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THE ANTARCTIC: MAIN RESULTS OF 20 YEARS OF RESEARCH IN THE ANTARCTIC

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The report contains a collection of papers read at the 2nd All-Union Conference on Antarctic Studies. These papers bring to light the more important results of 20 years of investigations and their application in exploiting the southern polar regions as well as pointing out further directions in antarctic research. Articles on meteorology, hydrology, fishing and human adaptation are included.

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TWENTY YEARS OF SOVIET RESEARCH IN THE ANTARCTIC

Moscow ANTARKTIKA: OSNOVNYYE ITOGI IZUCHENIYA ANTARKTIKI ZA 20 LET. DOKLADY KOMISSII in Russian No 17, 1978 pp 5-19

[Article by Ye.S. Korotkevich and L.I. Dubrovin]

[Text] Systematic comprehensive Soviet research in the southern polar region was begun in association with preparation for and the proceedings of the International Geophysical Year (MGG).

Participants in the First Soviet Antarctic Expedition disembarked onto the icy continent from the expeditionary vessel "Ob'" on 5 January 1956. They were the first Soviets to have stepped onto the shores of the Antarctic Continent. On 13 February the State flag of the Soviet Union was raised over the first Soviet scientific camp in Antarctica, called Mirnyy in honor of one of the ships of the expedition of F.F. Bellingshausen and M.P. Lazarev, and systematic scientific observations began in the observatory. The paths of the first scientific sled and caterpillar convoys led into the inner regions of the unexplored continent, the routes of scientific research flights led over the continent and ocean, and along the coastline of Antarctica to the east and west of Mirnyy, the routes of expeditionary vessels, on which were made comprehensive oceanographic and cartographic studies.

Soviet expeditionary research on the southern polar region has represented a systematic continuation of the job begun by Russian sailors, who discovered the icy continent, and the accomplishment of the intentions of leading domestic scientists who have long been interested in the nature of Antarctica. As early as in the 1740's, thirty years before J. Cook's second expedition and almost 60 years before the expedition by F.F. Bellingshausen and M.P. Lazarev, the great Russian scientist M.V. Lomonosov hypothesized that in the southern polar region there exist islands and a "mainland," and gave an idea of the physical geographical features of these regions brought about by cosmographic factors. At the end of the 19th and beginning of the 20th centuries to Antarctica were devoted studies by such famous Russian scientists as A.I. Voyeykov and Yu.M. Shokal'skiy.

Soviet scientists had planned to begin expeditionary research in Antarctica as early as the beginning of the 30's. The first plan for the Soviet

Antarctic Expedition was developed on the eve of the Second International Polar Year (1932-1933). Suggested for employment for expeditionary work was the whaling flotilla of the Kamchatka Joint Stock Company. According to the study plan worked out, called for were exploration of the coast of the Antarctic Continent and aerial photography by means of an airplane with its base on a ship, from Enderby Land in the west to the southern half of Ross Sea in the east. In keeping with an extensive program, it was proposed to make oceanographic and hydrographic studies, as well as glaciological, geological and geomorphological investigations. Meteorological and aerological observations were to have been made throughout the entire voyage. Appointed as participants in the expedition were the famous polar researcher R.L. Samoylovich, Oceanographer A.F. Laktionov and Geologist M.M. Yermolayev.

Unfortunately, this expedition to Antarctica did not take place, since the authorities of the Union of South Africa refused to render the necessary assistance to the whaling flotilla. In particular, they refused to supply the flotilla with fuel.

Realization of the plans for expeditionary research in Antarctica became possible only after the Great Patriotic War. Our scientists began to make scientific observations in antarctic waters on vessels of the Soviet "Slava" [Glory] whaling flotilla in 1946. But extensive comprehensive scientific research covering both the Southern Ocean and the Antarctic Continent began to be carried out by Soviet antarctic expeditions only 10 years later.

An organizing committee in the USSR Academy of Sciences headed by I.D. Papanin, prior to the proceedings of the MGG, developed an operations plan for the Soviet antarctic expedition. In July 1955 the decision was made to arrange for the USSR Academy of Sciences Comprehensive Antarctic Expedition. General leadership of the expedition was entrusted to the Presidium of the USSR Academy of Sciences, and organization of the expedition to the Northern Sealane Central Administration, which was at that time under the jurisdiction of the Arctic Scientific Research Institute. Associates of this institute, having had much experience in conducting scientific research in the arctic, took an active part in preparing for the expedition.

For the purpose of coordinating plans and programs for expeditionary work and for monitoring their fulfillment, the Presidium of the USSR Academy of Sciences on 16 September 1955 created the Council on Antarctic Research. Appointed as members of the council were distinguished scientists and directors of institutes and institutions having taken part in antarctic research.

Later, on 10 October 1958, the Council on Antarctic Research was abolished and in place of it, under the auspices of the USSR Academy of Sciences, was organized the Interdepartmental Commission on Antarctic Studies (MKIA). This was caused by the transfer of all functions relating to organization of the expedition from the Academy of Sciences to the jurisdiction of the USSR Ministry of the Maritime Fleet. The main goal of the MKIA remained coordination of scientific research on the Antarctic Continent and the Southern Ocean.

In the beginning the USSR Academy of Sciences Comprehensive Antarctic Expedition (KAE) consisted of two sections--continental and sea. These were essentially two independent expeditions. The first performed studies on the continent year round, and the second conducted research from expeditionary vessels in coastal antarctic waters and on the open sea. After the third expedition the amount of scientific research performed on ships was considerably reduced, as the result of which the sea section ceased to exist as an independent expedition, and beginning with the fourth expedition (1958-1959) only the naval detachment was working aboard ship.

A further change in the structure of the expedition took place in 1962, when the Eighth SAE [Soviet Antarctic Expedition] was divided into winter and seasonal expeditions. The staff and structure of the winter expedition remained basically as before. Enlisted for the seasonal expedition were all teams having conducted their studies during the summer season, regardless of whether they worked on board ship or on the continent.

In 1958 organization and leadership of the SAE were entrusted to the Arctic Scientific Research Institute, which from this time began to be called the Arctic and Antarctic Scientific Research Institute (AANII). At the same time began to be published the INFORMATSIONNYY BYULLETEN' SOVETSKOY ANTARKTICHESKOY EKSPEDITSII [Information Bulletin of the Soviet Antarctic Expedition], and the collection PROBLEMY ARKTIKI [Problems of the Arctic] produced by the institute received the title PROBLEMY ARKTIKI I ANTARKTIKI [Problems of the Arctic and Antarctic]. Soon after completion of the proceedings of the first expedition began to be published TRUDY SOVETSKOY ANTARKTICHESKOY EKSPEDITSII [Proceedings of the Soviet Antarctic Expedition], and from 1960 the collection ANTARKTIKA [Antarctica].*

For 19 years the main expeditionary vessel of Soviet antarctic expeditions was the specially equipped expeditionary vessel "Ob'" built in 1954. Participants in the expedition and cargo were transported on board this ship to Antarctica, and scientific observations were made on board it on the open sea and along the coast of the icy continent; in addition, it was used for piloting other vessels through the ice. In 1975 to replace the "Ob'" came the scientific expeditionary vessel (NES) "Mikhail Somov" (fig 1), specially built for Soviet antarctic expeditions. In 1967 the AANII scientific research vessels (NIS's) "Professor Vize" and "Professor Zubov" began to take part in antarctic expeditions. In addition to these vessels have been used diesel electric motor ships of the ice class, passenger motor ships, tankers, refrigerator ships and cargo motor ships. In recent years the scope of studies and the staff have been increased to such an extent that more than five vessels are required to provide for an expedition. For example, the 22nd

*This collection is prepared by the Interdepartmental Commission on Antarctic Studies.

SAE was sent to Antarctica on seven ships: the NES "Mikhail Somov," the NIS "Professor Zubov," the diesel electric motor ships "Kapitan Gotskiy" and "Penzhina," the passenger motor ships "Bashkiriya" and "Estoniya" and the tanker "Gelendzhik."

Caterpillar vehicles (tractors, towing vehicles, cross-country vehicles) are used for land route research and various transportation needs. For long trips through interior regions of the icy continent the powerful "Khar'kovchanki" snow cats first delivered to Antarctica in 1958 have shown themselves to be especially good.

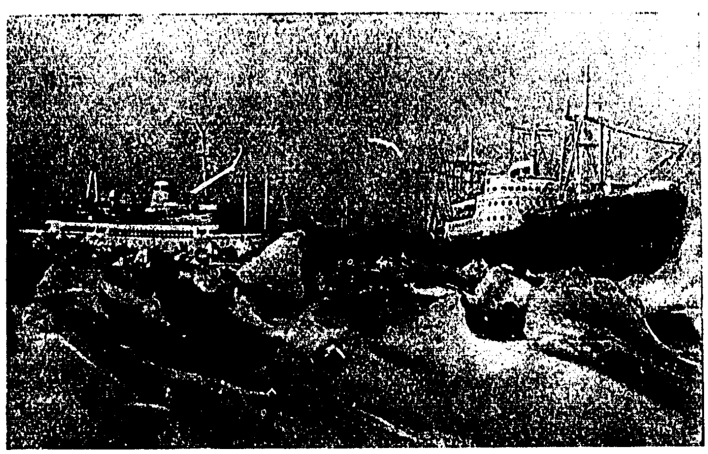

Figure 1. The NES "Mikhail Somov" and NIS "Professor Vize" in the Antarctic Ice

From the very first days of operation, on Soviet antarctic expeditions extensive use has been made of aviation, without which modern research in Antarctica is impossible. By means of airplanes and helicopters are being carried out reconnaissance explorations, aerial photographic surveys, radar measurements of the thickness of the ice cap, ice reconnaissance and other studies.

In addition, airplanes and helicopters are being used for transportation purposes, too, such as for supplying the intracontinental Vostok Station, for unloading vessels, for traffic between stations, etc.

For the purpose of performing systematic stationary observations, Soviet antarctic expeditions have created a network of scientific stations in different regions of the continent. At first, in keeping with the international agreement within the scope of the MGG, scientific stations were created in East Antarctica south of the coast of the Davis and Mawson seas. In creation of scientific stations the Mirnyy observatory (fig 2) was used as a base. So, as the result of the first sled and tractor trip into the interior of the continent, in May 1956, 375 km south of Mirnyy was opened the first intracontinental station in Antarctica--Pionerskaya.

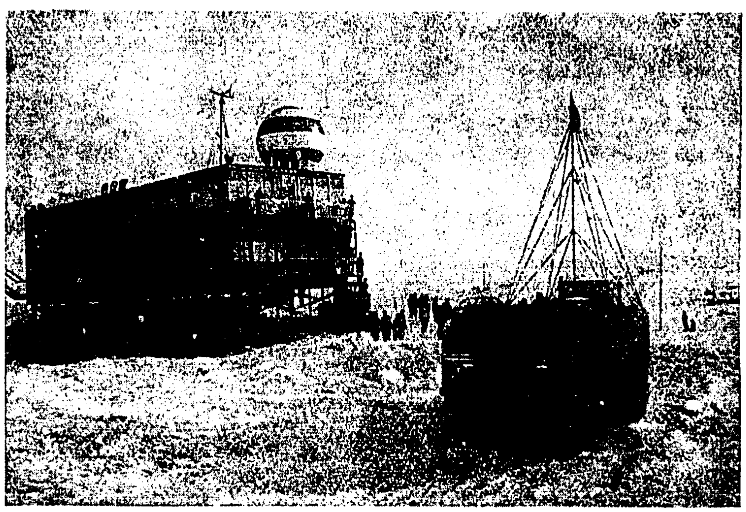

Figure 2. Two-Story House at Mirnyy Station

In the spring of the same year (in October) at Bunger's Oasis on the coast of Wilkes Land was created the Oazis station. In 1957 in the inner regions of East Antarctica were opened the Vostok-1 and Komsomol'skaya stations, and at the end of the year Vostok Station, located in the area of the South

Geomagnetic Pole. In February 1958 in the central part of East Antarctica appeared one more station--Sovetskaya--and in the middle of December a sled and caterpillar convoy, traveling more than 2100 km, reached the most remote point of the continent from the shore, where the temporary Pole of Inaccessibility station arose. So, for the purpose of making scientific observations according to the program of the MGG, Soviet antarctic expeditions during the period 1956-1958 created eight stations, and only two of them were located on the coast, while the remainder were situated in the most hard to reach regions, characterized by exceptionally severe natural conditions.

In March 1959 on the coast of Dronning Maud Land was opened the Lazarev station, and two years later in the same area the Novolazarevskaya station. In February 1962 in Enderby Land began construction of the Molodezhnaya station. It began to operate steadily in January of the following year. This station has been expanded each year and it soon was transformed into one of the largest scientific settlements in Antarctica, with a powerful radio center, rocket sounding station and computer splendidly equipped with scientific instrumentation areas and laboratories. In 1971 Molodezhnaya (fig 3) became the Soviet Antarctic Meteorological Center (AMTs) and the main base for Soviet antarctic expeditions. Then were opened two more stations: in 1968 the Bellingshausen station on King George Island (Waterloo), and in 1971 the Leningradskaya station on the northern coast of Victoria Land.

