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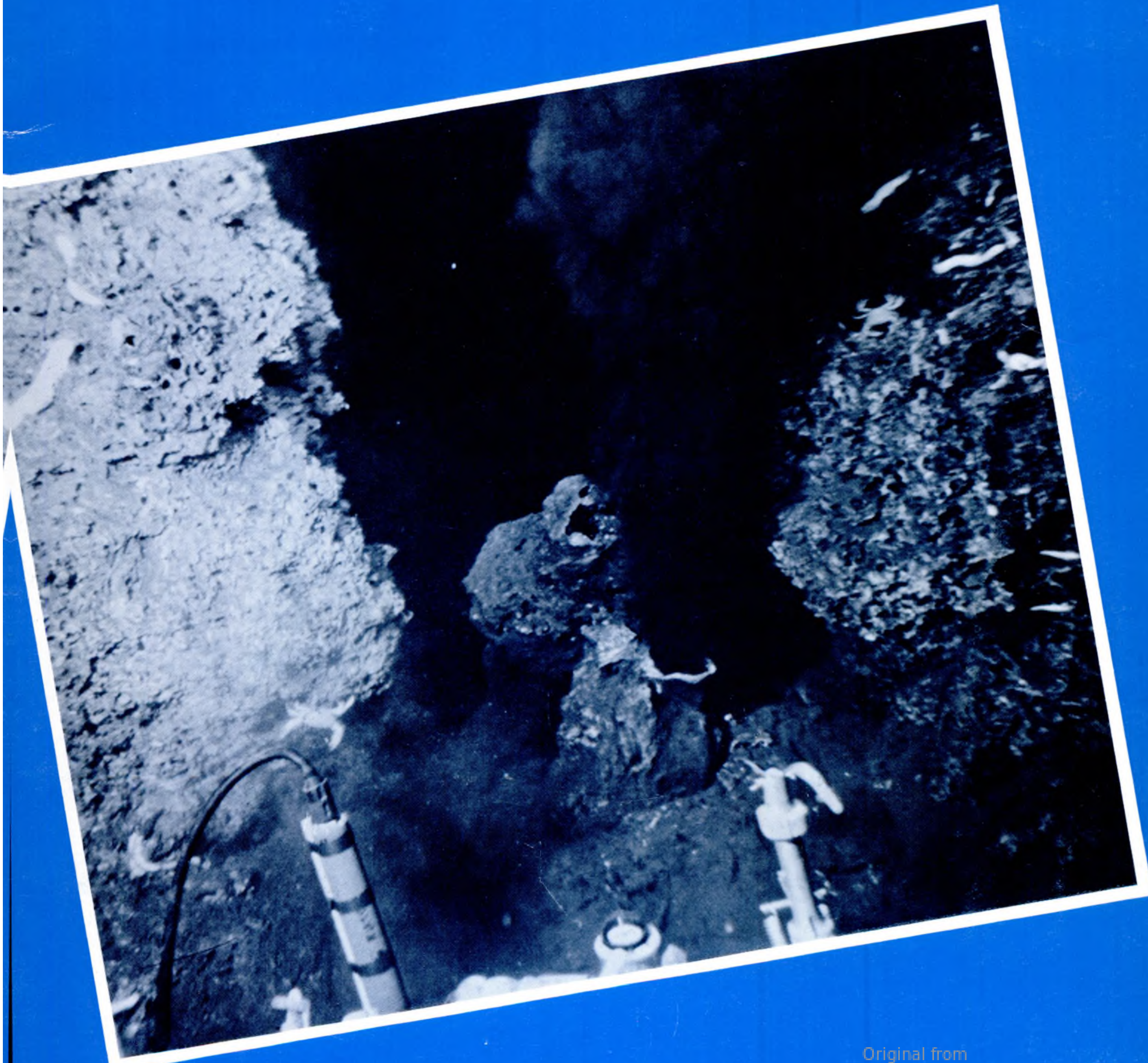
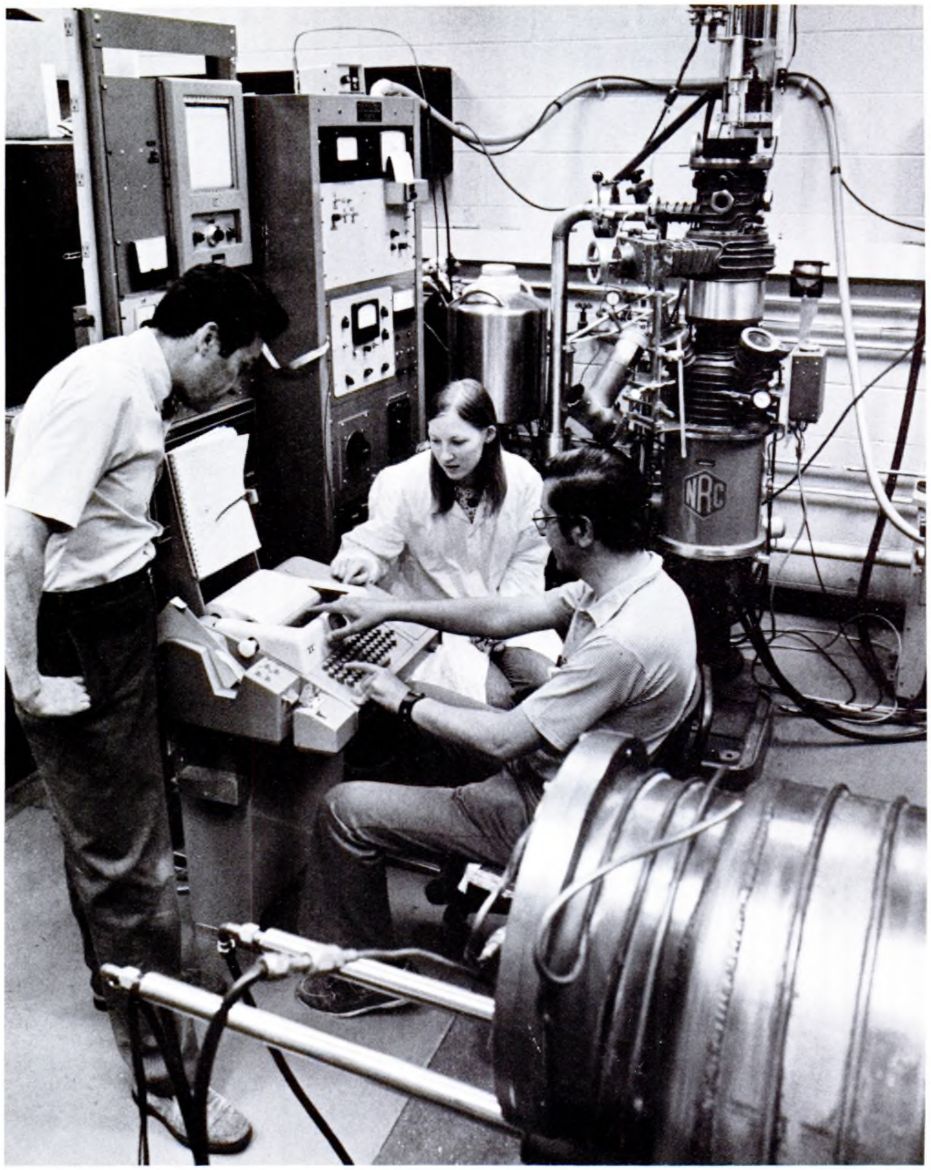


COMPUTER CONTROLLED CRYSTAL GROWTH



The Office of Naval Research supported the research which led to the initial development in 1972 of computer controlled growth of laser quality fluoride crystals at the Crystal Physics Laboratory of the Massachusetts Institute of Technology. The system used an optical diameter sensor and a small computer. Dr. Arthur Linz is explaining the system to a student while Professor David Epstein looks on.

This pioneering computer system was one of the first to efficiently grow crystals for laser research and was transferred to industry for commercial use. This system formed the basis for the more advanced concept developed later with ONR support.

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About the cover:

A "black smoker" 9,000 feet down on the floor of the Pacific Ocean. These phenomena are water eruptions of 350°C emitted from thermal vents located in rifts where the ocean floor plates are pulling apart. Gushing from these rifts of solidified molten magma, the "black smokers" are ladened with nutrients for the amazing colonies of marine life thriving around the thermal vents. Living among these deep-down creatures are giant clams whose meat is filled with hemoglobin; clumps of 12-foot long, red-tipped tube worms; and white, sightless crabs. This photograph was taken from ALVIN a deep-submersible owned by the Office of Naval Research and operated by the Woods Hole Oceanographic Institution. Some of ALVIN's equipment appears in the photograph.

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SUBMARINE HYDROTHERMAL VENTS AND ASSOCIATED GRADIENT ENVIRONMENTS AS SITES FOR THE ORIGIN AND EVOLUTION OF LIFE*

by John A. Baross, University of Washington
and Sarah E. Hoffman, Oregon State University

The hypothesis stated in this article, that life evolved from the environment of the hydrothermal vents in the primeval ocean, is a bit scientific serendipity resulting from research supported by the Oceanic Biology Program of the Office of Naval Research (ONR) to better understand the environmental limitations to life in the ocean. The program focuses on the microbiology, geochemistry, and hydrothermal activity of the deep ocean. Such knowledge is envisioned to provide useful applications to the Navy and its operations. For three years, Professor Baross and his colleagues have been collecting data from the ocean floor for ONR and from this research comes his speculations about the evolution of life. He is the first scientific to study extremely high temperature bacteria growth.

In a recent publication of the Journal of Biochemistry (Volume 97, 1985, pages 1521-1524), Drs. H. Yanagawa and K. Kojima of Japan provided evidence that hydrothermal environments augment the formation of stable biochemical structures. By subjecting a mixture of glycine, alanine, valine and aspartic acid in water containing silicon to temperatures of 250°C at 135 atm of pressure for 6 hours, these researchers were able to form stable peptide-lide polymers. These amino acids were chosen, as all evidence to date implies they were, the starting materials for prebiotic synthesis of polypeptides (proteins). These data plus results from recent oceanographic cruises on which Dr. Baross isolated bacteria from hot smoker vents on the ocean bottom and cultured the bacteria at high temperatures is providing the basic starting material to test Dr. Baross's hypothesis.

Editor

Hypothesis

We have proposed that life could have originated and evolved in association with hydrothermal vents in the primeval ocean during the earliest Archaean. These environments are significant for abiotic synthesis and biotic evolution because they encompass a multiplicity of gradients in physical and chemical conditions. These gradients result from the relationships between oceanic and atmospheric conditions and extensive crustal hydrothermal activity, allowing multiple pathways for the synthesis of prebiotic compounds, the origin and evolution of "precells" and "precell" communities, and ultimately the evolution of free-living organisms.

This hypothesis is plausible both in terms of the tectonic, paleontological, and degassing history of the earth and in terms of the laboratory synthesis of amino acids and complex organic compounds using thermal energy sources. Submarine hydrothermal vents are the only contemporary geological environment which may truly be called primeval, and they continue to be a major source of gases and dissolved elements to the modern ocean. The microbial assemblages in present-day hydrothermal systems could therefore be living analogues of the earliest microbial communities to develop on Earth. In this paper, we suggest several hypotheses related to our model for the origin and evolution of life in hydrothermal vent environments which can be tested in present-day systems.

* Reprinted from the *Origins of Life,* vol. 15, pp. 327-345, 1985

Introduction

The discovery of submarine hydrothermal environments has resulted in a profoundly greater understanding of the Earth's geological, geochemical, and biological history. It has also provided new insights and renewed interest in the origin and evolution of life on Earth.[1, 2, 3]

There are currently several hypotheses as to how and where life originated and evolved. Given that life arose on Earth, then the important question is what environments could provide all of the physical and chemical conditions for the sequence of reactions leading to organic compounds, self-replicating and information-carrying macromolecules, and eventually organisms and ecosystems. In order to have met all of the necessary conditions, there must have been environments encompassing an expansive range of closely-linked gradients in physical and chemical conditions. These environments must have included high concentrations of continuously-produced chemical precursors to biologically important organic compounds carried by fluids circulating through temperature gradients and across ample reaction surfaces. These environments would have provided an almost infinite set of conditions and variables, as well as combinations of conditions. A relatively shallow ocean with extensive hydrothermal activity, such as probably existed during the early history of the Earth fulfills all of these requirements.[4, 5, 6]

In a previous paper, we proposed that submarine hydrothermal systems possessed all of the necessary criteria to have been sites for the origin and evolution of life.[1, 2] We based our hypothesis on three lines of evidence: the properties of present day hydrothermal environments, the lithological associations of the most ancient fossils, and the laboratory synthesis of amino acids and complex organic compounds using thermal energy sources. In this paper, we expand on our original hypothesis taking into consideration new information on the geology and biology of present day hydrothermal systems, the geological and geochemical characteristics of Archaean fossil-bearing sediments, and the inferred properties of the Archaean ocean. We now extend our hypothesis to propose that life developed and evolved in a primeval shallow ocean in association with the multiplicity of gradients resulting from the interactions between variables now known to have been important during the early Archaean: the tectonism associated with seafloor spreading, the resultant hydrothermal alteration of newly-emplaced oceanic crust, and the composition of the ocean and atmosphere of the early Earth. We conclude with a discussion of some hypotheses related to the origin of life, which can be tested in present day submarine hydrothermal environments.

Hydrothermal Environments and Their Influences on the Archaean Ocean

It is increasingly apparent that the oldest sediments on Earth are marine and are stratigraphically associated with sequences of hydrothermally-altered crust.[1, 2, 7, 8, 5] It is axiomatic, therefore, that the earliest microbial communities on Earth were established in similar environments. The microfossil record in Precambrian sediments supports this.[2, 7, 9] It is therefore necessary to understand and model the sequence of geological, chemical, and biological changes in the Archaean ocean and atmosphere. The importance of present-day hydrothermal environments is that they have retained many of the characteristics of Precambrian systems and therefore are a "primeval" site for studying a range of biogenic and evolutionary processes and reactions.

Many recent papers have discussed current ideas on the early history of the Earth.[2, 7] Physical and chemical characteristics of the Archaean ocean and atmosphere and the extent of tectonic activity and rate of continent formation have been inferred from the geological and geochemical records of Precambrian strata (Table I). Evidence indicates that the ancient ocean was reducing,[3, 10] probably warm to hot ($>30°$ to possibly greater than 100°C), shallow (maximum depth $\sim$1000-2000 m), and considerably more tectonically and hydrothermally active than it is today.[5, 6] At the time the ocean was formed (4.2 Ga), it is likely that the whole Earth was covered with water and that hydrothermal activity was at least five times more prevalent than at present.[5] This conclusion is based on a model in which the overall rate of seafloor creation and subduction has steadily declined over the history of the Earth. The model indicates that the total oceanic ridge length at 3.5 to 4.2 Ga was between three and five times greater than at present.[5] Such an extended ridge length would have resulted in voluminous hydrothermal circulation of reduced elements and gases. Hydrothermal systems, such as the one shown in Figure 1, would have been very common features of the Archaean ocean floor.[5, 6]

Figure 1

Cross-section of the central 6 km of a seafloor spreading center with schematic diagrams of hydrothermal circulation systems superimposed (vertical not to scale). The diagram is designed to show primarily tectonic and structural factors on the left and primarily chemical features on the right. Seawater intake is controlled by a system of listric faults (heavy broken lines) and occurs along a network of interconnected fractures (wavy lines). Arrows show direction of seawater transport. Dotted region above magma chamber represents the emplacement of diabasic sheeted dikes. "Smoker" type vents (on left in diagram) discharge end member hydrothermal fluids (no measurable ambient seawater contamination) at approximately 350°C with flow rates measured in m sec^{-1}. This type of vent is associated with polymetallic sulfide mounds. Galapagos-type vents (on right in diagram) discharge water having varying proportions of ambient seawater mixed with hydrothermal fluid during ascent. Water temperatures in these vents ranges from ambient seawater temperatures to higher than 50°C, and flow rates are measured in cm sec^{-1}. The chemical characteristics of hydrothermal systems are the result of water-rock interactions at high temperatures. See text for details.

