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International Cooperative Study on Antarctic Science: Geology and Biology

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제 출 문

해양연구소 소장 귀하

본 보고서를 "남극 및 주변해역 공동연구"의 보고서로 제출합니다.

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우리나라는 1988년 2월 남극반도 북단 킹·조지섬에 상주기지를 완공하고 매년 정기적인 탐사대를 파견함으로써 본격적인 남극과학 연구의 토대를 마련하였다. 남극과학연구의 정치적 틀을 제공하고 있는 남극조약은 남극연구의 정보교환 및 국제공동협력을 명문화하고 있으므로 협의당사국(ATCP) 지위 취득을 목적에 둔 우리나라로서는 이 분야에 대한 활동의 중요성을 간과할 수 있다. 남극과학연구의 최신정보 및 전문지식을 확보하기 위해 국제사회에서 활발한 남극과학연구활동 수행국으로 알려진 미국, 영국, 호주 및 선도적 제3세계 국가 학자와의 공동연구는 지속적으로 수행되어야 할 것이다.

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Ⅳ. 연구개발 결과

남극 및 그 주변해역에 대해 우리나라에서 처음 수행된 이번 국제공동연구는 모두 10개국에서 15개의 주제가 발표되었다. 주요연구주제는 남극빙하, 지질, 생물등 3개 분야로 남극빙하의 생성과 변화요인, 남극의 지질 및 지체구조, 스코시아해의 어류 개체구조 및 영양분포 등이 토론되었다.

국제회의 형식을 통해 수행된 이번 남극 및 주변해역에 대한 공동연구중 특기할만한 것은 우리나라 세종기지 앞 바다인 브랜스필드 해협내 킹·조지분지에서의 석유부존가능성에 대한 발표이다. 이 결과는 1985년 11월 서독의 쇄빙선 폴라스턴호에 승선하여 조사에 참여했던 우리나라 연구자에 의해 확인되었는데 킹·조지분지에서의 유징발견은 이제까지 간접적인 자료에 근거했던 남극해역에서의 석유부존가능성을 직접적인 자료에 의해 최초로 발표했다는 점에서 매우 의의가 크다.

세종기지를 근거지로 우리나라도 남극해역에 대한 석유 및 자원탐사를 시작해야 함이 2천년대를 맞이하는 우리의 자세라고 생각할 때 우선 세종기지에서 비교적 가까우며 유징이 발견된 킹·조지분지에서 보다 체계적인 연구를 수행해 석유 및 자원탐사에 관한 지식을 축적하고 이 지식을 바탕으로 남극 본대륙지역 – 즉, 웨델해와 로스해 – 로 본격적인 탐사에 들어가야 할 것이 적극 요망된다.

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Preface

Antarctica, which comprises one-tenth of the earth's land surface, is one of the world's last great natural wilderness. It is a continent almost entirely covered by ice and snow, so hostile and remote that it has no permanent inhabitants and still receives relatively few visitors. Apart from the handful of research stations, Antarctica remains virtually untouched by human activities.

Although Antarctica is a frozen continent, its scientific value within the earth's geosphere-biosphere system cannot be overemphasized. For instance, the mass balance and dynamics of the large Antarctic ice sheet, and its paleoclimate records recovered from deep ice cores, are important indicators of past and present global climatic changes. In addition, it is in the Antarctic region that the sun-earth interactions are most intense. Hence, science has been a constant presence in the continent from the time of the first explorers.

Prompted by scientific interest, Korea has recently established a permanent Antarctic research station at the Barton Peninsula, King George Island of the South Shetlands Archipelago. With an official inauguration of the station in February 1988, Korea had devoted its scientific research efforts to include geology, biology and other related fields.

This volume is based upon the First International Symposium on Antarctic Science: Geology and Biology, held at Seoul, Korea, on November 4-5, 1988. The symposium was organized by the Korea Ocean Research and Development Institute under the joint sponsorship of the Korean National Committee on Antanctic Research. As its title indicates, the volume tries to examine the recent research outcome on Antarctic geology and biology-the two most important Antarctic disciplines.

The intellectual debts of this volume are to the many speakers and participants of the symposium who collectively contributed to the awareness and understanding of Antarctica. The editors are particularly appreciative to Mr. Robert B. Thomson, who under took a remarkable job of keynote speech at the symposium.

Further thanks go to the Ministry of Science & Technology and the Korea Science & Engineering Foundation for their financial support for me symposium and other programs of the Korea Ocean Research & Development Institute.

Last, but not least, the editors wish to express their gratitude to Mr. Moon Young Choe and Miss Eun Jin Choi of the Polar Research Division, KORDI. Without their dedication, this work would not have been completed on time.

Editors
January 1989

Part I. Introduction

Opening Remarks

Hyung Tack Huh

Ladies and gentlemen;

On behalf of the Korea Ocean Research and Development Institute and the Organizing Committee of this Symposium, I would like to welcome all of you, participants and observers, to the First International Symposium on Antarctic Science. You are all distinguished scholars, and each one of you represents the best in your profession. More importantly, you have been engaged for many years in a poineering effort to accelerate research in the area which is relatively less known to us but promises to be the major source of resouirces for the future generations.

Without doubt, Antarctica is one of the world's last great natural wilderness. Althouigh the continent is almost entirely covered by ice and snow, its scientific value within the earth's geosphere-biosphere system cannot be overemphasized. For instance, the mass balance and dynamics of the large Antarctic ice sheet, and its paleoclimate records recovered from deep ice cores are invaluable indicators of the past and present global climatic changes. In addition, it is in the Antarctic region that the sun-earth interactions are most intense. Hence, science has been a constant presence in the continent since the time of the first explorers.

As you may know well, Korea has recently established a permanent Antarctic research station at the Barton Peninsula, King George Island of the South Shetlands Archipelago. With an official inauguration of the station in February 1988, Korea has been accelerating scientific research efforts to include geology, geophysics, oceanography, biology and other related fields. It is therefore very timely and significant to hold an Antarctic symposium in Seoul, Korea. The purpose of this symposium is to review the recent research outcomes on polar geology and biology, the two most important Antarctic disciplines, thus providing an opportunity for scholars and experts to assess their current status at the global level.

I would like to take this opportunity to express our gratitude to the various organizations and individuals who helped make this meeting possible. First, I personally thank Dr. Robert Thomson for taking his time to come to this Symposium to give us a keynote speech. His experience and insight will certainly give us an idea on how to approach to the problems lying ahead of us. I also thank all the distinguished scholars from abroad and Korea for joining us in this endeaver.

We also owe much to the Korea National Academy of Sciences, especially to Dr. Bong Kyun Kim. We thank the National Academy of Science and Dr. Kim for their encouragement and support. The Ministry of Science and Technology, the Korea Science and Engineering Foundation and the Korean National Committee on Antarctic Research have supported us financially and in other ways for the realization of this symposium.

As I now declare the symposium open, I hope this gathering will be another meaningful contribution to the development of Antarctic Science.

Thank you.

Welcoming Address

Hak-Ze Chon

Professor Bong-Kyun Kim, Dr. Thomson, Dr. Quilty, Professor Yoshida, distinguished scholars and experts, ladies and gentlemen;

It is indeed a privilege and honor for me to make a welcoming address at the First International Symposium on Antarctic Science. From the bottom of my heart, I welcome all of you to this symposium.

On a personal note, as the President of Korea Advanced Institute of Science and Technology with which Korea Ocean Research and Development Institute is affiliated, I am deeply touched by the fact that the organizing committee, under the leadership of Dr. Hyung Tack Huh, has successfully organized this symposium. I am very much proud of and grateful to the organizing committee and the members of the committee.

I would also like to extend my special thanks to the foreign speakers and other participants for their hard work to contribute to the symposium. I firmly believe that without your contribution, this kind of international symposium on Antarctic science could not be organized successfully.

As all of you know well, through the conclusion of the Antarctic Treaty in 1959, the Antarctic continent was declared to be used exclusively for peaceful purposes and shall not become the scene or object of international discord. For over 29 years, the Treaty has proven an effective instrument in fulfilling the purposes for which it was concluded and in meeting new challenges.

For instance, the Antarctic Treaty has established a unique system for regulating and supervising scientific research which has reduced international conflict among nations and promoted large-scale cooperation, best typified by the various projects of the Scientific Committee on Antarctic Research. This cooperation as well as routine exchange of plans, research results and scientists is peculiar only to Antarctica in the world.

In addition, the Treaty has developed effective measures to protect Antarctica's extremely fragile environment, including the marine living resources of the continent. Since the early 1960s, more than one hundred sixty environmental protection recommendations have been adopted. These include the Agreed Measures for the Conservation of Antarctic Fauna and Flora, under which individual animals and birds can only be taken within very strict limits. Over twenty areas of particular ecological interest have been set aside as specially protected areas in which human activity is banned. This strong environmental concern has become a tradition of the Antarctic Treaty.

Another striking feature of the Treaty is its establishment of the principle of demilitarization. The Antarctic continent is the only area of the world where military installations and maneuvers are banned and all national activities are open to inspection by other countries. In short, the Antarctic Treaty is an extraordinary international arrangement without parallel anywhere in the world.

In recent years, for its potential resources and scientific importance, the Antarctic continent has become a fascinating geographical area. As a consequence, what we discuss today and what we are going to do in the future will have a significant implication in improving scientific knowledge about the continent. Viewed in this context, this international symposium on Antarctic science is just the thing we need and its importance can never be overemphasized.

As you may know well, Korea has recently established a permanent Antarctic research station at the Barton Peninsula, King George Island. Korea has become the 18th country that inaugurated a wintering-over station in the Antarctic. By actively engaging in scientific research in Antarctica, Korea would like to enlarge its polar-related knowledge and thus will contribute to the development of the Antarctic science.

Since we came here to talk about Antarctic science, I dare to say that we are now united in one on the Antarctic issue. We should contribute to widespread international support for the continuity of peaceful cooperation in Antarctic scientific research and for the environmental protection of the continent.

Once again, I sincerely welcome all of you and hope that your stay in Seoul will be both rewarding and enjoyable.

Thank you.

The Global Significance of Scientific Research in the Antarctic

Robert B. Thomson

The global significance of Antarctica was recognized before the Continent was discovered, for the ancient Greeks had believed that there must be a "Terra Australis Incognita" to balance the land masses of the Northern Hemisphere.

This possibility continued to intrigue man for centuries and "Terra Australis" first appeared on a world map by Orontius in 1531 and was copied by Mercator in 1583. But it was not until the 17th century that a real search began for this "Great South Land".

Years past and despite the great voyages of many famous explorers and navigators of the time no continent was sighted until early in the 19th century when Palmer, Bransfield, Weddell and Bellingshausen made claims of first sighting the "South Land". Then, in the 1840's the first landings in Antarctica were made and reports of this harsh and inhospitable land trickled out to the rest of the world.

Since that time Antarctica has seen two clearly definable eras of human intervention. First was the "Heroic Age" of Antarctic exploration which took place during the early part of this century when Scott, Amundsen, Shackleton, Mawson and then Byrd led the now famous expeditions that revealed the secrets and the fury of the Antarctic Continent to the rest of the world. Their expeditions encountered unbelievable hardships and some did not return.

The second era of man's involvement in Antarctica began in the late 1940's, expanding through the mid 1950's into the International Geophysical Year (IGY) of 1957/58 which itself was the first major world scientific effort that involved Antarctica. Previous international cooperative endeavours were the First and Second Polar Years of 1882-83 and 1932-33 which stressed the Arctic in their respective studies of geomagnetism, meteorology, and aurora phenomena with little attention given to the Southern Hemisphere. The IGY was in fact a new name given to the planned Third Polar Year but broadened in scope to include the whole globe. Selected priority areas were the Arctic, the tropics, outer space, and Antarctica which the international planning committee called "a region of almost unparalleled interest" whose "geophysical secrets" included the nature of the earth's magnetic field, the aurora Australis, and the ionosphere at this high latitude during the coming time of maximum sunspot activity as well as the impact of Antarctica's huge ice mass on global weather and the oceans.

The IGY activities in Antarctica provided a wealth of scientific information, especially that concerning our understanding of the solar/terrestrial relationship, the world's climate and the significant influence that Antarctica has on the rest of our globe. Also, during this period, international cooperation in science in Antarctica became firmly established and the major participating countries, in recognising the high value of the many past achievements to the scientific community, agreed to continue the IGY type of activity in the Antarctic for an indefinite period. They also agreed that other scientific disciplines not included in the range of IGY activities, such as biology and geology, should be encouraged in the future. The scientific era had begun!

Scientists working in many fields of research have come to recognize the real global significance of their research in Antarctica. But of course, Antarctica has long been an important part of this planet, therefore we need to look first at the science of our changing earth-its geology, to better define its relationship with the rest of our world.

The global importance of Antarctic geology stems from two principal aspects; firstly the relationship of the component parts of Antarctica to the other southern continents which has allowed Gondwanaland to be better reconstructed and the subsequent events, following the breakup of the super-continent some 200 million years ago, to be better traced, and secondly, (though related) the nature, age, and relationships of the various rock units of West Antarctica both to each other and to East Antarctica and the intervening Transantarctic Mountains.

The well respected South African geologist, Du Toit, in his book, Wandering Continents, stated, "The role of the Antarctic is a vital one. The shield of East Antarctica constitutes the 'key piece'—shaped surprisingly like Australia, only larger-around which with wonderful correspondences in outline, the remaining 'puzzle pieces' of Gondwanaland can, with remarkable precision, be fitted.

In fitting Antarctica into his Gondwanaland ressembly, Du Toit had to depend largely on the shape of the Continent because at that time, little was known of its geology. But, in recent years in addition to the "geodetic fit", geologists, paleontologists, and marine geophysicists working in the Antarctic, have aquired data making it possible to reconstruct the relative sequential positions of the Southern Hemisphere after spreading centres welled up under Gondwanaland and began to push the pieces apart. These spreading centres and the associated fracture zones are still active today and are the seat of much undersea activity in the Southern Hemisphere.

Studies of icebergs have also shown that not only do they influence global climate but they can also be indicators of climate change. It has been estimated that at any one time in the Southern Ocean, the total mass of icebergs is about one third of the mass of the pack ice at the time of its greater extent. Records indicate large anomalies in the incidence of icebergs and this has fundamental implications, since they suggest a potential capacity of the ice sheet to shed some of its capacity at an accelerated rate with subsequent global consequences.

The Antarctic Circumpolar Current is one of the major current systems of the world and is a unique feature of the world's oceans. It circles Antarctica from west to east driven by strong westerly winds. The Antarctic convergence, where surface temperature changes by several degrees in a few kilometres, is another important feature for here cold Antarctic water mixes with the warm water from the north. The resultant mixture is still sufficiently cold, and therefore dense, so that it sinks below the warm water and moves northwards in such large quantities sufficient to effect more than half the world's oceans.

The cold bottom-water which forms at the edge of the Continent is a product of a great mixing process as high salinity water, cooled by cold winds off the ice cap, becomes more dense and therefore sinks while the circumpolar deep water rises to the surface to replace the super-cooled water. The upward movement of this water creates a zone of upwelling, supplying to the surface water vast quantities of nutrients that contribute to the luxuriant growth of phytoplankton that is essential to sustaining the marine life of the Southern Ocean and surrounding areas. The phytoplankton, in turn, supports a correspondingly large crop of zooplankton, about half of which is krill, the primary food for whales and many species of seals. Krill is also consumed in substantial quantities by penguins, birds and at least thirty species of fish. More recently krill has become of interest as a possible source of high protein food for human consumption. Much more study has yet to be done to determine the amount of krill that could be taken without causing harm.

The life forms on the Continent are primitive, but nevertheless they do exist and persist in the most hostile environment we know on this planet. Much of the research carried out has been directed to detailed studies of the minute forms of life able to survive in the narrow life support zones offered by this inhospitable continent and so provide a much better understanding of how life itself has developed over the ages.

Over the years there have been many examples of where scientific research conducted in the Antarctic has alerted the rest of the world to developing problems that, if allowed to go unchecked, could have serious consequences for all. A recent example is the depletion of the ozone layer over Antarctica. Another of several years ago was the discovery of high concentrations of DDT in Antarctic fauna which led to most countries banning its use on farmlands.

There are many other examples of where Antarctic research has contributed to a better understanding of our world, but probably the most unusual one is in the collection of meteorities. Since 1969, when meteorites were first discovered in Antarctica by a Japanese expedition, the number collected in Antarctica far exceeds the total collected in all other parts of the world. Furthermore, the Antarctic meteorites have been remarkably well preserved in the cold, dry conditions of the ice-an important factor in the case of the most interesting group, the carbonaceous chrondites, which is easily contaminated.

Other major contributions from Antarctica have been made in human biology and medicine and the development of polar technology. Much of this has proven useful elsewhere especially in the planning and implementation of space programs.

The protection and preservation of the Antarctic environment continues to be a major concern and all countries are giving increasing attention to keeping human impact to an absolute minimum. One of the main reasons for this is to ensure that we do have an uncontaminated place from which to measure changes occurring in the rest of the world and thus continue to be able to bring attention to the international community when a global problem is identified from Antarctica.

I am confident that in the future, scientific research conducted in the Antarctic, will become increasingly important in recognising and solving global problems. Much of this will be concerned with the subjects I have discussed here and especially in all matters related to global climate change. New tools, most provided by the development and use of space technology, will vastly improve many of the present methods of observing, gathering, and distributing data. Also, the greater internationalisation of Antarctic research should lead to accelerating the flow of knowledge about Antarctica both within the Antarctic community and to the outside world as well. In our thoughts for the future we should however remember that global problems require global thinking and global strategy. If we also apply that philosophy when working in Antractica, then the global community will continue to benefit from our research activities there.

The geological mapping of Antarctica on a reconnaissance scale has largely been completed but because the Continent is almost 98 percent ice-covered, many aspects of Antarctic geology remain uncertain. There remain areas of "special concern" that require further detailed study, especially in coastal regions to allow careful comparison with the Gondwana sequences of other southern continents.

From the wide range of evidence gathered over the past three decdes, it is now generally agreed that Antarctica was indeed the southern anchor point of the super continent of Gondwanaland which also included South America, India, Africa, Australia and New Zealand in its great land mass. This research in Antarctica and the ocean floors of the Southern Ocean also confirmed the earlier theories of continental drift and plate tectonics. Not only is this important to our better understanding of the geological history of this planet, but also in assessing the possibility of Antarctica containing mineral resources.

Antarctica has however been more than a laboratory for the study of the evolution of the continents. During the IGY it was used most effectively as a platform to observe and record those phenomena associated with solar/terrestrial relationships. This same platform has facilitated the operation of some 40 observing stations for the past 30 years and much has been learnd about the Earth's upper atmosphere and outer space from these research programs. One of the earlier important discoveries was that not only is the magnetic field of the Earth modified by wave and particle emissions from the sun, but also a continuous outflow of plasma, better known as the solar wind, transports strong solar magnetic fields to the earth where they interact with the geomagnetic field in a region now known as the magnetosphere. Some of the practical benefits of this knowledge can be seen in the improvements to the international telecommunications systems and the development of space research programs.

These observations, having continued over almost three sunsport cycles, have also provided data which many workers have endeavoured to correlate with terrestrial changes, especially climate. While few have claimed much success in such endeavours, the recent concern about global climate change will no doubt draw much more attention to the question of how changes on the sun effect the climate on earth.

Antarctic scientists have long recognized the great importance of the icy continent as a principal heat sink in what is sometimes referred to as "the global climate machine" but which in fact is the global ocean/atmosphere system which transports heat from the tropics to the polar regions.

A substantial piece of the record of past climate, extending back in time more than a thousand centuries, is contained within the ice cap. It has been found that this ice sheet is a "settling tank" for all components of the atmosphere and wind transported material. Thus cores obtained from deep drilling of the ice have provided information covering global events, such as volcanic eruptions which have fed a considerable amount of debris into the atmosphere, in addition to containing a stratigraphic record of climate change.

The ice sheet has a marked influence on global weather as too has the sea ice that surrounds the Continent for the white cap is an effective radiator of the earth's heat, and sea ice is a good insulator over the ocean-two important factors that lower regional temperatures. The snow surface overall shows a negative annual radiation balance which has to be made up from elsewhere since Antarctica does not appear to be cooling. This is accomplished through the transport or heat by the atmosphere from other regions with positive heat balances. This has important implications in terms of global circulation systems, storm tracks, cloudiness, precipitation, etc.

Theories of ice ages are important to the "global scene". It has been suggested that because the Antarctic ice sheet is inherently unstable, it would surge periodically into the Southern Ocean and form a huge ice shelf. This would increase the world's albedo and lead to global cooling followed by glaciation. Because the ice-shelf could not be sustained, its eventual breakup would decrease albedo and glaciation terminated. But what sort of effect would such dramatic changes have on the rest of the world?

Estimates made of the result of a total melting of the Antarctic ice sheet suggest a sea level rise of almost 60 metres, which would of course bring disaster to most of the world's most populated areas. The East Antarctic ice sheet would respond to climate warming in a slow manner. However, the West Antarctic ice sheet is much more vulnerable to climatic warming because of its essentially marine enivornment thus disintegration and melting could take place over a comparatively few years, raising the world's sea level by about 4 metres.

The sea ice that surrounds the Continent varies in area from a minimum of about 3 million km^2 in late summer to a maximum of up to 20 million km^2 in late winter. Large variations in the extent of the sea ice between different years have been observed and such fluctuations are known to have a marked effect on global climate, for circulation intensity and poleward heat flow from the tropics varies according to the temperature contrasts between the tropics and Antarctica. However, the cause of these variations in the extent of the sea ice is not yet understood, primarily due to lack of adequate means of close monitoring, but future remote sensing programs supported from the new generation of polar-orbiting satellites to be launched in the 1990s, should aid in providing answers to this most important question effecting global climate.

Part II. Antarctic Glaciology and Mineral Resources

Changes in the Antarctic Environment over the Last Five Million Years

Patrick G. Quilty

Introduction

I commend the Korean authorities on hosting this symposium which marks the start of a major new phase of international co-operation in Antarctic science.

Even more, I commend them on the choice of topic. For too long, geology and biology have acted as discrete disciplines, whereas in fact, they are complementary and have a great deal to teach each other. At the recent V SCAR Biology Symposium held in Hobart, several speakers, including me, presented papers outlining what is known of the evolution of Antarctic biology. Much discussion suggested that the time has come for the two disciplines to co-operate more closely. In addition, integrating the two generates a multidisciplinary science and the multidiscipline approach will be important in the near future as we strive to solve major problems of global scope.

Life has been on earth for approximately 3.8 of the earth's 4.6 billion year history. Conditions in which life has existed have changed radically over that time, for example until 2.0 billion years ago there was no free oxygen in the atmosphere.

The study of life has been divided into two disciplines, *palaeontology*—the study of ancient life—and *biology*—the study of living things. My own approach recently has been to recognize biology as covering all life (past and present) and to divide it into two parts—*palaeontology* and *neontology* (the study of recent life). I believe the two facets are complementary and have a great deal to teach each other. The fossil record teaches a great deal that neontology does not but cannot be satisfactorily interpreted without a sound understanding of modern life forms, their distribution and how they survive.

The most important lesson to be learned from palaeontology is that life changes continuously with time. There is no such thing as a static balance of nature—life is highly dynamic. Probably no time in earth history has been as dynamic as the present due to the intervention of humanity and the changes it has caused to the earth, its atmosphere and oceans. It is possible that changes can occur more quickly, for example if an asteroid impact did cause the extinction of the dinosaurs (and many other groups of organisms) at the end of the Cretaceous (66.4 million years ago) (Kauffman, 1984).

The function of this paper is to review some of the changes which are now believed to have occurred in the Antarctic ecosystem over the last five million years and to examine how these may have affected the evolution of Antarctic organisms and the ecosystem itself. Lessons from these changes should be taken into account by humanity as we look for the consequences of our actions on the earth.

In the polar regions some changes to the earth have their greatest impact. These regions are now yielding a great deal of information leading to a documentation of marked change, which occurred at a rate much faster than anticipated. These data teach us how fast such changes can be.

Until recently much of the understanding of the evolution of the Antarctic ecosystem has come from data gathered outside Antarctica, much from the work of the Deep Sea Drilling Project (DSDP) in the Pacific and Atlantic Oceans, and in the Ross Sea. More recently, the Ocean Drilling Program (ODP) has taken on this role and the results of its endeavours will make major contributions as they become available.

The major results of relevance to come from ocean drilling have been from oxygen isotope records, particularly from the Southern Pacific, especially those of Shackleton and Kennett (1975). These have been utilised to suggest that the Antarctic glaciation in a modern form commenced in the mid Miocene (12-15 million years ago) and has steadily intensified since.

Other authors (e.g. Blank and Margolis, 1975) had also suggested a cold Pliocene and even that the Early Pliocene was as cold as during the glacial Pleistocene.

This hypothesis of steadily intensified glaciation is now being drastically reviewed following a remarkable series of discoveries in Antarctica over the last five years. These indicate that there have been rapid changes in the Antarctic environment over that time, changes much more rapid and significant worldwide than had been envisaged.

The new parameters include a few fossils and results of deep ice drilling, the latter to provide information on changes accompanying what have come to be known as Milankovitch cycles (Imbrie *et al.*, 1984) which operate on a 120-150 thousand year time scale.

Sea level can vary by as much as 200 m between glacial periods and totally deglaciated ones, as a result of ocean water being locked up in polar icecaps. Sediment sections studied to date from onshore Antarctica are biased towards intervals of high sea level and thus warmer conditions. Cooler intervals may be represented only in deep sea sections.

Pliocene Marine Fossils

Adamson and Pickard (1980) in a symposium held in Hobart, Tasmania in 1984, announced that sediments at Marine Plain, 10 km southwest of Davis Station in the Vestfold Hills, East Antarctica, are 3.5-4.5 million years old (Early-mid Pliocene), not 5-8000 years old as most other sediments in the area seem to be. The evidence for this age comes from studies of molluscs, diatoms and proteins in the molluscs. This has now been fully documented (Pickard *et al.* 1986, 1988; Harwood, 1986). The older dates are thus much older than can be identified from radiocarbon dating techniques which were used to obtain the younger ages (Adamson and Pickard, 1986; Zhang and Peterson, 1985).

The author visited the area in the 1984/85 austral summer and found the upper jaw and skull of a new genus, species and perhaps family of extinct dolphin (Fordyce and Quilty, in preparation). It is a highly evolved form with a long, edentate jaw and a high frequency echolocation system suggesting that it hunted and ate squid. A later (1985/86) visit showed that fossil bone is common in the area and a research program has now commenced to document the entire fauna from the area. During the 1985/86 visit, a geological map was compiled (Quilty, in press).

It is hoped that this locality will eventually yield a fauna of birds, mammals and fish representing a significant portion of the vertebrate fauna of the Antarctic ecosystem at the time.

Well preserved molluscs associated with the dolphin have given preliminary oxygen isotope results suggesting that water temperature was considerably warmer (perhas 5°C) at 3.5-4.5 million years than it is now. This is consistent with other indications recorded by Pickard *et al.* (1986, 1988) and Webb *et al.* (1984) which suggested warmer, much less glacial conditions on Antarctica at the time.

One major point of significance of the locality lies in the fact that it is the only place in Antarctica which has yielded post Eocene (37 million year) vertebrate fossils. This is especially significant because it was only after the Eocene that an Antarctic marine ecosystem evolved and became differentiated from the rest of the world.

Indications from elsewhere on earth (Stainforth *et al.*, 1975; Vail *et al.*, 1977; Haq *et al.*, 1987) all suggested that sea level was much higher in the Early-Mid Pliocene than since and that climates world wide were more equable.

Palynology on the Marine Plain sediments (E.M. Truswell pers. comm.) has not yielded evidence of terrestrial vegetation at this time. Examination of fresh material from drill cores will prove whether or not terrestrial vegetation existed at the time.

Fossil Plants

Webb and Harwood (1987) have reported the discovery of fossil wood at Oliver Bluff in the Beardmore Glacier region of the Transantarctic Mountains. This now occurs at 1800-1900 m above sea level but must have lived nearer sea level, the land being elevated since. Its age is not well defined yet but it is probably younger than 3.1 million years (mid Pliocene) and possibly than 2.5 million years (Late Pliocene). It could even be very early Pleistocene, less than 1.85 million years.

Carlquist (1987) studied the wood and identified it as *Nothofagus* most closely akin to the South American *N. betuloides* (Mirb.) Blume or Tasmanian *N. gunnii* (Hook.) Oerst. No leaves are yet known to support a particular identification.

The form was small and shrub like, and probably only one species was present, in turn suggesting that the South American affinity is the more likely. The plants grew adjacent to small lakes which developed on glacial sediments during interglacial intervals.

Significance of Dolphin and Wood

Both the dolphin and the wood, although of different ages, show that considerably warmer than present climates did exist in Antarctica during a significant part of the Pliocene. This is considerably in conflict with the oxygen isotope based curves of climate change presented by Shackleton and Kennett (1975).

Kennet (1985) presented new oxygen and carbon isotope data and these are more consistent with the idea of a warmer Early-Mid Pliocene. They are thus consistent with the indications from the dolphin's locality but are still in conflict with the wood discoveries. Kennett (*op. cit.*) data still suggest a cold climate at the presently understood age of the wood. This conflict is not yet resolved.

More Recent Discoveries

Although not documented properly, there have been other discoveries in East Antarctica which will contribute to the debate.

Sediments recovered from the Windmill Islands region (in the vicinity of Casey Station) are yielding diatoms and sponge spicules, probably of Pliocene age but lacking indicators of cold conditions (Harwood, pers. comm.).

Recently discovered sediments in the Larsemann Hills (100 km southwest of Marine Plain) are Late Miocene or Early Pliocene in age and have yielded an excellent foraminiferid fauna. No climate data are yet available from the Larsemann Hills material.

Pleistocene-Holocene

Oxygen isotope data from deep sea sediments (Emiliani, 1978) deposited during the last 750,000 years contain evidence of a 120-150,000 year cyclicity now referred to as Milankovitch cycles (Imbrie *et al.*, 1984).

Interpretation is consistent with a 100,000 year slow buildup of polar ice caps causing a sea level fall, in the most recent cycle of 130 m. At the peak of glaciation (the last was 18-25,000 years ago-Lorius *et al.*, 1985) the cycle changes and there is a rapid decay of polar ice caps and sea level rises approximately 130 m. After the 10,000 year decay, there is a period of stable sea level (as of last 8,000 years) of unknown duration, followed by a new slow ice buildup to commence the next cycle.

Although originally identified in deep sea sediment, the last cycle can be better studied in Antarctic ice (Lorius *et al.*, 1985) from deep drilling. It is best known now from a 2,300 m hole near the Soviet Vostok Station in East Antarctica.

There are Australian plans to drill over the next 10 years, through the thick Antarctic ice 700 km south of Casey Station and to study Milankovitch cycles over the last 0.5-1.0 million years. The detailed knowledge gained will allow better correlation with, and understanding of, the deep sea record.

Milankovitch cycles correspond to and cause complementary cycles in sea level change, pole-equator atmospheric pressure gradients (and hence wind strength) and atmosphere composition. In turn, there must be changes in ice extent, marine and terrestrial productivity, width of continental shelves, refuges for fauna and flora and so on. These must all have a dramatic effect on fauna and flora but these effects have not yet been subject to much study. Study to date has concentrated on the effects of sea level and sea temperature change.

Milankovitch cycles are now believed to be controlled by cycles in the orbital geometry of the earth around the sun. During periods of maximum glaciation (we are at present in an interglacial), the Antarctic ice cap is larger than at present (but by how much is unknown) and there is a northern hemisphere icecap larger than the Antarctic and covering much of

Canada, northwestern and northeastern U.S.A., much of Europe and Siberia.

It is to be expected that naturally the earth will "soon" begin another slide into a glacial period but humanity has intervened in the process, burning large accumulations of fossil fuel and deafforesting the planet causing the "greenhouse effect", probably operating in the opposite direction to the Milankovitch cycle effect. There has been little study to evaluate the conflicting influences.

To date, most studies on climate change have concentrated on temperature change because this can be modelled well, using oxygen isotope data. Related changes in continental shelf width, salinity, atmospheric composition must also have effects but these are not yet known and must form an important part of future studies. In addition, there are changes in marine characteristics such as the sea roughness, caused by increased wind velocity and other changes to marine water secondary to changes in salinity.

The effects caused by change will be most marked in polar regions, highlighting the importance of polar studies.

Conclusions

Recent studies show that change in the Antarctic region has been much more common and extreme over the last five million years than was previously thought. Over the last 750 000 years this can be explained in part by the Milankovitch cycle hypothesis but changes occurred prior to the younger well documented cycles. Milankovitch cycles may eventually be projected back in time.

When externally imposed change occurs, the ecosystem changes and when the external influence for change is removed, the ecosystem does not return to its earlier state but assumes a new short term balance. What will the response be to perturbations caused by fishing in the Antarctic?

Naturally, another Milankovitch cycle cooling should "soon" begin but the humanity caused "Greenhouse Effect" will probably override the cooling and cause a global warming. Perhaps humanity will learn to identify the "ideal" atmospheric composition and control the global climate to our advantage.

Research is needed on so many elements of the ecosystem and the elements of climate change. Antarctica will play a key role in these matters.

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Ice Streams and Ice Shelves: A Review of Some Recent Work by British Antarctic Survey Glaciologists

Elizabeth M. Morris

Abstract

In the 10 years since Swithinbank published his review of the glaciological work of the British Antarctic Survey (Swithinbank, 1977) there have been major developments in logistics and instrumentation. The collection of field data has been transformed by new surveying techniques using satellite signals, increased use of remote sensing from aircraft and satellites and advances in drilling technology. This paper describes some recent work of glaciologists in the Ice and Climate Division of the BAS and sets it in the context of current world-wide concern over the effects of anthropogenic climatic change.

1. Introduction

One of the most important scientific problems facing Mankind today is how to predict the effects of man-made changes in the Earth's atmosphere. We know that certain gases absorb the long-wave radiation emitted by the Earth's surface and therefore deduce that increases in their concentration will increase global average air temperature and change the pattern of climate around the world. The most important of these greenhouse gases is carbon dioxide. Over the last 160 thousand years carbon dioxide levels and air temperature have fluctuated together. There were high levels of carbon dioxide in the last interglacial period 140 to 110 thousand years ago, low levels during the glacial era (fluctuating with about a 20 thousand year period) and high levels again in the last ten thousand years (Barnola et al. 1987).

There have always been natural variations in the climate due to factors over which Man has no control. The most pronounced are the Milankovitch variations, produced by precession of the Earth's axis. Long term variations in global temperature, predicted from a complex model which incorporates the known orbital parameters, agree well with temperatures inferred from oxygen isotope measurements from deep ocean cores. It appears that the theory is sufficiently well-established to "authorise the prediction of the future natural climate" (Berger, 1980). Extrapolating the global temperature curve into the future suggests that in the next few thousand years the present decline in temperature should steepen as the world moves towards the next ice age. The question is, however, will Man's activities counteract the natural processes of climate change?

Since 1860 global mean surface temperature has in fact been steadily increasing, as has the concentration of greenhouse gases in the atmosphere (Wigley et al. 1986). Ever increasing combustion of fossil fuels and destruction of the tropical rain forest combine to raise the level of carbon dioxide in the atmosphere. It is predicted that over the period from 1980 to 2030 global mean surface temperature will rise by 1-2°C, in the case of the most restrictive strategies on fossil fuel consumption, or by 4-9°C under more likely conditions (Lamb, 1982). Levels of the chlorofluorocarbons, which have such a destructive effect on the stratospheric ozone layer and are also greenhouse gases, are also rising and reinforce our fears of major climatic change.

Using global circulation models it is possible to calculate the pattern of wind speed, air temperature and humidity over the earth for a hypothetical change in composition of the atmosphere. One such calculation shows the increase in June-August surface temperatures when carbon dioxide levels are doubled early in the next century (Washington and Meehl, 1984). A dramatic increase of more than 12°C in mean winter temperature is predicted for parts of land-based ice. A rise of some 50 mm over the last 50 years has already been recorded and that climate studies here may give the first confirmation that major global changes are underway.

More importantly, however, we note that increased global air temperature will produce and increase in sea level by a combination of thermal expansion of sea water and melting of land-based ice. A rise of some 50mm over the last 50 years has already been recorded (Newman and Fairbridge, 1986).

It has been calculated that if the entire Antarctic ice sheet were to melt, sea-level would rise by 55 m (Untersteiner, 1984). The effect on many coastal areas would be devastating. We need to know how rapidly the ice sheet will respond to global warming and whether there are any hidden positive feed-backs in the system which could produce a sudden rapid disintegration. This is the reason why Antarctic research is a crucial element in the study of climatic change.

Melting of the ice caps will have a feed-back effect on the atmospheric and ocean circulations and may enhance other aspects of climatic change. The problem of unravelling the links between the behaviour of the Antarctic ice sheet and future climate inspires much of the work of the glaciologists of the British Antarctic Survey.

In order to make quantitative predictions taking proper account of the very complex interlinked processes in the ice-ocean-atmosphere system, it will be necessary to develop coupled global circulation models for all three components. Progress has been made in coupled atmosphere and oceans models but modelling of complex real ice sheets, especially the Antarctic, is not well advanced. One of the main justifications for BAS glaciological research has been to collect field data and make theoretical process studies which will contribute to the knowledge required to construct an ice flow model for Antarctica.

2. The Antarctic Ice Sheet

The Antarctic ice sheet is nearly 5,000 m thick in places and fringed by shelves of floating ice. The British Antarctic Territory contains the Ronne-Filchner, Brunt and Larsen ice shelves around the Weddell Sea and, surrounding Alexander Island, the Wilkins, Bach, George VI and Wordie ice shelves.

In places the ice discharges rapidly from the Antarctic plateau in fast-flowing ice streams, for example the Rutford and Evans ice streams which flow into the Ronne Ice Shelf. Much of the base of the West Antarctic ice sheet is below sea level and hence is thought to be particularly vulnerable to climatic change (Stuiver et al. 1981). It is for this reason that much of the Survey's glaciological work concentrates on the dynamics of the West Antarctic system.

3. Requirements of an Ice Flow Model

Having established the long-term aim of our glaciological research-the construction of an ice flow model for the Antarctic which can be coupled to atmospheric and oceanic circulation models—it is then necessary to define the information required to achieve this aim. The first question is: what is the geography of the system? Where are the boundaries between the ice and rock, ocean or atmosphere? Secondly; what are the boundary conditions? To run the model it will be necessary to specify stresses, mass and energy fluxes, velocities and temperatures on the upper and lower surfaces of the ice, obtained either by measurement or using theoretical equations. Thirdly; what happens within the ice? Velocity and temperature profiles are required to establish initial conditions and check the predictions of the model. A constitutive law relating strain to stress must be defined. Lastly, we shall need as much information as possible on the behaviour of the ice sheet in the past. The most important test of any model will be whether it can reproduce known variations in the extent of the ice given the climatic variations known to have occurred over the last 100 thousand years.

Clearly it will be an enormous task to gather all the information required to run and test an ice flow model. No one nation will be able to achieve this alone. Cooperative international programmes are essential and BAS glaciologists already work closely with the West Germans and Norwegians (in the Filchner-Ronne Ice Shelf Programme, FRISP) and with US scientists in our ice core drilling programme.

(i) Geographical Studies

Let us consider first what progress has been made in the task of establishing the geography of West Antarctica. In the early days this was done on the ground by survey parties who often travelled long distances and spent many months alone except for their much-loved dog teams. Even today some geographical ground surveying is still undertaken, to record profiles of representative glaciers and ice caps as part of our mass balance studies. The profiles of six small glaciers first measured between 1972 and 1976 were relevelled in the 1985/86 season. The results indicate that, except in the Batterbee Mountains, the flow of small glaciers is in equilibrium with the present climate (Paren and Richardson, in press).

Remote sensing has transformed the mapping of Antarctica and is now our major source of data on the extent of the ice and the position of its upper boundary. Satellite images are particularly useful in detecting changes in the system. For example, Landsat images have been used to study the changing position of the Wordie Ice Shelf front which has retreated rapidly over the last 40 years. What was once a safe sledging route has now become a tangle of fractured ice blocks as the ice shelf disintegrates (Reynolds, 1988). The retreat of this ice front may be the first indication of major changes in the regime of ice shelves in the Antarctic Peninsula. As Swithinbank (1977) pointed out, it is also possible to monitor major calving events as they occur, using satellite data.

A major undertaking over the last two years has been the construction of a glaciological map of the Ronne Ice Shelf based on Landsat imagery taken in early 1986 (Swithinbank, Brunk and Sievers, in press). Many interesting features can be mapped using the satellite images: grounding lines, flow lines, ice rumples and crevassed areas. The map, produced jointly by British and German scientists, will be an invaluable source of data for the region.

Athough we have an ever-increasing knowledge of the geography of the upper surface of Antarctica, in order to model the behaviour of the ice we must also be able to map the underlying land features. In the early days of the IGY seismic sounding was the only technique available to determine ice depths. However, since then radio-echo sounding techniques have been developed to reveal sub-glacial topography and even structure within the ice sheet itself. Since 1975 BAS radio-echo sounding teams have covered a length of 34,000 km over the Ronne Ice Shelf (Crabtree and Doake, 1986). In a good season much can be achieved; for example, in 1975 BAS flew 40,000, and in 1982, 18,000 line kilometres collecting ice thickness and aeromagnetic data. However, other seasons have produced more modest results with 4-5,000 kilometres being flown.

When a good echo is obtained the position of the bed can be determined to ± 10 to 25 m in the vertical direction depending on the ice thickness. Modern navigation techniques ensure that the horizontal location of the track can be determined to $\pm 2{,}000$ m and in the future navigation by the GPS system should improve this considerably. Some radio-echo traces also show internal reflection layers. These probably arise because impurities deposited in the snow change the electrical properties of the ice (Paren and Robin, 1975). They are an invaluable indicator of internal deformation and especially useful when the flow in the ice sheet is disturbed by the presence of a mountainous bed.

Improving the design of radio-echo sounding equipment is a key element in our current work. At the moment we record data on film but we are in the process of constructing a digital recording system which should make data capture and analysis very much easier in the future.

Radio-echo sounding can also be carried out from the ground, with the advantage that spatial location can be very precise. We are developing a high-resolution impulse radar system to look at near-surface layering in the ice. This should be operational next season.

(ii) Boundary Conditions

We turn now to the problem of determining the upper boundary conditions for the ice sheet. Temperature, velocity, strain rates and the inputs of mass and energy are all useful quantities to measure. The problem is to obtain data over a sufficiently wide area and in the key regions where small variations in behaviour may have a large effect on the ice sheet. Some information may be deduced indirectly from satellite data. The microwave emissivity of a snow surface, for example, is related to its temperature, and microwave satellite images of the Antarctic give a broad picture of the spatial variations in surface temperature over the continent (Zwalley et al. 1983). Winter images show clearly the extent of the sea ice and

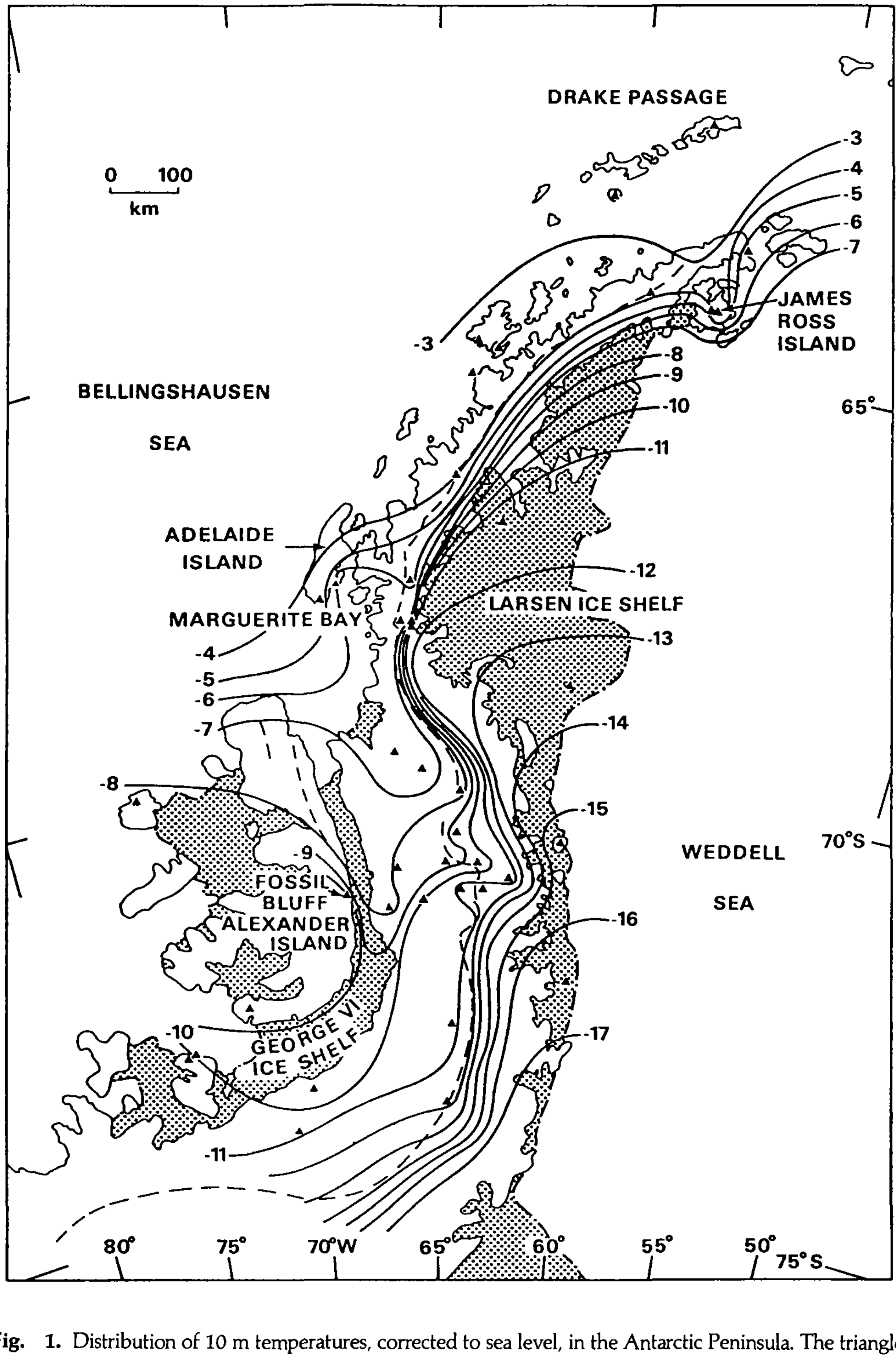

Fig. 1. Distribution of 10 m temperatures, corrected to sea level, in the Antarctic Peninsula. The triangles show the positions of temperature measurements. From Reynolds (1981).

polynyas—open areas of warmer water surrounded by the ice.

Satellite pictures can give only an instantaneous view of surface temperature. In some ways temperature measured at a depth of 10 m is a more useful indictor of the spatial variation in the surface temperature. The diurnal and annual oscillations are damped out so that, providing there is no percolation of meltwater, the 10 m temperature is a measure of the mean annual surface temperature.

Martin and Peel (1978) and Reynolds (1981) have drawn together measurements of 10 m temperatures made over many years in the Antarctic Peninsula. When these temperatures are corrected to sea-level, i.e. the cooling effect of altitude is removed, marked differences still remain (Figure 1). It may be seen that the Antarctic Peninsula forms a major climatic barrier with sea level temperatures some 70°C warmer on the west side than the east. This climatic work is slowly being extended as the range of BAS field parties increases.

The accumulation rate, which is not the same as the snowfall in areas where there is blowing snow, is measured using snow stakes or by digging a snow pit. A density profile must be measured to convert depth of snow to a mass input. It is also possible to derive the annual accumulation rate indirectly from oxygen isotope measurements in ice cores.

Velocity and strain rate on the surface of the ice may be measured directly from stake networks. Now that signals from satellites may be used for location, it is possible to undertake accurate work at key locations on the ice sheet even if these are far distant from fixed points on rock nunataks. For example, a stake network has been set up along an 800 km flow-line extending from the Rutford Ice Stream across the Ronne Ice Shelf to the Weddell Sea (Figure 2). The 28 sites were established over the 1985/86 and 86/87 field seasons by ground based parties who fixed their position using the TRANSIT satellite surveying system. This Doppler method gives position to within ±1-2 m after 20-30 satellite passes i.e. after 1-2 days. The GPS system which will soon be available is expected to be even more accurate.

Jenkins and Doake (in press) have calculated the velocity profile along the Ronne flow line assuming a steady state and making use of measured velocities at four sites which were revisited in 1986/87 (Figure 3). They also calculated the basal melting rate, which varies from about 1 m a^{-1} at the grounding line to -0.1 m a^{-1} and then back up to 3 m a^{-1} near the ice front. Supporting evidence for the zone of basal freezing is provided by radio echo-sounding results. In this region radar returns are significantly weaker than those obtained from thicker ice upstream where basal melting is thought to be occurring.

During an extremely sucessful season last year (1987/88) Jenkins managed to revisit all the sites on the flow line. When his field data have been processed we shall have measured velocities at 28 points to compare with the predicted values. This unique data set also includes 28 ice thicknesses, mean annual surface temperatures (10 m values) and accumulation rates. Strain and rotation rates are also known at 7 points.

Indirect evidence of surface velocities may be obtained from satellite pictures. A Landsat image of the Rutford Ice Stream taken in 1974 shows a distinct morphological pattern on the surface of the ice stream which can be identified again in a SPOT image taken 13 years later. The average surface velocity distribution over the 13 year period has been deduced by comparing the two images (Figure 4, Vaughan et al, 1988).

Lower boundary conditions are even more difficult to measure than the conditions at the upper surface, for the simple reason that in most cases it is impossible to gain direct access

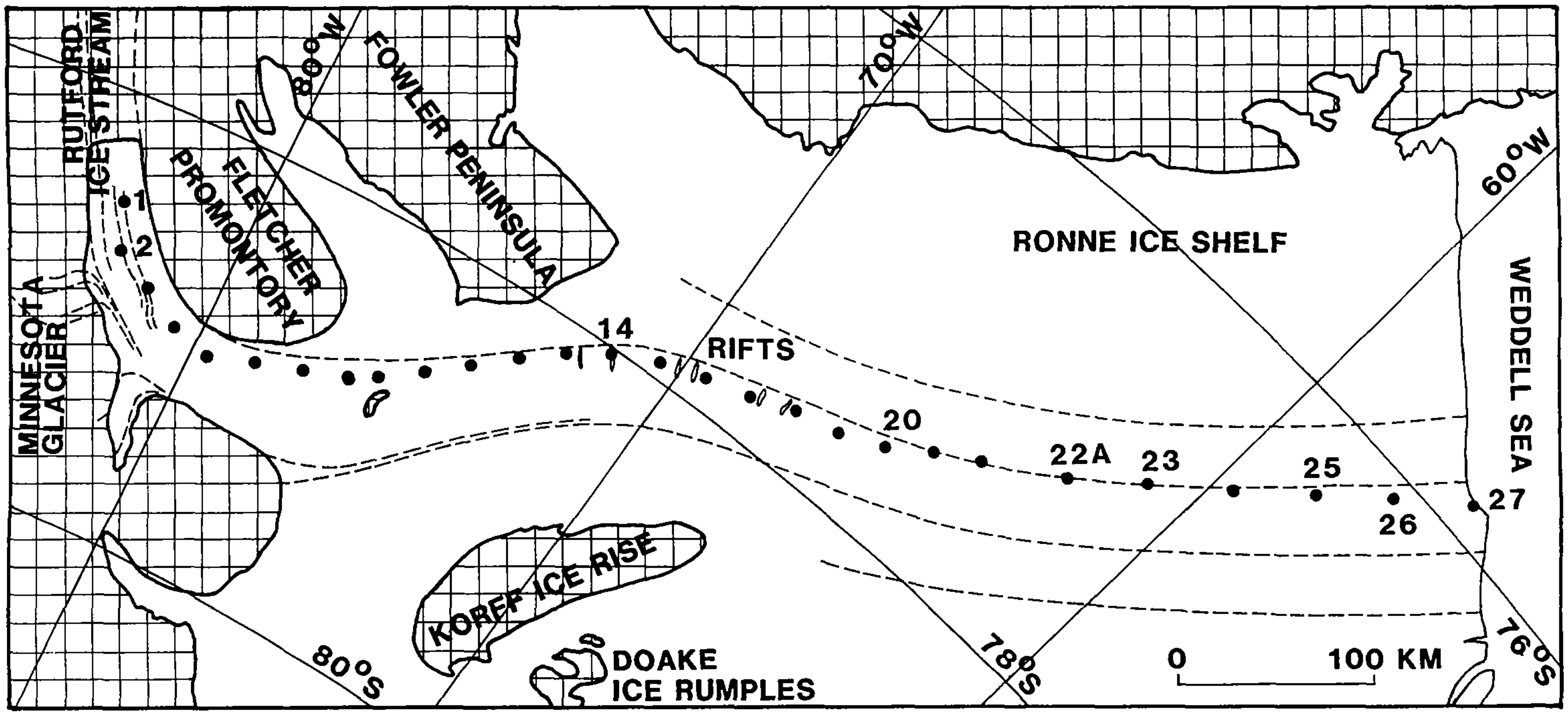

Fig. 2. Map showing positions of Ronne Ice Shelf survey sites (filled circles, some numbered) and flow lines (dashed lines(. Grounded ice is shown by hatching.

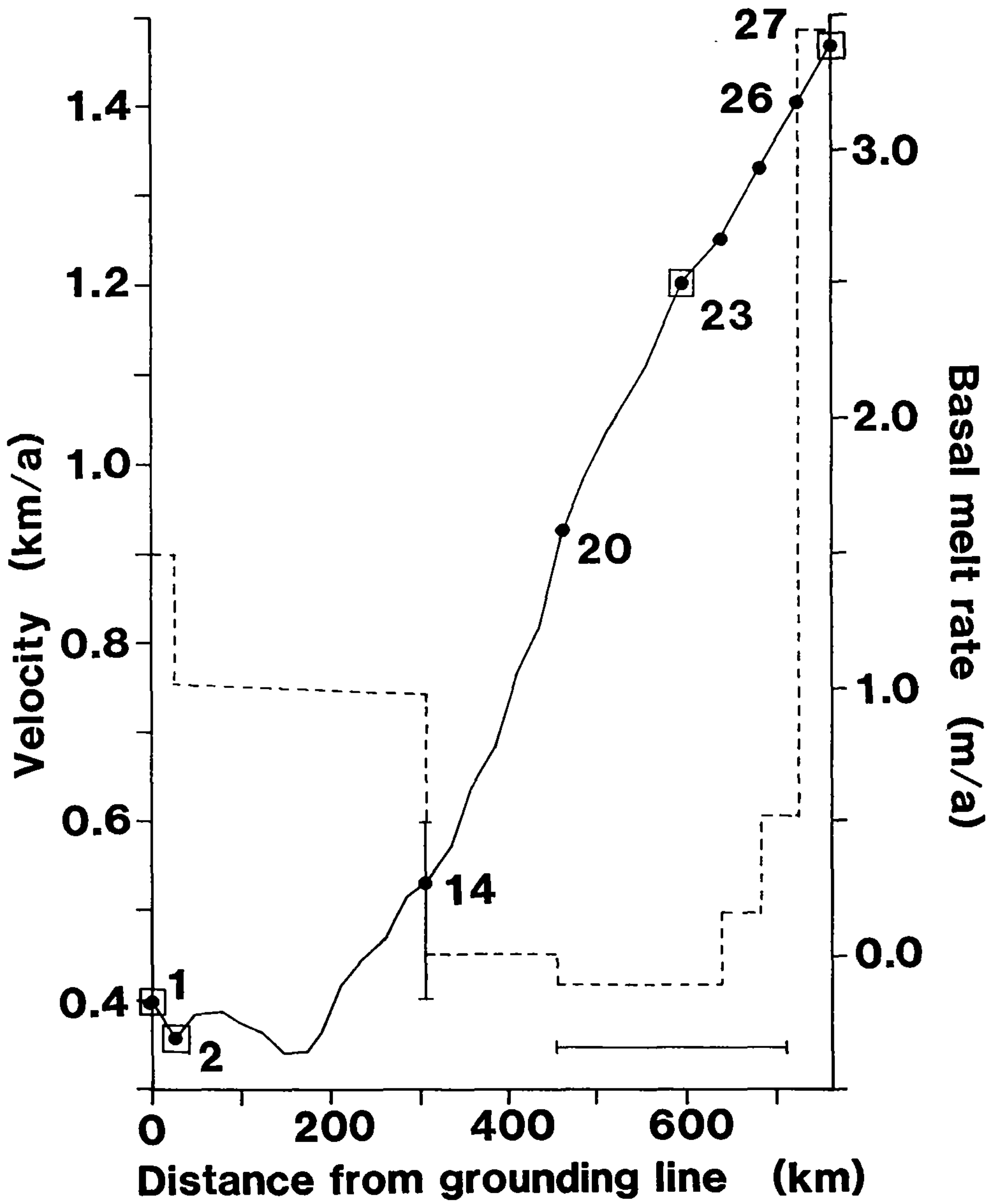

Fig. 3. Profiles of velocity (continuous line) and basal melt rate (dahed line) along the Ronne flow line. The numbered sites are shown on the map in Figure 2. Sites where measured velocities were used are boxed. The horizontal bar between 460 km and 710 km indicates the area where weak radio)echo reflections occur.

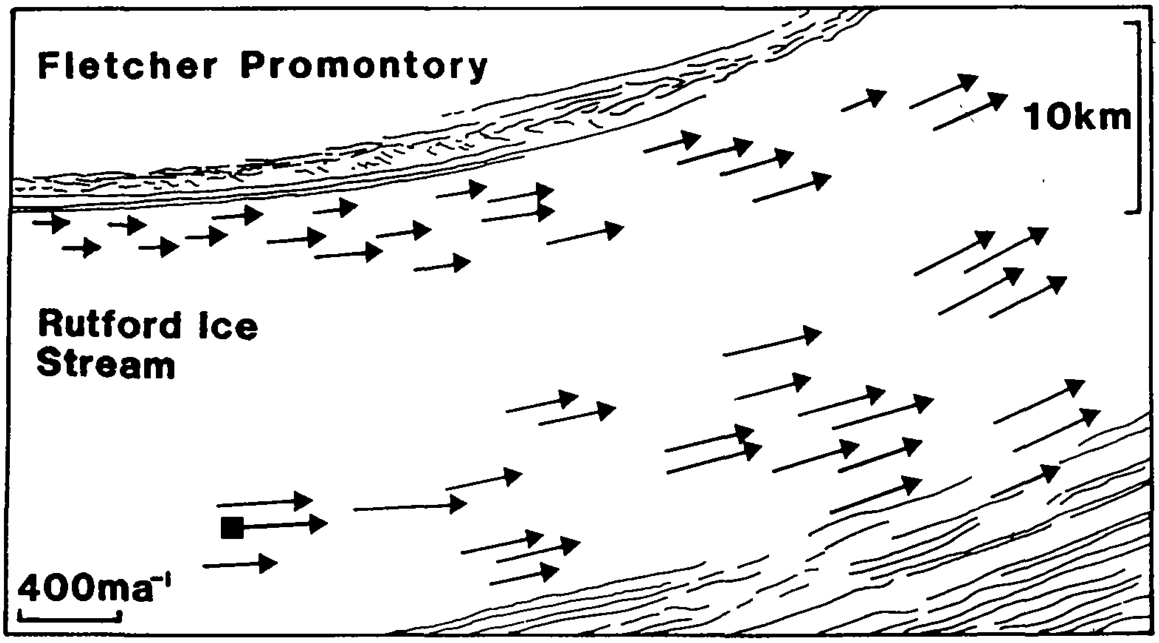

Fig. 4. Surface velocities on the Rutford Ice Stream deduced from satellite images. From Vaughan et al. (1988).

to the bottom of the ice sheet without drilling through the ice. All the same, the processes beneath the ice have a vital role to play in controlling the mass balance of the Antarctic.

Losses from ice shelves occur by calving or by melting on the under surface of the ice. BAS is cooperating in an iceberg observation programme (coordinated by the Norsk Polarinstitutt) which is attempting to quantify mass loss by calving around the entire coast of Antarctica. Ships and bases keep a record of all icebergs observed, classified by size, and this information is analysed and entered into a computer database by the Norwegians.

The study of processes beneath ice shelves has been a key element of the Survey's glaciological work for many years. Melting or freezing rates at the ice-ocean interface can be deduced from glaciological or oceanographic data. The glaciological method involves measuring ice thickness and velocity, accumulation and strain rates at the upper surface and deducing the mass flux at the lower boundary from the equation of continuity. One disadvantage of this method is that it is necessary to assume that the ice shelf is in a steady state.

Direct oceanographic measurements may be made using bore holes for access or by lowering instruments into a tide crack or polynya. Fortunately these instruments are becoming less expensive and therefore can be used even in situations where there is a risk that they will be lost. Some instruments are even left to record data over the winter and recovered in the next field season.

Temperature and salinity profiles (Figure 5) measured at the northern end of George VI Ice Shelf show that pure melt water from the ice shelf is being mixed with the warmer, more saline sea water (Potter and Paren, 1985). The melt rate is calculated to be between 1.2 and 3.6 m a^{-1}.

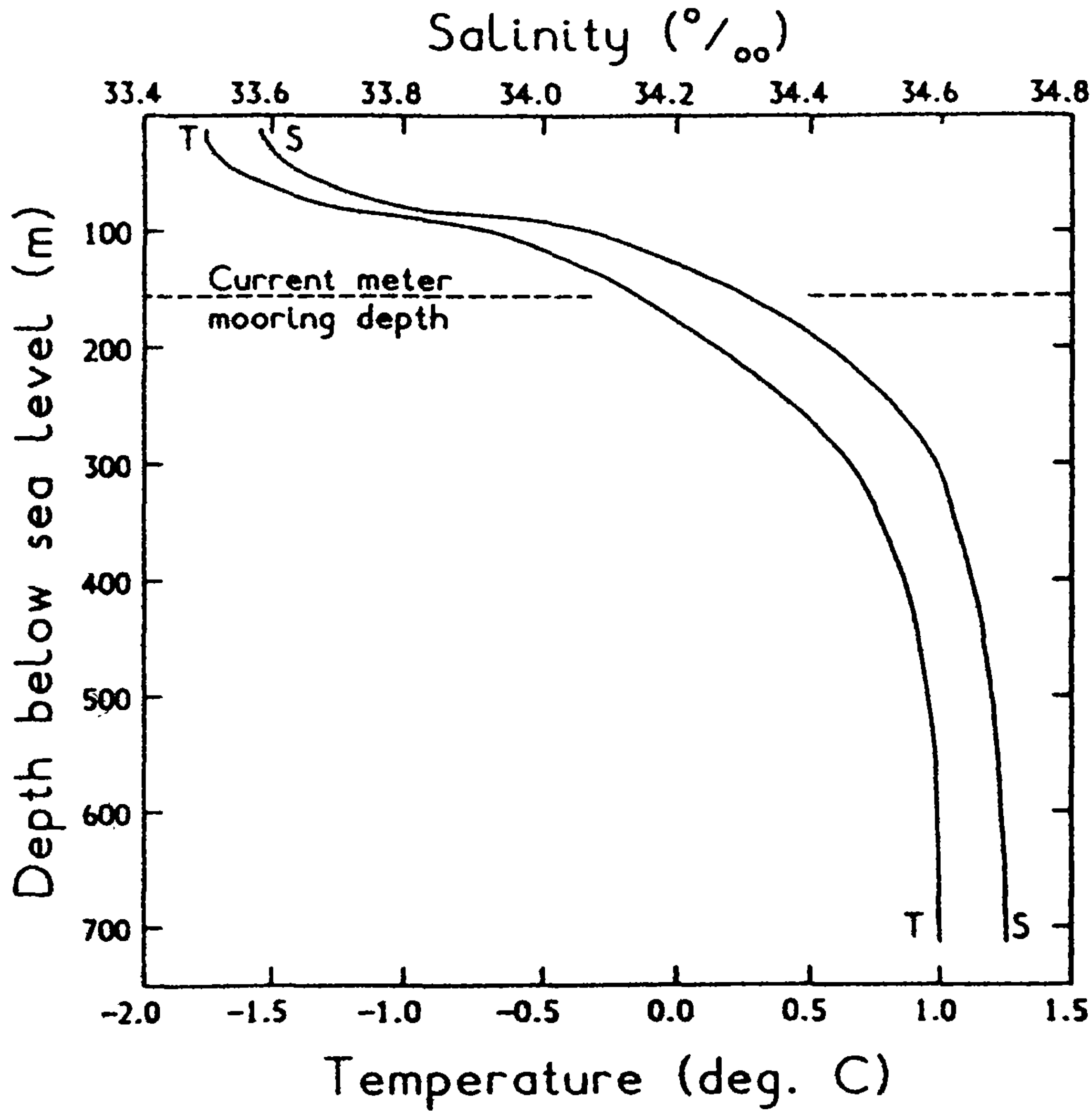

Fig. 5. (a) temperature and (b) salinity profiles under George VI ice shelf. From Potter and Paren (1985).

George VI Ice Shelf, like the ice shelves on the Pacific coast of the Antarctic Peninsula and those adjacent to the Bellingshausen Sea, is unusual; warm water from the Circumpolar Deep Water intrudes onto the continental shelf and penetrates beneath the ice shelf. Talbot (in press) has collated oceanographic data from the US National Oceanographic Data Centre database and profiles taken by the British Antarctic Survey to produce a hydrographic section, which runs *from 60° 21'S 79° 54'W onto* the continental shelf, into Marguerite Bay, along George VI Sound and out again to the ocean north of Peter I Island (Figure 6). The intrusion of the warm Circumpolar Deep Water (CDW) beneath the ice is revealed clearly by the potential temperature section (Figure 7) and by the salinity section (Figure 8). It is interesting to note

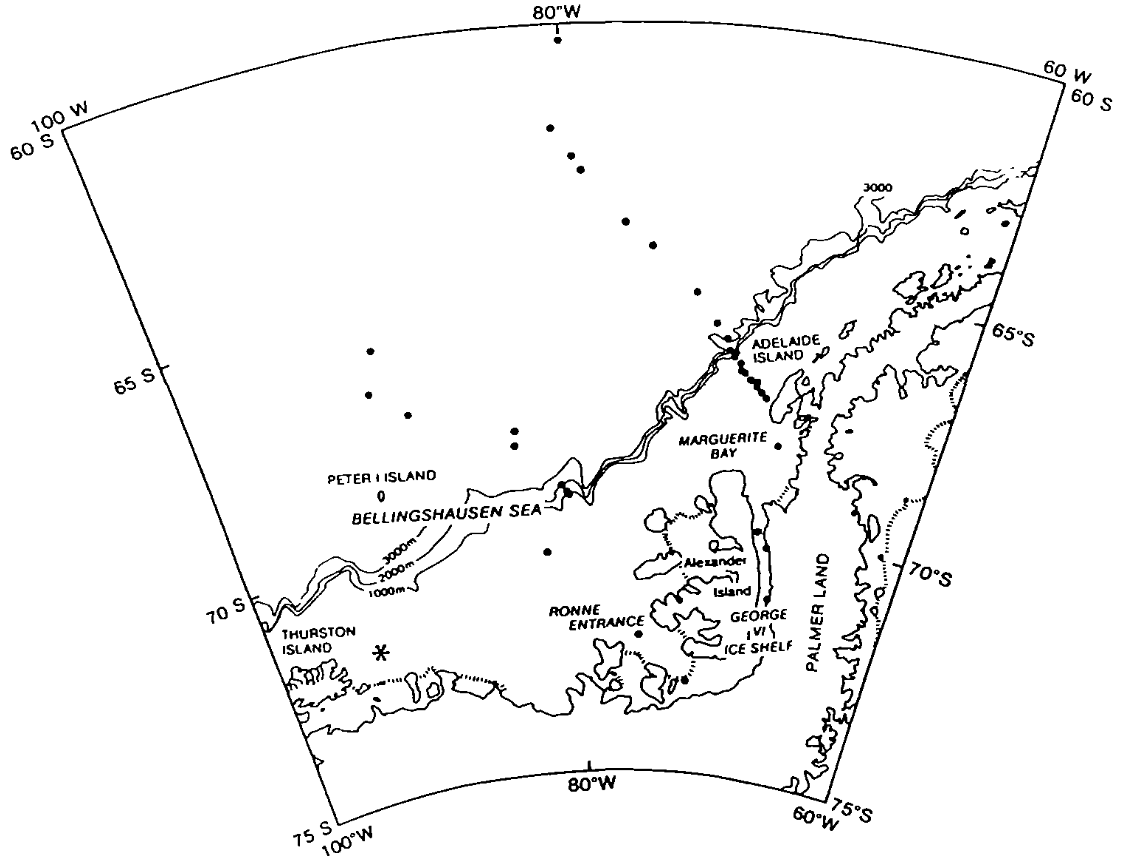

Fig. 6. Map of oceanographic survey sites. Talbot (in press, Annals of Glaciology, 11)

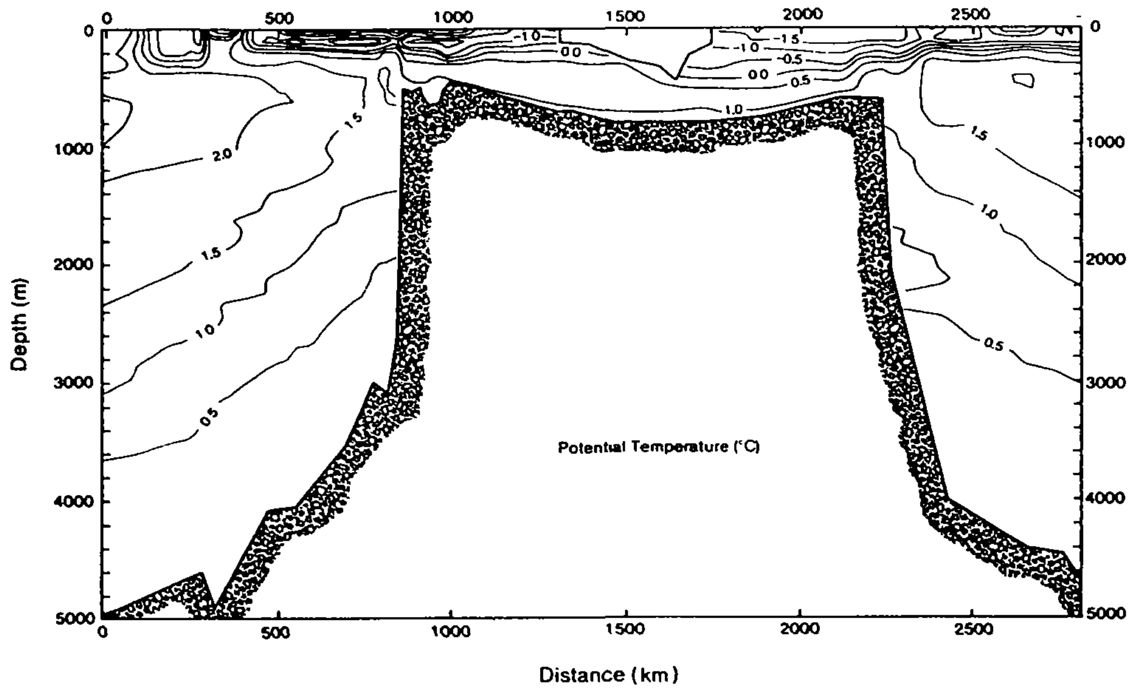

Fig. 7. Potential temperature variations along the hydrographic section. From Talbot (in press)

the absence of the near-freezing, highly saline shelf water (HSSW) which would otherwise block the warm water at the shelf break. Talbot suggests that a combination of high glacier ice melt rates and low net export of sea ice (both factors acting to reduce the salinity) inhibits the formation of HSSW in the region west of the Antarctic Peninsula. If this is so, we have established an important positive feed-back linking increased melt at the ice-atmosphere boundary with increased melt at the ice-ocean boundary.

Obviously we are keen to obtain data from the Ronne-Filchner Ice Shelf, but until now logistic and technical problems have prevented us from drilling through the ice. However, indirect evidence of the conditions at the lower boundary comes from the radio-echo sounding record. It appears that in some areas of the Ronne Ice Shelf the bottom echo strength is reduced. The interpretation of this is that a basal layer of saline ice has been produced by freezing on of sea water. The stronger echoes are produced in areas where bottom melting occurs and a smooth ice-sea water interface is formed. In the 1989/90 season we shall attempt to drill through the Ronne Ice Shelf near the Orville Coast in one of the areas where bottom plating of saline ice is suspected.

What about the conditions at the ice-land interface? Seismic sounding can give information on the strength of basal materials. For example, US work on Ice Stream B (which flows into the Ross Ice Shelf) has shown an area where the ice seems to lie on wet, deformable till (Alley et al. 1986). This is an extremely important result and a high priority task for the BAS glaciologists in the future will be to see if similar deformable bed areas producing high basal sliding rates occur under the Rutford Ice Stream.

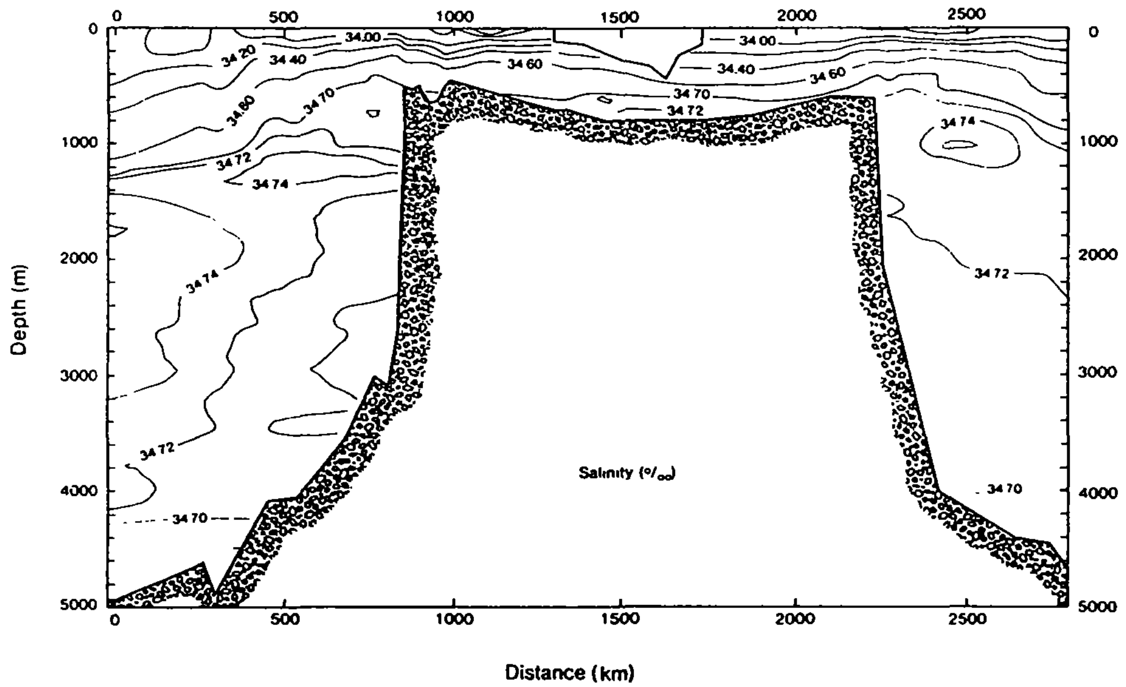

Fig. 8. Salinity variations along the hydrographic section—Talbot (in press, Annals of Glaciology, 11).

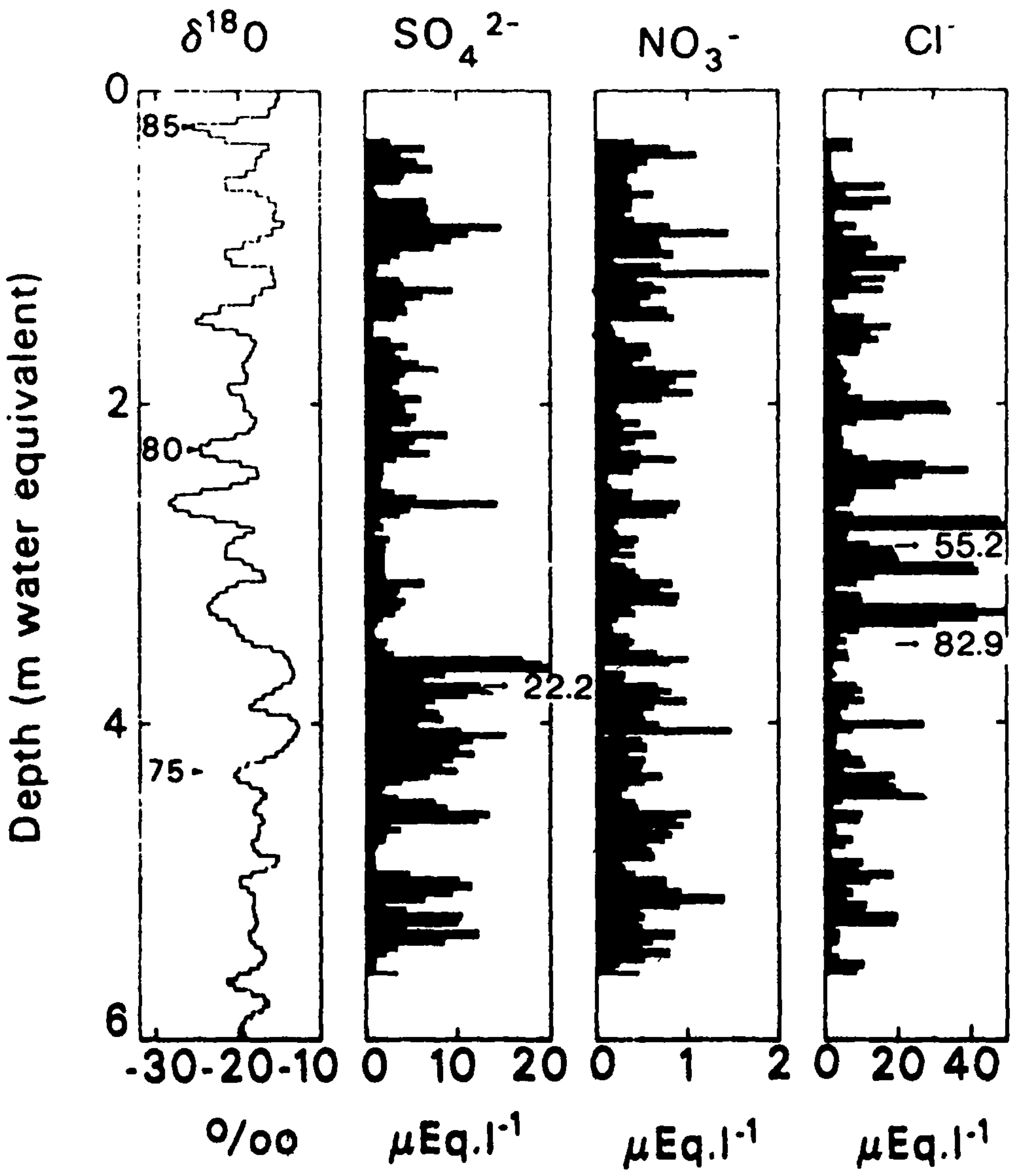

Fig. 9. (a) Chloride and (b) sulphate ion concentration in the Dolleman Island core. From Mulvaney and Peel (1988).

(iii) Internal Conditions

The measurement of conditions within ice sheets and ice shelves is in the end dependent on drilling technology, though some scraps of information can be derived by indirect means. So far BAS has only drilled bore holes to about 250 m and retrieved cores of up to 133 m. However, this is sufficient to penetrate to bed rock on small ice domes or through the thinner parts of ice shelves.

BAS glacier chemists are renowned for their work on trace metals and have developed special techniques for avoiding any contamination of the ice core. Their most recent core comes from Dolléman Island, a small ice dome on the east side of the Antarctic Peninsula on the edge fo the ice shelf close to the sea. The chemical record in the ice core collected here is sensitive to sea-ice extent in the Weddell Sea, an important indicator of the West Antarctic climate.

The concentration of chloride in the ice (Figure 9) shows an annual variation with a peak in the late summer when the sea ice extent is at a minimum. The chloride is derived from sea water spray and is an indicator of sea salt concentration. The excess sulphate concentration, tht is, the concentration of sulphate above the amount calculated from bulk sea-water composition is an indicator of biological activity in the sea. Sulphate ion concentration (Figure 9) also shows an annual variation but the peak is in mid-summer when the sunlight is strongest.

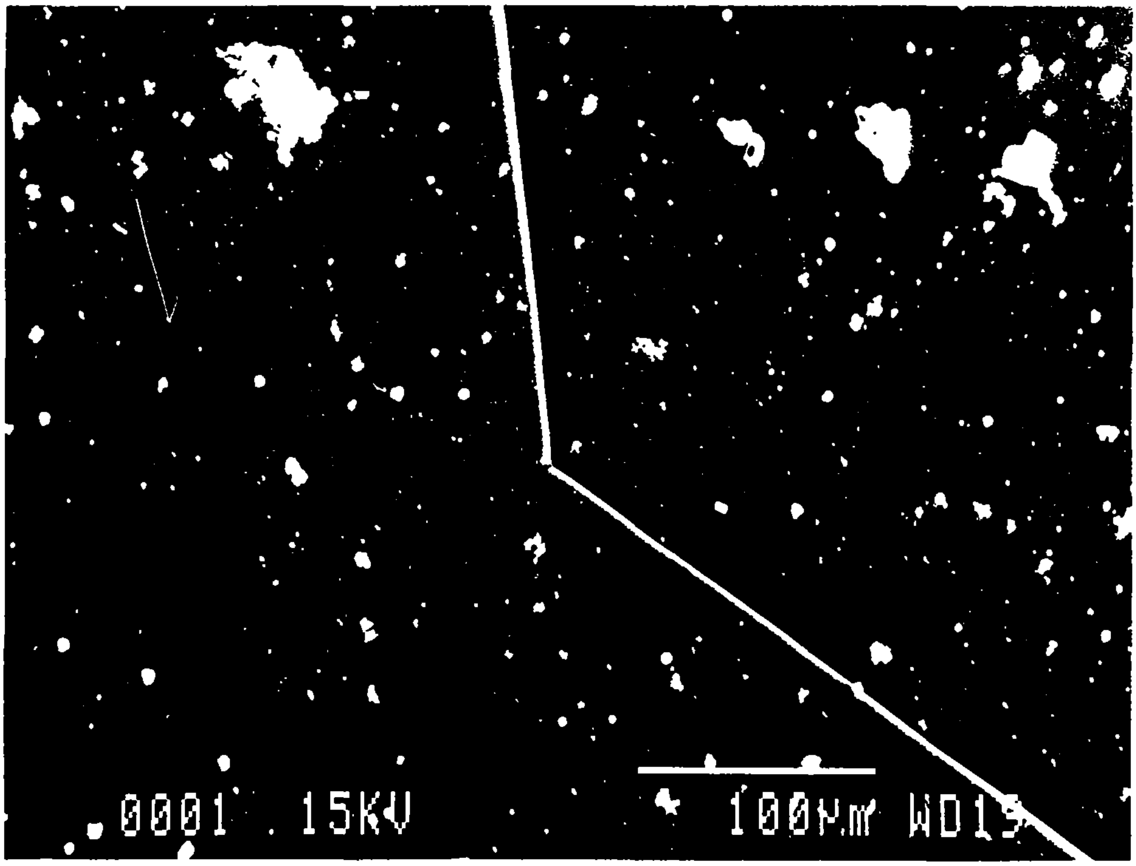

Fig. 10. Electron micrograph section through a three-grain boundary in Antarctic ice. From Mulvaney et al. (1988).

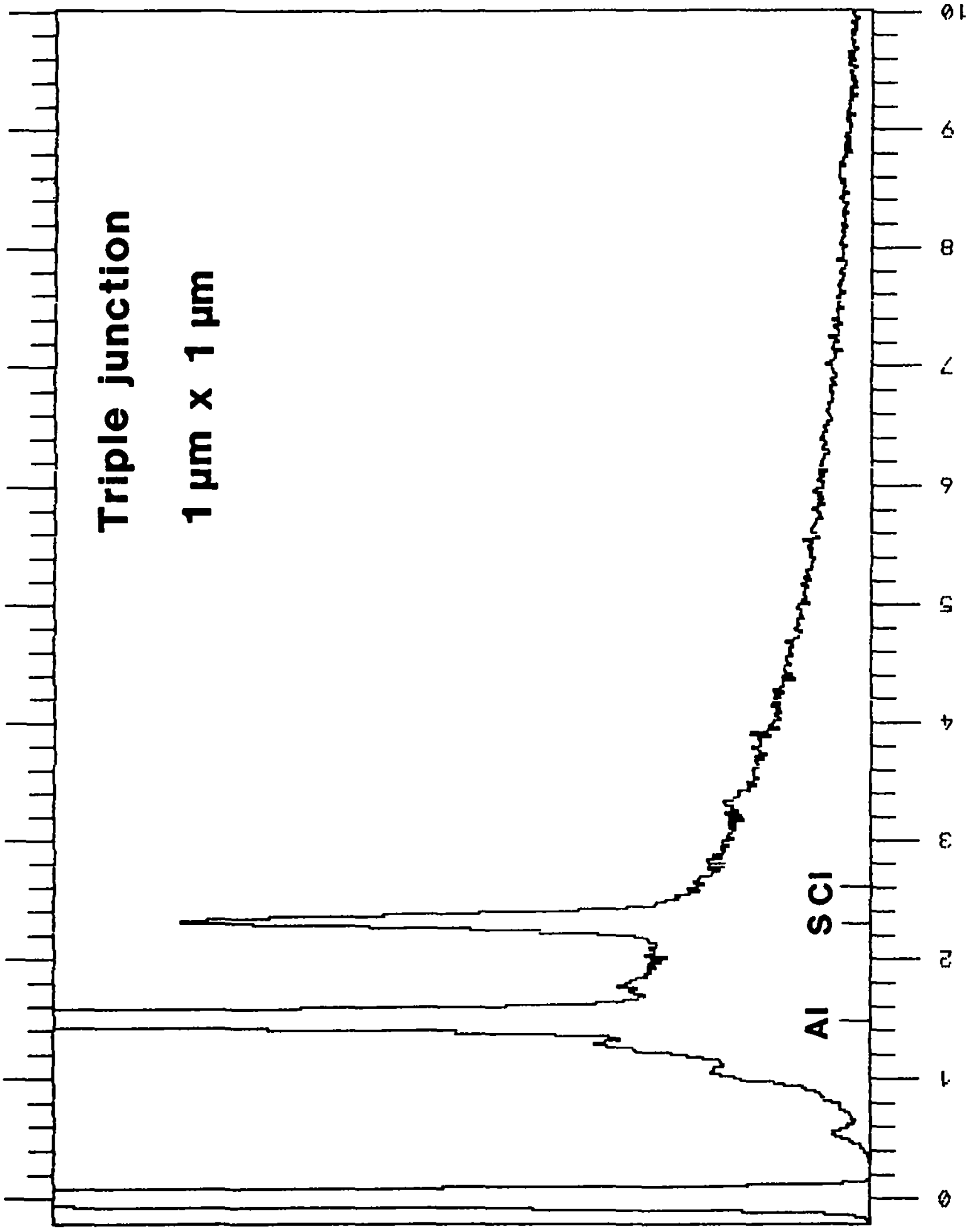

Fig. 11. X-ray emission from a triple junction in ice from Dolleman Island, Antarctica. From Mulvaney et al. (1988).

BAS scientists have developed a method for electrically profiling ice cores which can be undertaken in the field. The technique produces useful data on the ionic composition of the ice rapidly and without contaminating the core (Moore and Paren, 1987). We measure the dielectric conductivity of the ice at VLF-LF frequencies as a function of depth in the core. Comparison with the chemistry shows that there is a high correlation. Preliminary data indicate that both marine salts and acids affect the conductivity.

In collaboration with the University of Lancaster, BAS scientists have pioneered an electron microscope technique which allows us to measure the concentration of impurities at specific locations in an ice sample (Mulvaney et al. 1988). In a section through three adjacent ice crystals (Figure 10) the junction between two crystals is seen as a line and the triple junction as a point.