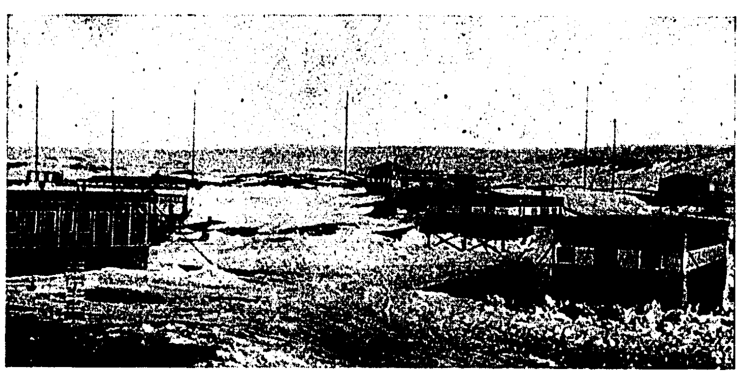

Figure 3. General View of Molodezhnaya Station

In addition to longterm operating scientific stations, Soviet antarctic expeditions created temporary and seasonal stations, which have been used to make shortterm stationary observations or have served as bases for seasonal field studies. For example, in the winter of 1960 in the area of Mirnyy three temporary stations were in operation for more than two months: Druzhba (on the West Ice Shelf), Mir (on Drygalski Island) and Pobeda (on glacial Pobeda Island). In 1972 the Sodruzhestvo base was created on Amery Ice Shelf, to provide for an extensive group of geological-geophysical and cartographic studies which continued for three summer seasons. In 1973 the temporary Russkaya station arose in West Antarctica on the coast of Marie Byrd Land.

Although 136 years had passed since the moment of the discovery of Antarctica by the First Russian Antarctic Expedition of F.F. Bellingshausen and M.P. Lazarev to the beginning of the MGG, and the icy continent had been visited during this time by many expeditions from various countries, very little was known about the nature of the South Pole continent and antarctic waters. The outlines of the continent's shores had been entered approximately on charts for a great distance. The thickness of the ice cap was estimated from indirect data. Even the altitudes of the surface of a great portion of the continent were unknown. Measurements of the thickness of the ice had been made at one comparatively not too great coastal section--in Dronning Maud Land--by the Norwegian-Swedish-British expedition (1949-1951). No data existed on the relief of the bedrock surface of the continent, almost completely concealed by a thick ice cap. Geologists of various expeditions had made only a reconnaissance exploration of relatively not too great areas--of not more than three to seven percent of the continent's area free from ice. Regarding the regions of East Antarctica where Soviet geologists later launched their studies it was known only that they are composed of ancient gneisses and distinctive granitoids. At this time geological charts of these regions did not exist; in place of them on geographical sketches were indicated only points where these rocks had been discovered. At this time a total of only a few scientific stations were in operation on the coast of Antarctica, and there were none at all in the interior of the continent; therefore, estimates of the climate of Antarctica, especially of its inner regions, were also made chiefly from indirect data.

Very little was known also about geophysical phenomena in this section of our planet. By this time scientists had at their disposal only fragmentary information relating to geomagnetism, but even then there existed no precise idea of the permanent magnetic field, nor of the spatial distribution of magnetic variations. There was entirely no knowledge about the gravitational field in Antarctica and about its seismicity, not to speak of phenomena in the ionosphere and phenomena associated with cosmic rays. Little was known about the hydrologic and ice cycle of antarctic coastal waters or about the fauna and flora of Antarctica. Therefore it is no wonder that during the period of the MGG, when various studies were launched in the southern polar region, conducted in coordination by expeditions from 12 countries employing modern technical facilities and equipment, such an extensive amount of scientific data was collected in Antarctica as had not been able to be collected over all the previous 100 odd years since the discovery of the icy continent.

Since the very first days of operation of Soviet antarctic expeditions reconnaissance explorations had been begun, by employing aviation, of regions adjacent to the coastal base. In almost every flight Soviet researchers gained new information. For example, as the result of a flight on 16 January 1956, from Mirnyy along the coast eastward to Knox Coast, were discovered many previously unknown islands and outcrops of bedrock, and alterations were observed in the contour of the Shackleton Ice Shelf. During flights into the interior of the continent it was determined that in the inner regions of East Antarctica the altitude of the ice cap's surface reaches 3500 to 4000 m. In Davis Sea and regions adjacent to the Southern Ocean regular aerial reconnaissance began to be carried out, which in the first few years of the expedition's work was carried out monthly, including during the winter period. Later, aerial reconnaissance began to be performed during the navigation period and in the area of other coastal stations.

Since the very first few expeditions there has been extensive development in aerial photographic survey work, the data of which has made it possible to make reliable charts of many sections of the coast and of mountain regions in the interior of the continent. By means of aviation participants in expeditions have made geological, glaciological, gravimetric, magnetic, meteorological, biological and other observations, and in recent years radar measurements of the thickness of the ice cap.

There has also been extensive development of scientific research by means of ground transportation. Soon after completion of construction at Mirnyy, in spite of the late fall period, in April-May 1956 was completed the first intracontinental sled and caterpillar trip into the interior of the continent, for a distance of 375 km. As a result of this trip was obtained the first information on the thickness of the ice cap, the relief of the glacier bed, climate features, and a series of data on the nature of the glacier slope southward of Mirnyy. At the end point of this route was created the Pionerskaya station. This journey, traveled under incredibly difficult conditions, formed the basis for research on the interior regions of East Antarctica by means of sled and caterpillar convoys. Participants in these trips as a rule made the following studies: seismic sounding of the ice cap, determination of the altitudes of its surface, magnetic, gravimetric and meteorological observations, and glaciological research. In addition, sled and caterpillar convoys were used also for the purpose of creating and supplying intracontinental scientific stations.

Later, in 1957, several sled and caterpillar trips had already been completed, and one convoy at the end of the year reached the area of the South Geomagnetic Pole, where the Vostok station was created. The Third Antarctic Expedition expanded even more extensively cross-country research in the interior of the continent. Its participants completed a journey from Mirnyy to the area of the Pole of Relative Inaccessibility, traveling a route more than 2100 km long. As a result of scientific observations made on this journey, interesting information was obtained on the thickness of the ice cap and the relief of the glacier bed, as well as data on meteorology and geomagnetism in the vast expanses of East Antarctica.

Participants in the Fourth SAE in the summer season of 1959-1960 completed the intracontinental Mirnyy - South Pole - Vostok Station journey, outstanding in terms of its significance (length of the route about 4000 km). On this journey for the first time were used the powerful "Khar'kovchanka" snow cats.

Of the other most significant sled and caterpillar journeys, from the scientific standpoint, mention should be made of the journey from Vostok Station through the Pole of Inaccessibility to Molodezhnaya Station, completed in 1964, and also the journey undertaken by the 12th SAE in the summer season of 1966-1967 along the Molodezhnaya - Pole of Inaccessibility - Plato Intracontinental Station (USA) - Novolazarevskaya route. During the course of 89 24-hour periods researchers surmounted more than 3400 km, and the route passed mainly through areas not previously visited by man.

In the period from 1971 through 1973 extensive comprehensive geological-geophysical and cartographic-geodetic work (employing aerial photography) was performed in the area of Amery Ice Shelf. In 1976 on the Filchner Ice Shelf was created the temporary Druzhnaya station, representing a base for carrying out a wide complex of geological-geophysical and cartographic-geodetic studies in the vast region of the Filchner and Ronne ice shelfs, the rock massifs surrounding them, and the adjacent water area of Weddell Sea.

So, during the past 20 years cross-country research on the continent (geological-geographic, aerial photographic surveys, biological, glaciological, etc.) by Soviet antarctic expeditions has been carried out along the greater part of the coast and in the interior regions of East Antarctica contiguous to it. During the period of this work geological land groups surveyed rock outcrops on the coast and in the interior of the continent. Soviet scientists having taken part in foreign antarctic expeditions surveyed many regions of West Antarctica and of the islands situated near it.

The routes of sled and caterpillar convoys of Soviet antarctic expeditions have led along the vast expanses between Novolazarevskaya Station in the west and the Mirnyy - Vostok - South Pole line in the east. On the most difficult journeys over the boundless snow-covered expanses of the central regions of the Antarctic Continent, at high altitude and in constant freezing weather, in 20 years sled and caterpillar convoys have traveled a total of more than 80,000 km. During this period Soviet antarctic expeditions have made more than 55 long and short journeys. In them have participated about 500 people, and the duration of these journeys has totaled more than 2500 24-hour periods, i.e., more than six and one half years.

During the past 20 years from on board the scientific research vessels "Ob'," "Lena," "Professor Zubov," and "Professor Vize" about 1500 oceanological stations were set up in the Southern Ocean, as well as at lower latitudes of the global ocean, and more than 1000 stations from on board the flagship of Soviet antarctic expeditions, the expeditionary vessel "Ob'." At these stations were made standard measurements of water temperature at different depths, and from the same levels were taken samples of water for hydrologic analysis. At almost 700 points were taken specimens of rocks from the ocean floor, and at more than 100 points instrument observations were made of the swell and currents, along with optical hydrologic observations. In addition, at many points biological specimens were taken (plankton, benthos and ichthyofauna). For a distance of more than 300,000 miles echo sounding measurements were made from the "Ob'," the results of which were used to make nautical charts; for a distance of almost 100,000 miles samples of sea water were collected for the suspended matter contained in it. On expeditionary vessels of Soviet antarctic expeditions were made systematic meteorological and actinometric observations, aerological sounding was carried out, actinometric sounding balloons and probes for studying cosmic rays in the stratosphere have been sent up, rocket sounding of the atmosphere has been performed, and magnetic observations and a number of other studies have been made.

The scientific research programs of Soviet antarctic expeditions have expanded every year (fig 4).

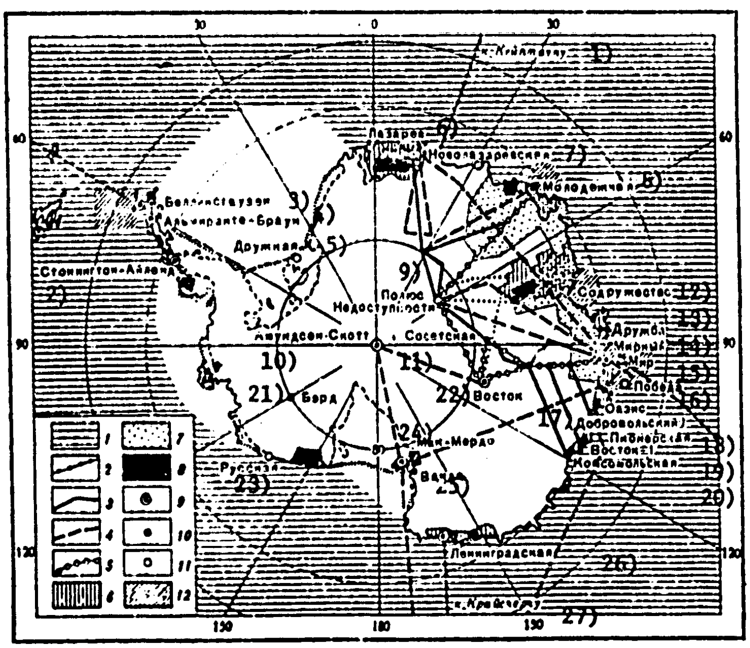

Figure 4. Chart of Operations of Soviet Antarctic Expeditions

[Key on following page]

1--ocean research areas; 2--key oceanographic sections; 3--routes of key sled and caterpillar research convoys; 4--routes of key research flights; 5--routes with trigonometric leveling; 6--aerial photographic survey area; 7--areas and some routes for radar sounding of ice cap; 8--geological research areas (in West Antarctica, sections surveyed by Soviet geologists working on the staff of foreign expeditions); 9,10--Soviet and foreign stations at which Soviet representatives have worked; 9--active; 10--closed; 11--temporary stations; 12--areas of detailed aerial survey and oceanographic studies

Key:

1. To Cape Town
2. Stonington Island
3. Bellingshausen
4. Almirante Brown
5. Druzhnaya
6. Lazarev
7. Novolazarevskaya
8. Molodezhnaya
9. Pole of Inaccessibility
10. Amundsen-Scott
11. Sovetskaya
12. Sodruzhestvo
13. Druzhba
14. Mirnyy
15. Mir
16. Pobeda
17. Oazis (Dobrovol'skiy)
18. Pionerskaya
19. Vostok-1
20. Komsomol'skaya
21. Byrd
22. Vostok
23. Russkaya
24. McMurdo
25. Vanda
26. Leningradskaya
27. To Christchurch

In recent years year-round observations have been made at six Soviet antarctic stations (Molodezhnaya, Mirnyy, Vostok, Novolazarevskaya, Bellingshausen and Leningradskaya). Cross-country field studies have been made chiefly in Dronning Maud Land, MacRobertson Land and Princess Elizabeth Land, and in the interior of the continent, in the territory between the Mirnyy observatory and Vostok Station.

Greatest attention is being paid to a group of studies in aerometeorology, which includes the following kinds of studies: meteorological and actinometric observations, aerological sounding, weather service, reception of satellite information, rocket air sounding, radar observations of meteor trails (IEM [expansion unknown]), observations of radioactivity of the atmosphere, observations of noctilucent clouds, and ozonometric observations.

Continuous, as well as special sporadic, observations are being made in a number of divisions of geophysics: geomagnetic, studies of the ionosphere and of radio wave propagation, observations of cosmic rays, terrestrial and stratospheric sounding, seismic observations and observations of brief-period fluctuations in Earth's electromagnetic field. In addition, geophysical methods are being extensively employed in glaciological, geological and other research.