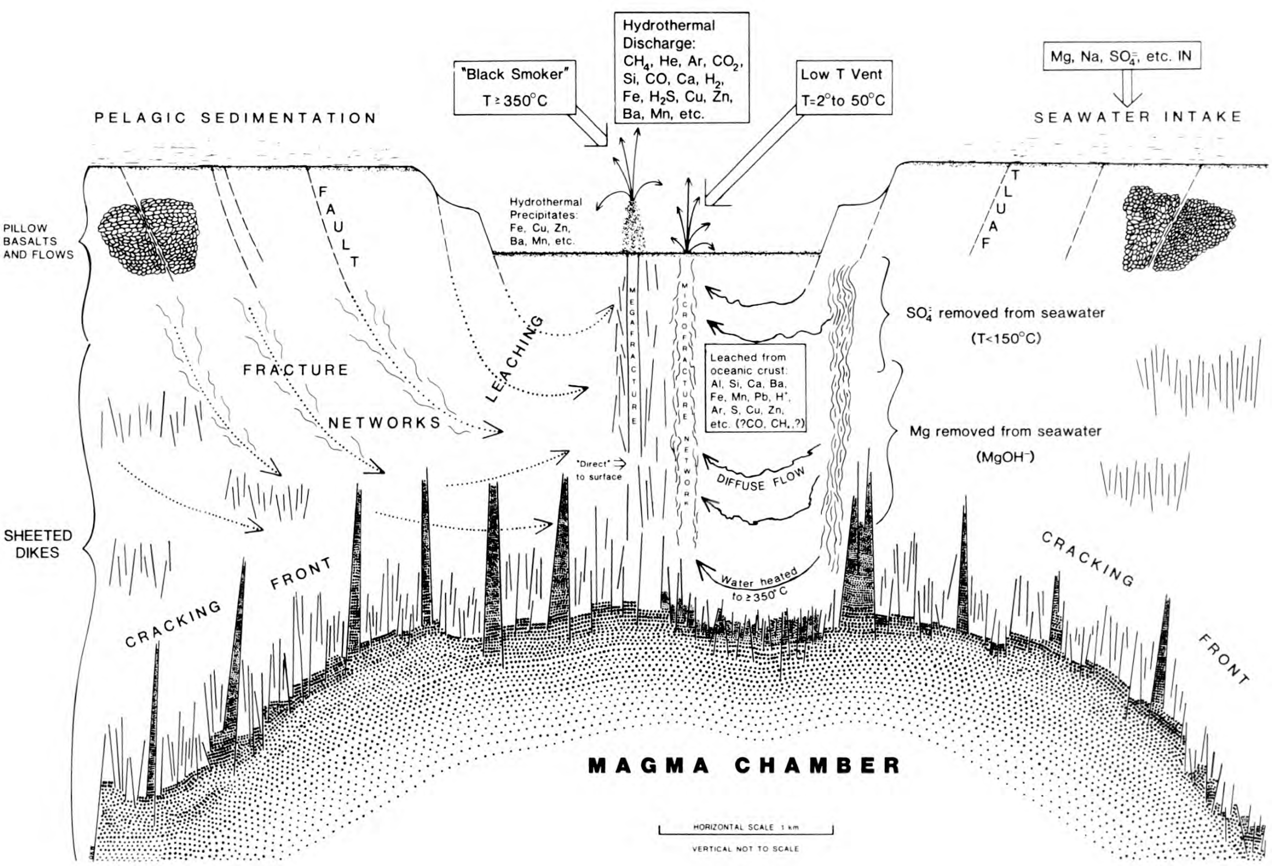


Figure 1 schematically shows the geological and geochemical features of hydrothermal circulation systems which occur along the central rift zone of modern spreading ridges. It summarizes the chemical reactions associated with hydrothermal vents, indicates sites of hot water extraction of chemical species from basalt and consequent gas formation, and illustrates the circulation patterns of both smoker (high temperature) and Galapagos type (low temperature) vents. Seawater intake occurs off-ridge. Water percolates downward through accumulated sediments and underlying basalts along zones of weakness created by a system of listric faults. Faulting and fracturing are facilitated by the movement of seawater. Seawater is believed to penetrate to the "cracking front," a zone of incipient crystallization directly overlying the roof of the magma chamber. The crystallization and hydrothermal cooling which occur along the cracking front cause further fracturing which leads to the emplacement of magmatic dikes. Thus, a continuous heat source is essentially assured by an almost self-perpetuating system. As long as magma is supplied to the magma chamber, the hydrothermal circulation system is inevitably active. Ambient seawater circulates through cracks in the crust, reacts at depth with basalts and diabasic dikes at temperatures up to at least 350°C, and ascends back to the seafloor enriched to varying degrees with magmatically-derived elements, gases, and inorganic compounds (Figure 1).

Fracturing in the central rift zone and at the cracking front also influences the transport of fluids upward. Large fractures, as shown on the left in Figure 1, deliver "pure end member" hydrothermal fluids directly to the seafloor. Interconnecting networks of small fractures, as shown on the right in Figure 1, allow ambient seawater to mix with hot hydrothermal fluids at various depths. As a result of these different structures, two types of vent systems occur on the seafloor. These are hot "smoker" vents in which there is, in the case of "black smokers," no mixing of colder water with hydrothermal fluids, and the cool Galapagos-type vents in which varying concentrations of ambient seawater penetrate through cracks and mix with hydrothermal water. Both types of vents have been found to occur along spreading ridge crests in the Pacific, along the East Pacific Rise and the Juan de Fuca Ridge.[11]

The chemistries of the 350°C hydrothermal fluids indicate that they are essentially transported via conduits extending from the point at which seawater is heated (at least 350°C) to the seafloor. Both black and white smokers have been described, and they differ in water temperature and composition.[12] The 350°C waters are enriched to the maximum extent with magmatically-derived elements and compounds and thus serve as an end member for determining the extent to which Galapagos type vent water has been diluted with ambient seawater.[13] Concentrations of the major chemical components of biological importance have been found to range from 0 to >4 mM for H_2S, 1 to >1000 uM for Mn, and from <1 to >200 uM for Fe. The concentrations of gases were also higher than saturation and ranged from 0.1 to 50 uM for CH_4, 1nM to >600 uM for H_2, and 10 to >100 nM for CO.[14, 15] All of these chemical components serve as the primary energy sources for the extensive microbial communities associated with these environments (see Figures 2 and 3). Submarine hydrothermal vents are also a source for all of the biologically important trace elements.

Although present-day hydrothermal systems are geologically and geochemically very similar to those in the Archaean, there are some important differences. At the present time, the surrounding oceanic environments are markedly different in that O_2, other electron acceptors (NO_3^-, SO_4^{2-}, and PO_4^{2-}), and a variety of additional compounds allow the abundant growth of a physiologically diverse community of microorganisms and complex assemblages of different vent animals.[16, 17, 18, 19, 20]

The major chemical components of exiting hydrothermal fluids are derived from water/rock reactions at high temperatures. It has been shown that the principal source of H_2S–S in the 350°C smoker vents is basalt and not seawater sulfate.[21, 22] Although part of the H_2S measured in warm Galapagos type vents comes from basalt, it is also possible that a significant proportion of the H_2S might result from microbial sulfate reduction which could occur at temperatures from ambient (2°C) to greater than 100°C. All warm waters sampled from the Galapagos contained sulfate-reducing bacteria. Some of the 350°C water samples also contained sulfate reducers which can grow and reduce sulfate and other oxidized forms of sulfur with H_2 or $C_1 - C_2$ organic compounds at 110°C and 1 atm pressure. (Baross, unpublished data and reference 15)

The actual reactions involved in the production of gases is not clear. Both H_2 and CO are common gases associated with volcanic activity. The major source of H_2 is believed to be the oxidation of magnetite ($Fe^{+2}Fe^{+3}{}_2O_4$) to hematite (Fe_2O_3), and CO is believed to originate within the magma from C-O-H-S equilibria. (see reference 18 for citations) Presently, there is some disagreement as to the source and levels of CH_4 entrapped in the mantle.[23] In some studies of hydrothermal systems, CH_4 concentrations have been found to parallel the concentrations of ^3He (^3He is a conserved gas of magmatic origin) to an extrapolated end member of 350°C water.[24] However, the concentrations of CH_4 and H_2 in Galapagos vent waters indicate that both biological production and consumption processes are occurring.[15]

Surface deposits consist predominantly of Fe^-, Cu^-, and Zn-sulfides, and in the case of smokers these sulfide mounds can exceed 15 m in height. Similar sulfide chimneys have been observed in Cretaceous sulfide deposits at Cyprus[25] and in the Oman ophiolite.[26] Such deposits should have been common occurrences once the ocean became oxygenated. During the early Precambrian, the reduced elements, gases, and other compounds should have remained in solution, resulting in an increasingly reducing ocean, until the interactions of continent formation, reduced hydrothermal activity, abiogenic and biogenic oxygen production, bacterial oxidative processes, and atmospheric influences began the sequence of changes leading to present-day conditions.

Based on this model of a warm to hot, hydrothermally driven, anoxic Archaean ocean, some inferences can be made concerning the first groups of microorganisms to evolve on Earth.[2, 3] Their catalytic reactions would change the geochemical characteristics of these environments which in turn would increase the diversity of microbial communities. At the present time, it is only at the immediate sites of hydrothermal activity that we find conditions most resembling those in the Archaean ocean. It is at these sites that we might find microbial communities having morphological and physiological characteristics analogous to those communities observed in Archaean oceanic sediments.

Biological Characteristics of Hydrothermal Vent Environments

Present-day ecosystems are based on photosynthetically-derived primary productivity and oxygen production. Only in environments having extreme conditions, such as temperatures above 55°, acid pH, or saturated levels of solute, do we see simple bacterial-based ecosystems.[27, 28] It is frequently inferred that photosynthetically-based food chains were established in the Precambrian. Evidence cited includes the morphology of filamentous microfossils in ancient sedimentary strata and the inferred presence of significant levels of oxygen in the atmosphere.[29, 30, 31, 4] In present-day submarine hydrothermal vent environments, the food chain is based upon chemosynthetic bacterial processes rather than photosynthesis. An abundant and diverse animal community is associated with this food chain.[16, 20] A variety of physiologically different bacteria have been identified and include sulfur and metal oxidizers, methane producers and consumers, hydrogen producers and consumers, and sulfate reducers.[15, 19] Bacterial numbers range from 10^5 to greater than 10^9 ml^{-1} in vent water with a productivity at least three to four times that of surface water.[32] In vent environments, abundant bacteria have been found in exiting vent fluids, in proximal ambient bottom water, on all surfaces, as endosymbionts associated with some animals, and in smoker environments (see Figures 2 and 3).[33, 18, 19, 15] Figure 2 shows a vent community and associated geological and geochemical features. The large vestimentiferan tube worm, *Riftia pachyptila* Jones, and the giant clam, *Calyptogena magnifica*, have endosymbiotic bacteria[17] and live close to warm water vents.[20] The polychaete tube worm, *Alvinella pompejana*, lives on the outer surfaces of chimneys at temperatures above 45°C (Baross, unpublished observations and reference 34). Fossilized remnants of similar organisms were found in association with metalliferous deposits of Cretaceous sulfide chimneys on Cyprus[25] and in the Oman ophiolite.[26]

Figure 2

Diagram of submarine hydrothermal vent environment showing discharges of the most abundant carbon and energy sources used by vent bacteria. Chemosynthetic bacteria are the "primary producers" in these environments and are present in discharging hydrothermal waters, on all surfaces, in the water column, and as animal endosymbionts. The most important energy sources in these systems are H_2S, H_2, CH_4, Mn^{2+}, Fe^{2+}, and CO.

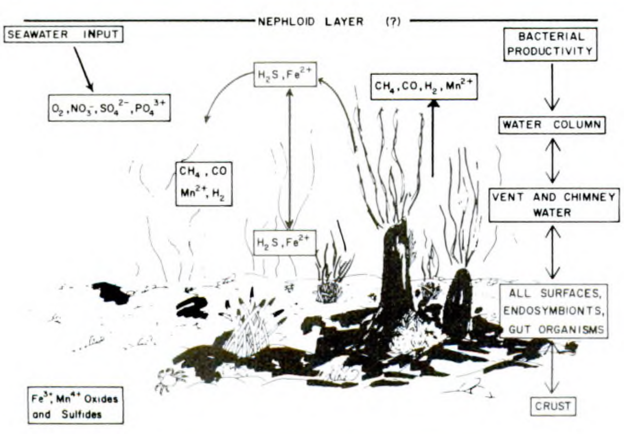
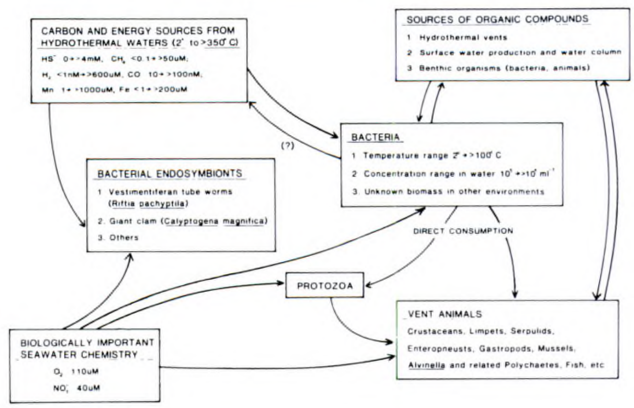


Figure 3

Schematic diagram of the food chain in submarine hydrothermal vent environments. Free-living, attached, and endosymbiotic bacteria serve as primary producers. Animals and the abundant aerobic chemolithotrophic bacteria rely on O_2 from ambient seawater. Methanogens and sulfate reducers are among the more abundant anaerobes.



It has been suggested that submarine hydrothermal environments could be a "uniformitarian analogue of primitive conditions."[2, 3] Here we propose that the earliest groups of microorganisms would be associated with hydrothermal systems and surrounding environments. The implications of this hypothesis are that over the first 2 billion years the microbial habitats evolved from hot to warm (>70 to <30°C) and were volcanic and anoxic. It is possible that temperature and eventually O_2 gradients were the major parameters regulating the evolution of ecosystems. This evolution proceeded from predominantly thermophilic and anaerobic prokaryotes to thermophilic prokaryotes including anaerobic and aerobic photosynthesizers (Photosystems 1 and 2), and eventually to complex systems which included eukaryotic green algae (temperatures below approximately 50°C). These temperature-regulated demarcations in community structure are currently seen in smoker and other thermal environments, and are also observed in the crater and thermal streams on Mt. St. Helens.[27, 35]

In terrestrial environments at temperatures between 50 and 70°C, cyanobacteria and chemolithotrophic bacteria dominate. The latter group are the dominant organisms associated with vent environments and use a variety of energy sources. However, some microbial processes, such as nitrogen fixation, nitrification, and methane oxidation, are not known to occur above 55°C. The absence of nitrogen fixation at temperatures above 50°C raises the question as to the source and speciation of nitrogen used by thermophiles in both present-day volcanic and Archaean aquatic environments. The source reactions for nitrogen are unknown, but in Archaean systems, it is presumed that NH_3-N was the most abundant form. At temperatures greater than 70°C, the microbial diversity decreases and methanogens, anaerobic sulfur metabolizers, thermoacidophiles, and some sulfur and metal oxidizers dominate. Many of the bacteria which have become established in the most extreme environments, and particularly in environments having temperatures greater than 80°C and/or acid pH, are members of the Archaebacteria. The Archaebacteria are a heterogeneous group of bacteria which includes methanogens, halobacteria, and extremely thermophilic acidophiles. They have been characterized by their unusual ribosomal RNA sequences, ribosome structure, membrane lipids and other macromolecules, as well as their physiology and ecology.[36]

Extremely thermophilic bacteria have been isolated from volcanic environmments where they grow at temperatures above 90°C.[37, 35, 38] Bacterial communities have been cultured from the superheated "black smoker" waters and shown to produce H_2, CH_4, and CO at 100°C and 1 atm,[39] or to incorporate ^{3}H-adenine at 90°C.[40] Evidence also indicates that one of these thermophilic microbial communities grew at 250°C at *in situ* pressures of 265 atm.[18] Their physiological and temperature growth characteristics indicate that they are Archaebacteria and that they may live in the crust at very elevated temperatures. We have suggested that these bacterial communities may be physiologically and biochemically analogous to the earliest group of microorganisms to evolve on Earth.[18]

Further analogy can be made between present-day volcanic environments and ancient microbial habitats based on evidence in the fossil record. The earliest evidence of unicellular fossils and stromatolites has been found in the 3.5 Ga Warrawoona Group (Pilbara Block, Western Australia)[41] and in the 3.5 to 3.3 Ga Swaziland Sequence (Barberton Mountain Land, South Africa).[42] The fossil-bearing strata in both localities are part of submarine sequences which include lava flows, pillow basalts, and chemical sediments which were probably derived from volcanic sources via hydrothermal activity.[2, 8] Complex microfossil assemblages have also been reported in the middle Precambrian chert environments which are believed to be marine and volcanically-derived.[43, 44, 45, 9] Complex communities of microorganisms having morphological similarities to these microfossil assemblages have been found in modern hydrothermal environments. Examples of these modern assemblages are shown in Figures 4 and 6.