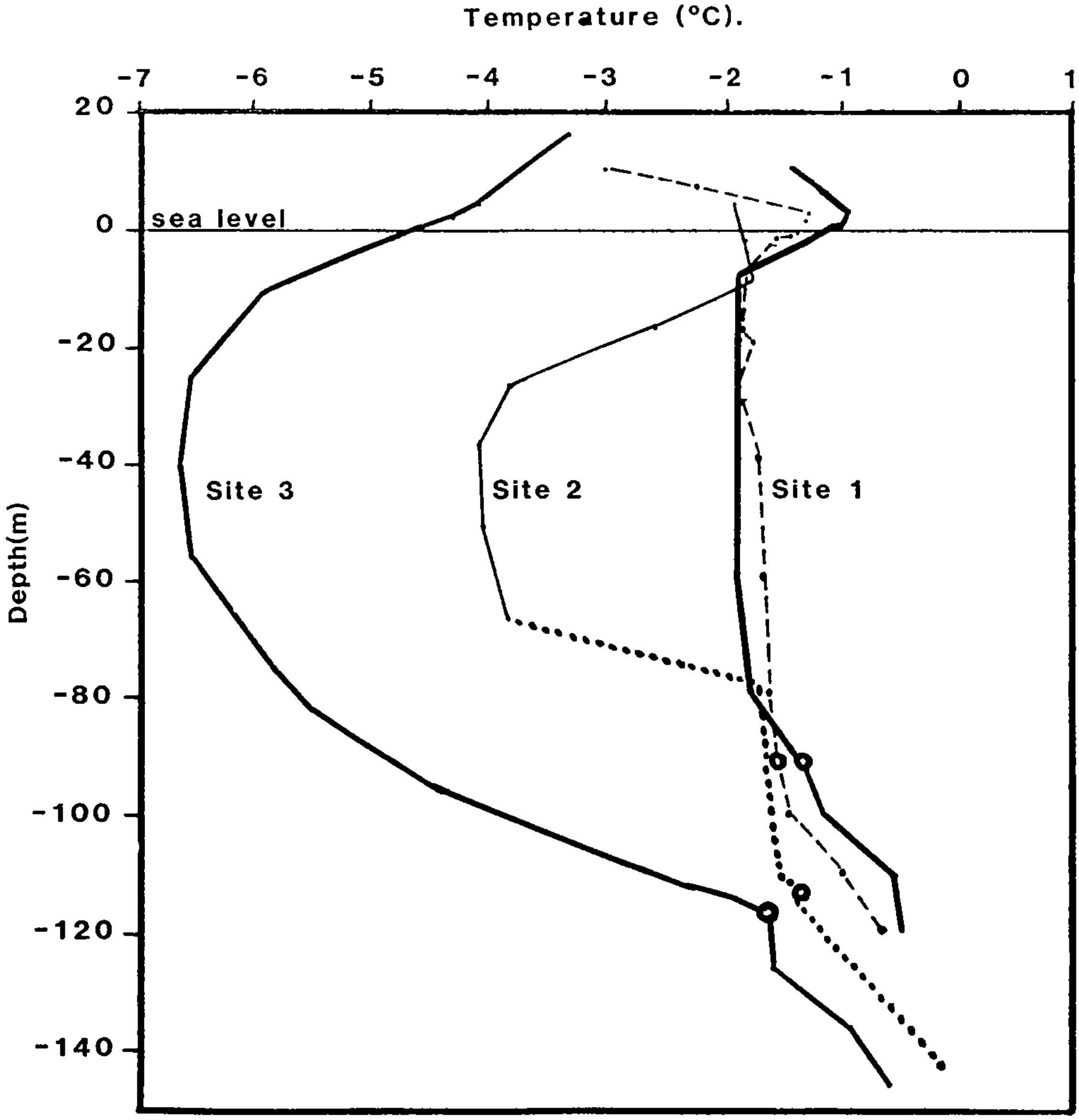

Fig. 12. Temperature profiles through George VI Ice Shelf.

The ice surface is covered in a thin aluminium layer (to make it electrically conducting) and the speckles are ice shavings and imperfections in the ice surface. The X-ray emission spectrum from the triple junction shows two peaks (Figure 11). One is at the wave-lenght expected for emission from aluminium and is produced by the aluminium glaze on the sample. The other is at the wave-length for sulphur. There is no peak for chlorine. The implication is that the sulphuric acid in the sample is concentrated at the triple boundaries whereas the sodium chloride is distributed at lower concentrations possibly throughout the ice grains. The location of the acid had already been predicted on theoretical grounds (Wolff and Paren, 1984).

Drilling can, of course, be used to make bore-holes rather than to take cores. Instruments lowered down the bore-hole can be used to obtain profiles of the ice properties, temperature for example. On George VI Ice Shelf strings of thermistors have been lowered into boreholes and left to record temperature profiles over the winter (Figure 12). The temperature near the surface of the ice shelf now is $-1°C$ to $-3°C$, which is remarkably warm. 50 years ago the surface temperature must have been about $3°C$ colder in order to produce the minimum temperatures which appear about 60 m down. The warming of the ice is due not only to conduction of increased sensible heat from a warmer atmosphere but als to convection of latent heat by increased melt water percolating into the upper layer of the ice shelf.

4. The Future

The very brief survey of some of our work given in the last section should make it abundantly clear that there is an immense amount of field work still required in order to produce adequate input and test data for a West Antarctic ice flow model. Nevertheless, we now feel that it is time to begin modelling work so that advances in theoretical and field studies can go hand in hand. BAS glaciologists are already testing a model developed by D.R. MacAyeal of the University of Chicago using our data from the Rutford Ice Stream. In the longer term, BAS is part of a consortium of UK universities and research institutes which plans to develop a UK ice flow model.

No survey of glaciological work in the Antarctic would be complete without some discussion of the influence of logistic restrictions on work in the field. Ten years ago the Survey had two Twin Otter aircraft, operating from an airstrip on Adelaide Island. With the purchase of a third Twin Otter it became possible to expand the sphere of operation of the Survey and increase the number of parties working in the 'deep' field each season. However, the logistic cost of establishing a field party on the Ronne Ice Shelf or Rutford Ice Stream using small aircraft is very high. Some 13 drums of fuel are expended to transport 1 drum to a deep field depot, for example. Clearly the long-term solution lies in the use of larger aircraft. The UK Government has just announced that funds will be made available for such an aircraft and for a gravel airstrip at Rothera Station. This will transform BAS operations in the deep field and allow rapid air access frm the Falkland Islands to the Antarctic Peninsula from 1991 onwards. In the short-term, the deployment of a fourth Twin Otter next season should ease the pressure on logistics and in particular allow an earlier start to the season.

The length of the field season (normally 5 months) has deterred many foreign and senior University scientists from visiting the Antarctic with the Survey. However, in the future, when direct air travel to Rothera base is developed, we expect that collaborative projects with other glaciologists will increase.

The British Antarctic Survey also, of course, makes every effort to maintain friendly links with the other Antarctic operators. We looks forward to exchanging ideas and information with our Korean colleagues from the Korea Ocean Research and Development Institute and wish them every sucess in their Antarctic research in the future.

Acknowledgements

I am grateful to my colleagues in the Ice and Climate Division of the British Antarctic Survey for providing the material for this review and to the Editors of Antarctic Sience, Annals of Glaciology, the British Antarctic Survey Bulletin, the Antarctic Research Series nd Nature for permission to reproduce figures first published in their journals.

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Hydrothermalism and Hydrocarbon Potential in the King George Basin of the Bransfield Strait, Antarctica

M. W. Han

Abstract

Submarine volcanism associated with the back-arc spreading in the Bransfield Strait, Antarctica causes seawater-basalt hydrothermal reactions as well as thermal interaction between the volcanism and organic-rich sediments in the King George Basin, which is a morpho-tectonic depression along the strait. Hydrothermal reactions are clearly evident in the anomalous porewater chemistry of the thickly sedimented King George Basin. Both chloride and the sum of the major cations (ΣNa, Mg, Ca, K) show significant enrichments downcore at all stations. The porewater chemistry of major seawater ions appears to be influenced by mixing of the end-member hydrothermal solutions, formed during seawater-basalt interaction, with unreacted (or diagenetically altered) seawater in the sediment column. Thermogenic gases and higher hydrocarbons in the basin, especially in the vicinity of basaltic dikes, strongly support the generation of hydrocarbon by the submarine volcanism. The discovery of thermogenic hydrocarbons may attest to an active petroleum source rock along the Antarctic continent.

Introduction

Much of seawater-basalt interaction appears to occur at depths normally as deep as 5 km within the oceanic crust (Hart and Staudigel, 1979). Such interaction is reflected in the porewater chemistry from sediment-covered mid-ocean ridge (MOR) flanks (Maris et al., 1984; Bender et al., 1985) or from areas where the oceanic crust is completely sealed by sediments (Mottl et al., 1983; Lawrence et al., 1975; McDuff, 1981; McDuff and Gieskes, 1976). Unfortunately, chemistry of hydrothermal solutions in sediment-covered system is much more complex than sediment-starved MOR system because hydrothermal solutions are obviously mixed with pore fluids which, in turn, may be altered by sediment diagenesis. Pore fluid composition in a sediment-covered hydrothermal system, therefore, must be regarded as a reflection of hydrothermal interaction among sediment, pore fluids, and basalts. Here, we document effects of sediment-covered hydrothermal reaction on the pore fluid composition in the King George Basin.

Bonafide characters of the hydrothermalism in sediment-starved MOR systems, such as hot vents (for example, from Corliss et al., 1979 to recently Rona et al., 1986) and giga plumes

(Baker et al., 1987; Cann and Strens, 1987), are now well documented and have revolutionized our concepts of seawater-basalt interaction (Edmond et al., 1979; Thompson 1983; von Damm et al., 1985a). Sediment-covered hydrothermal systems, though not violent and spectacular, have many unique characteristics which are not usually found in sediment-starved MOR systems: (1) generation of hydrothermal petroleum, (2) massive sill-injection into the sediment column, (3) greenschist facies metamorphism of the sediments, and (4) plumes of methane and heavier hydrocarbon compounds in the water column. These unique characters have initiated a new phase of investigation of sediment-covered hydrothermal systems and have been extensively documented, in particular, from the Guaymas Basin, Gulf of California (Lonsdale et al., 1980; Simoneit and Lonsdale, 1982; Einsele et al., 1980; von Damm et al., 1985b; Sweeney, 1980).

These characteristics of sediment-covered hydrothermal system are discovered from the King George Basin, Antarctica. Hydrothermal activity in the thickly sedimented King George Basin is significant in that the system is a unique site discovered so far under polar conditions and the basin, located underneath the most fertile waters of the circumpolar ocean, receives abundant marine organic matter and diatomaceous silica. The hydrothermal impact on this organic-rich sediments, therefore, greatly enhances hydrocarbon potential in the basin. A drilling along Antarctic continental margins has been limited to Leg 28 of the Deep Sea Drilling Project in the Ross Sea and off the Shackleton Ice Sheet (McIver, 1975). However, a conclusive evidence for thermogenic hydrocarbons was not established from this Leg. Here we discuss a hydrocarbon potential in the King George Basin where the thermal interaction between organic-rich sediments and submarine volcanism generates substantial amount of higher hydrocarbons.

Geologic Setting and Shallow Acoustic Structures

The King George Basin is one of several morpho-tectonic depressions along the Bransfield Strait, Antarctica (Fig. 1a). The strait was formed by back-arc spreading separating the South Shetland Islands chain in the north from the Antarctic Peninsula in the south. This spreading has been documented over the last 1.4 m.y. (Roach, 1978; Barker and Dalziel, 1983; Guterch et al., 1985). Prominent normal faults along the northern and southern margins run southwest to northeast, parallel to the strike of the Bransfield Strait. In the deep King George Basin normal faults develop, at least at present, predominantly along the southern basin margins (Fig. 1b). They expose scarps as their surface expression attesting to active rifting in the basin.

The basin, 60 km wide and 2 km deep, has a smooth floor covered by thick turbidites, but punctuated by volcanoes and numerous dike intrusions (Fig. 1b). The total sediment thickness in the basin is about 450 to 500 m (Guterch et al., 1985). The sediment cover, which thickens southeastward and consists of turbidite layers dipping in the same direction, is believed to be generated from the Antarctic Peninsula and to a degree controlled by the prominent fault distribution in the south (Fig. 1b).

The basin, located underneath the most fertile waters of the circumpolar ocean, receives abundant marine organic matter and diatomaceous silica derived from plankton, benthic algae from the shallow shelf region as well as glacial sediments of volcanogenic composition predominantly by turbidity currents (Suess et al., 1987; Wefer et al., 1982). Distinctive and correlatable turbidite layers across the basin are thus interlayered with sediments of a more

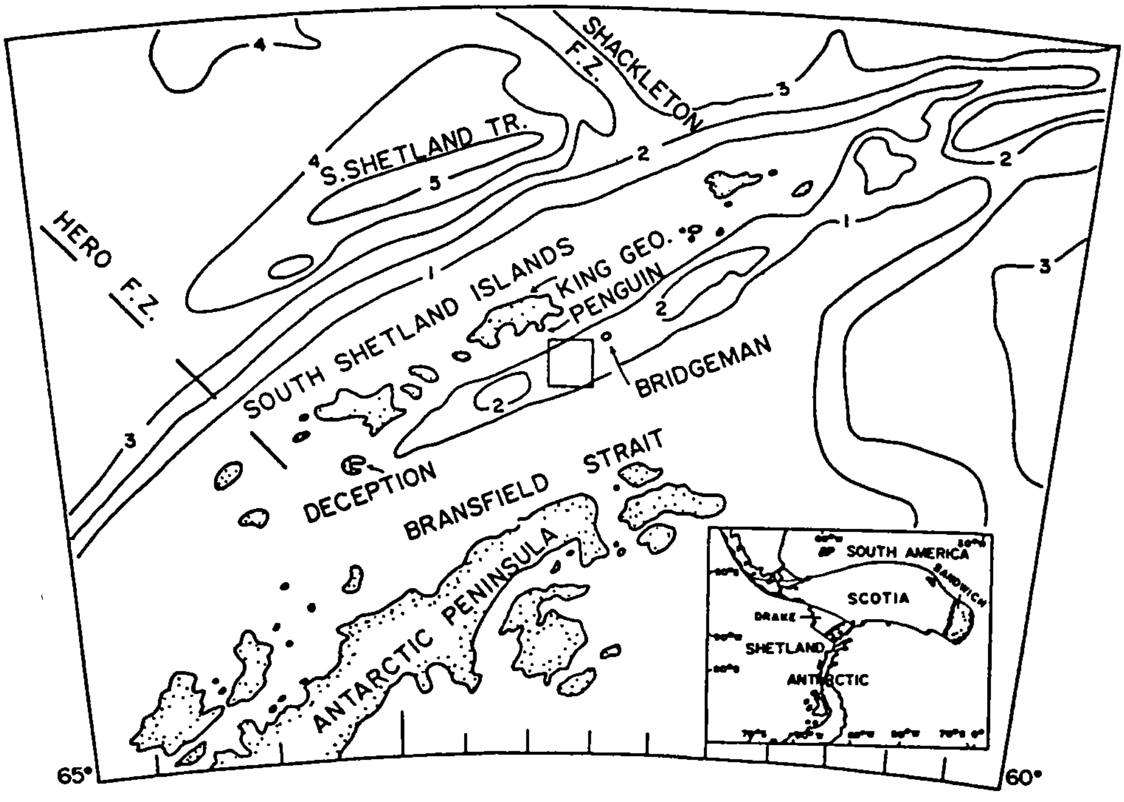


Figure 1a. The study area of the King George Basin in the Bransfield Strait, Antarctica (marked by a square). Regional tectonic map off the Antarctic peninsula is inserted. Subducton of the Drake plate into the Shetland trench initiated the spreading behind the Shetland Island arc.

hemipelagic type. The rate of sedimentation in the basin is very rapid ranging from 260 to 460 cm/1000 yrs, based on ^{210}Pb (Mangini, unpubl. data) and ^{14}C—activities (Erlenkeuser, unpubl. data). Resuspension of shelf-derived sediments and settling in deeper waters is evident from sediment trap deployments (Gersonde and Wefer, 1987). This process contributes to the high rates of sedimentation. Downslope slumping associated with the extensional faulting, is probably another cause for exceptionally high sedimentation rate. High organic carbon accumulation rate, 9.6 gC/m^2.yr, can be attributed to high seasonal primary production and a very high degree of organic matter preservation in these rapidly accumulating, strongly anoxic sediments (Suess et al., 1987).

Besides the volcanic activity observed as recently as the 1970s at Deception Island (Orheim, 1972; Roobol, 1982), which is located along the axis of the Bransfield Strait with the projected intersection of the Hero Fracture Zone (Fig. 1a), submarine volcanism associated with the process of back-arc spreading has been detected in the King George Basin. The major submarine volcanoes show an arch distribution from north to south at the eastern side of the basin forming a 'volcanic wall' on the eastern side (Fig. 1b). Two new sea mounts were discovered during our 1985 survey. Subsequent dredging of fresh basalts and pillow basalts as well as the encounter of hydrothermal petroleum in our gravity cores all attest to vigorous ongoing volcanic activity (Suess, 1988). Anomalous ^3He and Mn from hydrocasts in prox-

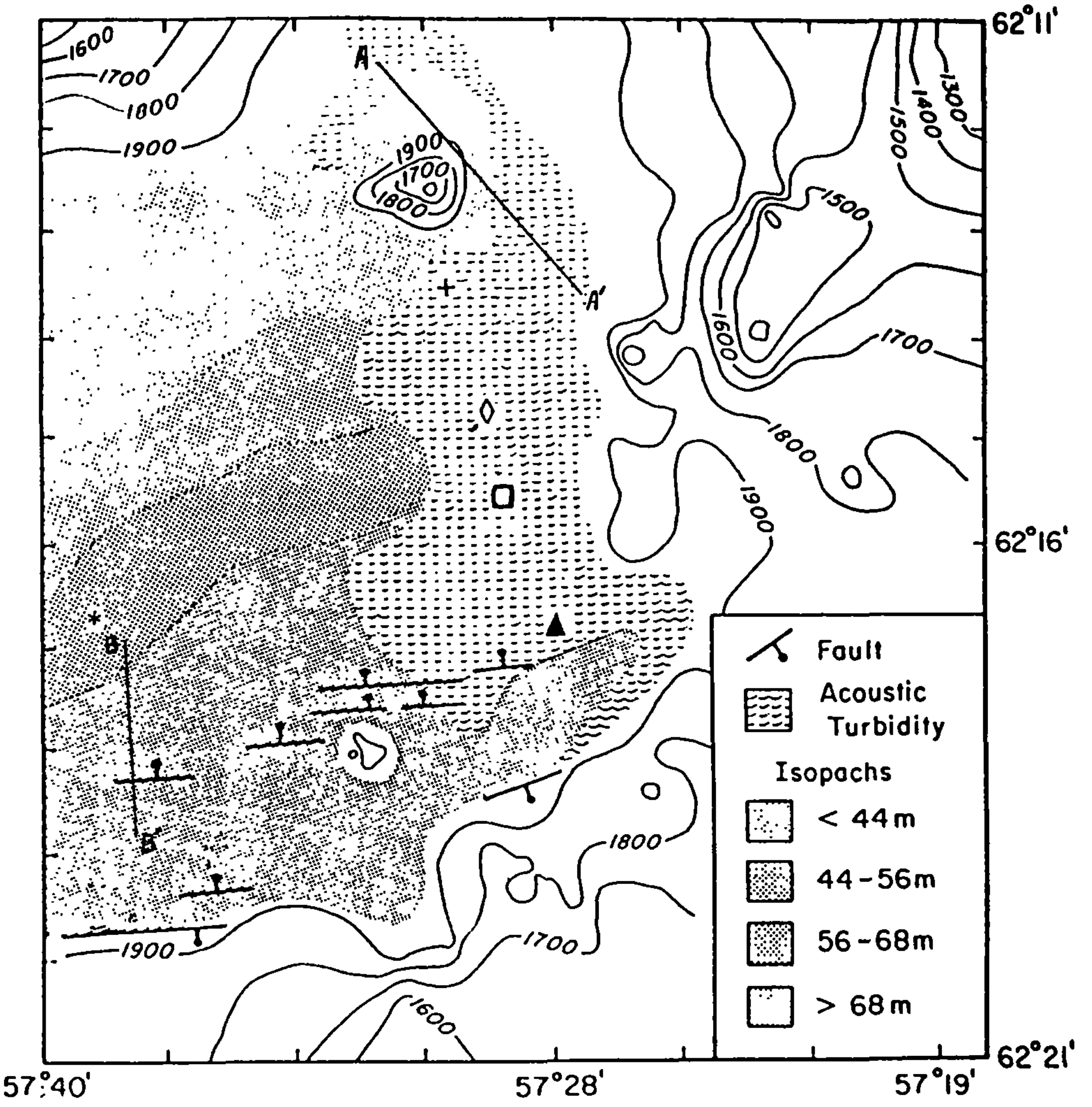


Figure 1b. Sedimentary and tectonic features in the King George Basin. In the deep King George Basin normal faults develop predominantly along the southern basin margins. The sediment cover thickens southeastward. Circular contours indicate major submarine volcanoes which are predominantly distributed in the northeastern and eastern end of the basin. Note the area of acoustic turbidity adjacent to the submarine volcanoes. 'Hydrothermal' core stations, 1346(▲), 1340(□), 1341(◇) and 1343(+), are located within the acoustic turbidity zone. A 'reference' core station, 1327(*), is located in the central basin.

imities of the submarine volcanoes in the basin suggest emanation of ^{3}He and Mn from the volcanoes (Schlosser et al., 1988).

An area of very pronounced acoustic turbidity (i.e., no acoustic reflection in the 3.5 kHz records) develops toward the center of the basin from the eastern 'volcanic wall' (Fig. 1b and Fig. 2a). It is from this acouistic turbidity zone that porewater chemistry shows distinct hydrothermal characters and high concentrations of thermogenic hydrocarbon gases are discovered. Though we suspect that the acoustic-turbidity is ultimately related to such submarine volcanic activity, the specific cause remains speculative. For the rest of the King George Basin, excellent acoustic penertration was achieved through sequences of turbidites with numerous reflectors. The shallow acoustic structures confirm the tectonics shown by the deeper air-gun seismics (Guterch et al., 1985). Variable deformation of sediments associated with dike intrusions strongly suggests that the King George Basin is a graben bounded by normal faults through which magma rises to the sea floor. The central basin portion seems to be undergoing rifting which likewise is associated with volcanic intrusions in the form of sills and dikes.

Methods

A working map of the bathymetry of the King George Basin was generated by a computer plot of the INDAS.10 navigation data which recorded positionings and water depths at 10 minute intervals during our survey of the basin in November 1985. A móre detailed, high-resolution bathymetric chart utilizing 5 second interval data will be prepared by the Alfred-Wegener-Institute for Polar Research in Bremenhaven, West Germany. Morpho-tectonic features such as faults, submarine volcanoes, intrusions, and the distribution pattern of sediment isopachs were mapped by superimposing the 3.5 kHz records over the contour map on which the ship track was projected (Fig. 1b).

During the cruise a transect of sediment cores was obtained from within the acoustic turbidity zone adjacent to the 'volcanic wall' in the eastern end of the King George Basin (Fig. 1b). Four gravity cores ranging from 5 to 8 m in length were acquired from the transect where hydrothermal activity was anticipated from our previous results (Suess, 1984) (Table 1 and Fig. 1b). These core stations are called 'hydrothermal' stations. For comparison a gravity core was sampled from the region in the central King George Basin unaffected by hydrothermalism (Fig. 1b). This core station will serve as a 'reference' station. Porewater samples were collected from the gravity cores. Porewater chemistry data consisting of Cl, Na, Mg, Ca, K, SO_4, NH_3, PO_4, SiO_2, total CO_2, and alkalinity were obtained from these cores.

Immediately after core collection porewater smaples were extracted from the gravity cores through 0.45 μm membrane filters at approximately in situ temperatures (0 - 3°C) to avoid a temperature-of-squeezing effect and other possible artifacts. An average of 250 ml of porewater was obtained from each squeezing. To accommodate with the manuscript length of the symposium our discussion is limited to the major elements, Cl, Na, Mg, Ca, and K. These elements were measured at the shore-based laboratory.

Table 1. Core locations in the King George Basin

Station	Latitude °S	Longitude °W	Water Depth (m)
1327	62°16.5′	57°38.7′	1978
1346	62°16.8′	57°29.1′	1979
1340	62°15.7′	57°29.2′	1980
1341	62°14.8′	57°28.7′	1980
1343	62°13.4′	57°30.3′	1970

Faber and Stahl's method (1983) was used for the analysis of the molecular and stable isotopic composition of the hydrocarbon gases. However, an aliquot of the degassed sample was measured directly by a GC onboard, while the remainder was kept in gas sample bulbs, until oxidized and run for isotope mass ratio at the shore based laboratory of BGR, Hannover.

Porewater Chemistry

The porewater composition from the four hydrothermal stations (1346, 1340, 1341, and 1343) within the acoustic turbidity zone in the eastern end of the King George Basin is characterized by the downcore enrichment of Cl (Fig. 2) and a corresponding increase in the sum of the major cations (Na, Mg, Ca, K) (Fig. 3). Such a distribution of the dissolved major ions of the hydrothermal stations is significantly different from that of the reference station (1327) in the central King George Basin. Here neither Cl nor the sum of the major cations shows any change with depth (Figs. 2 and 3).

Near the sediment-water interface, however, the porewater chemistry data at all hydrothermal stations converge to the composition of bottom water (Figs. 2, 4). This indicates that the intensity of the hydrothermal fluid movement is not strong enough to imprint its signal all

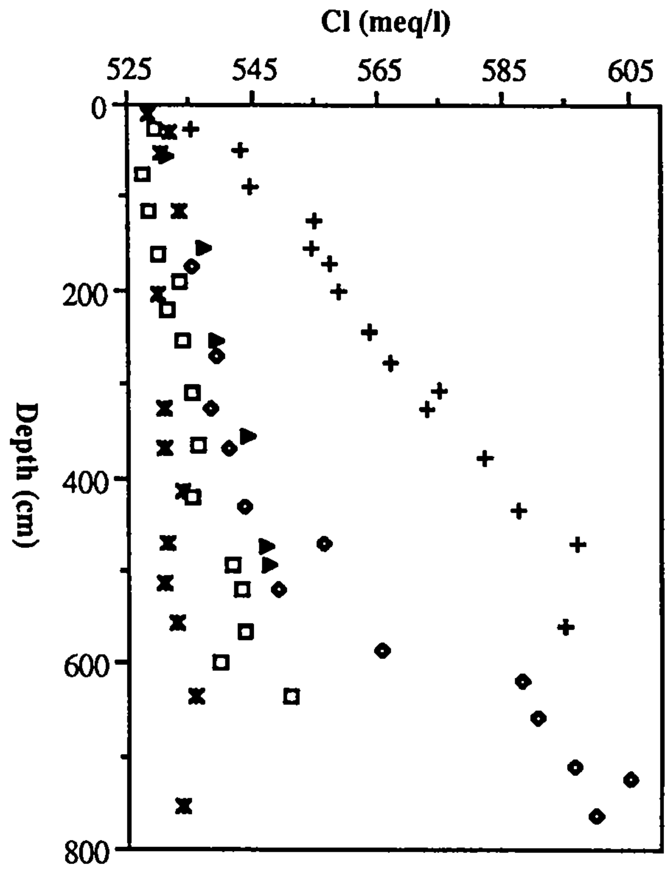


Figure 2. Depth profiles of the interstitial Cl concentration. At all hydrothermal stations, 1346(▲), 1340(□), 1341(◇) and 1343(+), Cl shows downcore increase, 3 to 14%, relative to the bottom water Cl. At the reference station, 1327(*), no significant change in Cl is observed.

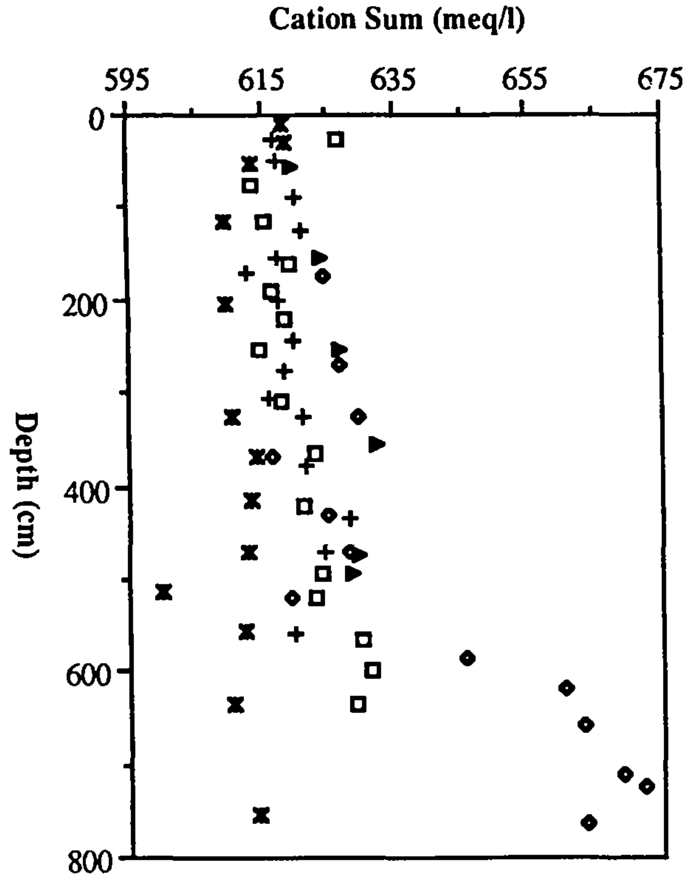
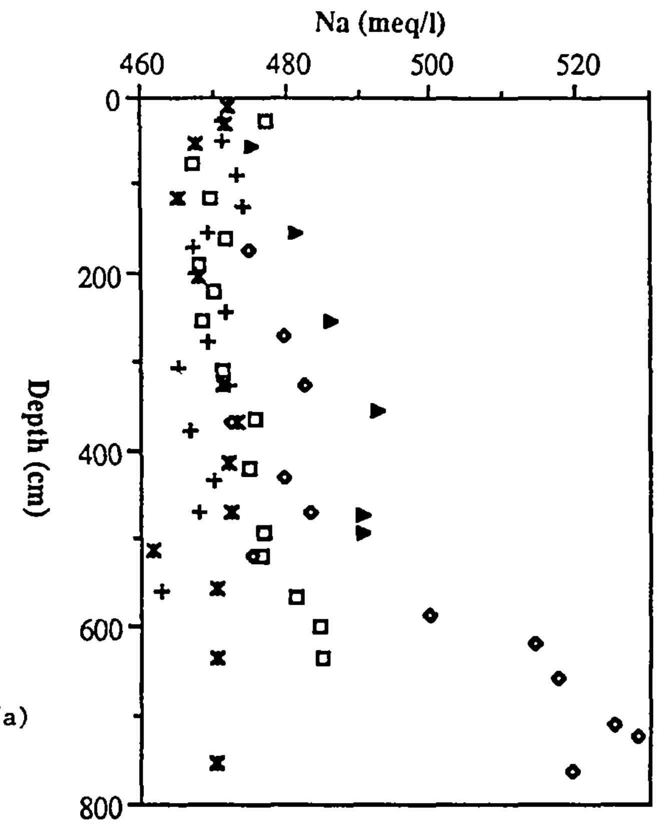


Figure 3. Depth profiles of the sum of the interstitial major cations (ΣNa, Mg, Ca, K). The sum of the major cations at all hydrothermal stations, 1346(▲), 1340(□), 1341(◇) and 1343(+), shows downcore increase (2% to 9%). AT the reference station, 1327(*), no significant change in the sum is observed.

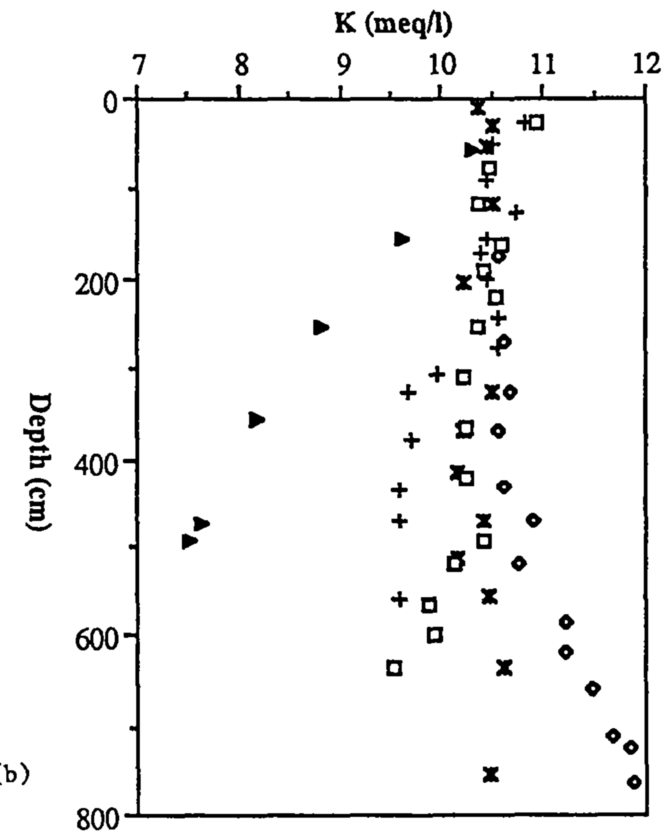
the way to the surface, i.e., the flow rates are not sufficient to flush out the bottom water and thus the hydrothermal water dissipates before reaching the sediment-water interface. Therefore, it seems unlikely to observe exiting hydrothermal water through chimneys as in the Guaymas Basin (Lonsdale and Becker, 1985; Merewether et al., 1985). Nonetheless, anomalouis ^{3}He and Mn in the bottom water (Schlosser et al., 1988) indicate that a hydrothermal discharge reaches the free water column in the KIng George Basin, perhaps through confined venting pathways rather than diffuse flow through the sediments (Han and Suess, 1987).

Chloride

Chloride, being a conservative ion, is not affected by early diagenesis in marine sediments. At the reference station (1327) interstitial Cl shows no significant change in its downcore concentration (Fig. 2). Hydrothermal solutions generated in laboratory experiments (Seyfried et al., 1986) as well as sampled from EPR hot springs (Michard et al., 1984; von Damm et al., 1985a; Edmond et al., 1979) have shown both enrichment and depletion of chloride relative


Na (meq/l)
460
480
500
520
0
200
400
600
800
Depth (cm)

(a)


K (meq/l)
7
8
9
10
11
12
0
200
400
600
800
Depth (cm)

(b)

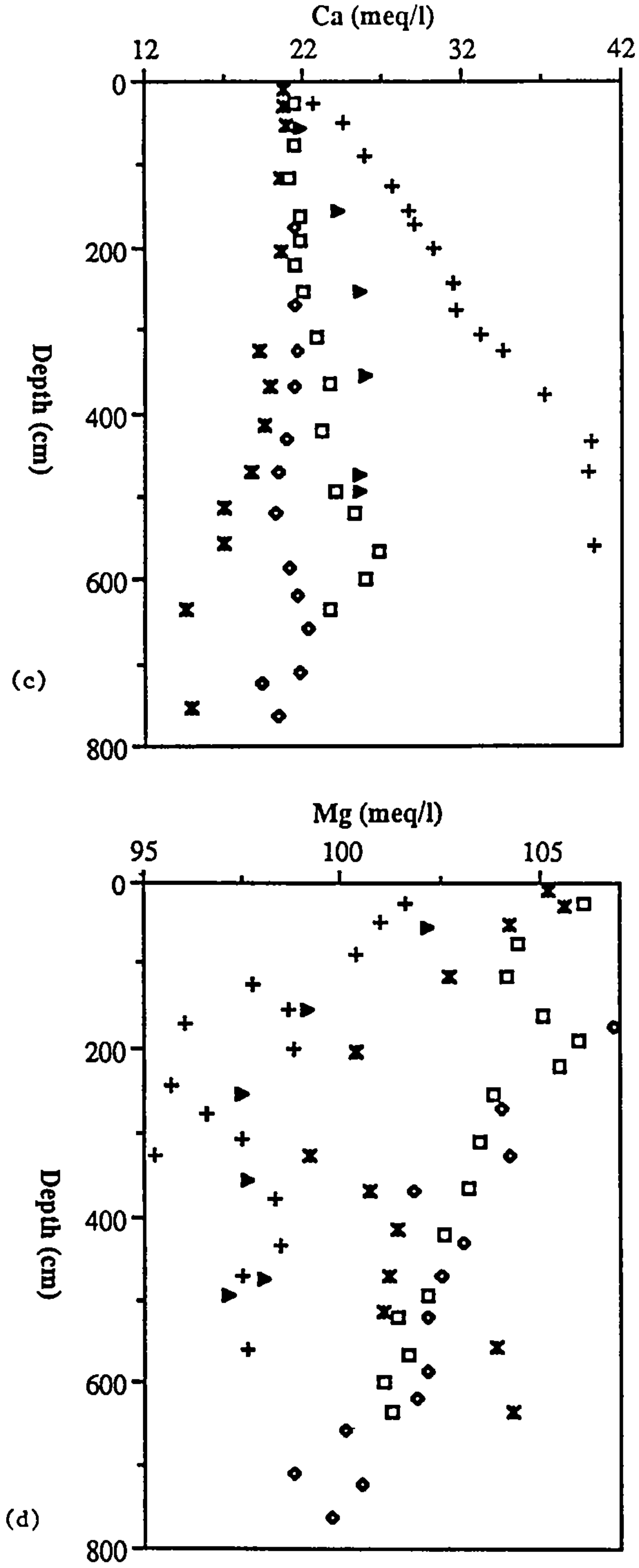


Figure 4. Downcore concentration profiles of interstitial major cations, Na, K, Ca, and Mg. The hydrother mal stations are 1346(▲); 1340(□), 1341(◇) and 1343(+).

Table 2a Percent gain or loss of interstitial major ions, rounded to the nearest one %. Bottom water concentrations are included for reference. Increments of Na and Cl concentrations are also included in the last two rows.

Ion	St 1346	St 1340	St. 1341	St. 1343	St. 1327	Bottom water
Cl	+4	+3	+12	+14	±0	528 meq/l
Na	+4	+3	+13	-2(-16*)	±0	471 meq/l
K	-33	-10	+14(+1*)	-10	±0	10.5 meq/l
Ca	+25	+26	0(-12*)	+100(+70*)	-30	105 meq/l
Mg	-8	-5	-7	-10	-8 to +1**	21 meq/l
ΔCl	23 meq/l	15 meq/l	63 meq/l	74 meq/l		
ΔNa	24 meq/l	14 meq/l	61 meq/l	-9(-75) meq/l		

* when correction is made for water loss due to basalt hydration,

**initially Mg decreases downcore but increase again at greater depths

to normal seawater. At all hydrothermal stations from the acoustic turbidity zone in the King George Basin where numerous extrusive and intrusive volcanic features are distrubuted throughout, however, chloride concentration consistently increases downcore in the pore fluids (Fig. 2). The increase rangses from 543 meq/l (Station 1340) to 602 meq/l (Station 1343), or 3% to 14% over the chloride content of the bottom water (Table 2a). In the Guaymas Basin, enrichment of the end-member chloride ranged from 8 - 18 % and was attributed to a loss of water to hydration (von Damm et al., 1985b). The increase in porewater Cl in the King George Basin is already close to the end-member Cl in the Guaymas Basin by 78%. The end-member Cl in the King George Basin, obtained from extrapolating our porewater data ranges from 605 meq/l to 727 meq/l, or 15% to 38% increase over the bottom water Cl. This Cl enrichment in the end-member solutions is about two times greater than that of Cl in the Guaymas Basin. Therefore, basalt hydration which appears to occur at low temperature by conductive cooling of basalt is further substantiated as a responsible reachtion mechanism for the great amouint of Cl enrichment in the King George Basin.

Any increase in Cl, however, may equally be explained by retrograde alteration reaction. An experimental study by Seyfried et al. (1986) on Cl-behavior during hydrothermal alteration of basalts concludes that Cl is taken up from seawater by the formation of Cl-bearing phases such as Fe-hydroxy chloride at high temperatures (400 to 450oC) and low water/rock ratios. As the system cools down Cl is released to the solution by retrograde alteration/dissolution of these Cl-rich mineral assemblages. According to Seyfried et al. (1986) this retrograde alteration/dissolution of basalts prevails at low temperature, less than 350°C, and with high water/rock ratios. Further investigation onto these two potential reactions is continued in the following.

Sodium

At all hydrothermal stations, except Station 1343, interstitial Na shows a downcore increase corresponding to that of Cl (Fig. 4a). The ratio of the percent increase between Na and Cl

Table 2b Types of reactions inferred from the changes in interstitial major ions

	St. 1346	St. 1340	St. 1341	St. 1343	St. 1327
Cl — Na	Hydration	Hydration	Hydration	Retrograde	None
Cl — K	Retrograde	Retrograde	Hydration	Retrograde	None
Cl — Ca	Retrograde	Retrograde	Retrograde	Retrograde	Ikaite Formation
Cl — Mg	Inconclusive	Inconclusive	Inconclusive	Inconclusive	Ion-exchange

is approximately one at hydrothermal stations 1346, 1340 and 1341 (Table 2a) indicating that the gain in Na is sufficient to balance the gain in Cl. This suggests that hydration of basalts is very likely, at least with respect to Na and Cl, at these stations (Table 2b). At the reference station (1327) interstitial Na does not show any change, indicating normal diagenesis (Fig. 4a).

Interstitial Na decreases downcore at Station 1343 despite the largest Cl increase. If the 14 % Cl increase were due to basalt hydration, the corrected Na decerase would be exaggerated to be 16 % suggesting a net loss of Na (Table 2a). Charge imbalance due to the hydration is then exaggerated to 149 meq/l, Cl - Na. If it is assumed that a Ca release balances the loss of Na, then the amount of Ca to be released should be 149 meq/l. As will be discussed in the following section of Ca, the calcium shows the greatest increase at Station 1343. The 100 % increase in Ca at Station 1343, however, would decerase to 70 % if hydration is assumed This corrected Ca increase suggests that a release of Ca would be only 30 meq/l. This insufficient Ca release to balance the Na loss suggests that basalt hydration is not likely at Station 1343. Therefore, at Station 1343, it is likely that a responsible reaction for the independent variations of Na and Cl is not basalt hydration but retrograde alteration which is characterized by Cl release in solution and Na uptake in basalt (Table 2b).

Potassium

Interstitial K remains essentially unchanged at the reference station (1327) (Fig. 4b), this indicates a lack of hydrothermal reaction but instead normal diagenesis at the reference station. Interstitial K decreases downcore at all hydrothermal stations except at Station 1343 which shows a downcore increase (Fig. 4b). Hydrothermal end-member solutions at Stations 1346, 1340 and 1343 thus appear to be depleted in K. Reportedly K is taken up by basalt during low temperature hydrothermal reactions (Seyfried and Bischoff, 1979; Seyfried and Mottl, 1982; Staudigel and Hart, 1983). Therefore depletion of K, in addition to Cl-enrichment, indicates low-temperature hydrothermal reactions in the basin.

If the 12 % increase in both Cl and Na at station 1341 were due to basalt hydration, the corrected K-increase for the basalt hydration would reduce to only 1 % (Table 2a). Since such a small enrichment is within the margin of accumulated errors from analyses and estimation of percent enrichment, the apparent percent change in K at Station 1341 may also indicate depletion of K in hydrothermal end-member solutions. This argument supports that at Station 1341 basalt hydration is a controlling reaction mechanism for the end-member composition of the hydrothermal fluid at least with respect to Na, K and Cl, rather than retrograde alteration/dissolution (Table 2b).

Calcium

Calcium shows downcore increase in the pore fluids of all hydrothermal stations except at Station 1341 (Fig. 4c). Interstitial Ca shows almost no change downcore at Station 1341. Generally, the overall increase in Ca at the hydrothermal stations 1343, 1340 and 1346 agrees well with the Ca-enrichment in hydrothermal solutions (Edmond et al., 1979, von Damm et al., 1985a). When correction is made for water loss by basalt hydration at Station 1341, interstitial Ca shows 12 % decrease (Table 2a). Therefore basalt hydration is not likely at Station 1341 at least with respect to Ca. Retrograde alteration reaction characterized by no change in Ca may be a responsible reaction at Station 1341 (Table 2b).

It is interesting to note that at the reference station (1327), interstitial Ca shows downcore decrease (Fig. 4c). The decrease in Ca is perfectly matched with the occurrence of calcium carbonate hexahydrate (= mineral ikaite) in the core (Suess et al., 1982). Ikaite formation is a diagenetic process which consumes porewater Calcium. No ikaite was found from the cores at any hydrothermal stations.

Magnesium

At all hydrothermal stations interstitial Mg decreases significantly downcore, which agrees with the reported depletion of Mg in hydrothermal solutions (Fig. 4d). At the reference station (1327), however, interstitial Mg shows a decrease followed by an increase downcore (Fig. 4d). Such a Mg concentration profile is entirely due to diagenetic reactions involving ion-exchange with clays, as recently elucidated by von Breymann (1987). In general, early diagenetic decomposition of sedimentary organic matter causes an increase of the total cation exchange capacity of the sediment due to removal of organic matter which blocks the clay exchange sites. Unblocking of the exchange sites causes an uptake of Mg from the pore solution and is responsible for the observed initial Mg-decrease. Subsequently, with increasing concentration changes of metabolties, —i.e. increase in total CO_2 and decrease in SO_4—the free Mg-ion concentration is effectively reduced by increased ion-pair formation. This process causes a re-distribution of Mg-ions by desorption from exchange sites of clay particles to maintain the ion-exchange equilibrium. The re-equilibration is responsible for the observed Mg-increase.

Consistent downcore decrease in interstitial Mg at all hydrothermal stations reflects hydrothermal alteration reactions; Chloritization of feldspars may be an appropriate hydrothermal alteration reaction for such Mg-changes (von Damm et al., 1985a). However, the ion-exchange reaction associated with diagenesis could also occur at all hydrothermal stations. Therefore estimates of the magnitude of hydrothermal alteration vs. ion-exchange remain inconclusive (Table 2b).

Hydrothermal Alteration Reaction

Signals for the hydrothermal reaction in the eastern King George Basin were evident in the downcore enrichments of Cl and the corresponding increase in the sum of major cations. Reported downcore changes in interstitial Cl from sediments of lakes or estuaries, however, have also been attributed to salinity fluctuation in the overlying water (Lerman and Weiler, 1970; Matisoff, 1980). Downcore enrichment of Cl at the hydrothermal stations ranges from 3% (Station 1340) to 14% (Station 1343). These changes can not be explained by salinity fluctuation in the overlying seawater, because the magnitude to which the salinity fo the overlying seawater would have to change can only be expected estuaries, tidal flats, or marshes. Even in these transitional, shallow-water environments the changes in Cl in response to salinity fluctuation of the overlying water are restricted to the uppermost sediment layer of less than 1 m in depth. Therefore, the downcore enrichments of Cl in the hydrothermal stations must be related to causes other than salinity fluctuation of the King George Basin water.

There are two processes which can result in increased Cl concentration in pore waters: retrograde alteration and/or baslat hydration, both of which are characteristically low-temperature hydrothermal reactions. At this point there is no independent evidence to determine which process is more influential in generating Cl-enriched hydrothermal solution, though Cl-enrichment itself indicates low-temperature hydrothermal reaction at the King George Basin. A one-to-one enrichment between Cl and Na at all hydrothermal stations, except Station 1343, definitely suggests basalt hydration in the area of the King George Basin at least with respect to Na and Cl. Basalt hydration is most strongly inferred at Station 1341 because of the accompanying K-distribution; (see the result section for potassium, Table 2b).

The large variation in concentration for each of the major cations between hydrothermal stations, however, does not rule out retrograde alteration/dissolution of basalt. At least with respect to K and Ca all hydrothermal stations, except Station 1341, suggest retrograde reactions. The Na-decrease, despite the Cl-increase, as well as distributions of Ca and K at Station 1343 suggests predominant retrograde reactions (Table 2b). Prograde basalt alteration during high-temperature reactions in the past might have generated greatly differentiated mineral assemblages with a wide range of composition. The end-member composition of hydrothermal fluids in the King George Basin at present, though, seems to be generated by low-temperature alteration of these differentiated basalt assemblages. The potential reactions are

Table 3 Potential low-temperature hydrothermal reactions and their likelyhood in controlling the pore water composition at the hydrothermal stations in the King George Basin.

(HOB)	Hydration of Basalts
(A-1)	Fe-hydroxy chloride + Na^+ + SiO_2 + Clinochlore + Clinozoisite = Plagioclase + Olivine + Ca^{++} + Cl^-
(A-2)	Fe-hydroxy chloride + Albite + Clinochlore + Clinozoisite = Plagioclase + Olivine + Na^++ SiO_2+ Cl^-
(B-1)	Anorthite + Na^+ + $Si(OH)_4$ = Albite + Ca^{++} + $Al(OH)_4$-
(B-2)	Anorthite + Ca^{++}+ $Al(OH)_4^-$ + $Si(OH)_4$ = Epidote + H_2O + H^+
(C-1)	Epidote + $3Mg^{++}$ + $2Fe^{++}$ *8+ H_2O = Chlorite + $2Ca^{++}$+ $Al(OH)_4$+ $7H^+$
(C-2)	Albite + $3Mg^{++}$ + $2Fe^{++}$ + $Al(OH)_4^-$ + H_2O $\doteq$ Chlorite + Na^+ + $8H^+$

Station	Likely	Unlikely
1346 and 1340	(HOB), (A-2), (C-1), (C-2)	(A-1), (B-1), (B-2)
1341	(HOB), (A-2), (B-2), (C-2)	(A-1), (B-1), (C-1)
1343	(A-1), (B-1), (C-1)	(HOB), (A-2), (B-2), (C-2)

listed in Table 3 along with an assessment of them controlling the porewater composition.

Occurrence of both retrograde dissolution and hydration suggests that the system in the King George Basin is a low-temperature hydrothermal system, probably at late stages of reaction. Depletion of interstitial K provides an additional evidence for low-temperature reactions. Laboratory experiments on seawater-basalt interaction indicate that K-uptake onto solid occurs at temperature of 70-150°C (Seyfried and Bischoff 1979; Menzies and Seyfried,d 1979). Based on this result it may be concluded that the raction temperature in the King George Basin may at least be 150°C.

Thermogenic Gases

The most interesting result of the hydrothermalism in the King George Basin was the discovery of significant quantities of higher hydrocarbon gases (C_2 - C_6). The sediment possessed a marked petroliferous order throughout the cores. These gas concentrations, normalized to CH_4, and their isotopic ($\delta^{13}C$) composition strongly indicate that they are thermogenic. At this stage it is not known whether the gas seep originates from a deep, mature reservoir rock, or from a shallow, young hydrocarbon sources generated by volcanic sill intrusions into the organic-rich sediments.

A downcore increase in hydrocarbon concentrations is shown (Fig. 5). Heavier values of $\delta^{13}C_1$ and $\delta^{13}C_2$ are strongly indicative of thermogenic character. Presence of sulphate throughout core precludes 'in situ' biogenic methane formation by fermentation. The empirical relationship between $\delta^{13}C_1$ and C_1/C_1+C_2 indicates that source organic matter generating the hydrocarbon gases is mature enough to be within the oil window (Fig. 6). This diagram unambiguously supports thermogenic origin of the hydrocarbon gases and very likely a deeply buried petroleum reservoir.

Free methane concentrations in sediments ranged downcore from a background level of several ppb to >50,000 ppb depending on the nature and content of sedimentary organic matter and rates of sulfate reduction, carbonate reduction, and bulk sedimentation. The highest concentrations of >50,000 ppb approach the saturation level (>95 %) of methane in seawater and consequently are thought to give rise to one type oa acoustically turbid structures in the shallow sediments of the King George Basin.

N-alkanes between C_{25} and C_{31} are the dominant saturated hydrocarbons. The presence of higher carbon number (C_{24+}) n-alkanes in all the samples indicates contributions of terrestrial organic material (Brault and Simoneit, 1988). In the deepest portion of the cores a relatively high contribution of rearranged steranes was observed. This steranes is characteristic of many oils and thus would not be expected in immature recent sediment. The decrase in extract content close to the surface may be due to vertical fluid migration that may remove soluble organic matter. The absence of lower molecular weight (n-C_{16} to n-C_{21}) n-alkanes could also be attributed to a water flushing alteration.

Thermogenic hydrocarbon seepages are common for most of the world's major petroleum accumulations. However, hydrocarbon quantities found in the King George Basin, though thermogenic, are not on the same scale as those seepages. They should certainly be referred to as a micro seeps. Nonetheless, our data present interesting initial geochemical evidence for active petroleum source rocks along the Antarctic continent.

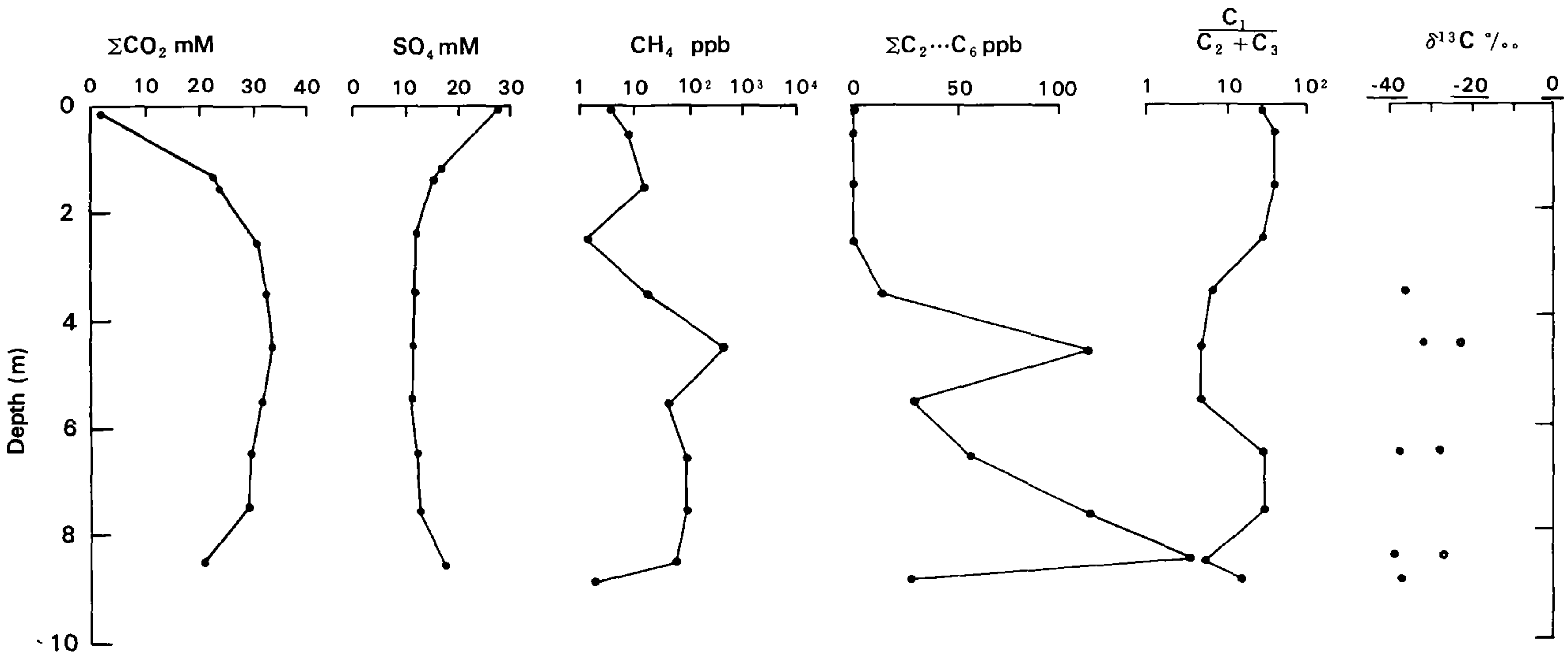


Figure 5. Downcore concentration profiles of hydrocarbon gases at Station 1341. Similar profiles are obtained throughout the hydrothermal stations in the basin *with a systematic increase in concentration from the southern to the northern stations.* Profiles of $\delta^{13}C_1$ (solid circles) and $\delta^{13}C_2$ strongly suggest thermogenic character of these hydrocarbons.

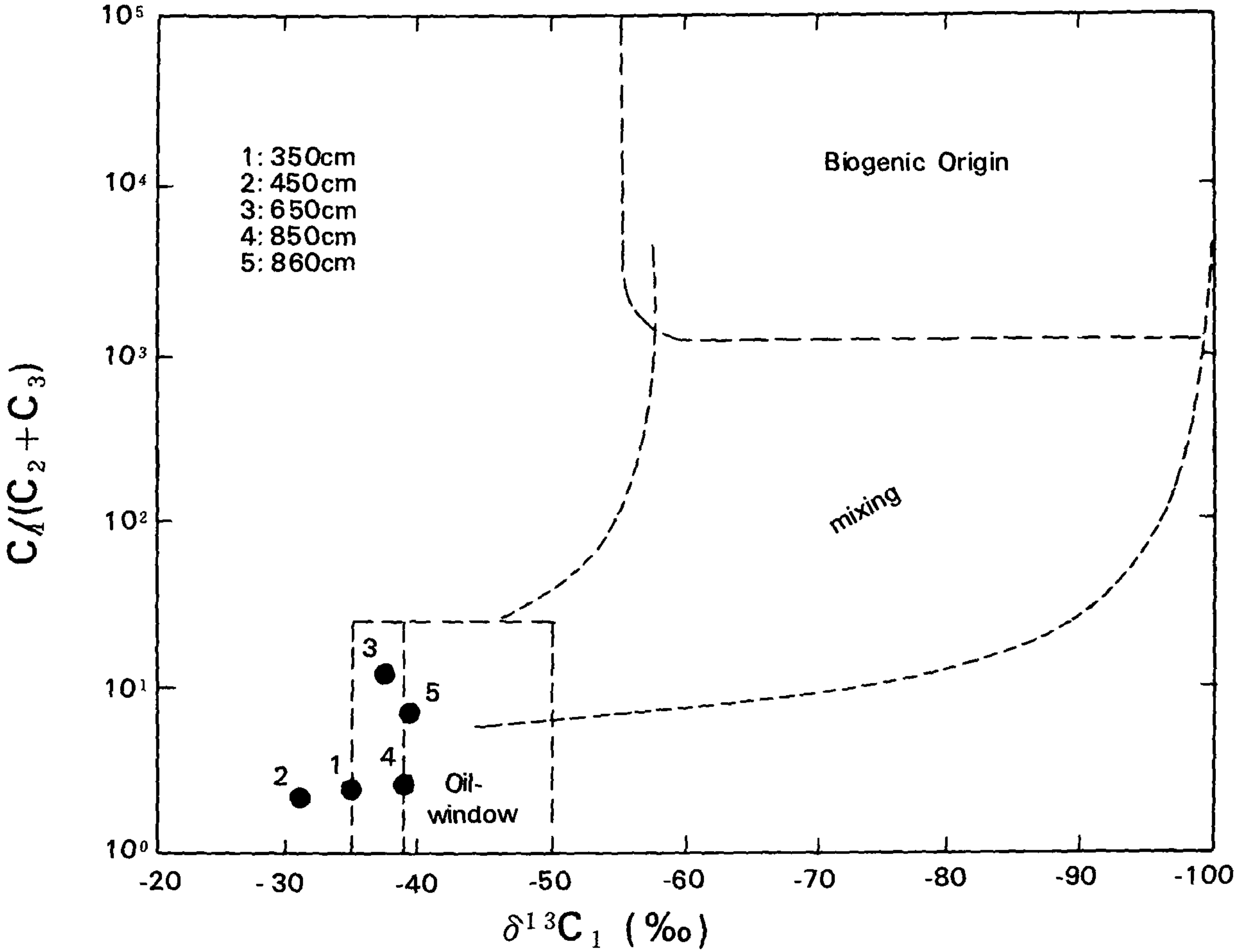


Figure 6. Empirical relationship between $\delta^{13}C_1$ and the values of C_1/C_2+C_3. The hydrocarbon gases are mature enough to be in the oil windown

Summary

1. Significant downcore enrichments of both interstitial Cl and the sum of major cations in the eastern end of the King George Basin clearly indicate hydrothermal seawater-basalt reactions underneath the thickly sedimented basin.
2. Cl-enrichment and K-depletion suggest low-temperature hydrothermal reactions in the basin (70 to 150°C). Both basalt hydration and retrograde alteration/dissolution are likely to be the reactions by which the hydrothermal solutions are generated.
3. A low-temperature regime in the basin generates far less intense hydrothermal activities than observed in the Guaymas Basin. However, the encounter of the hydrothermal pore fluids as shallow as 5 m below the seafloor indicates that the hydrothermal system is still capable of migrating hydrothermal waters upward.
4. The thermogenic hydrocarbons in the basin, especially in the vicinity of the basaltic dikes, strongly support hydrocarbon generation by submarine volcanism. Such evidence, coupled with the rcent eruptions of Deception Island, suggests that the Bransfield Strait is undergone back-arc spreading at high latitudes, i.e., south of 60 degrees. The discovery of thermogenic hydrocarbons in the King George Basin further substantiates the petroleum potential along the Antarctic continent.

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Part III. Antarctic Geology

Crustal Structure of the Ross Embayment, Antarctica

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Abstract

The Ross embayment, which encompasses the Ross Sea and Ross Ice Shelf is a broad area of crustal thinning the extension between East and West Antarctica. The Ross Sea is underlain by large buried basement-grabens that may extend for over 1000 km beneath the Ross embayment. These grabens are filled with up to 8 km of possible rift-related sediments that are unconformably overlain by up to 6 km of glacial and possible pre-glacial marine strata. The sedimentary sections are mostly flat-lying and undeformed, except in the Terror Rift of the western Ross Sea. The geometry and sediment fill of basement grabens lying beneath the Ross Ice Shelf is poorly known. Basement structures in, and adjacent to, the Ross embayment are apparently cut by major transverse faults that have influenced horizontal and vertical displacements across the embayment.

We believe that seismic-reflection data show evidence for episodic crustal extension in the Ross embayment; however, the timing is poorly constrained, by regional geology only. Significant extension (at least 100%), controlled by large-plate motions, has probably accrued principally during an early-rift period in late Mesozoic time. This time was marked by widespread graben downfaulting, crustal thinning, and mostly subsequent sedimentation. Deformation due to a late-rift period (Eocene and younger) appears, from seismic data, to have been localized principally at the Transantarctic Mountains, Terror Rift, and Marie Byrd Land. This deformation has been most severe in late Cenozoic time.

Introduction

The Ross embayment is the 800-km-wide structural depression that extends up to 1800 km across the Ross Sea and Ross Ice Shelf (Figure 1). The embayment separates the East Antarctic craton from the areas of West Antarctica that lie in Marie Byrd Land. Numerous authors have proposed that crustal extension within the Ross Embayment separated East and West Antarctica since Jurassic time. These ideas are based on regional geophysical and geologic mapping (Elliot, 1975; Hayes and Davey, 1975; Davey, 1981; Kadmina et al., 1983; Bentley, 1983; McGinnis et al., 1985; Schmidt and Rowley, 1986; Tessensohn, in press) and on global plate-motion studies (Molnar et al., 1975; Jurdy, 1978; Gordon and Cox, 1980; Stock and Molnar, 1987; Lawver and Scotese, 1987). However, only recently have multichannel seismic-reflection data, shown the nature and extent of rift-structures that are buried beneath the thick sedimentary sections within the embayment (Hinz & Block, 1983; Kim et al., 1986; Cooper et al. 1987a; Hinz and Kristoffersen, 1987; Cooper et al., 1988).

Seismic-reflection data show that as much as 14 km of sedimentary strata lie within three major depocenters in the Ross Sea: the Victoria Land basin, the Central trough, and the Eastern basin (Figure 1). These depocenters are part of a major rift zone, incorporating buried rift-basins and overlying glacial sediments, that may extend beneath the entire Ross embayment, and possibly beyond.

This paper describes the major crustal features of the Ross embayment region, and relates them to two episodes of crustal extension that we believe occurred first in late Mesozoic time and then in Paleogene and younger times. The times at which these events occurred is not tightly constrained because rocks older than early Oligocene age have not been recovered in-situ from the Ross Embayment.

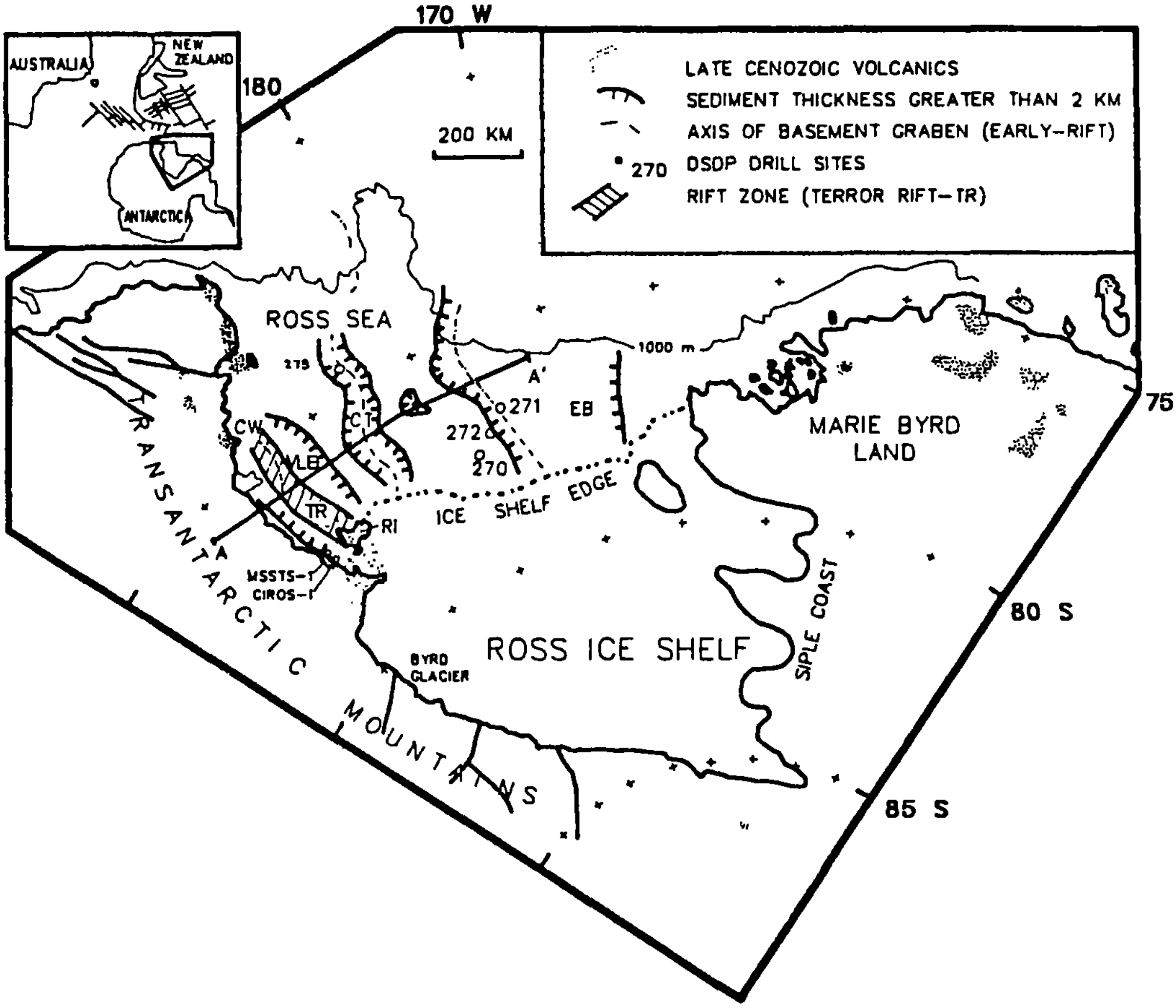


Figure 1. Index map of the Ross Sea showing major sedimentary basins, early-rift basement grabens, and the active Terror Rift. Modified from Cooper et al. (in press). CT-Central trough, CW-Cape Washington, EB-Eastern basin, TR-Terror Rift, RI-Rose Island, VLB-Victorial Land basin.

Geologic Framework

The Ross embayment is bordered on the west by the Transantarctic Mountains, and on the east by Marie Byrd Land (Figure 1). The geology of the Transantarctic Mountains is dominated by Precambrian and lower Paleozoic basement rocks, which are unconformably overlain by gently dipping Devonian through Jurassic strata of the Beacon Supergroup (Davey, 1987). Post-Jurassic rocks are limited to late Cenozoic volcanic rocks and minor Pliocene and younger glacial deposits. The Transantarctic Mountains have been uplifted principally since Eocene time (Fitzgerald et al., 1987).

In Marie Byrd Land, Paleozoic basement rocks are intruded by mid to late Cretaceous plutons. These rocks have been extensively eroded and uplifted to form a regional plateau, probably in late Cretaceous or early Tertiary time (LeMasurier & Rex, 1983). Late Cenozoic volcanic rocks, which form linear volcanic ranges, rest on this high-standing plateau.

The geology of the Ross embayment is poorly known, because few rocks have been sampled from the subsurface. Drilling in the Ross Sea (DSDP, Hayes and Frakes, 1975; MSSTS-1, Barrett and McKelvey, 1986; CIROS-1, Barrett et al., this volume) recovered only early Oligocene and younger glacial marine strata. Early Paleozoic basement rocks, similar to those in the Transantarctic Mouintains, were sampled at DSDP Site 270, in the middle of the Ross Sea. Late Cretaceous and Paleogene rocks are thought to underlie the Ross embayment (Davey et al., 1982; Cooper et al., 1988) because glacial erratics of these ages occur in the Ross Sea region.

Crustal Structure of the Ross Sea

Multichannel seismic-reflection profiles have shown that the Ross Sea is underlain by three major, and numerous minor, N-S trending, asymmetrical basement-grabens that are filled with mostly flat-lying, post-Paleozoic strata (Figure 2). Under the Ross Sea, the basement grabens are up to 175 km wide and they contain a two-tiered sedimentary section, which is up to 14 km thick: a) an underlying section, up to 8 km thick, of layered high-velocity (4.2-6.0 km/sec) strata that are confined to the basement grabens, and b) an overlying section, up to 6 km thick, of flat-lying and prograding deposits that cover the entire Ross Sea and are thickest at the edge of the continental margin (Figure 2). A buried regional unconformity separates the two parts of the sedimentary section, and this unconformity cuts across the top of buried basement platforms.

The basement grabens underlying the Ross Sea can be traced, in seismic data, from seaward of the continental shelf edge up to 450 km south to the Ross Ice Shelf edge (Figure 1; Cooper et al., in press). The graben forming the Victoria Land basin, however, ends abruptly at Cape Washington, about 300 km south of the continental shelf edge (Cooper et al., 1987a). The three major Ross Sea basement grabens may extend several hundred kilometers S-SE beneath the Ross Ice Shelf.

In the Ross Sea, the major basement grabens outline nearly the entire areal extent of two, of the three, large depocenters (e.g. the Victoria Land basin and the Central trough). However, the other large depocenter, the Eastern basin, is underlain by a major basement graben only beneath its western edge (Figures 2 and 3). The vast size of the Eastern basin, is due mostly

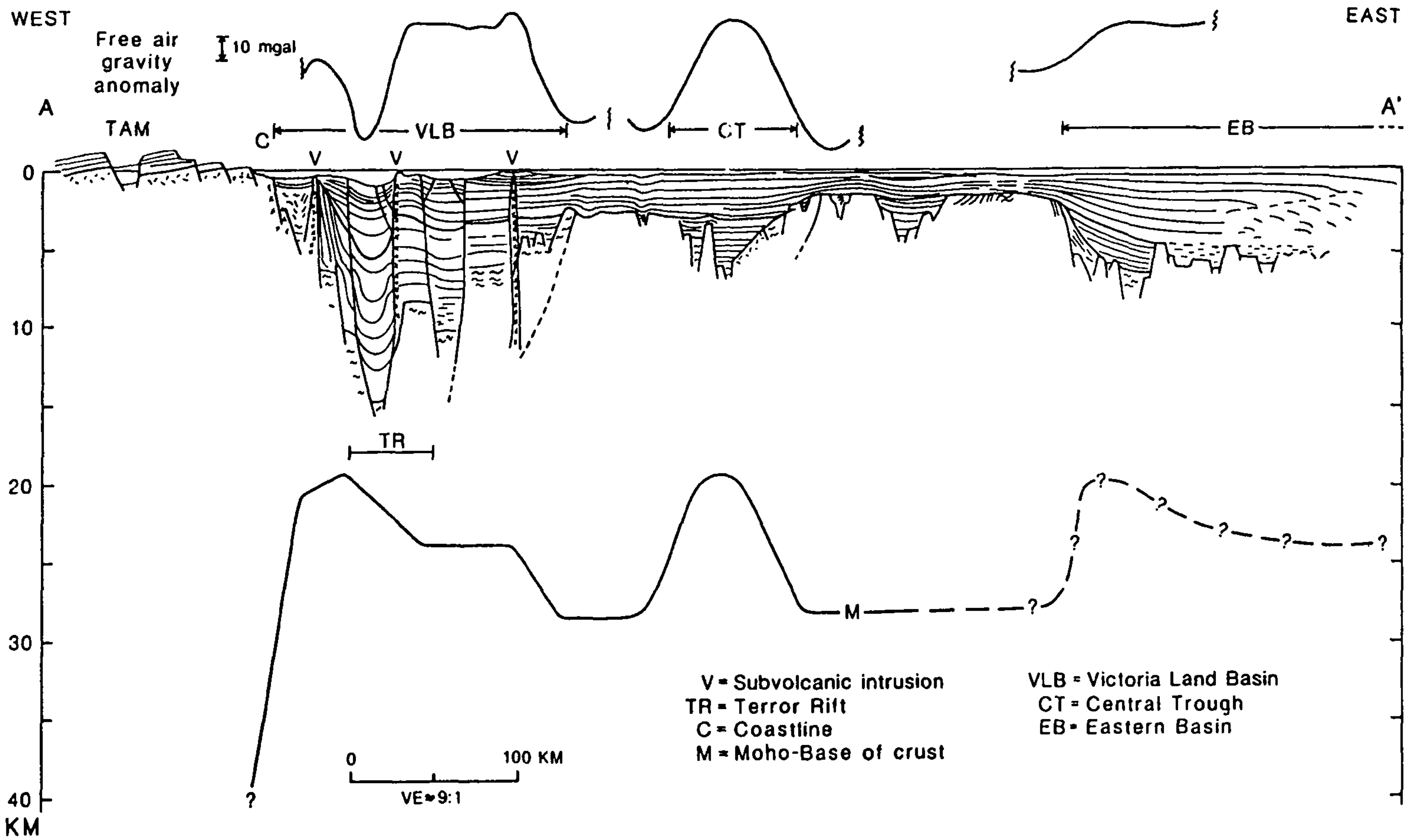


Figure 2. Generalized profile across the Ross Sea (modified from Cooper et al. (in press) Early rift grabens, which lie beneath a regional buried unconformity (heavier line crossing basement platforms) are delineated by positive free-air gravity anomalies and thin crust. Late-rift faults and intrusives deform the Victoria Land basin and some small basement grabens on shallow basement platforms. See Figure 1 for location.

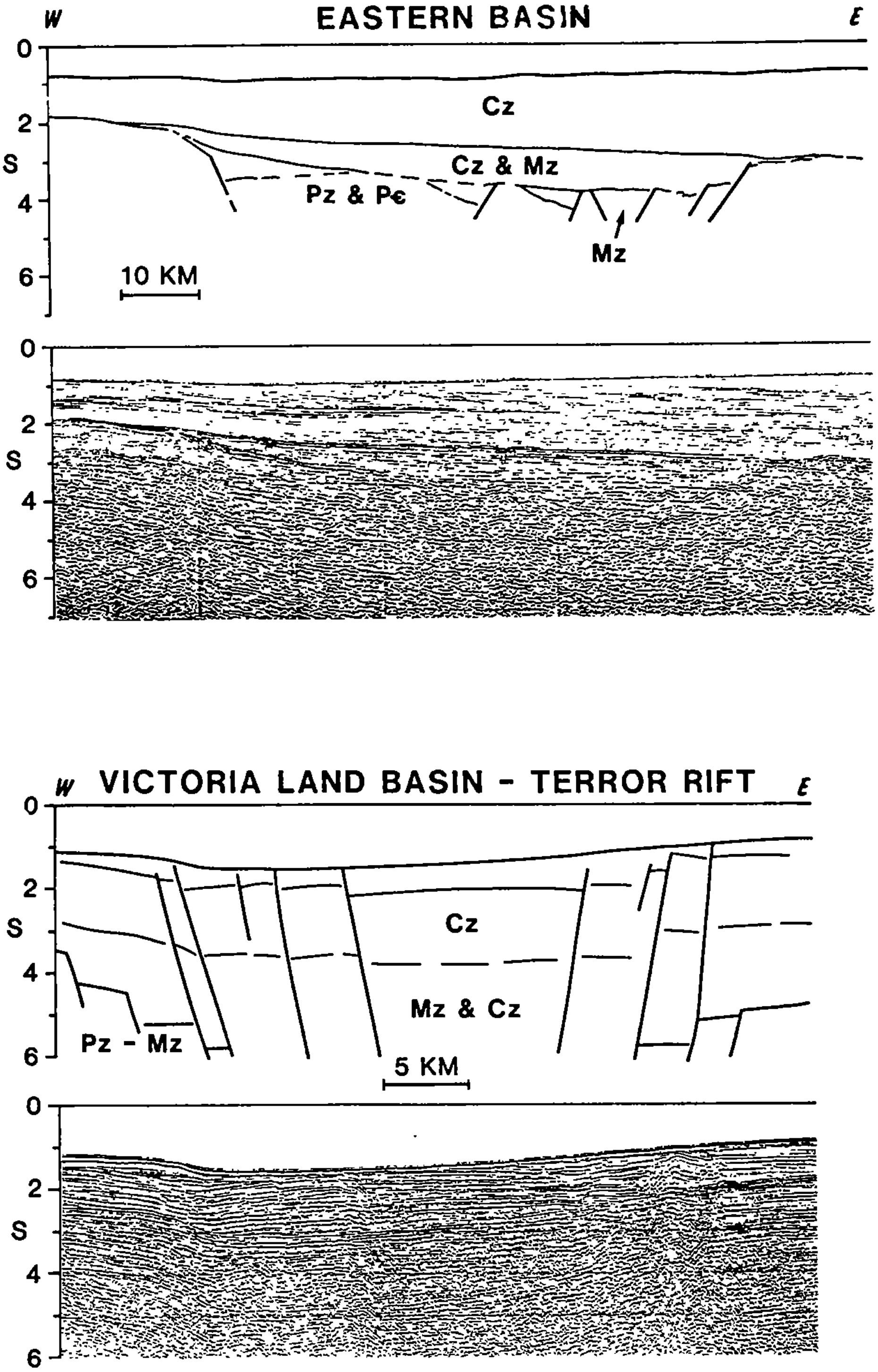


Figure 3. Generalized interpretations of seismic data across early-rift grabens beneath the Eastern basin and Victoria Land basin (modified from Cooper et al., 1988). Ross Sea faults that cut near-surface sedimentary starta are observed in sismic data only in the Terror Rift. The seismic sections lie close to the profile in Figure 2.

to a thick accumulation of seaward-prograding glacial deposits that cover a broadly subsided platform, rather than to a thick accumulation of rift deposits confined within a broad rift-graben.

Basement platforms, or horsts, separate the major grabens. The tops of these platforms are incised by small grabens that commonly contain either highly eroded, deformed strata or gently downwarped strata. Two periods of extensional basement-faulting are suggested by these two styles of deformation: one period occurred before the basement platform was eroded and the other period after the platform erosion.

With exception of the Victoria Land basin, the major Ross Sea depocenters appear to have been downfaulted prior to the formation of the now-buried regional unconformity and the deposition of sediments overlying the unconformity. Faulting within the shallow sedimentary section, above the unconformity, has only been seen in the Victoria Land basin.

The Victoria Land basin has a 50-60 km wide axial rift zone, the Terror Rift that extends between the active volcanoes at Cape Washington and Ross Island (Cooper et al., 1987a). The rift is characterized by a faulted bathymetric trough, coincident with the axis of the basement graben, and an adjacent (in the east) volcanically-intruded basement horst (Figure 2). In the Terror Rift, some basement faults extend upward through the entire sedimentary section and possibly offset the sea floor (Figure 3). Major basement faulting also occurs at the eastward-facing front of the Transantarctic Mountains, where faults are steep and planar to depths of 1-2 km, but may flatten at depth (Cooper et al., 1987a). Low-angle detachment faults are postulated beneath the Ross Sea and Transantarctic Mountains (Fitzgerald et al., 1987), however, seismic evidence for such faults is equivocal (Cooper et al., in press).

Rifting and faulting in the Victoria Land basin is associated, in places, with shallow subvolcanic intrustions and volcanogenic rocks. Seismic and magnetic data indicate that these rocks occur along the southern half of Terror Rift and near the edges of the basement graben underlying the Victoria Land basin (Figures 2 and 3; Cooper et al., 1987a; Behrendt et al., 1987). Jurassic and Cenozoic volcanic deposits are common onshore in Victoria Land and coeval rocks are likely to be offshore. However, volcanogenic rocks may not be a major constituent of the offshore sedimentary section, except near Ross Island, which is composed entirely of late Cenozoic volcanic rocks.

The thickness of the crust beneath the Ross Sea is known from seismic-refraction data only in McMurdo Sound, where it is 21 km thick (McGinnis et al., 1985). Gravity models for other areas of the Ross Sea, give crustal thicknesses ranging from 19-23 km under the Victoria Land basin to about 27 km under Ross Sea basement highs, and 40 km under the Transantarctic Mountains (Davey and Cooper, 1987). These measurements are consistent with previous interpretations of regionally thin crust under the Ross embayment (Smithson, 1972; Bentley, 1973; Robinson & Splettstoesser, 1984).

Other interpretations that thin (hot?) crust underlies the Ross embayment come from magnetic, heat flow, and seismic-reflection measurements. Marine and aeromagnetic data show a distinct long-wavelength magnetic low over the Terror Rift (Victoria Land basin), where heat flow values are above normal (Blackman et al., 1987) and layered reflections are observed in seismic-reflection data at 16 to 22 km depths (Cooper et al., 1987b; McGinnis & Kim, 1986). These observations may result from higher subsurface temperatures and a shallower Curie isotherm, possibly from layered intrusions or magma chambers within the crust (Behrendt et al., 1987; Cooper et al., 1987b).

Crustal Structure Beneath the Ross Ice Shelf

The structure of the crust beneath the Ross Ice Shelf is poorly known because few seismic measurements have been made, and inferences must be based principally on sub-ice bathymetry, gravity, and magnetic data (Bentley, 1983; Robinson and Splettstoesser, 1984).

Sub-ice bathymetric data indicate that long linear ridges and troughs parallel the axis of the Ross embayment, and they extend from the edge of the Ross Ice Shelf southeast to the Siple Coast (Robertson et al., 1982). These commonly steep-sided, ridges and troughs also occur in Marie Byrd Land and southeastward in the Byrd subglacial basin, where they have been cited as evidence for extensional block faulting beneath the ice (LeMasurier and Rex, 1983; Jankowski and Drewry, 1981; Jankowski et al., 1983).

Free-air gravity anomalies over the Ross Ice Shelf (Figure 4; Davey, 1981; Robertson et al., 1982) have nearly linear trends and are continuous over large distances; however, gravity trends diverge from bathymetric trends. In the Ross Sea, positive gravity anomalies occur over the axes of the basement grabens where sediments are thickest (Figure 2). Cooper et al., (in press) note that the positive gravity anomalies continue beneath the ice shelf and, here also, may delineate the axes of basement grabens that contain thick sedimentary strata. Gravity models across the Ross Sea, indicate that high-density intrusive? or mantle? rocks probably lie at 19-23 km depth beneath the major basement grabens (Hayes and Davey, 1975; Davey and Cooper, 1987). Similar high-density rocks may lie beneath postulated basement grabens beneath the Ross Ice Shelf.

The total thickness of sedimentary rocks under the Ross Ice Shelf is unknown, except where a few seismic measurements were obtained near the southern end of the ice shelf (Rooney et al., 1987; in press). These data show that less than 1.5 km of strata overlie basement. Aeromagnetic data, however, indicate that other areas near the head of the Ross Ice shelf may be underlain by up to 8 km of non-magnetic rock. The poor correlation between trends of linear bathymetric ridges and positive free-air gravity anomalies, except near the Siple Coast, suggests that high-density strata may underlie parts of the Ross Ice Shelf. Alternatively, the positive anomalies may be due to thin crust.

Thus, the extensional basement grabens that exist, and are filled with sedimentary strata, beneath the Ross Sea may continue beneath the Ross Ice shelf (Figure 4; Cooper et al., in press). Like the Ross Sea, these postulated grabens may be underlain by thin crust.

Transverse Structures of the Ross Embayment

Locally, at places within the Ross embayment region, major structural and physiographic features that parallel the axis of the embayment, are offset horizontally. Three subparallel offset zones have been identified across the embayment (A,B,C, Figure 4), and interpreted as major transverse basement faults (Cooper et al., in press).

The most notable zone (C, Figure 4) crosses the Ross embayment from the Byrd Glacier area, where the coastline and sub-ice topography beneath the Transantarctic Mountains is dextrally offset by nearly 140 km, to the 400-km-long bathymetric scarp forming the northwest edge of Marie Byrd Land. Within the embayment, bathymetric features and gravity anomalies (and rift grabens?) change trend by 40° at zone C. Additionally, zone C marks the southern

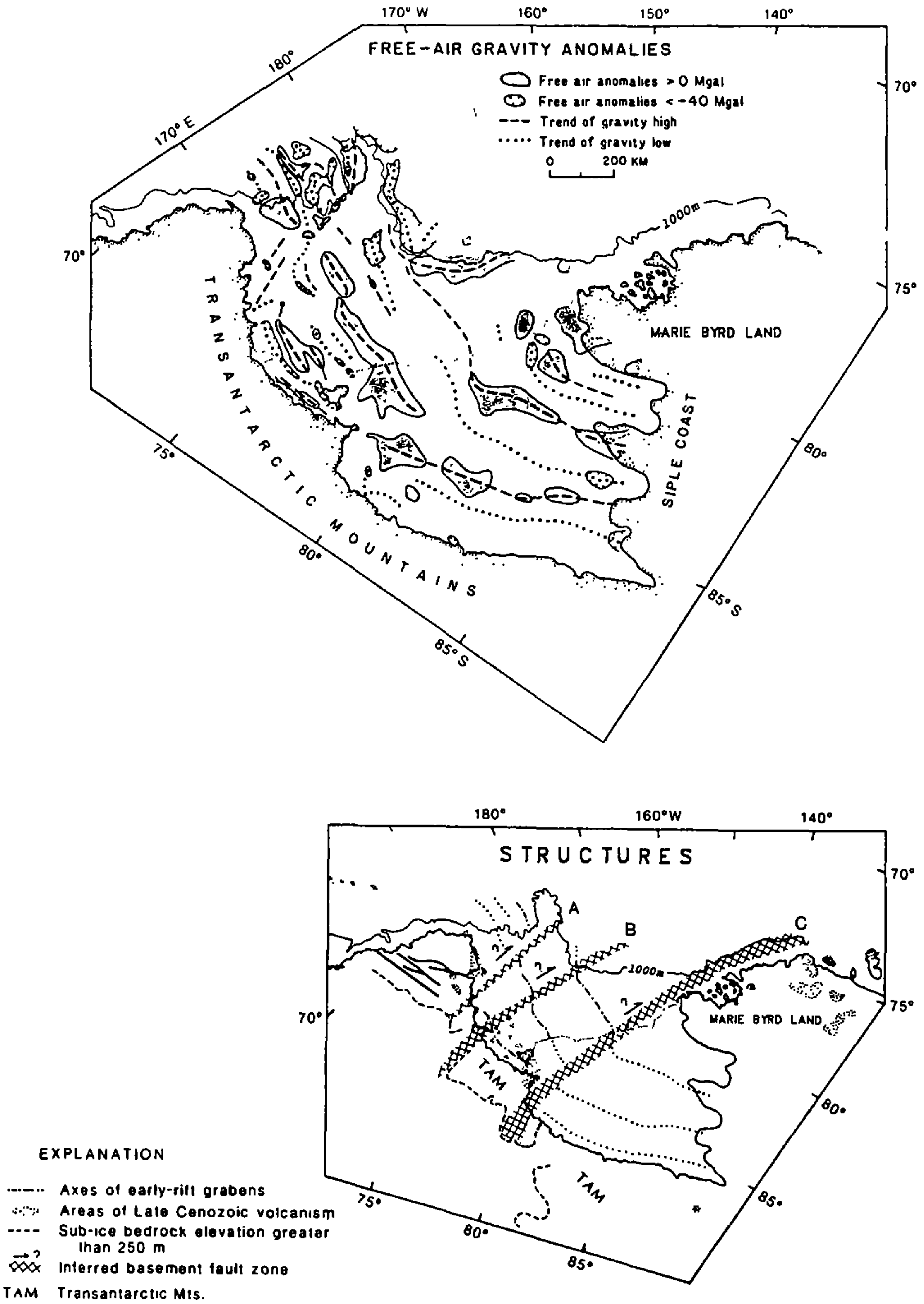


Figure 4. Gravity and structure maps of the Ross Embayment (modified from Cooper et al. (in press). Positive gravity anomalies (dark) delineate early-rift grabens in the Ross Sea and probably under the Ross Ice shelf, where trends of gravity anomalies and bathymetry features differ in most areas except near the Siple coast. Major transverse faults across the embayment may be Paleozoic features that were reactivated during the late Mesozoic breakup of Gondwana.

termination of major Cenozoic volcanism along the Transantarctic Mountains (with exception of two small localities, about 1000 km south of zone C, in the central Transantarctic Mouintains).