Glaciological observations are being made at almost every station and on journeys. In recent years at the Vostok station deep drilling of the ice cap is being performed by the thawing-through method. Since 1975 glacier and hydrologic research employing drilling of the ice cap has been taking place in the area of the Novolazarevskaya station.

Oceanographic research has been performed in recent times chiefly from on board expeditionary vessels, to not too great an extent at coastal antarctic stations, and, in addition, by gathering and analyzing satellite information and the data of aerial surveys of the ice.

In the last 20 years highly valuable information has been obtained on the structure of the atmosphere and a number of important conclusions have been drawn which have disclosed the laws of overall atmospheric circulation and have been conducive to improving forecasts of the weather and climate of the southern polar region. The successes achieved along this line in the first decade have been reflected fairly completely in studies by Soviet researchers.

The first decade of aerometeorological research in Antarctica has been called by V.A. Bugayev the period of descriptive climatology, when each report on meteorological phenomena was new, often sensational. Research in recent years has been distinguished by a tendency to explain the interaction of factors responsible for specific meteorological phenomena, to give them a quantitative estimate, which is required for shifting to a numerical description of the climate and making weather forecasts on a longterm basis. For example, from rocket sounding data at the Molodezhnaya station it has been established that seasonal variations in temperature in the upper mesosphere are of an opposite nature as compared with the stratosphere. A relatively high temperature in the upper mesosphere is usually recorded around mid-winter, and the lowest in the summer, which is caused by the heat balance of these levels. Warming in the stratosphere and cooling in the mesosphere alternate in synchronism.

An analysis of observations over many years has made it possible to reveal the difference in the content of ozone in the atmosphere in the Arctic and in Antarctica during the course of the year and to understand the reasons for this phenomenon.

It has been established that the cooling role of Antarctica as a continent extends only to the troposphere of East Antarctica and to the water area of the Southern Ocean contiguous to it. The drift and circulation of cold air masses from Antarctica are localized for the following reasons: 1) the smaller size of the atmosphere above Antarctica resulting from its cooling; it equals 99 X 7 X 10^{15} kg, which is 1.4-fold smaller than above the Arctic; 2) the specifics of the circulation mechanism above Antarctica, consisting in the inflow and descent of air over the high-mountain section and its flow at lower levels to the periphery, with subsequent drawing in of a great portion of this air flow into the antarctic circulation cell.

Another yardstick for measuring the cooling influence of Antarctica is the discharge of snow and ice into the Southern Ocean, as the result of which cooling of the surface air layer takes place. Just for thawing the snow discharged into the ocean 1 X 93 X 10^{11} J are consumed.

A balance chart has been made for the hydrologic cycle in Antarctica. The total annual advection of moisture to the continent has been determined at 2600 km^3, of which 2500 km^3 are consumed for precipitation. The ice evaporation vapor (160 km^3) is apparently drawn off by the runoff. Thus, the climatic runoff is about 270 km^3 of water per year.

As of the present time sufficiently reliable charts have been made for almost the entire continent, based on aerial photographic survey data for coastal regions and on data of cross-country airborne barometric leveling for interior regions. Now the problem is to refine and detail these charts for especially important sections, and it is necessary to update charts in regions of considerable changes in glacial shores. As the result of the cartographic work of Soviet antarctic expeditions and of aerovisual and ground surveys, more than 800 new geographical sites named by Soviet researchers have appeared on maps of Antarctica.

Since the start of the work of Soviet antarctic expeditions much attention has been paid to geological-geophysical studies At the present time it has become possible to make an extensive summary of the geology of Antarctica and a series of geological and geophysical charts.

There has been especially extensive development in recent years in comprehensive geological-geophysical, aerial photographic and geodetic studies in Antarctica in the area of the Amery and Lambert glaciers and in the Prince Charles Mountains. These have been distinguished not only by comprehensiveness (topographical, geodetic, gravimetric, magnetic, seismic and geological studies), but also by the use of the latest techniques and equipment. In particular, seismic depth sounding has been carried out, as the result of which a cross section has been obtained of Earth's crust and mantle surface for a distance of 600 km. A detailed geological and a series of geophysical charts have been drawn. A detailed study of the profile of the upper Proterozoic complex of the crystalline basement has demonstrated its high saturation with iron ore levels. A large-scale investigation of Permian deposits in the area of Beaver Lake has made it possible to construct their complete profile, in which more than 60 coal beds have been counted. The experience of these comprehensive studies has demonstrated their high effectiveness. Since 1976 similar research has been begun in the area of Weddell Sea, and it will be extended later to other regions of Antarctica.

Of course, the presence of a continent in the southern polar region creates favorable conditions for the study by means of ground observations of various electromagnetic phenomena in the upper atmosphere and in the space about Earth--Earth's magnetosphere. As the result of stationary geophysical observations over many years, including research on geomagnetism, the ionosphere, low-frequency radiation of the magnetosphere, polar auroras, and cosmic rays, new phenomena have been discovered, associated with the effect of solar activity on the atmosphere and the space about Earth. In particular, regular relationships have been established between the sectorial structure of the interplanetary magnetic field and Earth's magnetic field--its variations and disturbability, sporadic ionization in the E layer of the ionosphere, the movement of an auroral electrojet, and the dynamics of polar auroras. A new effect has been discovered in the modulation of galactic cosmic rays--the influence of the sun's total magnetic field on cosmic rays.

New kinds of magnetic field pulsations in the polar cap and at the geomagnetic poles have been discovered, characterizing the dynamics of processes at the periphery of the magnetosphere and at its tail end. Asymmetry has been discovered in the northern and southern hemispheres--a different reaction of the geomagnetic field (variations and pulsations) to the influence of the solar plasma.

A determination has been made of the distinctive features of the manifestation of a substorm in the generation of polar aurora pulsations and of the forerunners of a substorm in the form of magnetic field pulsations of a special type and intensity.

From stationary and field observations of ONCh [very low frequency] radiation was discovered the theoretically predicted region (KASP) of direct contact of the solar wind with Earth's atmosphere. An influence was discovered, of the sectorial structure of the interplanetary magnetic field on the pressure field of regions of Earth falling under KASP's. Ground geophysical studies have acted as an important supplement to satellite data.

In recent years successful use has been made of a new method of investigating the ionosphere--oblique sounding along the superlong Molodezhnaya-Moscow direction. This method has made it possible to obtain efficiently data on the state of the ionosphere which is of great importance in ensuring radio communications. All the greater importance has been gained by field studies on the continent for the purpose of studying the space-time features of Earth's magnetic field and its variations (the "Geophysical Testing Ground" project--installation of automatic stations), as well as the ONCh radiation of the magnetosphere.

Scientific observations made by the Soviet antarctic expedition have represented an important contribution to fulfillment of research goals during the period of the proceedings of the "International Year of the Magnetosphere."

In the area of studies of Earth's form, work has been done on making a catalog of gravimetric points and a gravimetric chart of Antarctica has been prepared. Based on seismic observations, a seismic zone was discovered around Antarctica, which has joined zones known earlier. Antarctica itself has been proven to be almost aseismic. A study of the propagation of seismic waves has shown that Antarctica has a continental crust structure. The same results were obtained on the basis of seismic depth sounding (GSZ). A study of microseisms in Antarctica has led to the discovery of the general hydrometeorological conditions for their formation. Seismic observations have been employed in recent times for the purpose of investigating the dynamics of the edge zone of Antarctica's ice cap.

For further advances in geophysical research it is necessary to set up several automatic geophysical stations with the immediate sending of data to a satellite. Stations will be set up at preselected points on the continent, observation results at which will make it possible to obtain the first-hand information required for diagnosing the state of the magnetosphere, the magnetic field and the ionosphere, for the purpose of utilizing it in developing forecasting methods.

During the first few years of operation of the Soviet antarctic expedition a systematic study was begun of features of the hydrologic and chemical hydrologic cycle of the Southern Ocean, the relief of its floor and of the ice cap, and of biological resources. As the result of these and subsequent studies, a determination was made of rather precise physical-geographic boundaries of the Southern Ocean, the key types of water masses were distinguished and their distribution was learned, the regions of formation of antarctic waters near the ocean floor were established, and the first approximate diagrams were obtained for the circulation of Southern Ocean waters. It was determined that the key circulation system of the Southern Ocean is the Antarctic Circumpolar Current, which determines the hydrological cycle of waters of the southern polar region. In addition to this a determination was made of the main features of the circulation of waters in coastal regions of Antarçtica, consisting in the existence of several stationary cyclonic cycles.

On the basis of a study of thermal and dynamic conditions, the major frontal surfaces of the Southern Ocean were found. In addition, it became obvious that the physical patterns established for the thermal and dynamic conditions of Southern Ocean waters cannot be explained within the framework of existing ideas on the nature of oceanic processes and must be related to the nature of large-scale interaction between the atmosphere and ocean. Besides, remaining unexplained are the key features of the structure of the circulation of Southern Ocean waters and the nature of the dynamics of intermediate and deep waters; quantitative estimates have not been obtained of water and heat exchange between Southern Ocean waters and the adjacent water areas of other oceans, as well as reliable estimates of flowrates of waters carried by the ATsT [Antarctic Circumpolar Current], which are required for hydrodynamical models of global circulation of the ocean.

These problems have formed the scientific basis for planning full-scale experiments relating to a comprehensive study of oceanic and atmospheric processes taking place in the Southern Ocean, the combination of which has represented the major content of the "Polar Experiment South" (POLEKS-Yug) program.

At the present time two full-scale experiments have been conducted within the framework of Soviet-American cooperation in the field of global ocean research in keeping with the POLEKS-Yug and AYSOS programs, aimed at studying the dynamics of the Antarctic Circumpolar Current (ATsT) and the Antarctic Polar Front (APF) as related to atmospheric processes. The results of full-scale experiments have considerably broadened existing ideas regarding the structure and dynamics of the ATsT and its interaction with the APF, and have made it possible to detect by direct measurements a slight countercurrent at water levels near the ocean floor in Drake Passage, and to estimate the energy characteristics of the atmosphere. The data obtained have been used to estimate flowrates of the ATsT in global models of the ocean's circulation.

Further study of the Southern Ocean involves the development of extensive research at large-scale testing grounds in the Scotia Sea, in the regions between Africa and Antarctica and between Australia and Antarctica. Called for are a comprehensive study of processes of large-scale interaction between the atmosphere and ocean, as well as a study of the structure and dynamics of waters of the ATsT and of its interaction with the APF.

Of the achievements of recent years in the field of glaciology, mention should be made of research on the ice cap by means of deep drilling, comprehensive research within the continent between the Mirnyy and Komsomolskaya stations, and also radar sounding of the ice. These studies are being conducted in keeping with the International Antarctic Glaciological Project (MAGP). As the result of an investigation of a 950-meter well and of the sample extracted from it at Vostok Station, information was obtained on the temperature state of the ice cap, the content of chemical elements in the ice and of isotopes of oxygen, and other parameters. These data have made it possible to construct a representation of the contemporary state of Antarctica's ice cap and to reveal trends in its development. They have made it possible to predict the change in Antarctica's climate for the future.

Studies in the area of Novolazarevskaya Station, where a through hole was made for the first time in the ice shelf, made it possible to obtain information on the hydrological characteristics of waters beneath the shelf. An analysis of soil taken from the floor has proven that an ice shelf has existed in this region for the last 10,000 years.

From the data of studies made in the interior of the continent at key testing grounds it is possible to explain the rate of movement of the ice cap. The data of a radar survey made by Soviet antarctic expeditions in recent years and the data of foreign expeditions (chiefly of the USA and England) were used to make a new chart of the subglacial topography of Antarctica.

In the future glaciological research in Antarctica will develop along two main lines: A study will be made of the water balance of Antarctica and of the paleoclimatology and paleogeography of Antarctica. The development of these subject areas will make it possible to approach a solution to the problem of forecasting the development of Antarctica's ice cap and a solution to the question of the balance of its mass.

The development of glaciological research involves first of all further development and more extensive application of methods of deep drilling the

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ice cap and of radiophysical methods of determining its thickness and the rate of movement of the ice, as well as an analysis of different forms of satellite information.

Every year different biological research programs are carried out, which cover basically the waters of the Southern Ocean. Proof has been gotten of the abundance and variety of organisms, not only in the open sea, but also in the coastal zone covered with sea ice. As the result of year-round diving investigations highly abundant data have been obtained relating to bottom-dwelling biocenoses and biocenoses associated with sea ice. Exceedingly interesting are microbiological studies made for the first time in the Southern Ocean, which have demonstrated the very low density of the bacterial population and the feasibility of using the bacteria method in separating water masses.

Much interesting data has been obtained as the result of research over many years on the ecology and life cycle of seals and birds.

Studies have been made to a considerably lesser extent on biocenoses of dry land, but here, too, great successes have been achieved. Studies have been made of bird colonies, the vegetative cover, and of biocenoses of lakes. At the present time we have a rather complete idea of the floral abundance and plant combinations of Antarctica. Confirmation has been given to data regarding the exceptional poverty of dry land biocenoses, but at the same time was found the capacity of organisms to adapt to extremely severe conditions previously considered unsuitable for their vital activity.