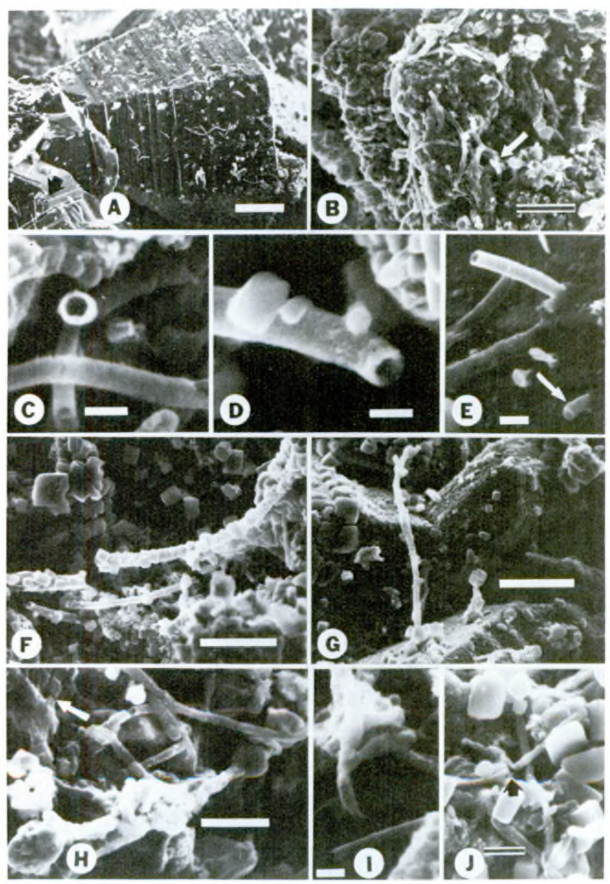


Figure 4 (A-J)

Scanning electron micrographs showing one of the dominant tube-forming microorganisms found on the sulfide chimney rocks obtained from hydrothermal vents along the East Pacific Rise at 21°N. (A) A sulfide crystal colonized by many filamentous microorganisms. Arrow points to vertical filaments. Bar is 25 μm. (B) An extensive colony of thin tube structures showing many hollow openings at the ends of the tubes. Top arrow points to one of the hollow ends; bottom arrow points to branching of the tubes. Bar is 10 μm. (C) High magnification of the tube structure denoted by the top arrow in Figure 4B. Bar is 1 μm. (D) Side view of the tube showing the tapering end. Bar is 1 μm. (E) Hollow tube extending out of the sulfide crystal; there appear to be bands around the tube. Arrow points to an apparently immature organism growing out of the crystal. Bar is 1 μm. (F) and (G) Tubes that have accumulated small sulfide crystals and other precipitated salts. Precipitates significantly increase the width of the tubes. Bar in both figures is 10 μm. (H) and (I) Some of the commonly observed swollen or bulblike structures which are connected by the hollow tubes. These were most frequently seen when the chimney rock samples were crushed. The ends of some of the tubes frequently showed closed swellings existing either as single structures or in pairs (Figure 4I; lower arrow in 4B). Bar in Figure 4H is 5 μm; bar in Figure 4I is 1 μm. (J) Filamentous tube with a dark band (arrow). Bar is 2 μm. Bands were frequently observed (Figure 4H, arrow). The samples were fixed in sterile artificial seawater containing 2% gluteraldehyde within minutes after the Alvin surfaced. Sterile techniques were used with all specimens. The fixed samples were dried by the critical point method, then mounted on aluminum stubs and coated under a vacuum with a layer of gold 10-20 μm thick. The samples were viewed using an International Scientific Instruments Mini-SEM, Model MSM-2, scanning electron microscope.

Figure 4 shows a composite of scanning electron micrographs of one of the microbial assemblages found on the sulfide chimney rocks. These filamentous tube structures have an inside diameter of 0.5 μm and appear as hollow sheaths, which are either attached to spheres of swollen cell-like structures (Figure 4I) or have closed and swollen ends (Figures 4B and 4J). The latter structures are most frequently observed in crushed sulfide chimney samples. Although these tube-forming organisms resemble to some extent known metal-oxidizing, sheath-forming bacteria such as *Leptothrix* and *Sphaerotilus* spp.[46], some evidence of branching, swollen segments and akinite-like structures (Figures 4H and 4J) suggest that part of this community may be fungi. EDS analyses of the tubes showed that they were composed mainly of silicon, with low levels of Fe, Mn, and Cu (Figure 5). Most of the other microbial mats observed on the sulfide chimneys were heavily encrusted with metals (Figures 6, A-D). Many of these mats were extremely dense with microorganisms (Figure 6C). The dominant metal deposited in these mats is iron (Figure 7, EDS of organisms in Figure 6C).

Figure 5

Scanning electron microscopic and energy dispersive x-ray spectroscopic (EDS) analyses of the tube structures shown in Figure 4. The top curve is a line scan of silicon over one of the tube structures from Figure 4. The uninterrupted line represents the area of x-ray analysis. The bottom scan is a total elemental analysis of the tube showing that it contains predominantly Si, with small amounts of Fe and Zn. The same levels of Fe and Zn were found in the surrounding sulfide crystals. Bar is 2 μm. Samples were observed and analyzed using a JEOL JSM-35 scanning electron microscope with EDS capability.

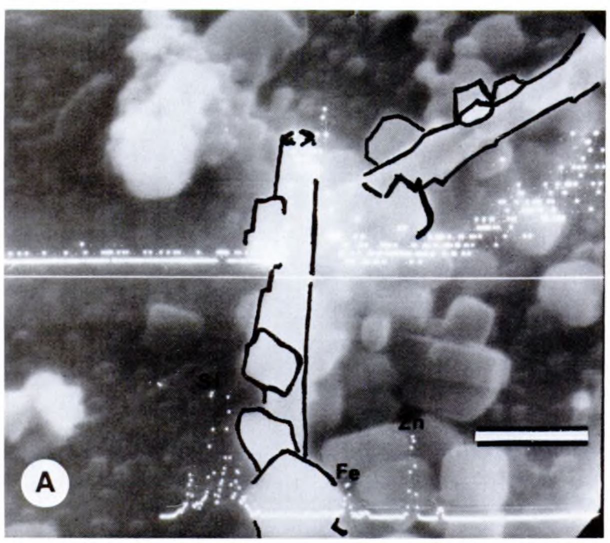
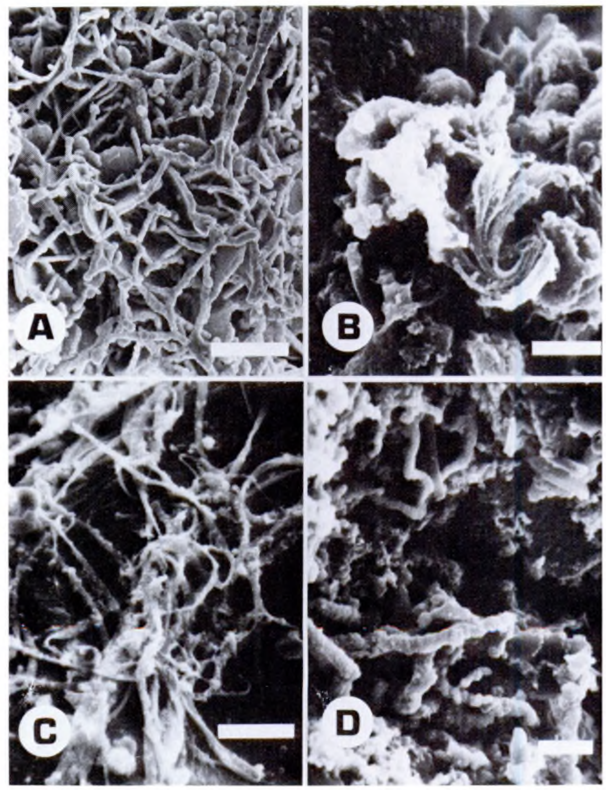


Figure 6 (A-D)

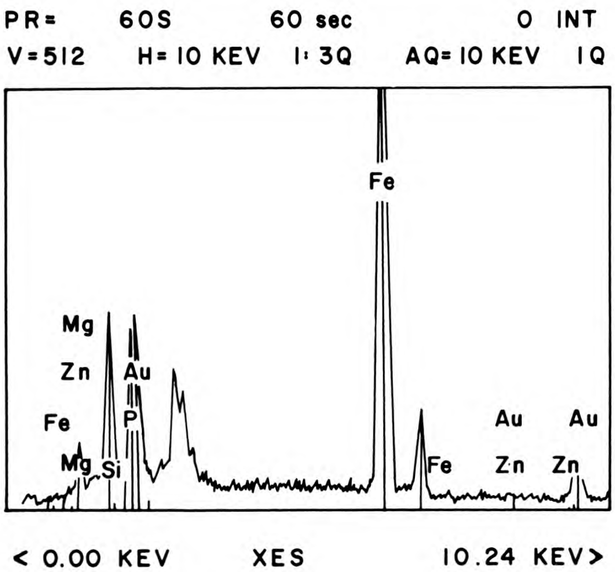
Scanning electron micrographs showing metal-encrusted bacteria found on the outer surface or imbedded in the sulfide chimney rocks from active "black smokers" obtained from 21°N along the East Pacific Rise in November 1979 (Figs. B, C, and D) and April 1982 (Figure A). Bar in A is 25 μm; in B and D, 5 μm; and in C, 10 μm. Samples were prepared as described in the caption of Fig. 4.



Although it is not known whether the silicon tubes are formed biotically or abiotically, the physical conditions in the environment around the chimneys definitely favor abiotic silicification. Hot vent waters enriched in silica are expelled into the cool ambient bottom water where the moderate hydrostatic pressures and alkaline pH of seawater favor precipitation of silica.[47] Amorphous silica was found to be a common constituent of the mounds and chimneys around vents along the East Pacific Rise.[48] The abiotic precipitation of silica sheaths around bacteria is known to occur in alkaline hot springs at Yellowstone National park where modern silica stromatolites have been observed.[49] It is interesting to note that the silicification of prokaryotic cells often increases the apparent size of an organism and also results in the formation of distinct morphological characteristics more indicative of eukaryotic organisms.[50] Thus, the interpretation of microfossils having a coating or sheath of silica or carbonate can be quite difficult.[51]

Figure 7

Line drawing of energy dispersive x-ray spectroscopic (EDS) analysis of the organism seen in Figure 6A showing deposition of Fe encrusting these microorganisms. Similar scans were observed for organisms shown in Figures 7A, B, and D. EDS analyses of uncolonized sections of chimney material showed greatly reduced levels of Fe and high levels of S, Zn, Cu, and Si.



Early Precambrian pyritic and siliceous rocks have been shown to contain a variety of fossil microorganisms that resemble both cyanobacteria and fungi in size and morphology.[29, 7] It has always been difficult to explain the existence of these comparatively advanced organisms in early environments which were believed to be deficient in oxygen and organic material. If, however, these organisms were in fact chemosynthetic bacteria living within or near submarine hydrothermal vents, the source of their nutrients is no longer a problem. We believe that chemosynthetic epiphytic bacteria evolved in hydrothermal environments before the formation of organic-rich stromatolites and that the filamentous tube-forming microorganisms and metal-associated microbial mats found attached to surfaces in present-day hydrothermal environments represent living replicas of some of the fossil organisms found in hydrothermally-derived Precambrian strata. The organisms observed on these sulfide mounds are definitely not photosynthetic and probably not heterotrophic, yet they have similar morphologies to some of the Precambrian fossils and particularly to those observed in the Gunflint (approximately 2 Ga) and other middle Precambrian cherts.[7] We believe that a detailed study of the epiphytic bacteria associated with oceanic hydrothermal vents and chimneys will lead to an understanding of the physiological groups of microorganisms which existed in Precambrian hydrothermal environments. In addition, it is possible that the extremely thermophilic Archaebacteria cultured from hot waters may also be physiologically analogous to the first organisms to appear in Archaean vent environments and thus would have preceded mat- and stromatolite-forming microbial communities.

The Origin and Evolution of Life in the Archaean Ocean

In a previous paper, we hypothesized that submarine hydrothermal environments provide all of the necessary conditions for abiotic synthesis of organic compounds, macromolecules, and perhaps "precells" leading to the development of living organisms.[1, 2] In our model, heat derived from the hydrothermal cooling of newly-emplaced oceanic crust provides the energy source for converting inorganic precursors into organic compounds. The characteristic convective flow in submarine hydrothermal systems (refer to Figure 1) can both remove and add precursors and products from the sites of reaction through gradients of temperature, pH, and composition. We now expand this model to include all of the possible gradients in the Archaean ocean as potential sites for a variety of abiotic, biotic, and ecosystem evolution to occur. The almost infinite multiplicity of gradients is summarized in Table II.

As shown in Figure 1 and discussed in Table II, all of the precursors and conditions for the abiotic synthesis of organic compounds exist in hydrothermal gradients while other gradients in surface waters and other interfaces provide a large number of different sets of chemical and physical conditions which are known to support a very diverse variety of microbially catalyzed reactions. Important microbial processes in these Precambrian ocean gradients would include the anaerobic utilization of H_2 and S^0, CH_4 production and consumption, anaerobic photosynthesis, and possibly some oxidative reactions in shallow surface waters having significant levels of photolytically produced oxygen. In the later reaction, banded iron formation could form in these environments in the absence of an active oxygen-producing photosynthetic community.[4] From the delayed ocean model of Towe[4], we can deduce that the early Archaean ocean (pre 3.5 Ga) was shallow and, consequently, that atmospheric conditions would have exerted a very important influence on microbial evolution. Furthermore, in a shallow ocean where hydrothermal activity was 3-5 times greater than in the present day ocean, concentrations of magmatically-derived chemical species would have been correspondingly greater as well. The development of biological diversity in these environments would have been influenced by the availability of light, oxygen and other photolytically-produced electron acceptors, CO_2 partial pressure, and UV radiation. Biological diversity would also have been greatly enhanced by the variety of available gradients so that there would have been many paths for evolution to follow.

Table I. Inferred Properties of the Early Ocean

Properties	References
1. Period of Formation Early or delayed, rapid or gradual accumulation.	4 and 7
2. Depth Depends on period of formation of continental masses, cooling history of oceanic crust, existence and extent of hotspot volcanism	4 and 5
3. Hydrothermal Activity Greater and more rapid seafloor spreading at roughly 3.5 Ga than present; ridge length up to 5 times present and consequently hydrothermal activity at least 3-4 times greater than present.	5, 6, and 53
4. Temperature Warm to hot (<30 to $>100°C$) depending on 1, 2, and 3 above and the atmospheric conditions such as presence and period of a greenhouse effect. Earliest evidence of glaciation dates to 2.2 to 2.7 Ga.	7, 10, 54, 55, 56 and 57
5. Chemical Properties Reducing conditions with high concentrations of H_2S, H_2, CH_4, NH_3, metals, etc., and possibly organic compounds including condensing compounds such as HCN and formaldehyde. Surface water interaction with greenhouse atmosphere having high concentrations of CO_2 and H_2O. Possible presence of significant concentrations of O_2 and other oxidized gases (CO, N_2O) produced by photolysis. Aerobic conditions at ~1.7 Ga.	3, 4, 7 and 57
6. Continent Formation No discrete continental masses at 3.9 Ga. Two periods of rapid continental accretion occurred between 3.8 and 3.5 Ga and between 3.1 and 2.6 Ga. Earliest sediments were hydrothermal and marine.	1, 2 and 5

Table II. Hydrothermal Vents and Associated Ocean Gradients. Properties and conditions important for studying the origin of life and related evolutionary processes (from Hoffman and Baross, 1984).