Two other fault zones (A,B, Figure 4) cross the Ross embayment, and offset the axes of rift-grabens in the Ross Sea and sub-ice topography in the Transantarctic Mountains. At the zones, gravity and magnetic anomalies are commonly offset, change character, or are aligned along the zone. One zone (B) appears to mark the northernmost extent of sub-volcanic intrusions in the Victoria Land Basin.

The three transverse fault zones may have a long history of displacement. Cenozoic activity is suggested by offsets in the late Mesozoic rift-graben axes and the post-Eocene mountain topography, and by the apparent control on the location of post-Eocene volcanic centers. However, faulting of offshore Cenozoic sedimentary rocks is not yet identified in seismic-reflection profiles that cross the zones. The zones may have initiated in Paleozoic time as basement terrane boundaries, and have been reactivated in the early Mesozoic during the initial breakup of Gondwana. Since then, lateral, vertical, and rotational displacements have apparently occurred in basement rocks across the zones, leading, in part, to the present elevations and orientations of structures in the Ross embayment.

Structural Evolution of the Ross Embayment

The Ross embayment has often been cited as the likely location of Mesozoic and younger intraplate crustal deformation - a major rift zone - between East and West Antarctica (Elliot, 1975; Molnar et al., 1975; Schmidt and Rowley, 1986). The onshore evidence for crustal extension in areas adjacent to the Ross embayment is strong, and is described below. However, the times at which the extensional events occurred in the Ross embayment is not tightly constrained.

In East Antarctica, rift-related tholeiitic dolerite dike, sills and volcanic rocks were emplaced throughout the Transantarctic Mountains in Jurassic time (Elliot, 1975). The large Rennick graben, of North Victoria Land, was downfaulted in post early-Cretaceous time (Grindley & Oliver, 1983a). Cenozoic events include the uplift, and block faulting, of the Transantarctic Mountains since Eocene time (50 Ma, Fitzgerald et al., 1987; Katz, 1982) and the eruption of alkalic volcanic rocks in Victoria Land since at least early Oligocene time (38 Ma, Barrett et al., in press).

In West Antarctic (Marie Byrd Land), mafic dikes were intruded in the mid-Cretaceous (90-110 Ma; Grindley & Oliver, 1983b), with uplift and erosion of a regional peneplain (now at 500-2700 m elevation) in Late Cretaceous? or younger times (LeMasurier & Rex, 1983). Extension in the Cenozoic is marked by alkalic volcanism since Oligocene time (27 Ma, LeMasurier and Rex, 1983).

Within the Ross embayment, strong evidence for episodic crustal extension can be seen in post-1980 multichannel seismic-reflection data (MCS; Figure 2 obtained across the Ross Sea. In most areas, old basement faults, along which the deeply buried basement grabens have subsided, do not extend upward through the overlying late Mesozoic? and younger sedimetary section. However, in the Victoria Land basin, faults and intrusive structures deform all basin-strata and extend nearly to the sea floor. On basement platforms, some small grabens (late

Mesozoic?) lie entirely below a flat erosional unconformity whereas other small grabens (Cenozoic) deform shallow strata as well as the buried unconformity. Along the flanks of the rift-grabens, more than one basement-unconformity exists indicating at least two periods of uplift and erosion (and rifting).

The relative times of extensional events can be determined from MCS data, however, the absolute ages are not known because sedimentary rocks have not been sampled in-situ from the deeply buried rift grabens beneath the embayment. Early interpretations of single-channel seismic and other geophysical data (Hayes and Davey, 1975; Davey, 1981) indicate that crustal extension occurred in the Ross embayment since late Cretaceous time, as a result of plate motions in the south Pacific Ocean. Schmidt and Rowley (1986) use onshore geologic evidence to suggest that the Ross embayment formed principally in early and middle Jurassic time as part of a Transantarctic rift with 500 to 1000 km of offset along major right-lateral transform faults. They also suggest Cenozoic block faulting, independent of the Jurassic event, in West Antarctica (Marie Byrd Land).

An episodic history of late Mesozoic and Cenozoic crustal extension for the Ross Sea and Ross embayment has been proposed (Figure 5; Cooper et al., 1987a), based on interpretation of multichannel seismic data. They suggest two separate periods of extension: 1) an early-rift period commencing in Jurassic but mostly in Cretaceous time and 2) a late-rift period commencing in Eocene but most intense in late Cenozoic time. Basement grabens throughout the embayment were downfaulted during the early-rift period. Crustal extension and thinning caused elevation of dense mantle and rapid subsidence of the grabens yielding the present positive-gravity signatures of the grabens. Major sediment-infilling followed exttension and resulted in the observed flat-lying graben starta. The late-rift period was marked by likely wide-spread uplift and erosion of the regional basement-platform unconformity, development of the Terror Rift with associated alkalic volcanism, and uplift of the Transantarctic Mountains, and block faulting in Marie Byrd Land.

Cooper et al., (in press) relate the early-rift and late-rift periods of crustal extension in the Ross embayment to times of major-plate motions. They suggest that the early-rift period coincides with pre-80 Ma slow-rifting between Australia and Tasmania, and with the initial post-80 Ma separation of New Zealand and Antarctica. The late-rift period commenced with the global Eocene reorganization of plate motions, which was accompaned by increased spreading-rates in the Indian Ocean.

Summay

Significant crustal extension, up to 100% or more (Lawver and Scotese, 1987) has occurred in the Ross embayment, and the evidence for episodic extension can be clearly seen in multichannel seismic reflection data from the Ross Sea. Most regional extension accrued during the early-rift period (late Mesozoic?) with downfaulting of the major and minor graben systems (Figure 5). More-recent extension, during the late-rift period (Eocene and younger), has caused crustal deformation that is localized principally in the western Ross Sea and Marie Byrd Land. If late-rift extension is accruing across the entire Ross embayment, then the deformation lies at crustal levels that are below the penetration of present seismic data.

The orientation of extensional structures within the Ross embayment has probably been

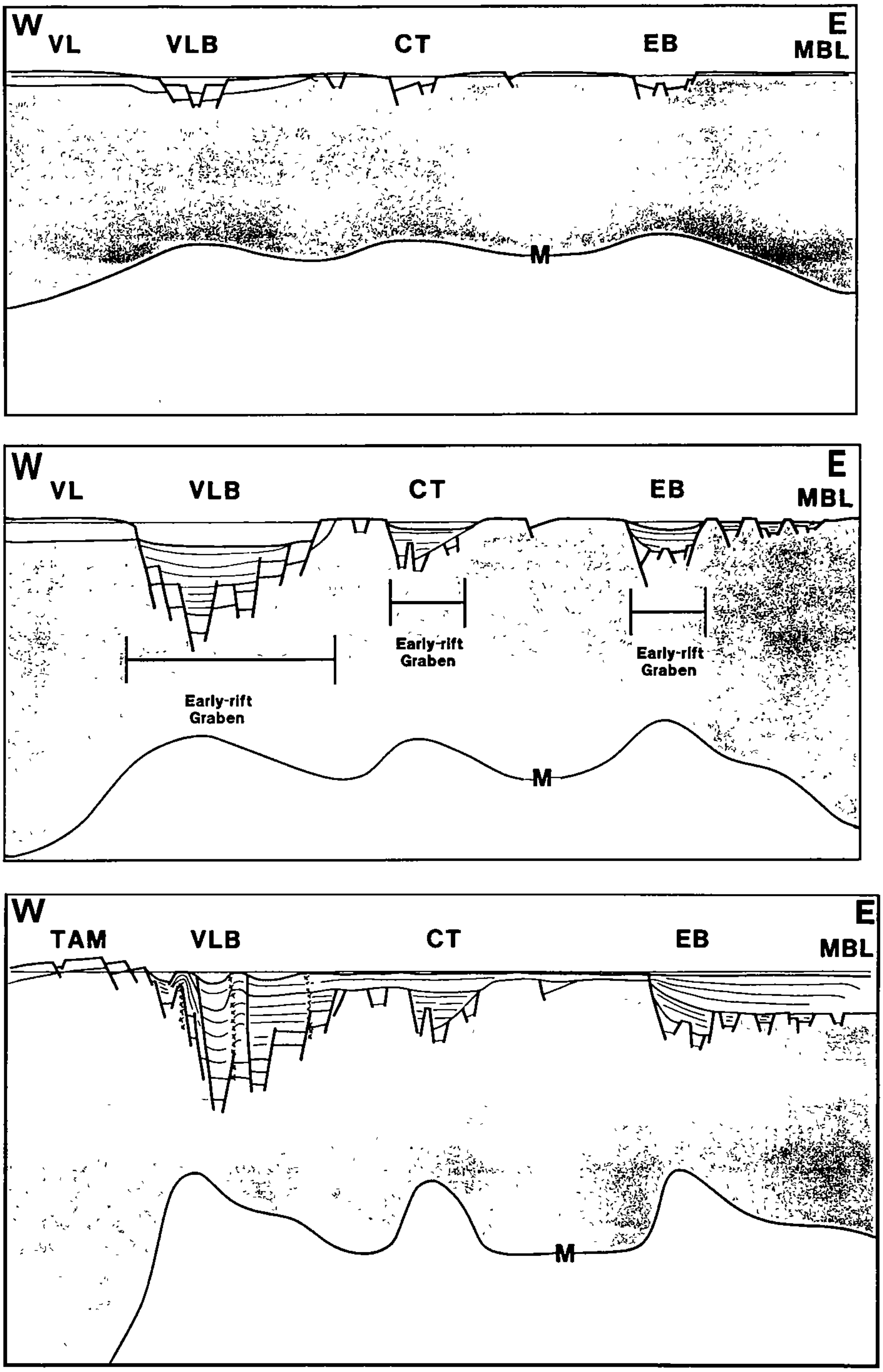
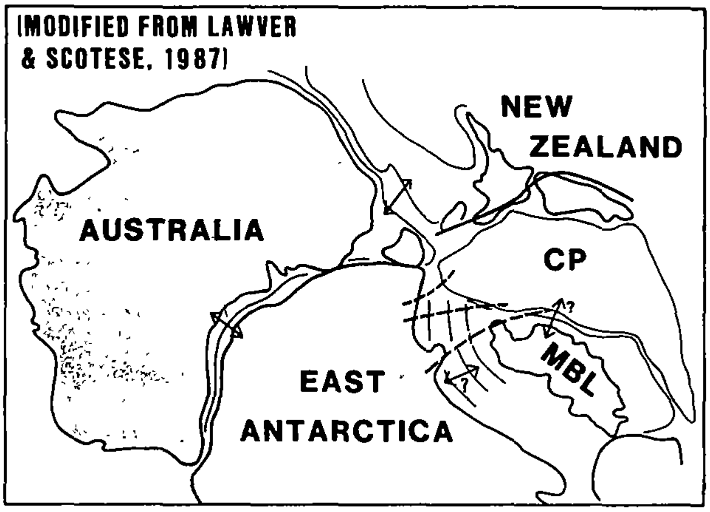
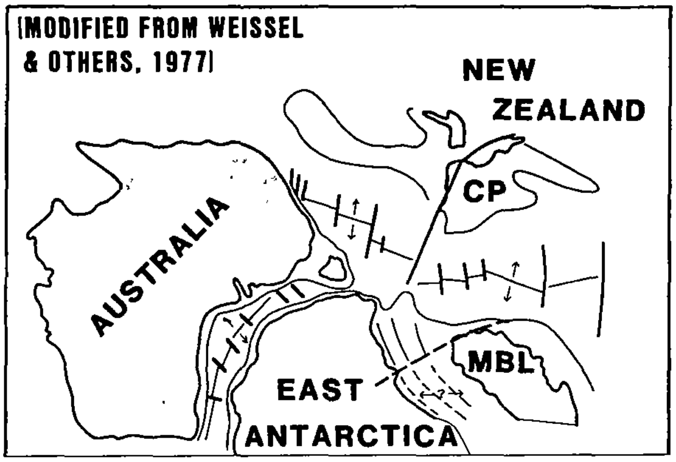


Figure 5. Plate models and cross sections showing the evolution of the Ross embayment and early-rift grabens (modified from Cooper et al., 1988). Most downfaulting of the basement grabens is believed to have occurred before Paleogene (late-rift) time.

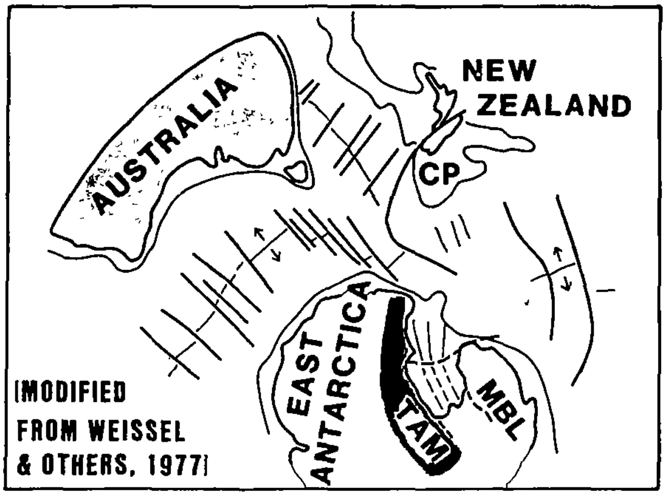
EARLY RIFT PERIOD : 140 - 85 MY



POST BREAK-UP : 65 MY



LATE RIFT PERIOD : 50 - 0 MY (at 10 MY)



controlled principally by large-plate motions occurring during the breakup of Gondwana. In addition, transverse basement-faults that cross the Ross embayment may be long-active (Paleozoic and younger?) features which have influenced the horizontal (strike-slip and rotation) and vertical displacements associated with the early-rift and late-rift periods.

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Investigations on the Antarctic Peninsula as a Microplate.

Luis E. Arias

Abstract

The Antarctic Peninsula is one of the several fragments which set up the West Antarctica, being a microplate in tectonic sense. The region is a mainland of arcute form with a concave trend to the east. A linear development of fore-arc, magmatic-arc and back-arc terranes have been recognized. The Peninsula formed as an island arc between early Jurassic and Miocene times when the Pacific Plate was subducted beneath the Antarctic Plate. The South Shetland Islands chain was originally part of this arc and separated from it by opening of the Bransfield Strait.

More than 80% of the Antarctic Peninsula outcrops are of plutonic origin and represent an Upper Triassic-Tertiary calc-alkaline suite, ranging from 209 Ma to 9.5 Ma. They intrude, and are often contemporaneous with, the *Antarctic Peninsula Volcanic Group* (Jurassic-Tertiary). However, recent radiometric results establish Ordovician-Devonian, and even Cambrian age for othogneisses.

The current knowledge of the Antarctica has been largely increased by the geophysics through many surveys developed in the last decade, all of them designed to gather seismic, gravity, magnetic and hydrothermal data required to solve the problems due to the ice-covered regions of the Antarctic Peninsula and its surroundings.

Introduction

During the last two decades a significative quantity of geological-geophysical information has been gathered to understand the tectonic nature of the Antarctica. In terms of global plate tectonics, in which the surface of the earth is divided into plates defined by seismically active zones or belts, Antarctica is part of the Antarctic Plate bounded for the most part by the mid-ocean ridges in the Pacific, Indian and southernmost South Atlantic oceans. The Antarctic Plate itself consists of the continent plus the ocean floor out to those mid-ocean ridges (Elliot, 1985).

The Antarctic continent is made up of two major tectonic units: the East Antarctic shield (mainly Precambrian) and the microplates of West Antarctica. Continental palaeomagnetic data suggest that in the Cretaceous, West Antarctica was separated into-at least-three tectonic units on different lithospheric microplates: Ellsworth Land/Antarctic Peninsula, Marie Byrd

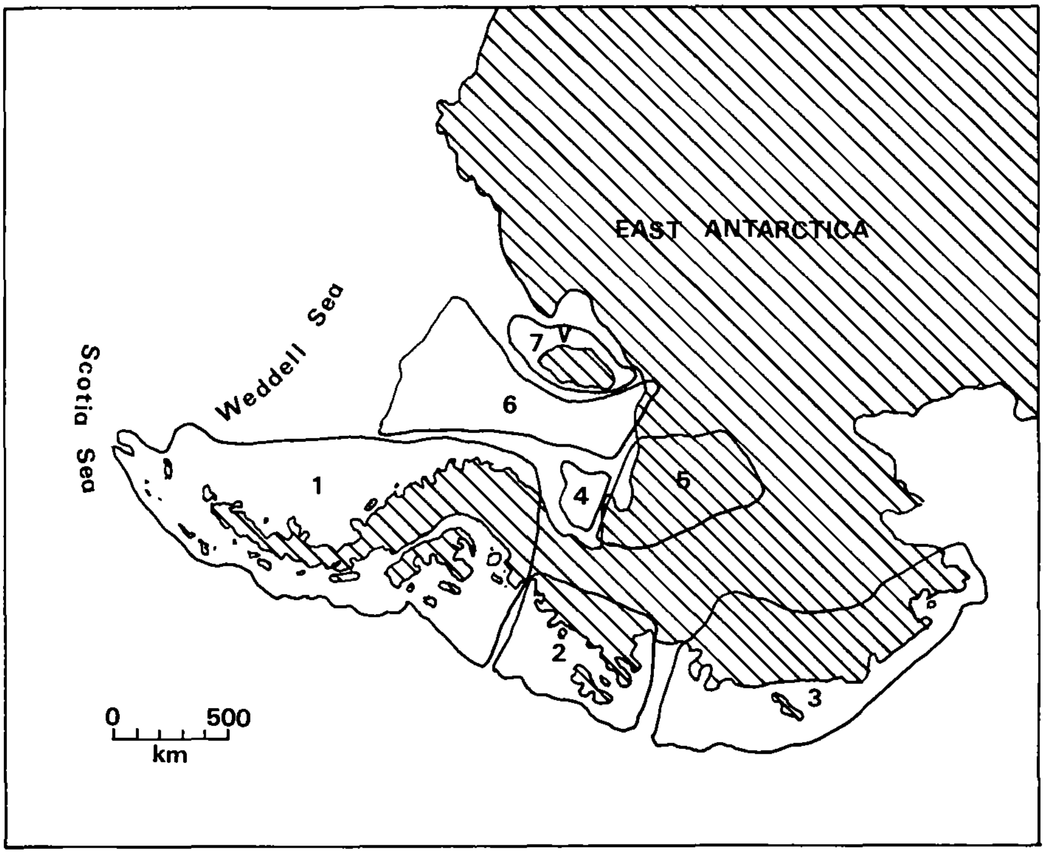

Fig. 1. Microplates of West Antarctica (Modified from De Wit et al., 1988).
1.- Antarctic Peninsula
2.- Thurston
3.- Marie Byrd Land
4.- Haag
5.- Ellsworth
6.- Filchner
7.- Berkner Island

Land and Ellsworth Mountains (Bentley, 1983). A recent presentation (De Wit et al., 1988) shows the West Antarctica subdivided into nine possible small microplates (Fig. 1) resulting from an approach adopted by participants in a workshop. However, those authors warned that today there is still considerable uncertainty about the number of these microplates, there being less agreement regarding to their positions 150 million years ago.

Tectonic and geographical setting

The boundary between the South American and Antarctic plates extends from the Bouvet triple junction in the South Atlantic, by way of the Scotia arc region, to the junction of the

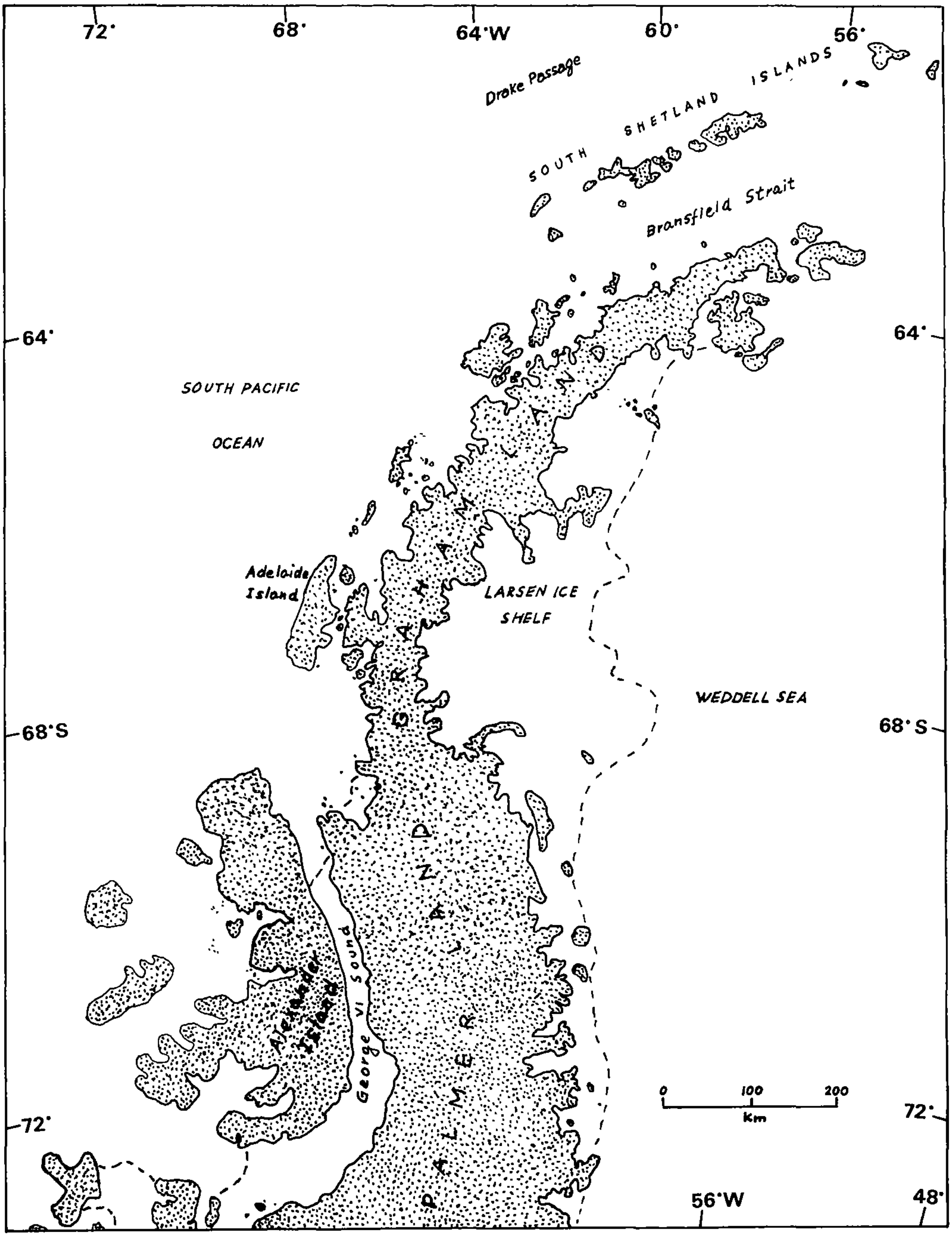

Fig. 2. Location diagram for the Antarctic Peninsula (Modified from Renner et al., 1985).

Chile Rise and Peru-Chile trench at about 45°S. The term "Scotia arc", according to Barker and Dalziel (1983), has been applied to all or part of the long eastward loop of islands and submarine ridges which surrounds the Scotia Sea on three sides. The much broader definition of its proper domain includes the South American and Antarctic Peninsula margins between 50°S and about 75°S, all of the Scotia Sea and the surrounding Scotia Ridge.

Tectonically, the Antarctic Peninsula is part of the circumpacific rim. In the south-east Pacific, the Antarctic Peninsula and South America are both actively involved in sea-floor spreading off the East Pacific Rise and the geology of both areas can be interpreted in terms of rigid plate tectonics. Williams et al. (1972) stated that the west-to-east geological zonation is caused by a Benioff zone dipping eastward beneath the continental margin.

West Antarctica is believed to consist of several continental fragments, geographically separate at depth, but united by the same ice sheet that covers the geologically distinct, larger and older stable continental shield of East Antarctica. One of these fragments is the Antarctic Peninsula (Fig. 2), defined (Renner et al., 1985) as the mainland peninsula north of a line joining Cape Adams (75°00'S, 62°34'W) and a point on English Coast (73°24'S, 72°00'W). From its base, the Antarctic Peninsula trends northward for 1500km, its arcuate form at first convex towards and then concave away from the ice-shelf fringed Weddell Sea. The point of inflection occurs around 69°S, where an obvious narrowing provides a natural division between Palmer Land, to the south, and Graham Land, to the north. Palmer Land is 250-280km in width with a central plateau region averaging 1800m in elevation. Its plateau ice is broken by *unataks* and isolated mountain chains, which reach a maximum of 2652m at Mount Jackson. The Graham Land plateau has an average elevation of 1400 m and is typically between 40 and 70km wide.

A linear development of fore-arc, magmatic-arc and back-arc terranes have been recognized in this region and attributed to subduction of the Pacific Ocean floor beneath the western margin of the former supercontinent of Gondwana. The Antarctic Peninsula formed as an island arc between early Jurassic and Miocene times when the Pacific Plate was subducted beneath the Antarctic Plate. The South Shetland Islands chain was originally part of this arc, but has since separated from it by opening of the Bransfield Strait. The separation is consistent with classical back-arc rifting (Fig. 3), but Suess (in press) holds that the duration and regional extent of this process have remained controversial.

The South Shetland Islands are 15 major islands and many small islands which form an ensialic island arc with a volcanic history extending back at least 140 Ma (Weaver et al., 1982). Smellie (1983) added that these islands have been situated on a consuming plate margin for at least 200 Ma, but igneous activity probably did not become established there until the earlieast Cretaceous.

The Bransfield Strait separates the Antarctic Peninsula from the South Shetland Islands along the only part of the Pacific margin of Antarctica where subduction did not end with the migration of a ridge crest into the trench. Subduction is understood (Barker and Dalziel, 1983) as totally coupled to spreading in western Drake Passage to the north, which produced between 40 and 64 mm/year of new ocean floor from 20 Ma to about 4 Ma, and virtually stopped. Bransfield Strait is about 100km wide and beneath it lies a 2km deep trough, with a steep northwestern slope up to the South Shetland Islands, and a more gradual southeastern margin towards the Antarctic Peninsula shelf.

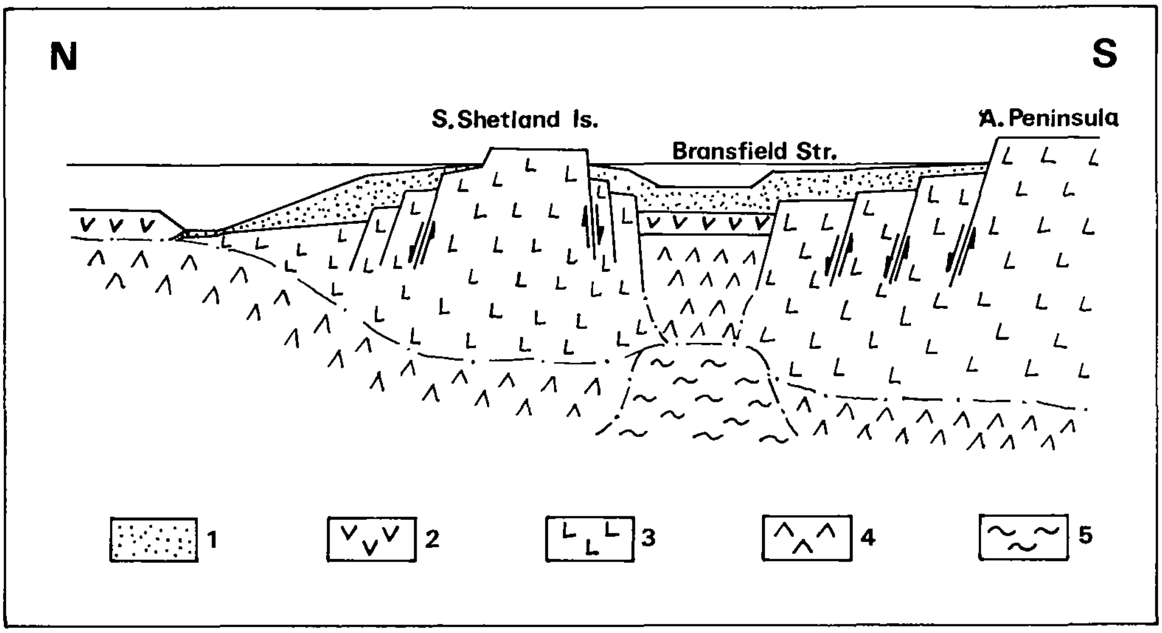

Fig. 3. Hypothetical origin of Bransfield Strait by a process of rifting. (Modified from Ashcroft, 1972)
1.- Sediments
2.- Volcanic rocks
3.- Acid crust
4.- Basic crust
5.- Mantle

Three major areas have produced controversy regarding reconstructions of Gondwana. These are:

— the location of Madagascar with respect to Africa;
— the fit of Sri Lanka and India with East Antarctica; and
— the location of the Antarctic Peninsula with respect to the

Falkland Plateau (both recognized continental fragments). This latter problem has three different solutions. The first one has been to ignore the problem and to simply show the Antarctic Peninsula overlapping the Falkland Plateau. An alternative solution has been to place the peninsula on the Pacific side of South America. The third solution has been proposed by Lawver and Scotese (1987), involving movement of the peninsula with respect to East Antarctica.

Within the Antartic Peninsula the concept of a twofold division of the tectonic history into *Andean* and *Gondwanian* events has been challenged. Recent advances in geochronology have blurred this distinction. Storey et al. (1987) suggesed that subduction-related processes, including accretion, magmatism and extention, were virtually continuous since at least Early Mesozoic times. These processes would have led to the development of a complex Mesozoic magmatic arc, which formed on Palaeozoic basement marginal to Gondwana. These authors specify that during the development of the arc a narrow segment of continental crust, containing the active arc ("Antarctic Peninsula"), split off from the rest of Gondwana and became part of West Antarctica.

Geological background

Antarctica is composed of two contrasting geological provinces: the Precambrian craton, constituting East (Greater) Antarctica, and the younger Phanerozoic mobile belt of West (Lesser) Antarctica. Their present juxtaposition and their relative positions in Gondwana reconstructions continue to be the subject of speculation, but a clearer understanding has emerged of the geological evolution of West Antarctica and its relationship to southern South America. The rock outcrops visible in West Antarctica scarcely suggest the extensive land mass hidden beneath the ice canopy. Several continental fragments, separated by deep trenches, are believed to exist, each having moved independently from original positions along the Pacific margin of Gondwana. The Antarctic Peninsula is one such fragment.

More than 80% of Antarctic Peninsula outcrops are of plutonic origin and represent an Upper Triassic-Tertiary calc-alkaline pyroclastic tuffs and breccias interbedded with lavas (Renner et al., 1985).

Models for the evolution of the magmatic arc on the Antarctic Peninsula have been based mainly on the geology of its northern part (Graham Land). Recently, Meneilly et al. (1987) worked on its southern part (northern Palmer Land) and showed rocks divided into four main units:

— paragneiss, some of which may be pre-Mesozoic continental;
— plutonic rocks of the magmatic arc, many of them deformed, ranging in age from Early Jurassic to, at least, Late Cretaceous;
— back-arc basin metasedimentary rocks; and
— volcanic rocks of the Antarctic Peninsula Volcanic Group.

These authors concluded that the geology of northern Palmer Land can be explained by continuous subduction and magmatism during the Mesozoic with peaks of magmatism and arc compression in the Early Jurassic and Early to Middle Cretaceous, separating a period of arc and back-arc extension in the Middle to Late Jurassic.

Parts of west coast of Palmer Land were studied by Smith (1987), who point out that there are many aspects of the geology of the Antarctic Peninsula which invite comparisons with Japan, in particular, the generation of an island arc on continental crust and the possible presence of an extensive marginal basin. Japan is known to comprise a number of interpenetrant arc-trench systems and, hence, if the above comparison between these two regions is valid, the preceding account of the geological history is probably a gross oversimplification.

Until recently, the presence of Palaeozoic granitoids in the Antarctic Peninsula was unproven. However, definitive radiometric results are now available, based on Rb-Sr whole-rock isochrons, which establish minimum Ordovician-Devonian ages for the progenitors of orthogneisses in eastern Graham Land and in northwestern Palmer Land (Harrison and Piercy, in press; Milne and Millar, in press). A 506 Ma U-Pb zircon age for one sample of these orthogneisses suggests an even earlier, Cambrian, origin (Harrison and Loske, in press).

Mid-Jurassic granitoids are well developed in the Antarctic Peninsula. They form a well defined belt of monzogranites extending along the east coast of Graham Land through northeastern Palmer Land into western Palmer Land, where they are petrologically more variable as well as partially recrystallized and sheared. Most andesites and rhyolites of the Antarctic Peninsula Volcanic Group are assumed to be related to this magmatic episode. Cretaceous granitoids are developed throughout the Antarctic Peninsula, where they form a broad belt west of the Jurassic arc in Graham Land but overlapping it in northern Palmer Land. Tertiary plutions are common along the west coast of the Antarctic Peninsula, where are predominantly Eocene in age, a time of relative quiescence in southern Chile. These rocks show a complete range of calc-alkaline compositions from gabbro to granite (Pankhurst, in press).

Geophysical investigations

The current knowledge of the Antarctica has been largely increased by the geophysics. Plate tectonic models attempting to show the evolution of West Antarctica have been handicapped by a lack of data in the ice-covered regions of the Antarctic Peninsula and its surroundings. This situation is now changing as a result of many surveys developed in the last decade, all of them designed to gather seismic, gravity, magnetic and hydrothermal data required to solve these problems.

Seismics

The first multichannel seismic reconnaissance survey in the Weddell Sea took place as part of the Norwegian Antarctic Expedition in 1976-77 (Haugland, 1982). The data show that stick sedimentary layers cover the continental shelf in the southern Weddell Sea and form a prograding continental shelf with no sign of major tectonic activity. There is no evidence of tectonic movement or faults in connection with the Crary trough, a north-east/south-west trending trench in the southeastern part of the Weddell Sea, that parallels the coast between 75°S and 78°S.

Seismic sounding has been used to determine bedrock depths beneath George VI Ice Shelf on the George VI Sound (Maslanyj, 1987). This region is a linear geomorphological feature on the west coast of the Antarctic Peninsula, separating Alexander Island from Palmer Land. It is a channel 500km in length with a width of 30km in the north widening to over 70km in the south. The George VI Ice Shelf is underlain by a deep steep-sided elongated trough, trending N-S in the north and E-W in the south, with bedrock depths exceeding 800 and 1000, respectively. This supports the concept that George VI Sound is, in part, an extensional feature.

New seismic data collected during the cruise of R.V. "Polarstern" in fall 1987 (Meissner et al., in press) underline the observations from the analysis of the magnetic anomaly pattern and provide additional details for the tectonic development in the N-W of the Antarctic Peninsula. A general physical-mathematical treatment of magnetic anomalies is carried out. A relationship between the spreading velocity in the various oceanic segments and the offset of magnetic anomalies is developed. Besides the spreading velocities, the "slab velocity" is defined, which carries the whole oceanic segment, including the ridge, toward the trench (before ridge-trench collision stops all movement). A part of this velocity might be caused by the Antarctic Continent or the Antarctic Peninsula in connection with the opening of Bransfield Strait.

Gravity and Magnetics

Igneous rocks have been sampled for paleomagnetic study at 47 sites in Graham Land and 22 sites in Ellsworth Land (Scharnberger, 1982). The primary purpose was to elucidate post-tectonic relationships among various parts of Antarctica. Cretaceous and Teritary rocks from both regions yield pole positions close to the present pole, indicating little latitude change for these regions since Cretaceous time. These results contrast with those from Marie Byrd Land and are interpreted that Ellsworth Land is part of an Antarctic Peninsula tectonic unit which was separate from Marie Byrd Land during Mesozoic time. These two regions were probably a part of two different lithospheric plates, and plate convergence has produced their present geographic relationship.

An aeromagnetic survey gave about 3500km of regional magnetic lines over the South Shetland Islands, the Bransfield Strait and part of the Antarctic Peninsula (Parra et al., 1984). Qualitative interpretation of the magnetic maps shows that the general structure of the area is characterized by large magnetic anomalies (northwest of the South Shetland Islands and southeast of the Bransfield Strait) associated with and produced by intrusive rocks of Cretaceous to Middle Tertiary age. This intrusive suite is apparently related to subduction, which ceased during the Lower Miocene giving way to an extensive tectonic phase characterized by a N-E trending system of normal faults.

A British Antarctic Survey (BAS) *Twin Otter* aircraft, equipped with a wing-tip magnetic sensor, was used for the regional aeromagnetic survey of the Antarctic Peninsula (Renner et al., 1985). The measurements made between 1959 and 1984 by the BAS at gravity stations on the Antarctic Peninsula have been recomputed within a stronger base station framework, recovering and processing over 36,000 line km of aeromagnetic profiles since 1973. The results are tabulated as absolute, Bouguer and free-air anomalies and are also presented in contoured form. A 1:1,500,000 Bouguer anomaly map reveals several anomalous trends, the most significant of which is an axial minimum attributed to crustal thickening asymmetrically distributed beneath the geographical axis of the peninsula.

In an attempt to radically improve the efficiency of Antarctic exploration, the Lamont-Doherty Geological Observatory of Columbia University is collaborating with the Naval Research Laboratory of Washington, D.C. and research institutes of Argentina and Chile (LaBrecque et al., 1986; LaBrecque, 1987). This program uses aircraft systems and its goal is a detailed mapping of magnetic and gravity anomalies over the basins and margins surrounding the Peninsula Antarctica. Gravity and mangetic anomalies are the basic data sets from which the structure, age and evolutionary history of a continental margin and ocean basins can be derived. With such a complete data set researchers will be able to identify targets to which ships or land parties can be directed in a more efficient manner. In its first two years the program has concentrated on the unexplored western Weddell Basin, where over 150,000km of aeromagnetics and nearly 50,00km of aerogravity have been gathered, to observed that the seafloor-spreading anomalies and fracture zone trends of this basin record the break-up of Gondwana over 160 million years ago.

A study based on the above program has been presented recently by Parra et al. (in press), where magnetic anomalies developed parallely to the western margin of the Antarctic Peninsula, are discussed. These anomalies are associated to the Cretaceous-Tertiary magmatic activity of broad description in the region. The location of a magnetic anomaly in the center of the Bransfield Strait, interpreted as the product of basic injections defining an incipient rift activated after subduction ceased (about 4 Ma ago), coincides with the extension of the active segment, being the line between the Hero fracture zone and the northern end of the peninsula.

Using new aeromagnetic and bedrock elevation data, Garrett et al. (1987a) oberved that the extension between the Antarctic Peninsula and Ellsworth-Whitmore Mountains crustal blocks has resulted in *horst* and *graben* structures showing large displacements of the magnetic basement. These authors pointed out that much of this rifting may have occurred during the Cenozoic and that the closure of this rift system during reconstruction of Gondwana reduces the overlap between South America and the Antarctic Peninsula, which is a common feature of Mesozoic assemblies of the supercontinent.

Reconnaissance aeromagnetic profiles across the Antarctic Peninsula were gathered as part of the US Naval Oceanographic Office Project Magnet Program (McGibbon and Garrett, 1987). Together with geological samples obtained in eastern Palmer Land, a (?) Palaezoic basement complex, sedimentary and volcanic rocks are identified. The volcanic rocks are associated with a Jurassic back-art basin and Jurassic-Cretaceous plutonic rocks. The chemical composition of microdiorites and syenites shows strong alkaline affinities-characteristic of anorogenic, intraplate environments-distinct from the calc-alkaline plutonic rocks common along the Antarctic Peninsula.

Linear belts 50-100km width of long-wavelength positive magnetic anomalies exceeding 500nT are observed on continental blocks of the Scotic arc (Garrett et al., 1987b). The most developed is the so-called West Coast Magnetic Anomaly, which may be traced for more than 1300km along the Antarctic Peninsula. Comparison of magnetic profile data after low-pass filtering and reduction to pole reveals a striking similarity between the individual anomaly belts. Correlation of the anomalies with positive gravity anomalies, seismic refraction data and geology indicates that the sources are linear batholiths intruded during Mesozoic-Cenozoic subduction.

Hydrothermal data

Studying anomalous heat flow, Dougherty et al. (1986) present a series of ridge crest-trench collisions occurred along the west coast of the Antarctic Peninsula during the Cenozoic. In January 1985 a marine heat-flow survey was carried out aboard the BAS research ship RRS "Discovery" southwest of the Anvers fracture zone, where a ridge crest-trench collision occurred approximtely 15 million years ago. Anomalous high heat flow has been discovered coming from the oceanic crust and continental margin to the west of the Antarctic Peninsula. The general pattern of high values seen here is probably due to the presence of a young plate in the extinct subduction zone.

The thermal interaction between back-arc volcanism and basin sediments in the Bransfield Strait has been studied recently by Suess et al. (in press). Their results indicate that the eastern portion of the Bransfield Strait basin is a site of presently active submarine volcanism at water depths of about 2000m. Volcanic activity is related to extensional tectonism in this strait, a phenomenon which would be expected from back-arc rifting. As a consequence, a great deal of hydrothermal interaction and fluid advection occurs at this heavily-sedimented ridge-crest segment. Hydrothermalism in sediments is delineated by the acoustic anomaly pattern adjacent to the presumed volcanic center. Within this zone of alteration, hydrothermal petroleum is generated and seeps to the seafloor. It is easily identified by stable carbon isotope and deuterium/hydrogen characteristics as well as by its compositional spectrum of light alkanes.

Conclusions

The Antarctic Peninsula is a keystone for the comprehension of current questions dealing with geological, tectonic and geographic matters involving not only the Antarctic continent itself, but the rest of the world.

There are many more studies carried out in the last two decades searching answers in this region. Here a few of them have been presented, choosing those more recent where important hypotheses are discussed.

The fit of the Antarctic Peninsula with the Falkland Plateau is still a non-solved problem, despite there are better interpretations based upon geological and tectonic data. The location of the peninsula and its eventual movement with respect to other microplates of the West Antarctica is a tentative approach to answer the question.

The geophysical methods have shown to be useful tools for englightening many hypothese related to the nature of both the under-ice floor and the crust depths.

All these resulting data help to increase the purely scientific knowledge, likewise to.stimulate the always present human interest for profitting by the discoveries, above all, in this still enigmatic and attractive region as Antarctica is.

Acknowledgments

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Marine Geology and Petrochemistry in the Maxwell Bay Area, South Shetland Islands

Byong-Kwon Park, Min-Sung Lee, Ho-Il Yoon, Sang-Heon Nam

I. Marine Geology in Marian Cove and Maxwell Bay

Introduction

Maxwell Bay and Marian Cove are typically glacially-eroded embayments located on the south-west coast of King George Island, South Shetland Islands (Fig. 1). Maxwell Bay has an average depth of 300m with a slope of less than 16° and is directly connected to the Bransfield Strait which is formed by back-arc spreading. The bay is approximately 10km long and 8km wide and bordered by abrupt and very steep slopes. The northern part of Marian Cove is bounded by Weaver Peninsula and the southern part by Barton Peninsula. These two peninsulas are composed mainly of Upper Jurassic (Adie, 1971; Thomson, 1972; Rex, 1976) or Lower Tertiary (Davis, 1982; Smellier et al., 1984) andesite and basaltic andesite. Later the peninsulas were intruded during the Eocene by dolerite, quartz-gabbro and quartzdiorite. Antarctic ocean floors generally differ from those in other marine regions. The ocean is covered by ice shelf or sea ice all around the year. Antarctic ocean has neither input nor a coastal zone dominated by waves. Glaciers supply unsorted sediment directly to the ocean. During the cruise conducted in February of 1988, we investigated marine geology and conducted sismic survey. The purpose of this paper is: 1) to show the sea-bottom topography of Maxwell bay, 2) to describe those sediments which have been cored in Marian Cove, and 3) to present our interpretations concerning the sedimentary processes that form these deposits.

Methods

The seismic profiles (3.5kHz) and one phleger core, 30cm long, were obtained in Maxwell Bay and Marian Cove, respectively (Fig. 2). The sediment color was determined by comparing the moist newly opened core (Kravitz, 1968) to the Standard Geological Society of America color chart. The sand-size distribution was determined by dry sieving. The silt and clay fraction was analyzed using a Micromeritics Sedigraph 5000D. The classification of sediment and textural parameters were obtained according to Folk and Ward (1957). Detrital grains larger than 63μm in sediment were considered ice-rafted. Average pebble size was obtained by measuring the long axis of all clasts. Clay-sized fractions of seven samples from at intervals of 3cm

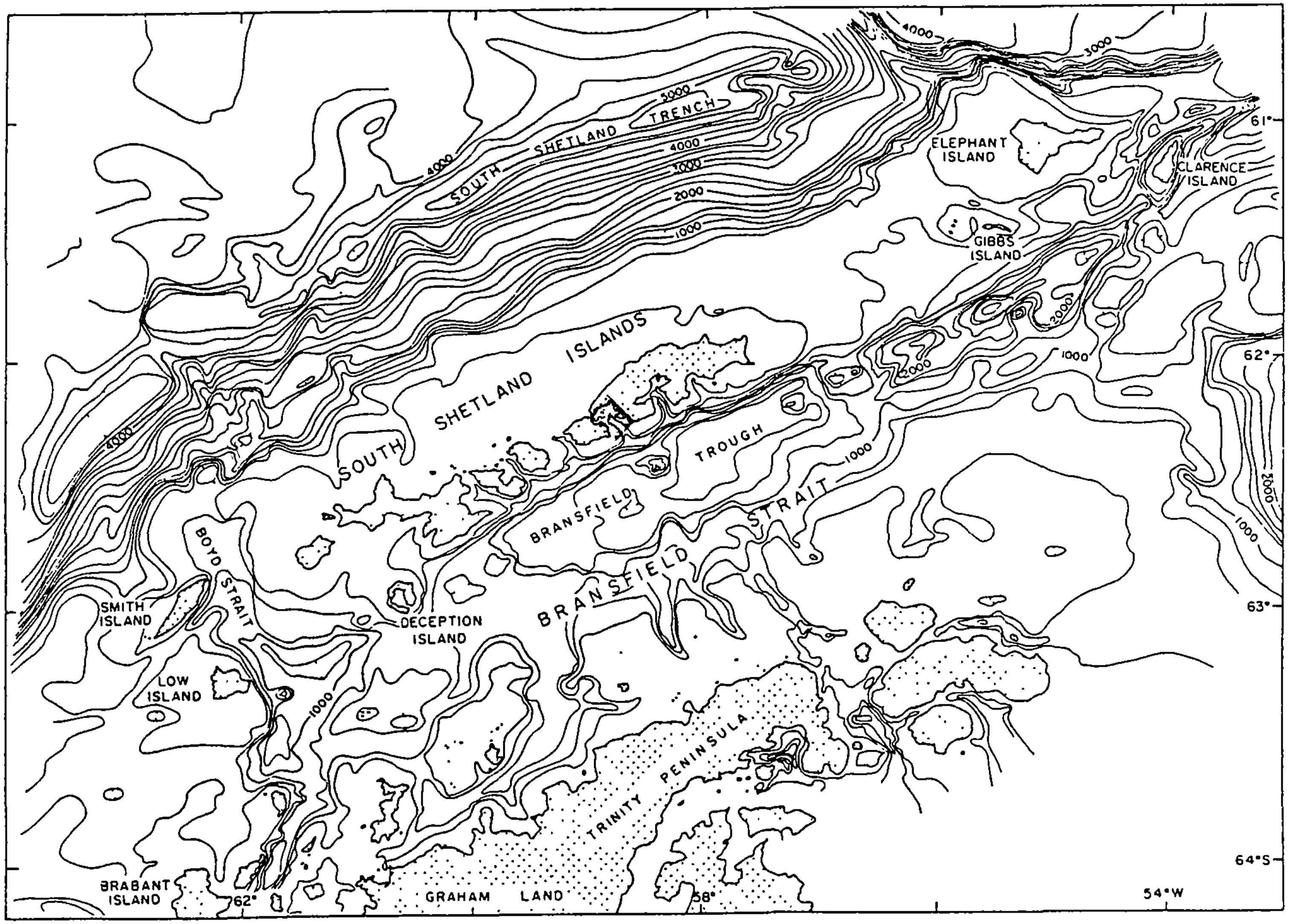

Fig. 1. Location map.

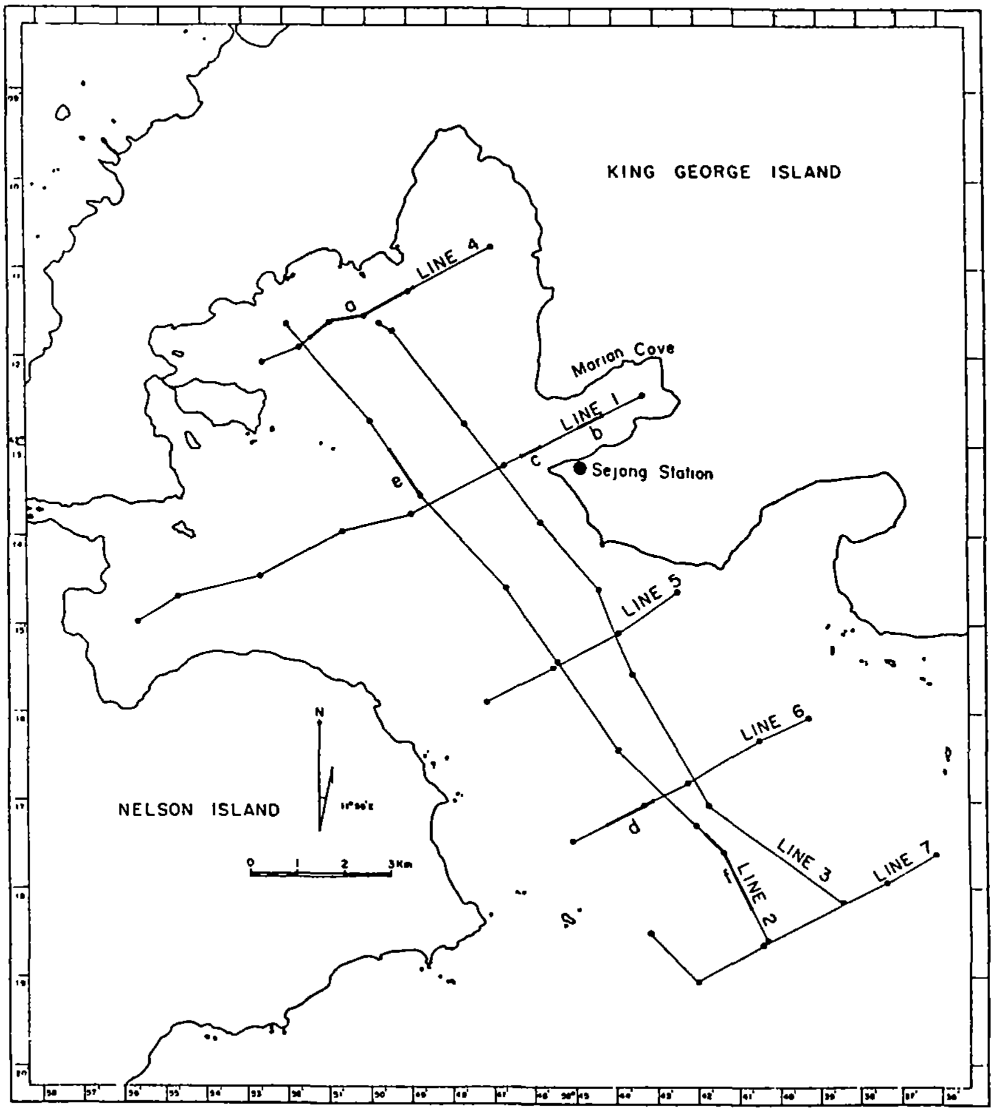

Fig. 2. A map showing ship's track for 3.5kHz subbottom profiler.

of core were studied by X-ray diffraction (XRD). The slides of clay fraction for XRD were (<2μm) prepared by the smear-slide method of Gibbs (1971). The analysis was performed with a Phillips diffractometer using Cu Ka radiation and a nickel filter at scanning speed of 1°20/min. For identification and semi-quantitative analysis of clay minerals, the methods of Biscay (1965) and Carrol (1970) were followed. Heavy minerals were separated from the 2-4Ø fraction using bromoform. In order to determine the weights of suspended particulate matter (SPM), water samples were collected in a Niskin bottle at one station at various depths during 24 hours. One liter of water samples was filtered through pre-weighed dry millipore filter papers with aperture of 0.45μm.

Descriptions

High resolution (3.5kHz) seismic profiles obtained from Marian Cove and Maxwell Bay reveal that the seabed topography is considerably rugged (Fig. 3) and U-shaped with a steep slope of about 19° to the southwest (Fig. 4). The basin is bordered by steep slope of Weaver

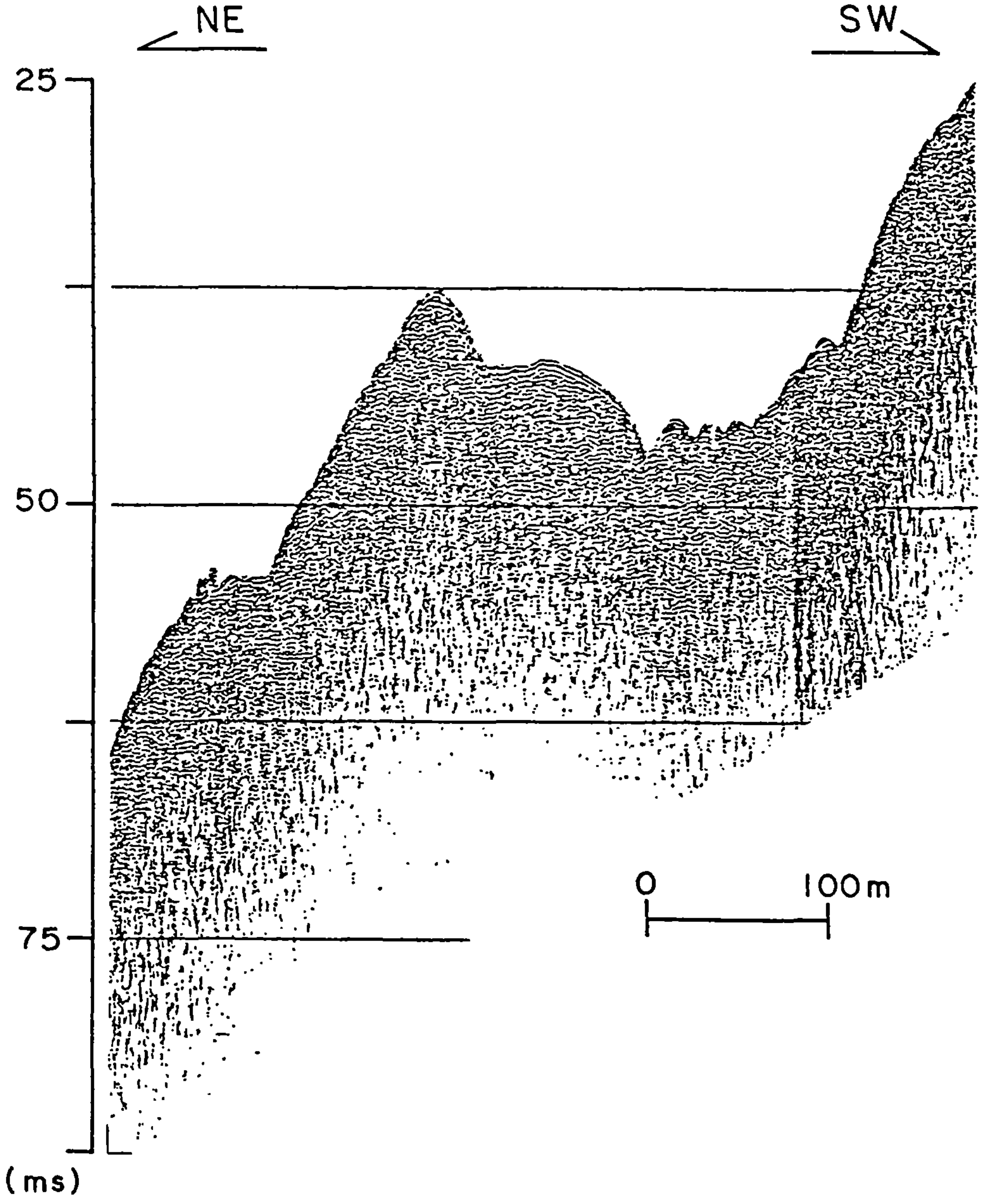

Fig. 3. 3.5kHz profile showing the rugged bottom topography by glacial erosion.

Peninsula and Barton Peninsula on the north and south, respectively. The gently sloping shelf of Maxwell Bay, up to 200m water depth is generally grading to the slope, characterized by highly irregular rugged topography and sediment sequence, showing discontinuous chaotic reflectors (Fig. 5). On the other hand, the slope is quietly steep (10°-38°), covered with thin films of sediment. This films are characterized by sheet flow deposits which is acoustically hyperbolic due to non-stratified sequence (Fig. 6). On the base-of-slope mass flow deposits including rock falls, slumps are also found. These are acoustically hyperbolic with no internal structure. The central basin of Maxwell Bay is characterized by the channel and horizontally stratified sequence (Fig. 7). This channel is approximately 300m wide and 15m deep. The

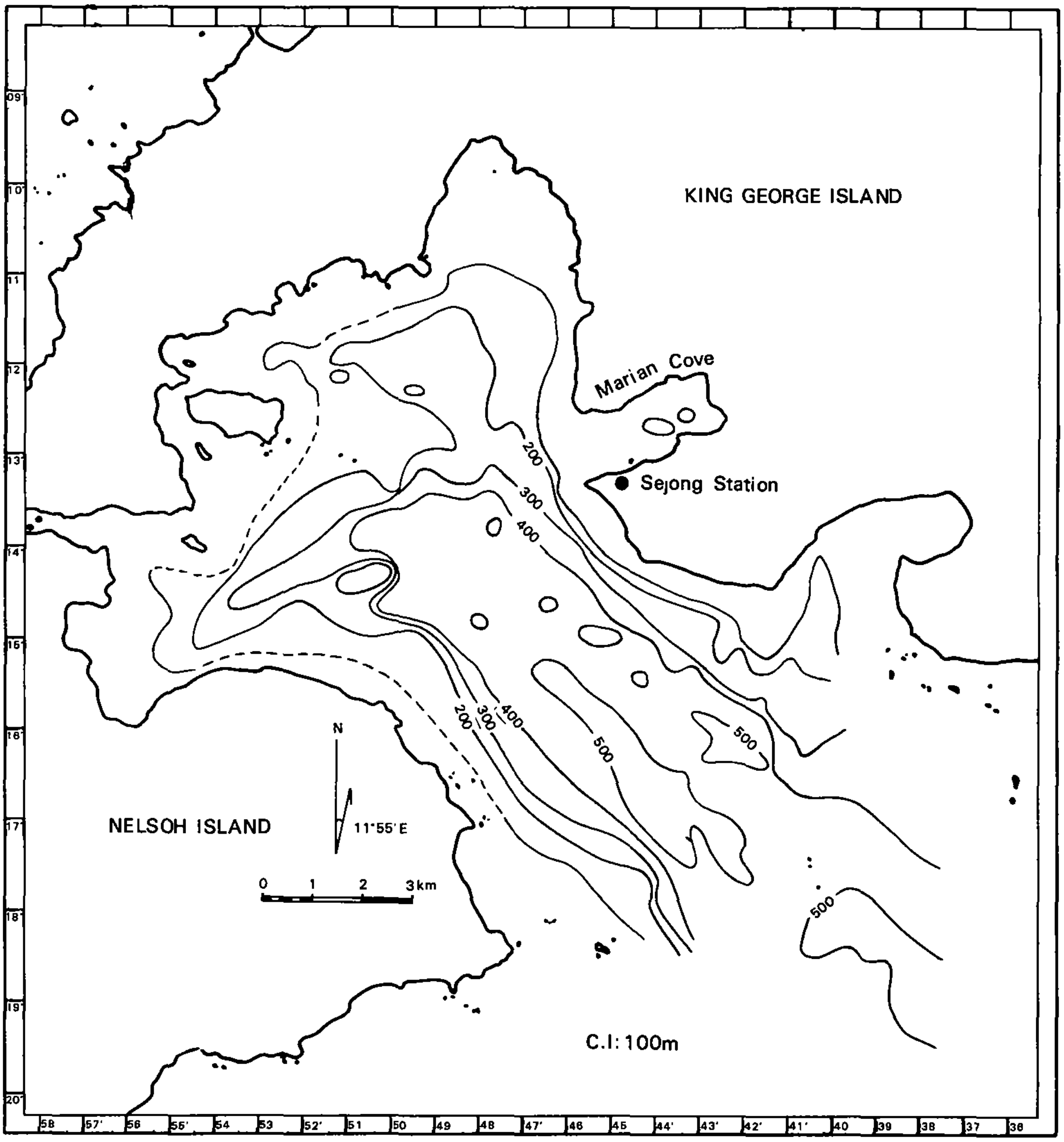

Fig. 4. Bathymetric contours of Maxwell Bay.

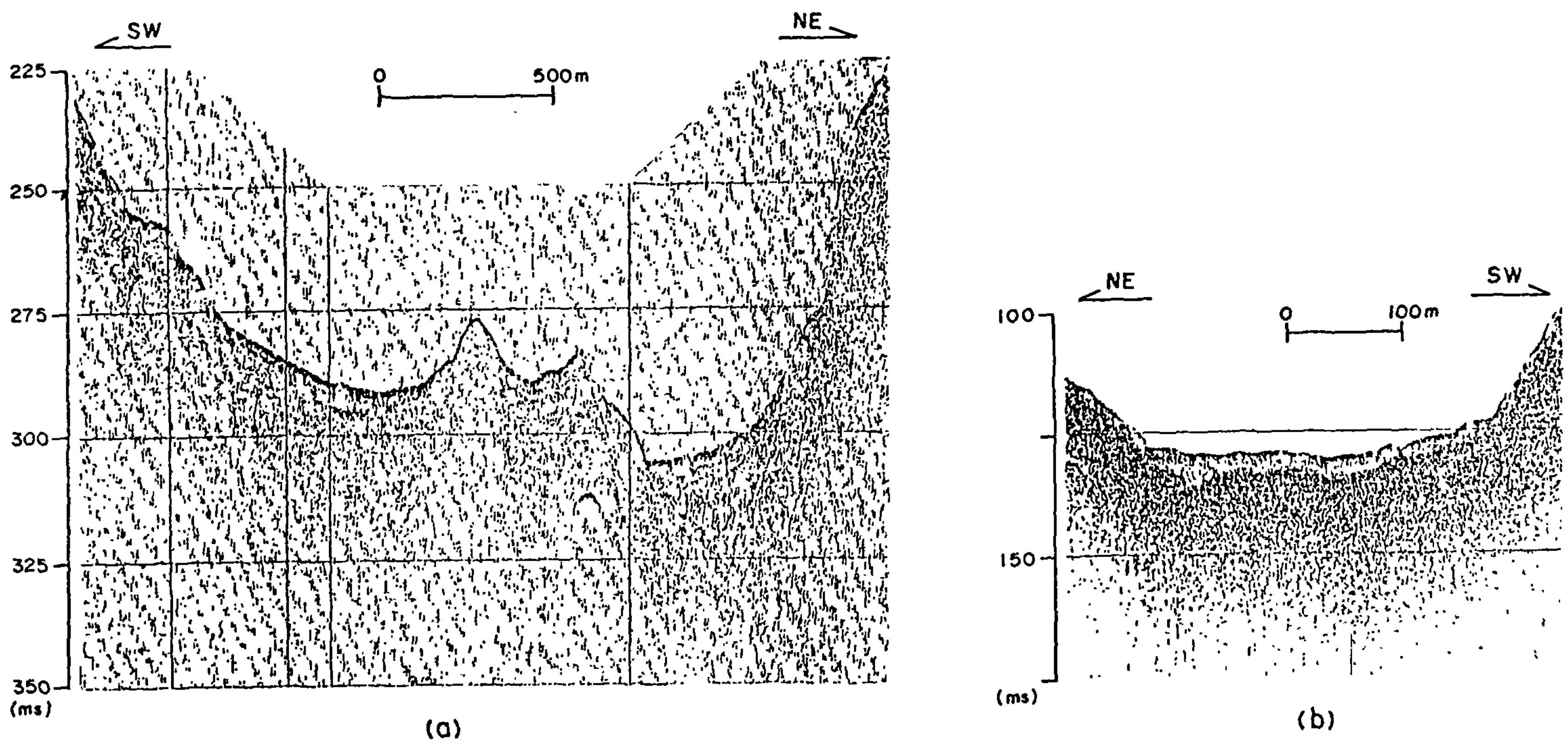

Fig. 5. 3.5kHz profiles of the shelf area in Maxwell Bay (a) and Marian Cove (b) showing discontinuous chaotic reflectors.

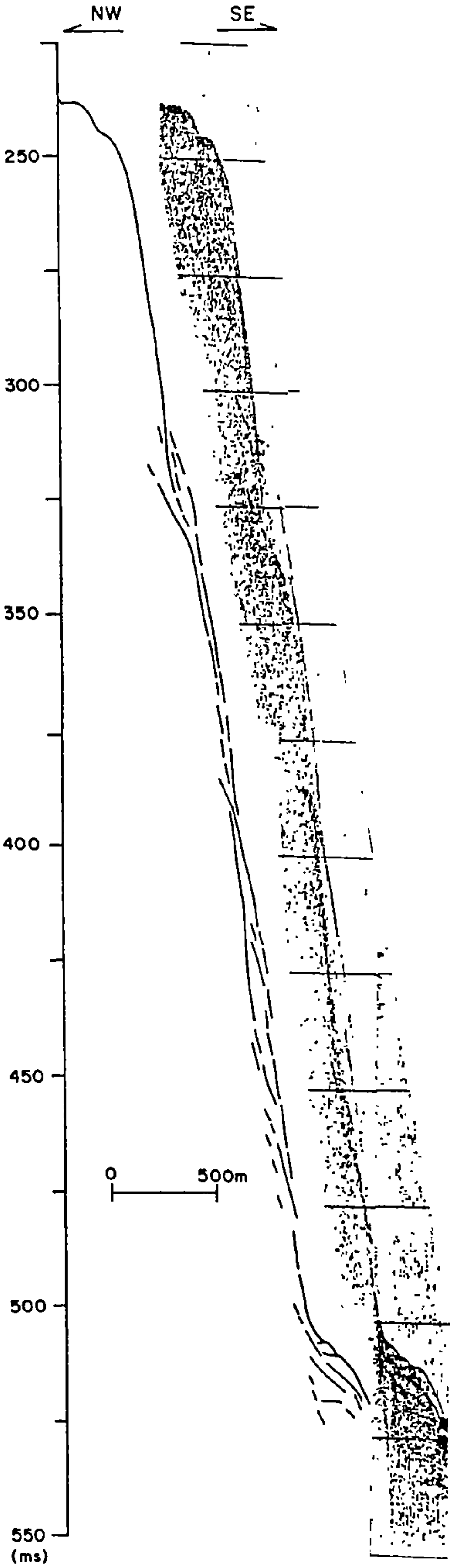

Fig. 6. 3.5kHz profiles with line drawing interpretation showing slides and mass flow deposits along the oversteepening sidewall.

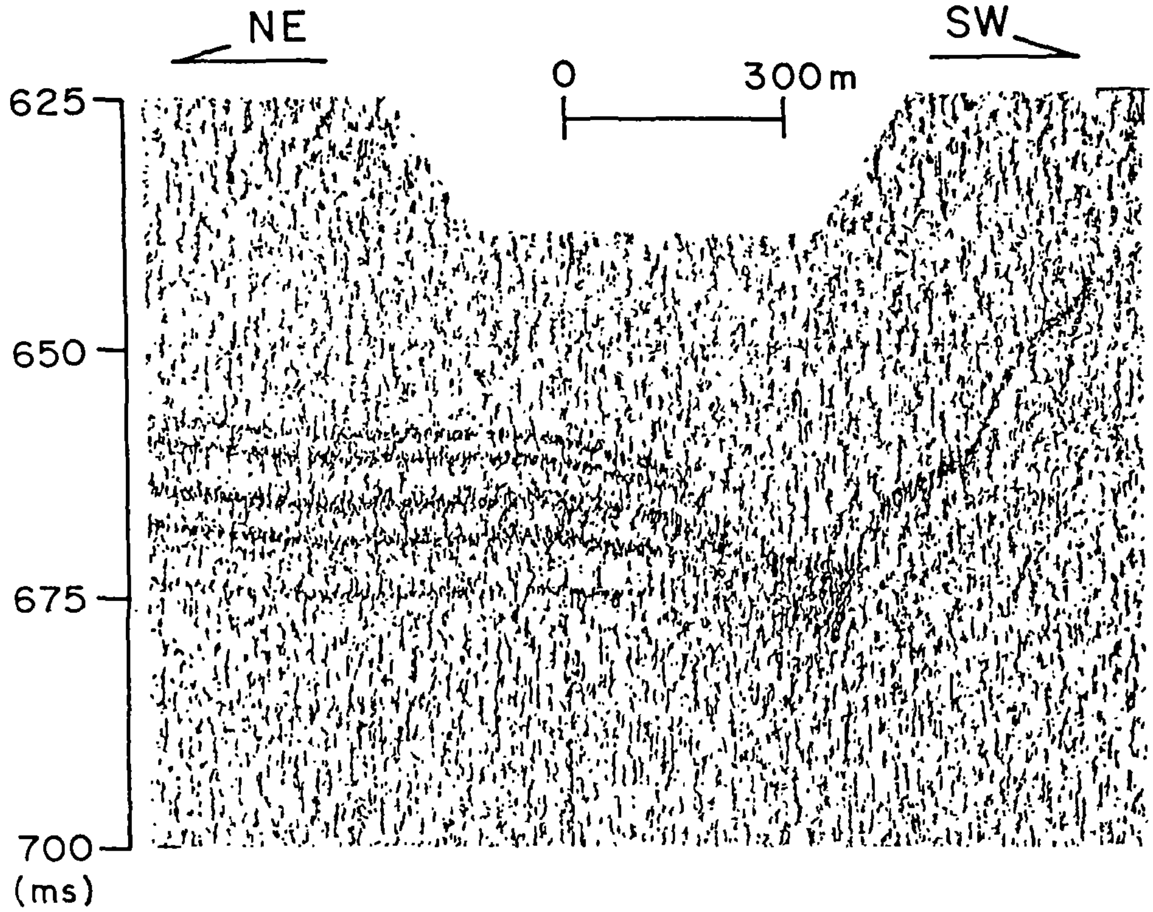

Fig. 7. 3.5kHz profile showing well-stratified turbidite sequence (left) and channel eroded by turbidity current.

horizontal strata is up to 25m thick, acoustically distinctive and conformable with ocean floor, locally showing hummocky surface morphology (Fig. 8). The core sediments obtained in Marian Cove are olive gray (5 Y 4/2) homogeneous gravelly mud in which gravels are scattered with no orientation (Fig. 9). According to Folk (1974), these sediments are very poorly sorted slightly gravelly mud. Mean grain size of these deposits ranges from 7.0Ø to 7.7Ø, showing the vertical textural and mineralogic homogeneity downcore, standard deviations from 2.11Ø to 3.0Ø skewness values from −1.1 to 1.3 and kurtosis values from 4.4 to 5.4 (Fig. 10).

The cummulative curves of the sediments represent apparently poorly-sorted coarse mode and well-sorted fine mode (Fig. 11). Frequency curves represent strong bimodality with the main mode at close to 8Ø and a second mode at approximately-3Ø (Fig. 12). Gravels randomly scattered in the core deposits have a mean grain size of 1cm to 3cm and consist mostly of andesites similar to those of Barton Peninsula and Weaver Peninsula. The gravels are relatively rounded and have well-polished surface indicative of hydraulic reworking (Fig. 13).

The core sediments typically contain microfossils, including foraminifera, diatoms, radiolaria and sponge spicules, however, benthic diatom assemblage was identified only in this study

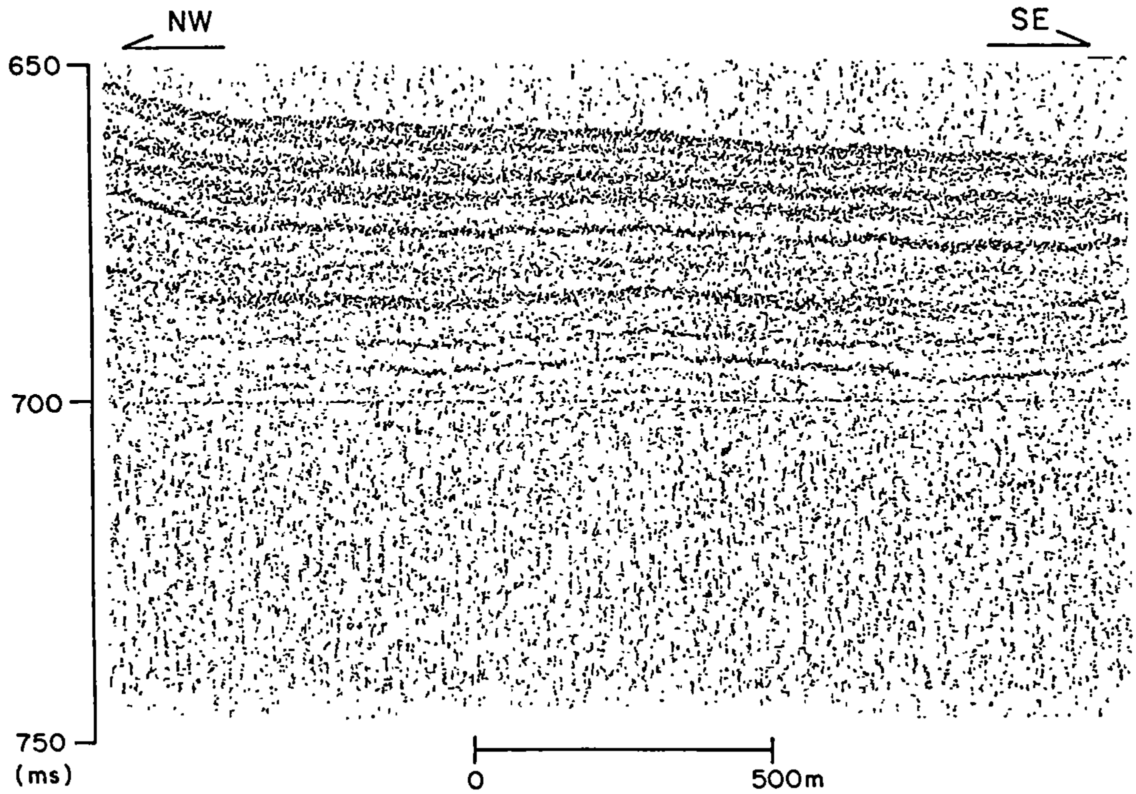

Fig. 8. 3.5kHz profile showing conformable, parallel, and well-stratified reflectors.

area. Fifty species of benthic diatoms were identified in Marian Cove. Among them, *Gomphonema cf. Kamtschatcum* is dominant species, generally forming 12 to 19%, while other species constitute <2% of the benthic diatom population (Table 1). Displaced shallow water-endemic diatom assemblages also sporadically occur through the core. Core sediments do not contain *Hemidiscus Karstenii Jouse* which is known to be extincted during the latest glaciation (Akiba, 1982; Barron, 1985). The clay minerals of 5 sediment samples were analyzed (Table 2). Illite is the predominant clay mineral (47 to 60.9%), chlorite (24.0 to 33.6%) and kaolinite (13.2 to 15.7%) occurs in significant amounts and smectite is the least amounts (1.5 to 2.3%). No correlations are noted between clay minerals and sediment textures (Fig. 10). Heavy mineral percentages also remain within the core section.

The concentrations of suspended sediments are measured through the water column of one point during 24 hours. The concentrations are 3-6 mg/l from 0-10m, 2 mg/l from 50m, and 4 mg/l from 75-100m, that is, relatively high values in surface and bottom water, and lower values at intermediate depth. The suspended matters from water column are observed under the SEM and EDX. These particles are mostly composed of a variety of complete diatoms and minerals, however, diatoms from bottom layer where diatoms are largely fragmented (Fig. 14). The relative element ratios of suspended matter are as follows: Si>Al>Ca>Fe>Mg.

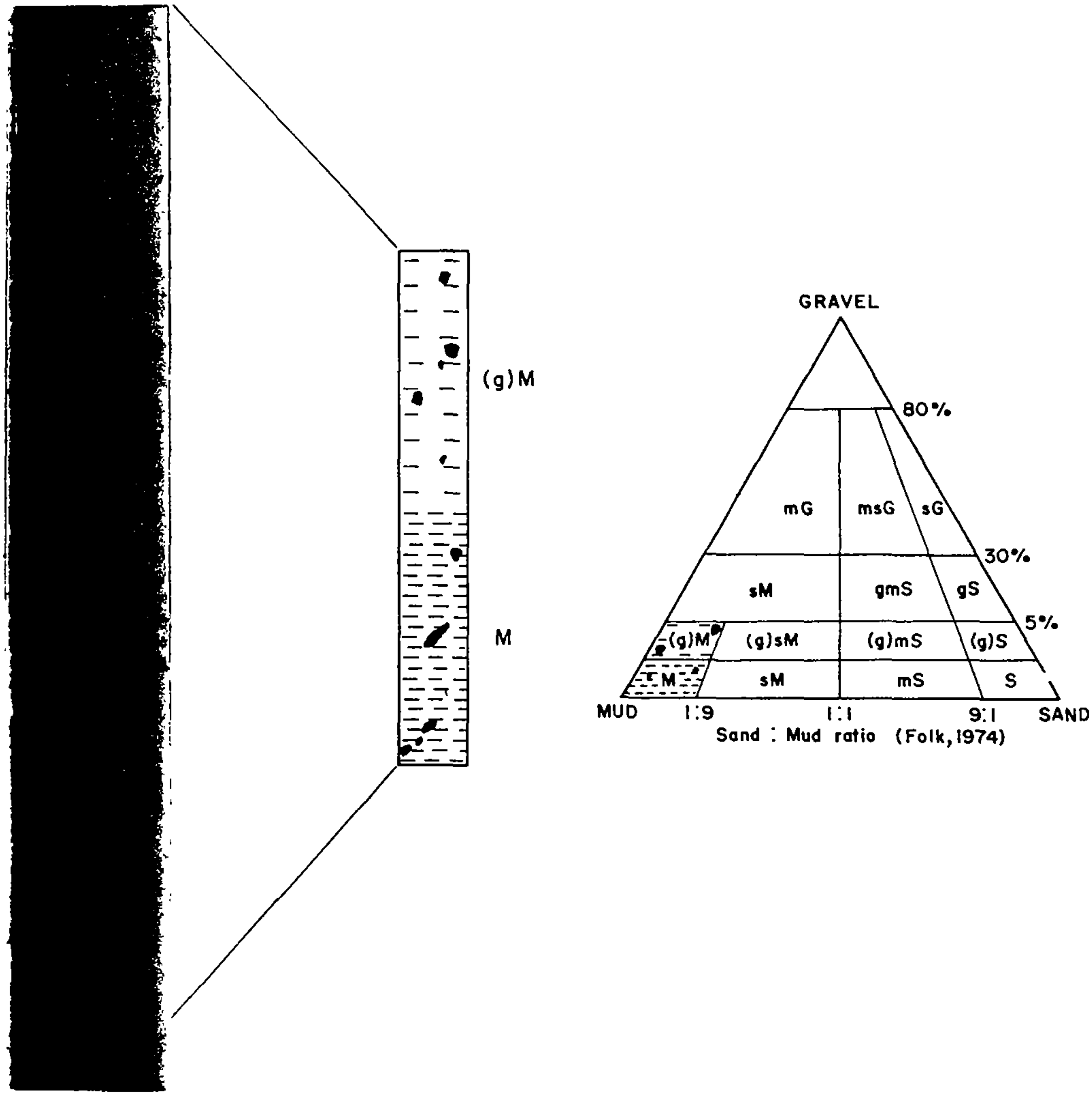

Fig. 9. X-radiograph, lithologic log, and sediment type of core sediment.

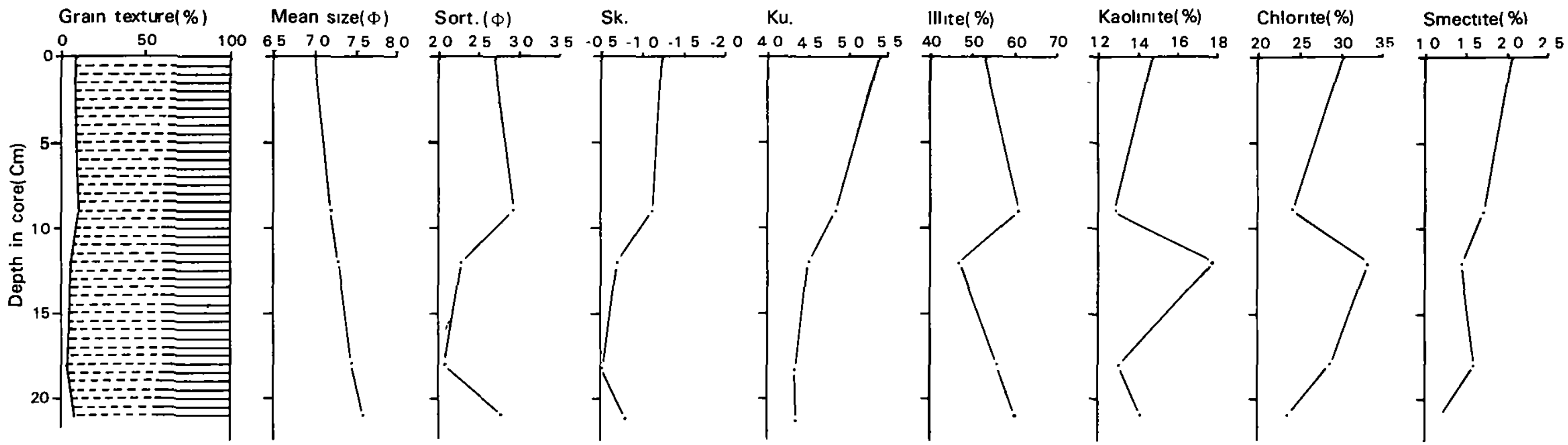

Fig. 10. Vertical distribution of textural parameters and clay minerals of core sediment.

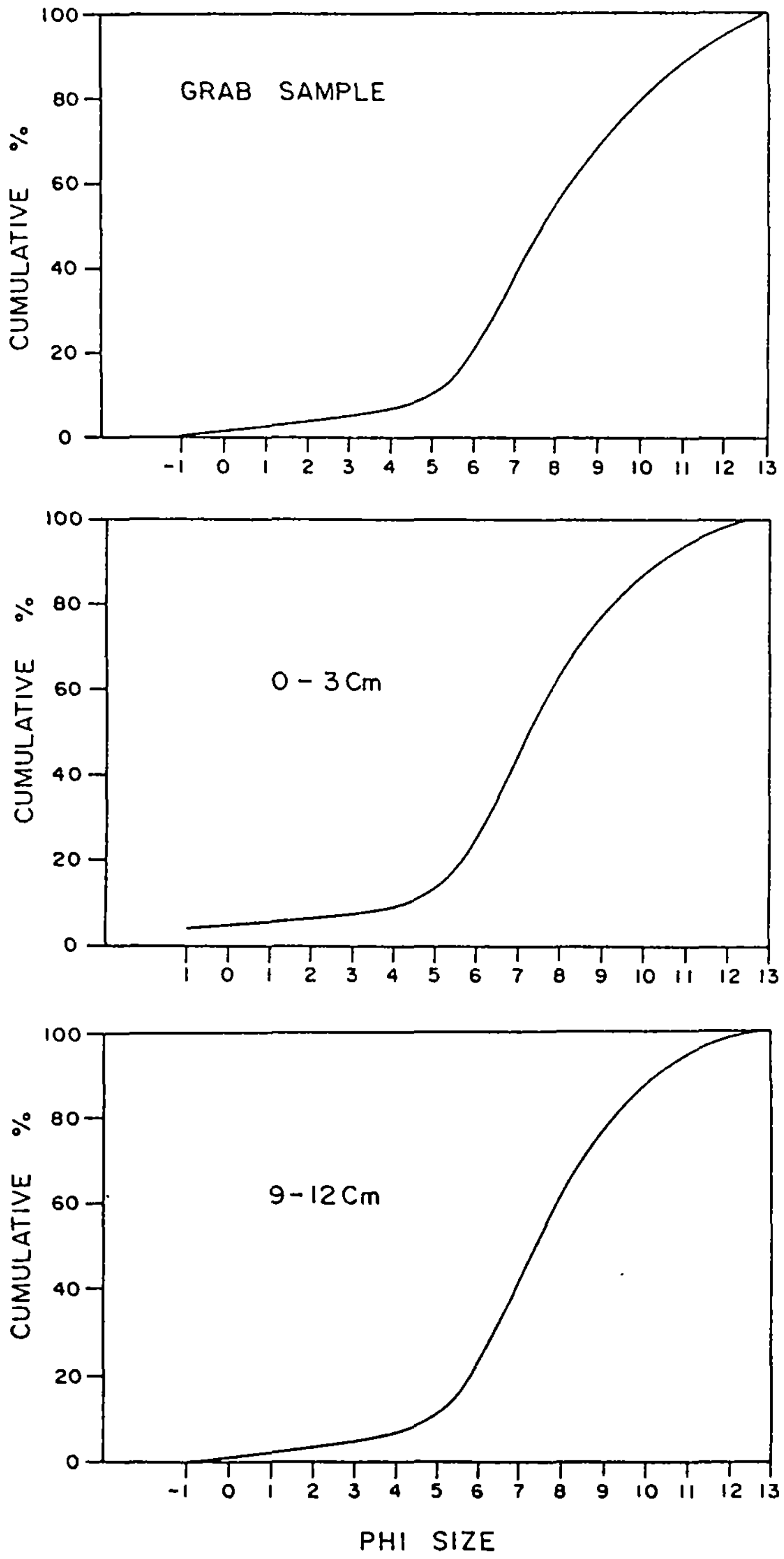

Fig. 11. Cummulative curves for core sediment showing transition from poorly sorted sediment at the base to well sorted sediment at the top

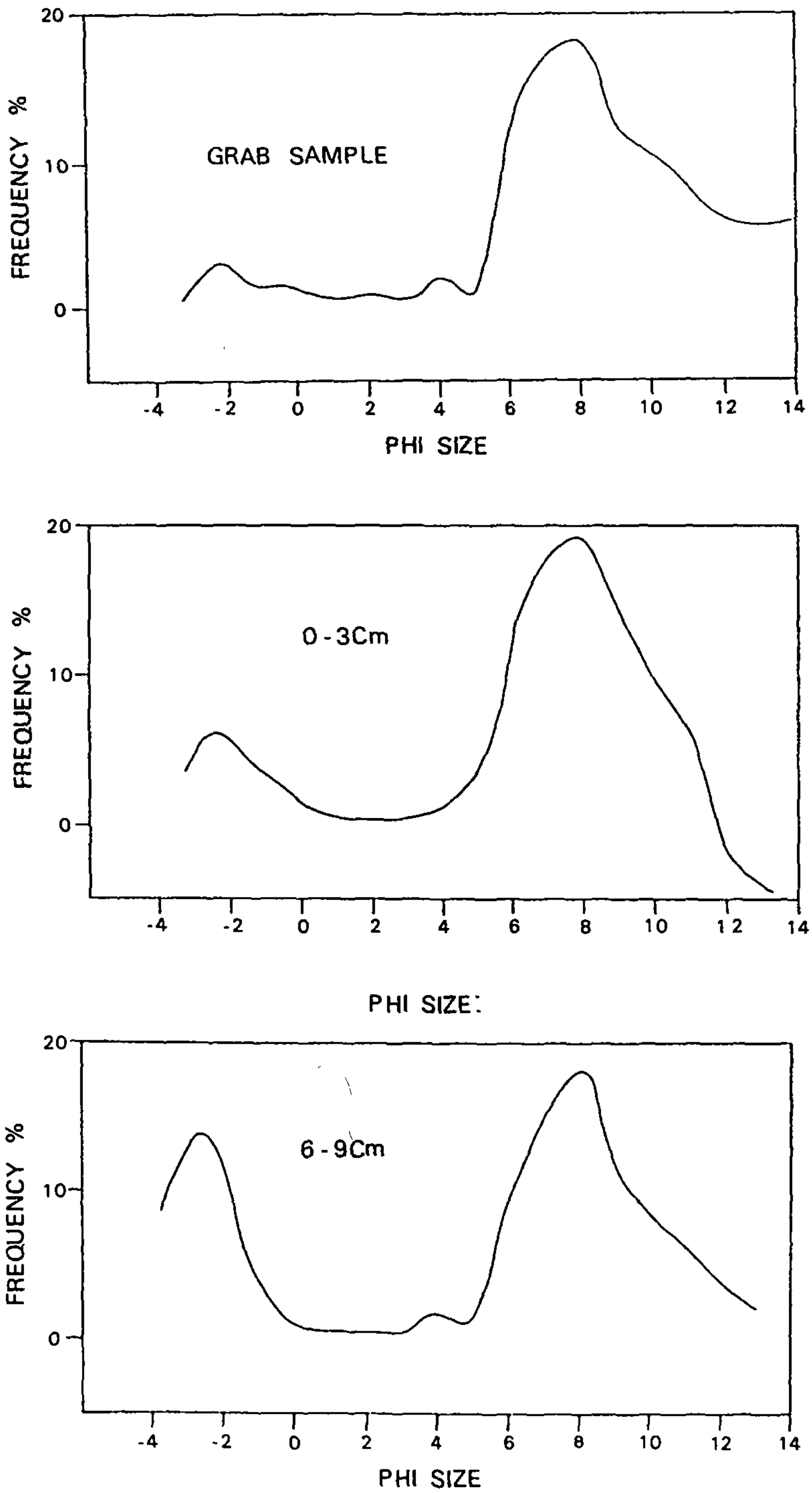

Fig. 12. Frequency percent curves of bottom sediments.