At each antarctic station, in addition to treatment and prevention work, medical research has been conducted, including a group of physiological studies of higher nervous activity and of other functional systems of the body in the process of adaptation; experimental hygienic and medical biological studies as applies to questions in space medicine; study of the adaptation mechanism; studies of changes in the functional state of the central nervous system under conditions of the influence of extreme factors; a study of the influence of prolonged isolation on the psychological and social compatibility of participants in the expedition; and a group of hygiene and sanitation studies relating to studying residences, the water supply and nutrition, and to other questions relating to general and communal hygiene at Soviet antarctic stations.

In addition to the above-mentioned studies, physicians at all stations have been carrying out a program of observations relating to a study of environmental pollution in Antarctica.

More than 40 institutions in our country have been taking part in the development of antarctic topics or have been utilizing in their own scientific research the data of antarctic expeditions.

In 20 years almost 9000 people have taken part in Soviet antarctic expeditions, of which 3400 have wintered at stations, about 2000 have participated in seasonal research, and more than 3600 have been crew members of expeditionary vessels.

Associates of Soviet antarctic expeditions, in keeping with the scientific exchange program, have been participants in the antarctic expeditions of foreign countries. Twenty-one Soviet scientists have worked on expeditions by the USA (at the McMurdo, Little America, Byrd and Amundsen-Scott stations and on the expeditionary vessel "Eltanin"), Great Britain (at the Stonington station), and Argentina (at the Almirante Brown station), and several people have taken part in seasonal field studies.

Scientists from other countries have worked on Soviet antarctic expeditions. They have conducted research at stations and on expeditionary vessels and have taken part in cross-country investigations on the continent. In 20 years more than 70 foreign scientists have taken part in the winter operations of Soviet antarctic expeditions, and in seasonal operations about 40, and more than 10 different foreign writers, newspaper correspondents and television and film personnel. They represented 14 countries: Bulgaria, Hungary, the GDR, the Mongolian People's Republic, Poland, Czechoslovakia, Rumania, Australia. Great Britain, Argentina, the USA, France, Japan and India.

Over the last 20 years more than 4000 articles on all branches of science represented in the programs of Soviet antarctic expeditions have been published in various publications. Dozens of monographs have been created on the most important problems of science. In 1969 publication was completed on the first two-volume atlas of Antarctica in the world, which was based on data of scientific research performed by Soviet antarctic expeditions. More than 60 volumes of TRUDY [PROCEEDINGS] of Soviet antarctic expeditions have been issued, and more than 90 issues of INFORMATSIONNYY BYULLETEN' SAE and 16 issues of the collection ANTARKTIKA.

The research conducted by Soviet antarctic expeditions during the past 20 years can be arbitrarily divided into two periods. The first period, which continued up to the mid-60's, was distinguished chiefly by general reconnaissance studies. During this period many new geographical sites were discovered, geographical charts were refined and for many areas the first reliable ones were made, the first ideas were obtained regarding the nature of interior regions of East Antarctica, etc. This period concluded with the publication of the two-volume atlas of Antarctica, in which the results of this research were summed up.

The second period is characterized by an in-depth study of natural elements, components and phenomena in Antarctica. As the result of research conducted during this period, monographs and detailed scientific developments have appeared which have shed light on the geology and deep structure of Earth's crust in several regions of Antarctica, cycle characteristics of the ice cap, the dynamics of waters and the ice cycle of the Southern Ocean, atmospheric processes over Antarctica, various geophysical phenomena, etc. During this period fundamentally new methods of research began to be developed, which have broadened to a great extent the capabilities of studying the nature of the southern polar region. Under this heading come radiophysical research and, in particular, radar sounding of the ice cap, the reception of satellite information, etc. In addition, during this period medical research has achieved extensive advances.

At the present time is beginning the third period of research in Antarctica, characteristic of which is the accomplishment of vast comprehensive, often international, research programs, such as the International Glaciological Project (MAGP) in which, in addition to Soviet scientists, are taking part scientists from the USA, Australia, England and France, the Polar Experiment (POLEKS-Yug), being carried out jointly with the USA, comprehensive geological-geophysical and cartographic studies in the area of Weddell Sea, etc.

Data accumulated as the result of research on the nature of Antarctica, as well as the experience of expeditionary work, have made it possible to begin mastering the southern polar region.

A clear example of the practical utilization of scientific data has been the hydrometeorological service for the operations of people in Antarctica, and, primarily, the furnishing of information and shortterm weather forecasts to commercial and expeditionary vessels and aircraft. At the Molodezhnaya AMTs longterm weather forecasts have begun to be issued for a short period in advance (three 24-hour periods, maximum). Ships sailing in the ice zone are supplied with information on the state of sea ice; forecasts of ice conditions have begun to be made.

Climatic data and information on ice cap conditions are being utilized in designing and constructing various kinds of structures (buildings, underground services, airfields, etc.). In particular, for the first time instructions have been developed for creating a takeoff and landing strip on the snow covering for wheeled airplanes.

Based on medical research and the experience of expeditionary operations, clothing designs have been developed, along with nutrition standards and housing equipment. Based on geophysical research, forecasts are being made of the state of the magnetosphere and ionosphere and of conditions for radio wave propagation. In particular, a forecast has been made for the reliability of radio communications in terms of the hours of the clock for seven major microwave links.

Especially extensive use has been made of the results of oceanographic and, primarily, of hydrologic research in mastering the biological resources of the Southern Ocean. Proof has been given of the feasibility of a fishing and shellfishing industry.

In carrying out measures of any kind in Antarctica, especially on the mainland, it must all the time be remembered that Nature in the polar lands reacts exceptionally sensitively to human activities. It is easily violated and is restored with great difficulty. In order not to inflict irreparable harm on Nature, on expeditions a study is being made of the influence of man on the environment and measures are being taken to lessen this influence.

Great successes have been achieved in 20 years of research in Antarctica. But every year scientists are confronted with new and newer, sometimes more difficult, problems than before, both in the line of scientific research and of mastering the Antarctic Continent and the Southern Ocean, the resources of which are enormous.

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ANTARCTIC RESEARCH COOPERATION ON INTERNATIONAL LEVEL HAILED

Moscow ANTARKTIKA: OSNOVNYYE ITOGI IZUCHENIYA ANTARKTIKI ZA 20 LET. DOKLADY KOMISSII in Russian No 17, 1978 pp 20-26

[Article by Ye.I. Tolstikov: "Antarctica--the Continent of Peace"]

[Text] The joint work of scientists from different countries in Antarctica is a graphic example of how, by uniting the efforts of scientists of a number of countries, it is possible to solve relatively quickly scientific problems for the solution of which one country would require dozens of years.

When the decision was made to hold the International Geophysical Year, scientists from many countries turned their attention to Antarctica, the least studied area of our planet. It was clear that it was impossible to solve problems on the global scale without having arranged for a definite system of geophysical observations in the extreme south of the globe.

Scientists from 12 countries expressed a desire to arrange for research in Antarctica. The Soviet Union got the most difficult and least studied region. Soviet scientists assumed the obligation of setting up stations inside the continent in the area of the geomagnetic pole and in the area of the Pole of Relative Inaccessibility. This was a courageous decision, since neither the conditions for nor the methods of setting up these stations were known. These obligations were based on the immense knowhow gained by Soviet polar explorers under the complex conditions of the Arctic.

From the very beginning of the work on the sixth continent very warm friendly relations were formed between scientists of different countries.

The scientific work in Antarctica required coordination. That is why the Scientific Council on Antarctic Research (SCAR) was formed in 1957-1958 by the International Council of Scientific Alliances (MSNS). The duty of SCAR was to develop programs and coordinate research in Antarctica, both between countries and with special scientific alliances (e.g., with the International Geological Alliance, the Geodesy and Geophysics Alliance of the World Meteorological Organization, and the International Biological Alliance).

The members of SCAR are countries taking part in the Antarctic Treaty and actively doing research in Antarctica, and international alliances united by MSNS and interested in doing research in Antarctica, as well as the World Meteorological Organization. Each country and alliance sends one representative each to SCAR.

SCAR issues annually a bulletin representing a report on its activities, as well as shedding light on major achievements in studying Antarctica. In addition, SCAR publishes the scientific results of symposia which it conducts.

SCAR is a very useful international scientific institution, which does much work associated with research on Antarctica. The Soviet Union is represented in SCAR by the USSR Academy of Sciences, which is a permanent member of SCAR.

For the development of programs and the coordination of scientific research in Antarctica, in our country has been formed the Interdepartmental Commission on Antarctic Studies under the auspices of the USSR Academy of Sciences, to which has been entrusted the functions of the Soviet Committee for Antarctic Studies. The permanent Soviet representative in SCAR is USSR Academy of Sciences Corresponding Member G.A. Avsyuk, chairman of the Interdepartmental Commission on Antarctic Studies.

The Interdepartmental Commission on Antarctic Studies has 10 representatives in SCAR work groups. They represent leading scientists in different fields of science.

An important place in the activities of the Soviet National Committee for Antarctic Studies is held by information operations. For this purpose the Soviet committee disseminates reports on foreign research, scientific symposia and conferences, and also writes and publishes in English an annual report to SCAR on the activities of Soviet scientists in Antarctica. Also published annually is the special collection ANTARKTIKA in Russian, in which are printed reports and articles on the most topical problems relating to antarctic research.

The Soviet committee does a great amount of work associated with correspondence between work groups and the SCAR Bureau, mainly with regard to program problems, as well as in connection with carrying out various measures, sessions of meetings and symposia, in particular.

We polar explorers can be proud of the fact that the friendly relations between scientists of different countries working in Antarctica were conducive to the fact that the Antarctic Treaty was concluded in December 1959 by the governments of Australia, Argentina, Belgium, Great Britain, New Zealand, Norway, the USSR, the USA, France, Chile, the Republic of South Africa and Japan.

According to this treaty, and in the interests of all humanity, Antarctica must henceforth be utilized exclusively for peaceful purposes and must not become an arena or subject of international controversies. In its territory it is forbidden to carry out any measures of a military nature, nuclear explosions, and the burial of radioactive waste. The treaty calls for research in Antarctica to be exclusively of a peaceful nature.

It is impossible for the vast area of Antarctica not to interest all countries from the viewpoint of maintaining peace. Our country, taking this into account, has adhered to the position of solving this problem on the basis of an agreement between all interested countries with mutual allowance for their rights and interests. But prior to 1958 some countries wanted to solve the problem of the legal status of Antarctica separately.

Seven countries (Great Britain, Australia, New Zealand, France, Norway, Chile and Argentina) made unilateral claims to sectors in this region, covering a total of about four fifths of the area of Antarctica.

These countries justified their claims with different kinds of historical, geographical and legal considerations. For example, England announced its claims because its subjects had discovered a number of territories in Antarctica. Chile and Argentina cited the fact that they had inherited the rights of Spain to the lands located south of the Strait of Magellan. In addition, they pointed to the territorial proximity of their countries to these regions of Antarctica. Australia affirmed its right by the proximity of Antarctica to it and, in connection with this, its great economic and strategic importance. France and Norway submitted claims on the basis that certain lands in Antarctica had been discovered by their citizens. But this sectorial division of the Sixth Continent would have ignored the rights and interests of other countries, of the USSR and USA, in particular.

Attempts at a sectorial division of Antarctica were fraught with the danger of transforming Antarctica into a region of rivalry and international conflicts.

The question of the legal status of Antarctica was raised several times. But special attention on the part of the global community was attracted to Antarctica's fate in connection with the holding of the International Geophysical Year. Scientists of 12 countries took part in scientific research in Antarctica in connection with the MGG [International Geophysical Year]. Our country set up six stations in various areas of Antarctica.

During the period of the MGG countries which had laid claim to sectors did not oppose the creation by other countries of bases in regions of Antarctica to which the former had laid claims.

Cooperation among scientists of different countries during the course of the MGG exerted a considerable influence on the solution to the problem of the situation of Antarctica in the international scheme of things by the summoning of a conference of interested countries.

The Soviet government thought favorably regarding the USA's suggestion to summon the Conference on Antarctica. Invited to the conference were only those countries taking an active part in scientific research on the Sixth Continent. The Conference on Antarctica opened on 15 October 1959 in Washington and concluded with the signing on 19 December of the same year of the first International Antarctic Treaty in history. As already mentioned, the fundamental principles of this treaty are the utilization of Antarctica for peaceful purposes alone, and freedom in scientific rese ch.

The Antarctic Treaty does not place any one country participating in it in an advantageous position in the question of territorial claims in Antarctica. The balance created by the treaty in various positions regarding the question of territorial claims in this region can and should ensure the realization of the fundamental principles of the treaty.

The Antarctic Treaty went into effect on 23 June 1961. Joining the treaty were Poland, Czechoslovakia, Denmark, the Netherlands and Brazil.

During this period were held eight advisory meetings, at which specific questions were discussed and recommendations were made.

The First Advisory Meeting (Canberra, 10-24 July 1961). It was deemed advisable to recommend that the governments of countries participating in research in Antarctica continue the practice, formed during the period of the MGG, of exchanging scientific information, scientific personnel and plans for scientific operations.

The Second Advisory Meeting (Buenos Aires, 18-28 July 1962). Measures were recommended, contributing to free access to the published results of research in Antarctica, and to regular presentation of scientific observation data at world data centers.

For the purpose of utilizing Antarctica for peaceful purposes alone, at these advisory meetings detailed recommendations were made regarding the regular and timely presentation by countries conducting research in Antarctica of information on all expeditions and stations in Antarctica, on the amount and kinds of equipment, on the number and areas of specialization of personnel, on scientific equipment, etc.