Environment	Properties, Conditions, Variables
I. Submarine Hydrothermal Vents (open and geologically continuous)	1. Temperature (~500°C to ~2°C in the present ocean; ~500°C to ?°C in the Archaean) 2. Pressure (? – dependent upon depth of the ridge). Present-day vents <1500 to >3000 m 3. Concentrations of reduced metals (microbial energy sources), trace metals, and gases (H_2S, CH_4, H_2, CO, N_2, NH_3, etc.) 4. Organic compounds (?) 5. Condensing agents (CN, CH_2O, polyphosphates, etc.) 6. pH (<4 to >7 in present-day hydrothermal systems; Archaean ocean reducing) 7. Reaction surfaces (clays, zeolites)
II. Surface Waters/ Archaean Ocean	1. Light 2. Temperature (?); greenhouse atmosphere in Archaean (Towe, 1983; Walker, 1983) 3. Pressure (dependent upon partial pressure of atmospheric CO_2) 4. Oxygen (? from photolysis) 5. N_2O, NO, other biologically important gases 6. Carbon and energy sources (see I-3 above)
III. Other Associated Environments	1. Submarine rock/water interfaces 2. Subaerial rock/water interface 3. Atmosphere/ocean interfaces

Our model for the origin and evolution of life in hydrothermal vent environments suggests several hypotheses which can be tested in present day systems (see Table III). Most of these topics have been previously discussed in this paper. Hypothesis number 7 (Table III) is proposed as an alternative way of approaching the question of how complex microbial communities formed in such a short time after the formation of the ocean (less than 500 million years). It is impossible to think of a single organism appearing and evolving through some single-stepwise accumulation of genetic information by coordinated sequences of rare events. It is far easier to imagine that life originated elsewhere and contaminated the early Earth. In our hypothesis, the evolutionary time necessary for free-living organisms to evolve from complex organic compounds can be greatly reduced by assuming that precursors to living cells were communities of "precells" which contained very small amounts of genetic material and were dependent upon other "precells" or communities for metabolism, synthesis, and replication. This hypothesis extends the views of Margulis[52] on the evolution of eukaryotes. Margulis proposed that eukaryotes evolved from prokaryotes through a series of symbioses.[52] We are suggesting that prokaryotes evolved from communities of

Table III. Some Hypotheses Related to the Origin and Evolution of Life Which Can Be Tested in Present-Day Submarine Hydrothermal Environments

1. *Heat from ridge crest magmatic activity was a primary energy source for abiotic synthesis of amino acids, purines and pyrimidines, macromolecules, and "protocells." All of these reactions can occur in the many different gradients and on large surface areas characteristic of the slow-flowing submarine hydrothermal vents (Table 2).*
2. *The earliest sediments where fossil microorganisms have been observed are volcanic and marine. Microorganisms which have been observed in present-day hydrothermal environments have similar morphologies to some of the fossil microbial assemblages seen in Archaean sediments.*
3. *The earliest microorganisms used magma-derived energy and carbon sources, including HS^-, H_2, reduced metals, organic gases (CH_4, CO_2), and possibly other abiotically synthesized organic compounds.*
4. *Possible specific physiological reactions carried out by bacteria in the Archaean were methanogenesis, sulfate reduction, elemental sulfur reduction (Pyrodictum occultum and Thermodiscus sp., for example), anaerobic photosynthesis (Photosystem 1), and possibly nitrogen fixation. Some oxidative microbial reactions may have occurred in shallow waters (see 5).*
5. *Microbial oxidation reactions occurred during the early Precambrian in surface waters having significant concentrations of photolytically-derived oxygen or in all aquatic environments in the absence of oxygen but with alternate electron acceptors (N_2O magnetite and related compounds, MnO_2, etc.).*
6. *The earliest groups of microorganisms were thermophilic (40->100°C) and chemolithotrophic, and thus were physiologically related to present-day Archaebacteria such as the thermoacidophiles, methanogens, and elemental sulfur metabolizers. Greater prokaryotic and eukaryotic diversity coincided with decreases in ocean temperatures below 30-50°C.*
7. *The earliest forms of life were communities of "precells" having small amounts of nucleic acids and capable of living only symbiotically as a community. Various mechanisms for genetic exchange and transposition of genetic segments were the rule.*

symbiotic "precells". The first self-replicating single cell would have developed not through an internal step-wise progression of rare events, but rather through prolific genetic exchange with other "precells" in the community, perhaps involving structures analogous to "transposable genetic elements" and viral-like particles. This model allows for many different "trial" combinations of sizeable genetic segments to have arisen very rapidly and for the more successful combinations to evolve into more complex entities and ultimately into the first free-living organism.

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Biography

Dr. Baross is Associate Professor, School of Oceanography, University of Washington. His area of research interest is marine microbial ecology specializing in understanding environmental processes responsible for limiting microbial growth in the ocean. Sarah Hoffman is a graduate student in geology at the College of Oceanography, Oregon State University, Corvallis.

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Profiles in Science

Dr. Jerome Karle, a native of Brooklyn, New York, joined the Naval Research Laboratory (NRL), in 1944. Since 1968, when a Chair of Science was established in his name, Dr. Karle has been Chief Scientist of the Laboratory for the Structure of Matter at NRL. His work in crystal structure analysis was recognized by the 1985 Nobel Prize in Chemistry, shared with Dr. Herbert Haumptman, a former colleague at NRL, who is now at the Medical Foundation of Buffalo, New York.

Karle's research has been concerned with diffraction theory and its applications to the determination of atomic arrangements in various states of aggregation, gases, liquids, amorphous solids, fibers and crystalline molecules and macromolecules. This research has resulted in new techniques for structure determination with a broad variety of applications.

During the past several years, Karle has been mainly concerned with the development of theory for analyzing macromolecular structures. The techniques applied to such problems are called isomorphous replacement and anomalous dispersion. Progress in this work has shown that much information is available from these techniques. Its efficient use, combined with synchrotron data sources and high-speed computers should greatly facilitate future analyses of macromolecules.

After obtaining degrees from City College of New York and Harvard University, Dr. Karle received his M.S. and Ph.D. degrees in physical chemistry from the University of Michigan. He is a Fellow of the American Physical Society, a member of the National Academy of Sciences and a past-president of the International Union of Crystallography. Dr. Karle has been a professorial lecturer in the University College of the University of Maryland, teaching courses in mathematics and physics, and a visiting professor at the University of Kiel in Germany. For the past 15 years, he has conducted the monthly meetings of the Washington Crystal Colloquium. He is married to Dr. Isabella Karle, also a well known chemist at NRL, who now and then collaborates with her husband on research projects. She is noted for her pioneering work in bridging the gap between the theoretical formulas for crystal structure determination and the practical methodology required to achieve useful applications.

A Nobel Laureate at NRL

Dr. Jerome Karle of the Naval Research Laboratory (NRL), Washington, D.C., was awarded the 1985 Nobel Prize in Chemistry for his work in developing direct methods for the determination of crystal structures by X-ray diffraction analysis. Dr. Karle shared the award with Dr. Herbert A. Hauptman, a former scientist at NRL working with Dr. Karle and now with the Medical Foundation of Buffalo, New York. In 1950, Karle and Hauptman published a fundamental research paper entitled, "The Phases and Magnitudes of the Structure Factors." This paper formed the basis for further research in structure determination by the "direct method" in X-ray crystallography.

Knowing the detailed molecular structure of a chemical can be crucial in determining how it works, or in trying to make the substance synthetically. Knowledge of molecular structure is important in understanding gene engineering, materials research and drug research. The research program at NRL has paved the way for the study of the molecular architecture of substances such as propellant materials which are of interest to the Navy as well as applications to the development of anti-cancer and anti-malarial drugs.

X-ray diffraction analysis involves the determination of the arrangement of atoms in crystals. When an X-ray beam impinges upon a single crystal, the beam is broken up. The resulting scattering of the X-rays are analyzed; their intensities and positions are measured. Drs. Karle and Hauptman showed that the phase values required for computing a structure could be derived from the intensities of the spots and developed the basic mathematics for doing this. It was thought that because phase values are lost in ordinary diffraction experiments, they could not be recovered.

The mathematical tools to solve the problem were derived from two sources, inequality theory related to non-negative Fourier series and the joint probability distribution of probability theory. The non-negativity criterion is applicable because electron density distributions in crystals are non-negative functions. Probability theory entered as a device for extending the range of applicablility of the inequality relations among phases and magnitudes that arise from the fact that the electron density distribution in a crystal can be represented by a non-negative Fourier series. The idea to apply non-negativity to the crystal structure problem occurred to Dr. Karle from experimental and analytical experiences in molecular structure studies by gas electron diffraction performed by Drs. Isabella and Jerome Karle. In the latter work, it was found that accurate probability distributions of interatomic distances in molecules could be obtained if the background scattering were adjusted so that a Fourier transform of the molecular intensity would be non-negative. Isabella Karle is the wife of Jerome Karle and is also a renowned chemist.

The foundation mathematics consisted of relationships among phases and intensities of scattering, phases alone, which had probable (approximate) validity. Probability measures for estimating the validity of the relations were developed by Hauptman and Karle and also subsequently by Professor Michael Woolfson, University of York, England, and Professor William Cochran, University of Edenburgh, Scotland. This mathematics led to a procedure that was applicable to centrosymmetric crystals and there were several investigations performed.

The first general procedure for application to both centrosymmetric and the generally more difficult noncentrosymmetric crystals was developed at NRL in the early sixties by Drs. Isabella Karle and Jerome Karle and called the Symbolic Addition Procedure. The Drs. Karle came to NRL in 1946 and have from time to time collaborated on their research projects. Jerome Karle had been an employee of NRL at the University of Michigan from 1944-46. During a news conference at NRL, Jerome Karle described his wife's contributions. "Early on there were broad gaps between the mathematical theory and the practical application of my work. It took a lot of pioneering and courageous research on the part of my wife to develop practical methods and to demonstrate the broad application of the mathematics. What was being programmed in the seventies she was doing in the sixties. We had computer programs then, but we never wrote them to be a black box; that is, they required some thinking on the part of the user. A virtue of the Symbolic Addition Procedure is that it does not require a sophisticated computer. In fact, much of the procedure can be carried out by hand.

"In the fifties there were no fast computers. Our X-ray analysis was dependent on photographs which had to be measured by eye, painstakingly slowly. Now we have automated gathering of data. Isabella was doing this (X-ray analysis) when essentially no one else would attempt it. I want to stress that the word pioneering really applies here. Her main contributions to the analytical developments were carried out through the sixties. Computers really didn't come to the fore until the seventies, and their sophistication is convenient but not crucial to the solution of the usual problems."

Ordinary structure determinations can often be performed at present in a few days or less. Some structure analyses are difficult to perform and may require considerable expertise and time. As the number of atoms increases beyond about 100 in crystals that lack a center of symmetry and are composed of atoms having essentially equal atomic numbers (except for hydrogen), the solutions of the structures become much less routine. The largest structure of this type to be solved by the direct method possessed more that 200 independent (non-hydrogen) atoms.

Direct determination of crystal structure by X-ray diffraction has revolutionized the fields of structural chemistry and biology. Many tens of thousands of structures have by now been solved and catalogued, thereby contributing to the pool of knowledge. The two laureates, each in his own way, are further developing the mathematical tools for the special techniques that are used to deal with large structures such as proteins. "My belief," says Karle, "is that in a few years the new mathematical tools will play a useful role in facilitating the solution of macromolecular structures."

Drs. Jerome and Isabella Karle pose with models of three-dimensional molecular structures.

A General Overview of SWATH Hydrodynamics*

by Choung Mook Lee
Office of Naval Research

Introduction

The small-waterplane-area, twin-hull (SWATH) concept has been actively exploited in the last two decades. Various advantages of the SWATH configuration have attracted innovative naval architects to develop this hull concept for commercial as well as military applications. The U.S. Navy should receive credit for advancing the SWATH concept because of substantial investments in research and development (R&D). The Office of Naval Research (ONR) for many years has been supporting fundamental research in SWATH hydrodynamics and recently investigating the possibility of a SWATH oceanographic research vessel. Equal credit should go to our colleagues in Japan for implementing the results of R&D into actual shipbuilding, starting with the 18-ton Marine Ace and going on to the 3500-ton Kayo.

A broad overview of SWATH ships was presented in the February 1985 issue of the Naval Engineers Journal.[1] In this article, one can view the history of the U.S. Navy's R&D efforts in SWATH development during the last 15 years covering such areas as hydrodynamics, structure, machinery and designs.

The paper starts with a general background introduction of SWATH hydrodynamics, followed by a status review of three major ship hydrodynamic subjects: resistance and powering, stability and motion, and maneuvering. The details of the theoretical and experimental analysis will not be presented here. The emphasis will be rather on the description of the essential assumptions or concepts leading to the final derivations and conclusions. In the discussion of each subject, the areas of interest for future investigation will be pointed out.

*Presented at the Ninth Energy-source Technology Conference, ASME, 24-27 February 1986, New Orleans.

†The terminology SSC is more commonly used in Japan. But in this paper it will be referred to as SWATH.

General Background of SWATH Hydrodynamics

A SWATH ship is composed of three main hull components, as shown in Figure 1; torpedo-like submerged lower hulls, narrow vertical struts, and upper cross-deck structures. A literature survey reveals that the first SWATH concept was proposed by Creed and Lewis to the British Admiralty in 1942 as an "aerodome" application. The history, starting from a single-hull small-waterplane-area ship through Lang's semisubmersible ship (S^3), is described in reference 2. Since the construction in 1973 of the U.S. Navy ship, the Kaimalino (190-ton), based on the S^3 concept of Lang[3], Seven more SWATH, or semisubmersible catamaran† (SSC) ships have been built throughout the world. Two of these were built in the U.S. (the 50-ton Suave Lino and the 60-ton Halcyon) and the rest in Japan (the 18-ton Marine Ace, the 340-ton Seagull, the 240-ton Kotozaki, the 240-ton Ohtori, and the 3500- ton Kaiyo).

Except for the Halcyon, the main particulars and other features of these vessels were given in a recent paper by Mabuci et al.[4] The main particulars of the presently existing SWATH type ships are shown in Table 1, identical to Table 1 of reference 4, but with the addition of the particulars of the Halcyon.

Among many other favorable features, the main motivation for accepting the SWATH concept has stemmed from its unique capability of maintaining a stable platform in adverse sea conditions. This particular advantage associated with SWATH ships is due to the submerged lower hulls with small waterplane areas. A fully submerged body induces significantly less wave force exciting the body to motion. As a result, a SWATH ship is subject to only 15 to 20% of the wave-exciting force of a monohull ship of equivalent displacement. Furthermore, by virtue of the smallness of the waterplane area, a SWATH ship has longer natural periods in heave and pitch modes. This advantage makes SWATH ships less vulnerable to the excitement of a large motion in moderate sea states compared to monohull ships, because the wave-encountering periods are normally less than the natural periods of SWATH ships. However, there are some disadvantages associated with SWATH ships. Perhaps, the major shortcoming is its small restoring capability in heave and pitch modes due to its small waterplane area. Most of the SWATH designs attempted so far show that in comparison with monohulls of the same displacement, the tons-per-inch-immersion and the moment-to-trim-one-inch can be as small as 20 to 40% and 10 to 20%, respectively. Thus, SWATH ships are far more weight sensitive compared to monohulls.

Since little information on the operational experience of full-scale SWATH ships is available today, it is difficult to analyze correctly the attributes and limitations of SWATH ships with respect to the monohull ships. However, some obvious features associated with a SWATH configuration can be evaluated. The results of such an evaluation is given in Table 2.

The SWATH configuration provides interesting hydrodynamic properties. Because it consists of two hulls adjacent to each other, the fluid disturbances generated by one hull will influence the flow field about the other hull. This hydrodynamic interaction between the two hulls significantly affects the performance of SWATH ships. Such interference effects are manifested in the wavemaking resistance of a SWATH ship. A question may arise on whether the hydrodynamic interference could best be utilized in cancelling the wave systems between the two hulls. Some earlier attempts[5] using this concept have shown that the gain is not so much as might be anticipated. For a SWATH ship the transverse force exerted on the two hulls may not be negligible even in a steady straight forward motion in calm water, whereas such force would be almost nonexistent for a monohull on a straight course.

Due to the smallness of the waterplane area, the hydrostatic-restoring capability in heave and pitch modes is also small. The small restoring pitch moment may cause a SWATH ship to be unstable at high speeds because the well-known destabilizing Munk moment, which is proportional to the heave added mass times the square of the ship speed, can far exceed the restoring pitch moment. The introduction of stabilizing fins to SWATH ships is to ensure the pitch stability as well as to augment the much needed hydro dynamic damping in heave, pitch, and roll motion. A further description of this aspect will appear in a later section of this paper.

The presence of a crossdeck structure above the waterline is a unique feature of a twin-hull ship. Although it provides a beamy deck area, the resulting penalty is not insignificant. This penalty is due to the wave impacts on the bottom of the crossdeck. Such impacts can cause main structural damage, hull vibrations, and human discomfort. Reduction in the frequency of wave impacts may be achieved by raising the crossdeck height above the water. Such an action however, would result in smaller restoring moment arms in roll and pitch due to the upward shift in the center of gravity and also a greater transverse bending moment on the cross structure due to the increase in vertical arm for the transverse components of wave load.