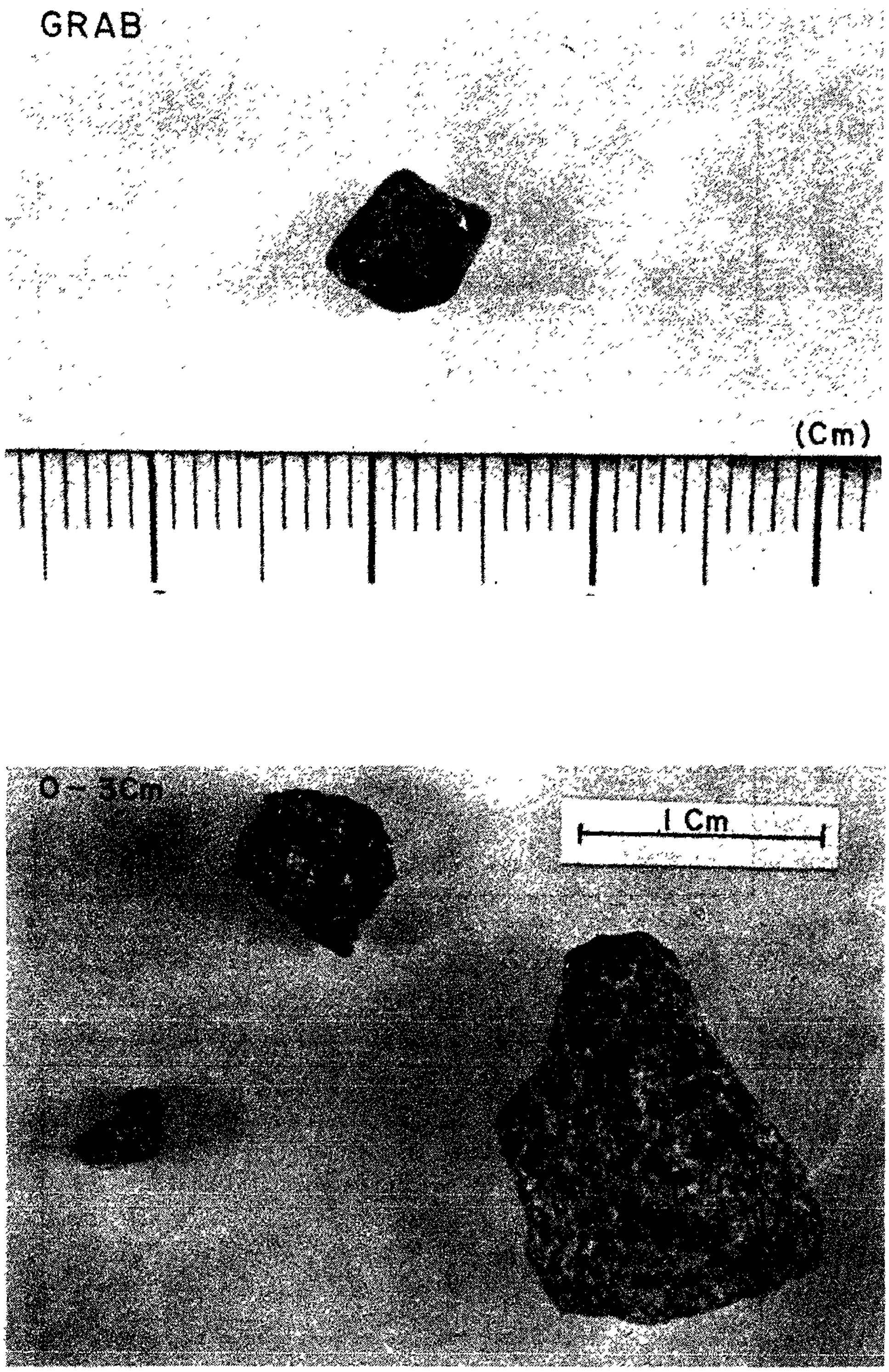

Fig. 13. Volcanic andesite sub-rounded gravels in the core sediment, showing the possible source from the adjacent Barton and Weaver Peninsulas.

Table 1. Occurance of diatom taxa in the Recent sediments in Marian Cove.

	AG			G2/5			G5/6		
	Abun.	No	%	Abun.	No	%	Abun.	No	%
Achnanthes groenlandica	F	6	13.8	F	8	1.2	R	2	0 3
A. sps.	F	11	2.1	F	23	3.4	C	24	5.6
Actınocyclus curvatulus	F	14	2.6	F	7	1.0	R	2	0.3
A. sps.	R	4	0.7	R	1	0.1	R	2	0.3
Amphora sp. A	R	2	0.4	F	7	1.0	R	4	0.9
Asteromphalus parvulus				R	3	0.3	R	3	0.5
Chaetoceros	G	7	1.3						
Charcotia actinochilus	R	2	0.4	R	6	0.9	R	3	0.5
Cocconeis cf. antiqua	R	5	0.9	F	7	1.0	F	5	1.2
C. costata	F	14	2.6	C	38	5.7	F	13	3.0
C. disculoides	F	20	3.9	F	16	2.5	C	25	5.9
C. pediculus							R	1	0.2
C. placentula							R	1	0.2
C. pseudomarginata				R	1	0.1			
C. cf. schuetii	F	8	1.3	R	3	0.3	F	6	1.4
Corethron cirophilum	R	4	0.7				R	1	0.2
Coscinodiscus lentiginosus	F	11	2.1	F	27	4.0	F	21	4.9
C. marginatus	F	6	1.1	F	14	2.1	R	6	1.4
C. stellaris var. symbolophora	F	1	0.1						
C. symbolophorus	R	1	0.1						
C. sps.	F	20	3.7	F	32	4.8	F	10	2.2
Diploneis smithi	R	1	0.1						
D. sp. A	R	3	0.6				R	1	0.2
Eucampia antratica	R	5	0.9						
Gomphonema cf. kamtschaticm	A	74	13.8	A	127	18.9	A	52	12.2
Gyrosigma sp. A	R	3	0.6	R	1	0.1	R	2	0.3
Hemiaulus sp. A	R	1	0.1						
Licmophora juergensii	F	20	3.7	F	21	3.1	F	5	1.2
L. aff. juergensii	F	11	2.0	F	32	4.8	C	22	5.2
Navicula directa	F	15	2.8	F	16	2.4	F	7	1.6
N. pupula	R	1	0.1						
N. radiosa	R	4	0.7						
Navicula sp. A	F	10	1.9	F	13	1.9	R	2	0.3
Nitzschia angulata	F	12	2.2	F	10	1.5	F	12	2.8
N. curta	C	50	9.4	F	30	4.5	C	22	5.2
N. cylindrus	R	4	0.7	F	9	1.3	R	1	0.2
N. kerguelensis	F	13	2.4	F	18	2.7	C	24	5.6
N. lineola	F	12	2.2	F	11	1.6	F	10	2.2
N. obliquecostata	F	7	1.3	R	2	0.2	F	8	1.9
N. ritscheri	R	3	0.6	F	13	1.9	F	7	1.6
N. separanda	F	7	1.3	F	11	1.6	F	11	2.6
N. sublinearis	R	4	0.7	F	3	0.3	R	3	0.5
N. vitrea	F	8	1.5	R	6	0.9	R	2	0.3

	AG			G2/5			G5/6		
	Abun.	No	%	Abun.	No	%	Abun.	No	%
N. sp. A	F	6	1.1	F	13	1.9	F	8	1.9
Odontella aurita	F	6	1.1						
O. weissflogii	R	4	0.7	R	1	0.1	R	2	0.3
O. sp. A				R	1	0.1			
Pinnularia quardratarea	R	1	0.1						
P. sp. A	F	6	1.1	R	3	0.3	R	2	0.3
Rhizosolenia hebetata forma hiemalis	F	7	1.3	R	5	0.7	F	11	2.6
R. styliformis	R	4	0.7	R	6	0.9	F	7	1.6
Rhoicosphaenia sps.	F	8	1.5	R	4	0.6	F	6	1.4
Thalassionema nitzschioides	F	12	2.2	F	18	2.7	F	7	1.6
Thalassiosira antarctica	R	4	0.7	R	4	0.6	R	7	1.6
T. gracillis	F	17	3.2	F	32	4.8	C	22	5.2
T. gracillis var. expecta	F	12	2.2	R	4	0.6			
T. leptopus	R	4	0.7	R	2	0.2			
T. sp. A	R	2	0.4	F	29	4.3	C	28	6.6
Thalassiothrix longissima	F	6	1.1	R	4	0.6	R	2	0.3
Trachyneis aspera	R	2	0.4	R	1	0.1	R	1	0.2
T. sp. A	R	1	0.2						
Tropidoneis sp. A	R	1	0.2						
Others	C	30	3.5	F	31	4.6	F	10	2.3
Total		535	100.		672	100.		427	100.

A: abundant (more than 10%), C: common (10 to 5%), F: few (5 to 1%), R: rare (less than 1%)

Table 2. Relative percentage of clay minerals in <2μm fraction of sediments

Depth (cm)	Illite	Kaolinite	Chlorite	Smectite
0- 3	53.19	14.73	30.02	2.06
6- 9	60.91	12.92	24.46	1.71
9-12	47.04	17.86	33.64	1.46
15-16	56.19	13.16	29.03	1.61
18-21	60.49	14.28	24.00	1.23
Grab	50.99	15.73	31.02	2.27
Average	54.08	14.78	28.70	1.72

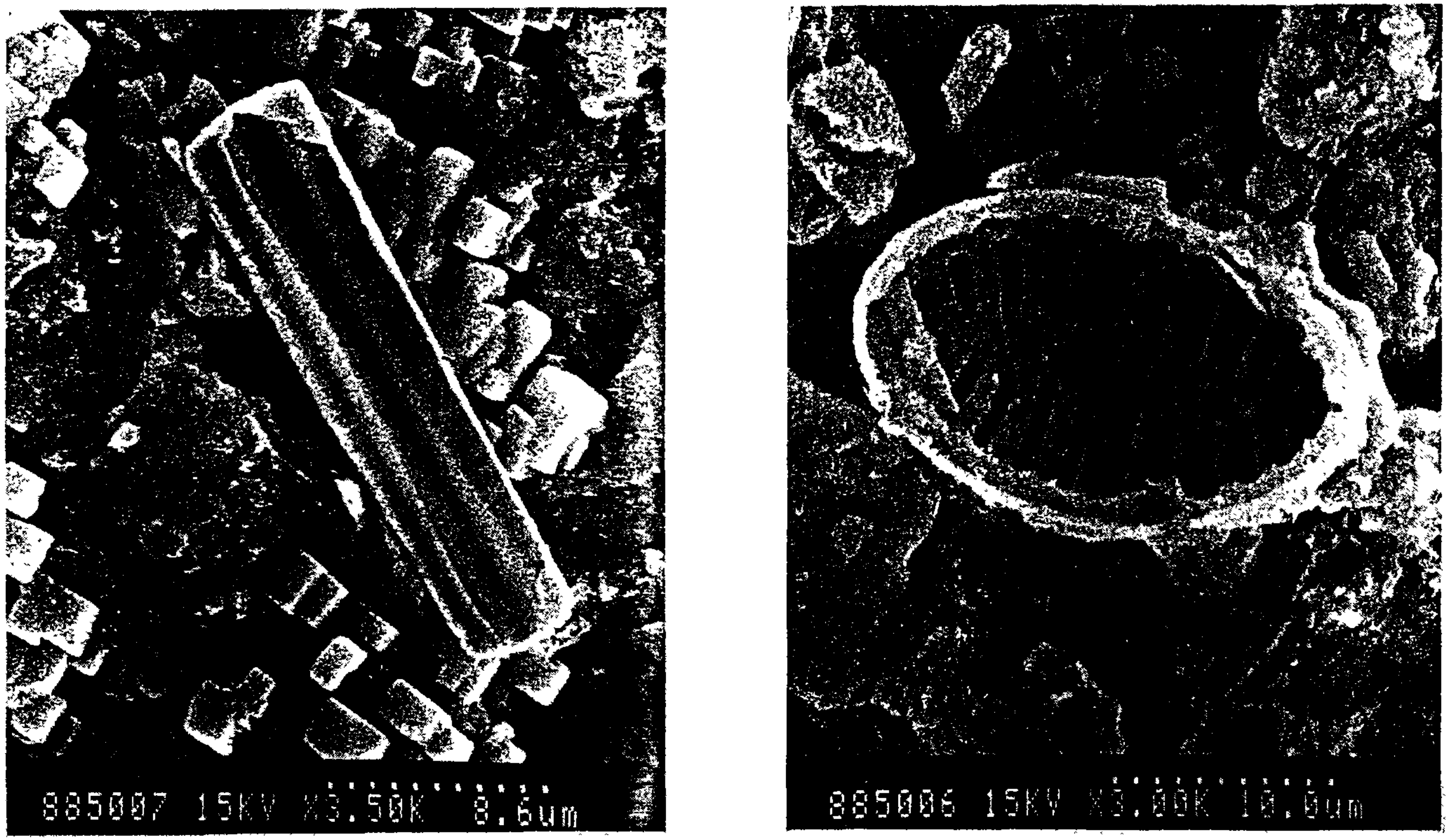

Fig. 14. Electron micrograph of various SPM in the surface waters(a) and intact diatom test in the near bottom waters (100m) in Marian Cove

Fig. 15. A pile of rubble containing rounded gravels in an rafting ice in Marian Cove.

Discussions

The 3.5kHz seismic profiles from Maxwell Bay and Marian Cove reveal that the sea-bottom condition is characterized by irregular, potentially unstable, glacially scoured topography on which gravity flow deposits are preserved in the form of rock falls, slide/slump deposits and turbidite (Anderson et al., 1983; Andamson et al., 1983; Embleton et al., 1975; Domack et al., 1983; Syvitski et al., 1987). Downslope movement most likely involves basinward transition from coherent slide to mass flow and finally turbidite, and it probably follows a transition path similar to that described by Hampton (1972). The rugged, unstable topography seems to play an important role in restricting glacier or marine processes to the bay as well as in initiating and sustaining sediment gravity flows down to the basin. On the other hand, sediment transport in the nearshore is largely dominated by glacial processes, i.e., ice-rafting (Fig. 15) and suglacial meltwater stream, and the ice-rafted sediments are redistributed by the processes of sediment gravity flows along the steep slope.

The core sediments in Marian Cove which consist of fine poorly sorted gravelly mud can be characterized by the presence of microfossils and bimodal grain-size distribution. The size-bimodality of core sediments reflects a combination of ice-rafting (from icebergs and ice shelves) and normal marine sedimentation. Their coarse mode fraction (sand to pebble size) displays poor sorting and includes subrounded faceted, lithic grains. This material comprises the ice-rafted component which concentration varies from 4.6% to 10.1%. The fine mode displays high degree of sorting and is generally negatively skewed. These deposits are quietly similar to the type 2 sediment group described by Anderson (1980). They concluded that these sediments reflect a ice-rafting and bottom current deposition.

For the most part, the gravels randomly scattered in sediments show relatively polished surface and consist of volcanic andesite which is the main geology of Barton Peninsula and Weaver Peninsula. The gravels may originate from the followings.

1) Contemporary ice-rafted material,
2) relict, deposited during low sea level of glacial age,
3) residual deposits resting on submarine rock outcrops.

In all cases, it is assumed that the well-rounded polished surface of gravels was produced by extensive reworking in hydraulic condition and then transported to the study area by ice-rafting which is one of the most important glacial depositional processes in the sea around Antarctica (Anderson et al., 1979; Anderson et al., 1980; Kurtz et al., 1979).

In fact, Marian Cove is free of ice cover during the summer and completely covered by ice during the winter. We also found several sediment-laden icebergs in Marian Cove, coming from nearshore environments during the austral summer in 1987.

Microfossil analysis reveals that the Marian Cove sediments abundantly contain benthic diatoms indicative of high biological productivity. The occurrence of fifty species of benthic diatoms suggests that the diatom assemblages are very much diversified, which is a common characteristics of polar regions. The presence of shallow water endemic diatoms suggests that the Marian Cove sediments are partially mixed with sediments supplied from shallow water environments. Characteristically, the disappearance of *Hemidiscus Karstenii Jouse* which had survived in Antarctic sea until the latest glaciation (Pleistocene) indicates that the Marian Cove sediments were mainly deposited during the Holocene time.

The high SPM content in surface water is generally influenced by organically and inorganically mediated process (McCave, 1972; Manheim et al., 1970; Meade et al., 1975). However the high value of SPM in Marian Cove seems to be mostly due to organic process. This can be explained by the similarity of the vertical distribution of SPM and also the high quantity of micro-organisms in the bay. In other words, most of SPM is supplied from the primary production (in particular, diatom production) which is very common in the Antarctic surface water.

Conclusion

1. 3.5kHz seismic profiles reveal that Maxwell Bay and Marian Cove are characterized by considerably rugged and U-shaped bottom topography, formed by glacial erosion. Rock falls, slide/slump and turbidite are found on steep slope, base-of-slope and channel in the basin.
2. Sediments in Marian Cove, olive gray homogeneous gravelly mud, were deposited in glacial marine sedimentary environments. The texture, sedimentary structures and composition of the sediments suggest ice-rafted processes. The result of size distribution shows the bimodality suggesting marine glacial sedimentation. Additionally, the gravels, consisting of volcanic andesite, which exhibit well-polished, rounded surface indicate that these are derived from Barton Peninsula and Weaver Peninsula through hydraulic reworking.
3. Benthic diatom assemblages include shallow water species such as *Achnanthes groenlandica* (Cleve), *Licmophora Juergensii* (Adgrads) as well as deep water ones. This implies the partial supply of terrigenous material from shallow water environments to Marian Cove. The absence of *Hemidiscus Karstenii Jouse* indicates that the Marian Cove sediments have been deposited since the Holocene transgression.
4. The close similarity of SPM distribution and plankton distribution indicates that the high value of SPM in surface water in Marian Cove seems to be due to organic process.
5. Sediment transport in Maxwell Bay and Marian Cove seems to be largely dominated by glacial processes i.e. ice-rafting, and meltwater stream. However, processes of sediment gravity flow undoubtedly play a key role in the redistribution of sediments.

II. Petrochemistry of plutonic and hypabyssal rocks

This study is intended to investigate the petrography and petrochemistry of the volcanic and plutonic rocks in Barton Peninsula, King George Island, Antarctica (Table 1). In particular, the relations between chemical composition of the rocks and tectonic settings are studied to understand the evolutional processes of King George Island. The chemical composition of the volcanic rocks exposed at Barton Peninsula is intermediate to acidic; those are andesite, dacite and rhyolite based on the classification of silica content (raw analyses recalculated to 100% anhydrous). The plutonic intrusions are quartz diorite and granodiorite based on the modal analyses of mineral composition (Tables 2 and 3).

Table 1. List of samples and classification of volcanic and plutonic rocks of Barton Peninsula.

Classification	Sample No.	Type of Rock
Volcanic	MC-1	altered dacite
Volcanic	MC-2	altered andesite, porphyritic
Volcanic	MC-3	andesite, porphyritic
Plutonic	MC-4	granodiorite, porjphyritic
Plutonic	MC-5	granodiorite
Plutonic	MC-6	granodiorite
Plutonic	MC-7	quartz diorite
Volcanic	Marsh	basaltic andesite
Volcanic	1	andesite
Volcanic	8	dacitic tuff
Volcanic	9	altered dacitic rhyolite
Volcanic	13	basalt
Plutonic	K-1	fine-grained granite
Volcanic	K-4	dacite
Volcanic	K-6	rhyolite
Volcanic	K-10	rhyolite
Volcanic	K-11-1	rhyolite
Volcanic	K-13	dacite
Plutonic	K-22	fine-grained granite

Major composition oxides and fifteen trace elements are analyzed by using automatic X-ray spectrometer for nineteen volcanic and plutonic rocks of Late Cretaceous to Early Tertiary age. The results of geo-chemical analysis are as follows: 1) The rocks belong to high alumina basalt series in subalkaline composition based on the plots of alkaline weight percentage versus SiO_2 content (Fig. 1). 2) The plots of Al_2O_3 versus normative pl (An $\times$100/(Ab+An)) indicate that the rocks belong to calc-alkaline series (Fig. 2). 3) Diagram of M (MgO)-F (FeO)-A (Na_2O+K_2O) suggests that the rocks are formed at the middle to final stages of magma differentiation following the similar process of calc-alkaline series (Fig. 3). However, some samples are different from typical calc-alkaline series and rather similar to tholeiite series. 4) Diagrams of SiO_2, FeO* and TiO_2 with increasing FeO*/MgO indicate the similarity with those of volcanic rocks in Amagi and Asama areas in Japan, suggesting origin of island arcs (Fig. 4). 5) The plots of Na_2O/K_2O versus Na_2O-K_2O indicate the similarity both to deep-sea tholeiitic and island-arc volcanic rocks (Fig. 5). The wide scattering of values may be the result of increase and decrease of Na_2O and K_2O content during alteration of some rock samples. 6) Diagram of TiO_2-K_2O-P_2O_5 suggests that the rocks are made from volcanism in non-oceanic area (Fig. 6). However, there is possibility of misinterpretion because the relative migration rate of TiO_2, P_2O_5 and K_2O during weathering and alteration processes is not considered completely. 7) The granitic rocks in the area belong to I-type granite and seem to be subvolcanic plutonics (Fig. 7). 8) The result of trace element study also indicates the rocks belong to calc-alkaline series (Figs. 8, 9 and 10).

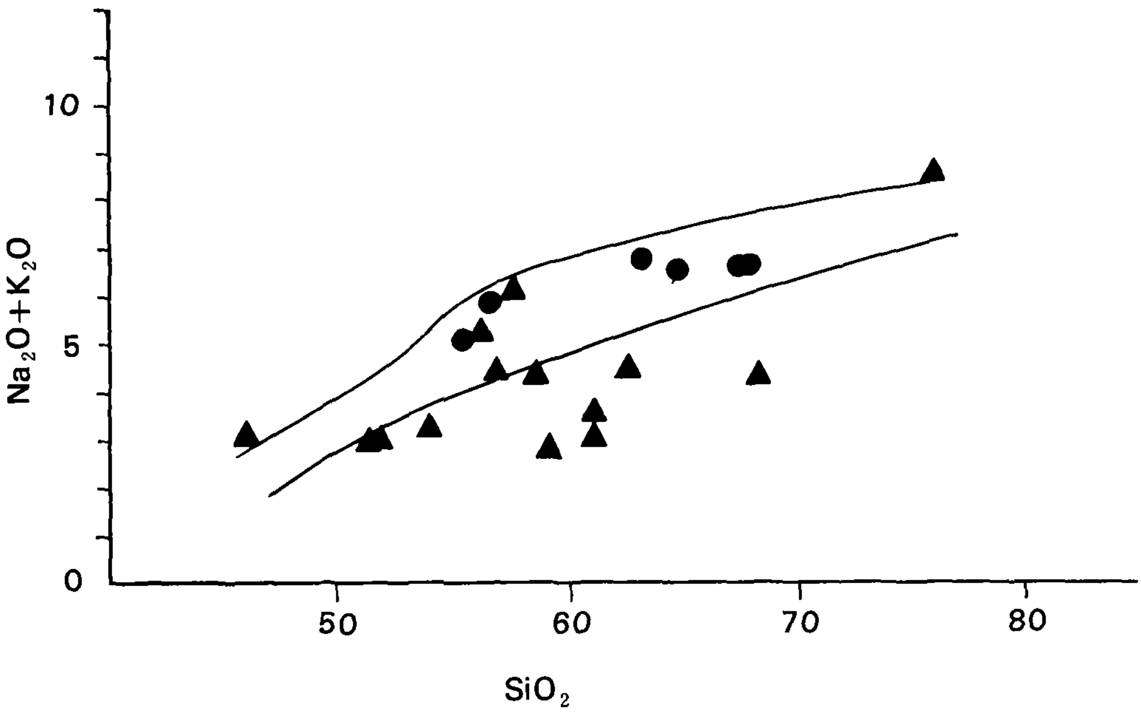

Fig. 1. Plot of total alkalis weight % versus SiO2 weight % for rocks of Barton Peninsula. Triangles represent volcanic rocks and circles represent plutonic rocks.

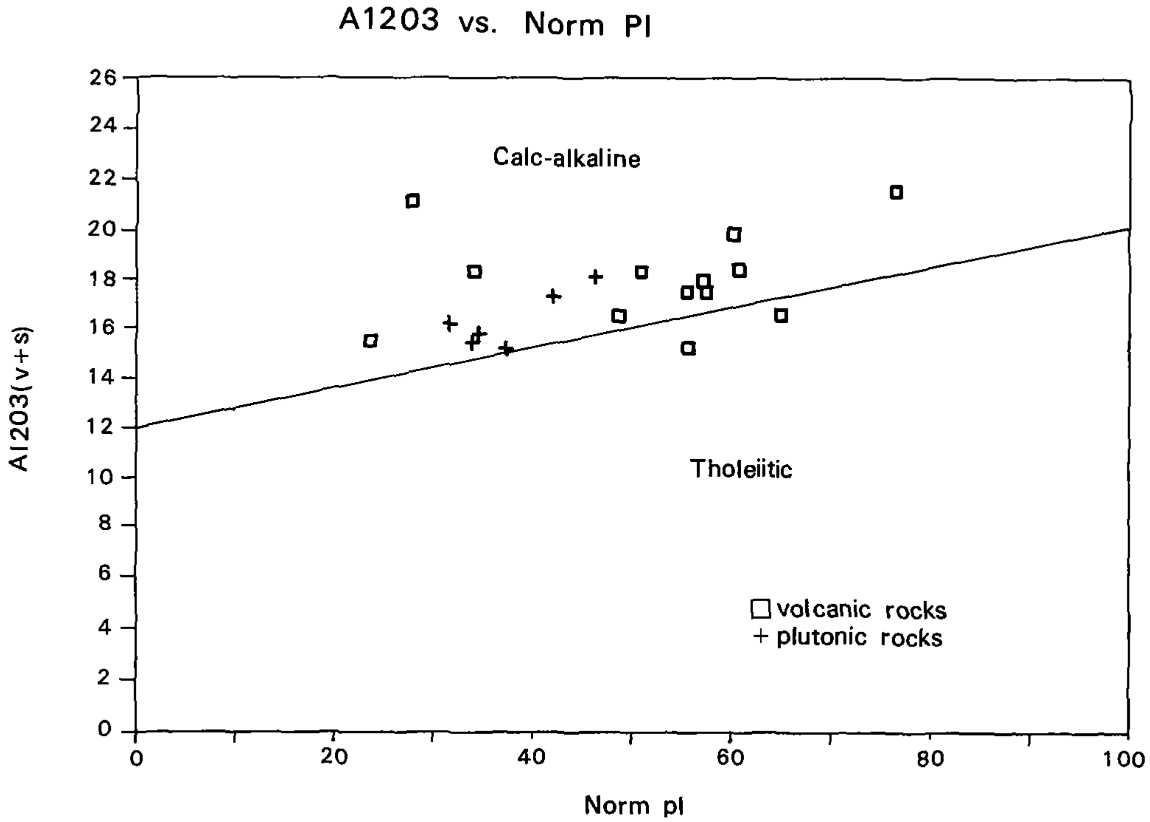

Fig. 2. Plot of Al_2O_3 versus normative pl (An × 100/(Ab+An)) for rocks of Barton Peninsula.

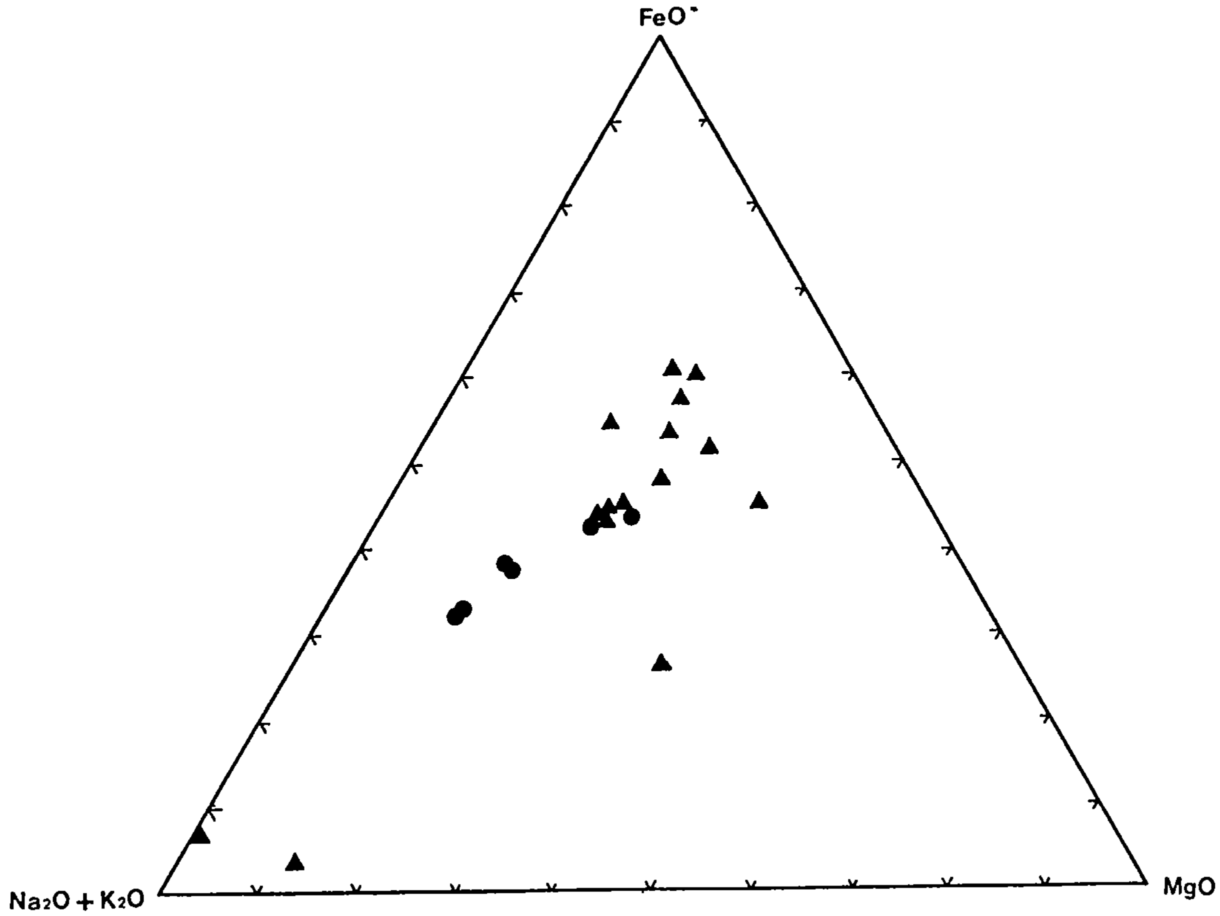

Fig. 3. Triangular diagram. of (Na_2O+K_2O)—(FeO^*)—(MgO)(AFM) for rocks of Barton Peninsula. Triangles represent volcanic rocks and circles represent plutonic rocks.

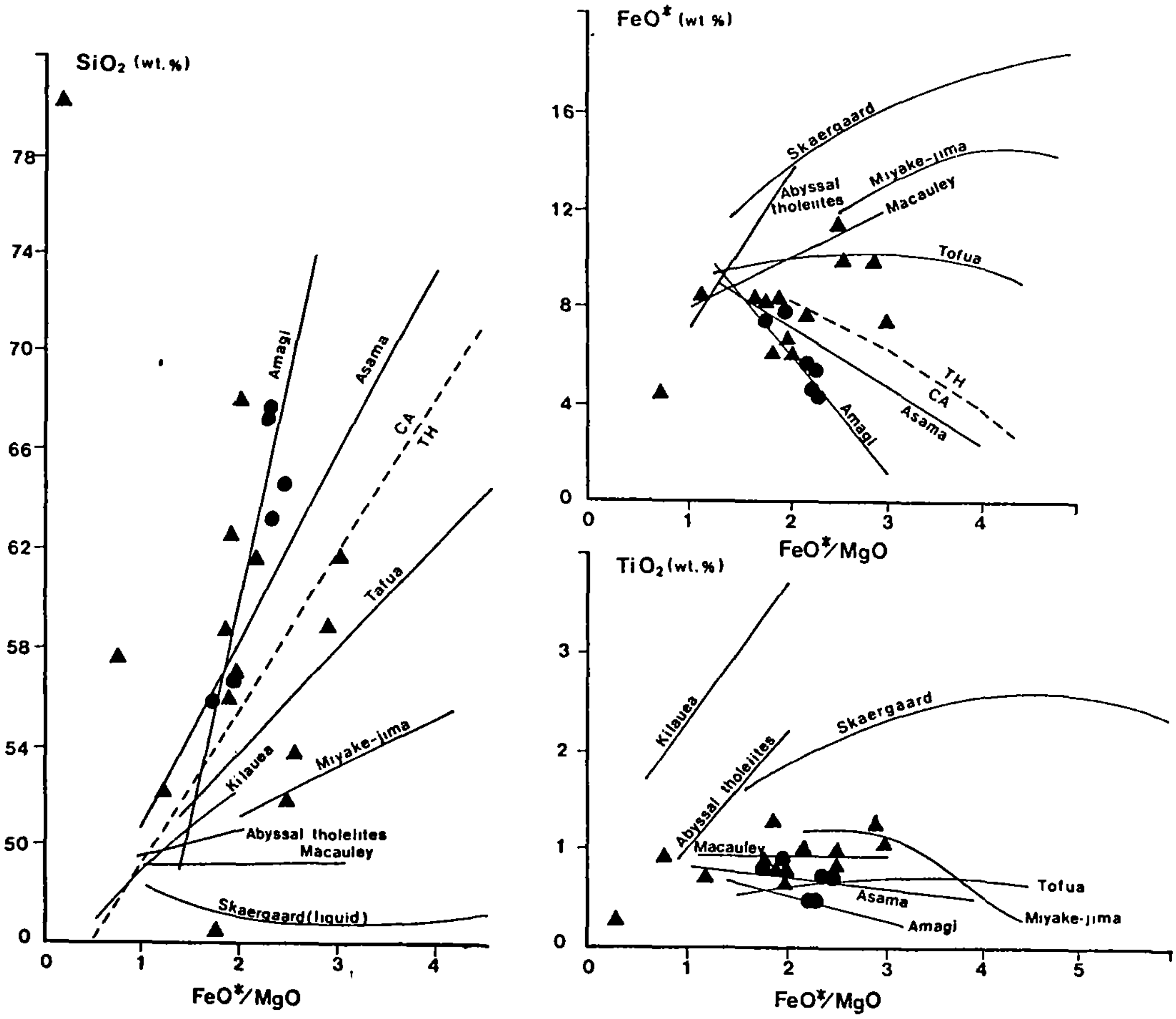

Fig. 4. Plots of SiO_2, FeO^* and TiO_2 versus FeO^*/MgO respectively, in order to distinguish tholeiitic (TH) and calc-alkaline (CA) series for rocks of Barton Peninsula. Triangles represent volcanic rocks and circles represent plutonic rocks.

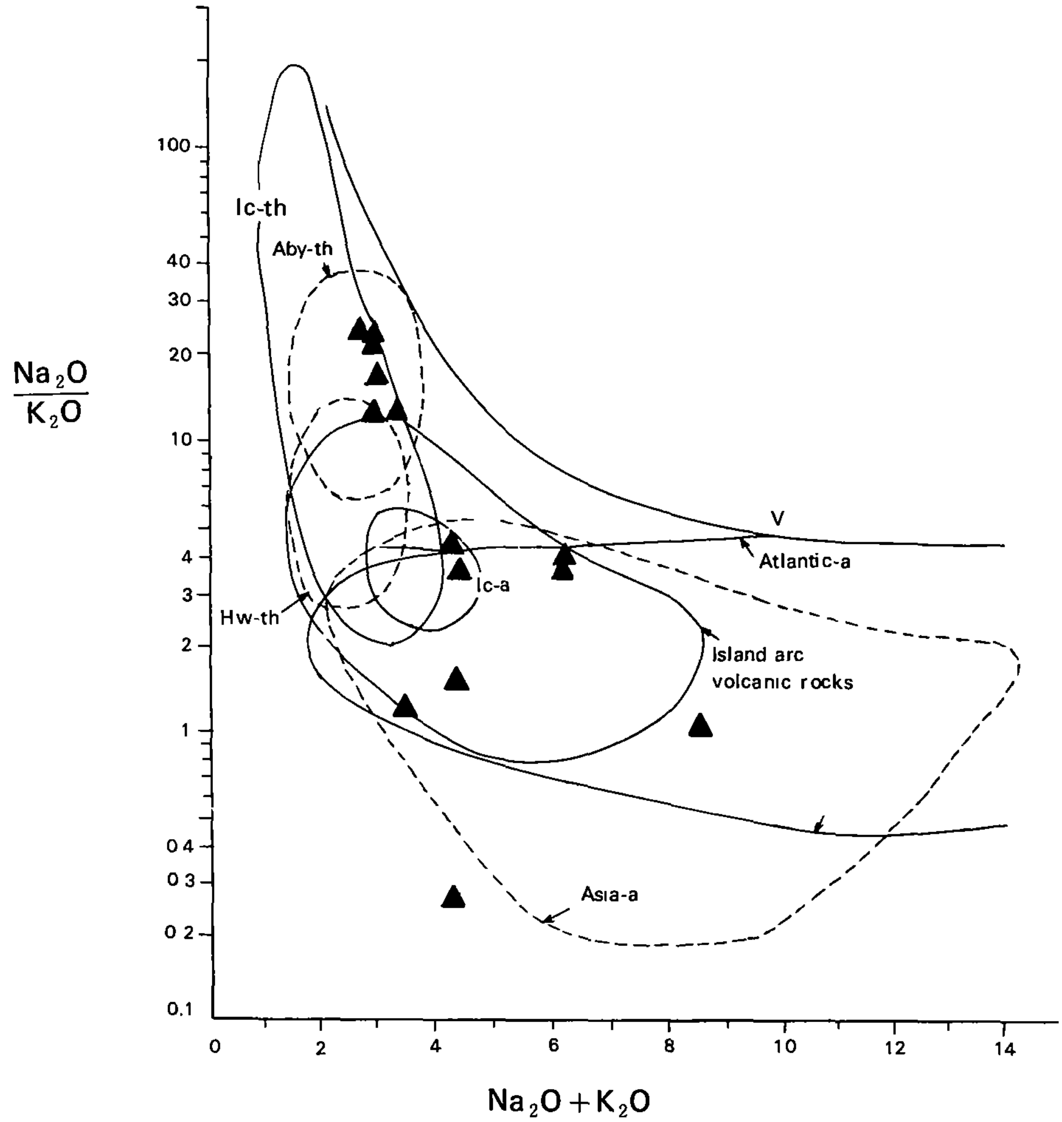

Fig. 5. Plot of Na_2O/K_2O versus (Na_2O+K_2O) for volcanic rocks of Barton Peninsula. Line v represents the upper limit of Na_2O/K_2O for all fresh volcanic rocks.

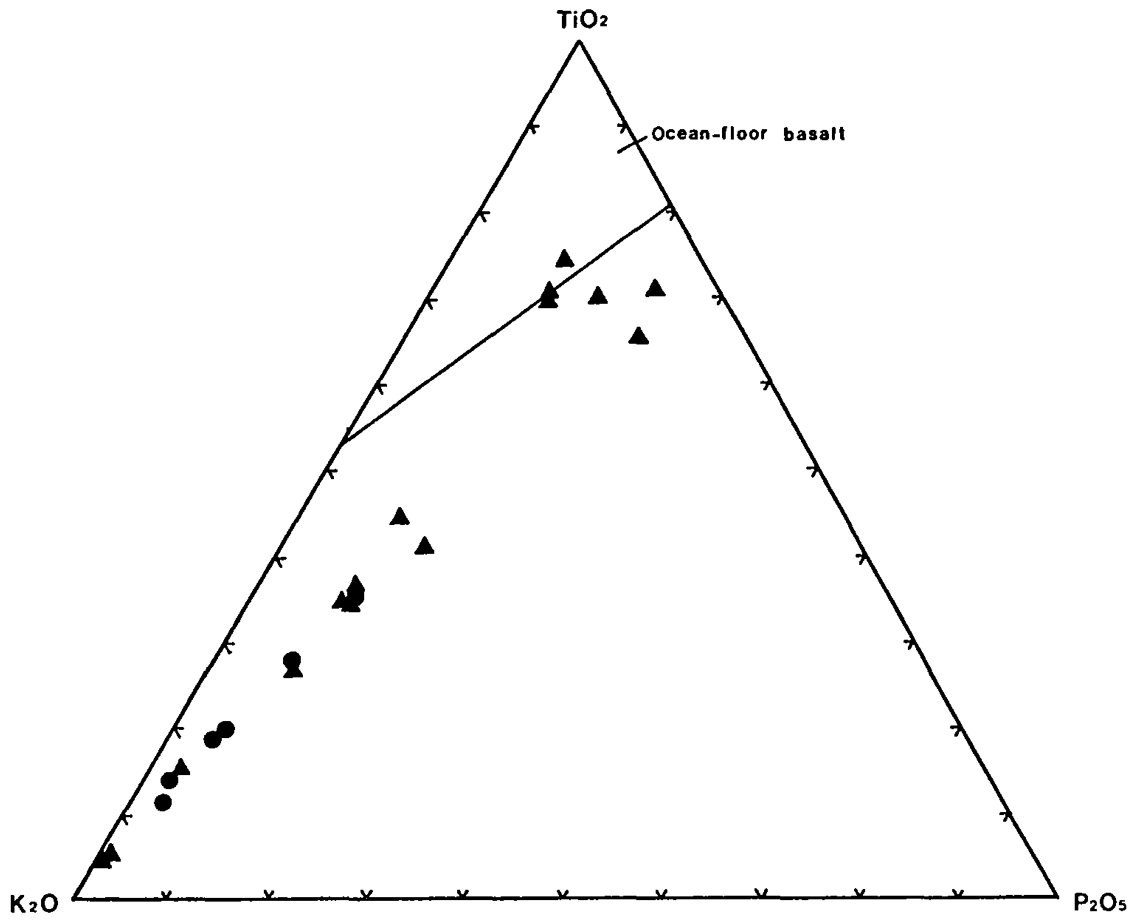

Fig. 6. Triangular diagram of TiO2 - K_2O - P_2O_5 with dividing line between oceanic basalt and non oceanic basalt fields.

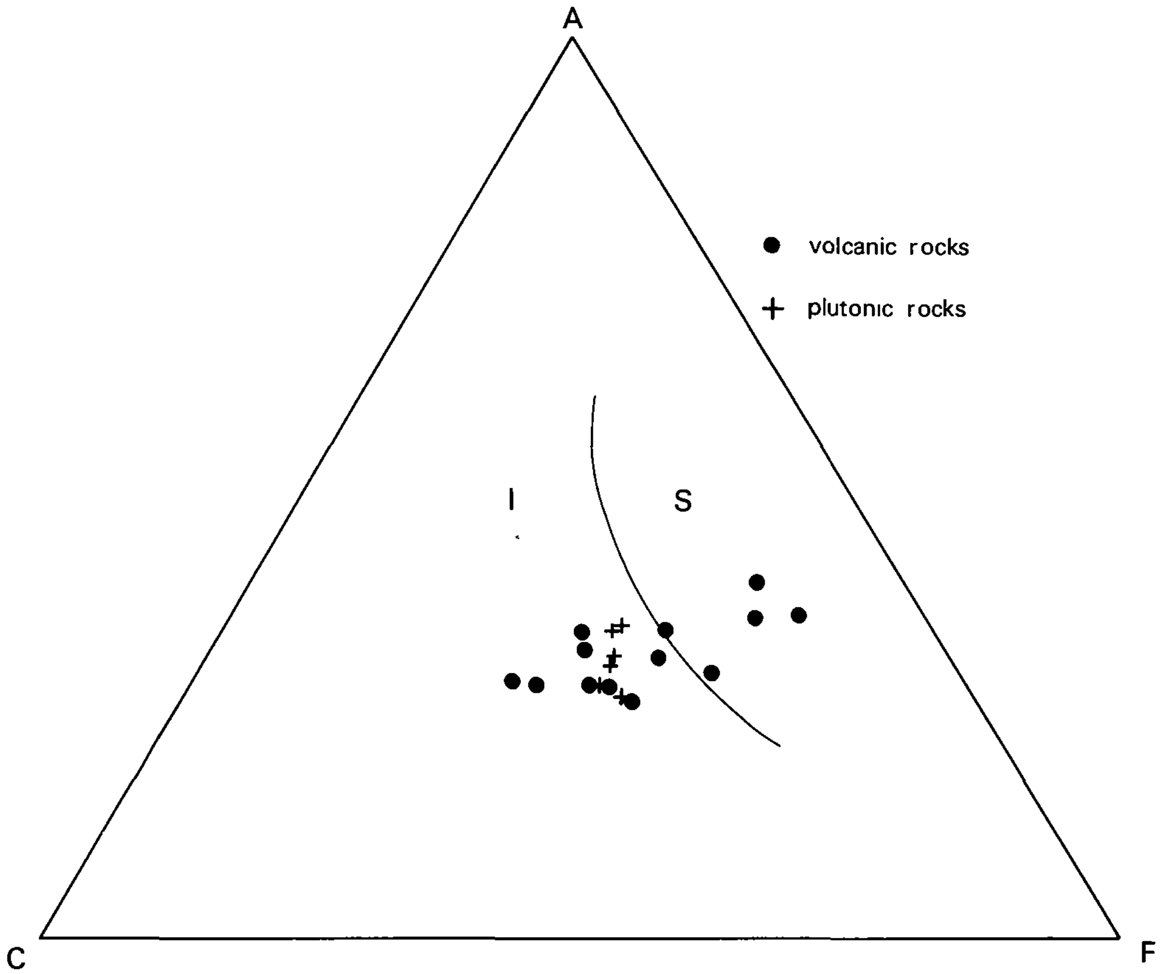

Fig. 7. Triangular diagram of ACF (molar ratio: A $= Al_2O_3 - Na_2O - K_2O$, C $= CaO$, Fe $= FeO + MgO$) for rocks of Barton Peninsula. Circles represent volcanic rocks and cross represent plutonic rocks. I and S mean field for I-and S-type granitoids, respectively.

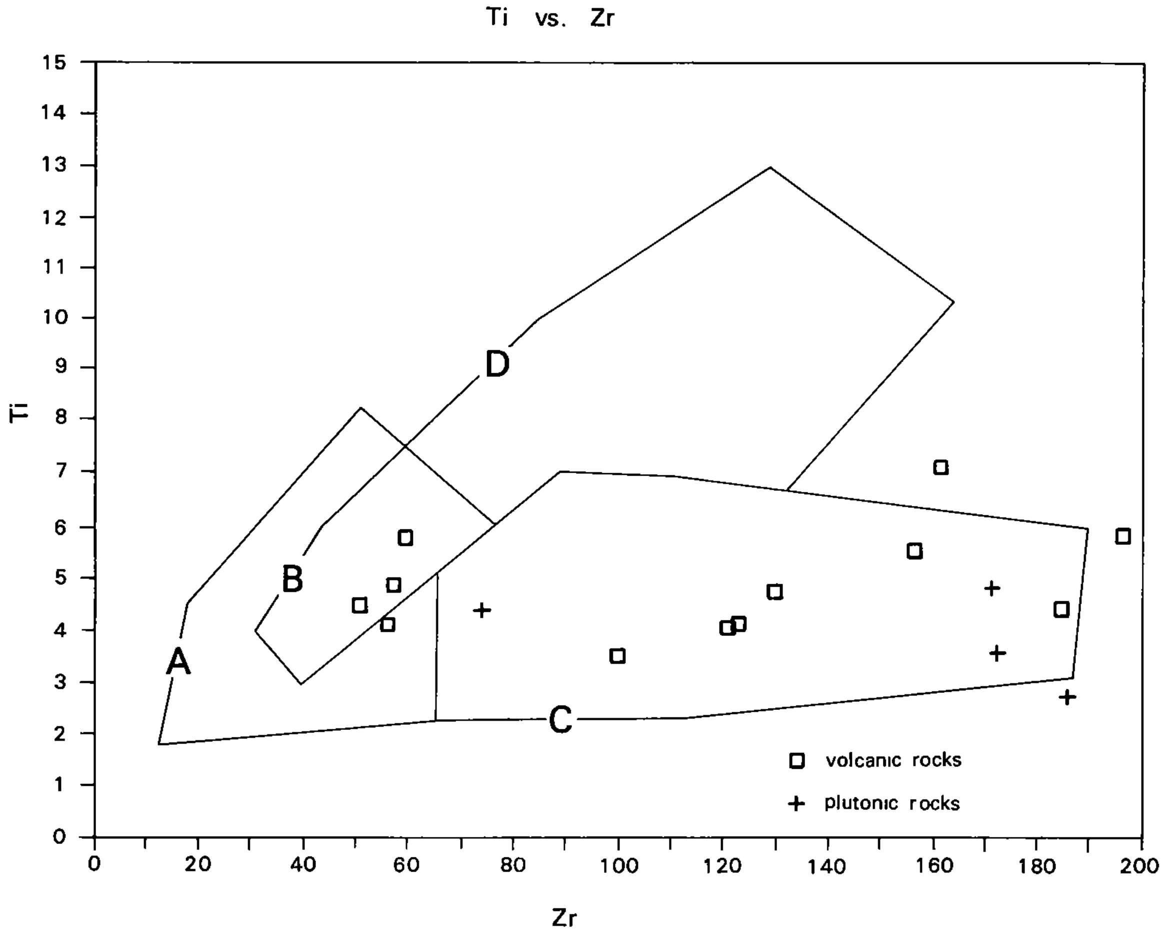

Fig. 8. Discrimination diagram using Ti and Zr. Ocean-floor basalts (OFB) plot in fields D and B; lower potassium tholeiites (LKT) in fields A and B; and calc-alkaline basalts (CAB) in fields C and B

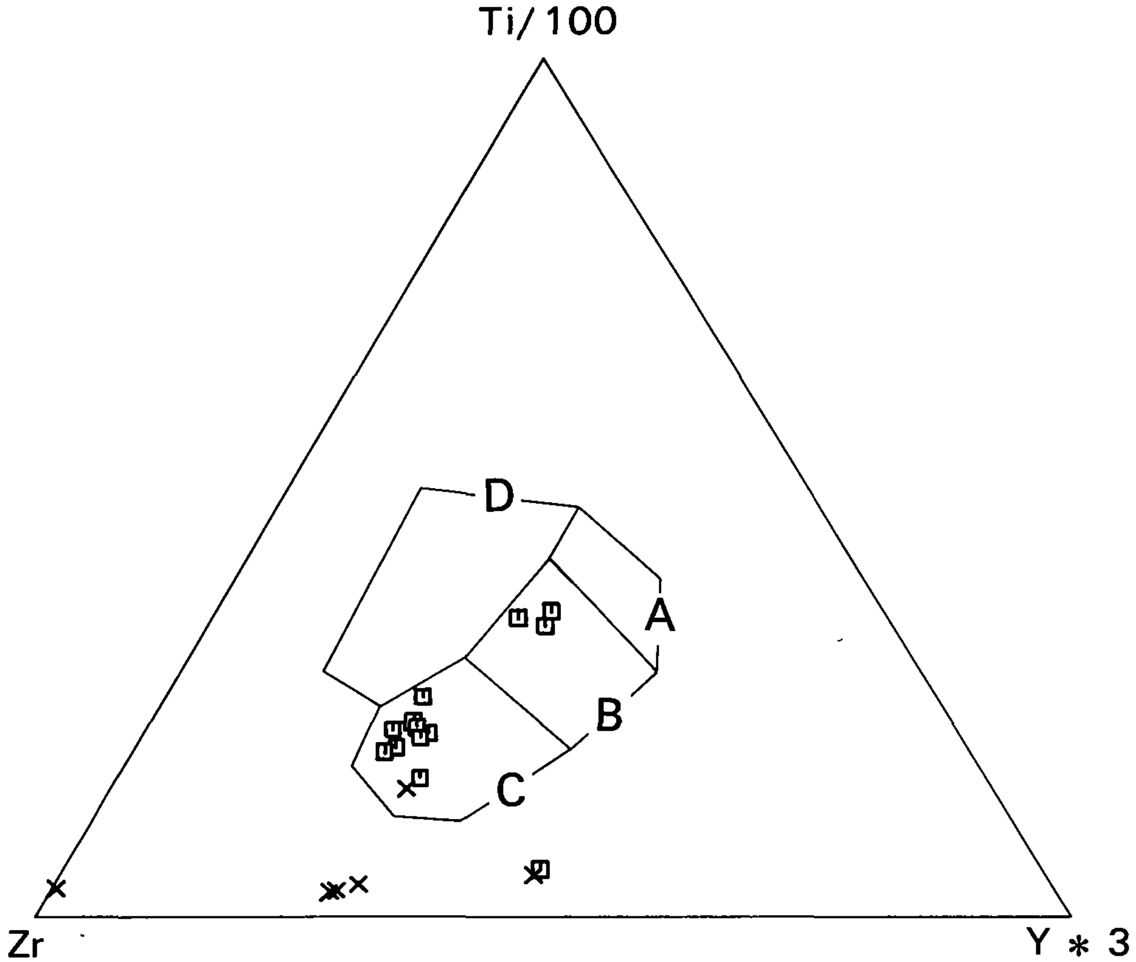

Fig. 9. Discrimination diagram using Ti, Zr, and Y. "Within-plate" basalts (WPB), i.e., ocean island or continental basalts plot in field D; ocean-floor basalts (OFB) in field B; lowpotassium tholeiite (LKT) in fields A and B; calc-alkaline basalts (CAB) in fields C and B.

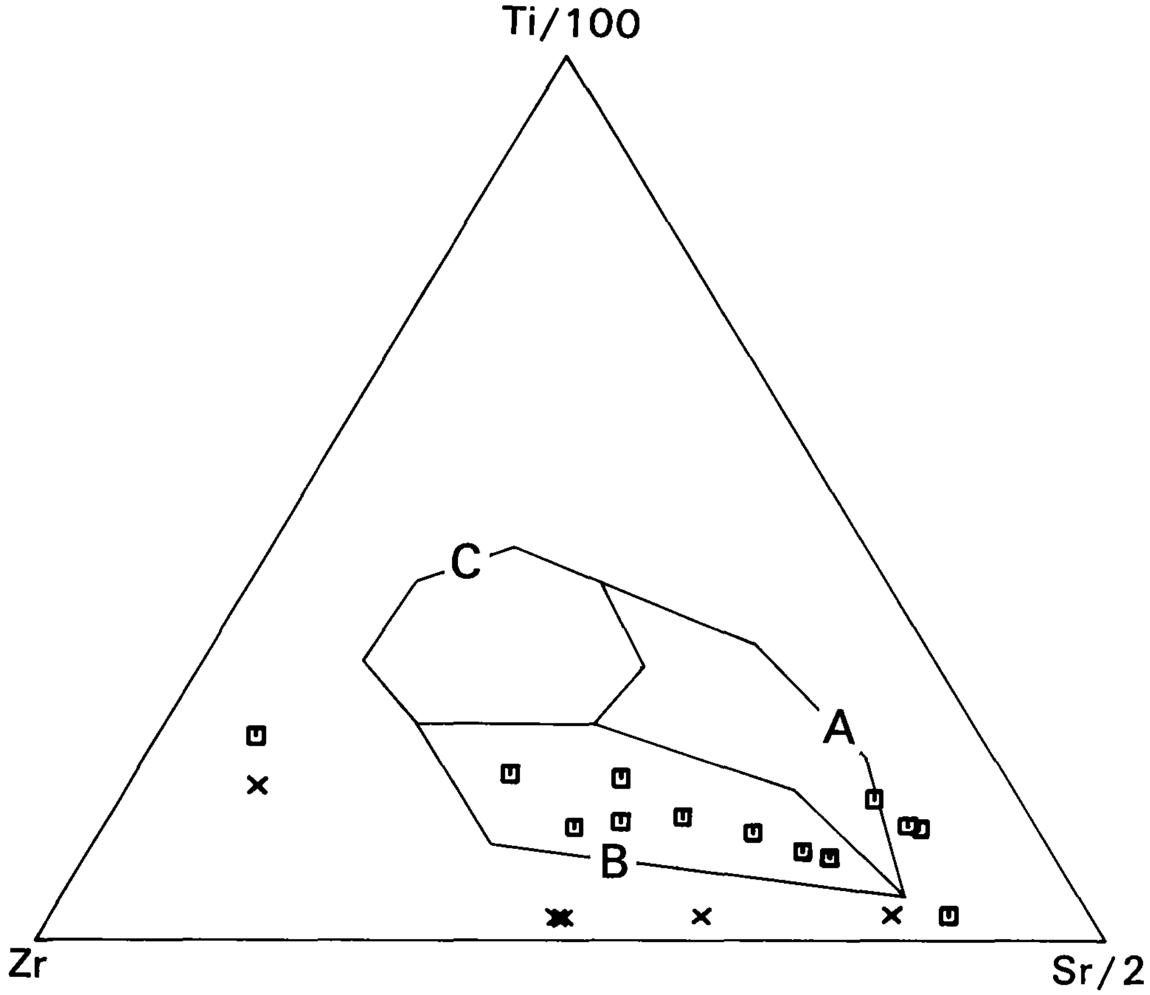

Fig. 10. Discrimination diagram using Ti, Zr and Sr. Ocean-floor basalts (OFB) plot in field C lowpotassium tholeiites (LKT) in field A and calcalkali basalts (CAB) in field B.

Table 2. Chemical analyses of major composition and norms of volcanic and plutonic rocks of Barton Peninsula.

	MC-1	MC-2	MC-3	MC-4	MC-5	MC-6	MC-7	MARSH	1	8	9	13	K-1	K-4	K-6	K-10	K-11-1	K-14	K-22
Si02	62.47	57.47	58.76	67.49	66.99	62.94	55.69	53.70	57.08	67.96	59.02	46.09	56.85	61.53	51.99	56.00	61.54	51.88	64.40
Ti02	0.60	0.83	0.71	0.49	0.49	0.64	0.74	0.97	0.71	0.77	1.22	0.83	0.84	0.97	0.69	1.17	1.01	0.76	0.65
Al203	17 54	21.13	18.37	15.24	15.49	16.25	18.14	18.01	17.52	15.51	15.33	21.67	17.36	16.54	18.49	18.39	16.64	19.92	15.86
Fe203	2.99	1.62	2.22	1.54	1.55	2.02	2.68	3.60	2.41	2.18	3.49	3.02	2.75	2.77	3.01	2.96	2 6	4.15	1.93
Fe0	5.39	2.93	4.00	2.77	2.79	3.63	4.83	6.48	4.34	3.92	6.28	5.45	4.96	4.99	5.42	5.34	4.79	7.47	3.48
Mn0	0.08	0.13	0.20	0.10	0.10	0.12	0.15	0.21	0.12	0.17	0.25	0.24	0.13	0.19	0.17	0.18	0.14	0.16	0.12
Mg0	4.27	6.12	3.29	1.83	1.87	2.34	4.17	3.87	3.34	2.94	3.34	4.76	3.88	3.47	6.83	4.44	2.43	4.51	2.11
Ca0	2.16	3.42	7.68	3.58	3 77	5.02	8.32	9.66	9.86	2.07	7.86	14.75	7.09	5.19	10.23	4.90	6.78	7.89	4.67
Na20	0.91	4.76	3.52	3.23	3.72	4.38	3.89	3.04	2.66	3.50	2.74	2.97	3.88	2.90	2.82	4.90	1.99	2.93	3.93
K20	3.39	1.35	1.02	3.56	3.06	2.43	1.13	0.25	1.70	0.77	0.11	0.22	1.97	1.07	0.12	1.28	1.63	0.14	2.65
H20(+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H20(−)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	j0.00	0.00	0.00	0.00	0.00	0.00	0 00
P205	0.14	0.19	0.19	0.12	0.12	0.17	0.19	0.16	0.20	0.15	0.37	0.13	0.24	0.33	0.17	0.40	0.31	0.13	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0	30.55	7.36	12.57	23.61	21.92	13.78	5.03	8.08	10.84	34.17	20.34	0.01	5.86	22.60	3.08	3.95	24.01	6.72	17.74
Or	20.04	7.98	6.07	21.08	18.08	14.38	6.69	1.51	10.05	4.57	0.69	1.31	11.64	6.34	0.73	7.59	9.68	0.87	15.69
Ab	7.75	40.28	29.80	27.35	31.52	37.13	32.94	25.77	22.55	29.64	23.01	13.90	32.86	24.59	23.86	41.47	16.88	24.83	33.31
An	9.79	15.73	31.27	16.55	16.51	17.45	28.69	34.73	30.83	9.33	29.29	45 93	24.13	23.55	37.44	21.70	31.60	38.28	17.76
Lc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C	8.77	6.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.49	0.00	0.00	0.00	1.97	0.00	0.98	0.00	0.90	0.00
Bl	0.09	0.00	4.53	0.35	1.16	5.17	9.21	10.01	13.70	0.00	6.03	21.44	7.74	0.00	9.78	0.00	0.00	0.00	3.64
Hy	17.24	18.16	10.71	7.58	7.30	7.49	11.65	12.43	6.69	11.80	12.38	0.00	11.59	14 29	18.97	16.82	11.28	20.59	7.42
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mt	4.34	2.36	3.22	2.23	2.25	2.92	3.89	5.21	3.50	3.16	5 06	4.39	3.99	4.02	4.36	4 30	3.86	6.02	2.80
Hm	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H	1.14	1.57	1.35	0.94	0.94	1.22	1.42	1.85	1.36	1.47	2.32	1.57	1.60	1.84	1 32	2.22	1.92	1.44	1.23
Ap	0.34	0.45	0.44	0.29	0.28	0.41	0.44	0.37	0.46	0.35	0 85	0.30	0.55	0.78	0.41	0.92	0 73	0.31	0.34

	MC-1	MC-2	MC-3	MC-4	MC-5	MC-6	MC-7	MARSH	1	8	9	13	K-1	K-4	K-6	K-10	K-11-1	K-14	K-22
Wo	0.00	0.00	2.32	0.17	0.59	2.64	4.73	5.09	7.02	0.00	3.06	11.02	3.97	0.00	5.07	0.00	0.00	0.00	1.85
En	10.64	15.24	8.20	4.56	4.65	5.84	10.40	9.65	8.33	7.34	8.25	6.69	9.66	8.65	17.03	11.05	6.07	11.24	5.26
Fs	6.59	2.91	4.71	3.19	3.21	4.18	5.72	7.70	5.03	4.46	7.10	3.71	5.69	5.63	6.65	5.77	5.20	9.35	3.95
Fo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C.I.	23.07	22.55	20.27	11.40	11.95	17.24	26.62	29.89	25.72	16.79	26.66	33.55	25.49	20.94	34.86	21.28	17.80	28.37	15.46
D.I.	67.12	61.71	48.45	72.04	71.52	65.31	44.67	35.37	43.44	13.87	44.05	20.51	50.37	55.50	27.68	54.00	50.58	33.34	66.76

Table 3. Chemical analyses of major and tracelements of volcanic and plutonic rocks of Barton Peninsula.

	MC-1	MC-2	MC-3	MC-4	MC-5	MC-6	MC-7	MARSH	1	8	9	13	K-1	K-4	K-6	K-10	K-11-1	K-14	K-22
Si02	62.667	57.571	58.900	67.595	67.100	63.068	55.847	53.899	57.225	68.118	59.229	46.235	57.016	61.704	52.147	56.168	61.711	52.106	64.531
Ti02	0.605	0.832	0.712	0.498	0.498	0.644	0.750	0.981	0.719	0.776	1.231	0.833	0.847	0.974	0.699	1.176	1.017	0.763	0.653
Al203	17.593	21.174	18.411	15.269	15.516	16.284	18.197	18.081	17.568	15.544	15.389	21.744	17.414	16.593	18 554	18.451	16.694	20.008	15.896
Fe203	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe0	8.113	4.406	6.015	4.171	4.204	5.466	7.276	7.276	9.755	6.538	5.904	9.457	8.202	7.462	7.509	8.161	7.214	11.260	5.238
Mn0	0.089	0.131	0.204	0.100	0.100	0.129	0.159	0.211	0.126	0.178	0.256	0.243	0.139	0.194	0.179	0.187	0.147	0.169	0.122
Mg0	4.286	6.132	3.301	1.834	1.873	2.351	4 188	3.891	3.352	2.955	3.325	4.799	3.891	3.486	6.858	4.453	2.445	4.533	2.117
Ca0	2.175	3.431	7.699	3.593	3.785	5.037	8.346	9.703	9.892	2.083	7.892	14.799	7.116	5.205	10.265	4.914	6.805	7.926	4.684
Na20	0.919	4.769	3.530	3.237	3.730	4.397	3.904	3.056	2.671	3.510	2.729	2.806	3.894	2.914	2.828	2.915	2.000	2.947	3.945
K20	3.401	1.354	1.030	3.573	3.065	2.439	1.135	0.257	1.705	0.775	0.117	0.223	1.976	1.076	0.125	1.288	1.643	0.149	2.661
H20(+)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H20(−)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P205	0.149	0.195	0.194	0.126	0.125	0.179	0.194	0.161	0.200	0.152	0.371	0.131	0.241	0.340	0.179	0.403	0.319	0.135	0.150
Total	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Rb	74.9	28.2	15.9	78.3	78.0	63.5	24.4	−1.8	23.4	20.1	0.1	−0.6	50.3	15.0	−1.9	28.0	45.9	−0.3	58.2
Sr	144.7	558.1	652.8	345.9	369.4	415.4	574.9	557.6	753.1	358.6	388.5	639.6	544.2	487.4	631.1	564.6	492.0	618.5	365.7
Ba	587.8	274.1	291.3	614.3	475.8	405.6	278.1	125.6	494.1	321.6	26.4	84.4	327.7	271 6	100.6	301.2	281 8	97.4	483.8
Y	17.1	20.1	20.0	24.0	24.7	27.7	21.8	18.7	17.2	31.5	25.7	14.9	24.0	25.1	16.9	32.5	28.6	15.4	25.7
Zr	99.9	130.0	121.2	185.6	200.3	172.3	74.0	59.6	123.1	184.5	161.6	57.3	171.4	156.5	55.9	237.8	196.4	50.7	202.1
V	186.7	278.3	172.8	84.0	81.7	115.7	200.1	252.5	182.9	75.4	297.3	285.6	209.7	224.1	227.0	180.1	175.5	239.7	138.4
Cr	8.7	16.6	10.6	4.6	4.3	6.7	15.1	7.1	20.4	−0.6	3.5	73.5	11.9	3.9	104.2	2.6	6.9	28.6	5.8
Ni	9.3	4.2	6.6	6.6	7.9	12.8	4.5	4 5	24.6	2.2	1.5	36.0	10.5	4.3	41 1	3.1	5.5	19.3	6 0
Cu	6.5	28.0	19.7	16.7	50.6	20.2	130.1	97.2	104.6	30.9	820.1	173.4	90.2	137.3	102.7	113.8	77.1	112.8	48.5
Zn	36.5	46.6	75.9	50.6	48.9	65.4	190.0	80.1	71.8	121.9	163.6	82.3	72.1	93.0	89.5	109.7	76.5	85.8	63.5
Ga	20.0	27.8	21.0	16.8	17.0	19.0	20.2	22.6	18.9	19.3	19.1	21.8	20.1	19.4	18.8	17.7	21 7	19.5	18.9
Pb	5.6	4.4	4.3	10.6	8.9	13.9	14.2	4.3	9.1	4.3	12.3	3.9	4.2	9.3	3.6	7 7	11.9	4.9	9.9
Nb	1.7	3.0	3.2	3.9	3.9	3.5	1.3	1.0	2.0	6.0	3.8	1.7	3.4	3.7	2.0	5.3	4.5	2.0	4.2
Sc	19.2	27.4	21.0	10.0	10.3	16.3	22.4	23.6	21.6	16.8	27.6	34 9	18.8	22.5	29.7	22.3	22.4	24.5	15.4
Th	2.3	3.7	4.5	8.2	8.4	9.5	1.0	1.2	2.7	5.0	4.2	1.4	5.4	3.9	1.8	6.9	5.4	1.6	9.4

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Petrology and Geologic Structures of the Barton Peninsula, King George Island, Antarctica

Pil Chong Kang and Myung Shik Jin

Abstract

The Barton Peninsula mainly consists of volcanic rocks (andesite, andesitic tuff and agglomerate), which are intruded by quartz-diorite in places. Rb-Sr and K-Ar datings for the quartz-diorite give ages of 63.4±4.3 Ma and 62.1±1.6 Ma, respectively. In particular, strontium initial ratio of the quartz-diorite revealed 0.7067, reflecting that the quartz-dioritic magma might have originated from mantle or igneous source. This suggests that the quartz-diorite can be correlated in age with the Andean intrusives of Tertiary age in Chile.

In the area are recognized alteration and mineralized which are apparently closely related to the intrusion of the quartz-diorite. The alteration occurred in the form of pyritization, epidotization, kaolinization and sericitization.

The lineaments recognized on the aerial photographs (scaled 1: 15,000), strike preferentially in WNW-ESE and NE-SW directions.

Typical landforms such as polygon structures, glacial lakes, cirques and inselbergs are common in the study area.

Recent tectonic activities are recognized by the presence of elevated old shoreline with beach pebbles about 3-4 m and 100 m above sea-level. This was resulted from the up-lifting during the Quaternary.

Introduction

The geological study was carried out as a part of the 1st Korean Antarctic Research Programme in the Barton Peninsula, King George Island, Antarctica, where the Korean Sejong Antarctic Station was installed in February, 1988. Most of the study area was well exposed, without snow-cover during the field work. Glaciers are placed in the glacial valleys and basins (Fig. 1).

Parts of the King George Island, especially the Barton Peninsula, have been studied by a great number of geologists of Britain, Chile, U.S.S.R. and etc. Among others, Ferguson (1921), Terry (1926), Jardin (1950), Hawkes (1961), Barton (1965), Grikurov (1970) and Davies (1982) have published papers and reports on the geology of the island.

This study focused on the petrology and lineaments including fractures which are expressed on the aerial photographs (scaled at 1: 15,000) of the Chilean Air Force.

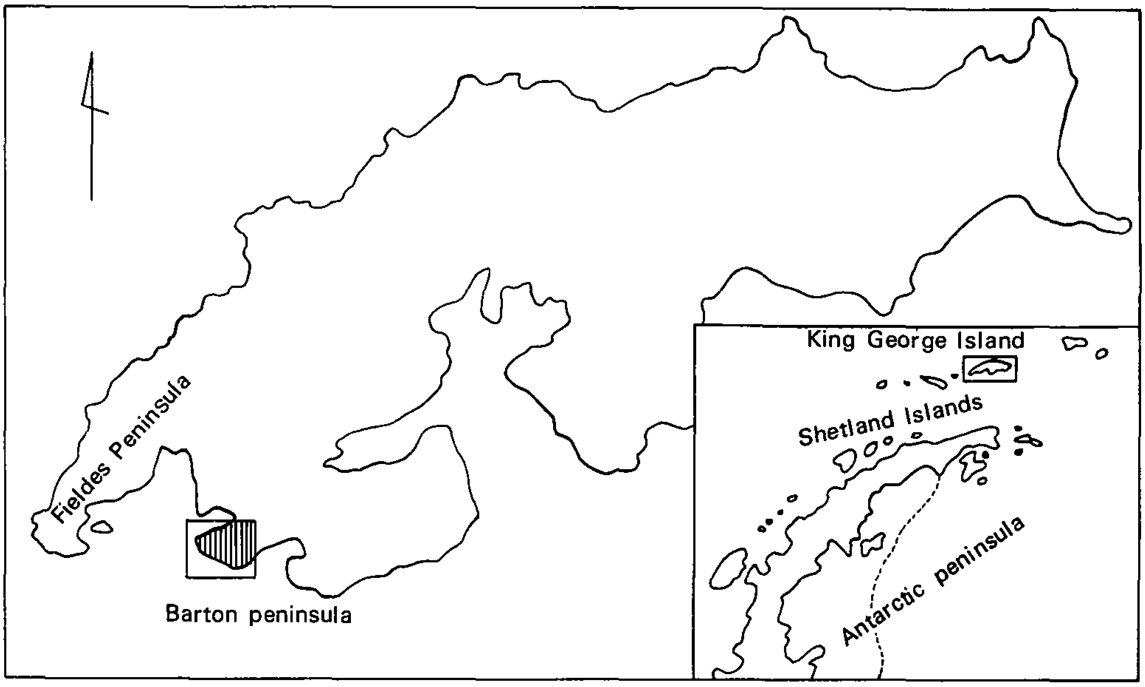


Fig. 1. Location mop of the study area.

Geomorphology

The area is a permafrost, and is characterized by typical glacial land-forms such as moraine deposits, polygon structures, glacial lakes, cirques and inselberges. Stacked terminal moraine deposits are distributed along the coast, indicating several times of glaciation. Screes fall down from the hill slope outcrops and cirques are developed along the hill rigdes.

The polygon structures are ubiquitous throughout the area, especially on the slopes of moraine and scree deposits: polygons are not distorted on the flat terraines, whereas they are ellipsoidal on the slopes as a result of creeping.

Geology and Petrology

The Barton Peninsula consists of volcanic rocks, quartz-diorite, and moraine deposits distributed in the coastal areas(Fig. 2).

Volcanic rocks:

The volcanic rocks include andesitic rocks, and overlying tuffs and agglomerates which are interlayered each other. The geological age of the rocks was inferred as Jurassic by Barton (1965). However, early Tertiary age was assigned to the quartz-diorite in the Noel Hill area by Davies (1982), on the basis of age data obtained by Grikurov (55Ma, K-Ar whole rocks) and Watts (45 Ma-106 Ma, K-Ar).

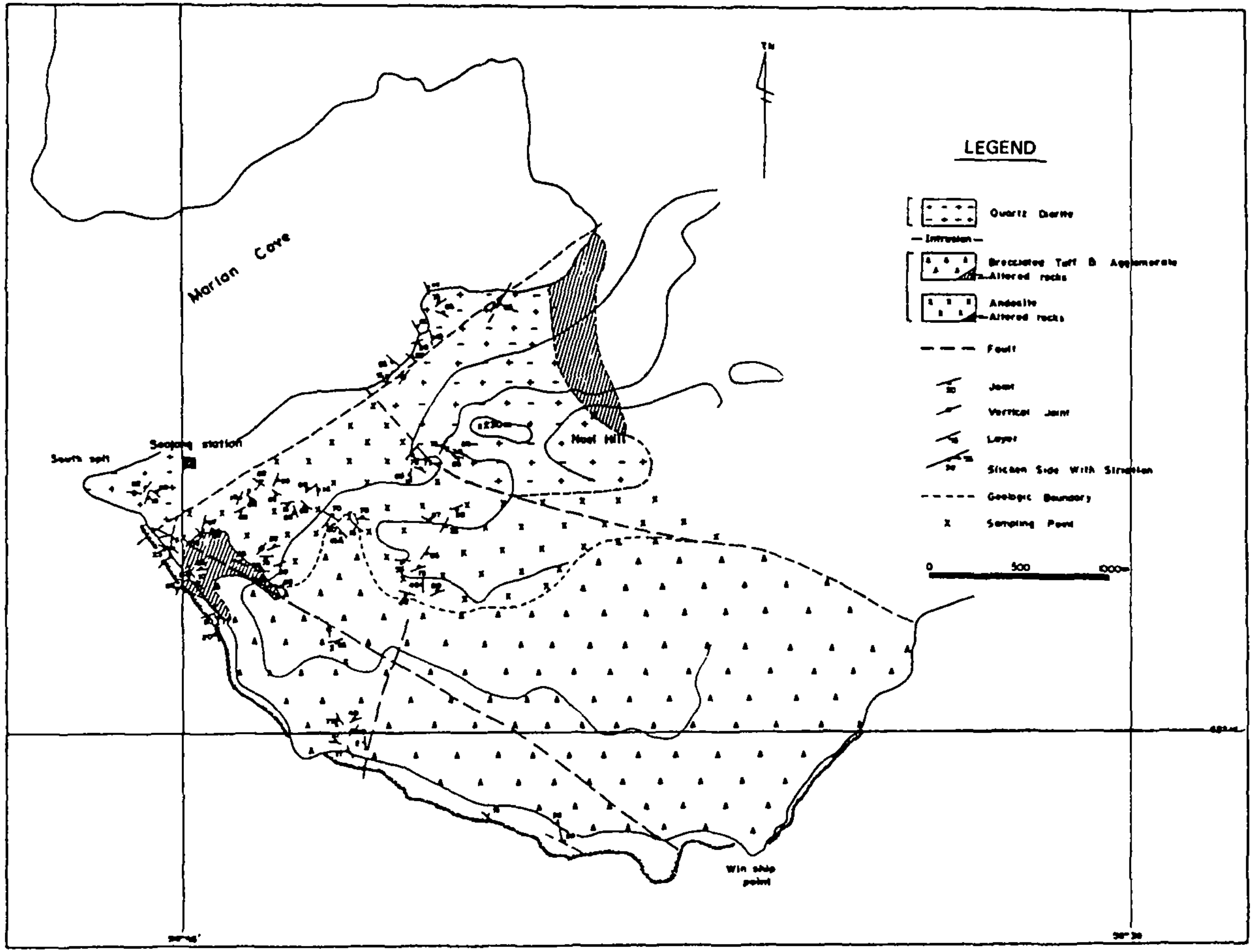


Fig. 2. Geological Map of The Barton Peninsula, King George Island,

Those rocks are altered by kaolinization, pyritization and sericitization which are caused by hydrothermal activities associated with the intrusion of quartz-diorite.

The andesites are aphanitic and porphyritic in texture. The aphanitic ones consist of hornblende, plagioclase (andesine-labradorite) and interstitial and tiny grains of augite, magnetite, pyrite, epidote and calcite. The porphyritic andesites are characterized by the presence of phenocrysts of plagioclase and hornblende which are 5-10 mm in size and are set in the groundmass of plagioclase (andesine-labradorite), hornblende and augite. Pyrite, epidote and calcite occur as secondary minerals in both aphanitic and porphyritic andesites.

The volcaniclastic sequence consisting of alternating tuff and agglomerate layers is widely distributed in the study area. The tuff layers are 1-2m thick and composed of volcanic ashes and lapilli less than 2 cm in size. The tuff is slightly altered, so that secondary minerals such as epidote, chlorite and amorphose calcite were formed.

The agglomerates consist of basaltic to andesitic breccias and lapilli, and the matrix which is made up of volcanic ashes and associated secondary minerals - calcite, epidote and opaque minerals.

Quartz-diorite:

According to Barton (1965), the quartz-diorite in the Noel Hill and the South Spit areas may belong to one of the Andean intrusives, which are widely distributed in the Andean orogenic belt.

The rock is fine to medium grained and granular in texture in the Noel Hill, being coarser than in the South Spit, where the rock shows interstitial granular texture.

In general, the rock comprises of hornblende, biotite, plagioclase (albite-andesine) and interstitial quartz in the Noel Hill, and hornblende, augite, plagioclase, quartz and magnetite in the South Spit. The intrusion of quartz-diorite into the volcanic rocks resulted in the alteration by pyritization, sericitization and kaolinization.

Hawkes (1959) also described allotriomorphic crystals of orthoclase, andesine, biotite, hornblende, and actinolite which was formed by alteration of augite from the quartz-diorite of the Noel Hill area. The similar mineralogical constituents have been reported by Barton (1965) and Davies (1982).

Geochemistry

Major Element Geochemistry

A total of 13 rock samples taken in the Barton Peninsula-three basaltic rocks (or basaltic andesites), eight andesitic tuffs and agglomerates and two quartz-diorites were chemically analyzed by Mr. Sung and Mr. Yoon (MDAC, KIER) (Table 1 and Fig. 3).

The silica content ranges from 45.33 to 56.28% in the basaltic rocks, from 49.62 to 58.00% in the andesitic rocks and 62.60 to 61.68% in the quartz-diorites.

Other major elements such as TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5 are contained in different proportion ın different rock types (Table 1), showing characteristic patterns in chemical content depending upon rock type.

However, the andesitic tuff and agglromerate show rather irregular patterns in chemical

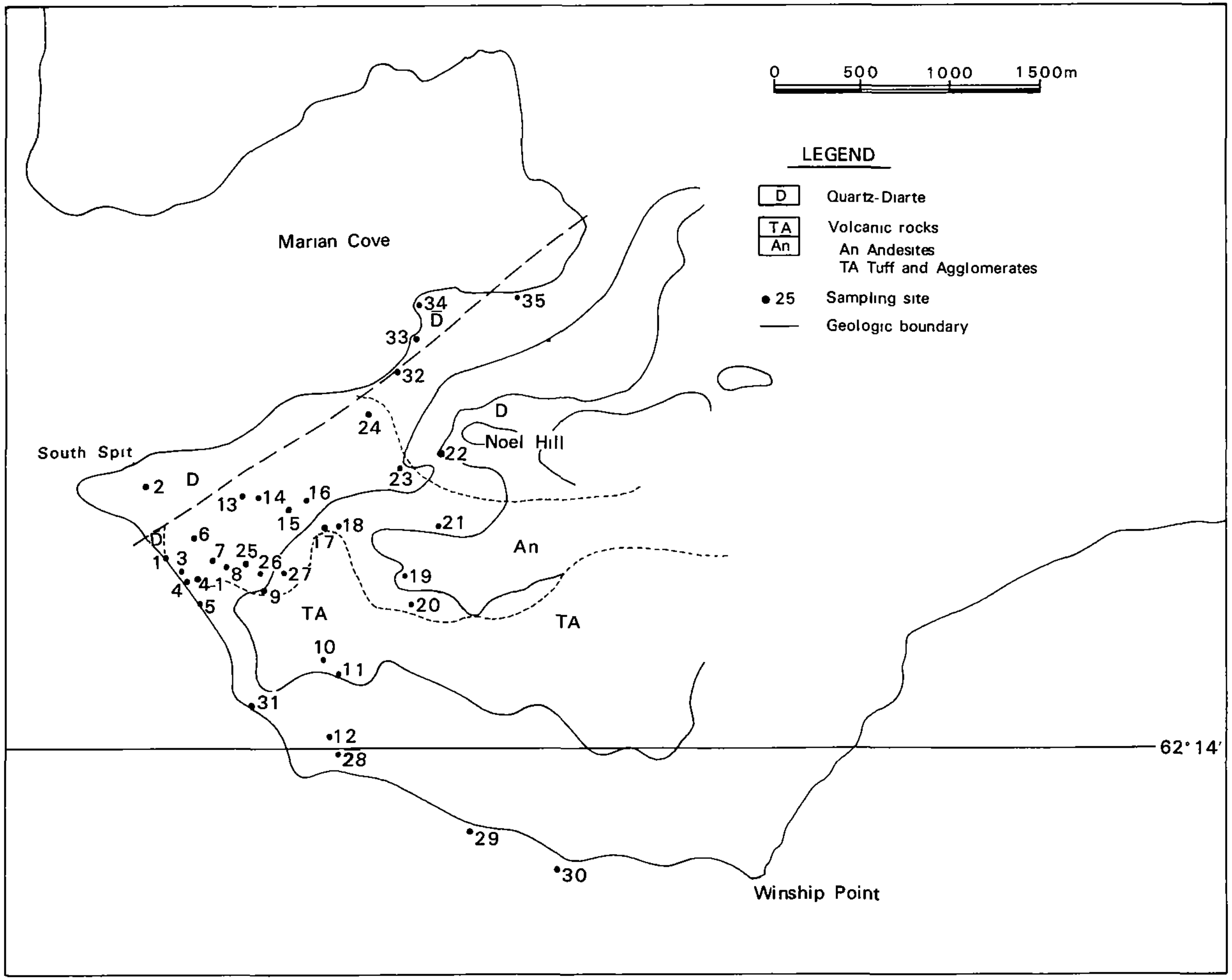


Fig. 3. Location map of sampling sites

Table 1. Chemical compositions and normative minerals of igneous rocks at Barton Peninsula in King George Island, Antarctica

	Major element oxides (%)												
rock type	basaltic rock			andesitic rocks									
sample No	009	017	027	001	003	004	011	011a	028	029	031	033	034
SiO_2	46.42	46.58	45.28	52.74	53 26	56 28	54 66	58 00	57 12	57 82	49.60	61.60	61 68
TiO_2	0 28	0.50	0 43	0 53	0 29	0 50	0 19	0 39	0 67	0 31	0 47	0.17	0 13
Al_2O_3	19 80	18 58	19 15	16 79	20 07	17 76	16 84	16.74	17 67	15 07	20 65	17 58	17 56
Fe_2O_3	4.33	4.14	4.35	4 42	3 54	3 91	4.66	4 29	3 08	3 17	7.29	3.44	3 04
FeO	4 50	6 07	4 75	3.14	4 43	5 75	2 86	3.14	4 21	2 71	2 21	2 64	3.46
MnO	0 13	0.15	0 13	0 13	0 16	0.20	0 18	0 15	0 20	0.13	0.14	0 11	0 10
MgO	5 30	8 26	6 20	3.87	4.26	3 65	4 37	2 48	3.36	2 68	3 94	2 55	3 04
CaO	11 25	10 27	9 21	6.96	7.97	5 05	5 16	6.10	5 78	6 17	5 47	4 71	4 83
Na_2O	2 08	2.16	2.06	3 58	3 34	2 59	2 92	1 94	3 46	3.34	3.06	4 02	3 96
K_2O	0 25	0 36	0 18	1.71	0.52	1 15	0 97	1 40	0.26	0 53	1 24	2 29	2 25
P_2O_5	tr	tr	tr	tr	tr	0.10	0 33	tr	0.26	0 12	tr	. tr	tr
SO_3	2.44	0.85	tr	3 64	0 75	0 77	2.65	1 58	tr	tr	tr	tr	tr
^-H_2O	0 58	0 25	0.40	0 21	0 16	0.20	0 48	0 27	0 30	0.75	0 40	0 29	0 18
Ig loss	2.62	1.81	7.74	2 27	1 12	2.07	3.72	3 51	3 61	6 01	6 52	1 01	0 57
total	99 98	99.98	99 98	99.99	99.97	99 39	99 89	99.99	99.98	99.99	99 99	99 98	99 98
Normative minerals (%)													
O	2 00	0 00	2 51	6.54	6.48	12.82	12 45	18 19	11 95	20.24	4.56	15 29	14 31
Or	1.57	2.20	1.16	10.07	3.14	7.01	6.15	8.74	1.68	3.36	7.75	13.71	13.40
Ab	18.66	18.87	18 98	32.77	28.86	22.61	26 52	17 35	30 48	30.32	27.38	34 47	33 77
An	46 50	41.23	46 25	26.30	39 32	25.17	25.18	31.97	28.09	26 34	28 69	23.47	23.67
Di	10.06	8.28	2 79	8.27	0 84	20 63	19 86	17 77	22 78	4 60	19 28	0 16	0.37
Hy	13 91	16 01	20 56	7 94	15 56	6.35	3 87	0.00	2 29	9 48	0 00	7 52	9 78
Ol	—	6 23	—	—	—	—	—	—	—	—	—	—	—
Mt	6 65	6 20	6 87	6.83	5.24	5.85	7 25	6 57	4 65	4.93	11 28	5.05	4 44
Il	0.56	0 98	0.89	1.07	0 56	0 98	0.39	0 78	1.32	0 63	0 94	0 33	0.25
Ap	—	—	—	—	—	0.24	0 82	—	0 63	0 30	—	—	—
Co	—	—	—	—	—	3.42	2 59	1 00	1 88	—	4.57	—	—
total	100.00	100 00	100.00	100.00	100 00	105.08	105 08	106 44	105 67	100.0	105.78	100.00	100 00

This rock classification is followed by SiO_2 content in the rocks

* abbreviation tr; trace amount

content from sample to sample, probably due to the differences of the rock types and proportions of clasts.

