions and on some of the flatter areas.

CONCLUSIONS

The six weeks of ship-board survey with R/V F. V. HUNT provided information to supplement and extend seaward the geological knowledge of the adjacent land areas. Forming the structural framework of the region is a succession of northeast-southwest-trending ridges that separate sediment-filled depressions (Fig. 17). Farthest landward of these ridges (250 km northwest of the Gulf of Pohai, and thus beyond the limits of Figure 2) is the Taihung—Great Kingan Range that was uplifted in Caledonian (Early Paleozoic) times. An older (Precambrian) uplift formed the Tai Shan—Laoyehling Range that is the backbone of the Shantung Peninsula at the head of the Yellow Sea.

Next of the ridges is the Fukien—Reinan Massif that was uplifted during the Middle to Late Mesozoic Era across the mouth of the Yellow Sea. So far as can be learned from the geology of China and Korea, this massif barred the ocean from the continent until the end of the Cretaceous Period. The only strata of Cretaceous age northwest of the massif are non-marine, but these reach a thickness of several thousand meters. Evidently, the barrier was breached in Paleogene Times because Paleogene and especially Neogene sediments are widespread and thick in the Yellow Sea, if our seismic profiles have been interpreted correctly. Deposition of these sediments was aided by the uplift of the Taiwan—Sinzi Folded Zone that was raised probably throughout Neogene and probably part of Paleogene time damming sediments from land to build the present continental shelf and to cover the floor of the Yellow Sea.

Beyond the continental shelf two additional ridges formed between Paleogene and Recent time. These are the Ryukyu Ridge and a parallel unnamed ridge that lies about half way down the east side slope of the Ryukyu Trench. A third ridge still farther seaward beyond the Ryukyu Trench has an irregular, deep, and discontinuous crest. Most of the ridges have recognizable continuations on land in Japan, but the manner of their junction with Taiwan is uncertain, owing to a lack of geological and geophysical data from the sea floor near Taiwan. The general appearance of the trends (Fig. 17) suggests a concentration or knotting of the structures near Taiwan, much like the constriction of the Himalaya Mountains northeast of India. The drag-like bend of the ridges, the great width of the shelf northeast of Taiwan, and the broad submarine canyon that separates the southwesternmost section of the deep-sea terrace from Taiwan, the probable main source of its sediments (Fig. 2) may all be results of an inferred right-lateral strikeslip fault that is shown in Figure 17. The sequence of generally younger ridges toward the southeast is typical of other parts of the Pacific margin (Umbgrove, 1947, pl. 5; Yanshin, 1966). Here, it has produced a step-like growth of the Asian continent. Between the ridges that lie seaward of the continental shelf are linear depressions that contain partial fills of sediment. In general, the fill is thickest, widest, and most continuous in the Okinawa Trough, and it is least important in the Ryukyu Trench that is farthest from the continental shelf and from the two large rivers that contribute sediment from nearly one third of the total area of China.

Most important for the oil and gas potential in the region is the sediment fill beneath the continental shelf and the Yellow Sea. In these areas sediments were deposited rapidly owing to the large area of China that is drained by the Yellow and Yangtze rivers. High contents of nutrients in the river effluents also lead to high organic productivity in the seas of the region. Surface samples from the sea floor contain as much as 1.5 per cent organic matter, but higher contents are to be expected at greater depths of burial that were not affected by glacially lowered sea levels.

The most favorable part of the region for oil and gas is the 200,000 sq. km area mostly northeast of Taiwan. Sediment thicknesses exceed 2 km, and on Taiwan they reach 9 km, including 5 km of Neogene sediment. Most of the sediment fill beneath the continental shelf is believed to be Neogene in age, on the basis of general low dips shown by the seismic profiles, outcrops on islands and on the sea floor, and thickness in well borings of Taiwan. Nearly all of the oil and gas that is produced on land in Japan, Korea, and Taiwan comes from

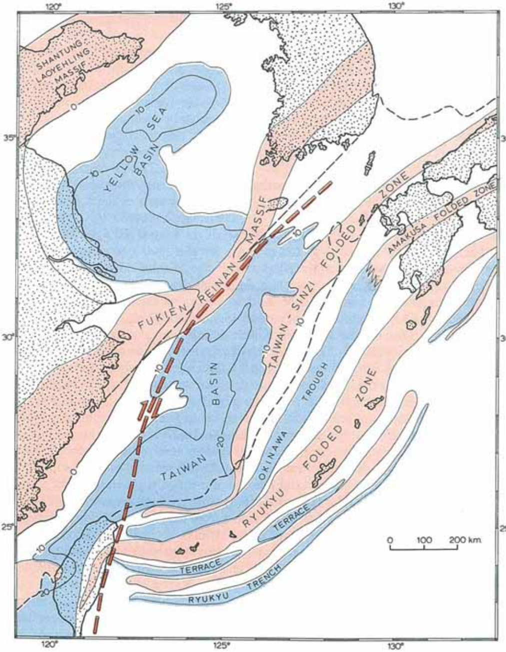

Figure 17. Generalized pattern of ridges and of troughs, basins, and trenches in the East China Sea and vicinity based upon the results of the cruise of R/V F. V. HUNT and previous information. Contours indicate sediment thickness (hundreds of meters) beneath the Yellow Sea and the continental shelf.

Neogene strata. A high probability exists that the continental shelf between Taiwan and Japan may be one of the most prolific oil reservoirs in the world. It also is one of the few large continental shelves of the world that has remained untested by the drill, owing to military and political factors, as well as to a lack of even reconnaissance geological information such as provided by this short survey.

A second favorable area for oil and gas is beneath the Yellow Sea where three broad basins are present. These basins are interconnected, but the center of one is near Korea and the centers of the other two are near the mainland of China. The basins contain a thickness of nearly 1.5 km of sediment, according to this survey, and the sediments probably have a higher content of organic matter than do the sediments beneath the open continental shelf. The good reflecting horizons within the bottom probably are sandy layers that can serve as reservoir beds between organic-rich source beds.

The present reconnaissance study depicted unconformities, anticlines, and faults below both the continental shelf and the Yellow Sea. Such features may serve as the local structures that trap quantities of oil and gas. Further detailed seismic studies are required within the general sedimentary basins in order to adequately portray the shapes and extents of these small structures. After completion of these detailed surveys, many of the structures may warrant the final test—by the drill.

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