Table 1 — Main Particulars of Existing SWATH Ships [4]

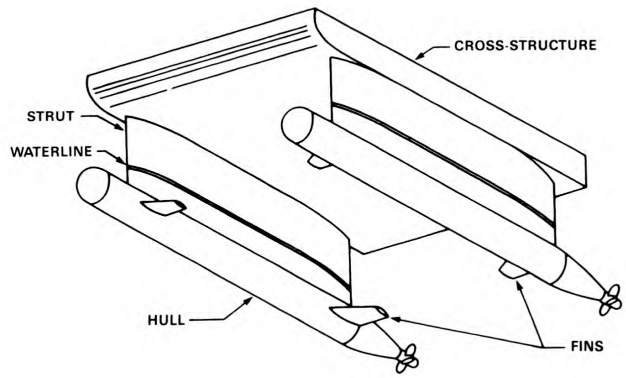
Ship Name	Marine Ace	Seagull	Kotozaki	Kaiyo	Ohtori	Kaimalino	Suave Lino	Halcyon
Kind of Ship	Experimental Craft	Passenger Ferry	Hydrographic Survey	Support Ship	Hydrographic Survey	Work & Demonstration	Fishing & Demonstration	Offshore Support
Completion	Oct. 1977	Sep. 1979	Dec. 1980	Oct. 1984	Dec. 1980	1973	1981	1985
Length O.A. (m)	12.35	35.9	27.0	60.0	27.0	26.8	19.2	18.3
Length P.P. (m)	11.0	31.5	25.0	53.0	24.0	23.5	16.8	—
Breadth O.A. (m)	6.5	17.1	12.5	28.0	12.5	13.7	9.1	9.1
Depth (m)	2.7	5.85	4.6	10.6	5.1	—	—	—
Draft (m)	1.55	3.15	3.2	6.3	3.4	4.66	2.13	2.1
Displacement (MT)	18.4/22.2	343	236		239	193/224	53	60
Payload (Complement)	(20 Personnel)	402-446 Pass.	abt. 36 Tons	abt. 860 Tons	(20 Personnel)		abt. 14 Tons	(20 Personnel)
Strut Type	Twin/Single	Single	Single	Single	Single	Twin	Single	Single
Hull Material	All Al	All Al	Hybrid	All Steel	Steel (Hull) & Al (Deck House)	Hybrid	All Al	All Al
Propulsion System	Gasoline & Bevel Gear 200 PS x 2	Diesel & Bevel Gear 4050 PS x 2	Diesel & Bevel Gear 1900 PS x 2	Diesel/Electric D/G 1250 KW x 4 Motor 860 KW x 4	Diesel & Bevel Gear 1900 PS x 2	Gas Turbine & Chain Drive 2250 PS x 2	Diesel & Bevel Gear 425 PS x 2	Diesel Caterpillar 3408 DITA x 2 V-Belt
Propeller	F.P.P.	F.P.P.	C.P.P.	C.P.P.	C.P.P.	C.P.P.	F.P.P.	C.P.P.
Fin Control	Automatic	Automatic	Manual	Manual	Manual	Automatic	Automatic	Automatic

The maneuvering characteristics of a SWATH ship are quite different from that of a monohull ship; it's twin propellers make possible the use of differential thrust for maneuvering. Particularly, the differential thrust provides an exceptional low-speed maneuverability. On the other hand, the strong directional stability, contributed by the long vertical struts, makes a SWATH ship difficult to maneuver at high speeds. Attempts have been made in the past to reduce the directional stability while increasing the yaw moment by rudder without increasing the rudder size. An obvious attempt to achieve these goals would be to shift the strut area toward the bow and to locate the rudder behind the propeller, thereby increasing both the yaw moment arm of the rudder as well as its hydrodynamic lifting effects.

More details of the current status of research in SWATH hydrodynamics will be described in the following sections.

Figure 1

SWATH configuration



Resistance and Powering

The resistance of a twin hull, cruising at a constant speed in calm water, is anticipated to be greater than that of a monohull of equivalent displacement. The first reason is the greater frictional resistance due to the increased wetted

Table 2 — Attributes and Limitations of SWATH Ships

ATTRIBUTES

- SUPERIOR SEAKEEPING—Less Motion in Waves, less Speed Loss in Heavy Seas, Better Course-Keeping Capability in Waves
- REDUCED OVERALL COST FOR ROUGH WATER OPERATION—Less Displacement and Operation Cost for Equivalent Mission than Monohull
- INCREASED LOW-SPEED MANEUVERABILITY—Better Station Keeping; Small Turning Diameter
- MORE FLEXIBILITY IN DESIGN FOR HULL PARAMETERS—Variable Combination of Upper Deck, Strut, Underwater Hull, and Hull Spacing
- INCREASED SURVIVABILITY—Emergency Redundancy due to Twin Screws; more Flexibility in Ballasting
- INCREASED CLOSED VOLUME/TON—Flexible Storage Space for Liquids and Auxiliary Machinery; Maintenance of Similar Deck Configuration through Upper and Lower Decks
- WIDER DECK AREA AND STABLE PLATFORMS—Better Capability in Launching, Retrieval, and Towing Objects; Better VSTOL Launching and Landing
- REDUCED HYDROACOUSTIC SIGNATURE—Less Self Noise for Sonars, Less Propulsor Noise (Contrarotating Propulsor), Reduced Cavitation Inception due to large Diameter with Slow rpm

LIMITATIONS

- REDUCED RESTORING CAPABILITY IN TRIM AND SINKAGE—More Weight Sensitive
- INCREASED WETTED SURFACE—More Frictional Drag, Greater Powering Requirement for Calm-Water Operation
- LIMITATION OF MAXIMUM DISPLACEMENT—Wider Beam and Deeper Draft Hampers Operations in Restricted Water
- ADDITIONAL STRUCTURE DETAILING—More Major Structural Joinings of Upper Cross Deck, Struts, and Underwater Hulls
- COSTLY TWIN-SHAFT PROPULSOR SYSTEM
- REQUIREMENT OF STABILIZING CONTROL SURFACES—Pair of Rudders, Forward and Aft Fins (May Require Automatic Control)
- INCREASED HEIGHT IN FREE BOARD—Inconvenience in Passenger and Cargo Transfer
- LACK OF DESIGN DATA BASE

surface, which can be up to 70% more than monohull ships. The second reason is the probable adverse flow interference between the two hulls. Little can be done to reduce the resulting frictional resistance due to the increase in wetted surface. However, the flow interference effect may be minimized by imposing a camber on each demihull to reduce the induced drag caused by the cross flow between the two hulls. In optimizing hull form for minimum wave-making resistance, a SWATH configuration provides more flexibility than a monohull because it allows a certain freedom in vertical distribution of its volume. For instance, the lower hull of a SWATH may be so designed as to play the role of a bulbous bow on the monohull. The first trial of optimum hull search for a SWATH ship was made by Pien[6] using the so called "stream curvature tracing." This was accomplished by allowing a slight camber to each demihull to eliminate the cross flow induced by the other hull. At first, the uncambered demihull was obtained by an optimization method applicable for monohull ships by finding optimum singularity distribution for a combined strut and underwater body configuration.[6] A more descriptive optimum wave-resistance hull form design procedure for Mitsui SWATH ships is given by Kusaka et al.[7]

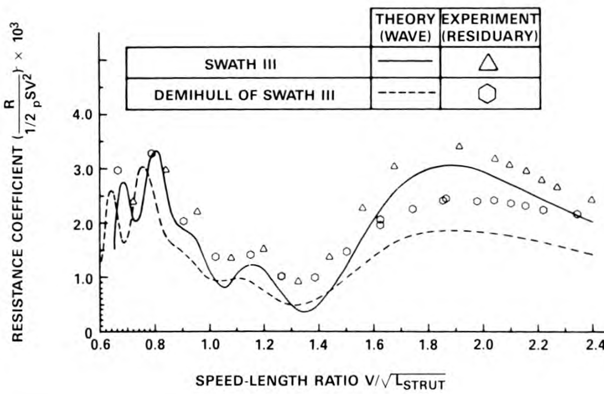
The analytical methods for predicting the wave resistance of a given hull form of a SWATH ship developed to date[8, 9, 10] have neglected the additional dipole and source distribution on the centerplanes. The justifying reasons for discarding the additional singularity distribution were that the necessary camber to eliminate the cross flow has insignificant effect on the wave resistance for a reasonably large ratio of the separation distance to the beam of the demihull, and also that the interference effect between the strut and the lower hull is small for thin struts.

Shown in Figure 2, borrowed from reference 8, are typical results from the calculated wave resistance and the experimentally obtained residual resistance for SWATH III. The general trend of the hull interference effect on wave resistance is well reflected by the theory. The SWATH configuration, generally consisting of a thin strut and an axisymmetric lower hull, seems to be well suited for application of a wave-resistance theory based on the thin- and slender-body assumption. Some refinements of the theory may be made either by taking into account the effects of cross flow between the two hulls or the effect of the flow interference between the strut and the lower hull. Another worthwhile major effort would be a distribution of Havelock sources on the demihull surface, rather than on the centerplane or center axis, with the image sources from the other hull, utilizing a higher order panel source distribution method (e.g., a parabolic source strength distribution on each panel, not a conventional constant source strength on a given panel).

In practice for some time has been the utilization of wave resistance theory for searching optimum hull forms for SWATH ships and for predicting the wave resistance of given hull forms. The historical development shows various attempts in configuring SWATH hull forms. The first attempt was to impose a longitudinal camber to both the strut and

Figure 2

Comparison of theoretical and experimental resistance of SWATH III



the hull, followed by both a coke-bottle shaped strut and lower hull. The use of tandem struts versus single strut per hull has also been actively exploited from the resistance as well as the motion viewpoint. The present consensus among SWATH designers appear to be a lenticular-shaped strut per hull with a coke-bottle shaped lower hull. Table 3 presents a summary of the past efforts in searching for an optimum SWATH configuration for resistance and powering sponsored by the U.S. Navy (from Reference 11).

In the prediction of the total resistance, there is a definite gap in employing reliable form drag corrections and correlation factors. These empirical correlation factors for predicting the resistance for full-scale surface ships are reasonably well derived from the existing model and full-scale experimental data base. However, the same is not true for SWATH ships. At present, there exists only intelligent guess work for these factors. As more full-scale SWATH ships become operational, the level of confidence in estimating these factors should increase.

In the early stage of SWATH investigations, it was expected that the propulsive efficiency of such ships would be greater than that of monohull ships due to the similarity of its stern shape to torpedoes or submarines. However, a few model experiments have shown that the expected high propulsive efficiency cannot be verified. The cause was diagnosed to be the nonuniform wake distribution due to the presence of the surface-piercing large struts. To improve the propulsive efficiency of SWATH ships, an attempt at the David Taylor Research and Development Center (DTNSRDC) has been made to extend the strut at the stern behind the lower hull as an overhang configuration and to employ contrarotating propeller with smaller diameters, down to 60% of the maximum diameter of the lower hull. A preliminary result indicates that the propulsive efficiency for SWATH ships could be increased up to 90% with an effective stern shape and contrarotating propellers. Whether such high propulsive efficiency could be attained in reality should be assessed more thoroughly in the future.

SWATH ships in general exhibit more speed sensitive characteristics in resistance and powering than do monohull ships. If a SWATH ship is designed for a low-speed operation, an optimization effort would be focused on reducing the frictional drag rather than the residual drag, because the former dominates total drag. An attempt then would lead to minimizing wetted surface area by shortening the lengths of the strut and the lower hull. On the other hand, if a SWATH ship is to be operating in a high-speed regime, a longer strut and hull would be desirable to reduce the residual resistance. However, extreme care should be exercised in the determination of hull configurations to avoid the apparent two local maxima inherently associated with the residual resistance characteristics of a SWATH ship. The difference in propulsive efficiencies between the local maxima and local minima is known to be as much as 7 to 8% of the maximum propulsive efficiency.

Thus, in the high-speed regime, more accurate knowledge is required on both the residual resistance characteristics and also on the propulsor-hull interactions with respect to ship speed. As to the latter characteristics, the scale effect would be of great importance. Currently, theoretical investigation of turbulent boundary layers and free-shear wakes of a SWATH is being conducted in the U.S. Preliminary results of this investigation will be compared with experimentally obtained wake distribution of a SWATH model. If the comparison shows the validity of the theory, it may be reliably used to predice the full-scale nominal wake. The effective wake prediction may then be possible by utilizing the method used for submarine configurations.[12] Prediction of appendage drag caused by stabilizing fins and rudders is another subject of uncertainty. An unreported investigation conducted at the

Table 3 — Summary of SWATH Model Experiments for Resistance and Powering [11]

A. Single Strut Per Hull Configurations

Designation	Design Displ.	Number of Hulls Tested	Type	Design Features	Hull Length Hull Spacing
Swath 1	25,000 Tons	Single, Pair	R&P	Simplified Strut	4.5, 3.6, 3.0
Swath 2	101,000	Pair	R&P	Elliptical Hull Cambered Twin Screw	5.0, 4.0, 3.0
Swath 3 A-E	3,760	Single	R	Varying Strut Shapes	
Swath 3A	3,760	Pair	R&P	Coke Bottle Strut	3.8, 3.3
Swath 4	4,000	Pair	R&P	Cambered Hull E Strut	3.8
Swath 5 A-B	4,3200	Single	R	Two Strut Shapes Coke Bottle Hull	
Swath 6-A	2,900	Pair	R&P	With Fins at Angle For Even Trim	3.2
Swath 6-A	2,900	Pair	R	Fins at 0 Angle of Attack	3.2
Swath 7	4,300	Pair	R	Spade Rudder	3.6
Lambda-A	1,830	Pair	R		3.6
Lambda-C	1,960	Pair	R	Carrot Shape Hull	3.4

B. Tandem Strut Per Hull Configurations

Designation	Design Displ.	Number of Hulls Tested	Type	Design Features	Hull Length Hull Spacing
SSP	190 Tons	Pair	R&P	Rudder Aft Of Propeller	2.0
RC-2	3,000	Pair	R	With & Without Elliptical Blisters	2.6
Strut/Hull Components		Single, Pair	R	4 Different Lenticular Struts	5.5, 2.8, 1.8
(1:30 Scale) Swath 8	1,875	Pair	R	Contoured Hull Shape	2.6
(1:12.5 Scale) Swath 8	1,875	Pair	R	Contoured Hull Shape	2.6

Key: R = Resistance Test: P = Powering Test

Maritime Research Institute, Netherlands (MARIN formerly NSMB) indicated that the stabilizing fin drag is highly dependent on the Froude number at high speeds. If this finding is true, there may be a further complexity in accounting for the free-surface effects added to the already difficult problem of estimating appendage drag in unbounded fluid. This may be a fruitful area to explore the possibility of using numerical methods for solving the low Reynolds number Navier-Stokes equations with a free-surface boundary condition.

Stability and Motion

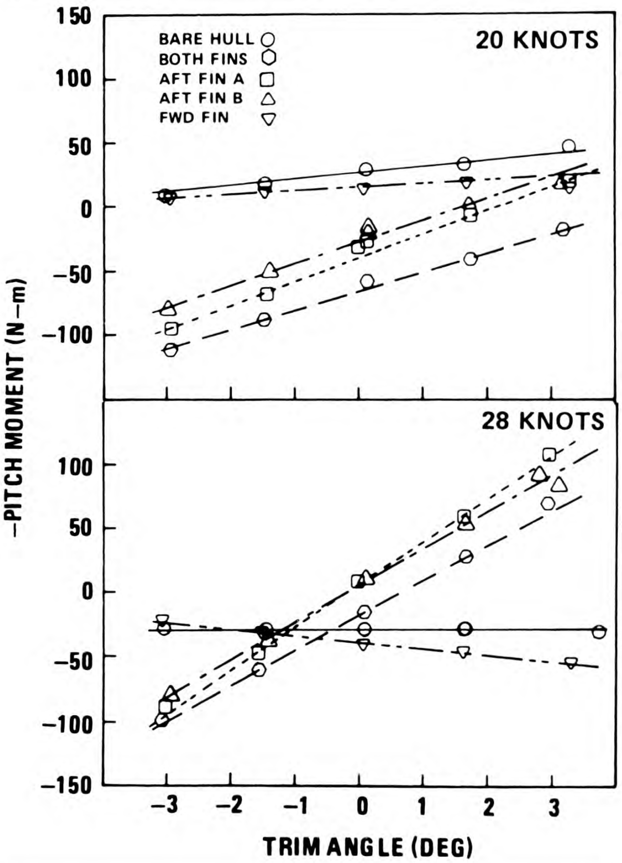
Well known is the fact that when a slender body is subject to a small angle of attack, a destabilizing moment, the so called "Munk moment,"[13] gradually increases the angle of attack and eventually makes the body totally unstable. The Munk moment is also known to be proportional to the heave added mass times the square of the speed. Due to this Munk moment, a SWATH ship with its slender lower hull and with small restoring pitch moment can become unstable in pitch beyond certain speeds. For conventional monohull ships, such pitch instability has never been experienced because the pitch restoring moment, given by $W\overline{GM}_l$, dominates the Munk moment, given by U^2A_{33}. Here, W is the weight of the ship, $\overline{GM}_l$ is the longitudinal metacentric height, and A_{33} is the heave added mass. The total pitch restoring moment for a ship without trim stabilizing fins is given by $C_{55} = W\overline{GM}_l - U^2A_{33}$. When $C_{55} \leq 0$, one can expect that a pitch instability will take place. For a SWATH ship, as U increases, the Munk moment can exceed the inherent pitch restoring moment $W\overline{GM}_l$, hence making $C_{55} \leq 0$. Figure 3 shows the experimental result of restoring pitch moment versus trim angle for a SWATH model designated as 6A. The negative trim angle means a bow-up trim. The greater the positive slope of a curve the greater the pitch restoring capability. When a curve shows negative slope, the body is unstable in pitch. Notice the results of the bare hull of SWATH 6A at 20 knots and 28 knots. At 20 knots, there is almost zero slope. By mistake, if forward fins alone were installed, the body would definitely experience pitch instability worse than in the bare-hull case. In fact, both theoretical and experimental results show that the SWATH 6A experiences pitch instability at 23 knots.[14]

A thorough theoretical analysis was presented in reference 14 starting with heave-pitch coupled stability equations and interpreting the meanings of the stability roots and the complex stability-root plane. The essential findings of the investigation are:[14]

1. Inception speed for pitch instability can be reliably predicted.
2. Optimum fin sizes for fixed forward and aft fins and their locations can be determined analytically.
3. Although only aft fins alone would provide sufficient stability, combination of fore and aft fins offer increased damping for heave and pitch motion.