Particularly some of the altered rocks contain unusally large amount of sulphur and volatile gas, which might be introduced in the course of crystallization of sulfides and hydrous minerals during the later hydrothermal stage.

The AFM of Alkalis-total FeO-MgO triangular diagram shows that the igneous rocks have been evolved from basaltic to andesitic rocks, and show a calc-alkaline trend (Fig. 4).

The Quartz-Plagioclase-Orthoclase triangular diagram using normative minerals of the rocks, indicates that the basaltic rocks (sample, No. 9, 17, 27) belong to gabbro or diorite clan, the andesitic tuff and agglomerate to quartz diorite or tonalite clan, and the quartz diorite belong to a quartz diorite or quartz monzodiorite clan (Fig. 5).

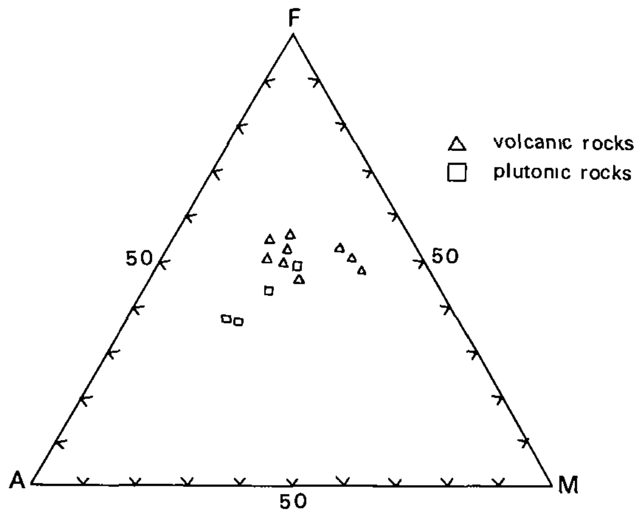


Fig. 4. Triangular diagram of (Na_2O+K_2O)—($FeO+0.9\ Fe_2O_3$)—(MgO), (A—F—M) for the Igneous Rocks of Bartan Peninsula in King George Island, Antarctica.

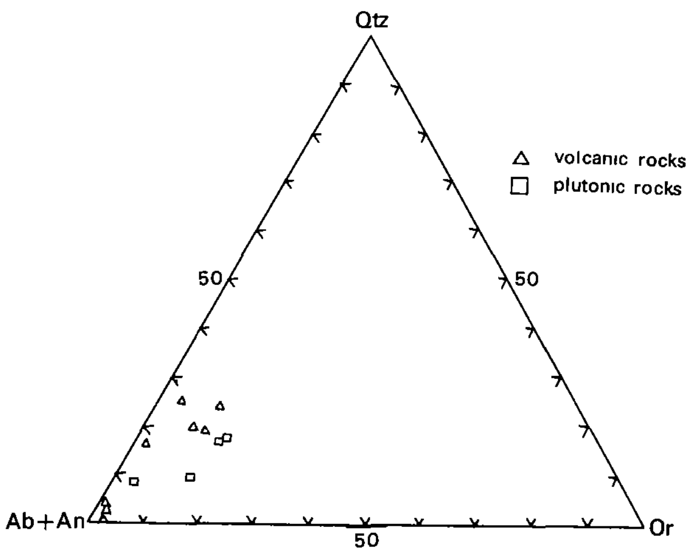


Fig. 5. Triangular diagram of normative Qtz-Pl (Ab+An)—Or for the Igneous Rocks of Barton Peninsula in King George Island, Antartica.

According to O'Connor's classification (1965), the aphanitic volcanic rocks (sample No. 3, 9, 17, 27) fall into the field of andesite, the andesitic tuffs and agglomerates (sample No. 4, 11, 28, 29, 31) into the field of tonalite.

Chemical composition of the magma had been gradually differentiated with time, from andesitic (andesite) through dacitic (tuff) to dioritic (quartz-diorite).

Accordingly, the rocks could be correlated with calc-alkaline rock suite of Andean orogenic belt.

Isotope Geochemistry

The biotite concentrates separated from the quartz diorite (No. 34) and whole rock were isotopically analyzed by Dr. Choo, S.H. in Table 2.

A two-point isochron of Rb-Sr was obtained, and it gives an age of 63.4±4.3 Ma with a strontium initial ratio of 0.7067, indicating the age after the rock was in 310°±40°C (Nishimura and Mogi, 1986) and mantle or igneous source of the magma (Fig. 6).

The age of the rock is almost coincided with some published data K-Ar biotite age 55 Ma (Grikurov, 1970) and 46 Ma-106 Ma (Watts) within error limits.

The quartz-diorite (sample No.1) was also isotopically dated by K-Ar whole rock method (Table3), and it gives an age of 62.10±1.62 Ma, which indicates the age after the biotite was in 270°±40°C (Nishimura and Mogi, 1986).

This age is very similar to the Rb-Sr two point isochron age of the quartz-diorite mentioned above, suggesting that once they were the same mass in the area, but now they are separately distributed by the faults (Fig. 2).

Table 2. Rb and Sr isotopic data of whole rock and biotite concentrate for the dioritic rocks taken at Barton Peninsula, King George Island, Antarctica

sample No.	^{86}Sr (ppm)	^{87}Rb (ppm)	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$
34 (wh)	44.6	14.55	0.7070	0.322
x	0.3	0.05	0.0008	0.002
34 (bi)	5.51	84.3	0.7203	15.1
x	0.03	0.7	0.0004	0.2

* wh; whole rock, bi; biotite concentrate, x; standard deviation

Mineralization

The alterations including epidotization (sassuritization) and pyritization occurred in the volcanic rocks, especially along the fractures. The alteration resulted from the intrusion of quartz-diorite, as evidenced by the zonal distribution of altered zone around the intrusive bodies in the Noel Hill and South Spit areas.

According to X-ray diffraction and chemical analysis data of the altered rock (the so-called

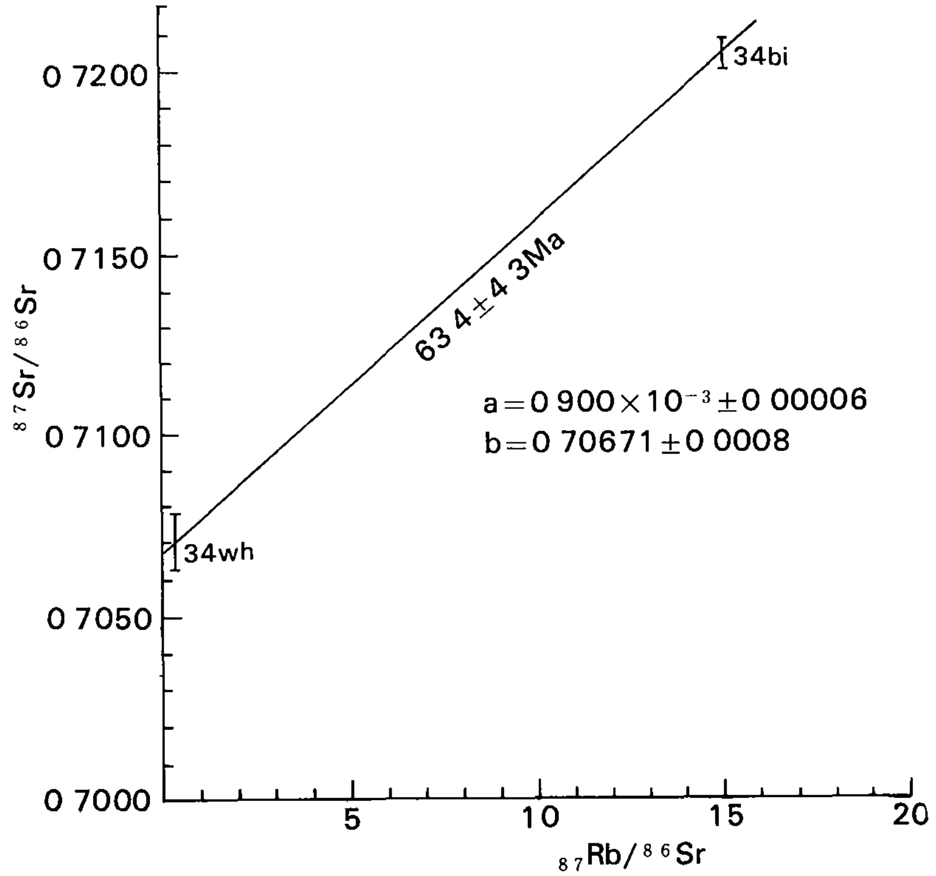


Fig. 6. Two-point isochron (whole rock-biotite) plot for the dioritic rocks of Barton Peninsula, King George Island, Antarctica.

Table 3 K-Ar age data of andesitic or dioritic rock in the Barton Peninsula of King George Island, Antarctica

sample No.	rock type	dated material	K (%)	^{40}Ar Rad		age (Ma)
				10^{-10} Mol/G	(%)	
No. 1	Quartzdiorite	whole rock	1.69	1.851637	54.35	62.10±1.6

Table 4. Chemical composition of Toseki and Limonite (analyzed in MDAC, KIER)
Toseki

SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	P_2O_5	TiO_2	MnO	$-H_2O$	$+H_2O$	Total
73.8	15.08	0.20	0.08	0.10	0.96	3.96	0.15	0.035	0.21	0.009	0.41	1.20	96.194

Limonite (ppm)

Cu	Pu	Sb	Cd	Co	As	Zn	Cr	W	Te	Mo	Au	Ag
185	86	160	75	20	14	10	20	10	10	10	ND	ND

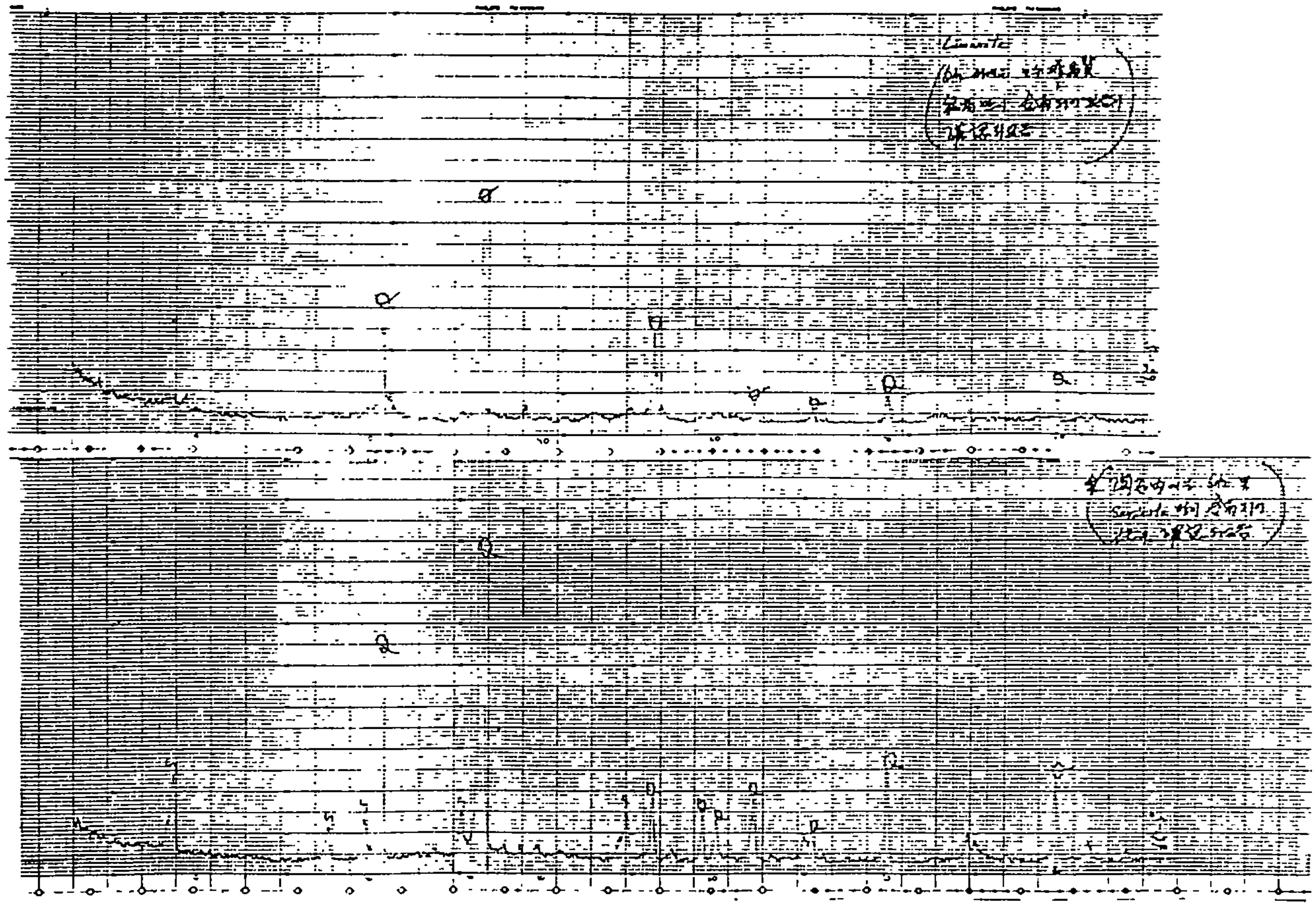


Fig. 7. X-ray diffraction pattern of Limonite and toseki

toseki) and gossanized ore samples (Table 4 and Fig. 7), the toseki consists of non-metallic minerals such as quartz and sericites, where as the gossanized ores (limonites) composed of amorphose ferro-metallic oxides and small amount of quartz.

Metallic mineralization is supported by the presence of high content of trace elements (Cu, Pb, Sb and W) in the limonite, comparing with those in normal earth crust.

Geologic structure

Notable structural features in the area are faults and joints: the three major faults (Davies, 1982) are the ENE-WSW trending one which runs through the andesite and the quartz-diorite,the WNW-ESE trending one which runs through the andesite and the quartz-diorite, the WNW-ESE trending one extending from the South Spit to the Winship Point, and the boundary fault between the quartz-diorite and the volcanic rocks in the west of the Noel Hill. The faults were formed during Tertiary or Quaternary times as evidenced by the fact they cut through the quartz-diorite of Tertiary age.

The faults, which are expressed on the aerial photographs scaled at 1:50,000, are rather densely spaced and are clearly exposed due to glacial erosion and mechanical weathering (Fig. 8).

The lineaments are statistically analyzed to find a general trend of strikes of their planes. According to the result, the lineaments trending W∼NW—E∼SE are most common in numbers and are longer than the lineaments of different trends. The NE-SW trending lineaments also extend for long distances but are small in number. The lineaments of two major trends intersect each other at about 60°(Fig. 8).

The joints are clearly visible on the out crops, but the measuring points for joints were selected systematically because of the limited distribution of outcrops. Strikes and dips of the joints are plotted on the stereonet (Fig. 9).

Sets of tabular joints, and E-W and NE-SW trending ones are a major group in abundance, whereas NW-SE trending joints are rare, in the quartz-diorite.

Tabular joints, and ENE-WSW and NW-SE trending joint are predomimant in the volcanic rocks.

The field data show that the joints in both rock types (quartz-diorite and volcanic rocks) are primary fractures formed during cooling and solidification stages. The joint sets except the one for tabular joints, concide well in trend with the major lineament sets. E-W, NE-SW and NW-SE directions being common trends in the lineament and joint fields.

Quaternary tectonism

According to the published data, the study area belongs to Andean tectonic zone which is tectonically active in present times. Old shore lines with beach pebbles and moraines or screes are well preserved along the coast at about 3 - 4 m above present sea level. In addition, well rounded pebbles, similar to beach pebbles, are also placed at about 100 m above sea level, 700 m southwestward from the Noel Hill.

Consequently it is apparent that the coastal area has been uplifted at least more than 100 m during the Quarternary.

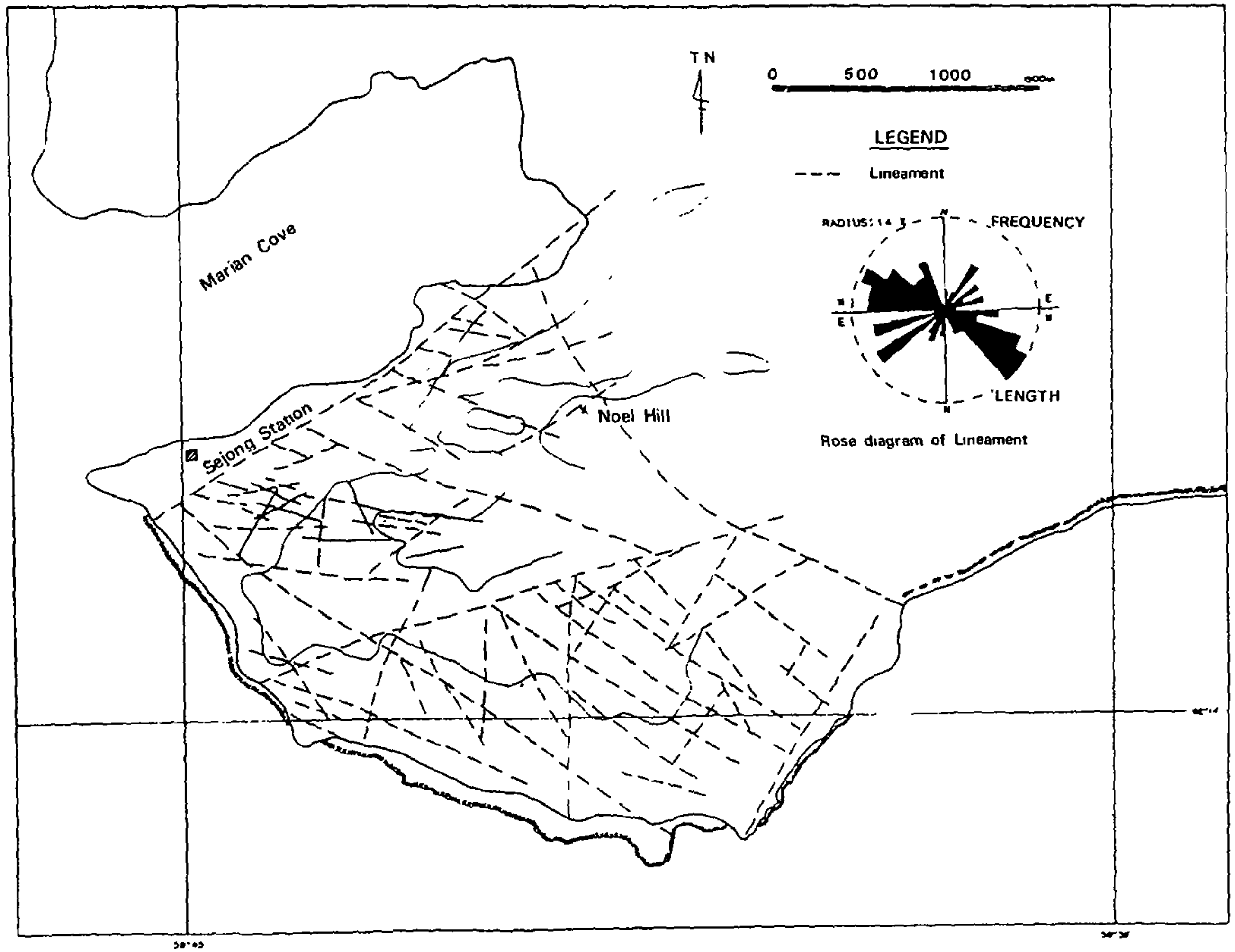
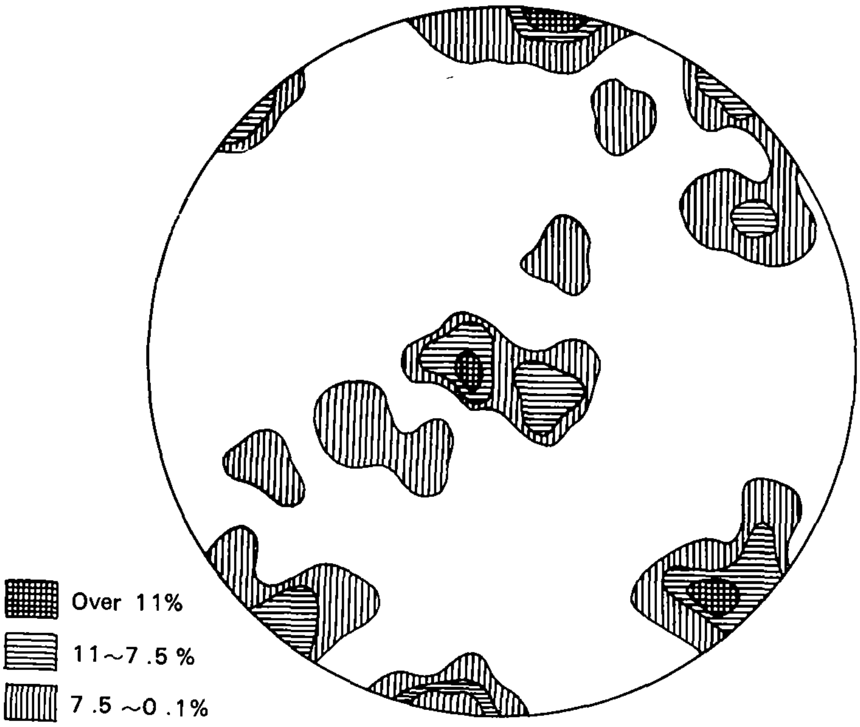
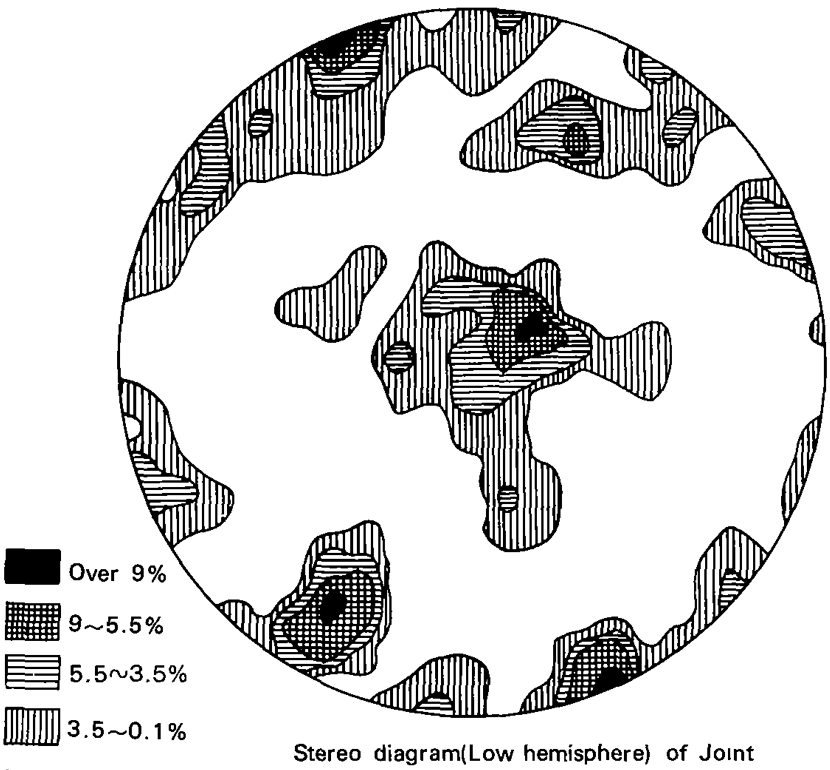


Fig. 8. Lineament map of Barton Peninsula, King George Island, Antarctica.



Total Joints 27

Stereo diagram(Low hemisphere) of Joint in Quartz-Diorite



Total Joints 54

Stereo diagram(Low hemisphere) of Joint in volcanic Rocks

Fig. 9. Stereo diagram of joints

Discussion and Conclusion

1. Barton Peninsula consists of the volcanic rocks such as andesite, andesitic tuff and agglomerates, and quartz-diorite which intruded the volcanic rocks in places.
2. The volcanic rocks are slightly altered by epidotization, sericitization and pyritization resulted from the intrusion of quartz-diorite, which belongs to the Andean intrusives.
3. The AFM (Alkalis-total Fe0-Mg0) triangular diagram shows that the igneous rocks of the area have been evolved from basaltic to andesitic rocks as in a calcalkaline trend.
4. The Quartz-Plagioclase-Orthoclase triangular diagram using normative minerals indicates that the basaltic rocks belong to gabbro or dioritic clan, the andesitic tuff and agglomerate to quartz diorite to tonalite clan,and the quartz diorite to quartzdiorite or quartz monzodiorite clan. However, according to the O'Connor's classification by the normative minerals, all the rocks are plotted in the field of dacitic rock.
5. The age of the quartz-diorite is about 64 Ma, using Rb/Sr two point isochron method of biotite and whole rock for the quartz-diorite, and andesitic to dioritic rock (sample No.1) gives an age of 62.10 ± 1.62 Ma by K-Ar whole rock method.Those facts suggest that initially the quartz-diorites must be a mass of quartz-diorite and separated by the later faults. In addition, strontium initial ratio of the quartzdiorites ($= 0.7067$) suggests that the quartz-diorite might have been originated from mantle or igneous sources.
6. The mineralization of the area can be inferred from the geochemical data of the altered rock and oxidized ore (limonite) samples: that is, nonmetallic mineralization is toseki, and metallic mineralization is inferred from the chemical data of the limonite containing much higher amount of Cu, Pb, Sb and W than the average content of the crust.
7. The lineaments expressed on the aerial photographs are generally matched with the joint sets except the tabular joint sets in trend; the dominant trends of the lineaments are WNW-ESE, NW-SE and NE-SW directions, and the major trends of the joints are tabular, E-W, NE-SE, ENE-WSW in the volcanic rocks and the quartz-diorite. The joints are inferred to be primary ones.
8. The area might be tectonically uplifted more than 100 m during the Quaternary, and is probably still active. The active tectonism is closely related to the tectonic movements in the Andean tectonic zone, from which the Barton Peninsula is extended southwards.

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Japanese Antarctic Earth Science Programs: Past and Future with Emphasis on Geomorphology

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Abstract

The development of the earth science programs in the Japanese Antarctic Research Expedition (JARE) since the IGY in 1957/1958 can be divided chronologically into six periods on the basis of objectives, research items, operational methods, and situation in research projects in each JARE. General and extensive field work of earth sciences including glaciology was carried out in the first period mainly for obtaining basic information on natural environments in wide area around Syowa Station, and this culminated in Syowa-South pole oversnow traverse in 1968/1969. After that, we conducted rather intensive earth science programs including large-scale geological mapping, petrological investigations, search for meteorites, deep explosion seismic experiments, and glacial geomorphology. The commissioning of a new icebreaker made the way for earth science activities in a wider area, and the field work in the Sør Rondane Mountains, which are situated 700 km west of Syowa Station and leave plenty of room for detailed earth science studies, became possible.

Geomorphological studies were not the main subject in earth science programs, but scientific results have been accumulated by glacial, submarine, and coastal geomorphological investigations as a basis study.

Collaborative investigations with New Zealand and the United States have played also an important role in the development of Japanese earth science studies.

We expect that the new stage of earth science investigations will start in the near future, investigations which consist of the establishment of the geophysical station as part of global networks for VLBI observation, absolute gravity measurement, and broad band seismic observation as well as field work in much wider region of East Antarctica.

1. Introduction

Lieutenant Nobu Shirase organized the first Japanese Antarctic Expedition and explored the eastern part of Ross Ice Shelf and a part of Edward VII Peninsula in the austral summer of 1911-1912 (Nankyoku-ki, 1913). Scientific contributions were much less compared, for example, with Scott's Expedition conducted contemporaneously. However, New Zealand Antarctic Place Names Committee rated this activity high and named the northeastern coast of Ross embayment *Shirase Coast* in 1961.

After 45 years since that time, Japan resumed her Antarctic activities on the occasion of the International Geophysical Year in 1957/1958 as Japanese Antarctic Research Expedition (JARE). Since then multi-disciplinary scientific investigations have been continued under the Antarctic Treaty System. Earth sciences research of Japan has progressed slowly but steadily, fluctuating more or less according to the development of programs of other scientific fields, because of limitations of manpower and budget for expedition.

The course of development of earth science programs can be divided chronologically into several periods, and a new stage will come soon. Geomorphological field work has been carried out intermittently within the framework of these programs, as basic but not main research subject. This report describes an outline of the chronological development of earth science programs, some geomorphological results, and expected subjects in future programs.

2. Chronological Overview

The six periods can be recognized in the development of the earth science programs on the basis of objectives, research items, operational methods, etc (Table 1).

2.1. The first period (1957-1968)

General and extensive field investigations were carried out for obtaining basic information on the natural environments of the region around Syowa Station which was established in February 1957. Geomorphological and some glaciological observtions in 1956/1957 summer and geological survey in 1957 winter (Yoshikawa and Toya, 1957; Tatsumi and Kikuchi, 1959a, 1959b) along the east coast of Lützow-Holm Bay were carried out in the first JARE (JARE-1). Aerial photography and ground control surveying were alo conducted to some extent (Fig. 1).

JARE-2 failed to occupy Syowa Station, being prevented by hard ice condition when m/s Soya was ice-locked and drifted for about 40 days. This drifting, however, provided some information on the nature of sea ice off Lützow-Holm Bay (Murauchi and Yoshida, 1959). The first inland traverse was carried out by JARE-3 wintering party for ice thickness measurement by seismic prospecting along a 360 km route towards southeast from the Syowa Station (Nagata, 1961). The party also established a seismological observation station at Syowa. JARE-4 made an inland traverse from Syowa Station to the Yamato Mountains for seismic prospecting of ice thickness and geological and geomorphological field work in the mountains (Ishida, 1962; Yoshida and Fujiwara, 1963; Kizaki, 1965). JARE-5 extended the traverse route up to 75°S, carrying out a gravimetric survey with Worden gravity meter (Oura, 1965). The summer party of JARE-5 made a reconnaissance survey along the Prince Olav Coast and part of Enderby Land, and established an astro-fix station on Sinnan Rocks in the easternmost part of the Prince Olav Coast (Yoshida *et al.*, 1961). The summer party of JARE-6 conducted an extensive aerial photography on the Prince Harald and Prince Olav Coasts. These data resulted in the publication of two 1: 250,000 topographic maps by the Geographical Survey Institute. The party also established the gravity station at Syowa by pendulum determination (Harada *et al.*, 1963).

Japanese Antarctic activities were interrupted for about four years from February 1962 to December 1965 due to superannuating of m/s Soya and the lack of a permanent organization for expedition. Japan resumed her Antarctic activities in 1965/1966 season with newly built icebreaker Fuji and the newly organized, small center for polar research. On this occasion, observation items were classified into two categories; routine observations (all-sky camera obser-

Table 1. Development of Earth Science Programs

- The first Period (1957-1968)
  - General, Reconnaissance Survey
    - Preparation of small-scale topographic map
    - Geological and geomorphological field work in coastal and inland ice-free areas
    - Oversnow traverses to Enderby Land, Yamato Mountains, 75°S: 38°E, Plateau Station, South Pole
- The Second Period (1969-1975)
  - Rather Intensive, Specific Survey
    - Preparation of large-scale topographic map
    - Geological and geomorphological field work
    - Search for Yamato Meteorites
    - Geochemical Studies
    - Publication of geological map
    - Glaciological Research Program in Mizuho Plateau (Establishment of Mizuho Station)
- The Third Period (1976-1978)
  - Supplementary Survey
    - Geological and geomorphological field work
    - Glaciological study at Mizuho Station
- The Fourth Period (1979-1981)
  - Regional Earth Science Studies and POLWX-South
    - Earth science project consisted of three subprograms
      - Completion of geological mapping in the vicinity of Syowa Station
      - Geophysical investigations of crustal structure
      - Marine geology and geomorphology of Lützow-Holm Bay
    - Glacio-climatological studies as POLEX-South
- The Fifth Period (1982-1984)
  - Eastern Queen Maud Land Project
    - Supplementary geological field work
    - Marine gravity survey
    - Traverse glaciology
    - Deep drilling of the ice sheet at Mizuho Station
- The Sixth Period (1985-1988)
  - Eastern Queen Maud Land Project
    - Earth science studies in the Sør Rondane Mountains region
    - Marine gravity survey
    - Traverse glaciology including shallow drilling of the ice sheet (Establishment of Asuka Station)

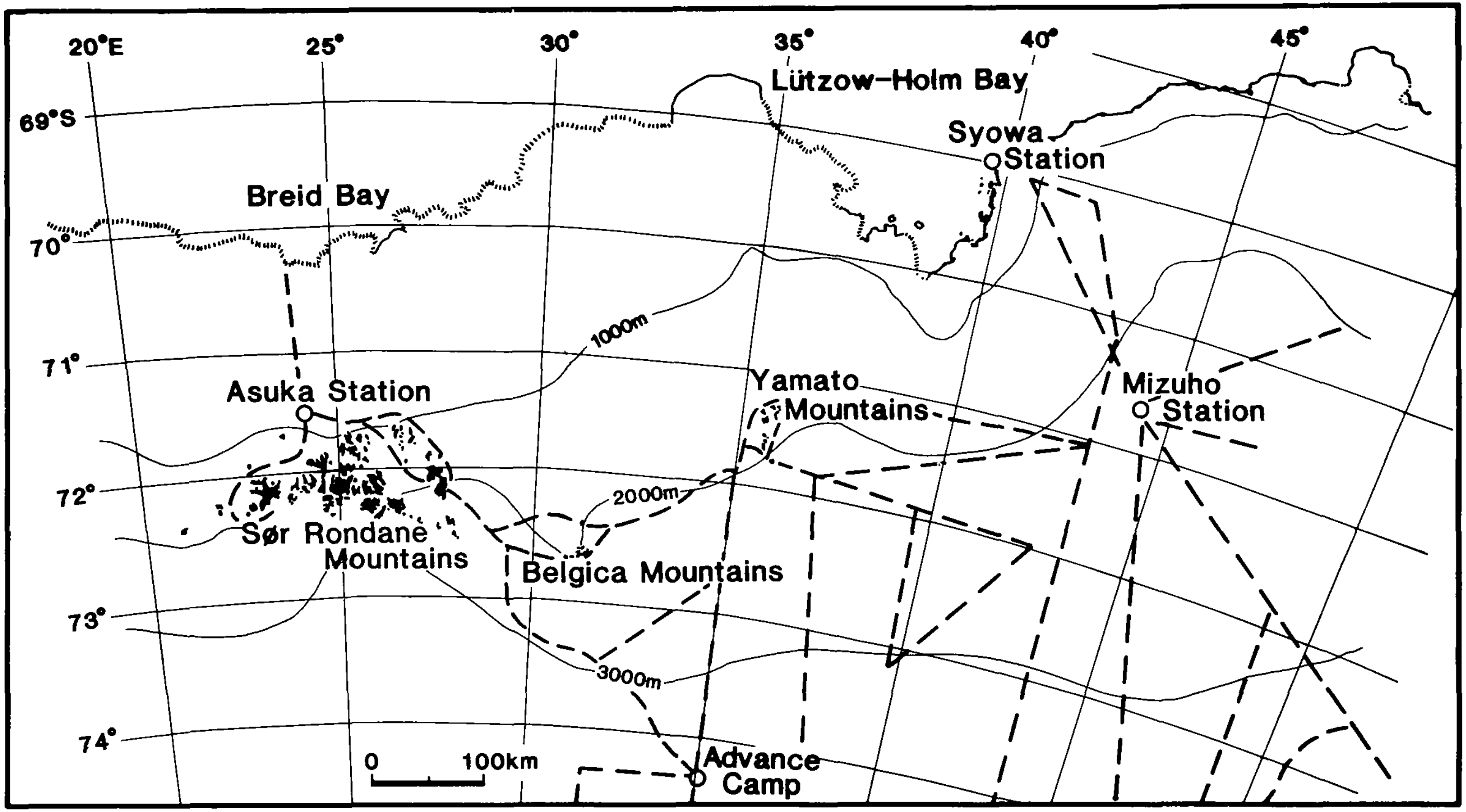

Fig. 1. Geographical map around Syowa Station

vation for aurora, fluxgate magnetic observation, ionosphere observation, meteorological observation, seismological observation, tide observation, oceanographic observation on board, and geodetic and cartographic observations) and research projects for other scientific research. Helicopters on board have been used mainly for cargo transportation. Since JARE-8 in summer of 1966/1967, they have been used for field work in various investigations in coastal ice-free areas. This has brought about the new phase in earth science programs. However, the main objective of earth sciences in a broad sense in JARE-7 to JARE-9 was to accomplish the oversnow traverse to and from the South Pole (Murayama, 1971). Thus, the first period lasted until JARE-9 in 1967/1969 in spite of the change in the organization of expeditions.

2.2. The second period (1969-1975)

The "Glaciological Research Program in Mizuho Plateau" was commenced by JARE-10 in 1969. This systematic program provided information on the mass balance and the dynamics of the ice sheet of Mizuho Plateau behind the Syowa Station. Ice drilling of 150 m deep at Mizuho Station about 300 km southeast of Syowa and 2230 m above sea-level gave the knowledge of environmental change in the near past.

On the other hand, the geological survey in coastal and inland ice-free areas progressed gradually, and publication of a large-scale (1:5,000 and 1:25,000) geological map started in 1974. Petrological and structural geological investigations were promoted significantly. The most prominent results seem to be a finding of meteorites. The glaciological traverse party of JARE-10 found 9 meteorites on a bare (blue) ice area near the southern part of the Yamato Mountains (Yoshida *et al.*, 1971). JARE-14 also collected 12 meteorites from almost same area (Shiraishi *et al.*, 1976). More systematic search for meteorites in JARE-15 and -16 yielded the collection of 970 pieces of "Yamato Meteorites" from "Meteorite Ice Field" (Yanai, 1978; Matsumoto, 1978). Geomorphological field work deatl with subglacial topography, coastal topography of ice-free areas and submarine topography of Lützow-Holm Bay.

2.3. The third period (1976-1978)

In this period, the main project in JARE-17 to JARE-19 was the programs as part of International Magnetospheric Studies, including rocket observations of aurora australis. Therefore, earth science programs were limited mainly to supplementary field work in summer for geological survey of coastal ice-free areas. We promoted, however, the publication of large-scale geological map on the basis of the field work in this period, and accumulated the data on landforms of ice-free areas and sea floor near the coast.

2.4. The fourth period (1979-1981)

The main projects from JARE-20 to JARE-22 in this period were the climato-glaciological program as POLEX-South and the multipurpose earth science program for the elucidation of crustal structures of the Lützow-Holm Bay region.

The latter program consisted of four sub-programs; 1) geological investigations of coastal and inland ice-free areas, 2) meteorite search in conjunction with geological and geomorphological field work in inland mountains, 3) geophysical investigations of crustal structures, and 4) marine geomorphology and geology of Lützow-Holm Bay.

The primary objective of geological field work was to complete geological survey for geological mapping of most of coastal and inland ice-free areas which extend over 80 km from Belgica Mountains through Yamato Mountains to the easternmost part of the Prince Olav Coast. The results, together with results obtained in the following period in 1982-1984, produced naturally the significant progress in petrologicl and structural geological research (e.g. Shiraishi *et al.*, 1987).

Search for meteorite in bare ice areas around Yamato Mountains, Minami-Yamato Nunataks and Belgica Mountains brought force some 3800 pieces of meteorite. The collection includes a lunar meteorite which give impact on meteorite studies in the world.

Geophysical investigations comprised gravity survey, aeromagnetic survey, heat flow measurement, and explosion seismic experiments. The continuous gravity measurement on board m/s Fuji started again in this period with a newly developed sea gravity meter. The highlight was the explosion seismic experiments which gave us the seismological crustal structure between Syowa and Mizuho Stations down to upper mantle and the knowledge about the technical problems (Ikami *et al.*, 1984).

Submarine topography of Lützow-Holm Bay was surveyed by an echo-sounder from surface of sea ice. The survey in this period together with accumulated data since 1968 provided the features of complex drowned valley system in Lützow-Holm Bay (Moriwaki and Yoshida, 1983).

2.5. The fifth period (1982-1984)

From JARE-23 in 1981/1983, we started the Eastern Queen Maud Land Project which consisted in fact of two different programs in the fields of glaciology and earth sciences from JARE-23 to JARE-29 (1987/1989).

Glaciological studies were conducted from 1982 to 1986, and consisted of 1) dynamics of the ice sheet in areas of Shirase Basin and behind the Yamato and Sør Rondane Mountains up to Valkyrjedomen by traverse glaciology including shallow (100-200m) drilling and resurvey of strain net and NNSS fixed stations, 2) deep (up to 700 m) drilling at the Mizuho Station, and radio-echo sounding for detection of ice thickness and structure.

On the other hand, the earth science programs from JRAE-23 to JARE-25 consisted of supplementary geological survey in coastal areas and marine gravity measurement. From 1983/1984 summer (JARE-25), the new icebreaker Shirase went into commission. Increase in the ship capacity of passenger and cargo transportation and of ice-breaking enabled us to broaden the scientific and logistic activities. The summer party of JARE-25 could conduct reconnaissance geological and paleomagnetic field work in the Sør Rondane Mountains region for the preparation of filed work which was to be the main purpose of the earth science program in the Eastern Queen Maud Land Project.

2.6. The sixth period (1985-1988)

JARE-26 established the first hut of Asuka Station on the ice sheet 40 km north of the central part of the Sør Rondane Mountains at the end of December, 1984. Since that time, earth science field work has been carried out by a field party of a small number of people. Geodetic control surveying, geological, geomorphological and paleomagnetic field work has been conducted in austral summer seasons. Connection of gravity measurement with the gravity station at Syowa Station was repeated several times.

The wintering party of JARE-28 in 1987 carried out geophysical investigations including radio-echo sounding of subglacial relief, aeromagnetic survey, gravity survey, and GPS (Global Positioning System) experiment in the vicinity of the Sϕr Rondane Mountains. The wintering of JARE-29 is conducting the meteorite search in bare ice areas around the mountains in 1988.

Sea gravity measurements have been continued since 1980. In addition, the program of intensive depth sounding for sea floor mapping started in 1987/1988 summer in the region from Breid Bay to offing of Lützow-Holm Bay. Geological and geomorphological field work for comparative studies for Pince Olav Coast-Sϕr Rondane Mountains region and other areas in East Antarctica also started in 1987/1988 summer. Field parties visited Mt. Vechernyaya near the Molodezhnaya Station and Mt. Riiser-Larsen in Enderby Land in February, 1988.

The first stage investigations of earth sceince of the Sϕr Rondane Mountains will continue till JARE-32 in 1990/1992.

3. Geomorphological Studies in JARE

The preliminary geomorphological study on Ongul Islands and Langhovde area in the Lützow-Holm Bay region by JARE-1 revealed glacial, periglacial and coastal geomorphological problems to be deepened or solved, and provided the guidepost for the succeeding investigations (Yoshikawa and Toya, 1957). The main problems are 1) characteristics of glacial erosion of the ice sheet and extent of the past (or former) ice sheet, 2) crustal uplift after shrinkage of the ice sheet, 3) currently active periglacial phenomena, and 4) recent change of features of some part of the ice sheet margin. Since that time, these problems and related subjects have been studied by not so many geomorphologists in coastal and inland ice-free areas and their surroundings. Short notes on these problems are presented in the following paragraphs.

3.1. Glacial landforms of ice-free areas

Characteristics of glacial landforms give clues to erosional and depositional processes by an ice sheet and to the glacial history of Antarctica. Some properties such as basal temperature condition of the past ice sheet can also be inferred from landforms.

Erosional features of coastal ice-free areas near Syowa Station well exhibit selective (or differential) erosion by the past ice sheet (Yoshida, 1983a). Geological structure of bedrock composed of crystalline rocks such as gneisses and granites, in particular, joint systems played an important role in "areal scouring" (Sugden and John, 1976) of the region. It seems important that the glaciated bedrock shows polished surface with striations and grooves. Particularly even p-form (plastically sculptured forms) can be found in some places (Fig. 2). The fact indicates that the ice sheet was the "wet-based" one when the ice scoured the terrain.

On the other hand, "selective linear erosion" (Sugden and John, 1976) excavated some parts of ice-free areas and sea floor adjacent to the coast without regard to small-scale geological structures of the bedrock. A steep cliff which seems to have been one side of glacial trough walls is seen in some places. The origin is not always clear. However, it was formed possibly by an ice stream of which one side was confined by a local rise of bedrock and the other

Fig. 2. Photograph of plastically sculptured forms

side by rather sluggish ice sheet. Such situation can be seen in several places of the ice sheet coast.

Striations, grooves and roches moutonnes give information on direction of the past ice flow. The general direction of the past ice sheet near the present ice sheet margin was more or less perpendicular to the coastline. There are two different striation directions in some places. However, it is difficult to judge that two different directions correspond to two ice advances in different stages or indicate the change of ice flow during the course of shrinkage of the ice sheet.

Striations found near the western edge of the Langhovde Glacier which flows from south to north show east to west flow of the past ice sheet. We can find a deep, drowned glacial trough at offing of the Langhovde Glacier. Therefore, the Langhovde Glacier would have flowed to the north at the stage of expanded ice sheet. On the other hand, east-west striations indicate east-west ice sheet flow beyond the Langhovde Glacier from the east. Near the mouth of the Shirase Glacier, the directions of striations in Instekleppane and Austhovde ice-free areas cross the direction of the present stream flow of the Shirase Glacier sharply as if the past ice sheet had flowed crossing over the large ice stream (Fig. 3). These facts seem difficult to be explained without assumption that flow direction of upper ice would be different from that of lower ice.

Glacial depositional features on the coast mostly consist of sparsely distributed ground moraines. We can find only rather thick glacial deposit in Skarvsnes area. It is thought to be lodgement till deposited under wet-based condition and named "Osen Glacial Bed" (Yoshida,

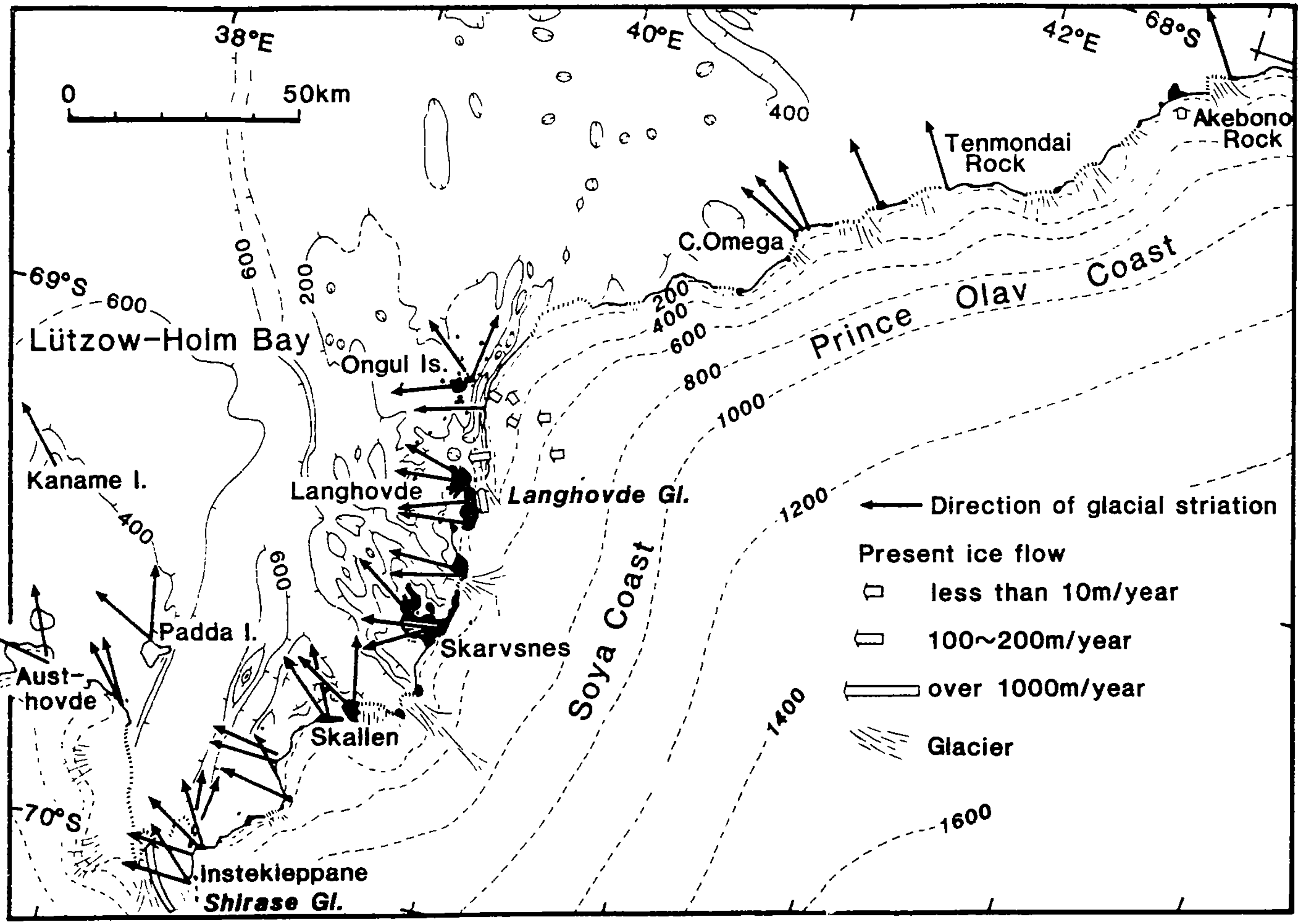

Fig. 3. Diagram shocoing the direction of galciers' movement

1983b). However, detailed study has not yet done.

The diamictites found in the Mt. Riiser-Larsen area of Enderby Land (Yoshida and Moriwaki, 1983) might be correlative with the Pagodroma strata which were found in the Prince Charles Mountains region and thought to be correlated with the Sirius Formation in the Transantarctic Mountains (McKelvey, personal communication). However, it waits also future detailed investigation.

The glacial landforms of inland mountains have been studied in the Yamato and the Sør Rondane Mountains. The Yamato Mountains consist of seven small massifs and some tens of nunataks and extend over 50 km in north-south direction, forming arcuate mountains. The highest massif protrudes above the ice sheet surface by 400 m in the east side (upstream side) and 800m in the west. Striations indicating abrasion by wet-based ice sheet were found in a few places. Part of summit areas seems also to be subjected to areal scouring. This suggests that the summit areas were covered by considerably thick ice sheet (at least 500 m?) which could cause pressure melting during scouring, or that elevation of the mountains was lower to some extent at the stage of ice cover than at present. Glacial pothole-like topography was found on the flat surface of Minami-Yamato Nunataks (Yokoyama, 1976). The topography may be either glacial potholes or tafoni. If they are glacial potholes, there should be considerable amount of subglacial water during their formation. However, it is difficult to reach any definite conclusion at this stage.

Depositional features are mainly ice-cored moraines on ridges and the ice sheet surface. Slight differentiation in thickness of moraines according to location is recognized, and it seems indicate the difference in lapse of time since deglaciation.

The Sør Rondane Mountains are much larger than the Yamato Mountains. Geomorphological survey is under progress and only preliminary results can be mentioned. The highest summit areas are thought not to have been covered with the ice sheet even at the maximum extent of the ice sheet. Moraines can be classified into six categories according to their degree of weathering, features, locations, etc.

3.2. Submarine topography

Submarine topography of the continental shelf of Antarctica is important for understanding of the past glaciation by the ice sheet, particularly in the Lützow-Holm Bay region where coastal ice-free areas are small in area. Preliminary survey by a lead sounder from surface of sea ice and limited echo-sounding on board suggested that deep submarine troughs might exist in embayments such as Lützow-Holm Bay and Amundsen Bay (Yoshida *et al.*, 1964). However, heavy sea ice in Lützow-Holm Bay disturbed detailed shipboard survey. Therefore, we introduced an echo-sounder which can be used from surface of sea ice (Yoshida, 1969). Fujiwara (1971) pointed out that 1) rises and troughs of sea floor show linear arrangement, suggesting the structural control of gneissic rocks on glacial erosion, 2) the shelf is divided into the inner and outer shelves, and this could have been caused by the presence of glaciation/nonglaciation boundary on the shelf or by glacial sedimentation on the outer shelf, 3) deep troughs with depths of 600-700 m have valley steps at about 400 m in depth, and latter depth seems conformable with bottom depths of broader and shallower troughs.

Succeeding surveys revealed the submarine topography of wider area of Lützow-Holm Bay

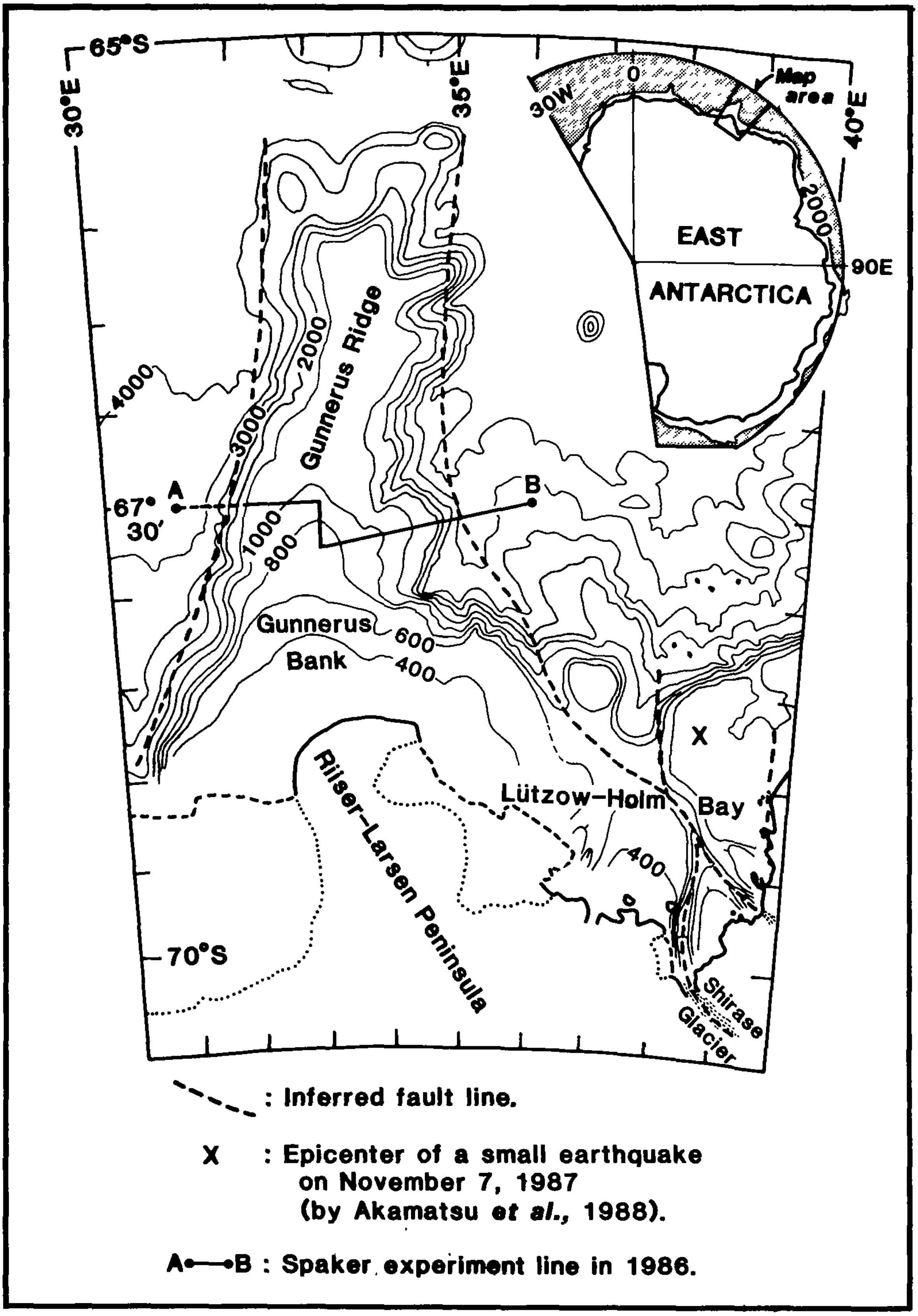

Fig. 4. Fault pattern in Lützow-Holm Bay.

(Omoto, 1976; Moriwaki and Yoshida, 1983). A large glacial trough extending from the mouth of the Shirase Glacier lies in the central part of Lützow-Holm Bay. The trough with 1560 m in maximum measured depth and another trough with 1148 m in maximum depth were formed probably by glaciation along faults. The sea floor of the bay is divided into the eastern and western parts by the central trough. The greater part of the western sea floor is 300 m deeper than the eastern sea floor, suggesting the displacement of bedrock by faulting. This fault seems to extend to the eastern margin of the Gunnerus Ridge (Moriwaki, *et al.*, 1987) (Fig. 4). Seismic profiling by a sparker system near the outer edge of the continental shelf at the mouth of Lützow-Holm Bay shows that the sea floor is composed of bedrock free from thick sediments (Moriwaki, 1984). Therefore, this part of continental shelf would have been glaciated by the past expanded ice sheet.

3.3. Raised beach topography

Raised marine features are known in many places of Antarctic coastal areas. The features are also widely distributed in ice-free areas on the Prince Olav Coast and the east coast of Lützow-Holm bay, indicating that the whole region had been submerged partially by the sea after deglaciation, and then has been uplifted to some extent. Most of raised beaches consist of sand and gravel derived from glacial till deposited in rather sheltered places as ground moraines, and often contain fossiliferous sand and silt. Raised beaches exhibit stepped topography composed of berm-like steps and beach faces in some places. But wave-cut bench and sea cliff develop only in a few places probably due to weak wave action and hard bedrock. This makes difficult to determine elevation of former sea-level from raised marine features. Therefore, different opinions still exist among Japanese researchers on the problem of the maximum height of sea-level (Yoshida, 1983a).

Saline lakes are also found in the coastal ice-free areas, and some of lakes were formed by cut off from arms of the sea caused by crustal uplift. These saline lakes show unique thermal stratification (Yoshida, 1970; Yoshida *et al.*, 1975; Murayama et al., 1988).

Radiocarbon dates of marine fossils appear to be classified roughly into two age groups; the one belongs to ages between 2,000 and 10,000 years B.P. and the other to ges between 22,000 and 34,000 or more years B.P. Radiocarbon dates on marine living organisms gave ages between 860 and 1300 years B.P. The average value is 1,120 years B.P. Ages between 2,000 and 10,000 years denote probably" post-Glacial". On the other hand, it is difficult to interpret without contradiction the relation between the raised beach topography and organic remains of the older age group at the present state of knowledge. Beach deposits show no sign of glacial cover after deposition. Some fossils belonging to the older age group exibit *in situ* occurrence. At present, we think that the past ice sheet had retreated from larger ice-free areas in the Lützow-Holm Bay region before 30,000 years B.P. Degree of weathering of bedrock in larger ice-free areas seems considerably large, compared, for example, with bedrock in the Antarctic Peninsula region. This appears to correspond to the earlier retreat of the ice sheet in Lützow-Holm Bay.

3.4. Periglacial topography

Current geomographological proesses on ice-free areas are mainly periglacial processes such as solifluction, cryoturbation, and wind erosion and deposition. However, these processes are not so active, because 1) the frequency of freeze-thaw is low, 2) an active layer is shallow, 3) thickness of soft sediments is thin, and 4) supply of water is limited. However, we are conducting experimental studies on horizontal and vertical movement of unconsolidated deposits, frost-rift of bedrock, thermal condition of surface and subsurface of bedrock and unconsolidated deposits.

The larger and smaller sorted polygons were found in the Mt. Riiser-Larsen area. It has been suggested that the smaller polygons seem to correspond to thickness of a present active layer of the permafrost, and the larger ones might have been formed in the past when the climate was milder than today (Makimoto *et al.* in press).

We expect that the study of periglacial phenomena will be useful for elucidating the climatic condiction and its change in the near past.

3.5. Geomorphological map

A detailed geomorphological map is useful to further studies of landforms qualitatively and quantitatively, or in other words not only morphogenetically but morphometrically. It became possible to carry out geomorphological mapping in the Lützow-Holm Bay and Yamato Mountains regions by production of a large-scale topographic map, preparation of aerial photographs, in particular color ones, and progress of ground survey to some extent. Therefore, the mapping project started in early 1980s, as a joint study by some of the Japanese geomorphologists, who belong to the group studying landforms under cold environments. As the detailed geomor phological mapping in such a sense was the first attempt in Antarctica, not only preparation of a geomorphological map but also a study of mapping method itself has been one of the objectives of the project. Therefore, the method and representation of "Langhovde" (Hirakawa *et al.*, 1984) in the coastal region somewhat differ from those of "Mt. Tyo" (Iwata *et al.*, 1986) in the Yamato Mountains. The mapping of selected areas and improvement of its method will be continued. This project will contribute to the comparative study of landforms in Antarctica and in other cold regions.

4. Collaborative Studies with USARP and NZARP

Japanese earth scientists including geochemists have been continuing their activities in the McMurdo Sound region in collaboration with United States and New Zealand scientists, activities which have been supported by Division of Polar Program, NSF, and Antarctic Division, DSIR.

In 1963/1964 summer, a Japanese team carried out preliminary geochemical and geomorphological studies in the Dry Valleys area for the first time. One of the results was the discovery of a new mineral, Antarcticite, at Don Juan Pond in Wright Valley (Torii and Ossaka, 1965). The Dry Valley Drilling Project (DVDP) started in 1972/1973 season as a collaborative investigation among New Zealand, U.S.A. and Japan on the basis of joint efforts from 1963/1964 to 1971/1972. The field work in DVDP terminated in 1975/1976 season. Not only field work but also three seminars in Seattle, Wellington and Tokyo yielded the fruitful results (e.g. Nagata, 1979). The DVDP was successfully succeeded by the MSSTS (McMurdo Sound Sediments and Tectonic Studies) and then the CIROS (Cenozoic Investigations in the Western Ross Sea) projects.

On the other hand, U.S.A.-Japan Search for Meteorites project was carried out in bare ice areas around part of the Transantarctic Mountains from 1976/1977 to 1978/1979 season. This project brought about also fruitful results, and was succeeded by the U.S. program.

Since 1980, geophysical studies on Mt. Erebus volcano have been conducted as the collaborative project among New Zealand, U.S.A. and Japan. The seismic observations using telemetry system recorded the new volcanic eruptive activity with a number of large explosions (Kaminuma, *et al.*, 1987).

5. For Future Programs

As stated above, the first stage of geological, geomorphological and geophysical investigations in the Sør Rondane Mountains will terminate in JARE-32 in 1990/1992. Geology and geomorphology of the Prince Olav and Lützow-Holm Bay regions will be studied again in depth for one or two years after 1992. Geological and geomorphological field work will be conducted also in wider areas to the west and the east of Prince Olav Coast-Lützow-Holm Bay-Sør Rondane Mountains region. Geodetic survey using GPS will also be attempted in wider areas.

On the other hand, we are planning to conduct sophisticated observations at Syowa Station as station geophysics. JARE-30 will construct the parabola antenna with diameter of 11 meters in 1988/1989 Summer for receiving signals from Japanese EXOS-D satellite for aurora observations and from Japanese MOS-1 satellite for observation of surface condition of the sea and icy regions in 1988/1989 summer. This antenna will be used for receiving signals from European ERS satellite in future. It is designed to be used also for VLBI (Very Long Baseline Interferometer) observation. If it is realized, we can measure accurate distance between Antarctica and other continents to detect the movement of the plates.

Syowa Station was selected as one of 36 absolute gravity measurement stations which constitute the International Absolute Gravity Base Station Network (IAGBN) subset (A) over the world in 1987. Therefore, we have to conduct the absolute gravity observation in the near future.

In addition, the improvement of earthquake observation system will be done in conjunction with the Pacific Orient Seismic Digital Observation Network (POSEIDON) as part of the Federation of Digital Broadband Seismograph Networks.

Thus, we strongly hope to advance the earth science programs in JARE qualitatively and quantitatively within the framework of international cooperation.

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A Summary of India's Geophysical Programme in Antarctica

Harsh K. Gupta

Abstract

Geophysical investigations in the Queen Maud land region of Antarctica were initiated by Indian scientists in 1982 when the First Expedition landed in Antarctica. Since then a suite of geophysical tools and techniques including geomagnetic, seismic, electrical, electromagnetic and radiometric methods have been successfully applied. Helicopter borne magnetic surveys were undertaken during 1987-88. The area of operation has been extended further south to Wohlthat and Humboldt Mountain regions. Salient results of geophysical work carried out by Indian scientists in Antarctica are summarized here.

Introduction

Indian scientist got involved with Antarctic research since December 1981 when the first expedition was launched by the Government of India. Since then, seven expeditions have been successfully launched, and at the time of writing this paper, preparations are underway for the VIIIth expedition to leave from Goa, on west coast of India in the last week of November 1988. The first expedition landed in the Princess Astrid Land region (Figure 1) and carried out scientific work in the adjoining shelf ice and the Schirmacher Hill region. The Third Indian Scientific Expedition set up a permanent base station "Dakshin Gangotri" during the summer of 1983-84. This double storeyed station, located at 70°05'S and 12°00'E, with a built up area of about 790 sq.metres, is self sufficient in all aspects and can accommodate upto 15 persons (Gupta 1984, 87), Nair and Gupta, 1986). The first wintering was carried by the Indian team during 1984-85 and since then the Dakshin Gangotri base station is continuously manned and operated. Over the years, an alternate living accommodation complex, a hanger, and a workshop adjacent to Dakshin Gangotri station have been added. In the mean time, at the Shirmacher Hill, a summer accommodation including three huts of 8 sq.meter each, a one-half container accommodation and a toilet cubicle have been commissioned and are used during the summer months.

In India, the responsibility for planning and coordination of the Indian Antarctic Program has been entrusted to the Department of Ocean Development. The scientists taking part in India's Antarctic Programme are drawn from various scientific departments and universities. So far, about 160 scientists have participated in Indian expeditions to Antarctica. There are

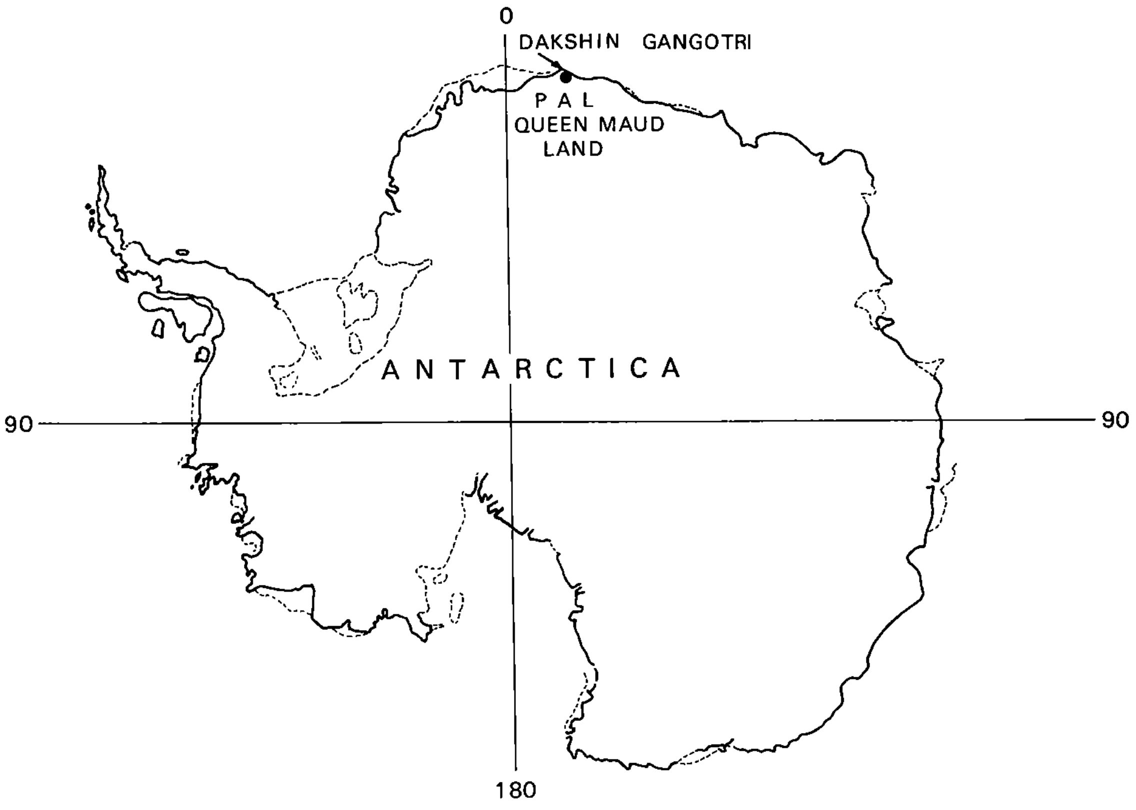

Fig. 1. Location of the Indian station, Dakshin Gangotri in Princess Astrid Land region.

examples of Indian scientists participating in the Antarctic programmes of other countries and vice versa.

The scientific disciplines pursued by Indian scientists in Antarctica include meteorology, upper atmosphere, geology and glaciology, geophysics including geomagnetism, remote sensing, isotopic studies and all aspects of oceanogarphy in Antarctic waters.

Geophysical work was initiated from the first expedition in 1982 and has expanded considerably over the years. The initial work was carried out involving magnetic measurements over the ice shelf in the Princess Astrid region. With the passage of time the geophysical techniques and tools used have multiplied and the area of field work has extended to Wohlthat Mountain ranges: during the summer months of 1987-88 an area of 12,000 sq.km was covered by helicopter borne magnetic surveys involving flying over 4,000 line km by geophysical terms from the National Geophysical Research Institute participating in the 7th Indian Scientific Expedition to Antarctica. In the present paper a brief summary of geophysical work carried out under the Indian Antarctic Programme is presented.

Geomagnetic studies

Geomagnetic investigations in Antarctica were initiated during the first expedition in 1982 when the earth's total magnetic intensity as well as field components X, Y and Z were monitored for a few days at Princess Astrid Coast (Iyengar and Rajaram, 1983). During the second expedition, eight magnetic profiles over the shelf ice, extending to distance of upto 10 km south from the shelf edge in the vicinity of the Indian summer camp were undertaken. The observed magnetic anomalies of 150 to 200 nT were interpreted in terms of a basic intrusion (Mittal and Mishra, 1985). Arora et al. (1985) have contoured the total intensity magnetic observations for the above mentioned 8 profiles. During the same expedition Rangarajan et al (1985) have reported two intensen magnetic disturbances on January 10 and February 4, 1983 and two magnetic substorms on February 12 and 13, 1983. These observations were made at 69°59'S', 11°55'E (Dipole latitude 65°30'S, longitude 54°30'E).

During the Third Expedition, detailed total intensity magnetic measurements were carried out using a couple of Geometrics Model G-816/826 Proton Precession Magnetometers. One magnetometer was continuously used for recording diurnal variations to make necessary corrections to the field observations carried out at the Schirmacher Hill region and on the shelf

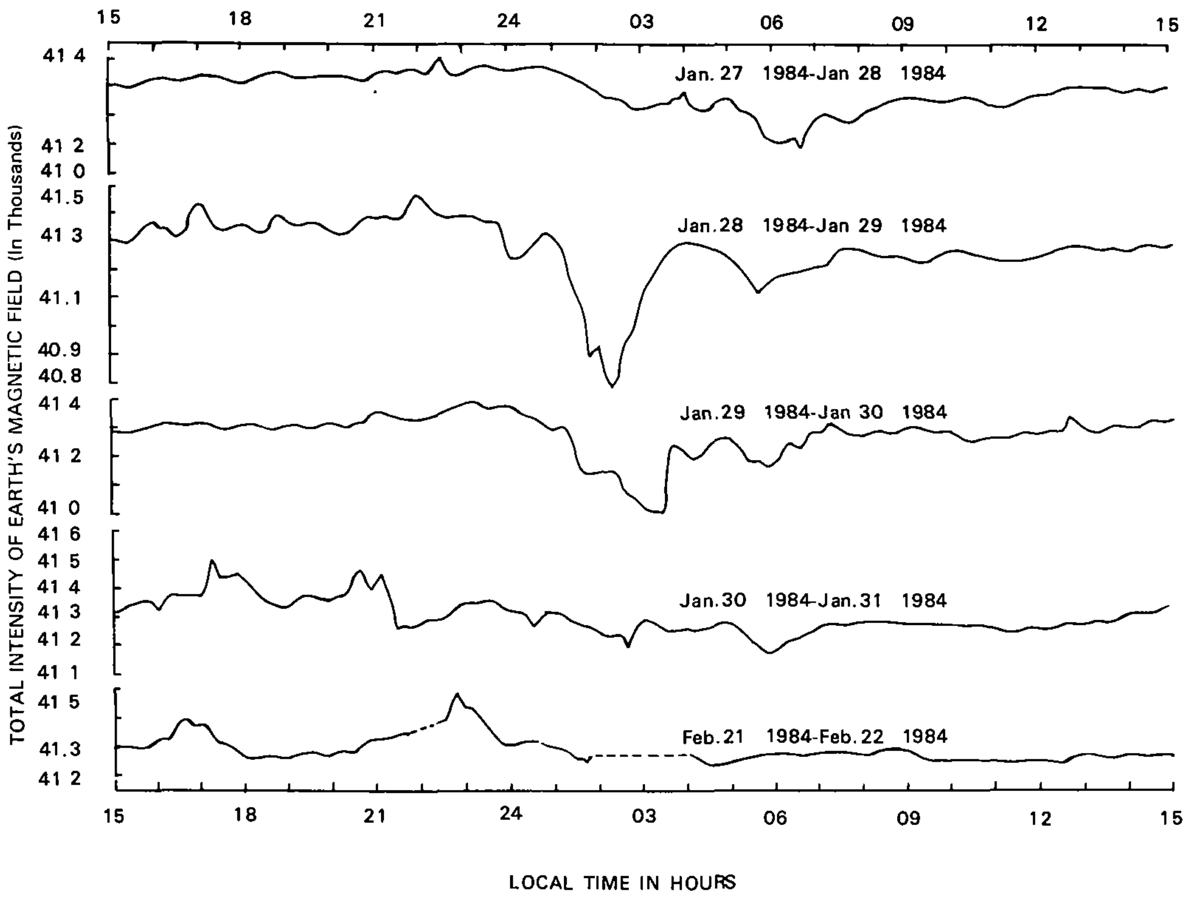

Fig. 2. The earths total magnetic intensity measurements at the Schirmacher Hill and Princess Astrid shelf region (from Gupta and Varma, 1986)

ice. Several sets of field observation data had to be rejected since magnetic storm like conditions prevailed during the time when field observations were made. Polar storms, typically observed in Antarctica, lasting 2-4 hours and having amplitudes of several hundred nT can be seen on January 28-29, 1984 record between 24 and 03 hrs (Figure 2).

During the Third Expedition a detailed geological map of the entire 35 sq.km area of the Shirmacher Hill region on 1:25000 scale was prepared (Sengupta, 1986). High grade quartzo-feldspathic gneisses and its variants with intercalated metabasics are the dominant rock types in the area. A number of magnetic profiles crossing well recognized geological contacts were undertaken (Gupta and Varma, 1986). Figure 3 depicts three of these profiles. On profiles DG 1 and DG 2, the contact of garnet biotite gneiss and sulphide bearing banded gneiss is characterised by magnetic anomalies of several hundred nT. The shape of anomaly indicates that while the DG 1 anomaly could be due to a sharp contact, the DG 2 anomaly may be due to an intrusive along the contact plane. If this be the case, the intrusive must have been considerably metamorphosed to account for the low order of magnetization in comparison to the anomaly across the contact plane along the profile DG 1. The profile DG 3, about 1500 m in length, does not show any significant anomaly except minor anomalies associated with the contact of sheared leucocratic gneiss and banded gneiss.

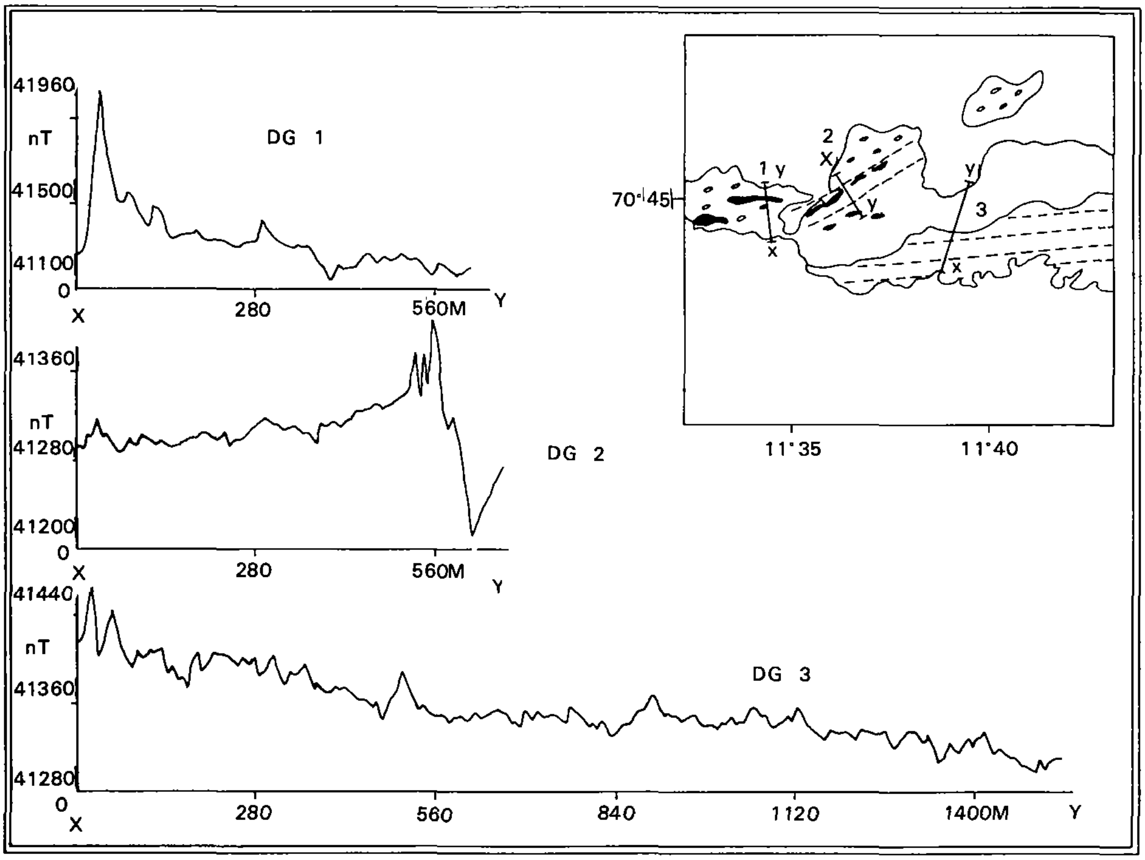

Fig. 3. Magnetic traverses across geological contacts in Schirmacher Hill region (from Gupta and Varma, 1986).

Figure 4 depicts six short magnetic traverses, three in E-W and three in almost N-S direction, crossing one another, with a short station spacing of six meters laid over augen gnesis in the Schirmacher Hill region (Gupta and Verma, 1986). Certain interesting anomalies, 600 nT to 900 nT in amplitude, are found to be associated with these profiles. Proximity of these traverses permitted contouring of the observed anomalies at 100 nT intervals (Figure 5). From this contouring, five anomalies have been picked up for quantitative interpretation using a graphical method (Koulomiza et al, 1970), where the field profile is decomposed into its symmetrical and antisymmetrical components using arbitrarily chosen conjugate points. The symmetrical and antisymmetrical components are analyzed separately. This procedure does not require any previous knowledge or assumption of the zero datum level or the centre of body. It is assumed that the anomalies are caused by intrusive bodies. The results of the analysis are presented in the following table:

Table Quantitative interpretation of magnetic anomalies in the Augen Gneiss Terrain, Schirmacher Hill (Refer Figures 4 and 5)

Anomaly	Depth (m)	Width (m)
AA	4.0	6.0
BB	10.0	2.0
CC	5.0	2.0
DD	3 0	2.0
EE	6.0	Contact

Certain assumptions made for quantitative interpretations include that the anomalous body is caused by the induction of earth's field, that the direction of magnetization is uniform throughout the body, and the remnant magnetization, if present, is also in the direction of earths field or is negligible.

The laying of magnetic traverses over the sheld ice was initiated during the Second Expedition, and was extended considerably during the Third Expedition. Gupta and Verma (1986) reported results of profiles running to some 28 km southwards from the shelf edge in the vicinity of the Indian station Dakshin Gangotri. The observed low amplitudes and localized fluctuations superimposed on broad variations were treated separately by Gupta and Varma (1986). Analysis, using Hilbert transform and graphical methods yielded comparable results. The broad anomaly could be interpreted as being caused by an about 12 km thick body with its top at a depth of about 3.5 km and a polarization angle of 60°. The laying of magnetic profiles was continued during the Fourth Expedition. Figure 6, from Verma et al (1987-a) shows the location of magnetic profiles during the 2nd, 3rd and 4th Expeditions, while Figure 7 depicts the magnetic contours drawn at 50 nT interval. Verma et al (1987-a) applied a suite of interpretation techniques and supported Gupta and Varma's (1986) contention that the Indian Station, Dakshin Gangotri, on the shelf ice is located above a NEE-SSW trending rift zone (graben) as reported by Bentley (1983). Similar results are reported by Jain et al (1988).

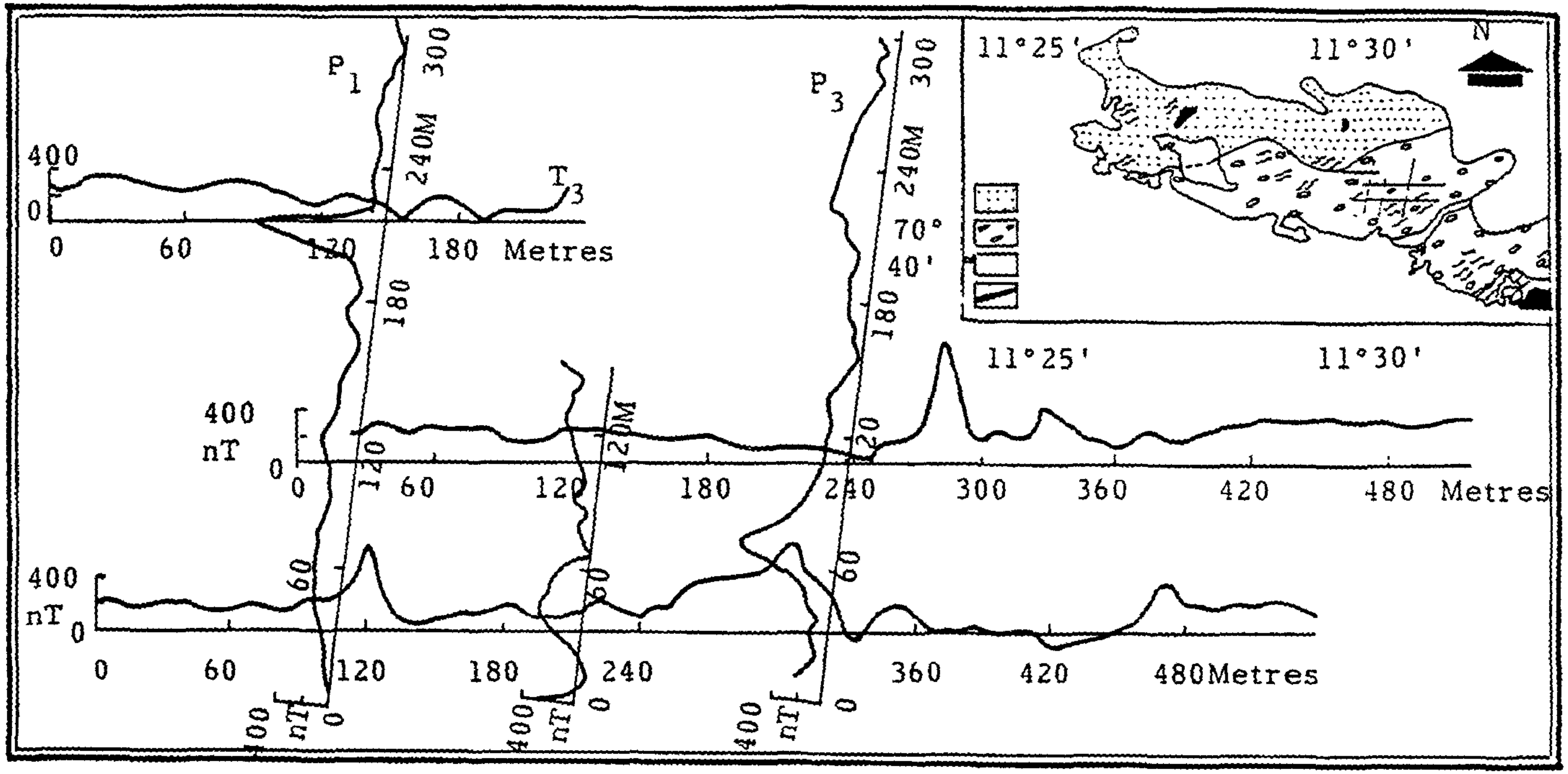

Fig. 4. Profiles showing magnetic response over augen gneiss in Schirmacher Hill region (from Gupts and Varma, 1986). Geological details are from Sengupta (1986).