The Third Advisory Meeting (Brussels, 2-13 June 1964). Eleven recommendations were made. The following are the main ones among these: information regarding airplane landing conditions and telecommunications, and the recommendation "On Coordinated Measures for the Protection of Fauna and Flora in Antarctica." The last recommendation is very important, since the foundation was formed for the protection of Nature in this unique region of our planet.

The Fourth Advisory Meeting (Santiago, 13-18 November 1966). Twenty-eight recommendations were made, including recommendations on regions to be especially protected, temporary guidelines for voluntary regulation of the pelagic seal trade in Antarctica, and tourism.

The Fifth Advisory Meeting (Paris, 18-29 November 1969). Nine recommendations were made, including on measures for improving telecommunications and on SCAR's suggestions on changing the temporary guidelines for voluntary regulation of the pelagic seal trade.

The Sixth Advisory Meeting (Tokyo, 19-31 October 1970). Fifteen recommendations were made, including on antarctic telecommunications, on improving meteorological operations, on research on the atmosphere by means of rockets, and on coordination of research involving the utilization of radioisotopes.

The Seventh Advisory Meeting (Wellington, 30 October - 10 November 1972). Nine recommendations were made, including on the influence of man on the environment, on a review of regions to be especially protected, and on regions of special scientific interest.

The Eighth Advisory Meeting (Oslo, 9-20 June 1975). Recommendations were made on regions of special scientific interest, on the exchange of information, on ocean resources, and on prospecting for minerals in Antarctica.

All these advisory meetings have taken place in the spirit of cooperation, in the search for compromise settlements for very complex problems. The Soviet government has approved all recommendations made. It must be regretted, however, that individual countries have still not approved certain recommendations, including such an important recommendation as "Coordinated Measures for Protection of Flora and Fauna."

It should be mentioned that SCAR is the scientific advisory agency for the Antarctic Treaty. This organization has contributed many useful suggestions and recommendations. The Antarctic Treaty is one distinct indicator of the possibility of a fruitful solution to highly complex international problems on the basis of mutually taking into account the rights and interests of nations, and, without doubt, represents a contribution to the matter of developing thorough cooperation among countries with different political systems.

The regulations regarding procedures in Antarctica established by the Antarctic Treaty in terms of their significance project beyond the scope of this region and can serve as a good example for making similar coordinated decisions aimed at the development of peaceable friendly relations in other areas of international cooperation.

Fulfilling the obligations assumed by the Soviet Union in connection with the proceedings of that highly prominent scientific measure, the International Geophysical Year, and in every way possible maintaining the spirit of international cooperation and mutual aid in the southern polar region, which later found reflection in the articles of the Antarctic Treaty, Soviet polar explorers from the very first days of operation of Soviet antarctic expeditions (SAE's) began to establish friendly contacts with foreign expeditions at work in Antarctica. They have taken part in the broad exchange of scientific information, have offered scientists from other countries the opportunity to work on the staff of Soviet expeditions, have arranged for exchange of scientists with foreign expeditions, and have always come to the assistance of polar explorers from other countries who were found in a disastrous situation.

The exchange of meteorological information and certain geophysical data began as soon as the Mirnyy observatory went into operation (in February 1956). Beginning with the Second SAE, the regular exchange of scientists began with antarctic expeditions of the USA.

Over the past 20 years 21 Soviet scientists have participated in the winter operations of foreign expeditions, and some people have taken part in seasonal field studies. Our representatives--weather forecasters, meteorologists, geophysicists, geologists and glaciologists--have worked at the American McMurdo, Little America V, Byrd and Amundsen-Scott stations and on the USA expeditionary vessel "Eltanin." They have taken part in field research, chiefly in various regions of West Antarctica. Irregular exchange of scientists has also taken place with expeditions of other countries.

Scientists of other countries have also been working on Soviet antarctic expeditions, part of them under the arrangement for exchanging scientists, and the directorship of Soviet antarctic expeditions has offered others an opportunity to do research together with Soviet polar explorers under the treaty stipulations. Coming under the latter heading are chiefly scientists from socialist countries. In the 20 years more than 70 foreign scientists have taken part in the winter work of SAE's, and about 40 in seasonal operations. In addition, more than 10 foreign writers, newspaper correspondents, and television and film personnel have worked on Soviet antarctic expeditions.

Representatives from a total of 14 countries have taken part in Soviet antarctic expeditions: Bulgaria, Hungary, the GDR, the Mongolian People's Republic, Poland, Czechoslovakia, Rumania, Australia, Great Britain, Argentina, the USA, France, India and Japan.

Joint studies with foreign scientists participating in SAE's are being conducted in a number of science programs. They cover glaciology, geophysics, geodesy and other disciplines. For example, in 1964 and 1969 Soviet glaciologists and geophysicists together with French specialists carried out glaciological research in the interior regions of East Antarctica between the Vostok station and Mirnyy Observatory, having organized for this purpose a special sled and caterpillar convoy. Beginning in 1963 joint Soviet-American geophysical observations began to be made at the Vostok station. USA specialists supplied scientific equipment to the station, a laboratory was created, and an antenna was installed for making observations of ultrashort radiowave propagation. The research program called for studies in a number of areas. Observations were made alternately by American and Soviet researchers. All observation data were duplicated and placed at the disposal of both countries. Thus, as the result of joint work the extent of scientific observations at the Vostok station was broadened considerably, and Soviet geophysicists gained additional valuable scientific data which has substantially broadened our ideas on the development of geophysical processes taking place in the area of Earth's South Geomagnetic Pole. These data have been used by Soviet scientists in their scientific studies.

Polar explorers of the 18th SAE took part in the installation of responders on icebergs, by means of which French researchers, utilizing artificial Earth satellites, are studying the drift of icebergs in the Southern Ocean. French scientists are placing the results of these observations at our disposal; they have been utilized in scientific developments in our physical oceanography. On the initiative and with the assistance of French scientists who have furnished the appropriate equipment, at the Molodezhnaya station observations of radium emanation are being carried out for the purpose of a profounder study of large-scale atmospheric circulation in Antarctica. As the result of this scientific cooperation, the French have furnished us with data from a number of other foreign Antarctic stations and, thus, Soviet scientists have gained valuable data for the study of atmospheric processes in the vast territory of the southern hemisphere.

Participants in Soviet antarctic expeditions together with scientists from France, the USA, Australia and Great Britain in recent years have been working on the International Antarctic Glaciology Program (MAGP). This research is being conducted by Soviet scientists for the most part in the most hard to reach and severe regions of East Antarctica. As the result of this coordinated research, data have been obtained for the vast region of the Antarctic Continent from Dronning Maud Land in the west to Victoria Land in the east. This territory has been covered by a dense network of air routes while sounding the thickness of the ice cap with radar. At a number of points by means of the latest radiogeodetic methods (utilizing navigational ISZ's [artificial Earth satellites]) a determination has been made with high precision of the rate and direction of movement of the ice. At the center of the region studied, at the Vostok station, as well as on the coastline in the areas of the Dumont d'Urville and Casey stations, deep bore holes have been made in the ice cap with core samples taken. Over the Mirnyy-Vostok section for a distance of more than 1400 km systematic observations have been made of snow accumulation, along with other studies. As the result of these studies a more detailed chart has been made of the topography beneath the ice, the morphometric characteristics of the ice cap have been refined, the rates of movement of the ice have been established (at a number of sections), and data have been obtained on the structure of the higher-kilometer strata of the ice cap and on its temperature state, which in turn has made it possible to solve in a first approximation the problem of the dynamic state of the ice cap and the trend in its development. Oxygen isotope studies of a core sample have made it possible to determine key features of climatic change during the last 50,000 to 60,000 years.

Accomplishment of this extensive research program became possible only as the result of the successful accomplishment of coordinated work by scientists of five countries, on the basis of the international cooperation called for by the Antarctic Treaty. Data from this research have been utilized in the scientific developments of Soviet scientists.

In conjunction with USA researchers, our scientists have been taking part in carrying out the POLEKS-Yug [Polar Exploration, South] program, etc.

In Antarctica the exchange of scientific information is taking place between expeditions of different nations, including the Soviet. The Molodezhnaya Soviet Antarctic Meteorological Center (AMTs) is receiving weather forecasting, aerological and meteorological information from almost all stations in Antarctica and is receiving information from artificial Earth satellites. In turn, the Molodezhnaya AMTs is gathering, processing and transmitting into the ether (circulating) extensive meteorological information, including data from all Soviet antarctic stations. This information is being utilized by vessels sailing in antarctic waters, by meteorological centers of countries in the southern hemisphere, and by airplanes. In addition, at Molodezhnaya weather forecasts are being made and transmitted into the ether, along with information on ice conditions necessary for expeditionary vessels sailing in the ice.

SAE participants, on the request of foreign expeditions, have more than once conducted aerial surveys of the ice, thus making it possible for vessels to approach coastal stations and to leave the ice zone. Foreign stations, too, never refuse meteorological information needed for flights of airplanes over routes where these stations are located. This information is furnished to us especially frequently by the Australians and Japanese.

A number of important studies are being made by foreign scientists on the staff of Soviet antarctic expeditions, especially by scientists of socialist countries. For example, highly valuable geodetic studies which have made it possible to determine correctly the rates and direction of movement of the ice cap in the areas of Mirnyy and Molodezhnaya, as well as precise astronomical observations at the Vostok station, have been made by GDR scientists. Interesting hydrobiological observations have been made in the area of Molodezhnaya by scientists from the Polish People's Republic. As already mentioned, Soviet-American geophysical studies at the Vostok station have proven very fruitful. Biologists and medical personnel from the GDR have made studies on discovering the biorhythms of the human being under antarctic conditions, and another group of specialists from the GDR has been involved in studying refraction, etc.

The participation of Soviet specialists in foreign expeditions has substantially broadened the capabilities of scientific research and has made it possible to cover new areas in which Soviet antarctic expeditions have not worked, and to become acquainted with the knowhow and techniques of expeditionary operations and with the modern equipment and instruments used by foreign scientists for studies in the southern polar region. For example, Soviet geologists and glaciologists, because of participation in expeditions arranged by the USA and Great Britain, have been present in many areas of West Antarctica, in Victoria Land, the Antarctic Peninsula and its surrounding islands. The data gathered in these areas has been used in scientific developments, and the information presented in reports on the organization of the operations of foreign expeditions has been taken into account in planning Soviet antarctic expeditions.

Many instances are known in which participants in Soviet antarctic expeditions came to the aid of polar explorers of other countries who were found in a calamitous situation. For example, in October 1958 Soviet polar explorers saved four participants in the Belgian Antarctic Expedition whose airplane had an accident in the area of the Crystal Mountains in Dronning Maud Land. This rescue operation was successfully carried out by the crew of an LI-2 airplane under the leadership of Pilot V.M. Perov, who flew out of Mirnyy. All its participants were awarded the Order of the Soviet Union and Belgian orders and medals.

In January 1960 the expeditionary vessel "Ob'" came to the assistance of the Japanese icebreaker "Soya" trapped in the ice. Physicians of Soviet antarctic expeditions have more than once rendered skilled medical assistance to participants in foreign expeditions (e.g., at the Bellingshausen station).

Soviet polar explorers are cordially received at foreign stations at which they must be present. Australian and Japanese polar explorers at the Mawson and Syowa stations have rendered assistance to our researchers in flights between Mirnyy and Molodezhnaya. A cordial reception was given Soviet explorers at the McMurdo station (USA) during the period of the flight of heavy airplanes from Moscow to Antarctica and at the Amundsen-Scott station (USA) during the period of the voyage to the South Pole.

The mutual exchange of specialists, the exchange of scientific information, and mutual assistance in expeditionary operations have strengthened the prestige and international authority of Soviet antarctic expeditions and have promoted the reinforcement of peaceful international scientific cooperation in the southern polar region called for by the Antarctic Treaty.

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STATUS AND PROSPECTS OF METEOROLOGICAL RESEARCH IN ANTARCTICA

Moscow ANTARKTIKA: OSNOVNYYE ITOGI IZUCHENIYA ANTARKTIKI ZA 20 LET. DOKLADY KOMISSII in Russian No 17, 1978 pp 51-74

[Article by A.I. Voskresenskiy]

[Text] The past 20 years of Soviet research in Antarctica have enriched meteorological science with highly valuable information on the structure of the atmosphere in this area and have made it possible to obtain a number of important results conducive to progress in knowledge of the laws of overall circulation of the atmosphere, in improving weather forecasts and in evaluating the climatic resources of the southern polar region.

In a number of studies dedicated to the 10th anniversary of Soviet research in Antarctica a complete analysis was made of the results obtained and the main guidelines were formulated for further research.

Without dwelling on these results, which are sufficiently well known both in the USSR and abroad, it should be mentioned that they all, as in the next 10-year period, were obtained at the level of modern science.

The greatest measure in the area of scientific organization in recent years has been the creation of a modern regional meteorological center (RMTs) at the Molodezhnaya station, whose operations are aimed at the accomplishment of two major goals:

1. Obtaining weather forecasting, satellite, meteorological, actinometric, aerological, ozonometric and other data required for studying atmospheric circulation and the climate of Antarctica.

2. Development and making of weather forecasts for the needs of southern polar stations, antarctic journeys, aviation, whaling flotillas and other vessels sailing in the waters of antarctic seas and the southern hemisphere.

The following are the key functions of the meteorological center:

1. Arranging for and carrying out a combination of standard meteorological and aerological observations and rocket sounding at Soviet southern polar stations in conformity with the requirements of the World Meteorological Organization.