Figure 3

Pitch moment versus trim angle for SWATH 6A with and without fins at 20 and 28 knots



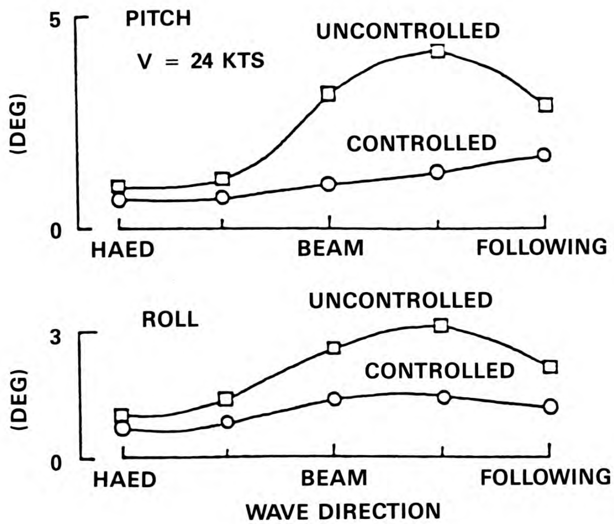
4. Oversized stabilizing fins could increase the coupling between heave and pitch motion and induce a heave mode instability.

The stabilizing fins could be effectively used for controlling the vertical-plane motion of SWATH ships in waves. In fact, all the SWATH ships built so far are equipped with either manually or automatically controlled fin systems to reduce the roll, heave and pitch motion. Figure 4, borrowed from Reference 4 shows the effectiveness of motion control by fins under an automatic control system.

The fact that a semisubmersible configuration is subject to much less wave-exciting forces and, therefore, less motion in waves was proven by theory[15] and experiment[16] in the mid 1960's. By the time the Kaimalino became operational, a theory based on the strip method of obtaining the hydrodynamic coefficients associated with the equations of motion for twin-hull ships was developed.[17] Later, the theory was refined to include the effect of viscous damping and stabilizing fins in the prediction of the six-degrees-of-freedom motion of SWATH ships.[18]

Figure 4

Pitch and roll motion with and without fin control for Seagull [4]



The equations of motion for SWATH ships are essentially identical to those for monohull ships. The major differences in the equations between monohulls and twin hulls are embedded in the hydrodynamic coefficients. The equations of motion are formulated under the assumption of linear relationship between the wave excitation and ship response.

Thus, the coefficients for the acceleration, velocity, and displacement terms are, respectively, virtual mass, damping, and restoring or spring constant. The wave-exciting forces are proportional to the amplitude of incident waves. In obtaining these hydrodynamic coefficients, the so-called strip method is employed, which assumes that for a given lengthwise strip of a ship the hydrodynamic behavior at any cross section is identical. Therefore, the hydrodynamic forces acting on a strip can be obtained by the two-dimensional hydrodynamic forces acting on a cross section of the strip times the length of the strip. For SWATH ships, this amounts to obtaining two-dimensional velocity potential solutions for twin cylindrical bodies with semisubmersible cross sections for forced oscillation and wave diffraction. The main difference of twin cylinders from a monocylinder is in the inclusion of the hydrodynamic interactions between the two cylinders.

To obtain the added mass, damping, and wave-exciting coefficients for the equations of motion (for six degrees of motion) in terms of the two-dimensional velocity potentials for a SWATH ship, substantial computer time is required—almost three to four times more than the case for a monohull ship. Thus, the pulsating-source distribution method, often called panel method, was not so effective in time and cost for usage in evaluating motion characteristics of numerous candidate SWATH hull forms in the preliminary design stage. To circumvent this difficulty, an approximate means of evaluating the hydrodynamic coefficients was developed.[20] This method is based on obtaining a far-field outgoing wave amplitude due to an oscillating demihull of a SWATH section. This wave amplitue is modified to account for the barrier effect presented by the other demihull. From the modified wave amplitude, the damping coefficient can be obtained. In terms of the given damping coefficient, one can invoke the Kramers-Kronig relations to obtain the added mass coefficient as the conjugate of the damping coefficient.[21]

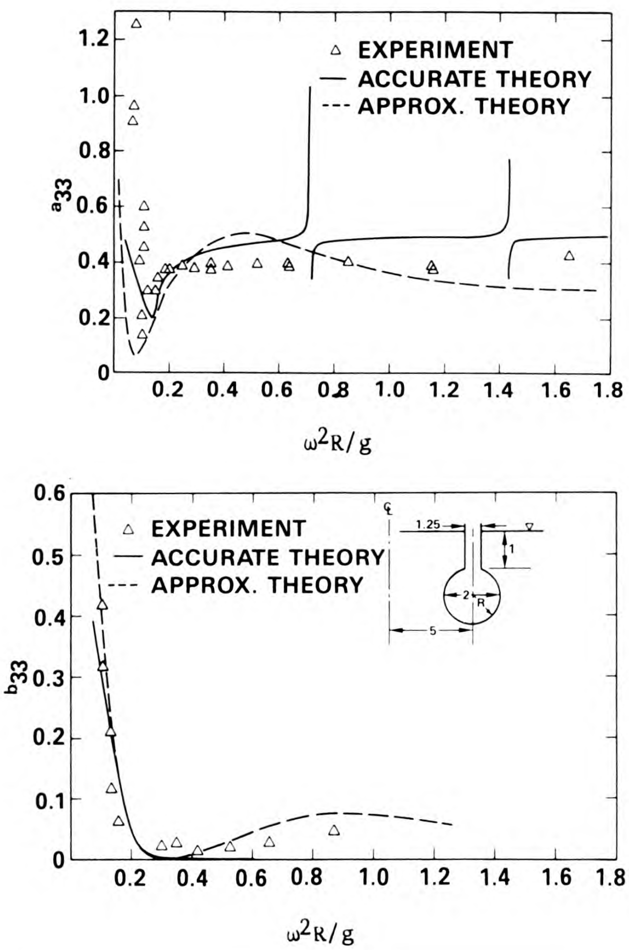
The approximate method[20] resulted in an-order-of magnitude reduction in computation time compared to the source-distribution method. Despite the crudeness of the theory, the results obtained by the method provided a fairly good agreement with the source-distribution method as shown in Figure 5. The "Accurate Theory" in this figure means the source-distribution method presented in Reference 19.

As shown by Newman[22], the damping coefficient of a body responding to waves is proportional to the square of the amplitude of the wave-exciting force of a corresponding mode of motion. Thus, a semisubmersible shape known to have a small magnitude of wave-exciting force has also a small magnitude of damping (about the same order of magnitude as viscous damping). A linear equation of motion representing a mass-dashpot-spring system under forced oscillation exhibits prominent resonant motion characteristics near the natural frequency, particularly for a system with a small damping coefficient. The magnitude of the peak amplitude is inversely proportional to the damping coefficient at the natural frequency. The computation of SWATH motion also presents highly exaggerated large amplitudes at the natural frequencies of heave, pitch, and roll motions if the viscous damping coefficients are not included in the computation. The behavior is quite similar to the computed roll motion characteristics of a monohull ship without viscous damping. Although the necessity for introducing viscous damping for monohull ships is normally limited to the equation for roll only, such is not true for SWATH ships. No reliable prediction of SWATH motion (not only in roll, but also in heave and pitch) can be made without including viscous damping effects. However, until now there has been no theoretical means for evaluating viscous damping for even two-dimensional bodies in oscillation.

An approximate method borrowed from an aerodynamic concept was introduced[18] in the evaluation of viscous damping. This concept is based on the estimation of a viscous side force acting on a yawed slender body proceeding with a constant speed. The expression for the side force includes two empirical coefficients. One of them is called a viscous-lift coefficient, and the other is called a cross-flow drag coefficient (see e.g., pages 405-421 of Reference 23.)

Figure 5

Heave damping and added-mass coefficients of a SWATH section



The horizontal stabilizing fins contribute significantly to damping of the vertical-plane motion through its lifting effect and cross-flow drag. The lifting comes from the time-dependent angle of attack on the fin due to vertical oscillation of the body in a wave field while proceeding with forward velocity. The foregoing damping effects of the stabilizing fins of a SWATH ship, as well as added mass and wave-exciting forces, are included in the hydrodynamic coefficients in the equations of motion.[18]

Verification of the hydrodynamic coefficients obtained by the methods described in the foregoing for SWATH configurations was made by model experiments conducted at DTNSRDC.[24] In general, a fairly good agreement was found between the computed and measured hydrodynamic coefficients. The same is true for SWATH motion[18] as shown in Figure 6. However, as can be observed in Figure 6, the method described in Reference 18 indicates the necessity for improvement of the analytical method for prediction of motion in the low encountering-frequency regime as in the case of motion at zero speed and in the stern-wave headings.

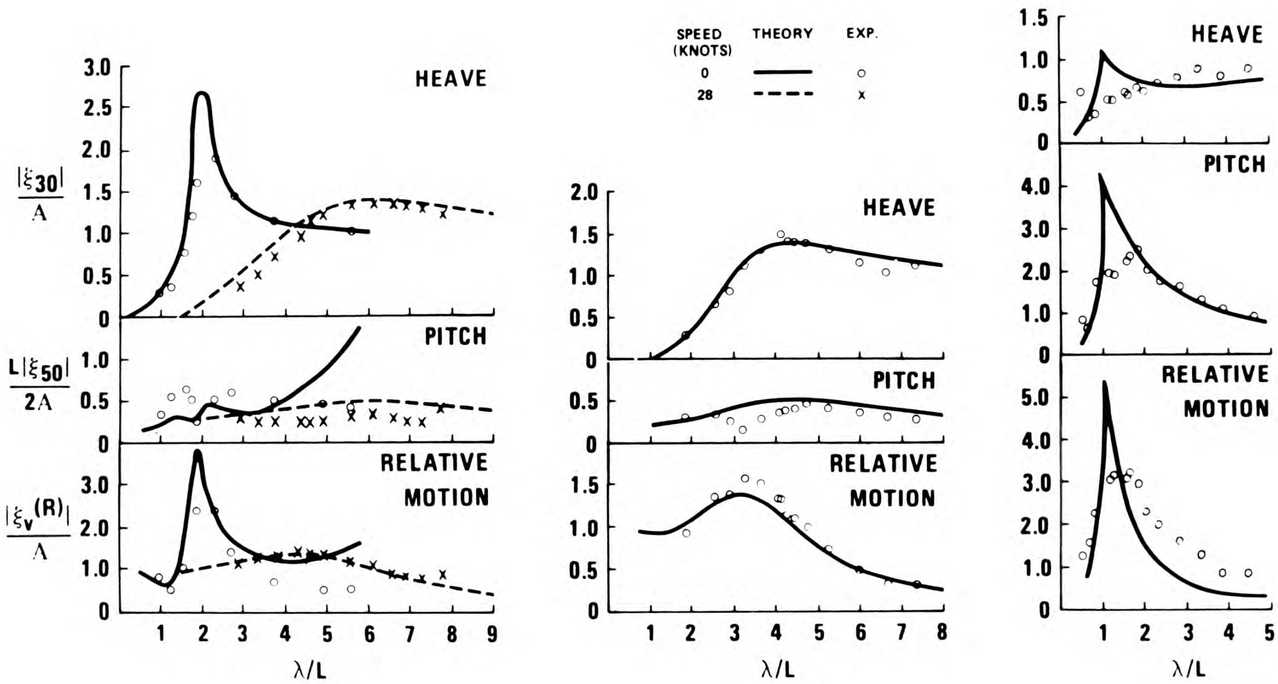
The motion prediction methods of Reference 18 assumes that the equation for surge motion can be decoupled from other modes of motion. However, due to the deep submergence of the main buoyancy volume of a SWATH ship, and therefore due to the large vertical arm, the surge force exerted on the lower hull could induce a fair amount of pitch moment. Hong[25] included the effect of the wave-exciting surge force on the wave-exciting pitch moment in the prediction of heave, pitch, and relative vertical motion. Another attempt to improve the evaluation of the hydrodynamic coefficients of viscous origin (i.e., the viscous lift and cross-flow drag coefficients) and of the stabilizing fins was made by McCreight and Stahl[26] by introducing explicit empirical formulas that were derived from experimental results of circular cylinders, flat plates, and submersible models.

The strip method, used to obtain the hydrodynamic coefficients associated with an oscillating body in a free surface, is an approximate theory valid for a high-frequency regime only. Thus, it may be anticipated that the hydrodynamic coefficients for low frequencies can not be obtained accurately by the strip method. Evidence of the shortcomings of the strip method was revealed in the prediction of the motion of ships in following waves at nearly zero wave encountering frequencies. For SWATH ships, model experiments have shown that the worst motion behavior is experienced in the stern waves. In these waves, a SWATH undergoes simultaneously coupled motion in six degrees of freedom. This is the condition at which a maximum utilization of an available motion control system is required to keep the ship under control, particularly so in high sea states. Thus, it is desirable to possess an analytical method of accurately predicting the motion of a SWATH ship in stern-quartering wave headings to assess the requirement for the control system and the control strategies. Unfortunately, the conventional strip methods do not seem to satisfy the foregoing need.

To improve the accuracy of predictions of ship motion at all frequency regimes, various theoretical attempts were made. Within the context of linear solutions for wave radiation and diffraction problems, these attempts were mainly focused on seeking asymptotic solutions which are uniformly valid for all frequencies by the so-called matched asymptotic method. The unified slender-body theory developed by Newman[27] was one of these attempts. This theory was extended to SWATH ships by Hong.[28, 29] The three-way comparisons of the results obtained by the strip theory, the unified slender-body theory, and model experiments for SWATH ships in following waves are given in Reference 28. Based on these comparisons, it is difficult to draw any definitive conclusions on the use of the unified slender-body theory for the prediction of the motion of SWATH ships in stern waves. One should be reminded that it is an extremely difficult task to

Figure 6

Motion of SWATH 6A for various wave headings and ship speeds



carry out accurate numerical computations associated with the unified slender-body theory for head- and following-wave headings. Furthermore, the degree of accuracy of the experimental results for SWATH motion in following waves is not very reliable because of the difficulty of maintaining the model heading and speed.

At present, it is not obvious how to improve the analytical means of predicting SWATH motion in stern waves. To make a fair verification of any theoretical results by comparison with experimental results in stern waves, the theory should be formulated in the time domain, including the effects of activating rudders and stabilizing fins. It is, of course, not an easy task to carry out necessary numerical computations for a time-domain solution of twin-hull motion excited by waves and control surfaces. However, this problem may offer a good challenge to those who want to make a serious investigation of SWATH motion at all speeds and wave headings.

Maneuvering

The hydrodynamic coefficients associated with the equations of motion in the horizontal plane for SWATH ships in a maneuvering mode in calm water may be separated into two categories: those coefficients of potential-flow nature, and those of dominantly viscous-flow nature. The former coefficients are the added mass and added inertia, memory effects contributed by the free surface, and lifting forces contributed by control surfaces. The latter coefficients are viscous-lift and cross-flow drag forces. In principle, the potential-flow solution should provide the values of the first-category coefficients; however, for the second-category coefficients there are no equivalent analytical methods, such as velocity potential functions. Moreover, unlike the case of ship motion in waves, the second-category coefficients play very important roles in the equation of motion in the horizontal plane, i.e., surge, sway, roll, and yaw motion.

The lack of analytical means of obtaining the second-category coefficients leaves no other options but to rely heavily on model experimentss to obtain these coefficients. Because the forces on a freely moving body cannot be measured, the models have to be restrained in all modes of motion except for linear or circular translatory motion. Therefore, terminology such as "captive model test" is frequently used in reports concerned with ship maneuvering problems.

Because the cross-flow drag coefficients in the equations of motion are associated with nonlinear terms (e.g. the cross-flow drag coefficient for sway motion $Y_{v|v|}$ is attached to the term $v|v|$) the equations of motion in the horizontal plane unavoidably become nonlinear. Hence, to be consistent with the nonlinear second-category coefficients, those in the first-category associated with the nonlinear velocity terms should also be retained in the equations of motion.

For SWATH ships, most of the investigations for maneuvering characteristics have been confined to experimental studies. The efforts in obtaining the hydrodynamic coefficients of SWATH and using these to investigate the turning characteristics of SWATH ships are reported in References 30-33.

Due to the dominant influence of the large surface-piercing struts of a SWATH, the most dominant nonlinear contributions are associated with free-surface effects. These effects, depending on the Froude number, could be partially related to changes in the strut wetted surface area because of changes in wave profiles along the struts. At high-speed turnings, significant ventilation and cavitation were observed to occur at the leading edges of the struts. When such a phenomenon takes place, the hydrodynamic behavior of the struts can drastically change, thus resulting in erratic behavior in a turning maneuver. As mentioned in the Introduction, because of the long struts with normally a greater side strut area aft of the longitudinal center of gravity, a SWATH ship has an extremely stable directionality at high speeds. The turning diameter of a SWATH ship, therefore, could be larger than that of a monohull ship. However, from full-scale trials, free-running model experiments,[34] and simulation studies,[33, 35] it was found that the turning radius of SWATH ships at high speeds can be reduced to that of monohull ships by shifting rudder locations behind the propeller and by banking the ship in turns by use of horizontal stabilizing fins.