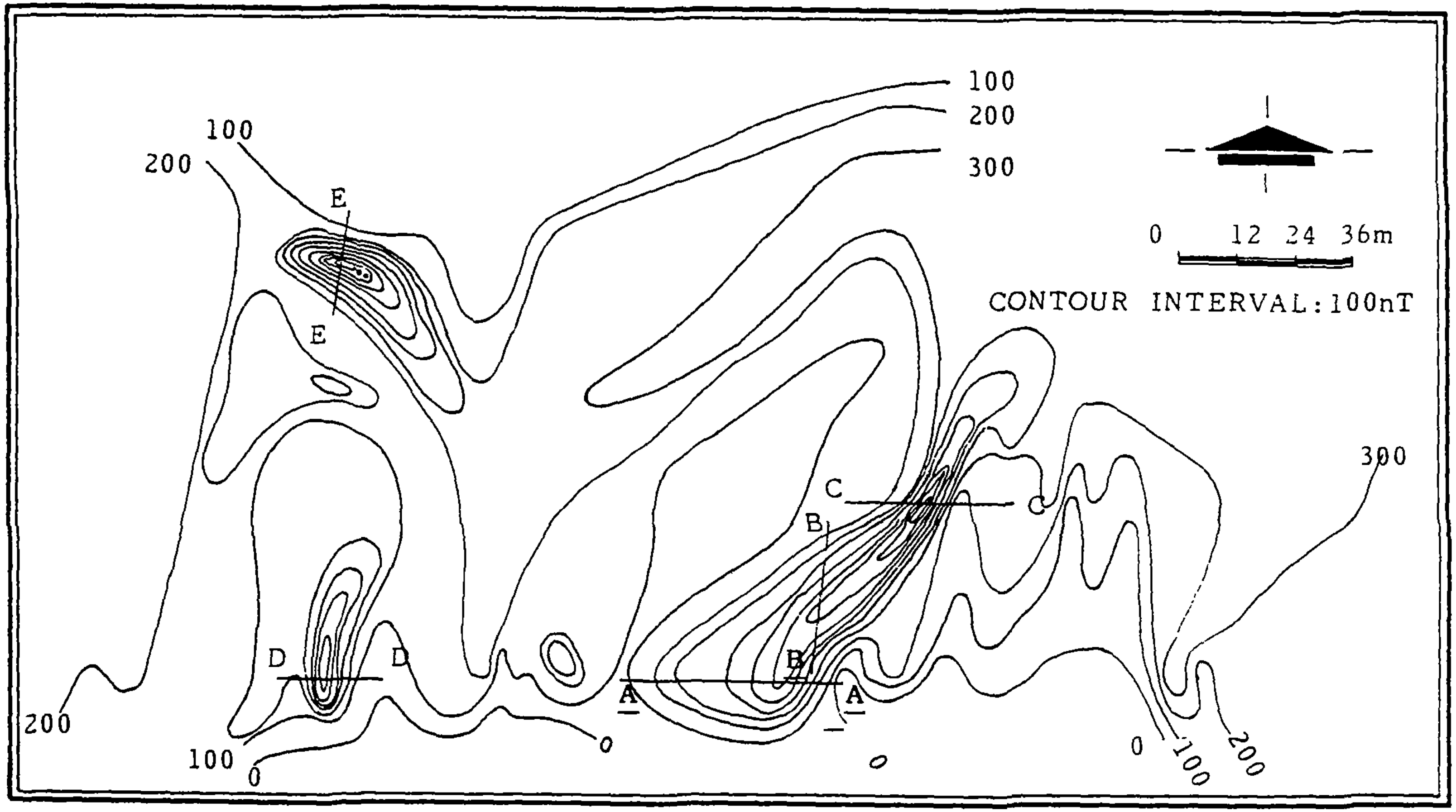

Fig. 5. Magnetic intensity contour map to demonstrate the influence of shallow intrusives on magnetic values over augen gneiss, Schirmacher Hill region (after Gupta and Varma, 1986). Profiles AA, BB, CC, DD and EE are considered tro quantitative interpretation.

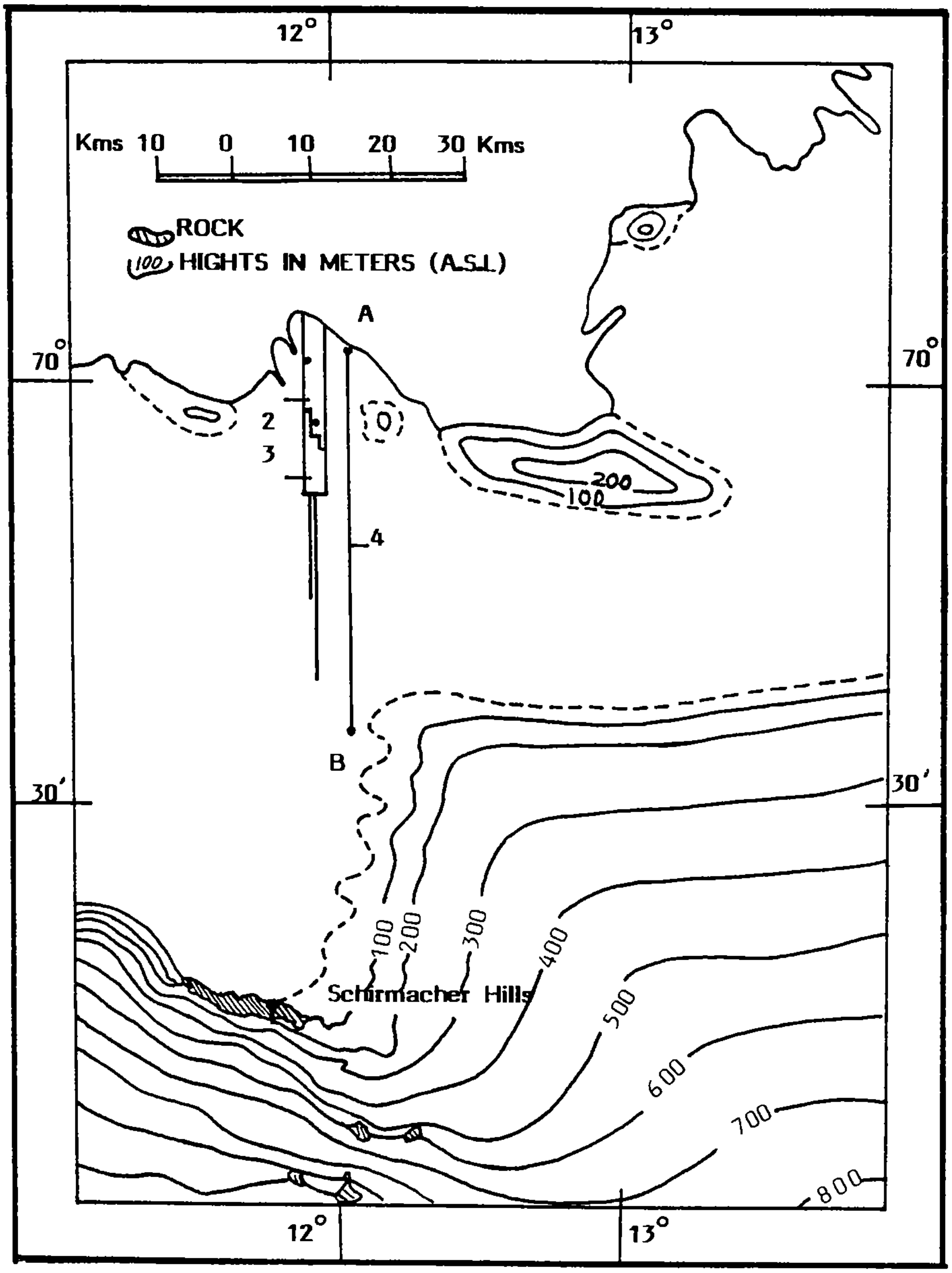

Fig. 6. Location of magnetic profiles over the shelf region during the 2nd, 3rd and 4th expeditions (from Verma et al 1987 a).

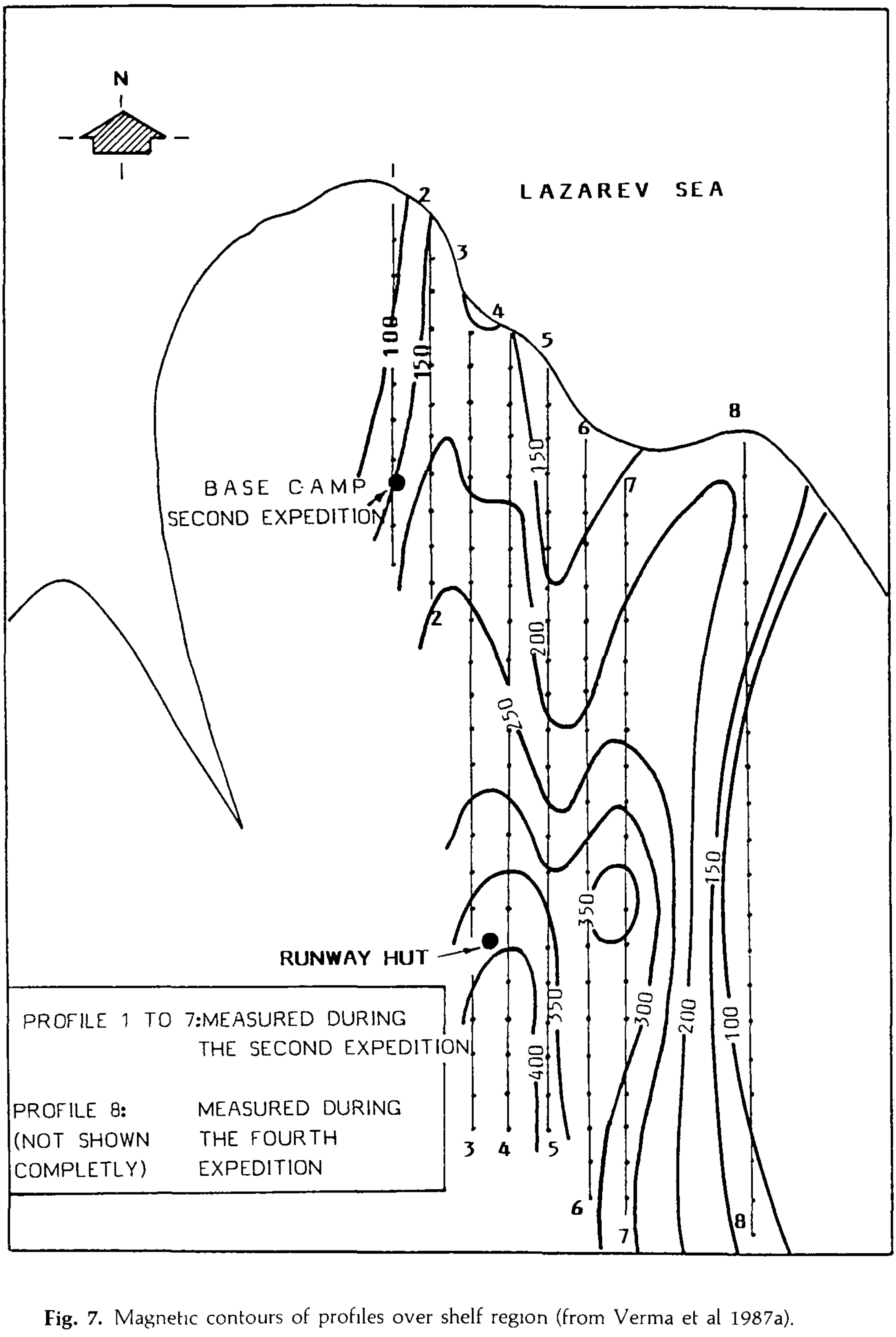

Fig. 7. Magnetic contours of profiles over shelf region (from Verma et al 1987a).

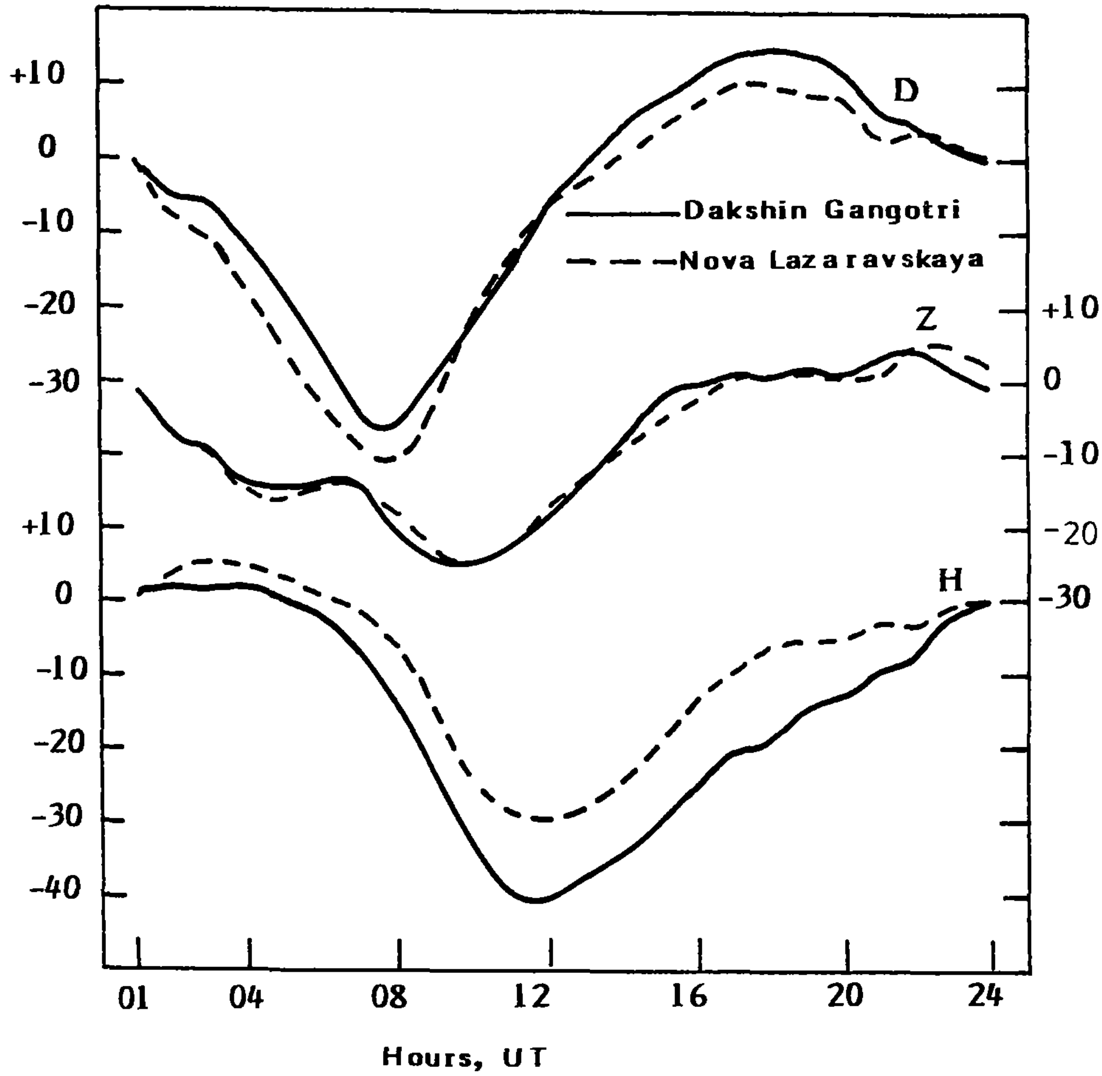

Fig. 8. Mean diurnal variation in H, Z, and D derived from records on quiet days at Dakshin gangotri and Novalazaravskaya (from Rangarajan and Dhar, 1988a).

During the Fifth Expedition a three component fluxgate magnetometer oriented to record magnetic field changes in the Horizontal (H), Vertical (Z) and Declination (D) components was set up (Rangarajan and Dhar, 1988-a). Figure 8 shows a record of the three components recorded at Dakshin Gangotri station as well as their comparison with the recording carried out at the nearby Soviet station, Nova Lazaravskaya (Rangarajan and Dhar, 1988-a).

Magnetic pulsation studies were also initiated during the Fifth Expedition. Rangarajan and Dhar (1988-b) point out that threr is a paucity of magnetic stations in Antarctica in the region of plasmapause and setting up of a station in Dakshin Gangotri fills up a vital gap and provides data from a subauroral latitude station. The data collected are subjected to the following analysis:

i) Power spectra
ii) 3-Dimentsional Polarisation Analysis

iii) Complex Demodulation Analysis for horizontal polarization and anomalous Z variation
iv) Single station transfer function computations for induction vectors at chosen frequencies

Rangarajan et al (1986) have made a case for setting up of a permanent station at Dakshin Gangotri, and this was achieved during the Sixth Expedition, when a permanent station was set up and geomagnetic observations were continued throughout the year (Indian Antarctic Research, 1987).

Exploratory seismic reflection surveys were carried out using SIE, 12 channel unit during the Fourth Expedition (Verma et al, 1987-b). The main purpose was to examine the capability of such surveys deploying SIE unit in delineation of sub-shelf structure including the thickness of the ice shelf, and to examine the suitability of gelatine-based explosives (SGC-80) in Antarctic environment. The area chosen for conducting seismic surveys is in the vicinity of Indian station and the profile was laid keeping in mind the results of magnetic surveys. Besides the up-hole geophone, typically the closest geophone was placed 100 m from the short point, and subsequent geophones were placed at intervals of 10 m each. Optimum gain for various geophones were set using a few test shots. The observed delay time at increasing geophone distances (Figure 9) was fitted with a variety of models and the one with the following

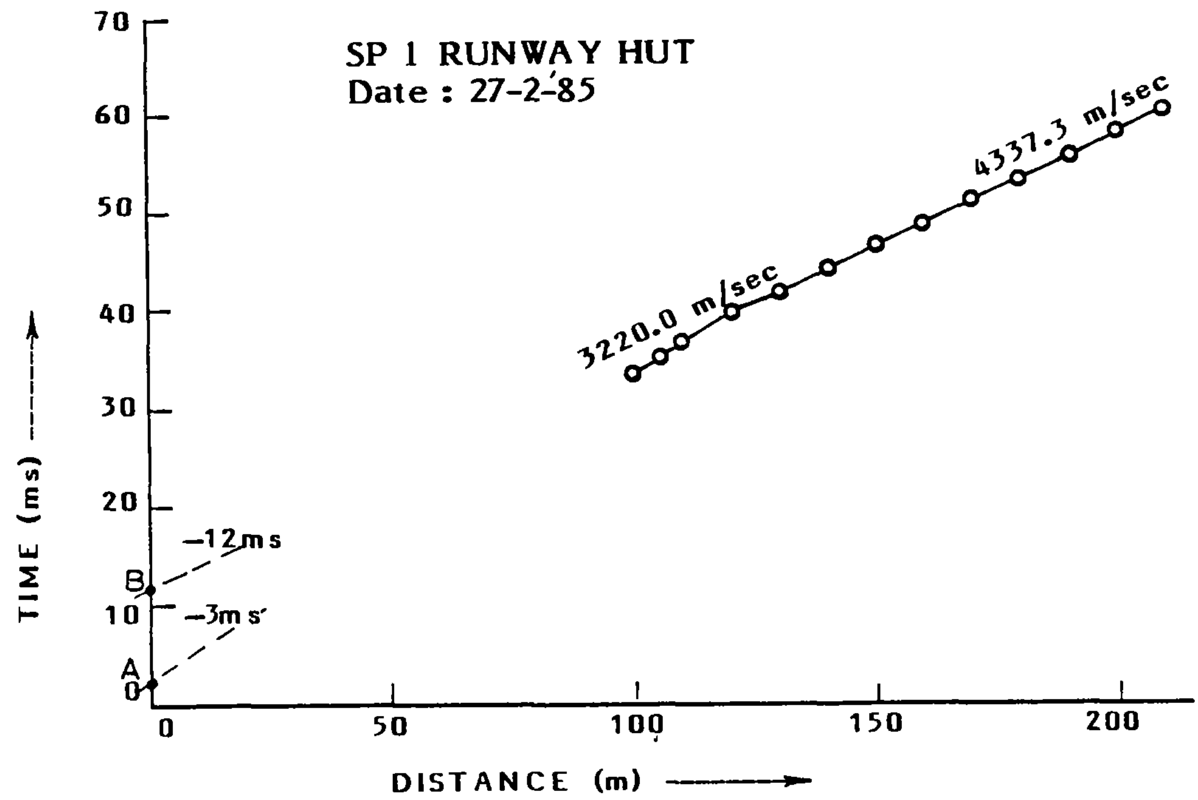

Fig. 9. Plot of delay time against geophone distance for seismic reflection survey on shelf ice (after Verma et al 1987b).

parameters gave the best fit:

Top porous ice layer	: 1m
Unconsolidated ice layer	: 19m
Consolidated ice layer	: 395m
Water layer	: 285m
(Depth to the besement	: 700m)

Figure 10 (Verma et al 1987-b) depicts the results of 1-D modelling. Since the first layer velocity of 3220 m/sec did not yield zero intercept time, a thin top layer consisting of porouis ice with a velocity of 1350 m/sec (density 0.35 gm/cc) had to be introduced.

Based on the results of magnetic and seismic surveys, Verma et al (1987-b) have developed a structural model shown in Figure 11, which provides a clue to the presence of water channels occurring at about 35 km south of the edge of shelf ice. According to them, the floating ice sheet is pivoted against the basement hill A in the south, while it is open to the sea in the north. Movements in body of sea water generates stress in the ice, further south of the hill, causing deep carcks. During summer melting occurs at these cracks causing water channels and lakes.

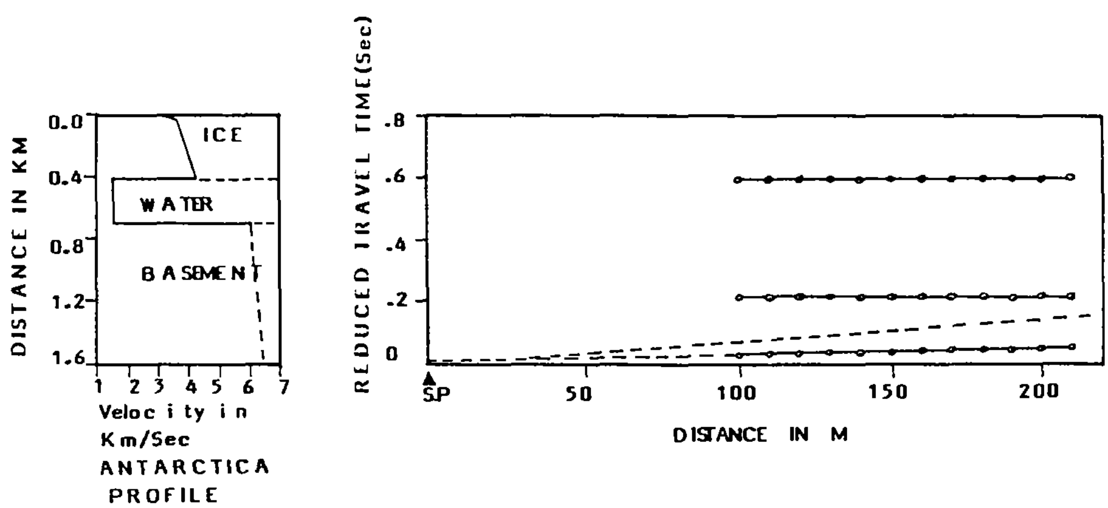

Fig. 10. Results of 1-D numerical modelling of the seismic reflection shown in figure 9 (after Verma et al 1987-b)

Electromagnetic and Electrical Measurements

Bhattacharya et al (1987) have reported results of transient electromagnetic (TEM), self potential (SP) and vertical electrical sounding (VES) surveys carried out at Schirmacher Hill (70°05's, 12°00'E) shelf ice. The main aim was to investigate the feasibility of these methods in Antarctic conditions and, obtains, if possible:

i) the thickness of ice shelf near the station
ii) the thickness of weathered zone in Schirmacher Hill, and
iii) investigate self-potential anomaly zone, if any, in the Schirmacher Hill region.

The field work carried out included SP traverses approximately perpendicular to the geological strike, at station intervals of 25 m over the Shirmacher Hills. The self potential

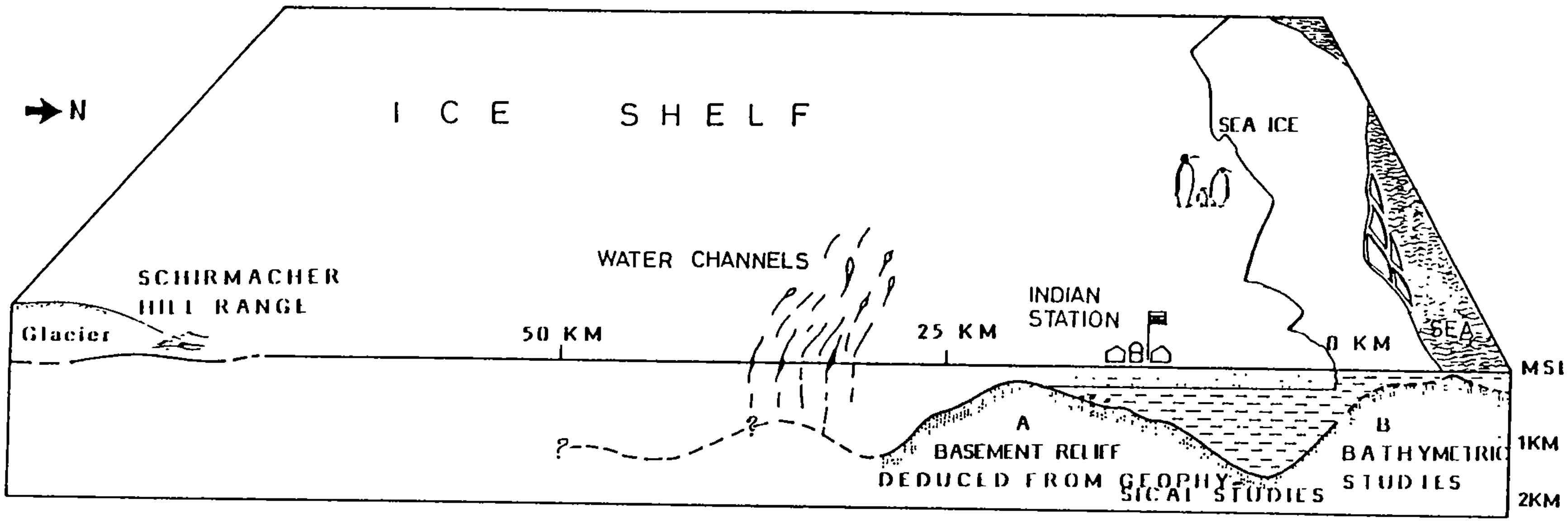

Fig. 11. Structural model derived around the Indian permanent station by Verma et al (1987b).

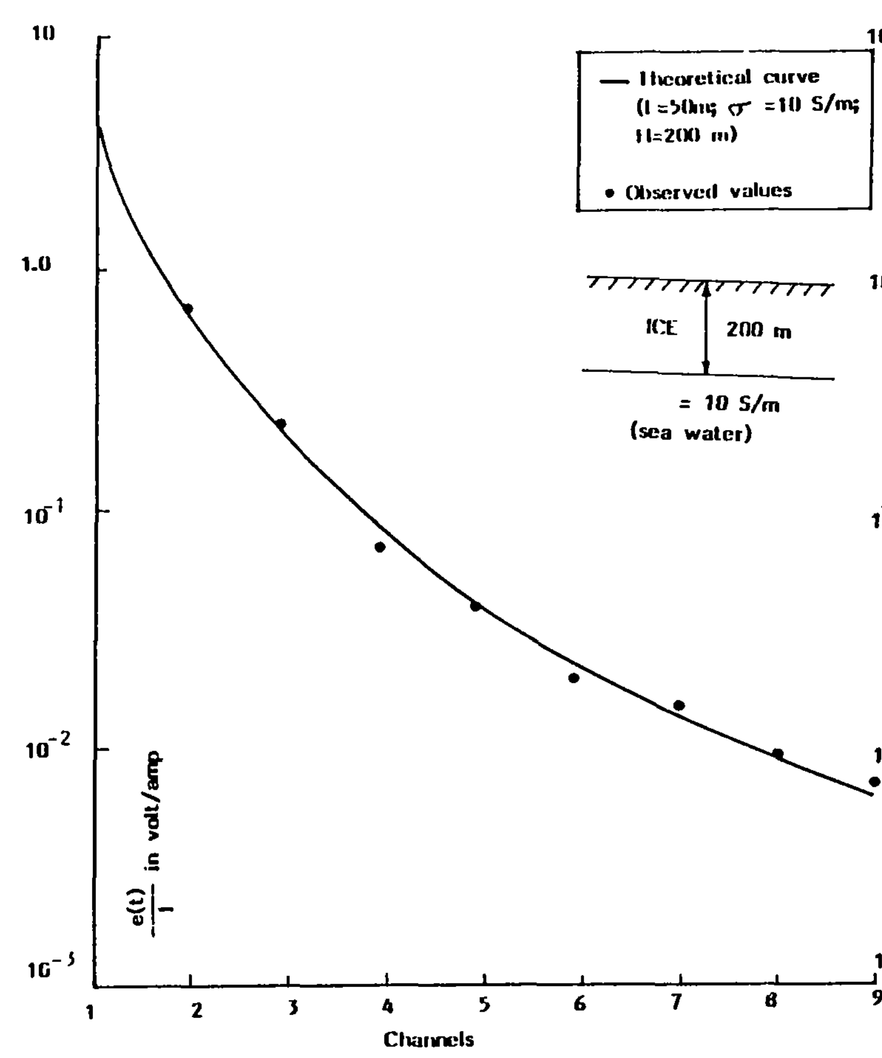

Fig. 12. Field observations and the theoretical model curves for TEM surveys over the shelf ice (after Bhattacharya et al., 1987).

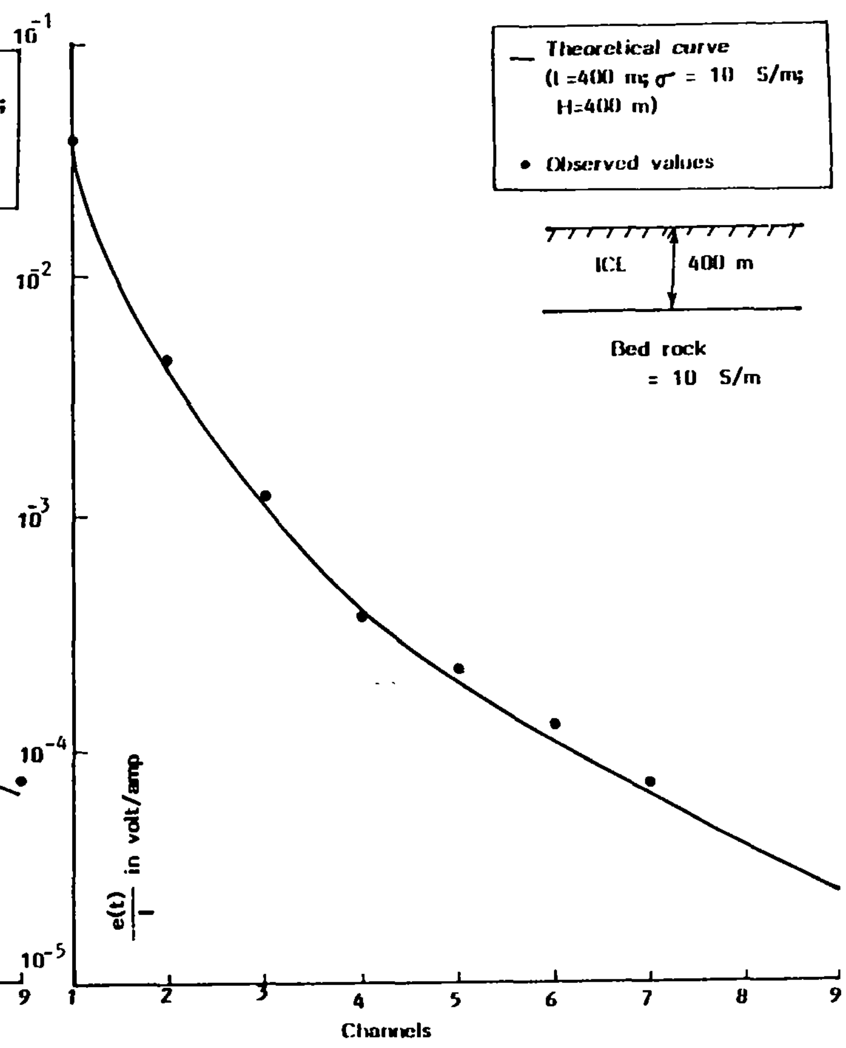

Fig. 13. Field observations and the theoretical model curves for TEM surveys on the ice cap covering the rocky surface, south of Schirmacher Hill (after Bhattacharya et al., 1987).

surveys were found to be devoid of any feature and showing local noise only. The TEM soundings carried over the Schirmacher Hill and the shelf ice provided reasonable estimates of the thickness of ice sheet on comparison with the theoretical curves (Figure 12 and 13). Bhattacharya et al (1987) conclude that the results obtained by them are consistent with those reported by Soviet team in the nearby Lazarev Coast (Atlas Antarktiki, Vol. 1, 1966).

In another interesting study Bhattacharya and Majumdar (1987) have correlated MAGSAT data collected over the Ross ice shelf with the available bedrock elevation data in the Ros ice shelf area and developed a model. This model has been used to generate bed rock elevations in Queen Maud land area from MAGSAT data. The results have good correspondance with the bed rock elevations available at a few locations in the Queen Maud region.

Radiometric and Geochronological Measurements

During the Fourth Expedition, radiometric surveys were carried out along a number of traverses on the Schirmacher Hill involving measurement of Potassium, Thorium, Uranium and total counts. No significant anomalies were found. However, high Potassium counts were recorded over feldspathic gneisses compared to hornblende/biotite gneisses (Verma et al 1987-c).

Geochronological studies were conducted on rock samsples collected from crystalline basement and dolerite dykes of Schirmacher Hill region. The K-Ar ages from crystalline basement ranges from 400-600 m.yr. while the dolerite dykes are dated from 97 to 180 m.yr. (Verma et al 1987-d). The age and composition of the dolerite dykes from Schirmacher Hill (Queen Maud land) is found to be similar to those reported for Karoo dolerites of Limpopo region in Africa supporting the hypothesis that some 170 m.yr. ago the Queen Maud land region was juxtaposed to Mozambique region of Africa (Verma and Mittal, 1988).

Helicopter Borne Surveys

For the first time, during the summer of 1987-88, helicopter borne magnetic surveys were conducted by the National Geophysical Research Institute team participating in the Seventh Antarctic Expedition. The surveys were carried out between the Schirmacher Hill and Wohlthat Mountains (Figure 14) using a Geometrics G-866 proton precession magnetometer for measuring total magnetic intensity. Decca Doppler 71 Tactical Air Navigation system was used for getting precise locations. In all, 4000 line km of magnetic data were collected along 400 profiles covering a total area of 10,000 sq.km. The analysis of data is in progress.

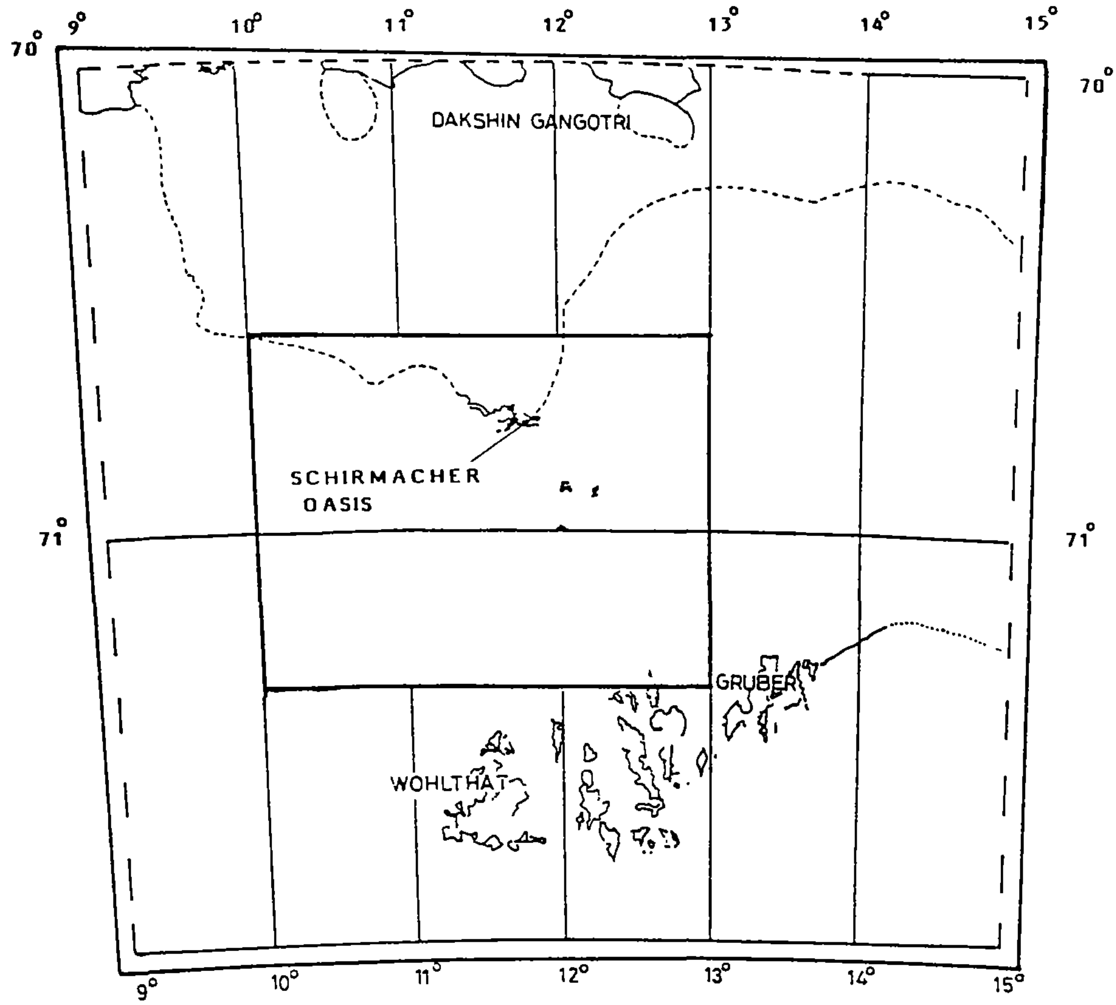

Fig. 14. Helicopter borne magnetic surveys between Schirmacher Hills and Wohlthat Mountains. The 12,000 sq.km area covered by 48 profiles flown over 4000 line km is shown by rectangle (from Workshop on Antarctic Studies, 1988).

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Oceanography of Maxwell Bay, the King George Island: Short-Term Variation of Chemical Property of Water and the Sedimentation of Particulate Matter in the Glacially-fed Antarctic Coastal Waters

Gi Hoon Hong

Abstract

Variation of chemical property of water (temperature, salinity, dissolved oxygen, nitrate, nitrite, phosphate, silicate, and *in vivo* fluorescence) was monitored through a 24-hour time series sampling in the shallow marine inlet (about 100m deep) of Marian Cove, Maxwell Bay, the King George Island during austral summer (February 1988). In the upper layer, time variation of nutrients and *in vivo* chlorophyll concentrations was largely attributable to the change of wind speed, which probably resulted in the low standing crop of phytoplankton since the upper water column was weakly stratified. Time variation of the chemical property in the deeper layer seemed to be influenced by tide.

Sedimentation of particulate matter was also studied through collection of particles in rapid transit and those suspended in the water column and those lie in the basin floor. The concentration of biogenic matter (POC, PN, and biogenic Si) in the settling particulates suggests that there was a significant non-biogenic material input from the adjacent land. Bulk sedimentation rate was relatively high (23gm^{-2} d^{-1}) compared to the oceanic waters of the Antartic. Vertical fluexs of POC, PN, and biogenic Si were 0.28g Cm^{-2} d^{-1}, 0.08 N m^{-2} d^{-1} and 0.41 g Si m^{-2} d^{-1}, respectively. Particulate Fe and Mn vertical fluxes were 1.40 g Fe m^{-2} d^{-1} and 0.03g Mn m^{-2} d^{-1}, respectively.

Introduction

Marine particulate matter is of considerable geochemical significance. It acts as a carrier phase for the transport of chemical elements from the surface waters of the ocean to the bottom sediments. It is also a site of heterogenous chemical reactions. Its composition and concentrations reflect dynamic water column processes such as primary production in surface waters, dissolution and degradation at depth, and vertical and lateral particle transport. Thus it is important to understand the sources and physical processes that control the distribution of this material. The most important source of marine particulate matter is *in situ* biological production, primarily by phytoplankton. In the nutrient rich antarctic waters, seasonal changes of solar radiation and stability of water in the upper layer are the major environmental factors governing the variability of phytoplankton productivity. During austral spring and summer, water column is weakly stable because melting ice can only provide buoyancy (Iwanami *et al.*, 1986). A combined effort of water column sampling, sediment trap experiments and sediment core collection has allowed us to begin to characterize the complex water column and seafloor processes which govern sedimentation on the antarctic continental shelf (Schnack, 1985; Harada *et al.*, 1986). However, little is known about the water column and particulate matter sedimentation processes in the glaciomarine inlet of Maxwell Bay, the Antarctic.

The purpose of this study is to investigate the short-term variation of chemical property glacially-fed marine inlet during the austral summer (Feburary 1988). A 24 hour time series observations was made at a single station in order to describe the short-term variation of water column chemistry. We plan to continue our studies to elucidate the relationship between those particles in rapid vertical transit and those suspended in the water column and those lie in the basin floor.

Materials and Methods

Marian Cove is located in Maxwell Bay of the King George Island of the Antarctic (62°13′15″S, 58°45′10″ W; Fig. 1). The cove is fed by tide-water glaciers. Some 95% of the surface area was covered by the permanent ice. Marian Cove is freeze up partially for the austral winter. Atmospheric pressure, temperature and winds are highly variable during summer and fall. From January to April, 1988, atmospheric temperature varied from −7.8°C to 9°C with average 10°C. Daily average wind speed was 3-10 m s^{-1}, and atmospheric pressure was low. The climate and geology of the King George Island is available in detail in KORDI (1988). The waters in Marian Cove is a part of the Maxwell Bay, which is in turn well communicated with the Bransfield Strait waters (Mullins and Priddle, 1987).

Water samples were collected using Van Dorn water sampling bottles at the depths of 0, 10, Feburay 18-19, 1988. Water temperature was measured using a reversing thermometers. An inductively coupled salinometer (Model 601 MKIV) was used for determinations of salinity. Dissolved oxygen was determined using a modified Winkler method (Carpenter, 1965). For suspended sediment concentration, a parcel of water was filtered immediately with pre-weighed glass fiber filter (Whatman GF/F). The filters and filtrates were frozen immediately for later analysis for organic matter and nutrient concentrations, respectively. Nutrients were analyzed using an Autoanlyzer (Technicon AA II) followed by the methods of Parsons *et al.* (1984). *In vivo* fluorescence was also measured with Tuner Design field fluorometer (Model 10-005R). Three pairs of sediment traps consisting of 15×75cm Plexiglass cylinders were positioned at 10, 50, 70m depth at Station 2 (Fig. 1) to collect settling particulates during 14-22 February 1988. A short sediment core was also obtained using a Phleger corer at Station 1. Trap and core materials were freeze-dried prior to analysis. Particulate organic carbon and nitrogen were determined using a CHN analyzer (Perkin Elmer 240C). Particulate biogenic silica content was determined by DeMaster's method (1981).

Results

Hydrograph and dissolved oxygen

A time series distribution of water temperature is shown in Fig. 2. In general, tempearture was higher in the surface (0.90-1.30°C) than in the bottom waters (0.4—0.5°C). Vertical

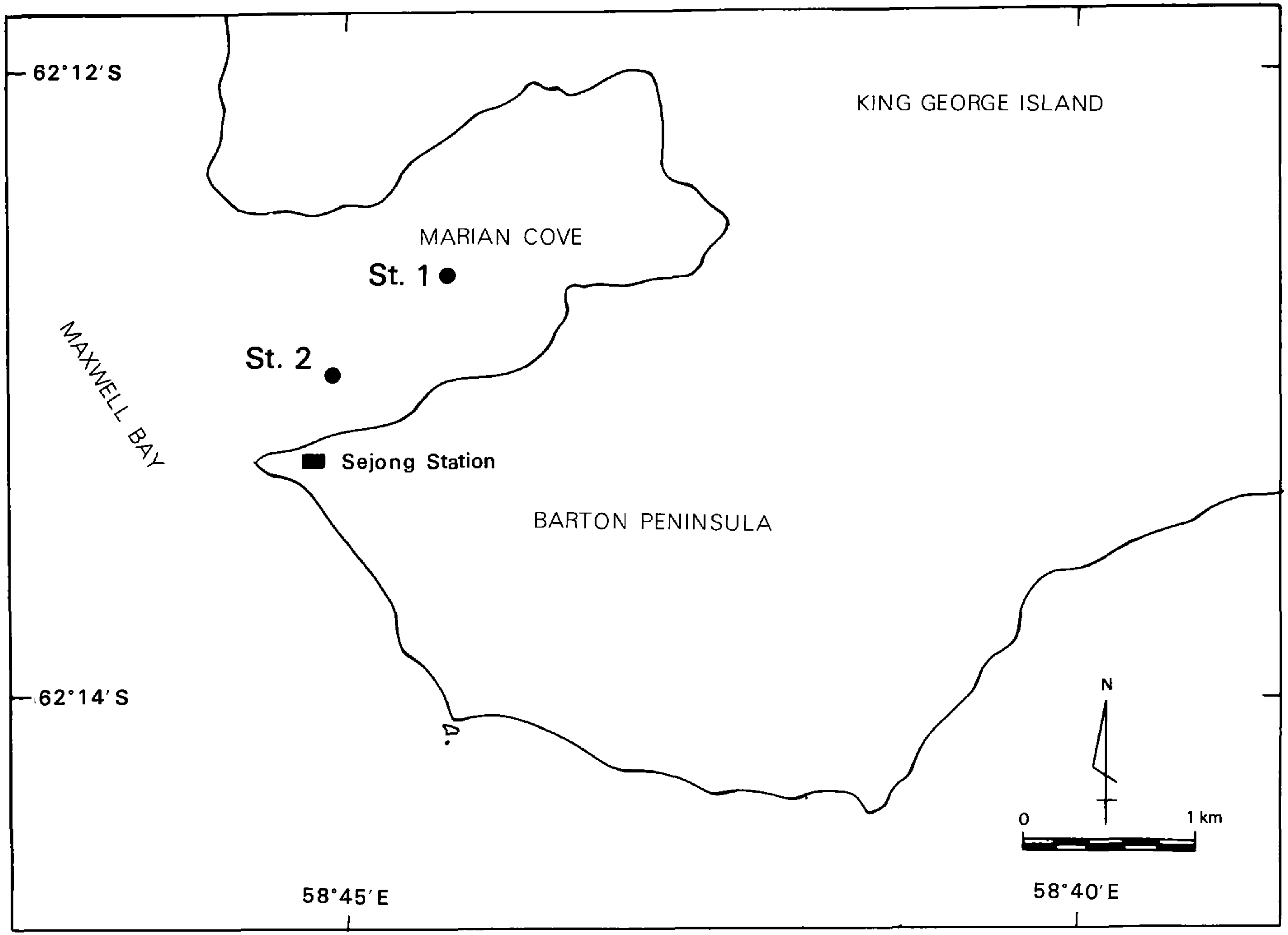

Fig. 1. Marian Cove, Maxwell Bay, the King George Island; Location of oceanographic stations

Table 1. Time series distribution of salinity (°/₀₀ in Marian Cove (St.1).

Time	Feburary 18				Feburary 19		
Depth	10:00	14:00	18:00	22:00	02:00	06:00	10:00
0m	34.15	33.59	33.62	34.59	33.63	33.59	33.41
50m	34.14	34.13	34.13	34.13	34.13	34.15	34.13
100m	34.21	34.16	34.65	34.07	34.15	34.16	33.62

temperature gradient was steepest between 50-75 m depth. Salinity was lower in the surface (33.63°/₀₀) than in the bottom waters (34.21°/₀₀; Table 1). The densities of waters (σt) were 26.98, 27.39, and 27.48 in 0, 50, and 100m depths, respectively. Time variations of temperature and salinity were not clearly seen in the upper 50m waters due to the paucity of measurements. In the waters below 50 m, however, it was noted some time variation of temperature possiblely due to tide (Fig. 2).

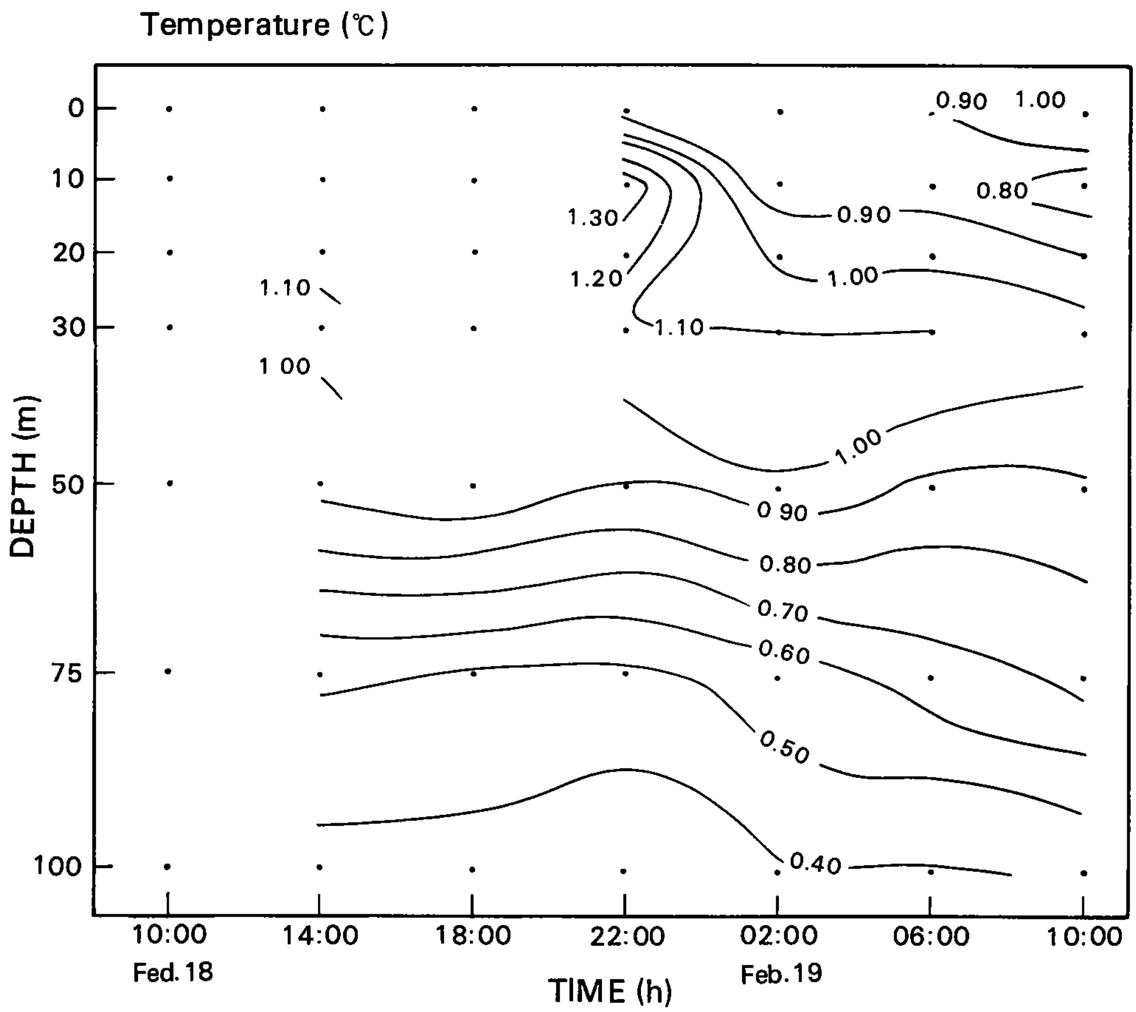

Fig. 2. Time series distribution of temperature (°C) in Marian Cove (St.1).

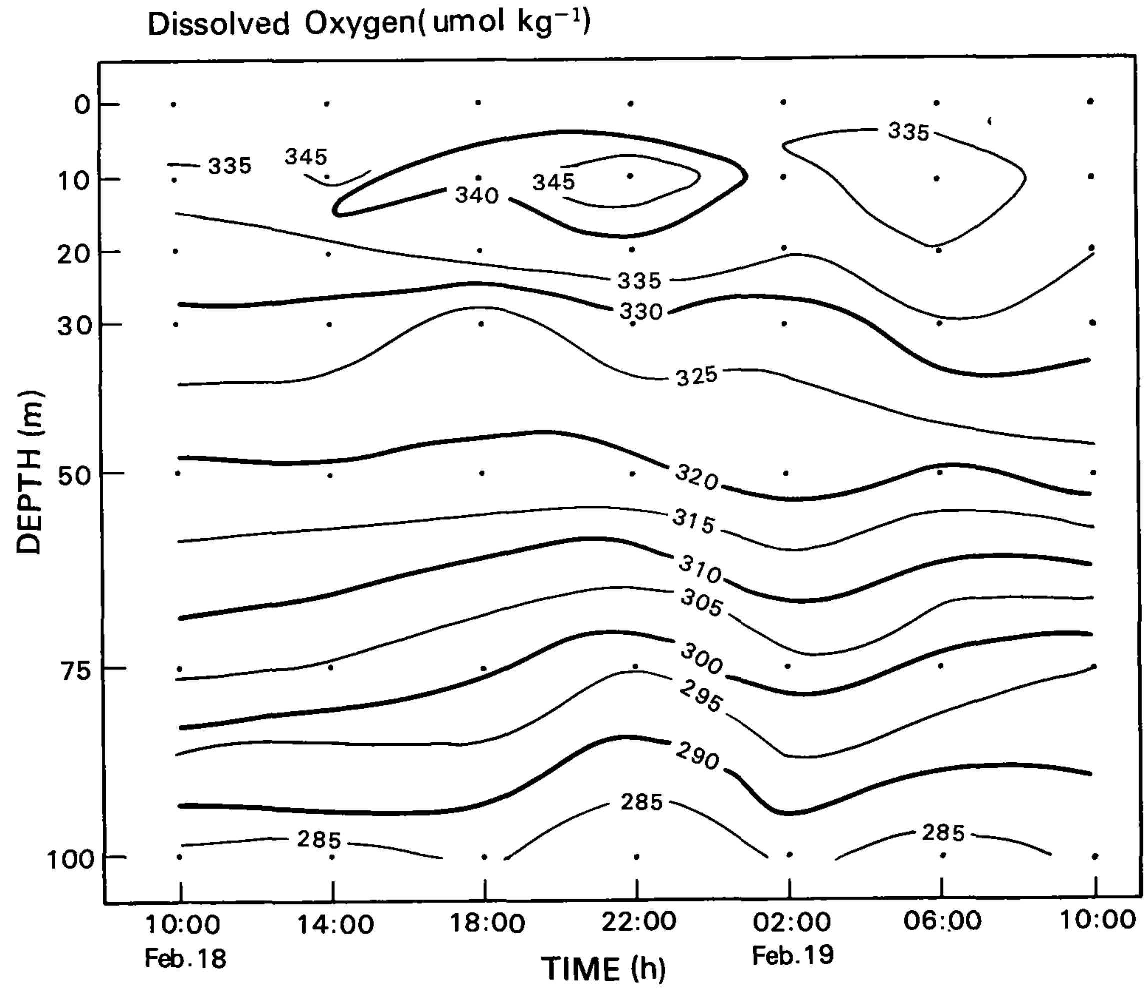

Fig. 3. Time series distribution of dissolved oxygen (μmol kg^{-1}) in Marian Cove (St.1).

A time series distribution of dissolved oxygen concentrations is shown in Fig. 3. Dissolved oxygen contents monotonously decreased from the surface (ca. 340 μmol kg^{-1}) to the bottom waters (ca. 285 μmol kg^{-1}). A time variation of dissolved oxygen contents with tide may be noticeable in the bottom waters.

Suspended particulate matter

Vertical distribution of suspended particulate matter (SPM) shows a three-layered structure (Fig. 4): high concentrations in the surface and bottom layers (3-6 mg l^{-1}) and low concentrations in the middle layer (2mg l^{-1}). In the surface waters, concentration maximum was found in 22:00h of February 18, 1988.

Only one set of samples obtained in 18:00h of February 18 were subjected to elemental analysis (Table 2). Particulate organic carbon (POC) concentrations varied from 79 to 150 μg l^{-1} with higher in the surface waters and lower in the bottom waters. Particulate nitrogen (PN) concentrations varied from 17 to 35 μg l^{-1}, and particulate biogenic Si concentrations varied from 21 to 36 μg l^{-1}. Mole ratios of C/N were from 5.2 to 7.6, which were nearly identical to the C/N ratios of the marine phytoplanktons (Redfield *et al.*, 1963).

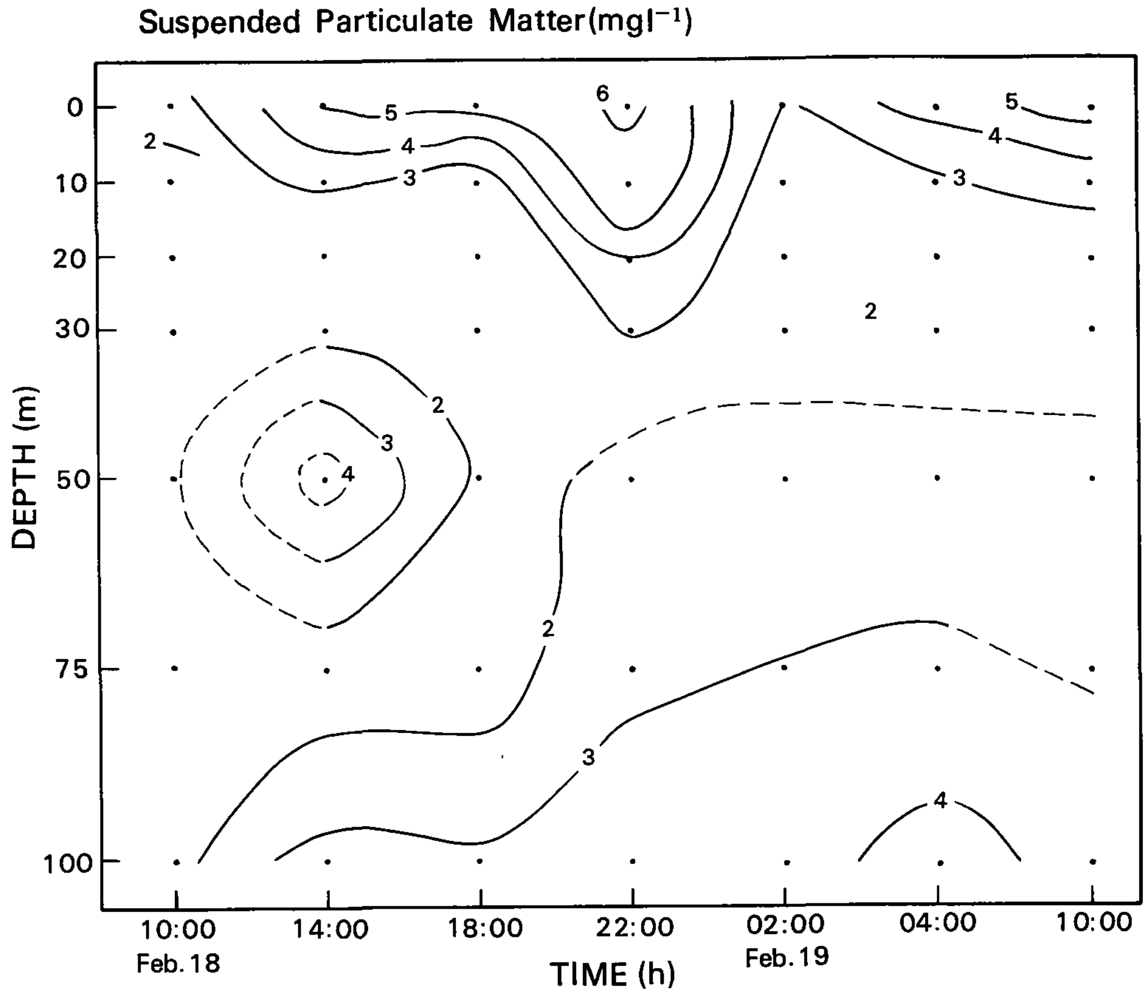

Fig. 4. Time series distribution of SPM (mg l^{-1}) in Marian Cove (St.1).

Table 2. Chemistry of suspended particulate matter

Depth (m)	Composition ($\mu g\ l^{-1}$) POC	PN	Biogenic Si	C/N
0	127.5	19.5	23.76	7.6
10	148.0	33.0	24.77	5.2
20	127.0	29.5	30.89	5.0
30	100.0	22.5	24.77	5.2
50	172.5	34.0	21.23	5.9
75	105.5	18.0	36.01	6.8
100	78.5	16.5	29.66	5.6

Nutrients

Twenty four hour time series distributions of reactive phosphate, nitrate, nitrite and reactive silicate were shown in Figs. 5, 6, 7, and 8, respectively. These nutrient concentrations in-

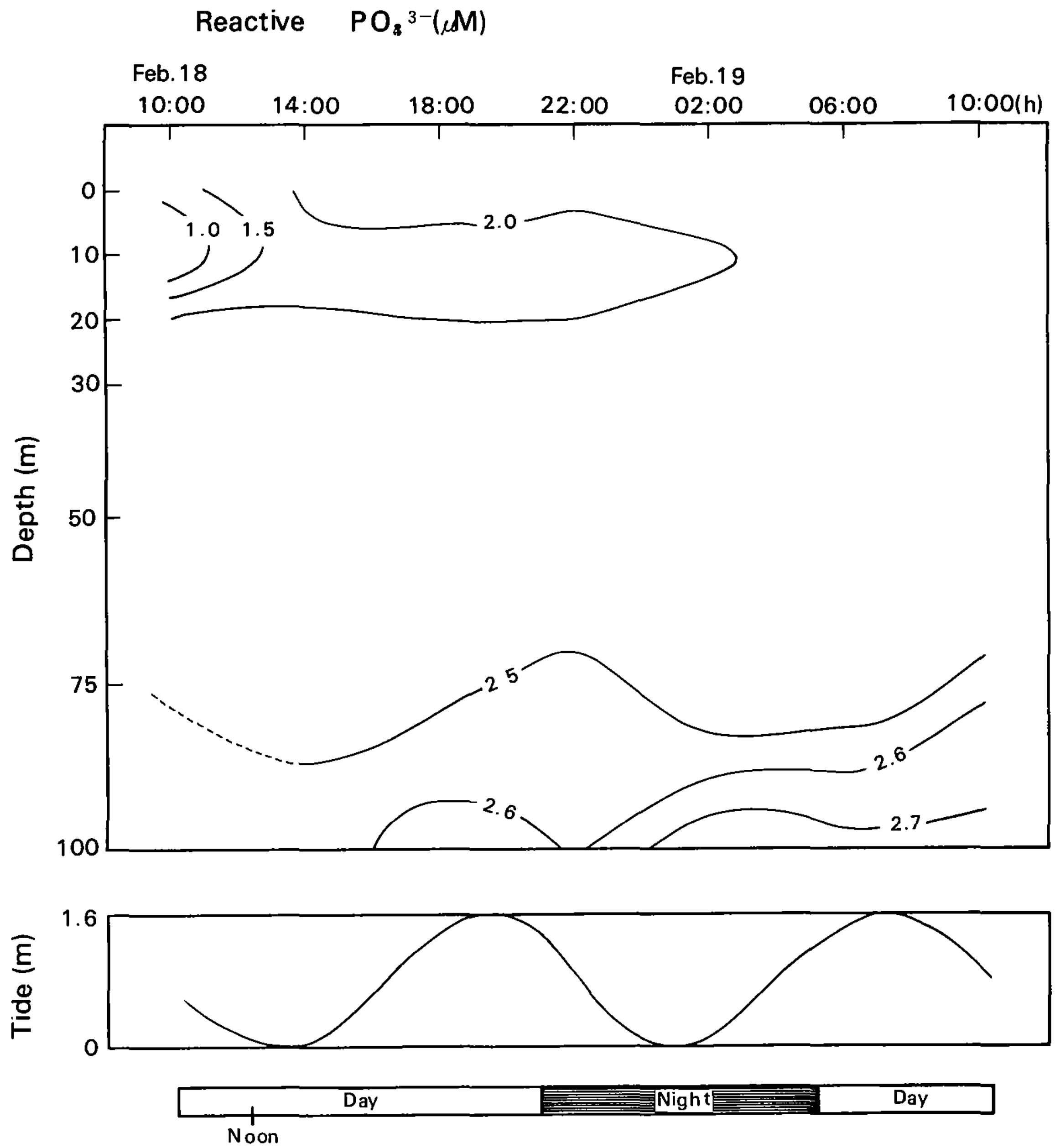

Fig. 5. Time series distribution of reactive phosphate (μmol l^{-1}) along with tide curve and daylight hours in Marian Cove (St.1).

creased monotonously with depth except a subsurface minimum (10 m depth). These minimum values were found in 10:00 h of February 18. In the bottom waters, the time series distributions of nutrients seem to be influenced by the tidal action. Reactive phosphate concentrations varied from 2.1 (0m depth) and 1.9 (10m depth) to 2.7 (100m depth) μmol l^{-1}. Nitrate concentrations varied from 20-22 (0m depth) and 19 (10m depth) to 24 (100m depth) μmol l^{-1}. Nitrite concentrations varied from 0.2 to 0.6 μmol l^{-1}. Reactive silicate concentrations varied from less than 60 to 80 μmol l^{-1}.

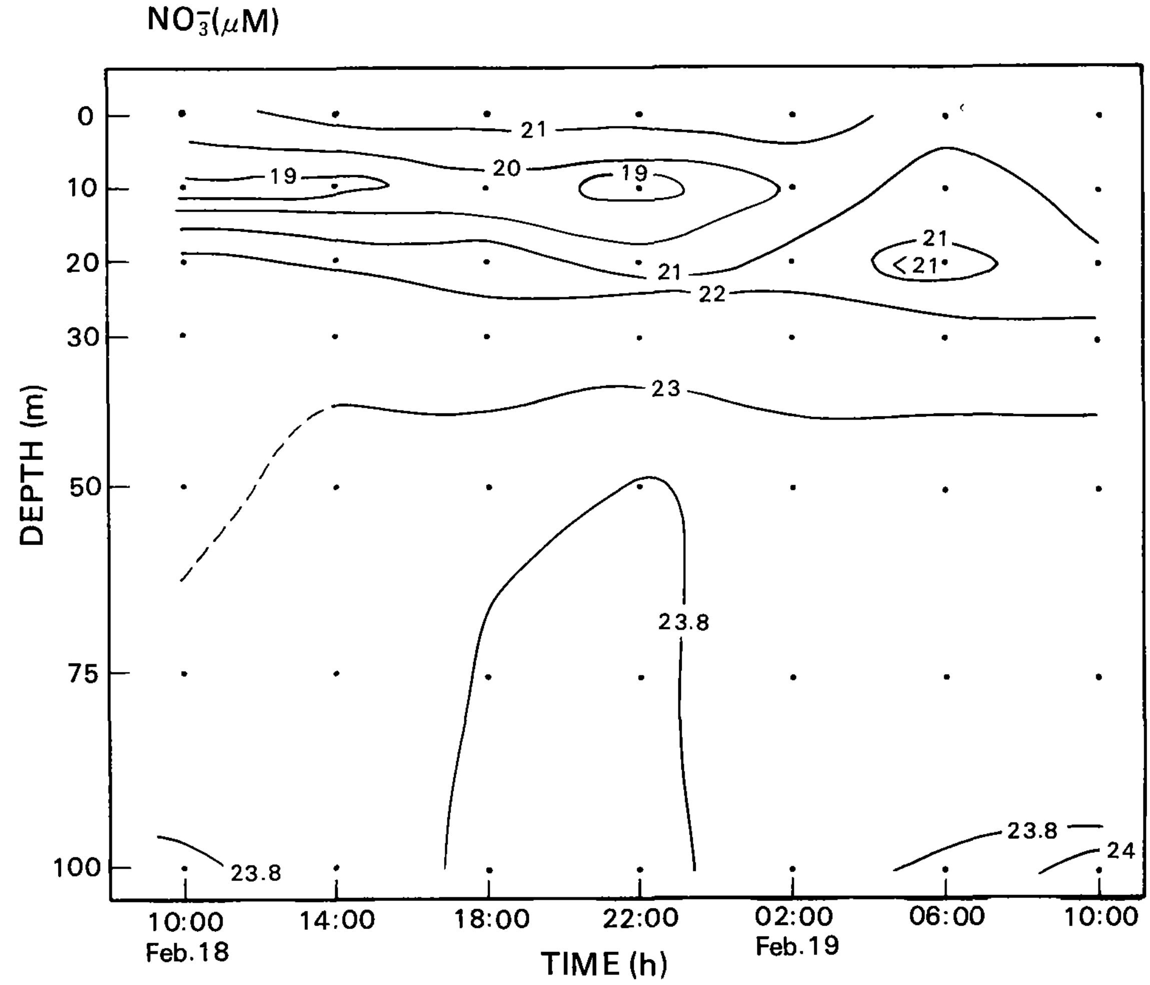

Fig. 6. Time series distribution of nitrate (μmol l^{-1}) in Marian Cove (St.1).

In Vivo Fluorescence

A time series of *in vivo* fluorescence concentrations is shown in Fig. 9 in arbitrary scale due to the limited number of samples available for calibration. Contrary to the distribution patterns observed in the nutrient concentrations, chlorophyll concentrations decreased with depth with subsurface maximum, and the maximum values were found in 10:00 h of February 18. Chlorophyll concentrations were 4-5 in 0 m depth and 8 in 10 m depth, and less than 4 in the near bottom waters in arbitrary scale. This arbitrary scale was calibrated to the chlorophyll *a* (aceton extracts; Parsons *et al.*, 1984) later in the laboratory (Seoul, Korea) using a limited number of frozen samples: Chlorophyll *a* (μg l^{-1}) = 0.8 (*in vivo* fluorescence, arbitrary scale) − 2.79, r = 0.99. The calculated chlorophyll *a* concentrations were 1-2 μg l^{-1} in Marian Cove.

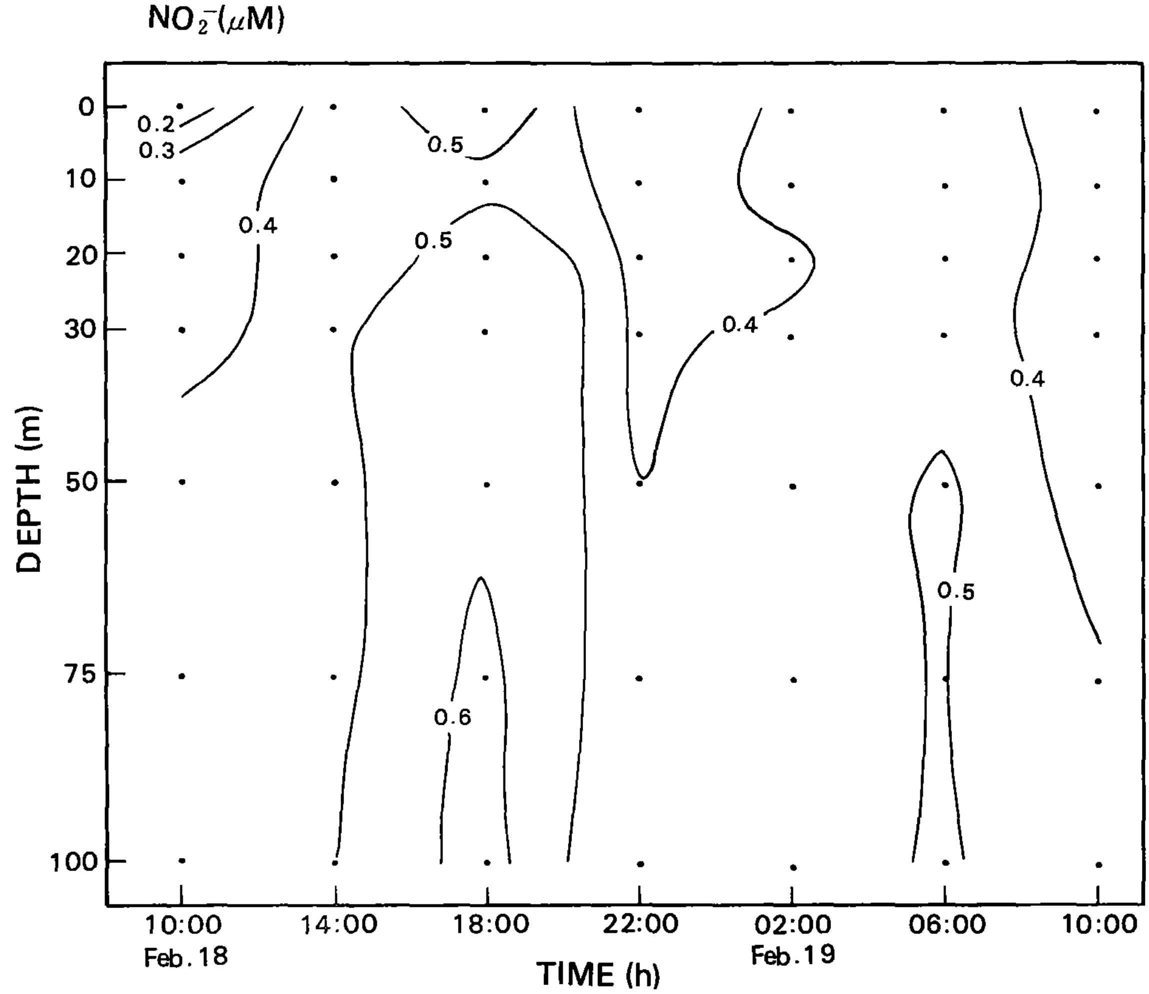

Fig. 7. Time series distribution of nitrite (μmol l^{-1}) in Marian Cove (St.1).

Settling and bottom sediments

Settling particulates collected in sediment traps were subjected to the elemental analysis (Table 3). Due to the retrieving failure, duplicate samples were not obtained. The depth average vertical flux of bulk sediments was 22.76±8.68 g m^{-2} d^{-1}. Even though a large uncertainty is involved, it is still instructive to calculate the annual sedimentation in the bottom from these data. The estimated annual sedimentation rate is 3.3±1.0 mm yr^{-1} assuming sediment density of 2.5 g cm^{-3}. The average POC, PN, and biogenic Si contents in the settling particulates were 1.22, 0.42, and 1.33%, respectively. The average Fe and Mn concentrations were 6.2% and 0.125% respectively. The average settling fluxes of POC, PN and biogenic Si were 0.28, 0.08, 0.31 g m^{-2} d^{-1}, respectively. The average particulate Fe and Mn fluxes were 1.40 and 0.03 g m^{-2} d^{-1}, respectively.

Bottom sediment compositions were also determined (Table 4). Sediment organic carbon and nitrogen varied from 0.29 to 0.35%, and 0.10 to 0.49%, respectively. Biogenic si content was from 0.26 to 0.53%. Fe and Mn were 5.1-5.7% and 0.0843-0.1014%, respectively.

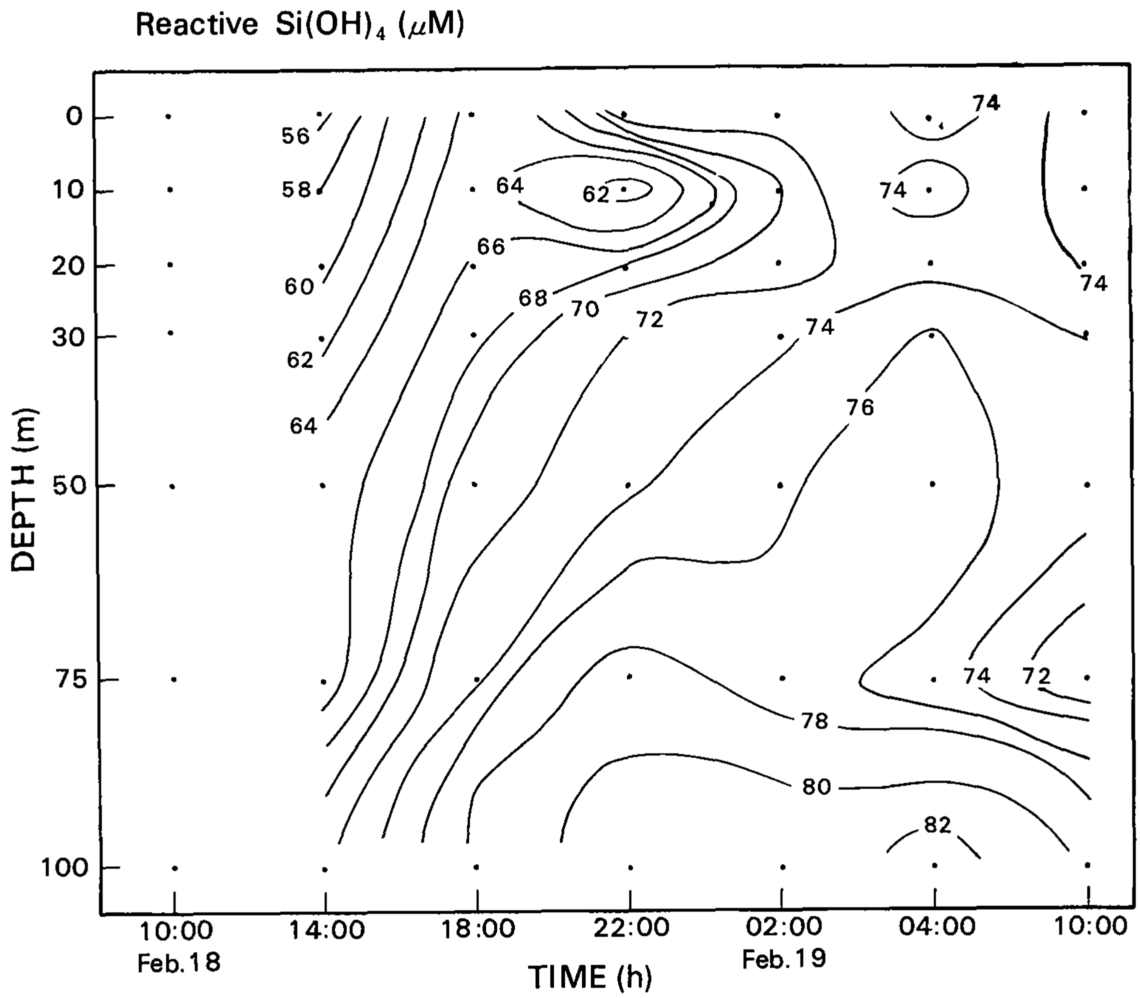

Fig. 8. Time series distribution of reactive silicate (μmol l^{-1}) in Marian Cove (St.1).

Table 3. Chemistry of settling particulates

Depth (m)	Composition (%) POC	PN	BSi	Fe	Mn	Flux ($g\ m^{-2}\ d^{-1}$) Total	POC	PN	BSi	Fe	Mn
10	1.20	0.67	—	6.2	0.125	21.38	0.26	0.14	—	1.33	0.027
50	1.11	0.16	1.30	6.1	0.125	32.05	0.36	0.05	0.42	1.96	0.040
70	1.36	0.42	1.36	6.2	0.125	14.85	0.21	0.06	0.20	1.40	0.019

* Note: BSi stands for the biogenic Si

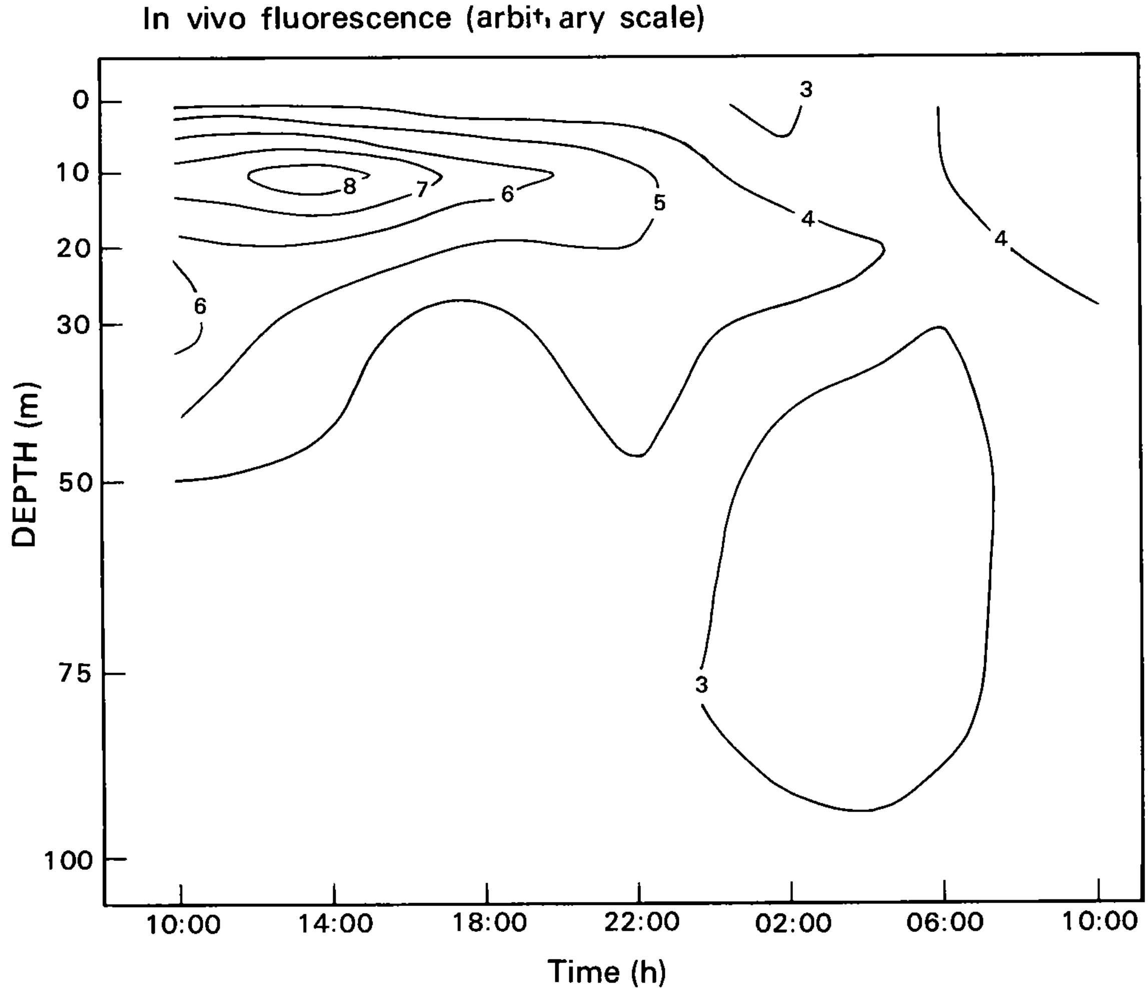

Fig. 9. Time series distribution of in vivo fluorescence (μmol l^{-1}) in Marian Cove (St.1).

Table 4. Sediment chemistry

Depth (cm)	POC (%)	PN (%)	Biogenic Si (%)	Fe (%)	Mn (%)
0 — 3	0.35	0.49	0.37	5.6	0.0943
3 — 6	0.34	0.19	0.37	5.1	0.0843
6 — 9	0.29	0.10	0.35	5.6	0.0886
9 — 12	0.31	0.19	0.26	5.6	0.0900
12 — 15	0.41	0.29	0.53	5.7	0.1142
15 — 18	0.41	0.10	0.40	5.5	0.0914
18 — 21	0.21	0.10	0.36	5.5	0.1014

Discussion

Short-term variation of water column property

Distributions of temperature and salinity show that the entire water column is weakly stratified (Fig. 2 and Table 1). The bottom waters is similar to the Bransfield Strait waters, which is originated from the Weddell Sea (Mullins and Priddle, 1987). In the adjacent Admiralty Bay, similar water circulation pattern was observed (Rakusa-Suszczewski, 1980). The presence of low salinity waters may be originated from the melting of sea ice (Iwanami *et al.*, 1986) iceberg and meltwater runoff from the adjacent lands (Syvıtski *et al.*, 1986). This low salinity water may help to stabilize the water column, since salinity contribution to density is much higher than temperature in the cold waters. However, during the study period, weather conditions were highly variable (Fig. 10). Atmospheric pressure had been increased continuously from 10:00 h of February 18 to the end of the sampling period. Though Beaufort Number had been remained about 1-2 (wind speed <3.3 m s^{-1}) in February 18, it increased above 3 (wind speed >5 m s^{-1}) with accompanying drizzle after mid-night of Februrary 18. Change of weather conditions are well correlated to the disappearance of the nutrient subsurface minimum passed midnight of February 18 (Figs.5-8). These are also coincided to the disappearance of the chlorophyll subsurface maximum (Fig. 9) and the decrease of the depth integrated phytoplankton cell numbers with time (KORDI, 1988). The daily observations of wind speed at King Sejong Station in the adjacent land shows that the portions of the daily wind speed higher than 5 m s^{-1} were about 50, 65, 87, and 84 % in January, Februrary, March and April 1988, respectively (KORDI, 1988). The time variations of nutrients (Figs. 5-8) and chlorophyll (Fig. 9) indicate the water column instability may result in the low standing crop of phytoplankton (about 1-50 × 10^3 cells l^{-1}; KORDI, 1988), since the comparatively low ver-

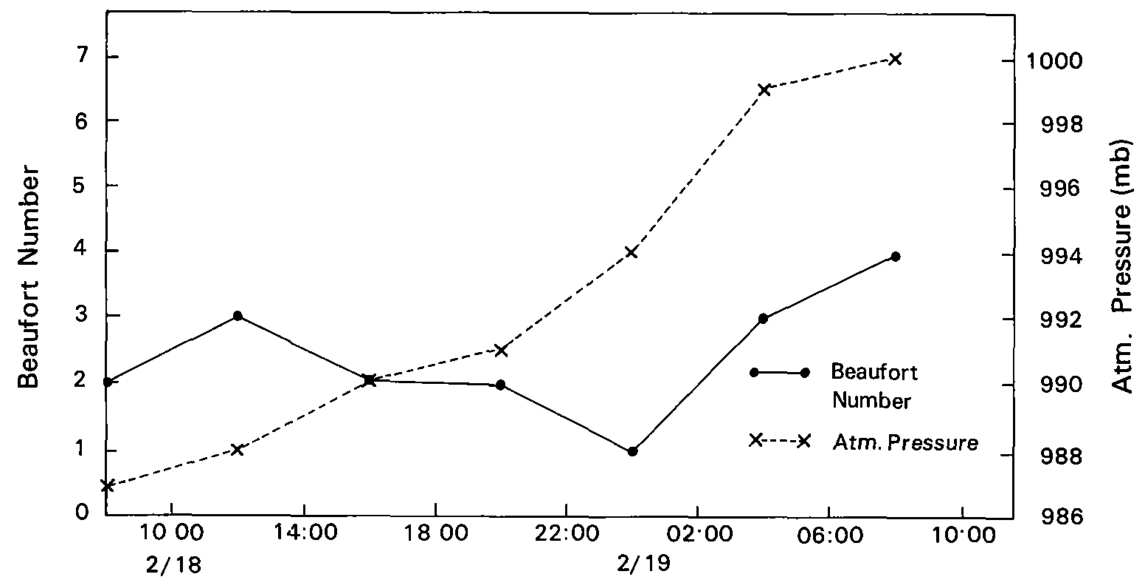

Fig. 10. Time series distribution of Beaufort Number and atmospheric pressure in Marian Cove (St.1).

tical stability of the water column prevents the phytoplankton from remaining in the optimal light zone long enough for extensive production. Cote and Platt (1983) have found that the normal progression of the phytoplankton community structure in a small subartic coastal inlet was periodically perturbed by transient phenomena such as winds. George and Heaney (1978; cited in Demars *et al.*, 1986)) showed that wind velocities $\geqslant 1.2 m\ s^{-1}$ were sufficient to breakdown patches of phytoplankton in small lake. Legendre *et al.* (1982; cited in Demers *et al.*, 1986) reported intermittent phytoplankton bloom's following stabilization of a water column previously destabilized by strong winds in the Artic coast. El-Sayed (1986) recently summarized the current understanding of the Antartic marine ecosystem. According to him, "the ocean south of the Polar Front contains a circumpolar phytoplankton population, living in a fairly uniform environment with sufficient light for photosysthesis (during the austral spring and summer), that is more or less adapted to cold temperature and has access to abundant nutrients, and yet the population is not only patchy, but its density is very low, except for the occasional blooms of diatoms". Among the various possible explanations for the low standing crop of phytoplankton in the Antartic waters, low water column stability and the high grazing pressure are believed to be largely responsible for. The grazing pressure is thought not to be significant due to the low density of zooplanktons of Marian Cove (KORDI, 1988). However, the areas of high krill concentrations are usually noted for the low standing crop of phytoplankton (El-Sayed, 1986). Nutrients and chlorophyll distributions observed during the 24 h time series may support to the argument that the low stability of the water column may be responsible for the low standing crop of phytoplanktons in Marian Cove. A more detatiled sampling program is expected to be employed for understanding high varibility of the water column processes.