2. Arranging for and carrying out scientific topic investigations in keeping with programs, as well as observations made on sled and tractor expeditions, during airplane flights, on vessels, and the like.

3. Gathering and processing of aerometeorological information, both from all stations in Antarctica, and on the scale of the southern hemisphere; transmission of this information by radio to other meteorological centers in Antarctica and to the World Meteorological Center in Moscow.

4. Making, analyzing and transmitting into the ether different kinds of weather forecasting charts and "nephological analysis" charts; developing weather forecasts for supplying reports to the maritime fleet, aviation and other users of meteorological information in Antarctica.

At the Molodezhnaya Station RMTs a rocket air sounding station has been set up, which operates in keeping with an international program. Radar of meteor trails has been begun and is being performed regularly, and camera observations are being made of mesospheric clouds. The reception and decoding of satellite information have been set up, the data of which are utilized in direct forecasting work. Work has been completed on the introduction of the "Meteorit" RKZ [rocket space probe] system for making aerological observations. Meteorological observations have been begun and are continuing at the Bellingshausen and Leningradskaya stations. Wind-temperature and actinometric radio air sounding is being performed at the Bellingshausen station. A number of qualitative changes have taken place in the area of measurements of meteorological parameters in the surface boundary layer and in actinometry. After the installation of a Minsk-32 computer at the Molodezhnaya station, the majority of observations have been processed by utilizing automated systems. Meteorological conditions in the atmosphere over Antarctica's water area are being studied in their totality from the scientific research vessels "Professor Vize" and "Professor Zubov." Thus, the last decade has been characterized by great successes in the area both of furnishing equipment and of broadening areas of research.

The first decade of meteorological research in Antarctica has been called by V.A. Bugayev the period of descriptive climatology, when each report on meteorological phenomena was new and often sensational.

The second decade can be regarded as a period of research on the interaction of factors responsible for specific meteorological phenomena, a period for their quantitative estimation and of preparation for a numerical description of the climate and for longterm forecasting (Voskresenskiy, 1977). Mention should be made of the fundamentally important work in this area performed at the Arctic and Antarctic Scientific Research Institute, the Central Aerological Observatory and the Hydrometeorological Center.

Rocket probe data have been summarized in studies by S.S. Gaygerov (1973, 1975). It has been established that seasonal temperature variations in the upper mesosphere, according to rocket probe data at Molodezhnaya, are of the opposite nature as compared with the stratosphere. A relatively high temperature in the upper mesosphere is usually recorded around mid-winter, and the lowest in the summer, which is determined by the heat balance of these levels. Warming in the stratosphere and cooling in the mesosphere alternate in synchronism.

G.U. Karimova (1975) has analyzed the content and variations of atmospheric ozone, an important component of the atmosphere, knowledge regarding which is extremely necessary in analyzing processes of atmospheric circulation and the dynamics, radiation balance and photochemistry of the stratosphere and in considering longterm changes in climate.

Observations over many years have made it possible to reveal a difference in the behavior of the total content of ozone in Antarctica and in the Arctic. In particular, the maximum ozone content in the atmosphere over Antarctica (350 to 376 X 10^{-3} cm) begins to be reached on average two months after the vernal equinox, while in the Arctic the ozone maximum is observed before the entry of this astronomical factor. This is explained by differences in the periods of existence of polar vortices in the northern and southern hemispheres, which govern the advective flow of ozone. To this fact are also due the shorter periods of an increase in ozone in Antarctica before reaching a maximum in the annual cycle and its subsequent drop to mid-level summer values.

The periods for the advent of the ozone maximum directly above Antarctica are shifted to a later period along a line from east to west (the Mirnyy station in October and the Argentine Islands station in November). An estimate of the probability of the appearance of a biologically harmful concentration of ozone in the stratosphere of Antarctica (200 mb level) has shown that it does not exceed 29 percent in summer and is practically absent in winter. The vertical distribution of ozone is highly non-uniform. The ozone content in the troposphere is on average from two to five percent, and from 92 to 98 percent in the stratosphere, and not more than six percent is concentrated in the layer above 10 mb.

In spite of the high scientific and applied value of these and other studies devoted to problems of physics and atmospheric circulation not studied previously, there are a number of great problems which have not found the required solution. Under this heading must first of all be placed those such as a quantitative estimate of the reasons responsible for the mechanism of atmospheric circulation above Antarctica, an estimate of heat, moisture and energy discharge, and the influence of Antarctica on the climate and weather of adjacent areas and on the circulation of the southern hemisphere as a whole. At the present time estimates of heat, moisture and energy flow are being published, to create the prerequisites for solving these problems ("Materialy po klimatu..." [Data on Climate...], 1976).

The climate of Antarctica, as is that of any geographical area, is in direct dependence not only on the distinctive features of the formation of thermal conditions and the hydrological cycle above the continent, but also on the influence of ocean areas on these components. The heat accumulated by the ocean's surface at tropical latitudes is transferred to the polar regions chiefly on account of atmospheric and, to a lesser degree, oceanic circulation. Regardless of the quantitative relationship of these factors, only atmospheric circulation is of major importance to Antarctica as a continent. Therefore, a study and understanding of Antarctica's climate are possible only with knowledge of conditions and atmospheric circulation above the water area of the Southern Ocean.

It should be added that for successful longterm forecasting of the weather and climate in the southern polar region is required a detailed study of large-scale interaction between the ocean, atmosphere and Antarctica as a continent.

Geographical Factors

In the general geographical scheme of things Antarctica has, we might say, a unique similarity to the Arctic--its high-latitude position. In much else these regions are almost totally the opposite.

At the center of the southern polar region is situated a high-mountain continent covered with ice and surrounded by ocean. In the arctic region the central position is occupied by the Arctic Ocean (equal in area to Antarctica), surrounded by dry land. The Arctic Ocean receives, along with radiative heat, a considerable percentage of its heat with currents from the Atlantic and Pacific oceans, as well as on account of warm fresh-water runoff from rivers. All this governs the great flow of heat from the ocean to the atmosphere. Antarctica, on the other hand, being a high-altitude glacial continent, displaces the densest layers of the lower troposphere, at the same time excluding the arrival of warm moist air streams from oceans. These factors to a considerable extent predetermine also the difference in temperature of the central regions of Antarctica and of the Arctic Ocean.

Astronomical factors influencing the flow of solar radiation in these two regions are also considerably different because of the perihelion position of Earth in relation to the Sun during the period of the antarctic summer. This fact provides Antarctica with a seven percent additional flow of solar radiation as compared with the Arctic.

Because of the exceptionally high optical transmittance of the atmosphere and the continent's altitude, its surface reaches 80 percent of the radiant energy arriving at the upper limit of the atmosphere. This figure is reduced to 59 percent on the coast, and becomes even lower on the Antarctic Peninsula. For this reason the vertical gradient of the radiation flux is twofold less than in the Arctic and equals a total of 0.020 $cal/cm^2 \cdot s$ per km.

Maximum radiation values equal 29 to 30 kcal/cm^2·month at intracontinental stations, 22 to 24 at coastal stations, and 14 to 17 kcal/cm^2·month at stations on the Antarctic Peninsula. Direct radiation equals 70 percent of the total radiation flux in central regions, 50 percent on the coast, and 20 to 30 percent on the Antarctic Peninsula. During the summer months the total radiation on the coast is greater than in the Arctic by a factor of 1.5 to 1.7, and in the spring and fall, by a factor of 1.2 to 1.3. The annual totals (95 to 105 kcal) are greater than in the Arctic by a factor of 1.3 to 1.5 and are comparable to annual totals in the equatorial zone. These radiation flux values are highly stable from year to year, and for the purpose of ensuring mean monthly values with a precision of five to 10 percent two and five years of observation of total radiation are sufficient, six and 30 years of direct radiation on the coast and two and four years at intracontinental stations.

Aperiodic fluctuations in solar radiation resulting from turbidity of the atmosphere from aerosols can reach significant values. For example, as the result of eruption of the Agung volcano, the direct radiation at Soviet stations at the end of 1963 was reduced 30 percent. On the whole, the values of aerosol attenuation over the coast of East Antarctica are negligibly low and cannot be paid attention to in estimating the radiation balance. As far as the central regions are concerned, characteristic of them is the process of formation of crystals outside of clouds, which results in considerable aerosol absorption, reaching 0.3 cal/cm^2·min.

At intracontinental stations, in spite of the heavy radiation flux, because of the exceptional conditions for reflection and radiation during the entire year, the absorbed radiation equals 6 to 7 kcal/cm^2 during the summer period, or 21 to 22 kcal/cm^2 per year, which totals the monthly total of solar radiation reaching the coast. The existence of a negative radiation balance predetermines a reduction in air temperature from year to year. But because of the advection of heat and the presence of latent heat, no reduction in temperature is observed.

Atmospheric Circulation

Numerous investigations made in recent times have made it possible to get an idea of the major traits of atmospheric circulation in this area. The major elements which form atmospheric circulation over Antarctica must be considered a circular cyclone zone, the circumpolar vortex and a system of surface anticyclone circulation, including flowoff.

Cyclone activity is the consequence of processes originating in the system of the planetary heat engine which governs global circulation. In terms of the entire system of the planetary heat engine, made up of cold centers at high latitudes and a heater in the tropical zone, the medium-latitude region represents a zone in which extreme temperature contrasts are observed. In this latitude zone occur the realization and conversion of these temperature contrasts into the energy of cyclonic vortices.

In the circular cyclone zone the low-pressure surface areas most significant in the climatic respect are situated in the area of the Lazarev and Riiser-Larsen, Davis and Mawson, Ross and Bellingshausen seas. This circular zone, representing a zone of convergence of lower troposphere air mass flows and runoff, is one of the major elements of atmospheric circulation at medium and high latitudes of the southern hemisphere. As will be demonstrated below, air running off over the continent's slopes in the low-pressure region to the coast of East Antarctica is lifted up, forming sections of meridional circulation. The circular zone is constricted with an increase in altitude and takes on the form of a conic surface. The circular zone is tilted in the direction of the cold, i.e., it reflects the familiar properties of the position of the axes of cyclonic vortices.

In fig 1 is shown the position of the axes of anticyclones of the subtropical zone and of cyclonic vortices having their origin in the area of the Ross and Lazarev seas. The axes of climatic low-pressure areas having the significance of centers of activity of the atmosphere are positioned along the 0 to 180° meridian and are slanted in the direction of a cold zone located in the stratosphere.

The low-pressure area over Ross Sea, forming under the influence of cylcone activity in the Indian and Australian sectors of the Southern Ocean, is well pronounced throughout the entire troposphere, and in the stratosphere becomes the central part of the circumpolar vortex of the southern hemisphere. This low-pressure area must be regarded as the main center of activity of the southern hemisphere's atmosphere.

The low situated in the Lazarev Sea sector has been traced clearly approximately to the level of the 500-mb constant-pressure area, and above this it takes the form of a trough of low pressure associated with the main cyclonic vortex of Ross Sea. The distinctive features of the vertical structure of lows forming the southern hemisphere's circular cyclone zone are due to various causes.

A possible reason for dissolution of this low in the upper half of the troposphere is the system of air circulation. It has already been accepted that in the troposphere of West Antarctica the advection of warm air and positive vertical velocities predominate, while in East Antarctica the advection of cold and subsidence do. The subsidence is localized over high sections of the glacial plateau and conforms to the central section of an extensive region of surface divergence of currents covering the surface of the continent. The process of subsidence represents a compensation for this continental divergence, formed by a system of surface winds, including runoff winds. Subsidence, enveloping the densest lower air layers, exerts a considerable influence on the formation of tropospheric circulation over the continent. Where the axis of a cyclonic vortex passes through layers with positive vertical velocities the vortex is well developed vertically and reaches the stratosphere, and the Ross Sea vortex possesses this property. The vortex whose axis is directed into the antarctic troposphere from the area of Lazarev Sea, approximately at the 500-mb constant-pressure area, reaches a zone of negative vertical velocities above the continent, which is one of the reasons for its dissolution.