Summary and Concluding Remarks

In the overview of resistance and powering of SWATH ships, there is presented a brief historical development of the theoretical prediction methods for wave resistance. In principle, the velocity potential function, representing the flow field disturbed by a twin-hull ship cruising at a constant speed in calm water, can be found by a combination of the Havelock source and doublet distribution on the hull surface below the waterline. The theories so far developed have not included the doublet distribution because the separation between the two hulls is deemed to be sufficiently large for SWATH ships to neglect the cross flow between the two hulls. A further simplification is employed in the current theories[8, 10] by distributing source of the known strength of $-Ut_x(x,z)/2\pi$ on the centerplanes of the struts by using the thin-ship assumption, and that of $-UA_x(x)/4\pi$ on the axes of the underwater body by using the slender body assumption. Here, t represents the local thickness of the struts and A the cross sectional area.

In the prediction of powering of SWATH ships, empirical factors representing the form drag, the hull efficiency and the scale effects are used, as in the case of powering predictions for monohull ships. A greater uncertainty in estimating the values of these empirical factors is experienced for SWATH ships than for monohull ships because of insufficient model as well as full-scale data base. Preliminary results obtained recently indicate that contrarotating propellers may offer propulsive efficiencies in the high 80's to low 90's.

Optimum hull shapes for SWATH ships for minimum wave resistance are sought by the conventional methods used for monohulls by searching the optimum distribution of the sources for minimum ship-wave energy spectrum functions.[7] The optimum shapes for high speeds ($F_n \geqslant 0.30$) tend to be coke-bottle shapes for the lower hull.

SWATH ships could experience vertical-plane at high speeds due to the small waterplane area, instability and, therefore, to ensure the stability, it becomes necessary to install the stabilizing fins. The fins also contribute significantly to the damping of the vertical-plane motion. It was found that a combination of smaller fore fins and larger aft fins provide good damping effects. Described in reference 14 are hydrodynamic analyses for investigating the vertical-plane instability and for searching for the size and location for stabilizing fins.

SWATH motion in waves is superior to monohull motion due to the smaller magnitudes of wave-exciting forces and the greater natural periods in heave and pitch modes. The existing theoretical prediction methods are based on the strip method for obtaining the hydrodynamic coefficients of the potential flow nature. The total damping includes the viscous damping contributed by the bare bodies and the damping due to the lifting effect of the fins.[18, 26] The inclusion of viscous damping is based on the empirical approach in estimating side forces on a yawed slender body.[23] To simplify the theoretical evaluation of the sectional added mass and damping coefficients, an approximate method was introduced.[20]. This method evaluates the damping coefficient from the amplitude of the radiating waves at the far field and invokes the Kramers-Kronig relations to obtain the added mass coefficients. Improvements of the earlier theoretical motion prediction method[18] is made by introducing the effect of the surge coupling into the pitch wave-exciting moment and by modifying the cross-flow drag coefficient in the evaluation of viscous damping.[25] Also, additional improvements are made by introducing more sophisticated empirical formulae for the viscous damping obtained from various sources of experimental data.[26]

The necessity for improving the prediction of motion of SWATH ships in stern waves is pointed out. In stern waves, a SWATH ship can experience a largely coupled motion in all six degrees of freedom. The correct method of predicting the motion of a SWATH ship under such a condition may be found from a time-domain approach.

The overview of SWATH ship maneuvering is fairly limited in its scope because of narrowly focused previous investigations on turning characteristics at high speeds. The strong directional stability contributed by the long struts makes the turning of a SWATH ship very difficult at high speeds. Hence, the past investigations concentrated on finding ways to improve the turning characteristics at high speeds. The hydrodynamic coefficients involved in predicting the radius of turning are mostly obtained by captive model experiments. From these experiments the most significant nonlinear effects on hydrodynamic coefficients were found to be contributed by the free-surface effects. It was reported that the turning radius of SWATH ships is reasonably well predicted by time-domain simulations.[32] The current efforts in improving high-speed turning concern reducing the directional stability by shifting the struts toward the bow, by shifting the rudder position behind the propeller, and by banking the ship while turning with fin controls.

The SWATH concept is one of the advanced concepts for marine vehicles. Compared to earlier concepts such as hydrofoil craft and air-cushion vehicles, the history of the SWATH concept development is not very long, and, as a result, we witness very little activity in the exploration of this concept except for the Japanese efforts leading to the oceanographic support ship Kayo. There is no doubt of the potential applicability of a SWATH ship for certain marine operations requiring a stable platform in rough seas. To convince shipowners to venture into this new hull concept is a difficult task remaining for SWATH enthusiasts. Most of the critical hydrodynamic questions associated with SWATH ships have been answered. The remaining core concerns to be overcome are assurances of structural integrity for the ship's safety and survivability and reasonable construction costs. The overview presented here is limited to SWATH hydrodynamics, mainly based on a research viewpoint. Readers who are more interested in the design aspects of SWATH should see Reference 1 as a starting point. It is hoped that this overview will provide some guidance to those who will be engaged in SWATH hydrodynamic research in the future.

Biography

Dr. Lee is a scientific officer in the Fluid Mechanics Program at the Office of Naval Research. His research interests and publications are in the field of hydrodynamics and in particular ship motion, stability and maneuverability. Before joining ONR, Dr. Lee was a research scientist at the David Taylor Naval Research Development Center for 16 years.

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A PRODUCTION RULE SYSTEM FOR MESSAGE SUMMARIZATION*

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The Navy's future message systems will perform many tasks, such as message dissemination and retrieval, that require computer interpretation of message content. At the Naval Research Laboratory with support from the Office of Naval Research, and the Office of Naval Technology the authors have built an experimental system that employs techniques of computational linguistics and artifical intelligence to extract information from Navy messages and perform message routing and summarization. The long-term goal of this work is to develop capabilities that will enable systems to handle a broad spectrum of military messages, from highly formatted messages with little English description to messages consisting entirely of English narrative. For the initial investigation described in the paper below, the research has been limited to the problem of Navy operational reports describing equipment failures; these messages obey strict formatting conventions but also contain important narrative descriptions. However, the message processing system can be extended to other message types with minimal modifications. Currently the system is being extended to cover tactical messages as well as equipment failure messages. In addition, the authors are investigating in some detail specific types of knowledge that are required for summarization. In conjunction with this research, they are designing a summarization system that will derive both a general purpose summary of a particular message, and a summary tailored for users' particular goals.

The system could be a money and time saver for the Navy. Because of improved routing only the necessary people would get the message, eliminating those many messages which, today, go to people who do not need them. Also, only a summary might suffice for most people; they can ask for a complete messages if it is important to know the details. The artificial intelligence language processes described in the article are established techniques; however, applying them successfully for summarization is a first in the field.

Editor

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Introduction

In summarizing a message, it is necessary to access knowledge about linguistic relations, subject matter knowledge about the domain of discourse, and knowledge about the user's goals for the summary. This paper investigates the feasibility of integrating these knowledge sources by using computational linguistic and expert system techniques to generate one-line summaries from the narrative content of a class of Navy messages. For deriving a knowledge representation of the narrative content, we have adapted an approach developed by Sager *et al*. at New York University. This approach, called *information formatting,* uses an explicit grammar of English and a classification of the semantic relationships within the domain to derive a tabular representation of the information in a message narrative. A production system, written in OPS5, then interprets the information in the table and automatically generates a summary line. The use of a production rule system provides insight into the mechanisms of summarization. A comparison of computer-generated summaries with those obtained manually showed good agreement, indicating that it is possible to automatically process message narrative and generate appropriate, and ultimately useful, summaries.

Behavior modeled in expert systems has generally been held distinct from that modeled in natural language understanding systems. Attempts at practical expert systems have been directed toward design,[1] diagnosis,[2] and interpretation,[3] among others. Practical systems for natural language understanding have concentrated largely on database interfaces[4,5,6] and database creation.[7] In this paper we investigate the feasibility of integrating techniques from computational linguistics and expert system technology to summarize a set of Navy equipment failure messages called CASREPs (casualty reports). A natural language analysis procedure automatically generates a tabular representation of the information contained in message narrative. A production rule system then interprets the tabular representation and identifies a clause that is appropriate as a message summary. We have chosen to use a production system for a natural language application because it facilitates understanding and modification of the system. More important for research purposes, a production system makes the operations involved in summarization explicit and, thus, can provide insight into the general problem of summarization.

Summarization can be approached at several different levels. Typically, strategies for summarization have taken a single-level approach. Summaries of stories have been derived at the high level of conceptual representation. Structural features of a graph reveal the central concepts of a story.[8] Goal-directed summaries have also been investigated in some detail.[9] We, on the other hand, have taken a multilevel approach, incorporating several sources of knowledge in the linguistic analysis and production rule system. This permits us to investigate not only the requirements of individual knowledge sources, but also their interactions.

Natural Language Processing

Each CASREP message contains a set of structured (i.e. *pro forma)* fields and a narrative describing the equipment failures. These narratives typically consist of two to twelve sentences and sentence fragments.

The central task of narrative analysis is the extraction and representation of information contained in narrative portions of a message. This task is difficult because the structure of the information, and often much of the information itself, is implicit in the narrative. Several formalisms, such as *scripts* and *frames*, have been developed to describe such information and have been used in text analysis.[10,11] We are using an approach called *information formatting* that was developed at New York University for the representation of the information in medical narratives.[7,12] In simple terms, an information format is a large table, with one column for each type of information that can occur in a class of texts and one row for each sentence of clause in the text. It is derived through a distributional analysis of sample texts. The narrative is automatically transformed into a series of entries in the information format table. This procedure involves three stages of processing: (1) parsing, (2) syntactic regularization, and (3) mapping into the information format.

First the text sentences are parsed using a top-down parser and the broad-coverage Linguistic String Project English grammar[13] extended to handle the sentence fragments and special sublanguage constructions (e.g. date expressions, such as *NLT 292300 Z SEP 82)* that appear in these messages. The grammar consists of a set of context-free definitions augmented by grammatical restrictions. It also uses a Navy sublanguage lexicon that classifies words according to their major parts of speech (e.g. noun, verb, adjective), as well as their special subfield classes (e.g. PART, FUNCTION, SIGNAL), and certain English syntactic subclasses. The parsing procedure identifies the grammatical relations that hold among parts of the sentence, principally subject-verb-object relations and modifier-host relations.

The syntactic regularization component utilizes the same machinery as the parser, augmented by standard transformational operations. The principal function of the regularization component is to reduce the variety of syntactic structures and word forms to be processed, without altering the information content of the sentences, thereby simplifying the subsequent mapping into the information format. Regularization includes: (1) standardization into subject-verb-object word order, e.g. passive to active; (2) expansion of conjoined phrases into conjoined assertions; (3) reduction of words to "canonical form" plus information marker(s); (4) filling in of certain omitted or reduced forms of information.

The third stage of processing moves the phrases in the syntactically regularized parse trees into their appropriate format columns. It involves two steps: (1) identifying connectives and (2) mapping into the information format. A connective word indicates a causal, conjunctional, or time relation between the two clauses it connects. The connective is mapped into the CONNective column of the format table; arguments of the connective are mapped into separate format rows, and their words are mapped into the appropriate format columns. The mapping process is controlled in a large part by the sublanguage (semantic) word classes associated with each word in the lexicon. In general, the formatting procedure is straightforward because most word classes are in a one-to-one correspondence with a particular format column.

The production system for message summarization operates on the information format that is generated for each message.

Production Rule System for Summarization

We have implemented prototype knowledge bases for two application areas: dissemination and summary generation.[14] While the dissemination application relies on information obtained from both *pro forma* and narrative data sets of a message, summary generation is based entirely on information contained in narrative portions of the messages. Such summaries, which up to now have been generated by hand, are used to detect patterns of failure for particular types of equipment. This failure information is crucial to decision-makers who procure equipment for new and existing ships. Typically, the manually derived summary consists of a single clause, extracted from the sentences of text. Only rarely is a summary generated from material not explicitly stated in the narrative. The single line summary results in a five- to ten-fold reduction of material. Clearly, the sharp reduction in reading material can ease the decisionmaking process, provided that the key information from the report regularly finds its way into the summary.

Our current system consists of a set of productions, implemented in a Lisp-based version of the OPS5 production system programming language. OPS5 permits the assignment of attributes and numerical values, or scores, to the working memory elements, and our system takes advantage of this. Productions operate on an initial database of working memory elements that includes data from the information formats and identify the crucial clause that will be used for the summary. Criteria for production rules are based on the manual summarization that is currently performed.

Several types of knowledge are required for message summarization. Knowledge of the possible relationships is reflected in the initial choice of what fields are available in the format system devised for the domain. This is represented by the columns of each message's information format table. Additional domain knowledge and knowledge of the nature of the application are embodied in the production rules of the expert system.

Each production rule incorporates one of three different types of knowledge necessary for summarization. The first type reflects an understanding of the subject matter of the equipment failure reports. These production rules assign semantic attributes or categories to working memory elements by explicitly specifying these words in a list in the rule. For example, the working memory element containing the word *inhibit* is assigned a category IMPAIR. Elements indicating a bad status (e.g. broken, corroded, failure, malfunction, etc.) have the category BAD assigned and so on. Other category assignment rules are concerned with level of generality, flagging equipment failures at the assembly level, and not at the more detailed part or more general system level, since assemblies are most important to the summary.

Other production rules are based on general principles of summarization, and these rules are typically inferencing rules. These identify causal relationships among working memory elements and may add information to the data base in the form of new working elements. We will see an example of this type below.

Finally, the end use that will be made of the summaries is also a guiding factor in some of the productions. To guide future equipment specification and procurement, one must know not only what went wrong and how often, but also why. Format rows that contain such information are identified as being more important by having the score of the row boosted. For example, causality is important to the summaries. Once a causal relationship is identified, the row specifying the 'cause' has its score boosted. Taken together, the productions are attentive to such matters as malfunction, causality, investigative action, uncertainty, and level of generality. In addition, the system has rules excluding from summaries format rows containing very general statements. For instance, universal quantification and mention of the top level in a *part-of* tree betray a clause that is too general for a summary line.

Summarization proceeds in three stages: (i) inferencing, (ii) scoring the format rows for their importance, and (iii) selection of the appropriate format row as the summary. First, inferences are drawn by a set of production rules. For example, the presence of one of the words in the IMPAIR category triggers an inferencing rule. If part 1 impairs part 2, we can infer that part 1 causes part 2 to be bad, and we can also infer that part 1 is bad. A set of production rules, summarized as rules (1) and (2) below, operate on the format lines to draw such inferences. The production rule in (1) infers that the second argument (part 2) of CONN is bad.

(1) if both (a) CONN contains an 'impair' word
and (b) the STATUS column of the 2nd argument of CONN [the connective] is empty
then both (c) fill the STATUS column of the 2nd argument with 'bad'
and (d) assign the word in CONN the attribute 'cause'.

For example, in Table 1, the connective word *inhibit* has been mapped by the formatting procedure into the CONN column, connecting two format rows, its first argument, *APC-PCC circuit,* a PART, and its second, *PA driver,* also a PART. Both rows have the PART column of the format filled.

Table 1

Simplified information format for the sentence: APC-PCC is inhibiting PA driver

Conn	Part	Status
	APC-PPC circuit	
inhibit		
	PA driver	

By a previous production rule, the *inhibit* has been categorized in the class of impairment verbs. Rule (1) replaces impairment by a format version of "cause to be bad." Specifically, the verb *inhibit* in the CONN column gets assigned the attribute 'cause'. Since the STATUS column of the second argument is empty, *bad* is inserted into that STATUS column. Thus, it is inferred that the PA driver is bad because it has been impaired.

Another production rule, summarized as (2), infers that the STATUS column of the first argument (part 1) of CONN is also 'bad' and inserts *bad* into the STATUS column since it has caused something else to be bad.

(2) if both (a) CONN has the attribute 'cause'
and (b) the STATUS of the first argument of CONN is empty
and (c) the STATUS of the second argument of CONN is 'bad'
then (d) insert 'bad' into the empty STATUS column.

In our example Table 1, 'inhibit' in the CONNective column has been assigned the attribute 'cause', and the STATUS of *APC-PPC circuit* is empty. The STATUS of the *PA driver* contains 'bad', by rule (1). So 'bad' is inserted into the STATUS column of the first argument, yielding *APC-PCC circuit bad.*

The second stage of the summarization system rates the format rows for their importance to the summary. When it comes time to score the various formats to determine the most appropriate one for the summary, since "bad" is a member of the class of words signifying malfunction, it will cause both arguments of *inhibit* to be promoted in importance. An additional scoring increment will accrue to the first argument but not the second because it is a cause rather than an effect. Another rule increments a format row referring to an assembly (a mid-level component), since such a format is more revealing than a format containing a statement about a whole unit or an individual part (such as a transistor). For example, *circuit,* the head of the PART phrase of the first argument is identified as belonging to a class of components at the assembly level. As a result, the score of the row containing *APC-PPC circuit bad* is incremented again.