Sedimentation of particulate matter

Sources of the SPM in Marian Cove may be divided into two categories: that carried in from outside the basin (allochthonous) and that produced *in situ* (autochthonous). The bulk of allochthonous sediment is supplied by sediment-laden melt water. Another possible source of allochthonous material is the influx of Bransfiled Strait waters *via* Maxwell Bay. Most reported SPM concentrations in the coastal waters of the Antarctic (less than a few $mg\ l^{-1}$· Leventer and Dunbar, 1985) are significantly lower than those observed in glaciomarine environments subject to major influxes of sediment-laden melt water, where concentration may be as high as $400\ mg\ l^{-1}$ in Port Valdez, Alaska, U.S.A. (Syvitski *et al.*, 1987). About $3\ mg\ l^{-1}$ of SPM was observed in the close proximity of Marie Byrd Land of the Antartic continent (Leventer and Dunbar, 1985). The SPM concentration in Marian Cove is higher than in the Bransfield Strait proper, however, much lower than the typical tide-water glacier environment in the northern hemisphere. In Bransfield Strait, SPM concentration is usually less than $1\ mg\ l^{-1}$ in the surface layer (Leventer and Dunbar, 1985). Since the SPM concentrations in the Bransfield Strait proper is lower than those in Marian Cove, influx of particles from the Bransfield Strait may be ruled out. Krebs (1983) observed a small summer phytoplankton bloom in November followed by a much larger spring phytoplankton bloom in early January and a fall bloom in early March at Arthur Harbor (Antartic Peninsula). In the Bransfield Strait, Water *et al.* (1988) observed that some 95% of the annual settling flux of particulates is encountered in the two most productive months (December and January), and of which biogenic components (carbonate, POM, and opaline silica) accounts for over 60 %. Therefore February 1988 sampling period is likely to miss the major bloom in this area. However, most organic matter seems to be originated from phytoplankons inferred from the C/N ratio of SPM (Table 2).

In general, the vertical flux of bulk sediments is usually about 0.8-1.4g m^{-2} d^{-1} in the surface waters of the Bransfield Strait (Dunbar *et al.*, 1982) and the Indian sector of the antarctic Ocean with large temporal variations mainly due to the phytoplankton blooms, of which 60 % are the biogenic material (Harada *et al.*, 1986). Schneck (1985) observed higher values (about 8 g m^{-2} d^{-1}) in the South Georgia Sea. POC vertical flux is usually about 0.28g C m^{-2} d^{-1} in the most antarctic continental shelf. The vertical flux of bulk sediment measured in Marin Cove is significantly higher than the antarctic oceanic waters due to the terrigenous input from the adjacent land. POC fluxes are comparable to the other antarctic oceanic waters, however, biogenic Si contents are significantly lower to those in the Bransfield Strait, which indicates the dilution of biogenic particles by terrigenous material. Most antarctic shelf sediments are greatly enriched in opal (10 to 20 %) and relatively depleted in organic carbon (2 %; Dunbar *et al.*, 1985). However, organic matter and opal content in Marian Cove were much lower than the oceanic waters due to the low primary productivity in the overlying waters. Lower values (<1 %) were also reported in Sulzberger Bay of the antarctic continent (Ledford-Hoffman *et al.*, 1986).

Although settling particulates had been sampled for only several days, and the sedimentation rate in the bottom was not estimated using radioactive isotope measurements, it is still helpful to construct the elemental budget in the benthic regime for understanding the biogeochemical environments of Marian Cove, King George Island. The importance of the degradation of biogenic matter in the water column may be supported by the decrease of dissolved oxygen concentration with depth (Fig. 3). A simple broadbrush elemental budget was constructed for particulate organic carbon, biogenic Si, particulate Fe and Mn (Table 5). The rain rate (Jr) was taken as the depth average vertical flux from sediment trap data, the sediment incorporation rate (Js) was estimated using the concentration of an element and the estimated sedimentation rate in the bottom, and the benthic utilization rate (Ju) was taken by subtracting the sediment incorporation rate from the rate. Of course, the Ju would include any lateral transport occurring between the depth of sediment trap moored and the basin floor. For particulate organic carbon, about 0.28 g C $m^{-2}d^{-1}$ arrives in the basin floor, of which 30 % will actually incorporated into the bottom sediment, and the rest of carbon raining to the seafloor will be degraded near the sediment-water interface or laterally transported elsewhere.

Table 5. Simple broad-brush elemental budgets in the benthic regime of Marine Cove, the King George Island.

g m^{-2} d^{-1}	POC	Biogenic Si	Fe	Mn
Jr	0.28	0.42	1.40	0.03
Ju	0.20	0.34	0.13	0.01
Js	0.08	0.08	1.27	0.02

Note: Jr, Ju, and Js stand for the rain rate, sediments incorporation rate, and benthic utilization rate, respectively (see text for fluxes).

Conclusions

Time series determination of chemical property of water column during the austral summer demonstrates a high varibility of nutrient concentrations and low standing crop of phytoplankton, which is attributable to the weakly stratified water column due to the small volume of ice melted freshwater and the prevailing high winds in Marian Cove. In the surface waters of Marian Cove, temperature and salinity varied from 0.90 to 1.30°C and from 33.69 to 34.59°/₀₀, respectively, for a just 24 hours sampling period. Dissolved oxygen content also varied from 313 to 332 μmol kg^{-1}. Nitrate, nitrite, reactive phosphate, and reactive silicate varied from 18.7 to 21.0, 0.16 to 0.50, 0.07 to 2.11, and 42.45 to 71.45 μmol l^{-1}, respectively. SPM concentration varied from 1.4 to 6.2 mg l^{-1}, and *in vivo* chlorophyll level varied from 3 to 8 in arbitrary scale.

Sedimentation of particulate matter was also studied collecting particulates in rapid transit and those suspended in the water column and lain in the basin floor. The low concentration of biogenic matter (POC, PN, and biogenic Si) in the settling and bottom sediments suggests that there is a significant material input from the adjacent land. Bulk sediment settling rate was 23 g m^{-2} d^{-1} which is higher than the normally observed values in the oceanic antarctic waters. Vertical fluxes of POC, PN, biogenic Si were 0.28 g C m^{-2} d^{-1}, 0.08 g N m^{-2} d^{-1}, and 0.41 g Si m^{-2} d^{-1}, respectively, for the sampling period (February 1988). Most particulate biogenic materials raining to the basin floor seem to be degraded in or near the sediment-water interface.

Acknowledgements

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Part IV. Antarctic Biology

Changes in the Population Structure and Biomass of Notothenia Gibberifrons from Shelf Area of South Georgia Island

Krzysztof E. Skora

Abstract

An analysis of the state of the Notothenia gibberifrons stocks in the South Georgia area was carried out. It was noted that since the 1975/76 season, the biomass of this species decreased more than five fold and the majority of fish presently caught did not reach the length and age of sexual maturity.

Introduction

The shelf of South Georgia is the most heavily exploited fishing ground of the Atlantic sector of the Antarctic. Notothenia gibberifrons Lonberg belongs to fish taken in this area in great numbers.

There are several publications dealing with its stocks. The fullest description of their state up to 1985 may by found in collective papers; Slosarczyk et al. (1984), Kock (1985), Kock, Duhamel and Hureau (1985), Kock (1986). Partial estimations of the biomass of this species are given by Mucha (1982), Gabriel (1987),Kalinowski (1987, 1988), Mucha and Zaporowski (1988). The papers of Linkowski and Rembiszewski (1978), White and North (1979), Skora (1980), Hoffman (1982) contain information on frequency of fish length classes and age grups (excluding the first). Boronin and Altman (1979) analyze the evaluation of mortality coefficients of this species on the basis of frequency in age-groups from paper by Boronin and Frolkina (1976).

The present paper gives an analysis of changes in the N.Gibberifrons population over the past 12 years of exploitation of its stocks in the South Georgia area.

Meterial and Method.

The basis for the paper were observations collected in the cruises of Polish commercial and research vessels (Table 1) exploring the South Georgia area in the 1975/76 - 1987/88 period (Linkowski and Rembiszewski 1978, Mucha 1982 and unpubl., Slosarczyk et al. 1984, Gabriel 1987, Mucha and Zaporowski 1988, Skora unpubl.).

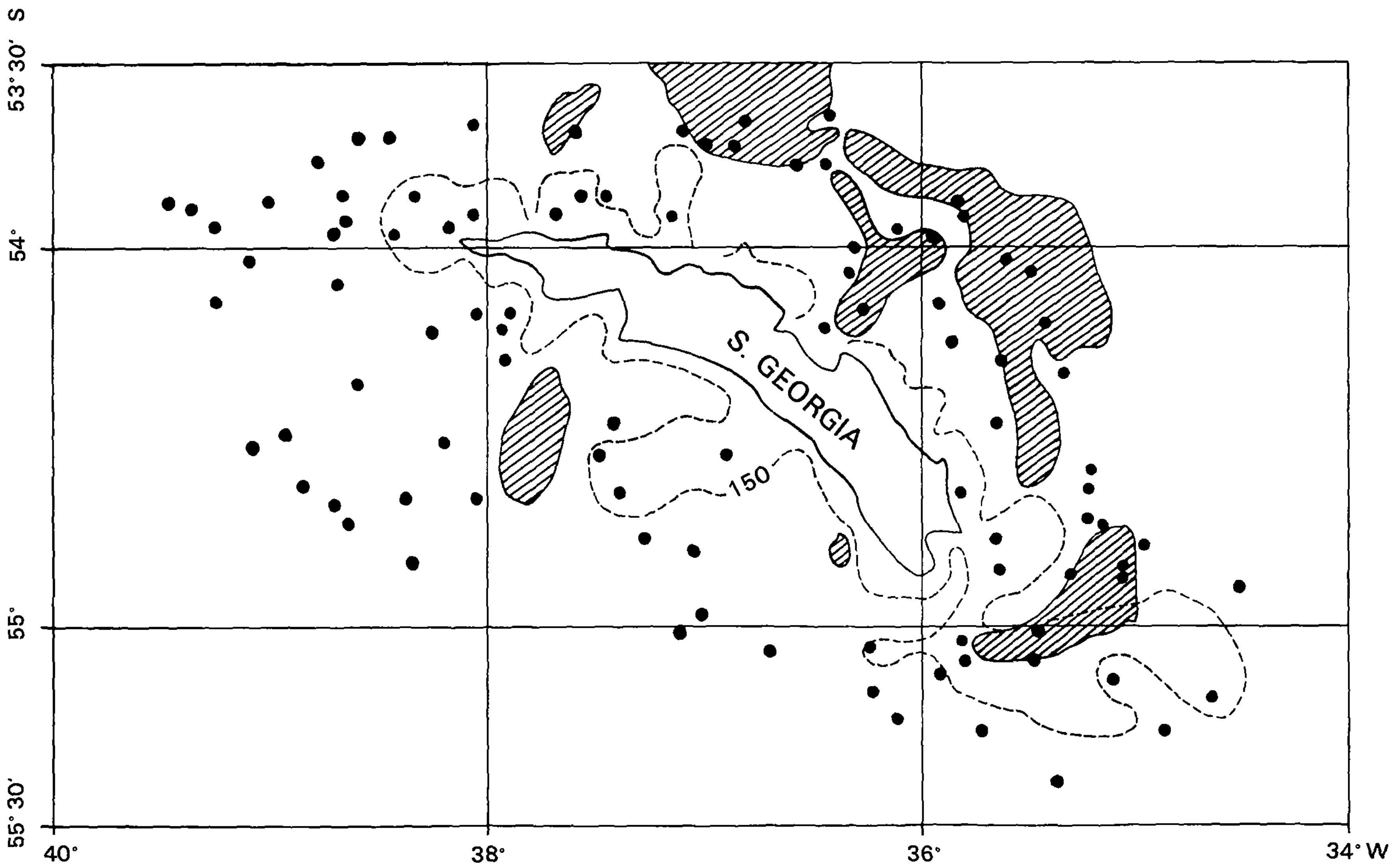

Fig. 1. Region of investigations.
- shaded areas - fishing grounds where the hauls to estimate the biomass in years betwen 1976 and 1985 were made,
- black dots - positions of hauls used for analyses for season 1986/87.

Table 1. Type of vessel and number of hauls used for biomass estimate

Season	Type of vessel	No of hauls made
1976/77	commercial	277
1977/78	commercial	243
1978/79	research	36
1980/81	commercial	507
1981/82	commercial	298
1983/84	commercial	116
1984/85	commercial	216
1985/86	commercial	235
1986/87	research*	109
1987/88	research	138

* In this and the following season, investigations were conducted together with an U.S. team within the framework of American AMLA and Polish CPBR 10.11.

Biomass estimates were based on the 'swept area' method. Date from the 1976/77-1984/85 period were calculated on the basis of catches attained by the Polish vessels within fishing grounds situated as a rule at greater depths than 150 m (Fig. 1). In the 1986/87 and 1987/88 seasons samples were collected from the entire shelf of the island, at depth range of 50-500 m. Each of the results of the estimated biomass refers to the area of 12851 km^2 of the island shelf (calculated by Everson (1980)). The CPUE index is given in kg/h and was calculted in each season for the same kind of trawl. Fishing effort was expressed as a number of vessel-days using bottom trawls only. Measurements of fish length refer to total body length (*longitudo* totalis) and rounded to the mearest centimeter below. Age was determined by the analysis of scales.

Results.

The greatest intensity of bottom catches of the Polish fishing fleet in the South Georgia area was in the 1979/80 season, equalling 1,232 days on the fishing ground (Table 2). A total of 7,274 tons of N.gibberifrons was taken then. However, this was smaller by 2,500 tons than the total catch two seàsons earlier (at a comparable fishing intensity). A result of 9,775 tons was attained mainly due to a prolonged fishing season (Fig.2). In these years the share of this species in total catches was high, and the in the 1979/80 season N.gibberifrons became dominant species of commercial exploitation, comprising 62% of the catch. Recent years, however, are characterized by decline in its importance. Catch rates (calculated for comparable bottom trawls) are decreasing. Until the 1984/85 season it ranged from 132 to 312 kg/h. For the past two years it was below 100 kg/h.

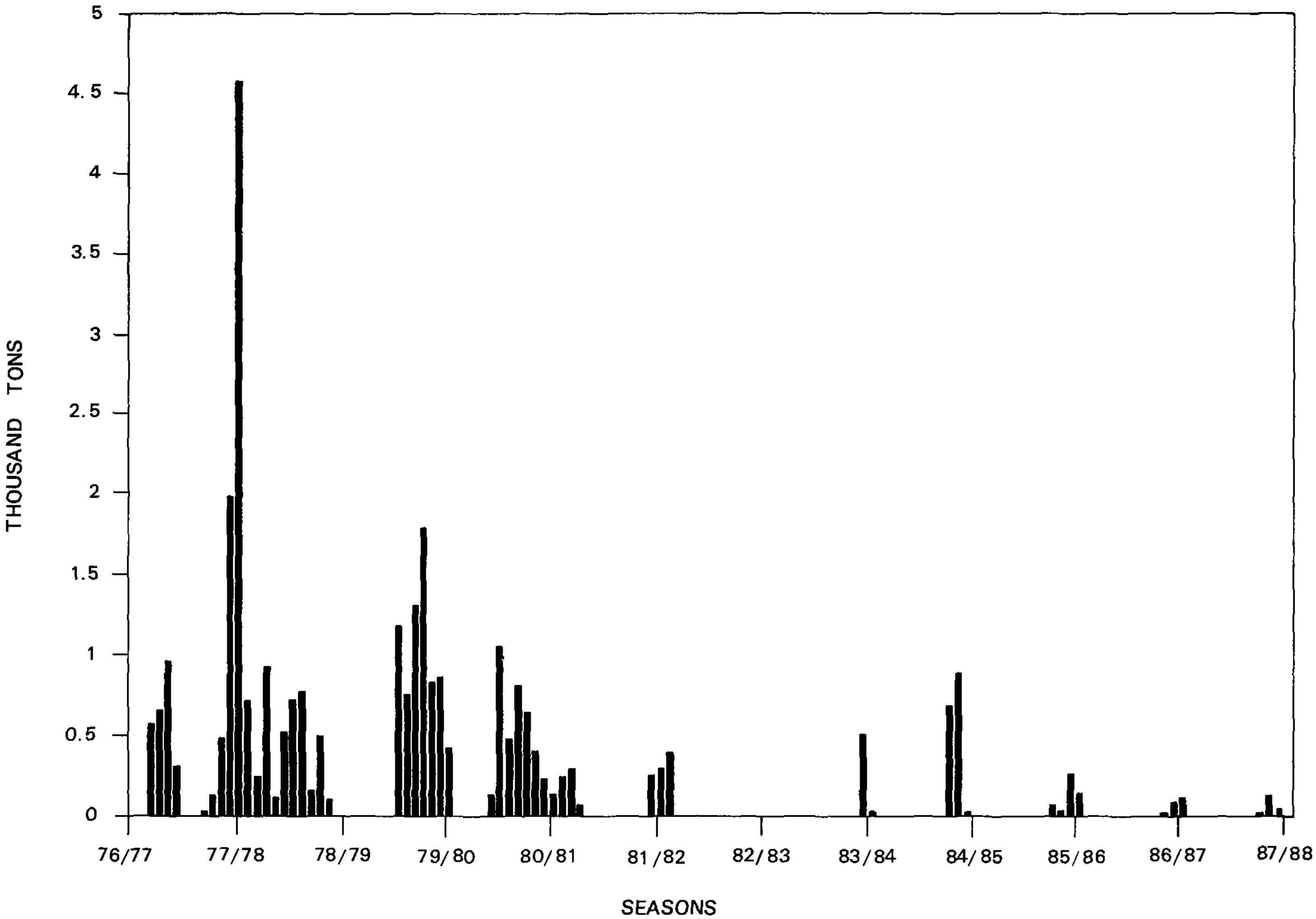

Fig. 2. Polish monthly catches of N.gibberifrons in the South Georgia area.

Table 2. *Size of catches of N.gibberifrons, fishing effort, CPUE and percentage of this species in total catches of Polish fishing fleet operating in the South Georgia area in 1976-1988.*

Season	Catch (t)	Fishing effort. (days on fishing ground)	CPUE kg/h	Share (%)
1976/77	2526	527	312	25
1977/78	9775	1201	132	40
1978/79	2228	203	?	38
1979/80	7274	1232	151	62
1980/81	4626	963	?	27
1981/82	970	401	247	12
1982/83	0	0	—	—
1983/84	531	93	182	5
1984/85	1583	194*	239	28
1985/86	512	97*	189	13
1986/87	222	150	86	8
1987/88	199	138	37	11

* — including pelagic catches

Biomass estimates (at 80 % confidence limits) gave quite different results for individual seasons (Fig. 3). The reasons for these are probably due to the imperfect sample collection methods. The highest biomass was obtained for the 1981/82 season-25,802 t and the 1976/77 season-22,339 t. At the same time these were the periods of highest CPUE for N. gibberifrons (247 and 312 kg/h).

The share of the biomass of this species among other species fluctuated between the extermes of 6.9 and 28.8 %. The last years point to a certain stability of this value around 11-18 %.

A noticeable decline of the biomass of this species after 1984 seems to be correlated with a decrease in total fish biomass estimates off South Georgia (Fig. 4).

Annual studies of fish frequency in length classes and age-groups exhibited tendencies of changes consisting in gradual elimination from the stock of large and older fish (Fig. 5). As a result, mean length dropped from 41.2 cm to 21.7 cm, and the age from almost 14 to 5 years (Fig. 6).

Discussion.

Notothenia gibberifrons is found in almost every bottom haul made on the South Georgia shelf below a depth of 50 m. Its distribution in individual depth zones is more uniform than is the case with most other species (Slosarczyk et al. 1984b; Kock 1985). It is distributed over the whole shelf area, with greater numbers being found in northern and north-eastern parts of the area (Kock 1986, Gabriel 1987). Adult individuals prefer depths from the 200-400 m range (Skora and Sosinski 1987). Outside of the winter spawing period (Kock 1985) this species does not form substantial concentrations allowing for species-directed fishery. this makes its biomass estimates more reliable. However, certain qualifications are necessary when evaluating the results attained.

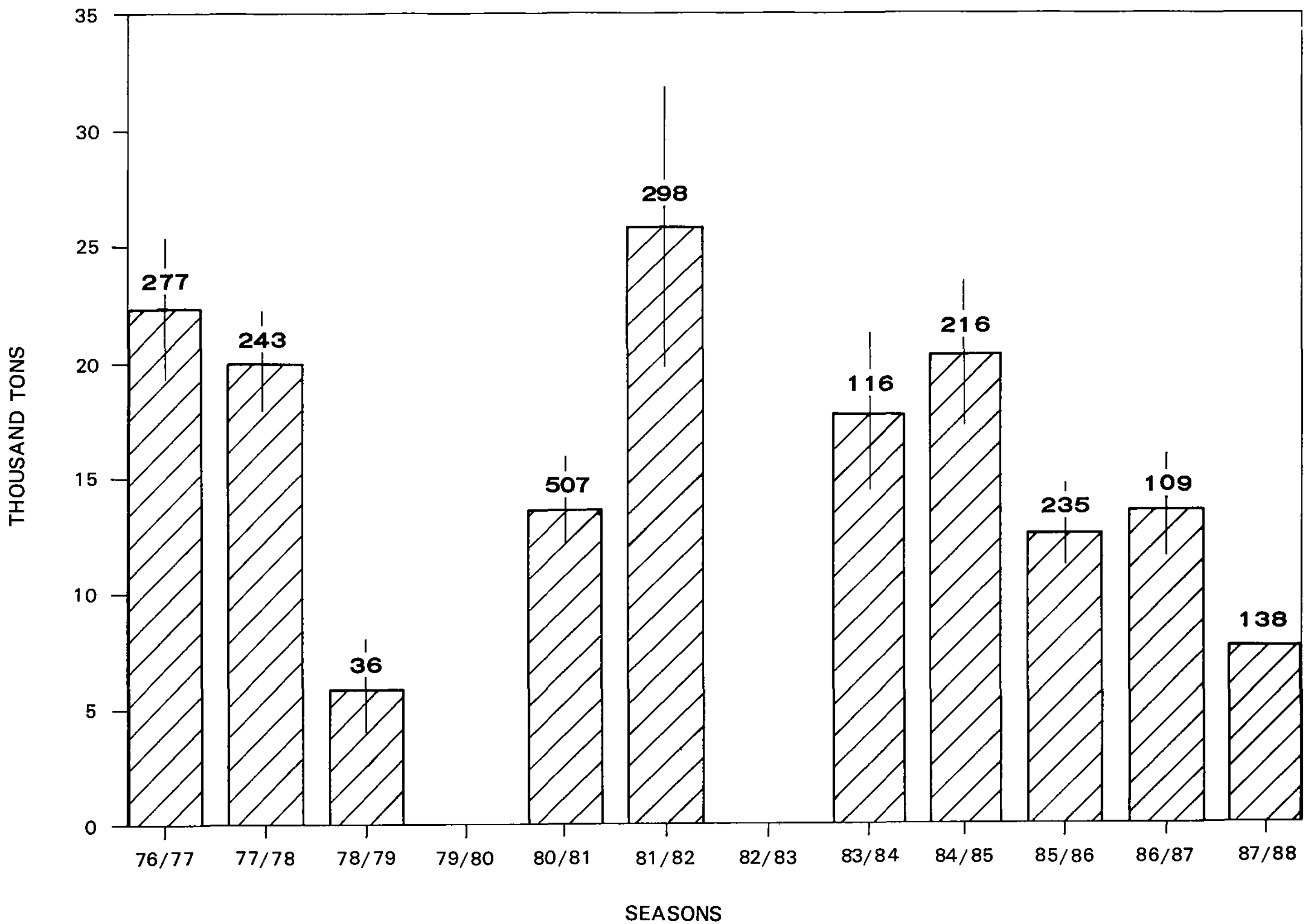

Fig. 3. Results of biomass estimates of N.gibberifrons made on the basis of Polish commercial and research vessels. /numbers over columns refer to number of hauls made. vertical line indicates standard deviation/

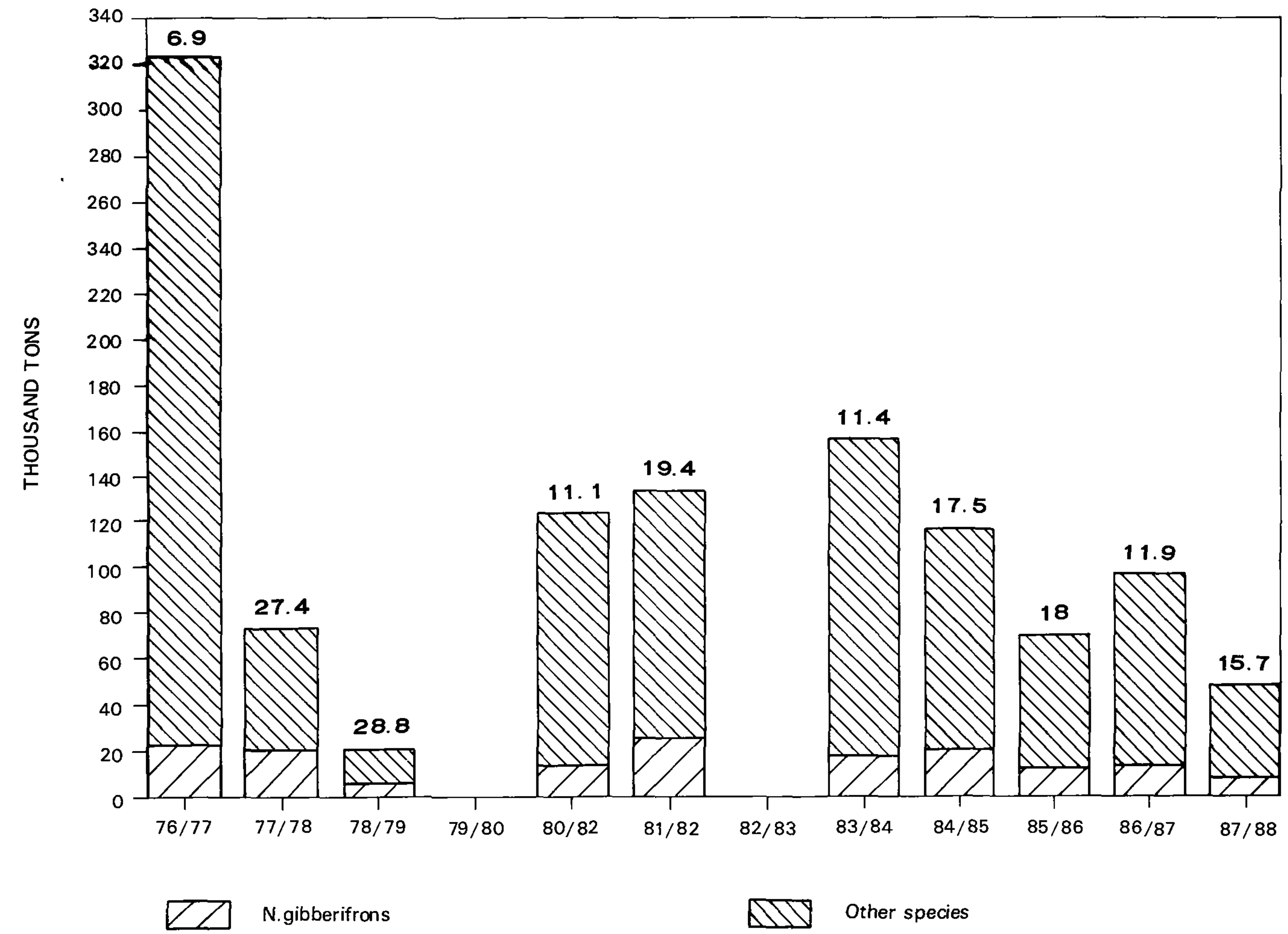

Fig. 4. The share of N.gibberifrons in total biomass of fish from South Georgia area. /numbers over columns refer to percentage/.

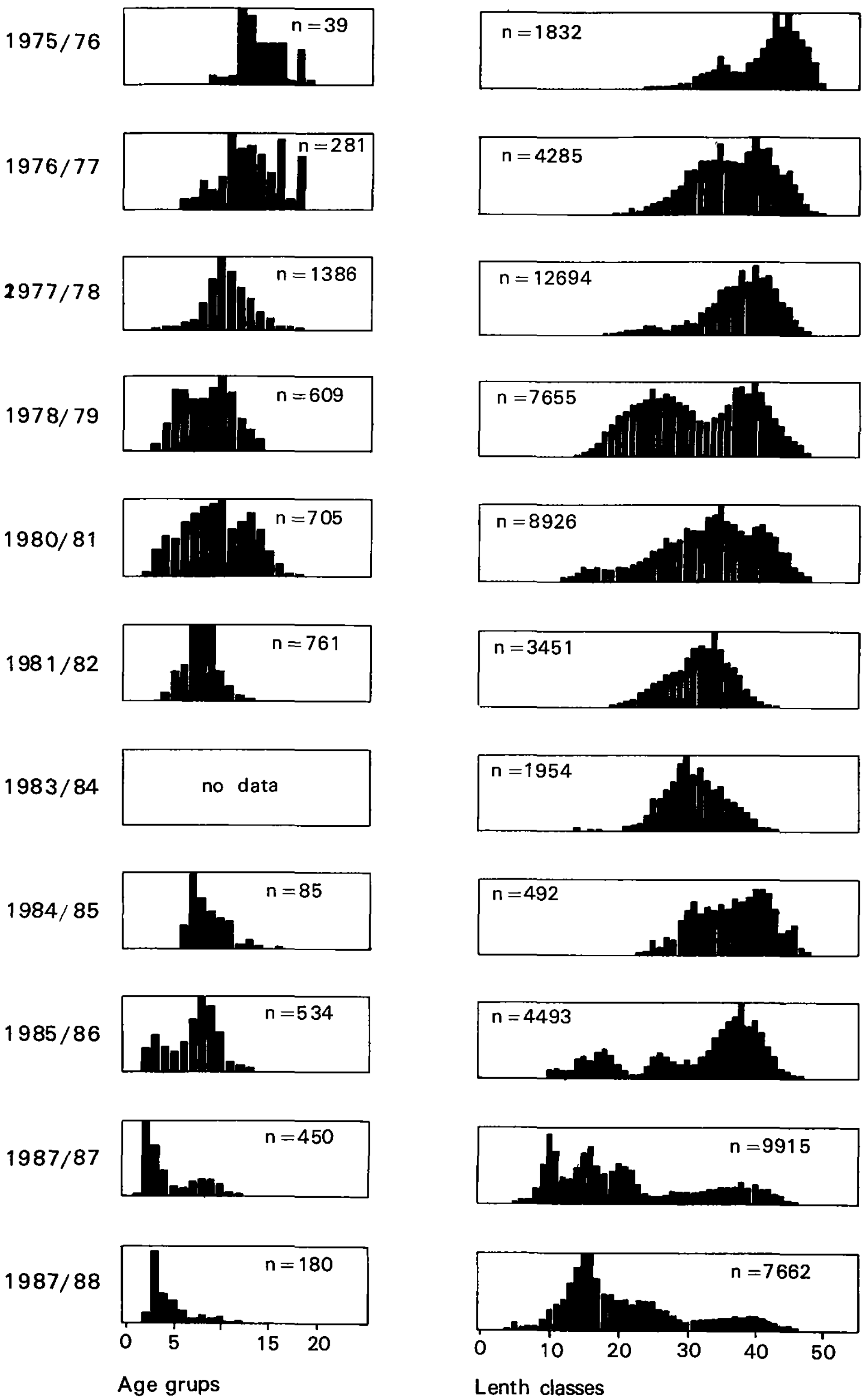

Fig. 5. Frequency of fish in age-grups and length classes in the South Georgia area.

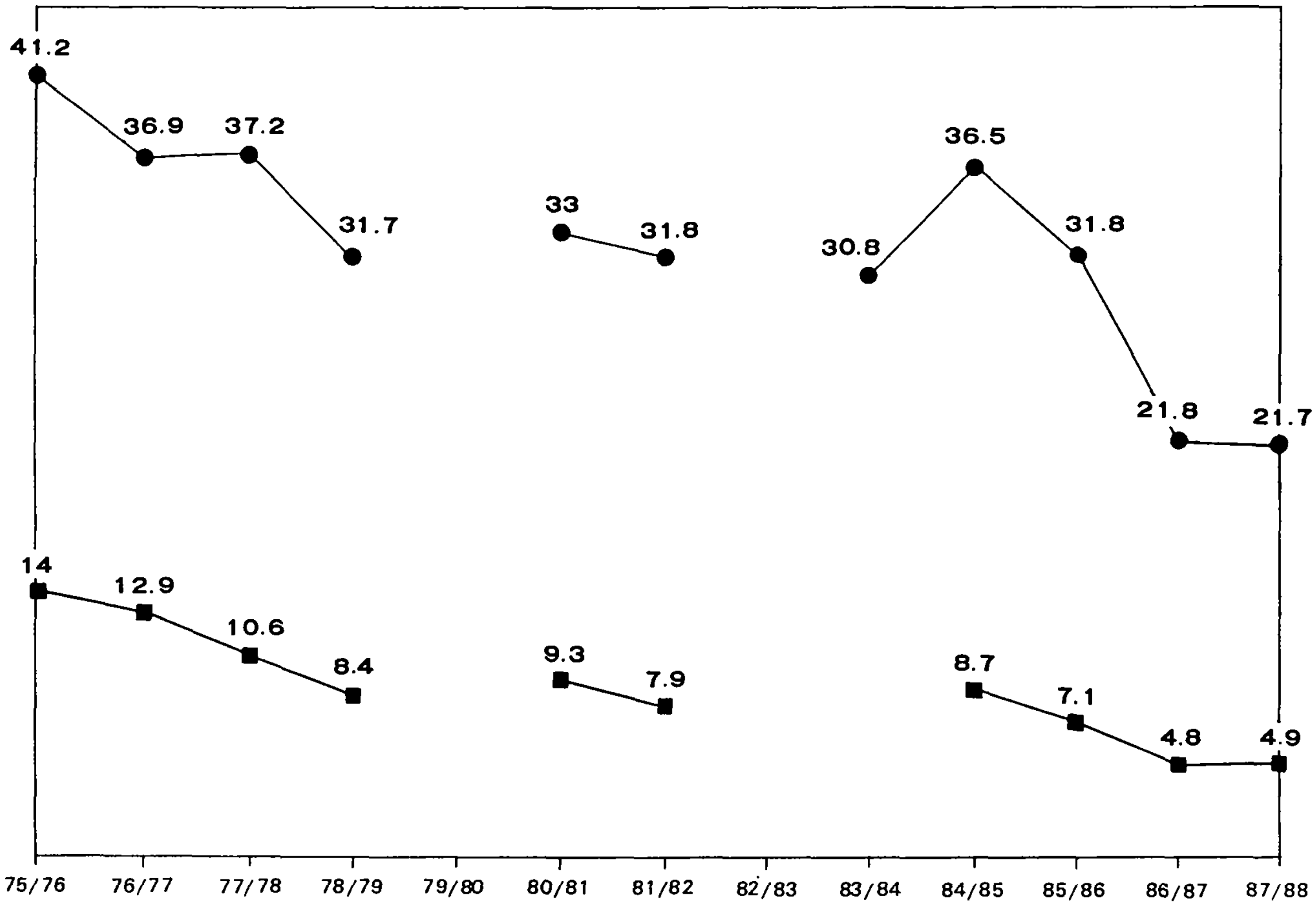

Fig. 6. Mean age and length in N.gibberifrons from the South Georgia area.

The main problem encountered when comparing the results from different years is the lack of similarity in fishing strategy, and hense data collection. The main factors are type of vessel and the manner of its operation on the fishing ground. This is why it is necessary to view differently data from research and commercial vessels. The latter concentrates their activites on fishing grounds with the highest CPUEs and this factor has an effect on overestimation of total biomass calculations. It also results in underestimation of this species which at the time occurs on fishing ground in lesser abundance than in other places. These facts are to a considerable degree true as regards the biomass estimates of N.gibberifrons.

Firstly, since N. gibberifrons is almost never the main target of exploitation (which is usually white-blooded fish) it may be expected that for this reason (Kock 1985), the results of estimates of its biomass (at least with respect to fish onto which fishing is directed) may be underestimated.

Secondly, in most cases (within the 1976-1986 period) the basis for calculations were catches made in northern and north-eastern parts of the shelf, i.e., on places characterized by more abundant occurrence of this species. Thus, a transfer of those data onto the whole shelf of South Georgia probably gives an exaggerated estimate of total biomass.

Results from the cruises of research vessels* seem to be free of these errors (Kock 1985, 1986, Gabriel 1987, Mucha and Zaporowski 1988). They were characterized by similar and optimum methods of investigations.

Their comparison unequivocal points to the decrease in the biomass of N.gibberifrons in the area studied (Table 3) and the data from commercial vessels, despite seasonal fluctuations in the estimates, confirm this unfavourable trend to a considerable degree.

Table 3. Biomass of N. gibberifrons in the South Georgia area estimated on the basis of catches of research vessels.

author	Kock 1985	Kock 1985	Kock 1985	Gabriel 1987	Mucha, Zaporowski 1988
season;	75/76	77/78	84/85	86/87	87/88
tons;	40094	20100	15762	11234	7621
SD;	64.7%	35.2%	28.4%	14.9%	

*The 1978/79 season must be an exception - the biomass estimate was based on a very small number of houls - 39.

Since the determination of fish biomass by swept area method is not free from errors (Kock 1985), it will be important to investigate new methods which could, at least in a relative manner, verify the estaimtes made. An attempt of such a venture may be found in the papers by Kalinowski (1987 and 1988). Using hydroacoustic equipment the author calculated the biomass of N.gibberifrons in the South Georgia area. In the 1986/87 season it equalled 15,950 and a year later 13,946 t. This confirms, although in a less radical way, a decline in the stocks of this species.

Looking at diagrams of fish frequency in length classes and age-groups in this and other papers (Boronin and Frolkina 1976; Linkowski and Rembiszewski 1978; White and North 1979; Hoffman 1982; Kick 1985; and 1986; Kick, Duhamel end Hureau 1986) a gradual disappearance of large specimens is coming clearly* visible. In 1971 over 70% of the stock consisted of fish aged 11-14 years (Boronin and Frolkina 1976). The situation was still similar in the 1975/76 season. Until that moment, the effect of the fishery on the stocks of N.gibberifrons was still negligible (Kock 1985). An increase of the pressure of the fishery became visible in the following years. Beginning with the 1978/79 season, mean length of fish caught fluctuated around the size at which this species undertakes spawning for the first time. A radical decrease in mean length of fish and their age was observed in the last two seasons. The length did not exceed 22 cm and age 5 years. This fact is only partly a result of a greater number of hauls carried out on a shallow shelf, i.e., in places where young fish were found in greater abundance. The establishment of fish frequency for both of these seasons in length classes of individuals caught at depths below 150 m did not bring about a radical increase of those parameters. Their values were, respectively: in the 1986/87 season - 27 cm, in the 1987/88 season - 23 cm. Both of these values, together with the size of the biomass estimated for these seasons, point to a radical hazard for regeneration of the stocks of N.gibberifrons. Their present condition; 7,621 tons is already five times smaller than 50094 t estimated at beginning; (Kock 1985). Over the years 1977-1988 CPUE decreased almost eightfold (from 312 to 37 kg/h).

The results presented above show that legal regulations established at 1984 CCMLR session* might not be sufficient to protect the ecologically desirable state of stocks of fish from the species N.gibberifrons exploited on the South Georgia shelf.

Acknowledgements.

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2. I would like to thank Mr. Miroslaw Mucha of the Sea Fisheries Institute in Gdynia for making available his as yet unpublished results of biomass estimates of N.gibberifrons from the South Georgia area from 1983-1986.

* A ban on fishing in the 12-mile zone off South Georgia and a ban on smaller mesh size than 80 mm in the N. gibberifrons fishery.

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Nutrient Distribution in the Scotia Sea

Dong Beom Yang

Abstract

Nutrients, chlorophyll *a* and physical measurements were made in the Scotia Sea in December 1987. Surface temperature below 0°C was found in the southeastern stations of the study area with a thermal front near Elephant Islands and S. Orkney Islands. Vertical section along 65°W shows subsurface minimum temperature located at a depth of approximately 150 m which is thought to define the bottom of the winter mixed layer. Subsurface nitrite maximum layer was located above this depth. Surface nitrate concentrations ranged from 10 to 15 μg at N/ℓ in the northwestern stations whereas less than 10 μg at N/ℓ of nitrates were detected in the southeastern stations. Silicate concentrations in the upper layer were high in the southeastern stations suggesting the influence of Weddell Sea Waters which are known to contain high amounts of silicates. In terms of phytoplankton biomass the study area can be divided into 3 regions; northwestern stations, southeastern stations and the middle stations located between these two areas. Northwestern stations are characterized by low concentrations of chlorphyll. The southeastern stations are extremely high in chlorophyll *a* with more or less uniform distribution within the euphotic zone. It appears that nutrient concentrations cannot be a limiting factor for the growth of phytoplankton.

Introduction

Antarctic Ocean is characterized by extensive upwelling which brings nutrient-rich deep waters to the surface (Gordon, 1967).

For this reason, waters south of the Antarctic Convergence are high in nutrients, which nitrate concentrations generally in the range of 15 to 30 μg at N/ℓ. Many efforts have been made to study the reason for the high concentrations of nutrients in the Southern Oceans (Rudd, 1930; Clowes, 1977). Although the Antarctic Ocean is characterized by extensive upwelling, the interaction between the physical mixing processes and the biological processes are not nearly as well understood as in other upwelling areas. One of the most studied areas of the Antarctic Ocean is the Antarctic Circumpolar Current (ACC)-Weddell Sea Waters (WSW) boundary region in the Scotia Sea (Foster and Middleton, 1984; Deacon and Moorey, 1975; Deacon and Foster, 1977). The Scotia Sea extends westward from the S. Sandwich Islands to the Antarctic Peninsula and is bound by a series of submarine ridges and island. A large component of the waters in the Scotia Sea is derived from Circumpolar Waters that flows eastward through Drake Passage. The other major component is provided by Weddell Sea Waters, which are distinguishable from circumpolar waters because of their low temperatures and salinities and higher silicate concentrations. Several investigators have traced the Weddell-Scotia Confluence across the Scotia Sea by its effect on the temperature and nutrient distribution (Gordon, 1967; Gordon *et al.*, 1977). It has an important effect on the distribution of krill. The extensive studies on the distribution and concentrations of krill carried out in the Scotia Sea (Marr, 1962; Makarov, 1974) emphasized the significance of the Weddell Sea as a spawning area for krill, and the importance of the cyclonic circulation of that sea to the life history of krill. Many krill biologists have recently called attention to the need for oceanographic data on the rates of movement of water masses and on primary production rates to allow assessment of rates of immigration of krill in different regions (Mauchline 1979).

During our expedition dense krill swarms were found along the Weddell-Scotia Confluence. Thus it would be interesting to study the hydrographic condition and nutrient distribution around the boundary region.

Materials and Methods

Positions of the hydrographic stations are shown in Fig. 1. Data were collected on Korean fishing fleet *Dongbang* 115 during 2 December and 18 December 1987 in the Scotia Sea. Water samples were collected at 10 depths using Nansen Sampler. Water temperature was measured using reversing thermometer attached on the Nansen sampler. Samples for determining nutrient concentrations were filtered through Millipore membrane filters. Immediately following filtration the filtrate using Technicon Autoanalyzer II following the method described by Zimmermann *et al.* (1977) Chlorophyll *a* was determined on acetone extracts using the method of SCOR-UNESCO (1966).

Results and Discussions

Horizontal distribution of surface temperature in the Scotia Sea is shown in Fig. 2. Surface waters in the northwestern stations are relatively warmer than in the southeastern stations. Surface temperature below 0°C was found in the Southeastern stations with a thermal front north of S. Orkney Islands. At 30 m depth water temperature below 0°C was also found in the southeastern stations (Fig. 3). One of the method which are commonly used to define the boundary between Antarctic Circumpolar Current (ACC) and Weddell Sea Waters (WSW) is to locate an isotherm along the center of the areas of steepest horizontal temperature gradient. Marin (1987) also used 0°C isotherm to define the boundary between ACC and WSW. Thus southeastern stations of our study area are considered to be largely influenced by WSW and northwestern stations by ACC. Vertical section of temperature along 65°W shows subsurface minimum temperature located at a depth of approximately 150 m which is thought to define the bottom of the winter mixed layer (Fig. 4). Along this section subsurface maximum concentration of nitrite were found at about 100 m depth, just above the minimum temperature (Fig. 5). The reason for the formation of nitrite maximum is not clear but it is suggested that water column above the minimum temperature is quite stable and nitrite ac-

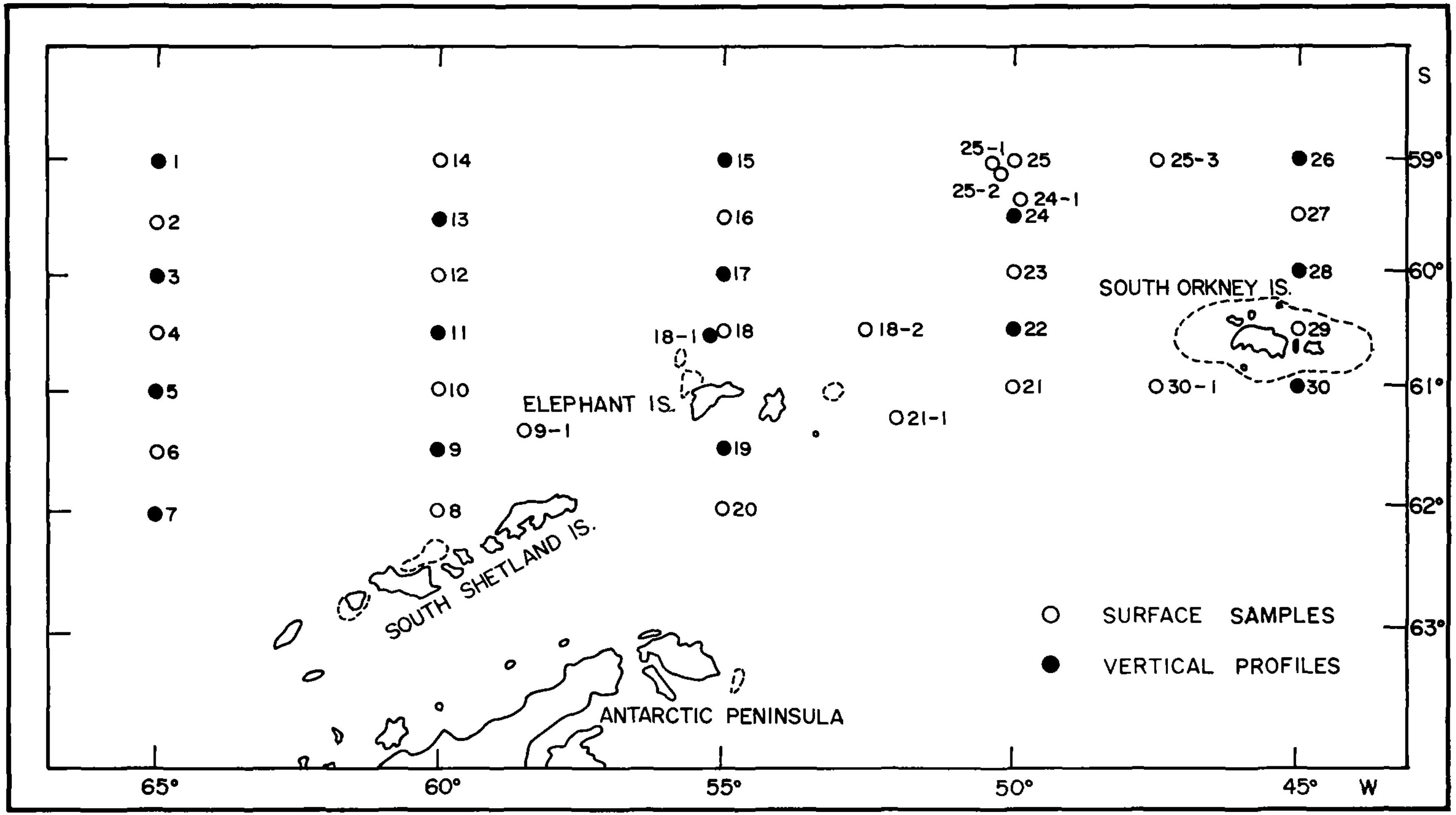

Fig. 1. Sampling location in the Scotia Sea.

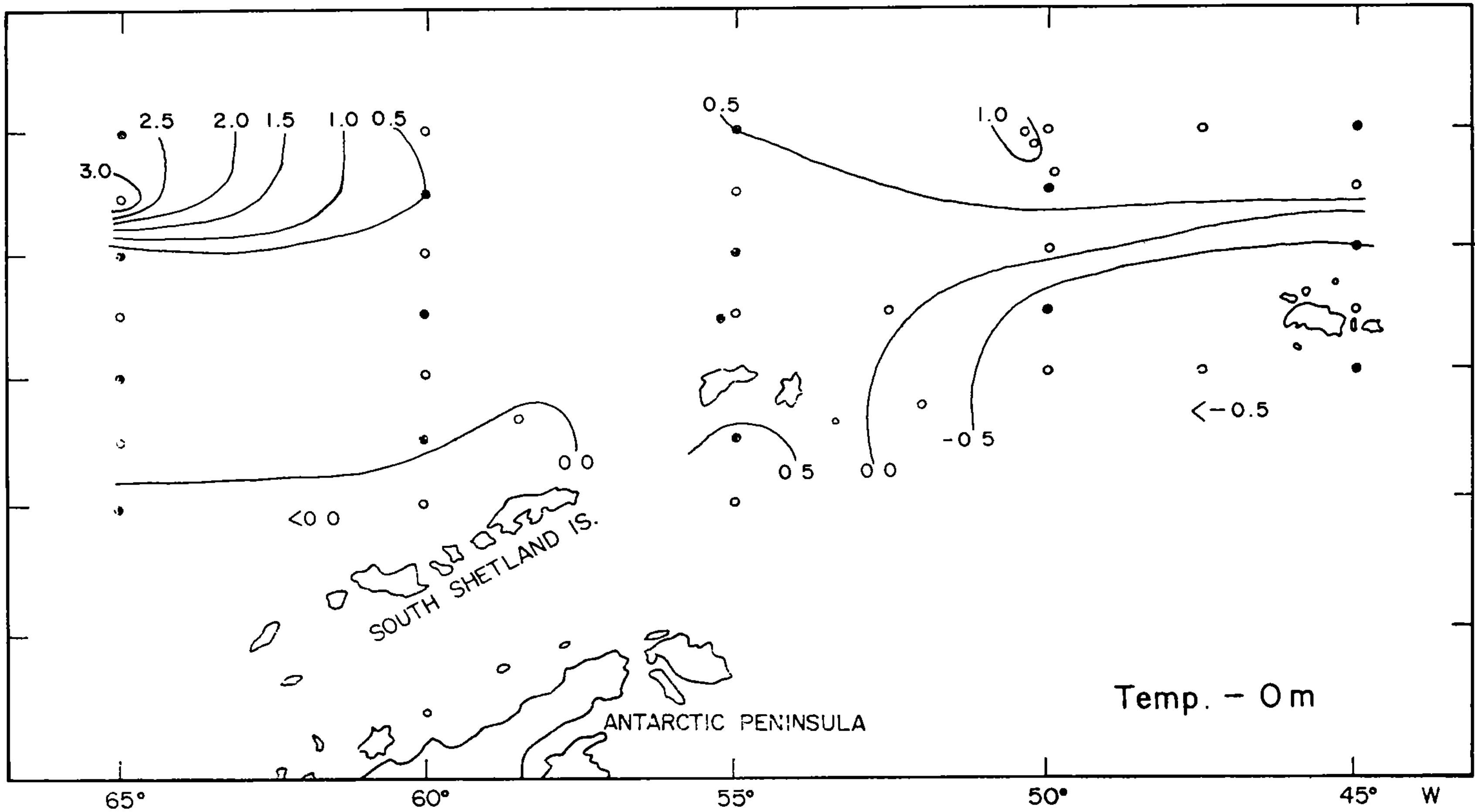

Fig. 2. Distribution of temperature in the surface waters in the Scotia Sea (°C).

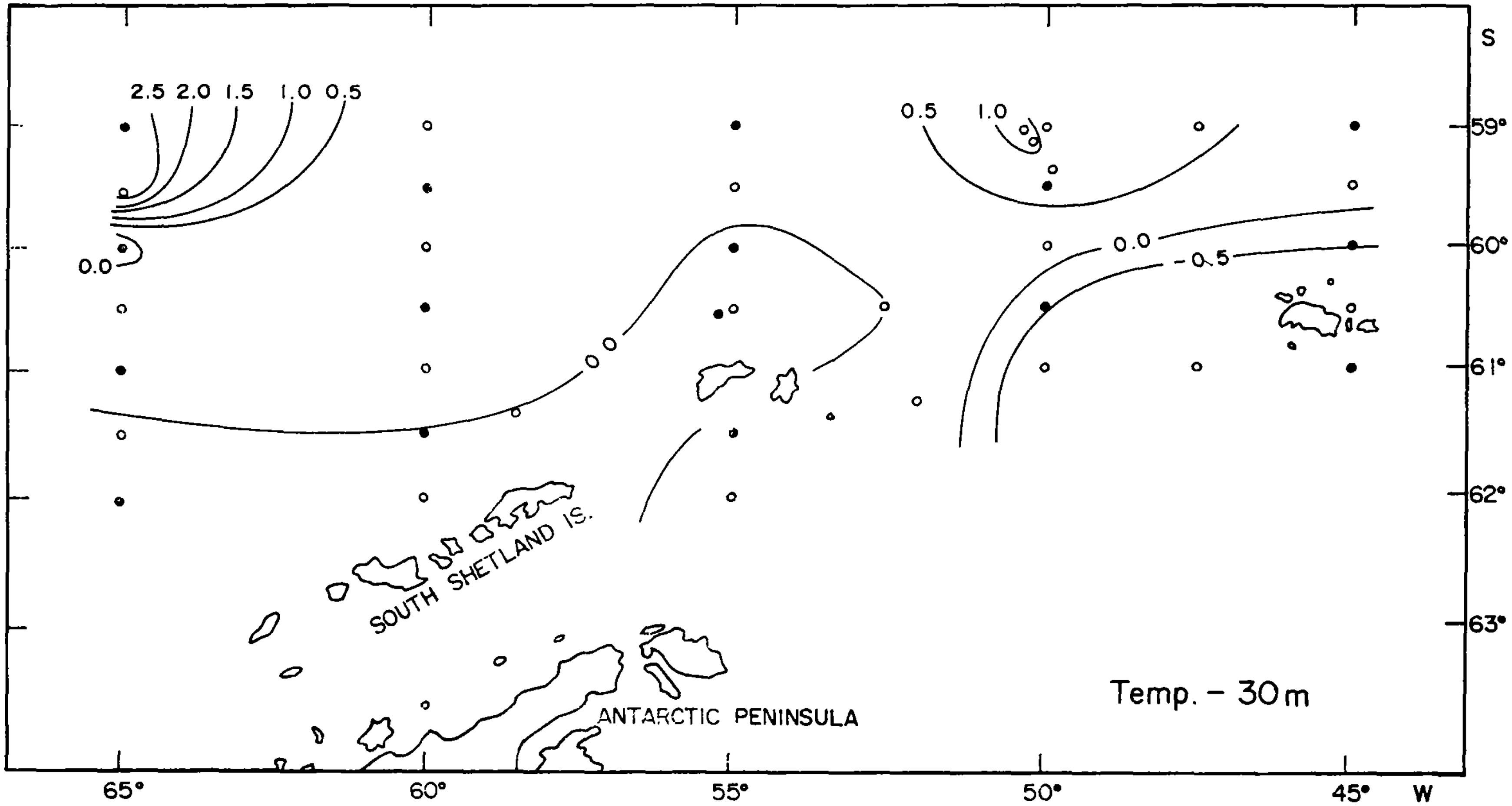

Fig. 3. Distribution of temperature at 30m depth in the Scotia Sea (°C).

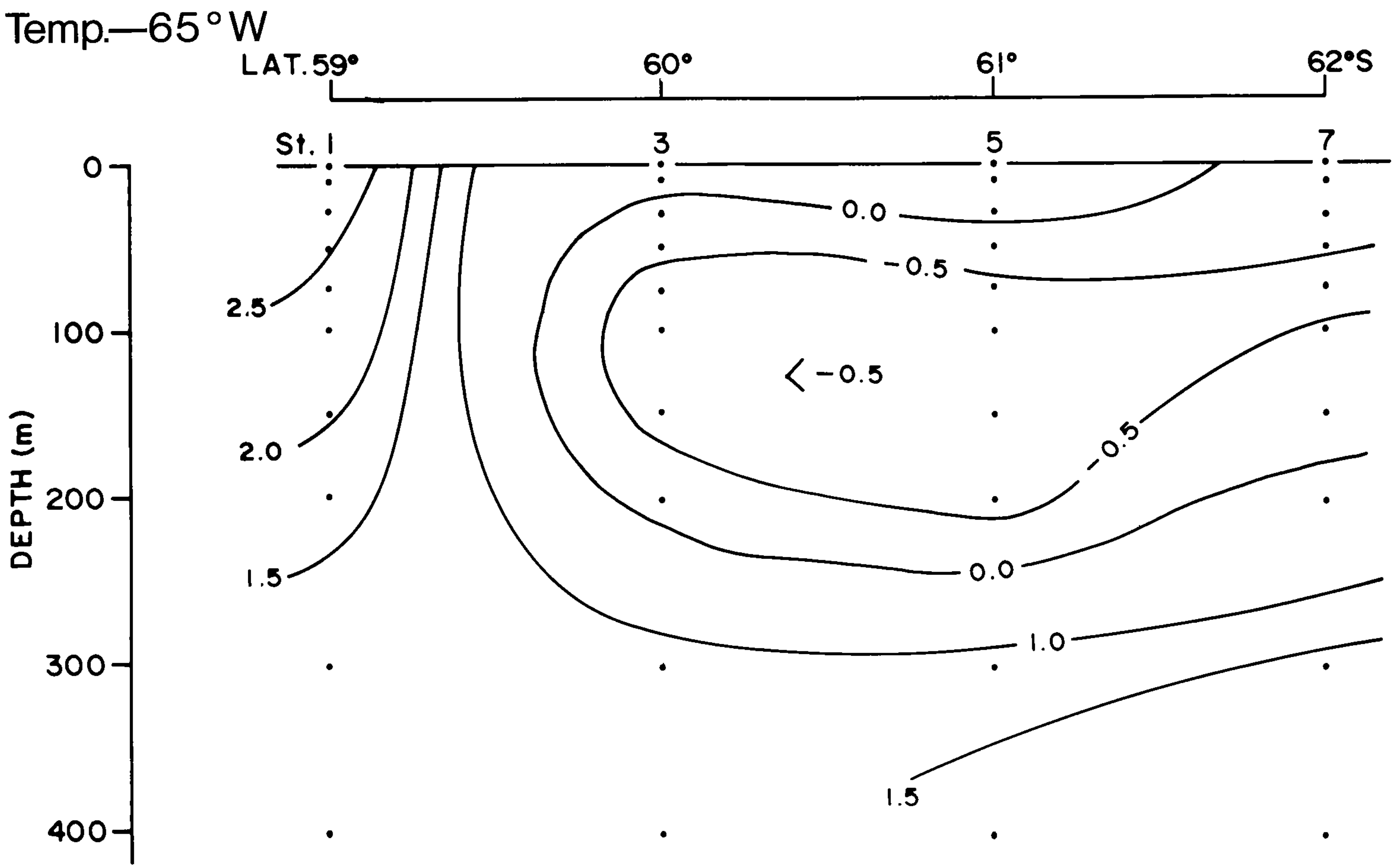

Fig. 4. Vertical section of temperature along 65°W in the Scotia Sea (°C).

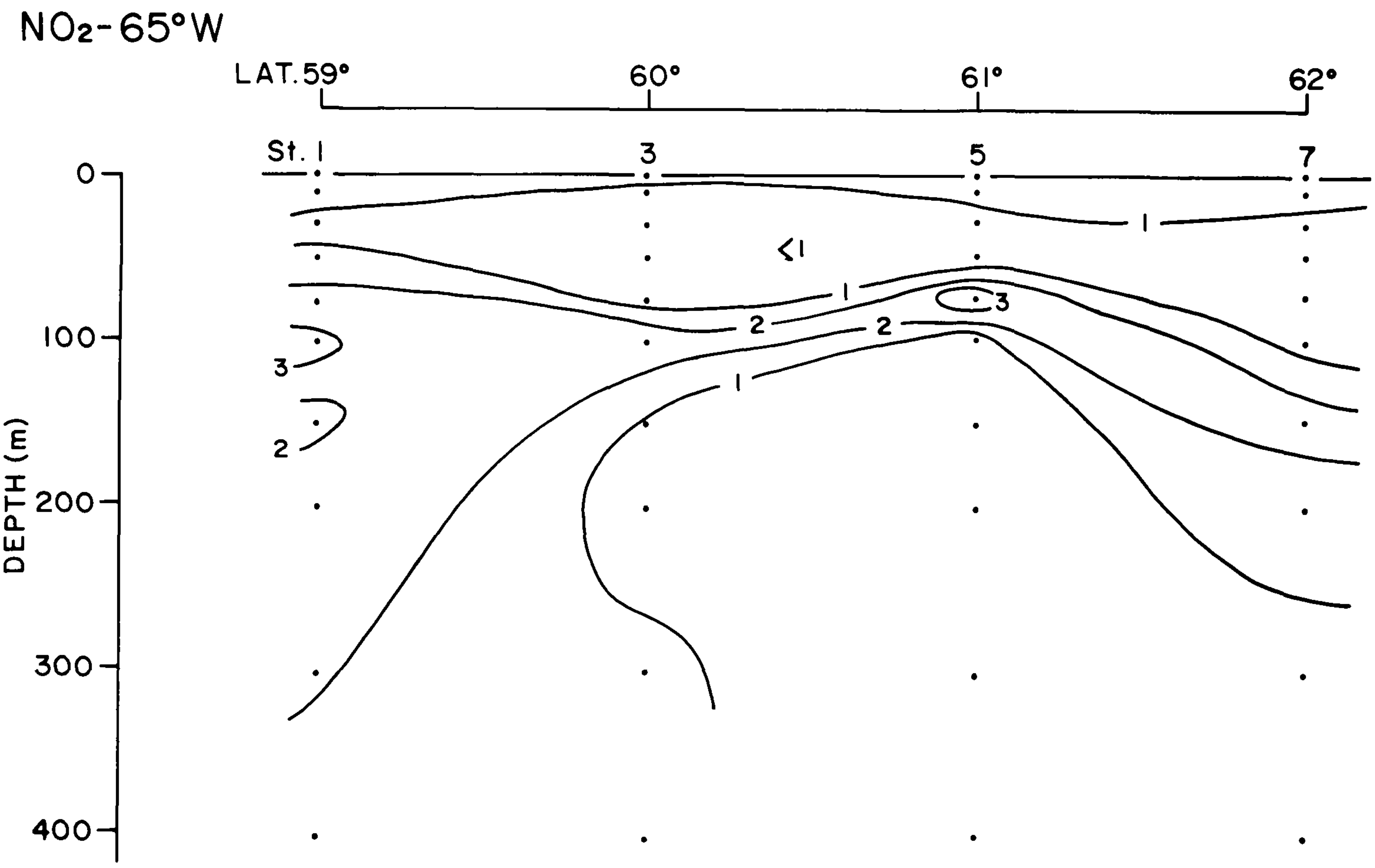

Fig. 5. Vertical section of nitrite along 65°W in the Scotia Sea (μg at N/1).

cumulation is possible due to the ammonium oxidizing bacteria in the light deficiency.

In the northwestern portion of the Scotia Sea where the influence of ACC is dominant, nitrate concentration in the surface waters ranged between 10-15 μg at N/ℓ (Fig. 6). Surface nitrate concentration were below 10 μg at N/ℓ between Elephant Islands and S. Orkney Islands. Vertical section of nitrate along 45°W showed almost uniform distribution from the surface to 100 m depth (Fig. 7). At St. 26, subsurface maximum of nitrate (34.78 μg at N/ℓ) coincided with low temperature (−0.34°C). Michel (1984) has pointed out that small nitrate maximum showing 1-3 μg at N/ℓ more of nitrate than surrounding waters occurred at 200-300 m in the Scotia Sea. But this was not found during our survey.

In the surface waters silicate concentrations showed no consistent horizontal gradient north to south (Fig. 8). But at 30 m depth silicate concentrations showed a marked difference between two zones; low in northwestern sectors and high in southeastern sectors. (Fig. 9). High silicate contents found in southeastern stations suggest again the large influence of WSW in this area. According to Carmack (1973) silicate concentrations reached 110-120 μg at Si/ℓ and surface concentration exceeded 60 μg at Si/ℓ in the Weddell Sea. But in the circumpolar waters silicate contents are 2-3 times lower than those values. Reid *et al.* (1977) pointed out that in the Atlantic sectors of Southern Ocean silicate concentrations were high in Weddell Sea Waters showing dramatic change of its concentrations between 50° and 60°S. This distribution pattern, which is very different from most of the other nutrients, reflects its assimilation and polymerization by diatoms and silicoflagellates. Bogdanov *et al.* (1969) used near-surface silicate concentrations to delineate the position of Weddell Sea and circumpolar waters. Michel (1984) has also demonstrated water temperature below 0°C means the marked influence of WSW and showed high concentrations of silicate.

The possible effects of inorganic nutrients on Antarctic phytoplankton should be interpreted in relation to our knowledge of nutrient uptake and growth kinetics. When such quantitative data are treated by the Michaeilis-Menten enzyme kinetics, the Ks constants (half saturation constants) will give some insight into the interpretation of nutrient effects on natural populations. Studies with marine phytoplankton have shown Ks constants of about 0.1 to 6.5 μg at N/ℓ for nitrate (Thomas and Dodson, 1974; Eppley and Thomas, 1969) and about 0.5 to 3.3 μg at Si/ℓ for silicate (Paasche, 1973). In our study area, these nutrients are in high concentrations and most likely are not limiting phytoplankton growth.

Recent work has shown the importance of ammonia as a nitrogen source in the Antarctic Ocean. They emphasized that heterotrophic bacteria are as active in the Antarctic as in temperate waters and that excretion by krill of ammonia is likely to be a significant fraction of the nitrogen required by phytoplankton (Biggs, 1982; Olson, 1980).

. Horizontal distribution of chlorophyll *a* concentrations in the surface waters during the study period is shown in Fig. 10. Northwestern stations are characterized by low concentrations of chlorophyll *a*. Surface chlorophyll *a* concentrations were lower than 1 mg/m^3 at the northwestern stations. At St. 30, south of S. Orkney Islands surface chlorophyll *a* content was 7.15 mg/m^3 suggesting the spring bloom of phytyoplankton. High chlorophyll *a* contents were also found south of Elephant Islands. At the middle stations, surface chlorophyll *a* contents were 1-3 mg/m^3. It is quite interesting to note that, during our study period, phytoplankton bloom occurred only in southern stations influenced by Weddell Sea Waters while low chlorophyll contents were found in the middle stations where dense krill swarms were found.

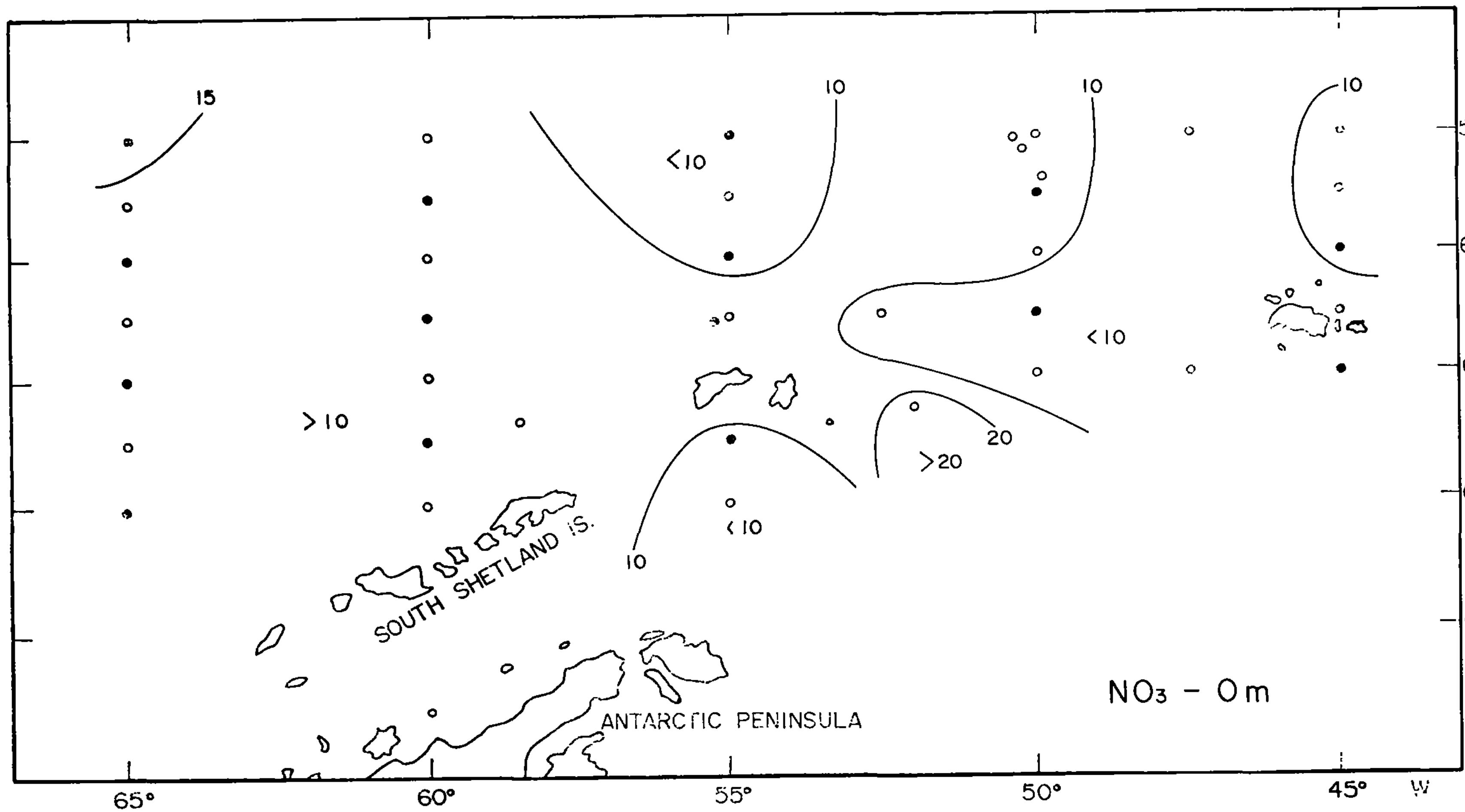

Fig. 6. Distribution of nitrate in the Surface waters in the Scotia Sea (μg at N/1)

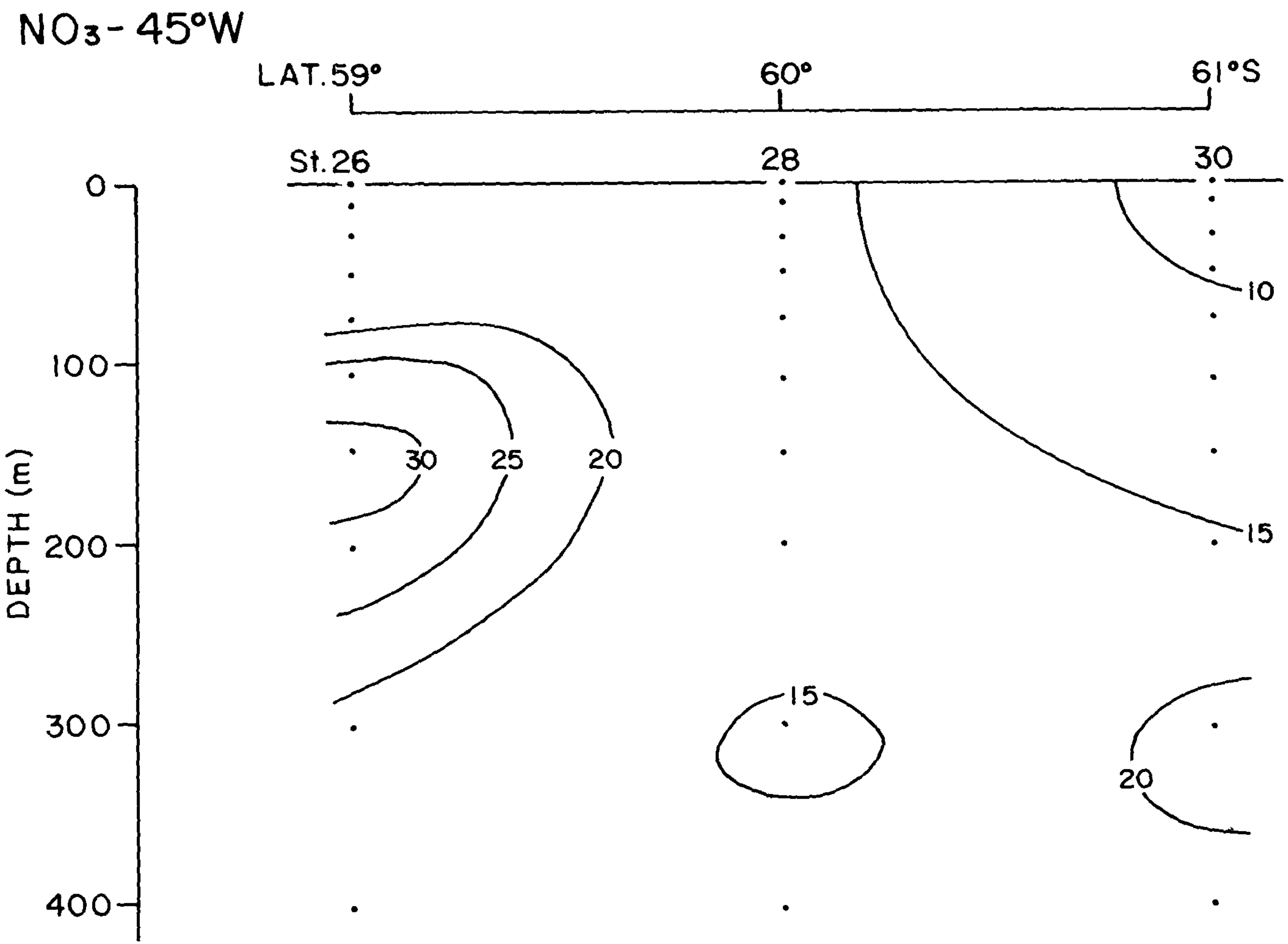

Fig. 7. *Vertical section of nitrate along 45°W in the Scotia Sea* (μg at N/1).

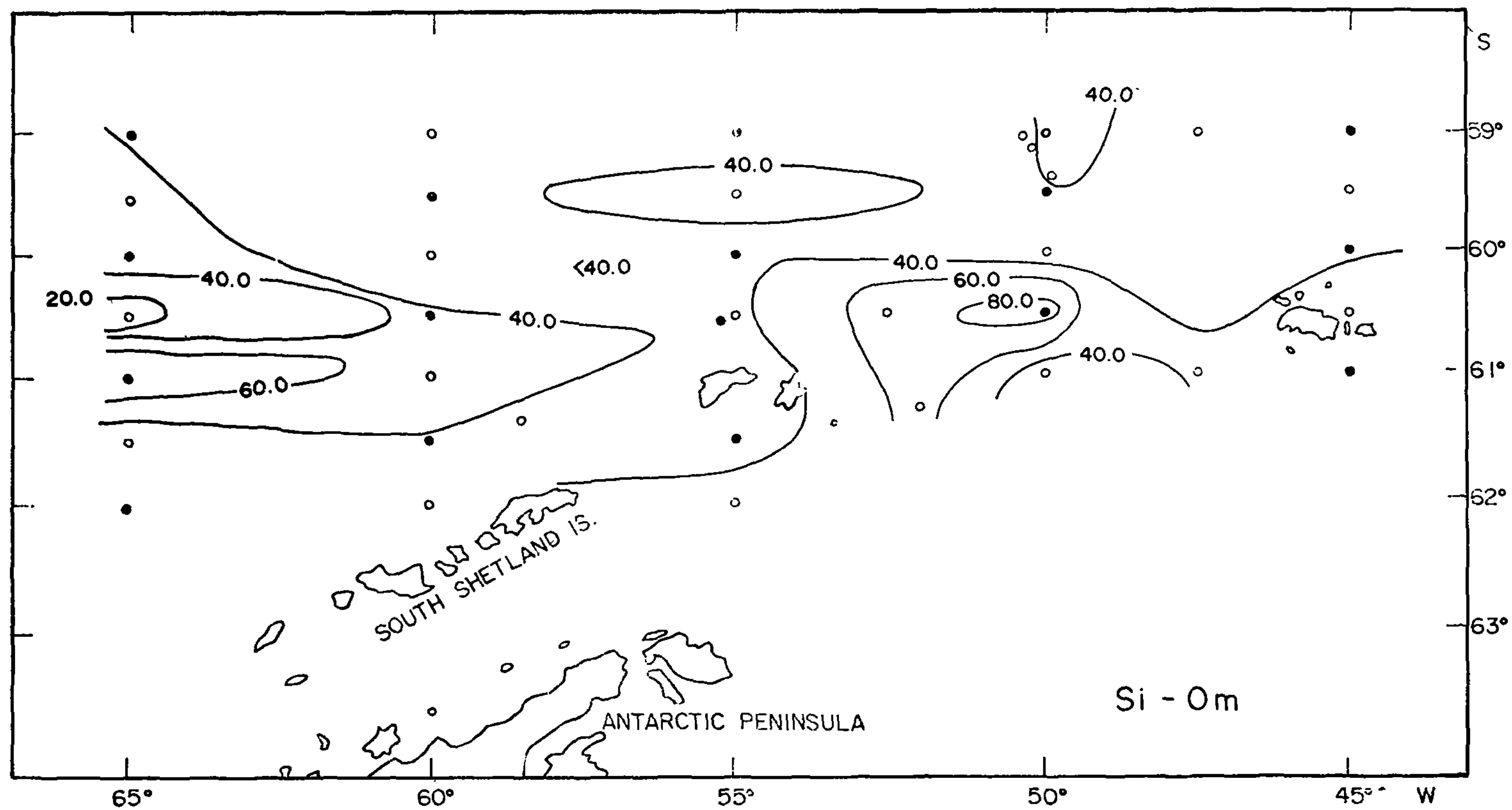

Fig. 8. Distribution of silicate in the Surface waters in the Scotia Sea (μg at Si/1).

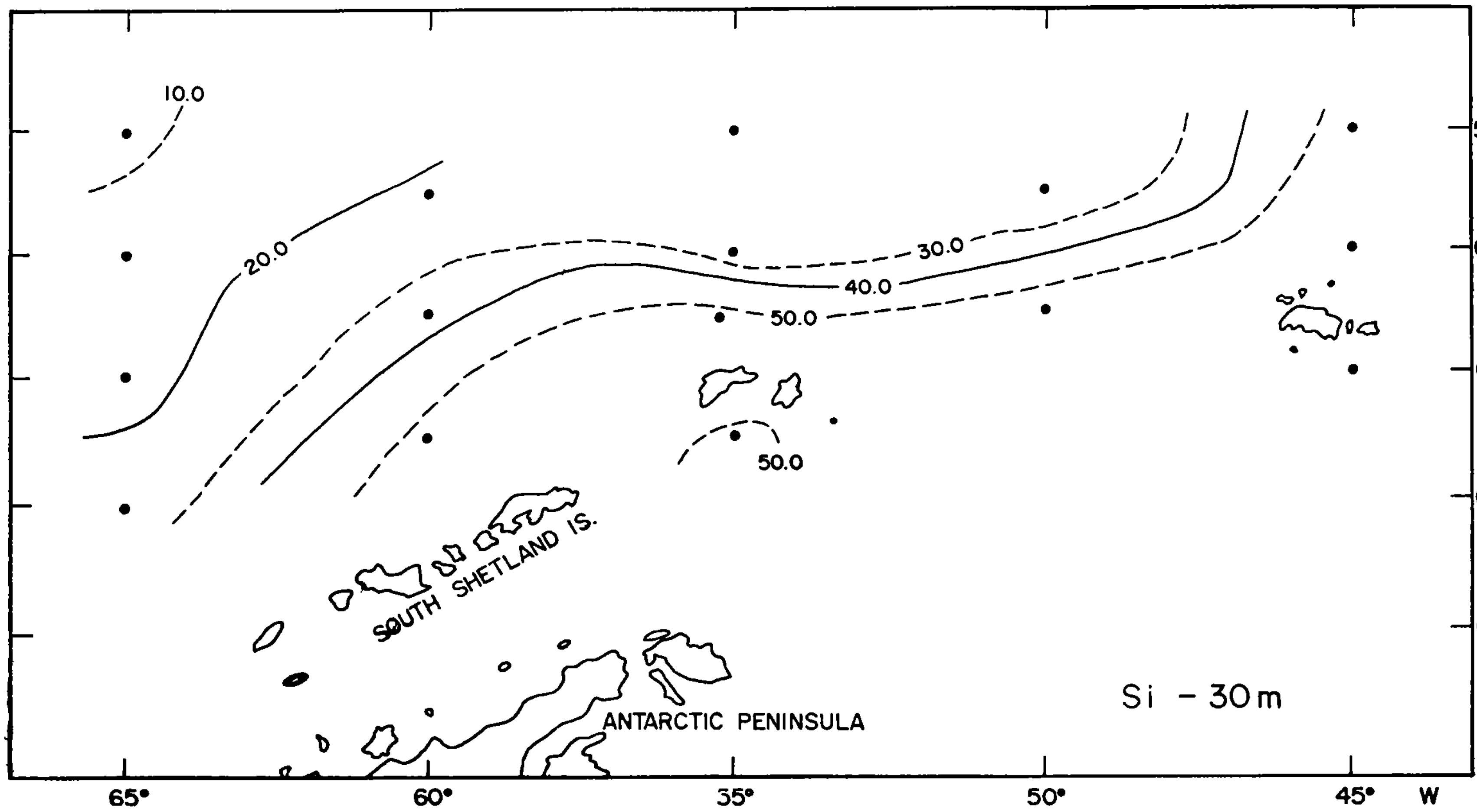

Fig. 9. Distribution of silicate at 30m depth in the Scotia Sea (μg at Si/1).

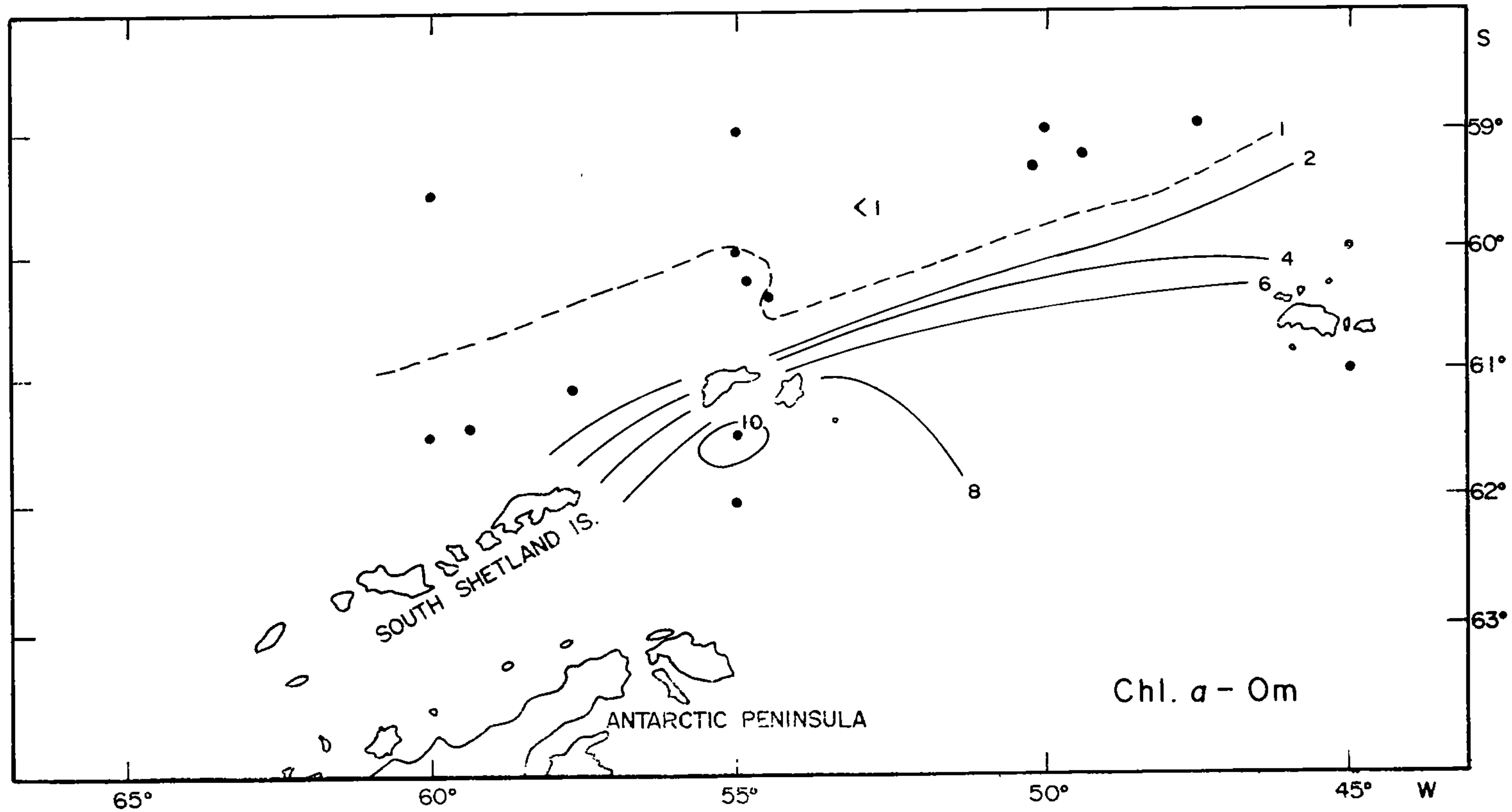

Fig. 10. Distribution of chlorophyll a in the surface waters in the Scotia Sea (mg/m³).

Chlorophyll *a* concentrations in the Southern Oceans are known to be low despite the high nutrient concentrations due to the Antarctic Divergence. Fukuchi (1980) reported surface chlorophyll *a* concentrations of 0.21-0.33 mg/m³ in the Southern Ocean as a whole. Howevei high chlorophyll *a* contents were occasionally measured near S. Shetland Islands and Elephant Islands during spring bloom. Burkholder and Mandelli (1965) measured 25 mg/m³ of chlorophyll *a* in the Gerlache Strait, and El-Sayed (1971) found 190 mg/m³ of chlorophyll *a* in the surface waters off Filchner Ice Shelf in the Weddell Sea during the extensive bloom of phytoplankton in 1968.

Early workers emphasized the richness of the phytoplankton crop but recent work has shown that the rate of primary production is quite low, being comparable to oligotrophic waters. The growth period of antarctic phytoplankton is generally restricted to a few months. The annual production cycle in the Antarctic is characterized by increasing plant biomass during the spring to a short-lived peak, followed by a decline to very low values in the winter.

Previous work has considered several environmental factors which might limit the phytoplankton growth in the Antarctic Ocean. These are temperature, light, nutrient, and stability of the water column. Several investigators have drawn attention to the importance of the stability of the water column in controlling production (El-Sayed, 1971). High stability favours the maintenance of the phytoplankton population in a zone of favourable light intensity. El-Sayed and Mandelli (1965) also attributed the low productivity of the Southern ocean to the comparatively low stability of surface waters, which prevents the organisms for remaining in the optimum light zone long enough for extensive production. One of the probable reason for the phytoplankton bloom in the southeastern stations of our study area is the stability of water column encountered by melting waters in spring. Unfortunately we don't have sufficient hydrographic data to support this suggestion.