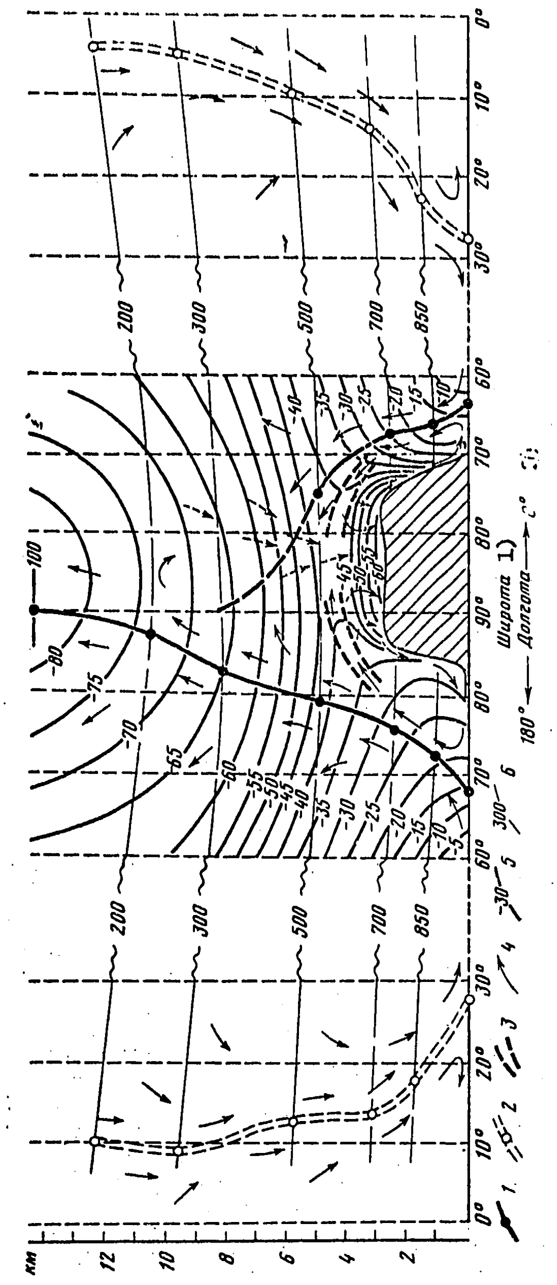

Figure 1. Mean Position of Axes of Climatic Lows in the Ross and Lazarev Seas:
[Key on following page]

1--axis of lows; 2--axis of subtropical anticyclone; 3--zone of vertical divergence; 4--direction of air movement; 5--isotherms; 6--constant-pressure areas

Key:
1. Latitude 2. Longitude

This sketch of the spatial position of axes of the circular zone and of axes of major lows requires the additional analysis of layers which directly border upon the surface of the ice cap and in which signs of anticyclone circulation have been discovered. Attention on the part of meteorologists is constantly being paid to the problem of the antarctic anticyclone. Ideas regarding the antarctic anticyclone have not infrequently been contradictory. But at the present time we know that there is no stable anticyclone over Antarctica. This has been distinctly proven for West Antarctica by P.D. Astapenko (1960), and this question will be discussed below with respect to East Antarctica.

It is necessary to differentiate between at least two kinds of anticyclones which can be found above Antarctica. First, there are instances of anticyclone circulation which originate over the mainland in the form of centers of not too great vertical and horizontal length. Secondly, there are anticyclones of considerable vertical and horizontal length having a connection with high-altitude tropospheric ridges which reach Antarctica during the intense development of meridional processes. In spite of this, certain writers discuss antarctic anticyclones without differentiating between these two kinds (Astapenko, 1960; Gaygerov, 1964; Zhdanov, 1970).

Let us discuss anticyclones of only the first group, since they can appear as the result of local anticyclogenesis caused by regional features of the continent. Now we know that many features of surface circulation of air over the mainland are of an anticyclone nature. In particular, the system of surface wind currents represents an extensive region of horizontal divergence with its origin over the highest sections of the East Antarctica ice cap. An extensive circular surface region of horizontal divergence cannot exist without vertical compensation, i.e., requires the existence over interior sections of the mainland of settling of air from the layers above. As already mentioned, this type of settling has been observed over East Antarctica.

The existence of quasi-stable surface divergence and compensation for subsidence, as we know, is a necessary element of any anticyclonic circulation system.

It is possible to establish from the vertical wind distribution at coastal stations of East Antarctica that the replacement of surface anticyclonic circulation with tropospheric cyclonic can take place on average between constant-pressure levels of 700 and 500 mb. But this does not mean that steady anticyclonic circulation predominates on slopes of the mainland. In analyzing certain cases of wind observations at Soviet intracontinental stations, S.S. Gaygerov (1964) found that in the layer of about 3 km above the surface of the glacier both anticyclonic and cyclonic circulation have been observed to an approximately equal degree.

The ability to identify signs of the existence of an antarctic anticyclone has become realistic by constructing charts of the 600-mb constant-pressure level, i.e., of the first standard level which is not in contact with the level of its highest sections. In analyzing AT-500 and AT-600 charts for 1958-1970 it was found that only at level AT-600 (fig 2b) are pressure fields found which can be interpreted as anticyclonic. Cyclonic fields predominate on AT-500 charts at all seasons: The main center of the cyclone region is found to be in the area of the Ross Sea and Ross Ice Shelf, and the trough of low pressure occupies East Antarctica (fig 2a).

Over interior sections of the continent the 500-mb constant-pressure level is separated from the underlying surface by an atmospheric layer about 1.5 to 2 km thick. Since cyclonic forms of baric topography are well pronounced at AT-500 and anticyclonic located below them at AT-600, then the layer between these constant-pressures levels (about 1200 m) represents a transitional layer from the lower anticyclonic to the upper cyclonic system. With this vertical pressure field structure there must be a vertically oriented deformation field formed by the positive vertical velocities of the cyclonic vortex located on top and the descending currents which are involved in compensation of air masses running off along the slopes. This field, as a necessary part of the interaction between the tropospheric cyclonic vortex and the surface wind system, represents a layer of vertical current divergence.

In analyzing changes in atmospheric pressure and mass at the Vostok station it was found that the most dynamic layer in which interseasonal changes in atmospheric mass most of all influence the formation of surface pressure is the layer contained between the 600- and 500-mb levels. This can serve as one of the characteristics of the vertical divergence layer (Aver'yanov and Voskresenskiy, 1972).

For Antarctica it is extremely important to study the mechanism of interlatitudinal circulation and of vertical movements on the synoptic scale. A.M. Gusev (1959) provided a theoretical foundation for the pattern of meridional circulation.

A single opinion is still lacking regarding a quantitative estimate of all elements of this mechanism, since the few verifications of the pattern have been based on disconnected data from several stations with not too great a number of observations.

For the Mirnyy - Vostok - Amundsen-Scott section we have estimated the momentum as the transfer of an air mass from one region to another through a unit area in the horizontal (ρV_y) and vertical (ρW) directions.

To construct a profile of the transfer of an air mass in the meridional direction over the Antarctic Continent, an analysis was made of the mean monthly values of meridional components of the resulting wind (V_y) for each year. In keeping with the orientation of the section, the values of V_y characterize the redistribution of air between the eastern and western hemispheres.

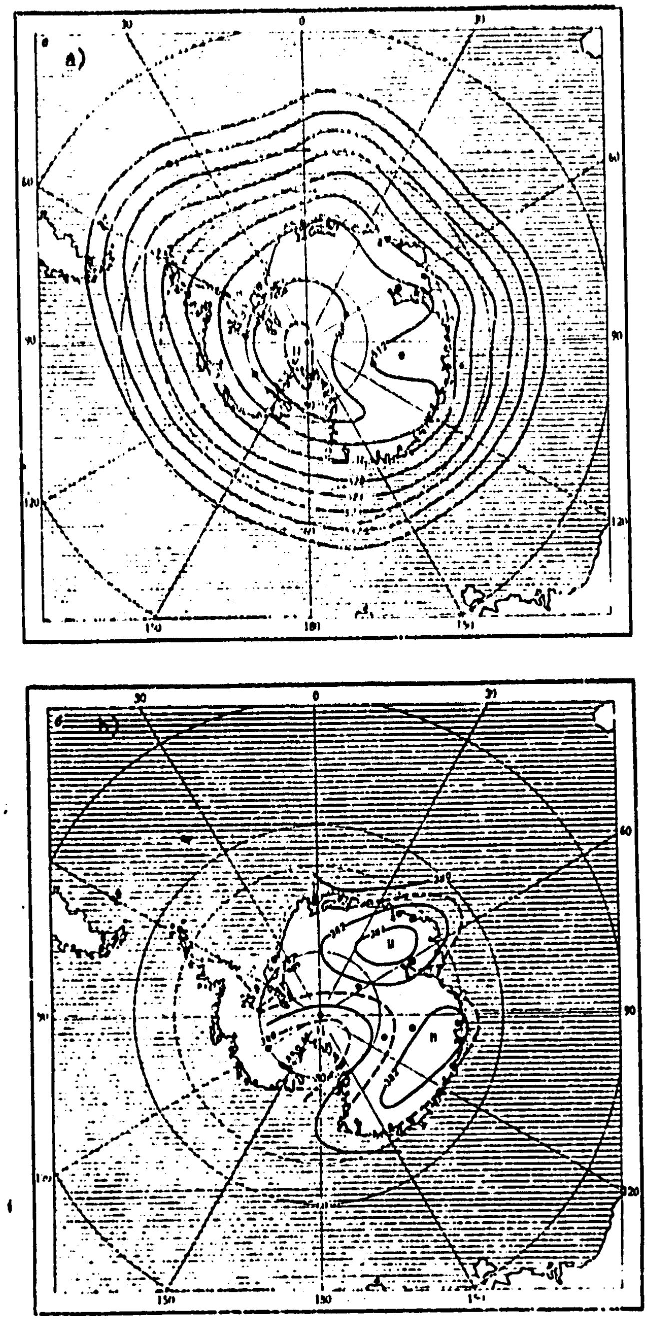

Figure 2. Mean Pressure Field of Level at 500-mb (a) and 600-mb (b) Levels in January

Over the Amundsen-Scott station this movement of masses is in accord with the zonal components of the resulting wind velocity. For the purpose of elaboration of the structure of transfer in the surface layer, in addition an analysis was made of mean monthly values of V_y for many years at three additional levels in the layer from Earth to the first constant-pressure level.

The air mass transferrable in the meridional direction for each month according to data of many years at the level of Earth and at any standard constant-pressure level was determined by the equation:

$$\bar{F} = \frac{1}{n} \sum_{i=1}^{n} (\rho V_y)_i \, , \tag{1}$$

where n is the number of years, $(\rho V_y)_i$ is the mean monthly value of the momentum for each year, and ρ is the density of the air, defined as:

$$\rho = P/RT \, .$$

For the purpose of computing the velocities of vertical movement, we utilized a method based on solving the equation for the first law of thermodynamics. The utilization of this method makes it possible to limit oneself to the data of a single station, which is especially important under conditions of the extremely slight aerological illuminance of the antarctic region and determines the advantages of the method selected over others.

The heat flux equation, taking into account advective, adiabatic and non-adiabatic changes in temperature, has the form:

$$\frac{\partial T}{\partial t} = -\left(U \frac{\partial T}{\partial x} + V \frac{\partial T}{\partial y}\right) - (\gamma_a - \gamma) + \frac{\varepsilon}{C_p} \tag{2}$$

(the letter symbols here are the conventional ones).

Local changes in temperature, $(\partial T/\partial t)_1 = \partial T/\partial t$, are determined from the data of daily radiosonde observation, as the difference in the mean temperature of the layer over a 24-hour period. Advective changes in temperature, $(\partial T/\partial t)_g = -[U(\partial T/\partial x) + V(\partial T/\partial y)]$, are calculated from the data of a single station[8] by means of the thermal wind equation:

$$\left(\frac{\partial T}{\partial t}\right)_r = \frac{lT_m}{g(Z_2 - Z_1)} V_1 \cdot V_2 \sin \alpha, \tag{3}$$

where T_m is the mean temperature of the layer, ℓ is the Coriolis parameter, g is the acceleration of gravity, $(Z_2 - Z_1)$ is the thickness of the layer, V_1 and V_2 are the velocities of the wind at the lower and upper boundaries of the layer, and α is the wind rotation angle in terms of altitude.

Non-adiabatic changes in temperature, $(\partial T/\partial t)_{na} = \varepsilon/C_p$, are occasioned in our hypothesis by the radiation factor.

Taking into account the slight variability of circulation conditions in the southern polar region from year to year, we thought it possible to utilize calculated data for mean monthly radiation flux in different atmospheric layers at high latitudes in the southern hemisphere given in the "Aeroclimatic Handbook" (1972), in which taken into account as absorbing and radiating components of the atmosphere are water vapor, carbon dioxide gas, ozone, oxygen and cloudiness, i.e., the calculations must be considered fairly complete. The difference of these calculated data from the actual in each specific year results in a much smaller error than omission of the radiation factor in solving the heat flux equation.

Adiabatic changes in temperature, $(\partial T/\partial t)_a = -(\gamma_a - \gamma)\omega$, are defined as the remainder of heat flux equation (2). The velocity of vertical movements we arrive at from the equation:

$$\omega = \frac{1}{\gamma_a - \gamma}\left(\frac{\partial T}{\partial t}\right)_a. \qquad (4)$$

The results of these calculations demonstrate good agreement of the velocities arrived at with the sign and intensity of the development of atmospheric processes.

The mean monthly values over many years of the air mass transferred in the vertical direction through a unit area are calculated in the following manner:

$$\bar{F}_\omega^{\rho} = \frac{1}{n}\sum_{i=1}^{n} (\rho'\omega)_i, \qquad (5)$$

where $(\rho'\omega)_i$ is the mean monthly values of the momentum for each year, and ρ' is the mean density of the air in the layer.

The results of the computations are presented in the form of sections in the meridional and vertical directions over Antarctica along the Mirnyy - Vostok - - Amundsen-Scott - Byrd line for January and July (fig 3).