The third and final stage of summarization is to select the format row or rows with the highest rating. As a result of the various production rule actions, the winning format row is "PART: *APC-PCC circuit;* STATUS: *bad.*" While other format rows may also have positive scores, only the row with the highest score is selected. The system does not preclude selecting several format rows if they have equally high scores.

Implementation

The LSP parser is implemented in about 15,000 lines of Fortran 77 code. The parser runs on a DEC VAX 11/780 under the UNIX and VMS operating systems and requires 2 megabytes of virtual memory when executing, of which two-thirds is list space for holding the grammar, dictionary entries, etc. The English grammar, regularization component, and information formatting components are written in Restriction Language, a special language developed for writing natural language grammars.[15] The dissemination and summary generation applications programs are written using the OPS5 production system. In total, there are 63 production rules in the applications programs.

Experimental Results

The purpose of this experiment was to test the feasibility of automatically summarizing narrative text in Navy equipment failure messages using techniques of computational linguistics and artificial intelligence. Computer-generated results were compared to those obtained by manual summarization procedures to evaluate the performance of the system. The manual summaries were prepared independently of our experiment by experts who routinely summarize such messages.

Since both the natural language processing components and the applications programs were under development while this experiment was being carried out, 12 casualty reports were used for debugging the programs. Subsequently, 12 other reports were used for the computer-human comparison. For an appropriate summary line to be generated, it is necessary that 100% of the sentences in a text be processed correctly by the natural language procedures. The natural language analysis procedures processed 100% of the sentences contained in the documents; this percentage includes 9 sentences (25%) that were paraphrased and rerun because they were not correctly processed on their first run. Paraphrasing these sentences brought the total number of sentences from 36 to 38. The sentences were paraphrased to expedite processing since the major purpose of running the messages was to investigate methods of summarization and not the performance of the natural language processing system. 70 format lines were generated from 38 sentences in 12 messages.

The computer-generated results of the summarization program compare favorably to those obtained manually. Figure 1 shows a comparison of the two sets of results for the 12 test documents. The discrepancies between the computer-generated results and the manual results are sumarrized in Figure 2.

Figure 1

Comparison of machine and manual summary results

Doc.	Machine # format rows	Manual # sentences	Agreement Machine/Manual
1.	1	1	1/1
2.	1	1	1/1
3.	1	1	1/1
4.	1	1	0/1
5.	1	2	1/2
6.	2	1	1/1
7.	1	1	1/1
8.	2	1	1/1
9.	1	1	0/1
10.	1	2	1/2
11.	1	1	1/1
12.	1	2	1/2
	14	15	10/15

Figure 2

Analysis of machine and manual summary results

#	Discrepancy	Doc.
1	word not included in category list	4
1	second manual summary not about bad-status	5
1	second manual summary not in narrative text	10
2	different summaries generated	9, 12

Agreement between machine and manual summaries is obtained when the text contained in the format row selected by the automatic procedure agrees with the text in the manually generated sentences. The discrepancies in the *Agreement* column of Figure 1, as specified in Figure 2, can be categorized as follows. One (message 4) is the result of a failure to enter a word on a category list in the production rule system. As a result, the word was not categorized as a BAD-STATUS, and the score of its format row was not correspondingly boosted. Two errors (messages 5 and 10) were due to the program selecting one format line, although manual generation produced two sentences. In the first case (message 5), the additional text in the manual summary did not concern a description of a bad status. Rather it was a description of a good function status (i.e. *Drive shaft was found to rotate freely.).* In message 10, the extra manual summary consisted entirely of text that was not contained in the message narrative. Our system does not automatically generate text, nor could it have made the inferences necessary to do so. In both these cases, however, the line that the program selected agreed with one of the manual summaries.

The most significant discrepancies (a total of 2) were caused by the system selecting more specific causal information than was indicated in the manual summary. In message 9, which contains the sentence *Loss of lube oil pressure when start air compressor engaged for operation is due to wiped bearing* the manual summary line generated was *Loss of LO pressure,* while the system selected the more specific information that indicated the cause of the casualty, i.e. *wiped bearing*. Similarly, in message 12, the system selected the line *low output air pressure* from the assertion *low output air pressure resulting in slow gas turbine starts* since it indicated a cause. The program did not identify the second part of the manual summary because its score was not as high as that of the cause *low output air pressure*. However, its score was the second highest for that message. This suggests that it may be more appropriate to select all the summary lines in some kind of score window rather than only those lines that have the highest score.

In two cases (messages 6 and 8), the system generated two summary texts, although the manual summary consisted of only one sentence. Two summary lines were selected because both had equally high scores. Nonetheless, one of the two summaries was also the manual summary.

In conclusion, the summarization system was able to identify the same summary line as the manual summary 10/15 times (66.6%). For 10 out of 12 messages, the summarization system selected at least one of the same summary lines as the manual generation produced. For two messages, the system was not able to match the manual summary, in one case, because the crucial status word was not in the appropriate list in the production rule system and, in a second case, because the automatic procedure identified the more specific causal agent.

Conclusion

The results of our work are quite promising and represent a successful first step towards demonstrating the feasibility of integrating computational linguistic and expert system techniques. We recognize that much remains to be done before we have an operational system. Our work up to now has pointed to several areas that require further development.

Refinement of the semantic representation. Our current information format was developed from a limited corpus of 38 messages, including those in the test set. Even within that corpus not all types of information have been captured - for example, modes of operation, relations between parts and signals, and relations and actions involving more than one part. Some of this information has been incorporated into the expert system. For example, part-assembly-system information has been encoded as a categorization rule. However it is clear that enrichment of our semantic representation is a high priority. We are considering the use of some external knowledge sources to obtain this information. One possibility is to access machine-readable listings of Navy equipment.

Intersentential processing. Our current implementation does almost no intersentential processing. This has proved marginally adequate for our current applications, but clearly needs to be remedied in the long run. One aspect of this processing is the capture of information that is implicit in the text. This includes missing arguments (subject and objects of verbs) and anaphors (e.g. pronouns) that can be reconstructed from prior discourse (earlier format lines); such processing is part of the information formatting procedure for medical records.[16] It should also include reconstruction of some of the implicit causal connections. The reconstruction of the connections will require substantial domain knowledge, of equipment-part and equipment-function relations, as well as "scriptal" knowledge of typical event sequences (e.g. failure - diagnosis - repair).

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Biographies

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Research Notes

National Transonic Facility at Langley Research Center

A jointly-sponsored research project of the Office of Naval Research, David Taylor Naval Ship Research Development Center and National Aeronautics and Space Administra tion is being conducted at DTNSRDC and NASA's Langley Research Center. The objective of the research is to investigate the scale effect of the flow around a submerged slender body by using the newly built National Transonic Facility (NTF) at the Langly Research Center.

This facility was built to extend the wind-tunnel capability in generating the Reynolds number (Re) up to $2X10^9$. The Reynolds number is an important physical parameter in fluid mechanics representing the ratio of the fluid inertia force to the viscous force i.e. UL/ν where U is the flow velocity, L the characteristic length of body, and ν the kinematic viscosity. In general, a smoothly attached laminar flow can be realized for a flow around a circular cylinder for $Re = 5X10^5$, and in the regime of $Re = 10^6$ the flow becomes turbulent. The Re for surface ships and submarines is typically in the range of $Re = 10^8$ to 10^9. The NTF is designed to reduce the kinematic viscosity ν by cooling the air flow to the temperature of 78° K by spraying liquid-nitrogen (LN_2) into the tunnel air flow and by increasing the tunnel pressure up to 8.8 times the atmospheric pressure. The NTF is the largest cryogenic wind tunnel in the world and represents one of the greatest engineering accomplishments in the U.S. The conventional pressurized wind tunnel can generate highest Re only up to 10^8.

The joint project will be the first experiment for the Navy in which the model will be subject to a full-scale flow condition. The flow velocities in the stern region of the model will be obtained in the range of $Re = 10^7$ to 10^9, and the effect of Re on the stern flow, which has a significant effect on propulsor inflow, will be analyzed. Undoubtedly, if the experiment is successful, it will generate valuable fundamental scientific data, paving a way to bridge the critical gap in extrapolating the hydrodynamic results obtained from model experiments to full-scale conditions.

(Choung M. Lee, ONR)

Micromechanics Theory Provides Guidance for Composites Design

Recent advances in understanding failure mechanisms and in applying fracture mechanics in uniaxially reinforced glass-ceramic composites permit, for the first time, the design of composites with optimum mechanical properties. The key observation is the frictional forces exerted by the fibers, on the matrix of the ceramic composites, oppose the opening of cracks in the matrix. A closely coordinated experimental and theoretical program by researchers at the University of California and Rockwell Science Center, sponsored by The Office of Naval Research, combined mechanistic determinations and theoretical continuum analysis to define transitions between several failure mechanisms, provide strength/crack size relations for each mechanism, and relate strength and/or toughness to microstructural properties of the composite. The analytical expressions are summarized in the form of a failure mechanism map which has been used very successfully in homogeneous materials. The ONR program results in the first application of this useful mapping concept in complex composites. With this technique, the influence of microstructural properties on strength, toughness and transitions between failure mechanisms can be readily assessed from analytical expressions and thus provide guidance to the materials scientist in designing composite microstructures for optimum mechanical properties.

(S.G. Fishman, ONR)

Successful Operation of DoD Beam Line at Stanford Synchrotron Radiation Laboratory

In 1982 an agreement was made between the Office of Naval Research, the Defense Advanced Research Projects Agency, the Army Research Office, and the Air Force Office of Scientific Research to provide funds at Stanford University for designing and constructing a new beam line at the Stanford Synchrotron Radiation Laboratory (SSRL). The novelty of this new line was to incorporate undulator magnets in the beam, to concentrate the light intensity into wavelength ranges determined by the properties of the undulators. Subsequently, a set of four different undulators was considered, which would be interchangeable and thus give rise to operation in different ranges of photon energy. In the beginning, the use of underlators in this system was untested. Subsequently, the French and the Russians have proven that undulators do work, but in each case intensities were low due to improper focussing of the beams in the electron storage rings. (The Russian experiment is frequently referred to as the "Siberian Snake.")

Recently, the first radiation from the SSRL facility was obtained using the high energy undulator. Extremely high beam intensities were found. Rough estimates to date suggest that in the range of photon energy selected, that this source will be at least one hundred times more intense than any other one in existence. The whole operation was brought on line at the proposed cost and only a few months beyond schedule. Other research components, mirrors, monochromators, experimental chambers are installed and are now being tested.

(Larry R. Cooper, ONR)

NCEL Moves Forward With Offshore Platform Experiment

Mr. David R. Shields and Dr. William J. Nordell at the Naval Civil Engineering Laboratory (NCEL) are getting ready to deploy a large, moored, prism-shaped, semisubmersible platform as part of a Motion Measurement Experiment (MME). The steel platform is approximately 15 m. on a side and 10 m. high and made of tubular members. Platforms of this size are considered appropriate for use in offshore Tactical Air Combat Training Systems (TACTS) for supporting electronic tracking and data relay equipment. The purpose of the MME is to gather data on the environment (forcing) and platform motions (response) for use in validating computer models that will be used for actual TACTS design and installations. This experiment will be conducted during mid-1986 off the Southern California coast. The MME platform is also of interest as a data gathering system for other engineering and oceanographic tasks. Since the behavior of the platform will be well understood and precisely modelled, the opportunity will exist for making high resolution measurements at sea from a platform whose motions can be eliminated from the data.

(E. A. Silva, ONR)

A Promising New Immunological Adjuvant Investigated

A few years ago an immunologist at the Scripps Clinic, Dr. Michael Goodman, observed that minor chemical modifications of the 8 position of the purine guanosine could cause the molecule to greatly stimulate B lymphocytes, the cells responsible for antibody production. The most potent form of the molecule is 8-mercaptoguanosine, where a sulfur atom replaces a hydrogen normally found in guanosine. This observation has been developed with ONR funding by Dr. James Mond at the Uniformed Services University to look at both the mechanism of action and possible applications of 8-mercaptoguanosine (8-MG) as an immunological adjuvant for vaccines. Guanosine plays many significant roles in cells, including serving as a component of the nucleic acids. Mond demonstrated that 8-MG, following phosphorylation, was incorporated into RNA but not DNA, lessening the likelihood that it would be mutagenic for cells. Its association with a class of regulatory proteins that modulate membrane signals, called G-proteins because of their dependence on phosphorylated guanosine, is under investigation. With regard to immune function, 8-MG was shown to potentiate in mice the formation of protective antibody to a bacterial polysaccharide antigen, pneumococcal p-14, to which mice do not ordinarily respond. It also stimulated antibody formation in immature mice and genetically deficient mice, suggesting that it replaces certain T lymphocyte functions. Finally, it was shown to enhance monoclonal antibody clone production 10-1000 fold as a consequence of enhancing the rate of formation of productive clones. The latter observation will be considered for patenting. While 8-MG may prove to be too potent (toxic) for human use, its applications in monoclonal technology and its use for investigation of the role of guanosine in immune regulation represent significant outcomes of this ONR task.

(J. A. Majde, ONR)

l/f Noise in Metal Oxide Semiconductor Feild Effect Transistor (MOSFETS)

There have been many efforts over the past 20-25 years to understand the origin of the voltage noise in semiconductor MOS devices which has an amplitude which varies inversely with the frequency - "l/f noise." More recently, focus was placed on determining the validity of one of two proposed models, the carrier number fluctuation model or the mobility fluctuation mode. There are recent results from Office of Naval Research supported work by Professor T. Hsaing at the University of Rochester, in which the noise in p-channel MOSFETs is shown to be stationary (constant in time), Gaussian, and uncorrelated in space, which are used to expand on a simple model proposed by McWhorter to explain the data. In the McWhorter model, electrons are randomly captured and released, by defects or trapping centers in the semiconductor under the influence of a low electric field. In the new model, the traps are assumed to have an energy dependence and a depth dependence at the Si-Si0, interface. Trapping times are partially explained as due to different probabilities for tunneling depending on the distance of the trap from the interface.

The model is based on a charge carrier number fluctuation assumption, with a distribution of time constants in the fluctuation. These same processes can then be put into a mobility calculation to compute mobility fluctuations that arise from traps influencing the transistor conductance through a scattering mechanism.

These results produce a model which greatly clarifies the picture of noise in MOSFETs.

(Larry R. Cooper, ONR)

NRL Rocket Experiment Studies Comet Halley

Shortly after Comet Halley made its closest approach to the sun on February 9, the Naval Research Laboratory (NRL) launched a sounding rocket to obtain far-ultraviolet (far-UV) images of the comet. These far-UV images will be analyzed by NRL scientists to determine the comet's chemical composition.

Dr. Robert McCoy, NRL's principal investigator in the project, reports that the experiment, which will fly aboard a NASA sounding rocket, represents one of only two U.S. rocket observations planned for the 1986 return of Comet Halley.

Although several other countries have space probes to observe Comet Halley, the instrumentation on the NRL rocket payload provided a unique opportunity to image the entire coma (the luminous halo surrounding the nucleus of a comet) with high spatial resolution at a number of wavelengths in the far-UV.

The NRL rocket payload consisted of two far-UV electrographic Schmidt cameras, which are similar to those developed by NRL's Dr. George Carruthers and flown on sounding rockets and Skylab, and operated from the surface of the moon during the Apollo 16 mission. (electrographic cameras convert UV images into electrons and store them on electron-sensitive film.)

One of the far-UV cameras images the atomic hydrogen Lyman-alpha emissions from the comet's coma at a wavelength of 121.6 nanometers (nm) (1 nanometer equals one billionth of a meter) to determine the production rate of hydrogen from H_20 and OH (parent molecules of atomic hydrogen). This camera, which pointed out from the rocket's side, had a 20-degree field of view, and obtained direct images of the comet at 1-, 3-, and 10-second intervals.

A second camera, pointed at a diffraction grating inside the rocket, obtained simultaneous images of the coma at wavelengths from 125 to 180 nm. Objectives spectrograms obtained by this detected atomic oxygen, carbon, and ions such as $CO+$. This camera has a 15-degree field of view and took exposures with 3-, 10-, and 30-second exposure times.

The NRL rocket, which was launched in late February from White Sands Missile Range, New Mexico, reached an apogee (highest altitude) of 192 miles. Although this altitude is insignificant when compared with the distance between the earth and Comet Halley, it is sufficient to lift the cameras above the UV-absorbing layers of the earth's atmosphere.

The entire flight lasted about 10 minutes, yielding 5 minutes observation time before the payload parachuted onto the New Mexico desert.

(Robert McCoy, NRL)

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