Conclusion

In the Scotia Sea two water masses with different characteristics come in contact, the Antarctic Circumpolar Current and Weddel Sea Waters. During our expedition, it was shown that surface temperature below 0°C was found in the southestern stations of the study area with a thermal front near Elephant Islands and S. Orkney Islands. Surface nitrate concentration ranged from 10 to 15 μg at N/ℓ in the northwestern stations whereas less than 10 μg at N/ℓ of nitrates were detected in the southeastern stations. Silicate concentrations were high in the southeastern stations suggesting the influence of Weddell Sea Waters. Above results might suggest the existence of Weddell-Scotia Confluence between northwestern stations and southeastern stations of our study area. The southeastern stations were extremely high in chlorophyll whereas low chlorophyll contents were measured at the middle stations where dense krill swarms were found. The stability of the water columns encountered by melting waters in spring might favor the phytoplankton bloom in the southeastern stations influenced by Weddell Sea Waters. But our data are not sufficient enough to discuss the reasons for the phytoplankton bloom in the study area. More studies should be conducted in this region to understand and cycling of nutrients and mechanism of primary production because important krill swarms were found in the middle stations of the Scotia Sea.

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Egg-Laying and Fertility in Pygosceles Papua

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Juan C. Puig Bur and Juan A. Sanchez Mendez

Abstract

It is carried out different types of eggs removing in three series of nests. Each experience is made at different stages of the egg-laying and broodiness periods, what gives us the following results:

a) different stimulus of egg-laying.
b) support of fertility.
c) at the brief period of egg-laying a very important contribution of nutrients is produced.

Introduction.

This working group, which is not integrated by nutritionists, was made up to study eto-ecology on Pygosceles with a well-defined goal of protectionism according to the Antarctic Treaty. Convinced that the real protection will be achieved with a maximun knowledge on flora and fauna.

This work was developed in the Summer Antarctic Campaign 1987/88 and is still not completed in any aspects, but let us know different elements and make general interpretations in the nutritional and ecological area at the very moment of egg-laying and incubation time. (17)

In this specie, in a 20 days period (normal duration of egg-laying) to a maximun of a 40 days period, duplicate or more the egg-laying and we estimate in 135 grs. each egg so it can be seen that in a very short time a very important contribution of nutrients is produced. (21) (4) (2)

Pygosceles papua according to its reproduction instinct has well-defined periods such as gallantry, egg-laying, incubation, chick's breeding, etc., in which there are almost not individualities, that is to say, all members of a nest, with some little difference in days, have almost a simultaneous evolution. For this reason, when appears an atypical case, it is self-evident in such an uniform group.

Year after year while following the observations of chick's growing from its birth date, we can find two exceptional events:

1) The smaller chicks are left in a kindergarten; these chicks have a good conformation and growth but they are one or two weeks younger than the average age-group.

2) Nests with a well developed chick and a cooled egg with the dead embryo.
For these two main reasons, this work was developed to search an explanation of these events.

Methods and Materials.

— Pygosceles papua
— Identification materials for nests and animals.
— Paint.
— Scales.
— Gauge.

In the nesting areas located in the map by letter "A", in Ardley Island, three nest groups are selected and called "a", "b" and "c" which are pointed out with wooden stakes fastened in the ground.

The group "a" has three nests; "b" has eight and "c" has seven.

"a") group of nests with two eggs each; this means they have completed their egg-laying.
"b") group of nests that are in the middle of the egg-laying, with one egg each.
"c") group of nests that in spite of having a normal egg-laying of two eggs each, the removing phenomenon begins 10 days after having completed the stage. (10)(20)(9)(5)(3)(6)(8)

On 03.11.87 the situation was the following (See graphic representation):

"a": The three nests have two eggs each, one is removed from each nest leaving only one.
"b": The eight nests have only one egg each; all of them are removed.
"c": The integrating nests are marked; they have two eggs each.

The following day, all nests were checked out and once we were sure they were occupied by an adult penguin we observed the same situation that the day before.

09.11.87

"a": The three nests are still occupied and with only one egg.
"b": Seven nests have a new egg (2nd. egg-laying of these females) and the eighth nest is still empty. These seven eggs are removed so that the eight nests of this group will stand empty.

13.11.87

"a": Three nests with one egg each.
"b": The nest that in the date before was empty has now on egg; from the remaining seven nests, five have an egg (3rd. in its serie) and the other two are empty. All eggs are removed leaving empty the whole nests.
"c": The seven nests have two eggs each which are removed leaving empty the whole nests.

19.11.87

"a": They still have only one egg. It is normal the incubation process.
"b": On 13.11.87 two nests were empty, today one of them has an egg (3rd. egg-laying of the female) the other one has no egg but it is occupied. Another three nests have an egg belonging to fourth egg-laying and the remaining nests are empty. In brief, we have:
   — three nests with the fourth egg-laying.
   — one nest with the third egg-laying (pointed with a stake).
   — four nests empty; two of them belongs to second egg-laying and the other ones belong to third egg-laying.

From this group all eggs that were found till that date, are removed.

"c": The seven nests have a new egg; all of them are removed.

It must be pointed out that at this date, a routinist inspection of the various nesting areas in different locations of the island, shows us that 95 % approximately of nests have two eggs so we can assure that egg-laying has finished. We approach to this interpretation since all females has already laid two eggs (annually supposed).

26.11.87

"a: Only one egg is being incubated in the three nests.

"b":The eight nests are still covered by an adult penguin and only one of them has an egg which belongs to a female that has already laid four eggs, that is to say, this is the fifth egg which is not removed in order to observe its fertility.(9)

"c": Only a nest has an egg which is not removed, the other six nests are empty.

16.12.87

"a": There is a chick in a nest that was born approximately on 05.12.87, another nest is still with an egg and the third nest has two eggs.

"b":Two nests are forsaken; four have two eggs; two have only one egg. There are nine eggs- one more is left to observe its fertility at the fifth egg-laying on 26.11.87-which were laid between 23.11.87 and 15.12.87, so there will be births between december 1987 and January 1988.

"c": There are four nests that had been forsaken, one of them on 26.11.87 had an egg which disappeared unknowing the cause of this fact. Two other nests have two eggs and the seventh nest has only one egg.

29.12.87

At this time, egg-laying are still being recorded in groups "b" and "c".

"a": No changes were observed.

"b":Four nests were forsaken. Three with two eggs (3rd., 4th. and 5th. egg-laying). One nest with a chick aged one or two days what give us evidence that, a thrid or fourth egg laid by a female from the beginning of its egg-laying is still fertile.

"c": There are four forsaken nests and three with two eggs belonging to 4th. and 5th. egg-laying.

06.01.88:

A new egg-laying is recorded in group "a".

"a": There are two nests each one incubate two eggs and the chick of the third nest was left by its parents in a kindergarten, leaving in this way its original place.

"b":Four forsaken nests. Two with two eggs each. One with an egg and a chick. One with a chick.

"c": Only three nests are still occupied having two eggs each.

17.01.88

"a" One nest has two eggs. Another nest has two just born chicks.

"b":Four nests are still occupied and three of them have two chicks each and the fourth has only one chick.

Taking into account the birth date and once we made and inspection on 16.12.87, we estimate that the egg-laying took place a few days befoer that date.

"c": There are only two occupied nests, one has two eggs and the other one has an egg and a just born chick. Due to the birth date we estimate that egg-laying took place about

13.12.87.

29.01.88

"a": There is only one nest with two chicks aged about two weeks and watched over by a couple of adult penguins. The other nest was forsaken and the eggs had disappeared. With reference to the third nest, the chick was in the kindergarten.

"b": There are only three occupied nests with two chicks each watched over by an adult penguin. The chick of the fourth nest has already been included in the kindergarten being self-evident because of its small size due to its under age.

"c": There is only a nest with a chick and a cooled egg with the dead embryo. The other nest was forsaken and without eggs.

Results.

Group "a":

The removing of an egg of the two laid by the female during the egg-laying period, slowly stimulate a new process of ovulation with the natural goal of replacing the eggs that have been lost and in this way to preserve the amount of progeny. Due to the final results we can observe the nest that achieved two chicks on 17.01.88, the egg-laying had to occur about 10.12.87, that is to say, the egg left on 13.11.87 was lost due to unknown causes. We achieve to prolong the egg-laying and incubation periods and an increment of 50% in the ovulation average.

Group "b":

These are more interesting results. The normal egg-laying period for this island is between 2nd. and 19th. November, that is approximately 20 days. The incubation period goes to 30th December, therefore four results can be taken from this group: (15)(13)(14)

1) The lack of two eggs (total egg-laying) is a strong stimule that lead to new ovulations and therefore new eggs.(17)
2) Considerable increment -30 to 40 days- in the egg-laying an incubation periods. (20)(16)(13)
3) In figures, the egg-laying was stimulated about 200 to 300%; all eggs were fertile and producing -at the end of incubation- viable chicks which are able to achieve a very good growth but younger than the average of the majority. Undoubtedly this is a natural defense of Pygosceles papua against the eggs loss that normally happen whether the eggs come off their nests and parents do not put them again into place or they are caught by depredators birds.(12)
4) It is considerable the amount of forsaken nests. Perhaps this is caused by an hormonal physiological depletion of the adult penguins.(17)(6)

Group "c":

This group give us two main results:

1) When egg removing is made too late -that is nearly the final stage of egg-laying- the ovulation possibility becomes difficult, perhaps provoked by a decrease of the normal hormonal level so that the nest forlornness is greater.
2) When both eggs inside the same nest have a greater difference than 10 days from the moment of its egg-laying, the first chick has enough time to grow in such a way that it manage to displace the other egg far away from the warmth source -its father- or pull it out the

nest what causes a cooling of the egg and consequently the embryo death. (See photograph).
No morphological differences of eggs -weight and shape- were seen. (4)(21)(2)

Discussion.

As a general idea Pygosceles papua has an egg-laying of two eggs.(20)(21)(4)

Our experience with reference to the performed observations made clear two main events that an explanation had not been found yet, should it be only one egg-laying of two eggs, next to each other in a very short period of time, it could be found:

a) Small chicks with normal growth but well-known differences at kinder-garten.

b) chicks in the nest with very good growth but a delay in the other egg which does not finish its evolution (displaced eggs).

So that this fact could happen it is necessary distanced births provoked by accidents or non biological phenomena of the species.

The experience shows us that exists a reaction in defense of the species to compensate losses in this evolution period.

The experience also shows us an unexposed aspect or at least it was not taken into account, the egg-laying of this birds is a very important nutritional element to another species such as skuas and sea gulls. (21)(4)

This phenomenon is not noticed from the nuritional point of view because of the high compensating answer of Pygosceles.

Conclusion (Preliminary)

— From the physiological point of view, hormonal verifications will have to be done in order to determine the observations that have been already done. (11)(7)(16)(14)(10).

— Undoubtely if these are experimental works, they are justifying a real event of the nature. (1)

— The quantification in tons. and the amount of eggs in such a short period of time (20 days) are not possible to be estimated but taking into account the great number of individuals that compose this species it is evident the importance in the feeding chair of the antarctic cycle.(22)(19)

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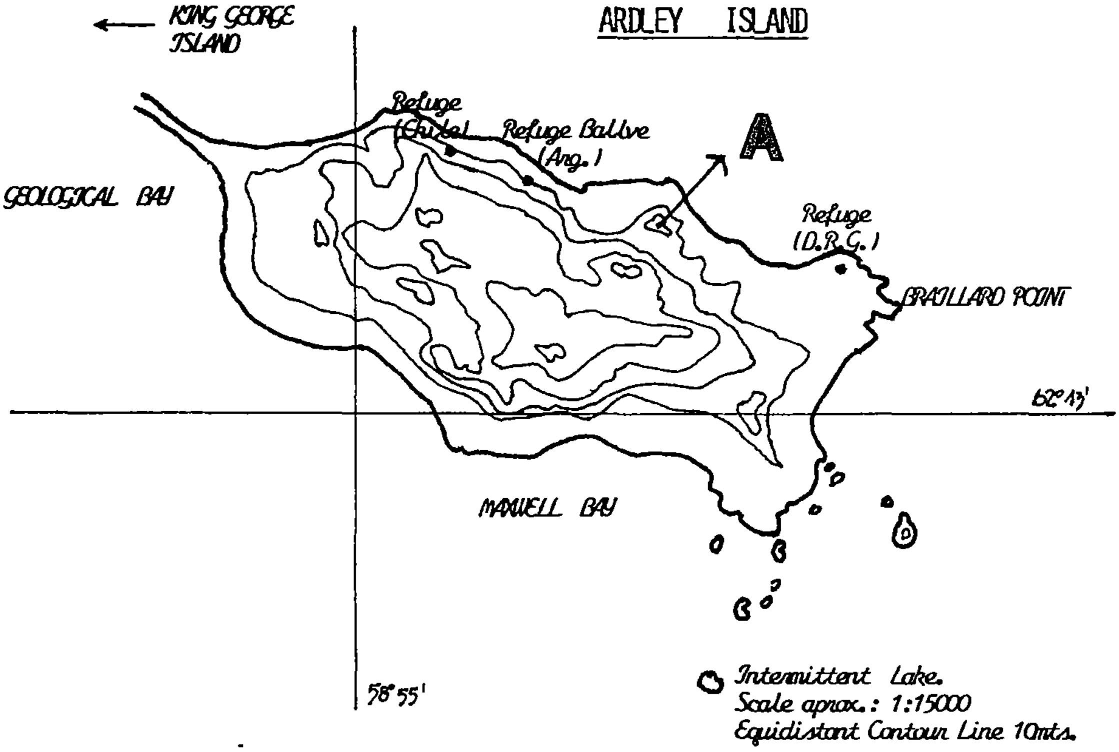
WORKING PLACE



GRAPHIC REFERENCES OF THE WORK:

Egg in the nest.

Egg removed from the nest.

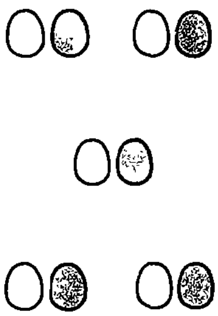
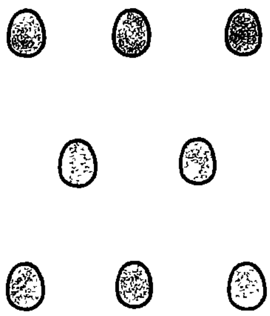
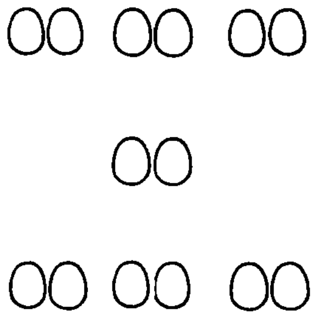
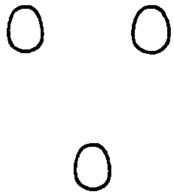
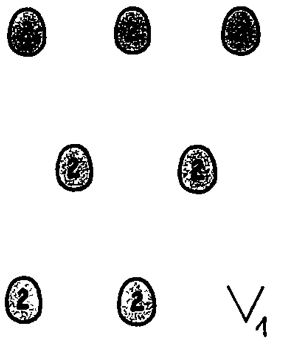
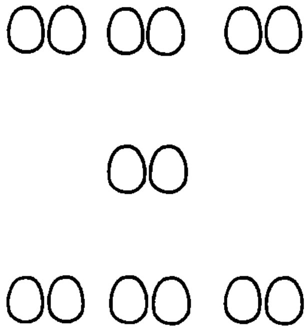
Empty nest.

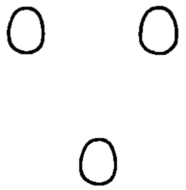
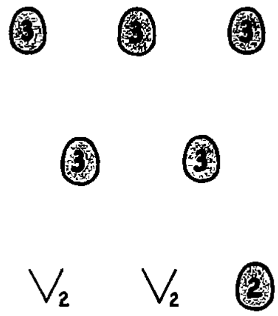
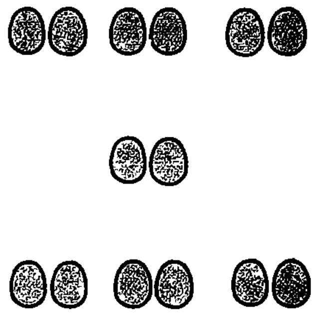
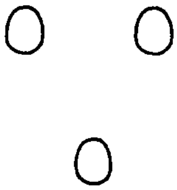
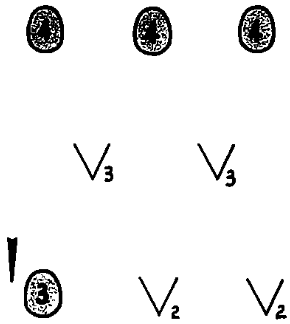
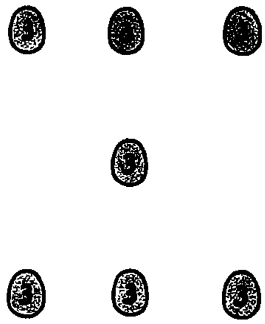
Born chick.

Chick in the kindergarten.

Wooden stake.

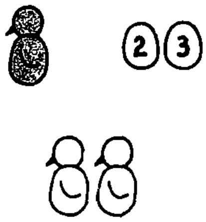
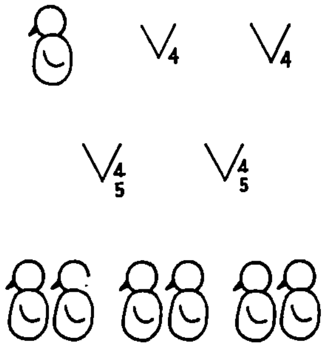
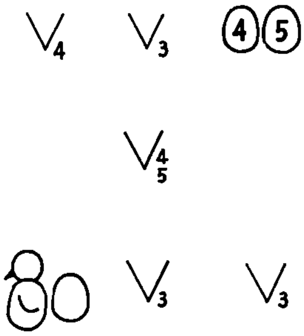
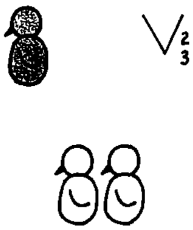
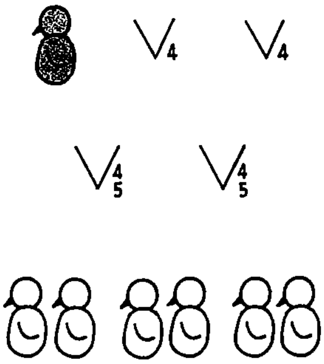
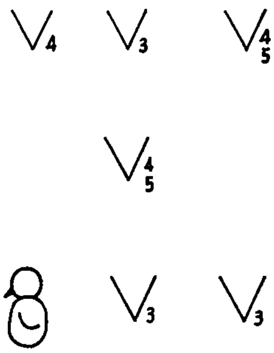
The number inside the egg or accompayning V indicates to which egg-laying corresponds.

DATE	GROUP "a" Total 3 nests	GROUP "b" Total 8 nests	GROUP "c" Total 7 nests
3/11/87	 3 nests, 2 eggs each 1 egg is removed from each nest	 8 nests, 1 egg each All eggs are removed	 7 nests, 2 eggs each Eggs stand in their nests
9/11/87	 3 nests go on with 1 egg each	 7 nests, 1 egg, 2nd. egg-laying. 1 empty nest. All eggs are removed.	 7 nests, 2 eggs each Eggs stand in the nests

DATE	GROUP "a"	GROUP "b"	GROUP "c"
13/11/87	 3 nests are still with one egg each.	5 nests, 1 egg, 3rd. egg-lay. 1 nest, 1 egg, 2nd. egg-lay.  2 nests are empty. All eggs are removed.	 7 nests, total egg-laying more than 10 days of incuba-tion. All eggs are removed.
19/11/87 95% 2 eggs .	 3 nests are still with 1 egg each.	3 nests, 1 egg, 4th. egg-lay. 1 nest, 1 egg, 3rd. egg-Lay.  4 empty nests {2=2nd. egg-lay. 2=3rd. egg-lay.} All eggs are removed.	 7 nests, 1 egg each, 3rd. egg (Laying. All eggs are removed.

DATE	GROUP "a"	GROUP "b"	GROUP "c"
26/11/87	○ ○ ○ 3 nests are still with one egg each	1 nest, 1 egg, 5th. egg-lay. this is not removed. ⑤ V_4 V_4 V_3 V_3 V_3 V_2 V_2 7 empty nests: 2 = 4th. egg-laying 3 = 3rd. egg-laying 2 = 2nd. egg-laying	1 nest, 1 egg, 4th. egg-lay. this is not removed. ④ V_3 V_3 V_3 V_3 V_3 V_3 6 empty nests.
16/12/87 Birthdate aprox. on 5 Dec.	 ② ②③ 1 nest, 1 chick 1 nest, 1egg, 2nd. egg-lay. 1 nest, 2 eggs { 2nd. egg-lay. 3rd. egg-lay.	2 nests, 2 eggs { 3rd. egg-lay. 4th. egg-lay. 2 nests, 2 eggs { 4th. egg-lay. 5th. egg-lay. ⑤ V_4 V_4 ④⑤ ④⑤ ④ ③④ ③④ 1 nest, 1 egg, 4th egg-lay. 1 nest, 1 egg, 5th. egg-lay. 2 empty nests.	2 nests, 2 eggs { 4th. egg-lay. 5th. egg-lay. 1 nest, 1 egg, 4th. egg-lay. V_4 V_3 ④⑤ ④ ④⑤ V_3 V_3 1 nest: 1 egg disappears. 3 forsaken nests.

DATE	GROUP "a"	GROUP "b"	GROUP "c"
egg-laying are recorded in groups "b" & "c" 29/12/87	② ②③ 1 nest. 1 chick. 1 nest, 1 egg, 2nd. egg-lay. 1 nest, 2 eggs {2nd. egg-lay. 3rd. egg-lay.	V_4 V_4 $V_{4,5}$ $V_{4,5}$ ④⑤ ③④ ③④ 1 nest, 1 chick 3 nests, 2 eggs each 4 forsaken nests.	3 nests, 2 eggs each. V_4 V_3 ④⑤ ④⑤ ④⑤ V_3 V_3 4 forsaken nests.
egg-lay. is recorded in group "a". 6/1/88	1 nest, chick in the kindergarten. ②③ ②③ 2 nests, 2 eggs each, 2nd. and 3rd. egg-laying.	1 nest, 1 chick. 1 nest, 1 chick, 1 egg. 2 nests, 2 eggs each. V_4 V_4 $V_{4,5}$ $V_{4,5}$ ④⑤ ③④ ④ 4 forsaken nests.	V_4 V_3 ④⑤ ④⑤ ④⑤ V_3 V_3 3 nests, 2 eggs each. 4 forsaken nests.

DATE	GROUP "a"	GROUP "b"	GROUP "c"
17/1/88	1 nest, chick in the kindergarten.  1 nest, 2 eggs 1 nest, 2 chicks	1 nest, 1 chick.  3 nests, 2 chicks 4 forsaken nests.	1 nest, 1 chick, 1 egg.  1 nest, 2 eggs. 5 forsaken nests.
29/1/88	1 nest, chick in the kindergarten.  1 nest, 2 chicks. 1 forsaken nest.	1 nest, chick in the kindergarten.  3 nests, 2 chicks each. 4 forsaken nests.	1 nest, 1 chick.  6 forsaken nests.

Chilean Antarctic Research: Main Biological Contributions for the Antarctic Conservation

Daniel Torres

Abstract

Long before the establishment of the Antarctic Treaty, Chile had already started some projects on biological research in Antarctica. The book 'Biologia de la Antartica Suramericana' (Mann, 1947) was the base on which many scientists began their scientific research line in the Antarctic.

For the purpose of this contribution, a synopsis on three research programs, will be given by which their activities, permanence, and contribution to the knowledge for the conservation of the Antarctic ecosystem, I want to mention here. The first one is 'Studies on benthic communities' whose research activities began in 1966, and have been centralized mainly in Chile Bay, Greenwich Island, and in Port Foster, Deception Island (South Shetland Islands), specially in the latter where sucessive volcanic eruptions have given the opportunity to know part of its dynamics which, naturally, differs from the first one. The results of this research have permited to the Antarctic Treaty Parties to declare such places as Sites of Special Scientific Interest (SSSI), No26 and 27, respectively.

Another scientific program is 'Antarctic fish ecology'. It was initiated in 1969, in Greenwich and King George Islands, but since 1972 until now has been developed in South Bay, Doumer Island, Palmer Archipelago. This is the 'model place' on which the trophodynamic of Nototheniidae has been studied, as well as the characteristics of the habitats occupied by the different fish species, their bathymetric distribution, some reproductive strategies, etc. The results of these studies -some of them unexpected- has permitted to give antecedents to Convention for the Conservation of the Antarctic Marine Living Resources (CCAMLR), for conservation purposes, as well as for the Antarctic Treaty to establish part of the South Bay as a SSSI N°11.

At least, the program on 'Ecological studies on marine mammals', started in the austral summer 1965-66, carrying out the first census of Pinnipedia in the South Shetland Islands and Palmer Archipelago, permited after that to focus scientific research on the Antarctic fur seal (*A. gazella*) population at the beginning of their recovery in these islands. The finding of a small breeding colony of this species at Cape Shirreff, gave the basis by which Chile asked for its protection to the Antarctic Treaty Parties, proposition that was accepted and established as a Specially Protected Area No11, whose status remains until now. In that place, periodical

census and tagging activities have been done from 1981-82 to date, which results show a constant population increase.

The results of these three Antarctic research program have given interesting antecedenrts for the Antarctic Conservation, the CCAMLR purposes, and for the related ecosystem such environmental protection established in the recently approved Convention on the Regulation environmental protection established in the recently approved Convention on the Regulation of Antarctic Mineral Resources Activities (CRAMRA).

Introduction

After the scientific success obtained during the held of the International Geophysical Year in the season 1957-58, an important and trascendental step was fulfilled by twelve nations with Antarctic interests, some of them with territorial claims: On December 1st, 1959 was signed the Antarctic Treaty, which came into force on June 23rd., 1961.

The primary purpose of the Antarctic Treaty is to ensure 'in the interest of all mankind that Antarctica shall continue for ever to be used exclusively for peaceful purposes and shall not become the scene of object of international discord'. The Tréaty provides for 'freedom of scientific investigation in Antarctica promotes international cooperation in scientific investigation in Antarctica' and encourages 'the establishment of cooperative working relations with those specialized Agencies of the United Nations and other international organizations, having a scientific or technical interest in Antarctica'. And the Article IX, f) of the AT states: 'preservation and conservation of living resources in Antarctica' (Antarctic Treaty System, 1987).

Taking all these purposes as a base of our scientific activities, the researchers of different universities along Chile, with the support of the Instituto Antartico Chileno, are dedicated to develop activities that -besides to contribute to the Antarctic knowledge and its natural resources- they can give scientific basis to develop conservation in the area. Consequently, the purpose of this contribution is to present a results of three lines of biological research and their global contribution for the conservation of the Southern Ocean ecosystem and the related ones.

Scientific research work and its contributions

1. Benthonic Communities

Dr. Victor A. Gallardo, from the Universidad de Concepcion, began his field research in the summer season 1966-67, working in both soft and rocky bottom bays, with the purpose of knowing the diversity and differences from one to another benthic communities. The main places were located at Chile Bay, Greenwich Island and Port Foster, Deception Island, South Shetland Islands (Fig. 1). The objective proposed for the first site, according to Gallardo and Retamal (1988) was to test the hypothesis that the benthonic communities should have a high specific diversity as a result of its environmental stability along the geological time. The field work was suspended due to volcanic eruptions in Deception Island. That situation gave an excellent opportunity to scientists to study immediately after the phenomenon its effects on the benthic fauna.

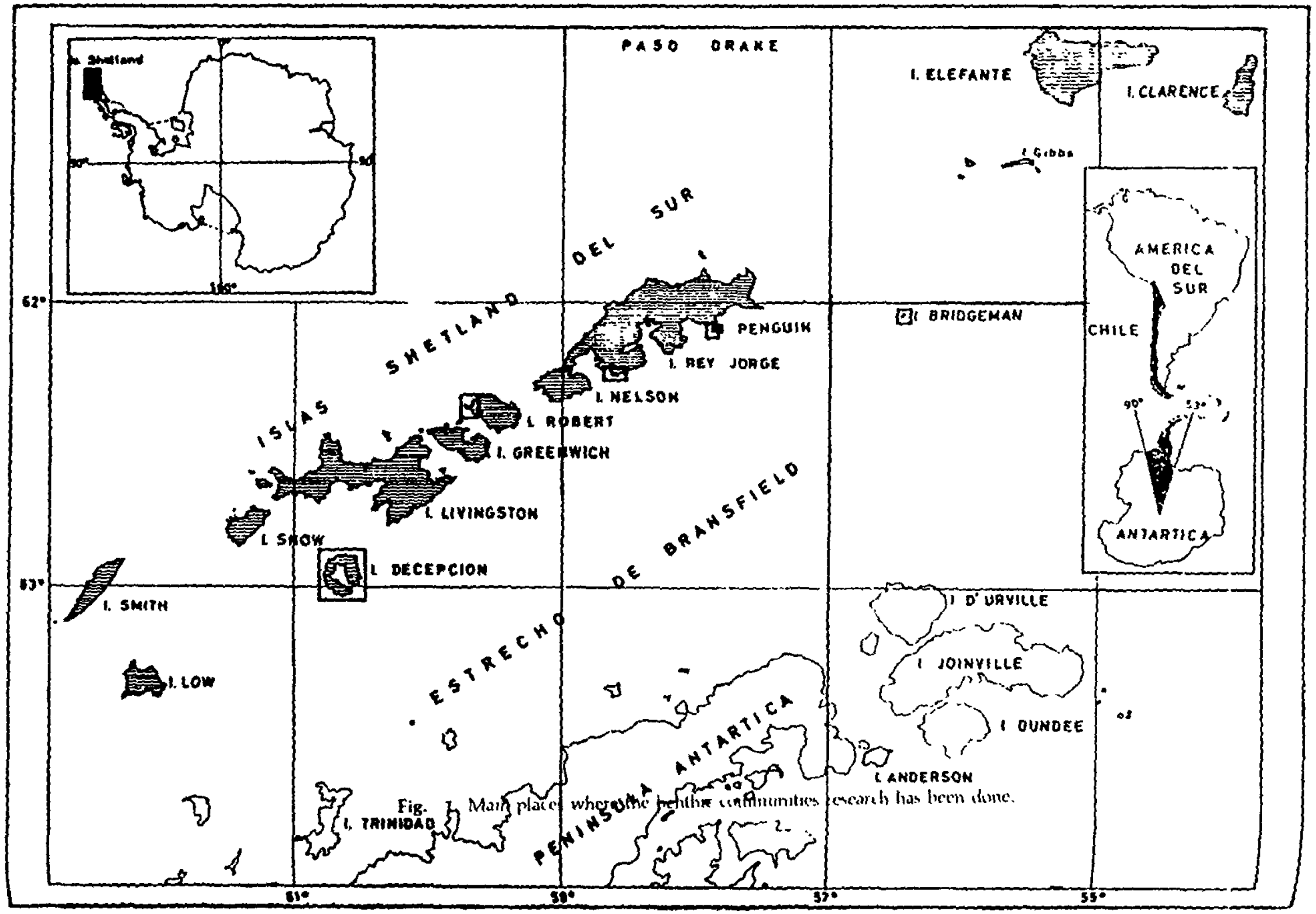


Fig. 1. Main places where the benthic communities research has been done.

In this way, the long term research began in order to follow step by step the recovery of the benthic communities in Port Foster, having the Chile Bay as a comparison or control reference.

Results:

a) Port Foster, Deception Island.

According to Gallardo and Castillo (1970), on 21st. and 31st. December 1967, a limited survey was carried out to take note about the effects caused by the volcanic eruption on the infauna of Port Foster. With Petersen grab samples and dredge hauls they obtained evidences that a great bottom area had been covered by volcanic ash with a layer of 30 cm., or 50 cm. according to Valenzuela *et al.* (1970) who give figures of 52×10^6 m^3 of material expelled, which had caused a mass mortality of the benthic fauna. This mortality was observed seventeen days after the volcanic eruption (Gallardo, 1987). Besides, the high temperature reached by water near the eruptive zones, the chemical and physico-chemical factors, the uplift of the bottom, the high concentration of toxic compounds such a sulphur, contributed to increase the mentioned mass mortality. All these factors may have also altered the primary productivity of the surface layer. The absence of fishes and other organisms was other alteration observed, too.

After that experience, other volcanic eruptions occurred at Port Foster in 1969 and 1970. Since then, the recovery progress of benthic fauna communities has had important changes among their principal components, due to drastic changes occurred especially by abiotic factors.

Table 1 shows a summary about the group changes observed at Port Foster from 1967 to 1981.

In addition to this information, in 1982 Echinodermata and Polychaeta were the dominant groups (INACH, 1982), while in January 1985 Echinodermata (*Ophionotus victoriae* and *Sterechinus neumayeri*) were the dominant orgnaisms at Port Foster (Gallado, 1987). Outside Port Foster, Amphipoda and Echinodermata have been always dominant, including other groups less representative such as Porifera, Bryozoa, Coelenterata and Tunicata. This diversity can be explained by the presence of a rocky bottom which is more stable than that of Port Foster, and permits the intersticial and epifaunal life.

The principal factors of this variation are: the modification of that ecosystem as a whole and the bottom type, including changes in abiotic factors (temperature, nutrients, salinity, O_2, pH, sedimentary movements with water masses, spring-summer snow-melt and the consequent addition of mud and coastal sediments, including eolic action) and biotic dynamics such as the primary productivity, phytoplankton feeders, types of zooplankton larvae which can enter Port Foster by means of external water masses, etc. So, some pioneer species under favourable conditions could have begun the recolonization.

In Port Foster there are scarcity of organic detritus because of the continue bottom changes due to burial action of ash and sediments and or dilution. But the high benthic density of detritivorous and filter feeders should be done and efficient use of the organic matter made available (Larrain, 1981). The most important groups successions was Polychaeta, Echiurida, and Cumacea.

Table 1 Percentage changes of prinicpal benthic groups at Port Foster, Deception Island*

Date	Group	%
Dec. 1967	Polychaeta	23.9
	Bivalvia	16.1
Jan. 1969	Bivalvia	59.6
	Amphipoda	23.0
Mar. 1969	Polychaeta	63.7
	Ophiuroidea	8.7
	Bivalvia	8.1
Dec. 1969	Polychaeta	66 0
	Bivalvia	14.6
	Amphipoda	14 1
Dec. 1970	Polychaeta	78.3
	Bivalvia	8.7
Jan. 1972	Echiuroidea	46 5
	Polychaeta	34.7
Jan. 1973	Echiuroidea	59.3
	Amphipoda	31.5
Jan. 1975	Polychaeta	37.5
	Cumacea	23.9
	Amphipoda	17.6
	Echiuroidea	16.4
Dec. 1976	Polychaeta	48.8
	Cumacea	30.7
	Amphipoda	13.3
Jan. 1978	Cumacea	65.4
	Polychaeta	25.8
Jan. 1981	Polychaeta	70.9
	Cumacea	23.3

Antarctic Treaty System, 1987. Handbook of the Antarctic Teraty System, Part 1, 5th, Edition. (Ed.): main invertebrate groups collected in Chile Bays

b) Chile Bay, Greenwich Island.

According to Gallardo (1987) the survey carried out in this undisturbed bottom fauna showed an infaunal community whose results are summarized in Table 2.

As we can see from the above figures, Polychaeta are the principal components of this benthic fauna. The analysis of 40 quantitative smaples collected in 39 benthic stations revealed 206 species distributed into 26 families in a total of 13,307 individuals. The Polychaeta Errantia comprises 11 families, 71 species, and a total of 535 individuals while the Sedentaria containes 15 families, 135 species, and a total of 12,772 individuals (Gallardo *et al.*, 1988); among Crustacea, Cumacea and Amphipoda are the principal representatives; and among Mollusca the Pelecypoda are also important in abundance as well as in biomass.

Table 2 Abundance and biomass of main invertebrate groups collected in Chile Bay

Groups	Abundance	Biomass
Polychaeta	61.3 %	46.6 %
Crustacea	15.2 %	2.4 %
Mollusca	12.1 %	15.7 %
Foraminifera	2.1 %	1.0 %
Echinodermata	1.7 %	14.9 %
Ascidiacea	<1.0 %	10.4 %

Data from Gallardo *et al.*, (1977).

Other important finding obtained by Chilean benthologists in Chile Bay is the evidence of two distinct assemblages distributed, according to Gallardo *et al.* (1977), along each side of approximately 100 m isobath. These asemblages differed from each other primarily in the presence of a large number and biomass proportion of one Polychaeta species: *Maldani sarsi antarctica*. Because of this, the deeper assemblage has been called '*Maldane* bottom', on which besides the Polychaeta, Mollusca and Pelecypoda are significant larger. The average number of individuals in the '*Maldane* bottom' was 602.8 per 0.1 m^2, and in the shallow bottom was 338.6 per 0.1 m^2. The mean biomass was not significantly different: 18.9. per 0.1 m^2, and 16.4g. per 0.1 m^2, respectively.

Following the information given by Gallardo *et al.* (op. cit.), according to their data, the following species exhibit an important degree of affinity with the '*Maldane* bottom': The Pelecypoda *Genaxinus bongrainii* and *Cyamomactra denticulatum* and the Tanaidacea *Typhlotanais greenwichensis.* The Pycnogonida species also appears to be a part of this assemblage.

On the other side, the following fauna appears to have an important preference by the shallower bottom: the Pelecypoda *Yoldia eightsi* the Cumacea *Eudorella gracilior,* and all the Ascidiacea and Gastropoda species.

Through the years of sampling, in Chile Bay it has been found some changes on density as well as in biomass of benthic fauna; but this variation is not comparable with that occurred in Port Foster bottom fauna. So, it is possible to conclude that in Chile Bay there is a relative stability, while at Port Foster there exists and aperiodical one, due to the impredictible volcanic eruption and the constant activity in this particular ecosystem.

It is not necessary to give more antecedents to explain the importance of continuing the studies at Port Foster in particular, as well as in other Antarctic areas, not only from the pure science point of view, but from the ecological one, because the benthic Antarctic communities have an important rol in relation with the population dynamics of some living resources, such as the fish species, some of whose stocks have been overexploited as it is well known by all of us. But this relation is not unique, because it is related to the recent CRAMRA approved in June 1988.

All these studies have led to Antarctic Treaty members to create both at Chile Bay (Fig. 2) and Port Foster (Fig. 3), the SSSI's to continue there this kind of studies. From the samples obtained new taxa has been described: Bryozoa: 1 family, Cellarinellidae, by Moyano; 8 Genera, *Cellarinelloides, Paracellaria, Trilaminopora, Larvapora, Jeqolcapora, Klugeflustra, Nematoflustra*

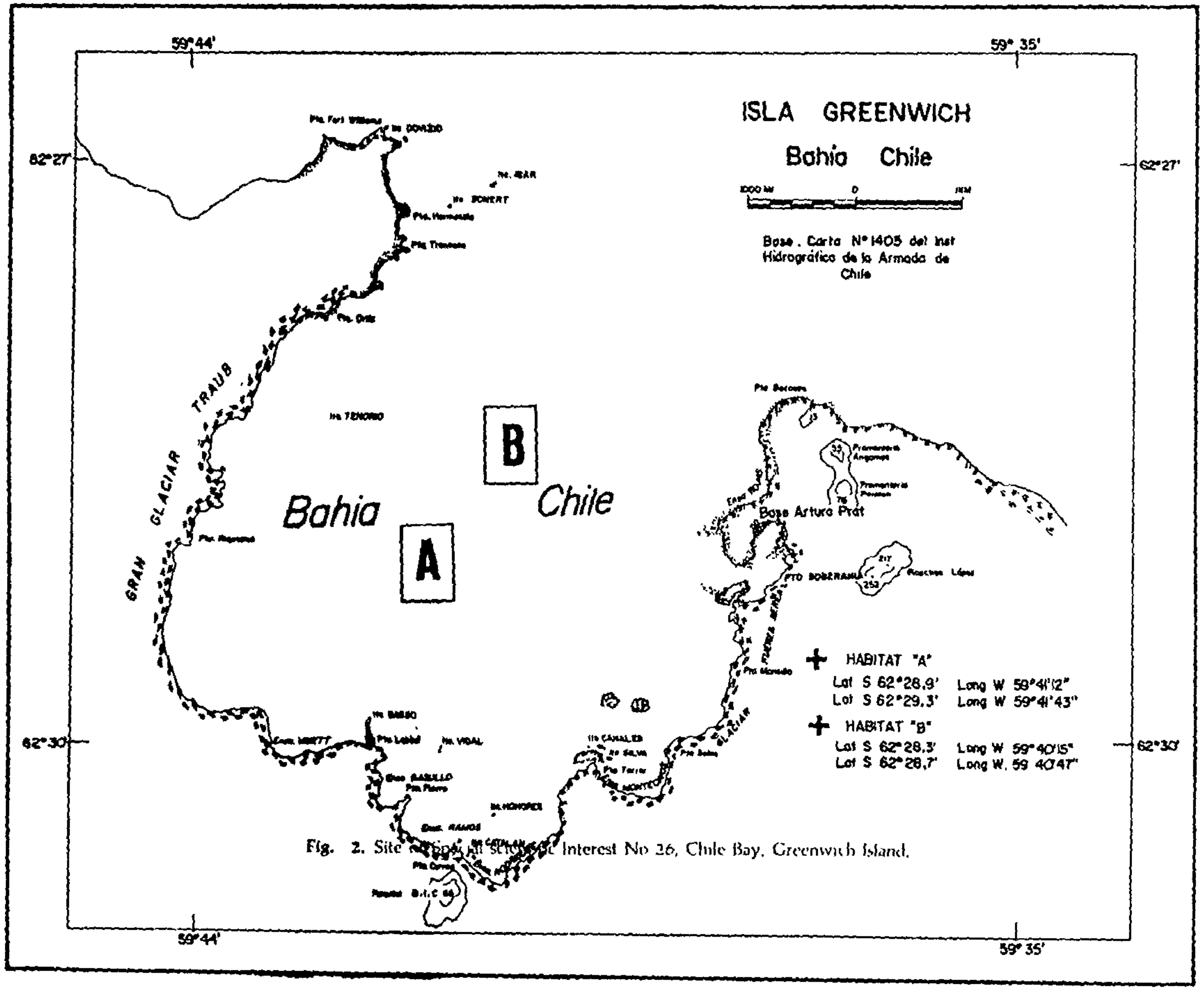


Fig. 2. Site of Special scientific Interest No 26, Chile Bay, Greenwich Island

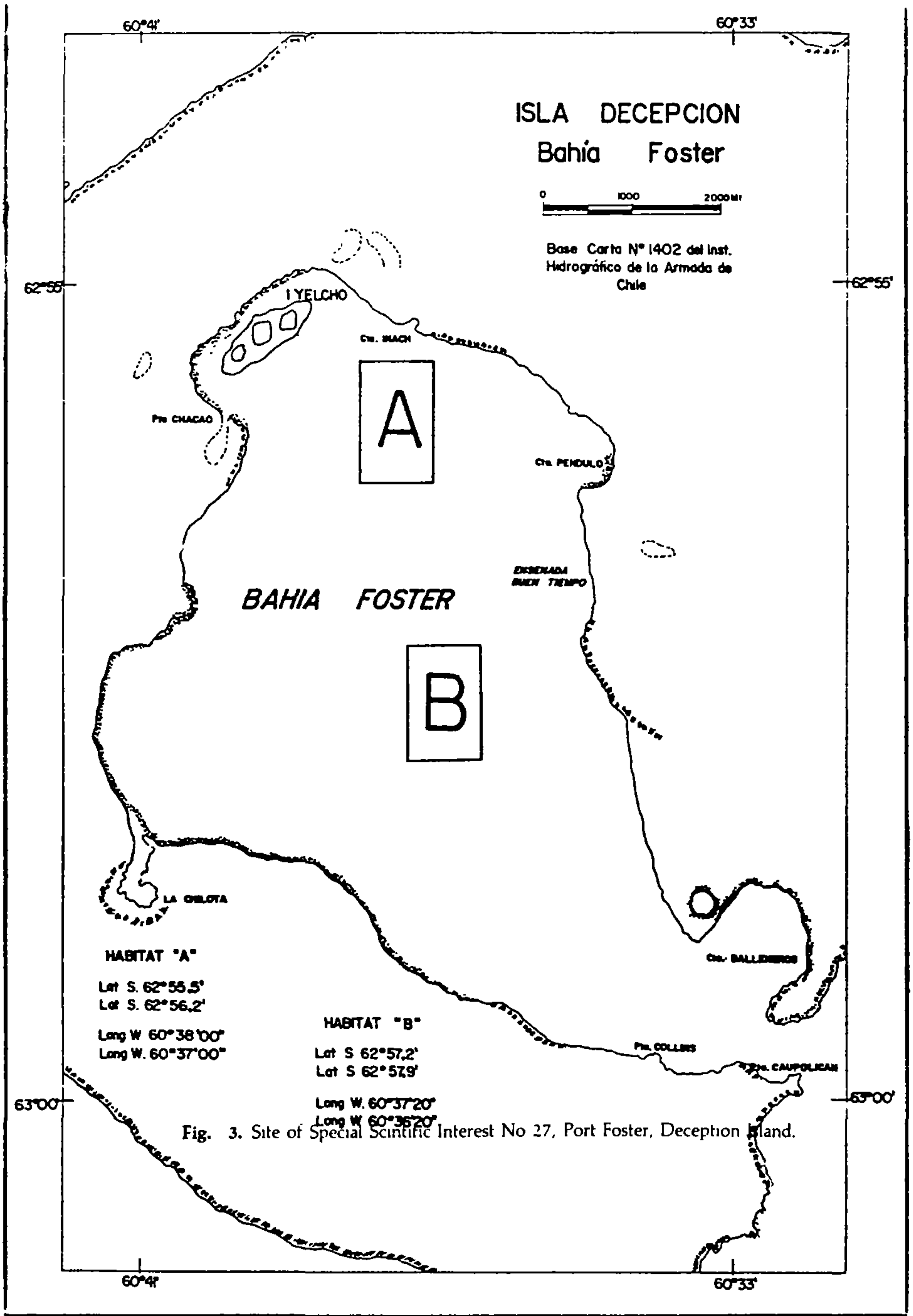


Fig. 3. Site of Special Scintific Interest No 27, Port Foster, Deception Island.

and *Dendroperistroma*, by Moyano; 12 n. sp. by Moyano; Tanaidacea, 1 n. sp., by Shiino; Ostracoda, 1 n. sp., by Kornicker; and Amphipoda. 1 n. sp., by Barnard and Clark (Gallardo and Retamal, 1988).

2. Antarctic fish ecology.

During the 1965-66 Antarctic season fish samples were obtained by the author. They were stocked in the Hideobiology Section of the Museo Nacional de Historia Natural of Santiago. That sample was given to a student (Mr. Carlos Moreno) who began to investigate the stomach contents of the species sample. This was the beginning of the Chilean Antarctic fishes ecology studies.

From 1969 to date, this project has been developed by Dr. Carlos Moreno, Universidad Austral de Chile, Valdivia, and his group.

From 1969 to date, this project has been developed by Dr. Carlos Moreno, Universidad Austral de Chile, Valdivia, and his group.

The principal objective of this project has been to know the position and function of fishes in the Antarctic trophic web (Zamorano and Duarte, 1982). According to these authors, the Antarctic fishes have a relative low species number, so there are not taxonomic difficulties to work with it.

The study has been mainly developed in south Bay, Doumer Island, Palmer Archipelago. This bay has been considered by Chilean scientists as a 'model bay' from which they are obtaining abundant information to be compared with other places, specially those where fish species has been exploited.

Results

The first captures were obtained using boulters, taking note about depth, species captured, the microgeographic distribution (Fig. 4, taken from Fig. 2 of Moreno *et al.*, 1977), and the stomach contents, whose analysis gave light about their trophic relations. In that trophic web fishes are an intermediate link between the marine benthic invertebrates and marine birds and pinnipeds (Fig. 5). On the other hand, the Antarctic fishes are able to consume a great prey diversity, among which it can be found Amphipoda, Isopoda, Mollusca (Gastropoda and Bivalvia), Polychaeta, juvenile fishes, krill and other items. For instance, the Table 3 shows the food items of *Notothenia coriiceps neglecta* (Moreno and Zamorano, 1979/80).

This is one of the most common and abundant fish species at South Bay and it feeds mainly on Amphipoda (*Bovallia gigantea, Gondogeneia antarctica* and *Orchomene* sp.).

These species are normally scarce in the habitat, but they are found in an important proportion in the stomachs. Because of this, Chilean scientists say that this species has a 'positive selectivity'; that is to say, that the fish selects its prey. In other cases, some prey species are abundant in the environmental as well as in the stomachs. That is why, this situation is called 'consumption by abundance'.

With these antecedents and with the knowledge of the bathymetricdistribution of the Antarctic fish species at South Bay (Fig. 6), the scientists team group decided to explore the South Bay by Scuba methods. The subaquatic observations allow scientists to obtain a great amount

Table 3 Food Items obtained from *Notothenia croriicep neglecta* Nybelin, at South Bay, Palmer Archipelago (n=108)

	Number	% of N	Frecuency	% of F
NEMERTINEA				
cf *Lineus corrugatus*	88	0.1	6	5.6
ANNELIDA				
Polychaeta				
Polynoidae	26	0.3	16	14.
Nereidae	1	0 01	1	0.9
Indeterminatae	11	0.1	7	6.5
ARTHROPODA				
Isopoda				
Plakarthrium tipicum	106	1.4	16	14.8
Glyptonotus antarcticus	19	0 3	14	13.0
Cymodocella tubicauda	29	0.4	12	11.1
Antarcturus sp.	31	0.4	19	17.6
Amphipoda				
Bovallia gigantea	826	11.1	90	83.3
Paraceradocus miersii	5	0.06	4	3.7
Gondogeneia antarctica	4324	58.2	93	86.1
Orchomene sp.	1014	13.7	27	25.0
Jassa falcata	98	1.3	32	29.6
Indeterminate	126	1.7	20	18.5
Euphausidae				
Euphausia superba	331	4.4	29	26.9
MOLLUSCA				
Gastropoda				
Laevilacunaria bransfieldersis	228	3.0	46	42.6
Margarita antarctica	25	0.3	14	13.0
Nacella concinna	32	0.4	10	9.3
Eatoniella kerguelensis	166	2.2	27	25.0
Pellilitorita pellita	2	0.03	2	1.9
ECHINODERMATA				
Asteroidea	1	0.01	1	0.9
CHORDATA				
Ostheichthyes				
Trematomus bernachii	4	0.05	3	2 8
Notothenidae indeterminate	4	0.05	4	3.7
ALGAE				
Desmarestia			63	57.4
Phyllogigas			40	36.5
Iridaea			13	11.3
TOTALS	7417	100		
Analized stomachs			115	
Empty stomachs			7	

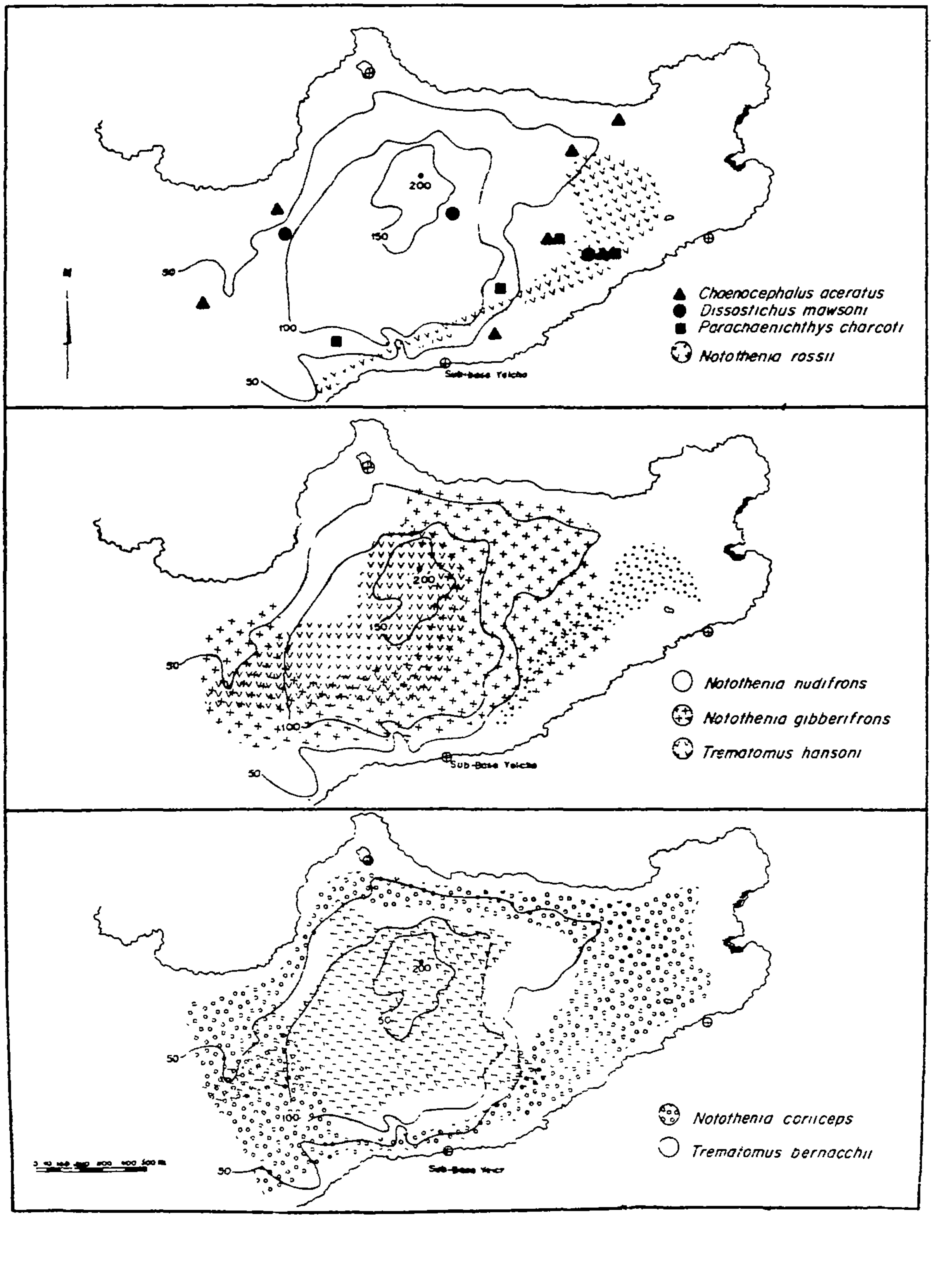


Fig. 4. Microgeographic distribution of fishes population obtained with boulter in South Bay, Doumer Island (After Moreno *et al.*, 1977).

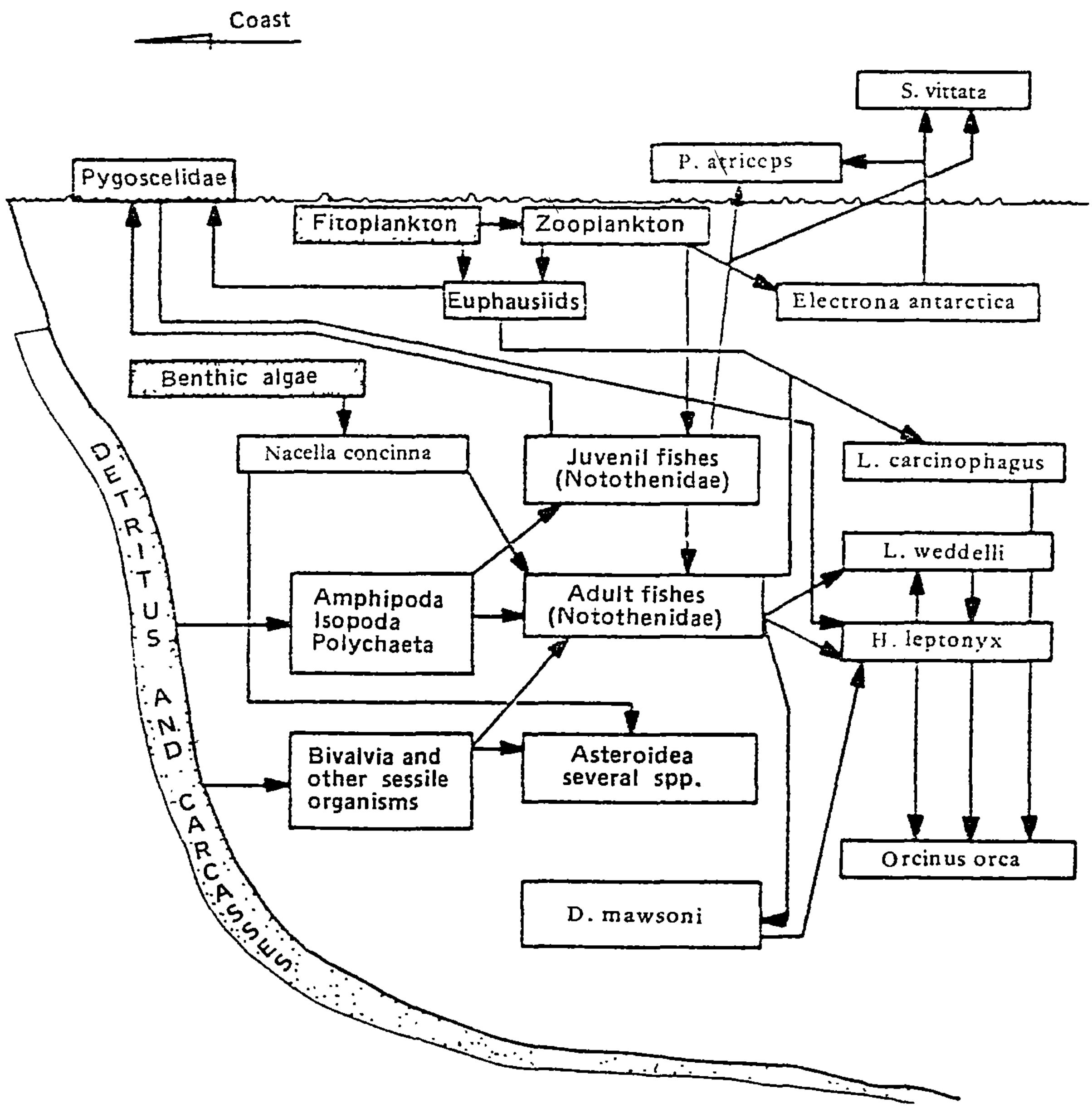


Fig. 5. Schematic food web at South Bay (After Zamorano andDuarte, 1982).

of information about fish ecology. Now they know that distribution and abundance of Antarctic fishes at South Bay are due to a closely connected relation with the different bottom types and the food resources found there.

An interesting finding was that reported by Moreno (1980). He found that *Trematomus bernacchii* (= *Pagothenia bernacchii*) is abundant in areas of mud and pebble bottoms, and in zones of mud and sand with an important community of Tunicata, Brachiopoda, Bryozoa and Porifera at 30 m. depth. Here, inside a sponge *Rosella nuda* he found some eggs and adult specimens of *T. bernacchi*. In how many other areas around Antarctica could occur the same situation?. This is an interesting point to investigate not only from the point of view of fish ecology, but of benthonic one. More over, it is a matter of a great concern not only for CCAMLR, but also for the CRAMRA.

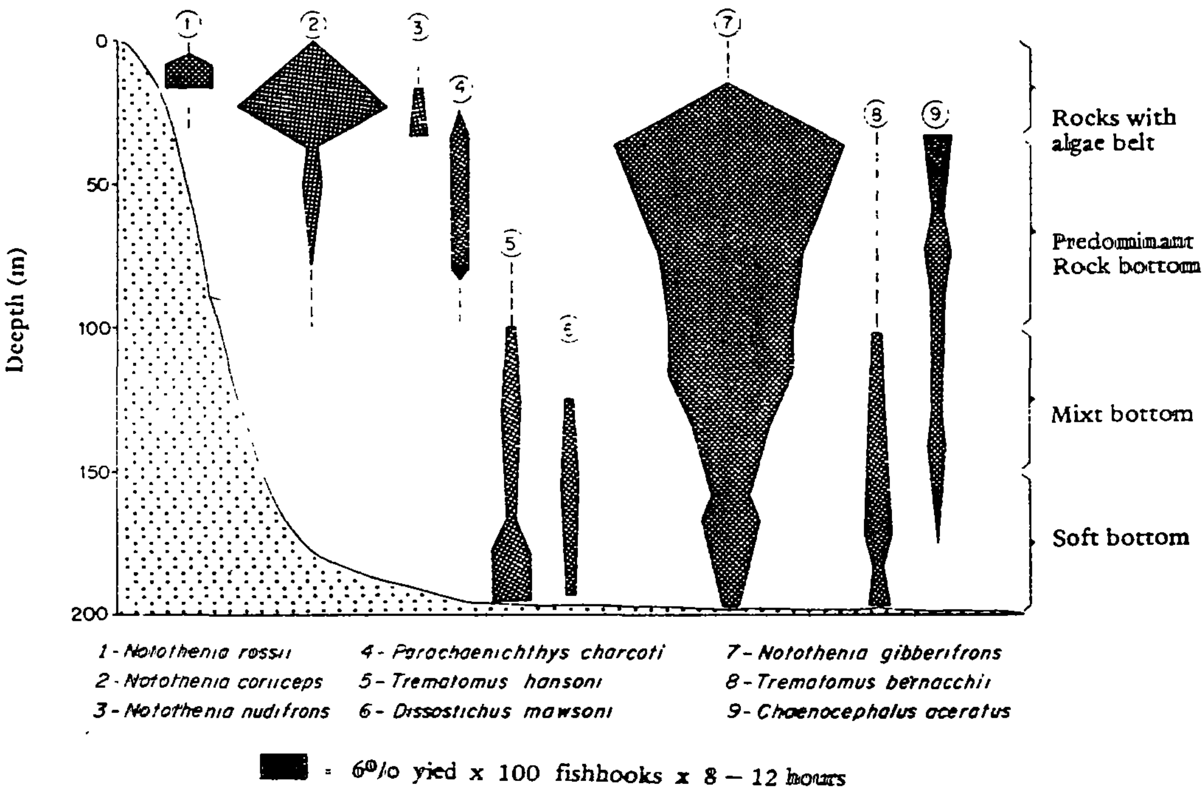


Fig. 6. Bathymetric distribution of fishes population collected from the bottom of South Bay, during the Antarctic summers 1972, 1973, 1976 and 1977 (After Moreno *et al.*, 1977).

If drilling and dredgings take place in wide Antarctic areas without having enough knowledge of the structure of the benthic communities, they could cause a great damage not only to that communities but to other organisms whose populations or some stage of them can be disturbed with unknown consequencies for the Antarctic ecosystems as a whole.

Going back to Moreno's findings, they illustrate the importance of studying the bottom communities. *T. bernacchii* is known as a fish species which is possible to find near the sponge *Rosella nuda* as a strategic way to avoid being eaten by seals. It is clear also that the fish uses the sponge as a reproductive relationship. Table 4 (taken from Moreno (op. cit.) illustrates this position.

Three of these specimens were observed in the same position and in an aggresive behaviour. The only complete egg mass then obtained had 1,730 eggs. So, it is easy to understand the importance of studying and mapping the principal areas in which this situation is used to understand the importance of studying and mapping the principal areas in which this situation is used to occur.

Another interesting ecological finding at South Bay was that related to fish juvenile populations. On the soft bottom areas, it has been possible to observe great quantities of them. Special attention was drawn by empty shells of *Laternula elliptica* inside of which Moreno *et al.* (1982) discovered juveniles specimens *Pagothenia borchgrevinki* and *Notothenia gibberifrons*.

Table 4 Association of *Irematomus bernacchii* and *Rosella nuda* observed in depths of 30 to 40 m in South Bay, Doumer Island

High of R. nuda (cm)	Osculum diameter (cm)	With adults T.bernacchii	With egg masses
40	12	--	+
27	8	female	+
39	11	--	+
33	8	female	−
31	13	male	-
46	18	--	+

Bivalvia *L. elliptica* has a total length of 10 cm., it lives buried in the substratum, with an average density of 65 individuals /m² (Zamorano and Duarte, 1982). The question is: how *L. elliptica* can be deposited on the bottom surface?.

According to dive observations carried out by Moreno *et al.*, (1982), when an iceberg drifts over the shallow soft bottom, they can plow a furrow in the area crashing or diging up specimens of *L. elliptica*. After that, those authors have observed the Asteroids *Labideaster annulatus* and *Odontaster validus* consuming *L. elliptica*. In this way, the empty shell can be occupied by juvenile fishes.

Other organisms which feed on unburied *Laternula* are the Asteroide *Cryptasterias turqueti*, the Nemertina *Parbolasia corrugatus*, the Gastropoda *Neobuccinum eatoni*, and two Amphipoda species which left the shells completely empty. So, two factors, one physical (iceberg - plowing) and another biological (predation) play an important rol to provide refuge, inside *Laternula*'s shell, to juvenile fishes (Zamorano and Duarte, 1982).

Regarding *Notothenia coriiceps*, it can be usually found in rocky bottoms, especially in areas with the belt algae *Phyllogigas grandifolius* between 5 m to 25 m depth (Fig. 6).

Notothenia gibberifrons is an eurioic species in relation with bottom types, such as rocky, soft and mixed bottoms. The adult of this species is less abundant below the inferior limit of *Phyllogigas grandirfolius*. Some juveniles are most abundant on the rocks and sand covered by the above mentioned algae.

According to similarity analysis test applied to fish population, at South Bay it is possible to distinguish two fish groups as follows:

1) Rocky bottom fishes (including the algae belt): *Notothenia coriiceps neglecta, N. nudifrons, N. rossii* and probably *Parachaenichthys charcoti*.
2) Soft bottom fishes (including sponge communities): *Trematomus bernacchii, T. hansoni, Dissostichus mawsoni* and *Chaenocephalus aceratus*. It is possible to include *N. gibberifrons* in these groups, in spite of being a generalist species related to the habitat, since it is possible to find it more represented in this sector (Moreno *et al.*, 1977).

The importance of these studies at South Bay has given a scientific basement to declare that area as a SSSI (Fig. 7).

This is, of course, a small sample of the information obtained at South Bay through the

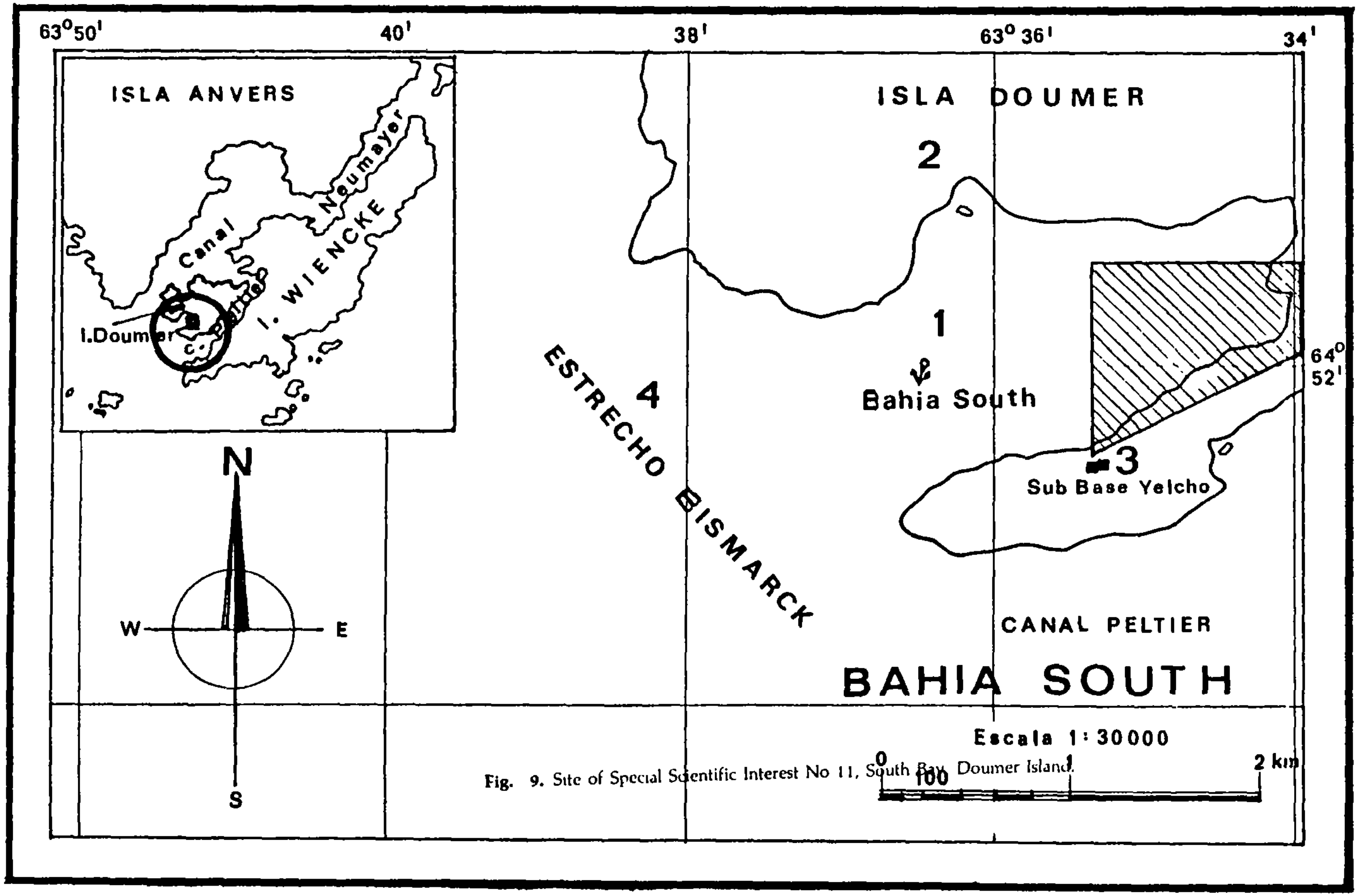


Fig. 7. Site of Special Scientific Interest No 11, South Bay, Doumer Island

program of Antarctic fish ecology. As it was stated above, some of this information could be useful for CCAMLR since it is possible to extrapolate some findings to other Antarctic and Sub-Antarctic areas where the fish population has been over-exploited. It is necessary to develop interdisciplinary studies on the bottom communities, specially in the areas on which it is possible to find important places for oviposition and refuges for juvenile fishes.

Similar importance can be of interest for the CRAMRA, specially by the areas just detected as 'possible' places where some exploration or prospecting mineral activities may be developed. Is there enough knowledge about the benthic communities located at mineral interest areas, especially petroleum?

3. Antarctic Pinniped research.

These studies began under the direction of Dr. Anelio Aguayo, former Director of the Estacion de Biologia Marina de Montemar, Universidad de Chile, during the Antarctic summer season 1965-66. Then the first census of Pinnipedia were carried out in the South Shetland Islands and Palmer Archipelago, with the logistic support of the ship AP45 'Piloto Pardo', of the Armada de Chile, and its two helicopters (Aguayo and Torres, 1967). After other attempts in 1966-67 and 1967-68 to repeat the census in the area, the survey realized in 1972-73 gave similar results for each seal species, in spite of the impossibility to visit the Piloto Pardo Islands (Elephant, Seals, Clarence, Aspland, Gibbs, O'Brien and Eadie Islands) and Smith Island. The results of these two census for the South Shetland Islands are shown in Table 5.

Due to the summer season it is possible to explain the low number of pagophilic seals. The situation changed clearly when the census were done in areas with pack-ice in open sea or in closed bays (*Lobodon carcinophagus,* 81.3 %; *Leptonychotes weddelli* 10 %; and *Hydrurga leptonyx,* 8.3 %).

The reason why we found *M. leonina* in such an amount, it was explained by ther international protection given after its over-exploitation. According to the information we had then the recovery began at South Georgia, from where the animals migrate to other sub Antarctic islands.

With respect to *A. gazella,* the species had just begun its revcovery after the over-exploitation which left the species on the verge of extinction. That was the reason why Chile proposed an international agreement to declare Cape Shirreff, Livingston Island as a Specially Protected

Table 5 Antarctic seals censused in the South Shetland Island in the Seasons 1965-66 and 1972-73

Species	N	%	N	%
Mirounga leonina	25.748	85.44	24.387	81.16
Leptonychotes weddelli	2 210	7.33	1.460	4.85
Lobodon carcinophagus	1 596	5.30	103	0.34
Hydrurga leptonyx	74	0.25	16	0.05
Arctocephalus gazella	507	1.68	4.001	13.58
Total	100.00	30.0		
		47	99.98	

Area (SPA), when we found there a small breeding colony. The proposal was accepted and declared as a SPA No11, which status has not been yet modified.

In the season 1977-78, trying to get to Cape Shirreff in order to start population studies on *A. gazella,* it was only possible to reach the southern coast of Byers Peninsula. There, the distribution nucleous of *M. leonina* during the post-breeding season was studied instead of fur seal population (Torres *et al.,* 1981).

In the 1981-82 season, with the logistic support of the Fuerza Aerea de Chile (FACH) it was possible to overflight the coast of King George, Nelson, Greenwich, Robert, Livingston, Snow and Deception Islands. In November 1981, the result of our census was 6,335 animals whose relative composition was: *M. leonina,* 3,948 (62.32%); *L. weddelli* 1,605 (25.33%); *L. carcinophagus,* 601 (9.48%); *H. leptonyx,* 17 (0.03%); and *A. gazella,* 162 (2.6%) (Torres *et al.,* 1981).

The scarce number of animals recorded was undoubtly due to the month that the census was taken. This because in previous operations, also covering most of South Shetland Islands, the number of *M. leonina* was clearly higher, being Livingston Island where this species had the greatest number of specimens during their post-breeding season. In second place, there follows King George Island, emphasizing that in the sector located between Potter Cove and Thomas Point there was the majority of animals.

With respect to pagophilic seals *L. weddelli,* this is, no doubt, the most abundant species in the South Shetland Islands area. They are found on the beaches covered with snow, or ice, and a few in the closed bays. Nelson Island is the palce where the largest number of these has been observed. It would be supposed that in Admiralty Bay, King George Island, because of the frequent ocurrence of a late thaw, it could be a favourable habitat for this species; nevertheless, it has not proved to be so, as corroborated by observations made at that site by Polish scientists.

On the other hand, *L. carcinophagus* can generally be found on the ice platform, in places such as Fildes and Admiralty bays when they are frozen. The leopard seal *H. leptonyx,* is scarcely represented, commonly and, as usual, only lone animals are found, normally on floe ices near the coast, or sometimes resting ashore.

The most evident variation was observed in the number of Antarctic fur seals whose most important breeding sites were found at Seal Island, Elephant Island, Stigant Point, King George Island, and Cape Shirreff, Livingston Island (Torres *et al.,* 1981). All figures have shown the increasing trend of this species. As a consequence of this increasing population an interesting finding was that recording in February 1973. About 300 *A. gazella* were recorded in Lajarte Island (64o 14'S; 63o 24'W), north of Anvers Island and that was reported by Aguayo *et al.,* (1977). New sightings of these animals have been registered in zones where they would not have dwelled before, as the islands that form the archipielago located adjacent to the west coast of the Antarctica Peninsula.

The activities we initiated in 1981-82, could, in some way, constitute antecedents about the displacements of *A. gazella* inside or outside of the area. In fact, after choosing Cape Shirreff as the principal location to study the Antarctic fur seal population, a tagging program and terrestrial censuses began (Fig. 8). Other activities related to the population dynamics of *A. gazella* included a field cartography of Cape Shirreff, in order to divide it by sectors, coun-

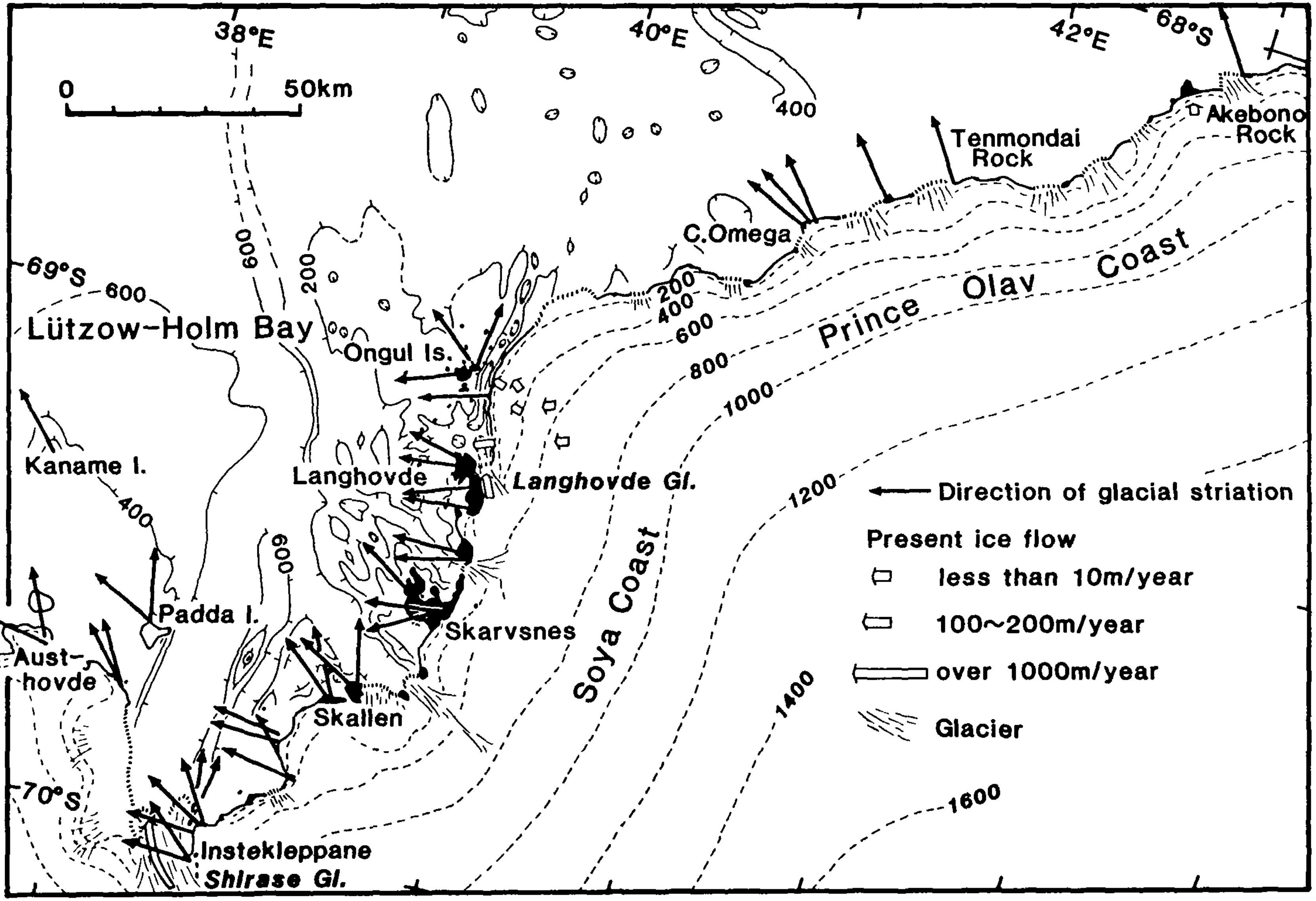


Fig. 8. Geographical locations of study sites of *Arctocephalus gazella* at South Shetland Islands.

ting and mapping their distribution, marking fur seal pups with coloured taggs, and making behavioral observation Torres, 1983).

In the Antarctic season 1984-1985, at Cape Shirreff, 1,570 animals were counted along the coast, giving a 63.9% of population increase related with those obtained during 1983-84.

The population structure of this species at Cape Shirreff was as follows: 463 males (47.9%), 258 females (26.6%) and 248 pups (25.6%) in the breeding season 1983-84. In 1984-85, the numbers were 826 males (51.9%), 360 females (23.9%) and 384 pups (24.2%). This increase in population suggests that the rookery size capacity at Cape Shirreff has not been yet reached. Because of this, it is probably that in the future the population may increase further with a lower ratio of peripheral animals and an increasing number of females per territorial male (Torres, 1986).

During the summer season 1986-87 a survey on *A. gazella* in the South Shetland Islands was carried out by Bengtson *et al.* (1987). They corroborate out findings saying that three fur seal pupping sites were identified as potentially good locations for incorporation into the CCAMLR Ecosystem Monitoring Program Network: 1) Seal Island, Elephant Island, 2) Stigant Point, King George Island, and 3) Cape Shirreff, Livingston Island. Their census in this last location was of 3,345 animals. This activity was important since we were not able to go there that season; so, now we have a continuous recording of the total population there. This project has continued its activities in part with the support of the Instituto Antartico Chileno.

Last season 1987-88, we went to Cape Shirref where we counted a total of 4,757 animals whose relative composition was: males, 720 (15.14%), females, 2,249 (47.28%), pups, 1,066 (22,.41%), and juveniles, 722 (15.18%). There we were able to tag only 701 pups, because of their great weight and mobility, pups having near two months old.

According to our records, the *A. gazella* shows an exponential growing (Fig. 9), (Oliva *et al.*, 1987) and, as we have sectorized Cape Shirreff in six sections for comparative purposes, according to Oliva *et al.*, (1988) the proportion of adult males has diminished, while female proportion has growing, as well as pups and juveniles in all six sections. So, the number of 'harems' has increased from 83, in 1984-85, to 232, in 1987-88. The average of female per reproductor increased from 4.61 (sd = 4.07) in 1984-85 to 9.42 (sd = 7.65) in 1987-88.

It is possible to say that the reproductive population of *A. gazella* population is rcovering in all their distribution area, and as a migrant species could possibly reach lower latitudes during wintering. The findings on the beach of the Hoste Island (53o30'S, 68o97'W), Chile, of a carcasse of a juvenile animal tagged at South Georgia, may support this hypothesis (Torres 1966, Torres *et al.*, 1979), and the recording of alive juvenile animals of *A. gazella, on* Alejandro Selkirk Island (33o46'S 80o46'W), (Juan Fernandez Archipelago, Chile) should reinforce thisw position (Torres, *et al.*, 1984). Besides, it is an irrefutable evidence that the Southern Ocean ecosystems has an influence in that of the South East Pacific. New other evidences support this situation, since the Sub-Antarctic fur seal, *Arctocephalus tropicalis,* has increased its presence at Alejandro Selkirk. *L. weddelli* and *H. leptonyx* have also been found in that archipelago.

Now, at the light of the results of our research, corroborated by other scientists, Cape Shirreff has been proposed to change the SPA status to a SSSI, with the purpose of developing more intensive scientific research in the area. The Conservation Subcommittee of SCAR has recently approved such proposition, during the meeting held at Hobart, Tasmania, Austrialia,

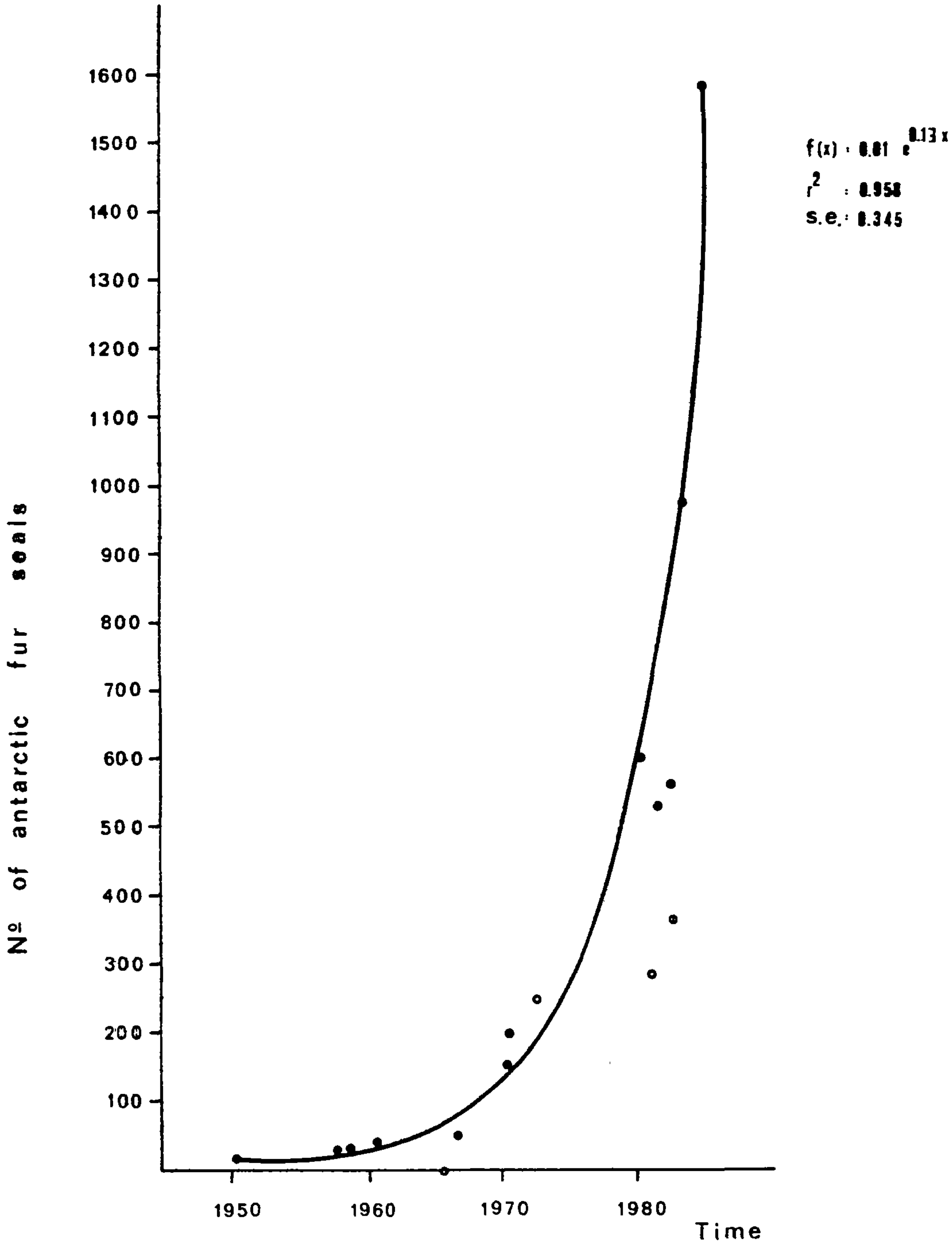


Fig. 9. Growth of the Antarctic fur seal population at Livingston Island (Cape Shirreff (0), and Stigant Point (0), KingGeorge Island. (After Oliva *et al.*, 1987).

24-25 August, 1988.

Meanwhile, the protected *M. leonina* population has experimented a declination of about 60 % in some subantarctic islands. Possibly the recent over-exploitation of fishes could be the cause of such a declination. On this matter and about Pinniped in general, it is opportune to transcribe part of the document written by the Convener of the SCAR Group of Specialists on Seals:

"New information on the status of seal popultions was reviewed. The abundance of Antarctic fur seals continues to increase throughout the species range. Elephant seal populations in the Indian Ocean Sector continue to decline. The South Georgia elephant seal population appears to be stable.

For crabeater, leopard, Ross and Weddell seals further analysis has been carried out on census data obtained up to 1983. Revised correction factors have been developed for time of day of counting, related to seal haulout curves. This re-analysis has had the general effect of lowering previously published population density estimates. Comparison of the corrected density data from the Western Weddell Sea in 1968-69 and in 1983 whow declines in density from 11.38 per nm2 to 4.28 per nm2; for the Pacific Ocean Sector the decline is from 4.93 per nm2 in 1973/74 to 1.95 per nm2 in 1983. Two possible explanations are suggested for the apparent decline. First, a change in the distribution of seals, either a movement from one area to another or a new pattern in local distribution might have ocurred. This may be related to the fact that 1983 was a very anomalous year with krill absent from areas where they were formerly abundant. A second possible expalnation is that crabeater seals in these two areas may have declined in abundance in recent years. It is conceivable that increased competition for food could have contibuted to a real decline. There is an immediate need for specific research to assess and monitor the Antarctic ice seals. This will be expansive, and funds and logistics will have to be provided' (Laws, 1988).

Conclusions

Al three programs briefly exposed here have produced important contributions for the Antarctic conservation. Upon the basis of their results we have now Chile Bay, Port Foster and South Bay as SSSI's, and Cape Shirreff as a SPA. All three scientific research programs have given useful information for CCAMLR as well as for CRAMRA conservation purposes

For future exploitation activities of the Antarctic natural resources in the Southern Ocean, it would be of importance to reinforce this kind of studies and all those whose objectives refer to the structure and dynamic processes of the Antarctic ecosystem. Otherwise, the *Homo sapiens* will be responsible of any kind of furture alteration caused to that ecosystem and the related ones. We must understand that the past over-exploitation of great whales, elephant seals and fur seals, and the present over-exploitation of some Antarctic fish species are lessons to be learned by all of us. We have no right to destroy or pollute the last pristine environment of the world, because other generations not borned yet, will ahve the same right we have now to enjoy and made a wise use of the Antarctic nature.

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