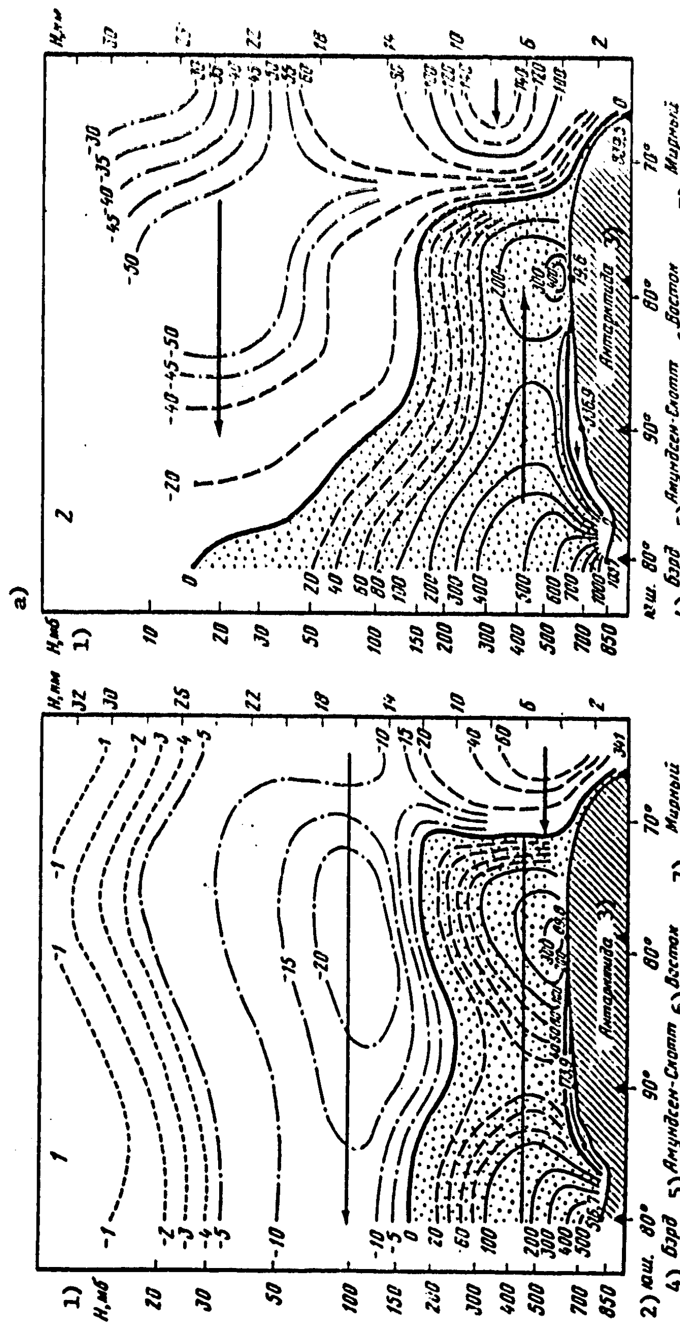

Figure 3. [Continuation, caption and key on following page]

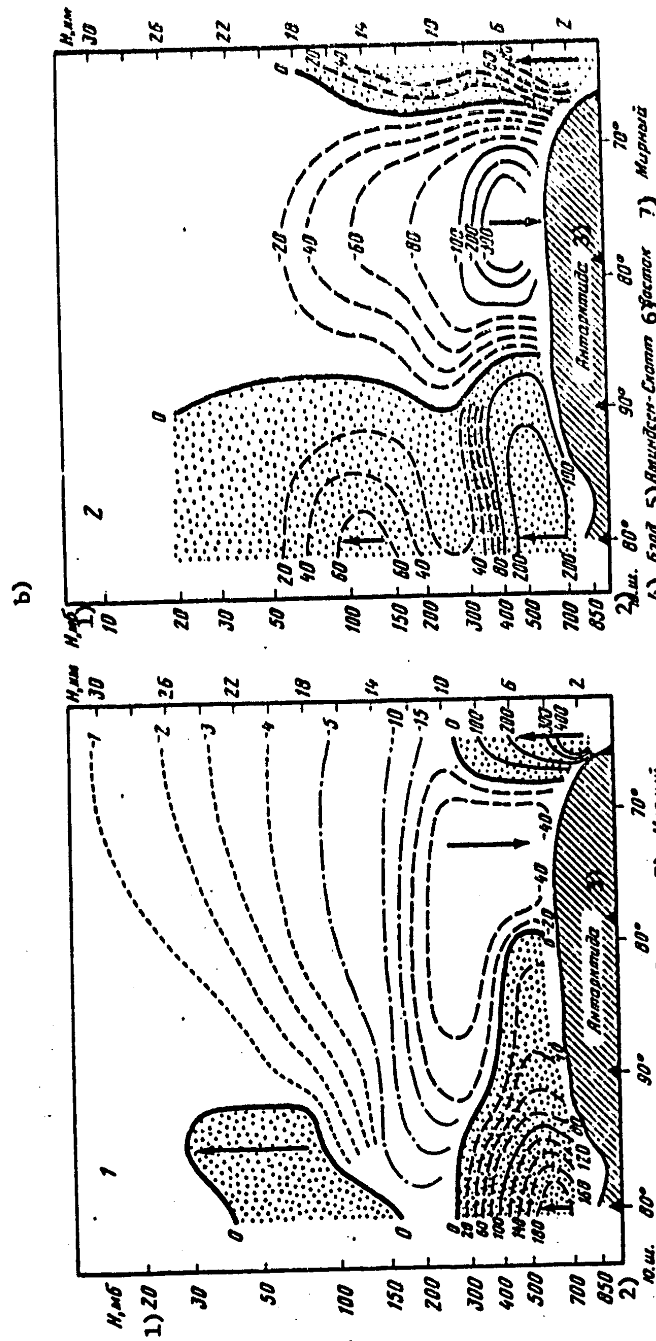

Figure 3. Transfer of Air Mass over Antarctica in January (1) and July (2): a--meridional (10^{-3} g/cm^2·s); b--vertical (10^{-6} g/cm^2·s)

[Key on following page]

Key:

1. H, mb
2. South latitude
3. Antarctica
4. Byrd
5. Amundsen-Scott
6. Vostok
7. Mirnyy

In January (fig 3a, 1) in the troposphere and lowest layer of the stratosphere are observed two major air mass flows aimed toward one another. From regions of the Pacific Ocean the air travels through the geographical pole and the Vostok station to the central regions of East Antarctica. Above the Byrd station this flow extends to an altitude of 12.5 km. In the same region are observed maximum values of momentum, reaching near Earth's surface 516.7×10^{-3} $g/cm^2 \cdot s$; at the opposite end of the continent--through the Mirnyy station area--the air moves from regions of the Indian Ocean to the plateau. These meridional flows meet at the plateau. Because of the convergence of momentum, here is formed a surplus of mass, part of which is compensated by the runoff of air in a thin surface layer through the Amundsen-Scott station area into the area of the Mirnyy station.

In higher atmospheric layers is observed a unified meridional transfer of masses from the Indian Ocean coast of Antarctica through the geographical pole to the Pacific Ocean coast. Thus, in the summer period, in spite of reduced temperature contrasts, the pattern of horizontal air movement in the meridional direction appears rather clear. The key features of this pattern are the convergence of masses in the troposphere over the central regions of East Antarctica and the runoff of air from the dome in a thin surface layer.

In keeping with the pattern of horizontal movement of air masses, a field of vertical movement also forms in the atmosphere (fig 3b, 1). For example, in the zone of convergence above the plateau are observed descending movements with maximum velocities in the troposphere on the order of 0.17 to 0.20 cm/s, which corresponds to a momentum in this region of from $50 \cdot 10^{-6}$ to $55 \cdot 10^{-6}$ g/cm^2. Ascending movements are observed in the troposphere of the coastal zone of East Antarctica (up to 0.45 cm/s in the 850 to 700 mb layer) and over the Byrd station (0.21 cm/s in the middle troposphere).

Meridional flows generally reach their maximum values in July. The greatest changes have occurred in the stratosphere. Whereas in the summer period over the region discussed has been observed a unified flow of masses from the Indian Ocean to the Pacific Ocean coast, in the winter air from the Pacific Ocean predominates over West Antarctica.

The meridional flow of air masses in the stratosphere is most intense in the region of the coast of East Antarctica, where momentum values are almost an order of magnitude higher (from $35 \cdot 10^{-3}$ to $45 \cdot 10^{-3}$ $g/cm^2 \cdot s$) than the corresponding values typical of the area of the Byrd station (from $2 \cdot 10^{-3}$ to $9 \cdot 10^{-3}$ $g/cm^2 \cdot s$). This also explains the possible anomalies in temperature conditions observed most often over the coast of East Antarctica. They represent the prerequisites for springtime rearrangements of the temperature and pressure field in the stratosphere.

The vertical transfer of air masses varies little from fall to winter (fig 3b, 2). The mechanism of mass movement is maintained as before, with the predominance of descending movements over East Antarctica and of ascending movements, more pronounced than in the fall, over West Antarctica, whereby the distinctive feature of these movements is an increase in the intensity of vertical transfer over the entire region considered, especially in the stratosphere.

The advent of summer conditions in the stratosphere is most often accomplished through regions of East Antarctica. In October the amount of air transferred here from the ocean is reduced in all layers of the atmosphere. This takes place chiefly because of a reduction in cyclone activity during the spring period as compared with the winter. The most intense air exchange is observed in the 200 to 150 mb layer. In precisely this section of the stratosphere the total transfer of the quantity of air is increased from July to October. Consequently, here take place great meridional disturbances, corresponding to the process of the intrusion of an anticyclone from ocean regions onto the mainland.

The intensification of the influx of air in the stratosphere from the direction of the Indian Ocean is compensated not only on account of its partial flowoff in the direction of West Antarctica, but also because of the activation of descending movements of masses, whose role in the formation of the spring circulation cycle is most significant. Beginning in the upper layers of the stratosphere, intensification takes place in the descent of air over East Antarctica, along with the spreading of descending movements to West Antarctica. For example, over the Amundsen-Scott station ascending movements are recorded in the spring only in the troposphere. Over the coast of East Antarctica in the middle stratosphere the velocity of descending movements reaches 0.8 to 1.0 cm/s.

In Antarctica's air column up to the 20-km point, the mass of the air on average for a month equals $99.7 \cdot 10^{15}$ kg, and its variations over the course of the year equal two percent. This air mass, because of the high-altitude nature of the continent, is 1.4-fold lower (in comparable areas) than the mean mass over the Arctic, but the intensity of air exchange is greater in Antarctica than in the tropical zone of the northern and southern hemispheres and the Arctic at comparable areas. This fact indicates the large role of vertical movements of air over Antarctica and of the low-pressure zone near the coast in air exchange.

It is sufficient to note that the prevailing figure for the descent of air over the continent from a maximum in the 700 to 500 mb layer equals on average $115.6 \cdot 10^{15}$ kg/month.

The regular receipt of satellite information in Antarctica begun in 1970 has made it possible to discover a number of features which have substantially refined our ideas regarding the circulation and dynamics of the atmosphere in the southern hemisphere. Unlike ideas formed earlier, artificial Earth satellite data have demonstrated that the zonal paths of cyclones are distributed over a rather extensive area. The axis of this area, characterized by a maximum number of paths, passes approximately along 58° latitude south, but not near the coast, as was thought earlier. The northern boundary of zonal paths of cyclones migrates from 45 to 50° latitude south in the warm season to 35 to 40° latitude south in the cold. This fact has been reflected also on charts obtained for distribution of the cloud cover.

In studying atmospheric processes in the southern hemisphere it was established that here all processes can be generalized into three forms of circulation: a zonal and two meridional. On this basis atmospheric processes at high latitudes in the southern hemisphere have been given a standard classification. This standard classification has made it possible to extend the macrocirculation method of weather forecasting of the AANII [Arctic and Antarctic Scientific Research Institute], as well as the hydrodynamic method based on utilizing a spectrum model of the dynamics of planetary atmospheric circulation, to the high latitudes of the southern hemisphere.

Experiments have been conducted on mathematical modeling of circulation in the southern hemisphere at the AT-500 level. A determination was made of the nature of the influence of nonlinear factors on the formation of a longterm trend in the development of atmospheric circulation. Experiments in forecasting AT-500 for eight to 10 24-hour periods have been run on the "Minsk-32" computer. The correctness of these experimental forecasts has been about 80 percent.

Thermal Conditions

The role of the polar regions is great in the formation of thermal contrasts on the planetary scale, and, consequently, of the intensity of overall atmospheric circulation, since the greatest temperature ranges are observed in these regions.

The mean annual air temperature in the surface layer along 70° latitude north and south equals -9.2 and -11.0°C. Furthermore, the annual temperature range in Antarctica equals 17.1°, whereas in the Arctic it equals 31.6°. Consequently, the thermal conditions of the coast of Antarctica are more "marine" than those of the coastal regions of the Arctic Ocean. Of course, a great, if not a major, role in the stability of the air temperature on the coast of Antarctica belongs to the foehn effect during the period of flowoff winds. For this reason on the coast of East Antarctica in the cold season of the year the air temperature is five to seven degrees higher than in the analogous season in the Arctic. And in the warm season of the year in Antarctica, in spite of the increased influx of shortwave solar radiation resulting from the perihelion position of Earth in its orbit, because of the glacier's high albedo, the air temperature turns out to be nine to 11 degrees lower than that of the Arctic.

The vertical distribution of air temperature has made it possible to determine the structural features of the atmosphere's composition. At intracontinental stations the troposphere is colder than at coastal, and the stratosphere is warmer in summer and colder in winter. In the troposphere the difference between the mean temperature in January and July in the 500 to 300 mb layer equals about 12°, and in the stratosphere reaches 45 to 55° at the 10 to 20 mb level. The above-mentioned reasons for temperature stability in the surface layer (advection of sea air and adiabatic warming as it descends) result in the fact that the continental features expected in the upper troposphere are not observed.

The spatial position of isotherm levels over Antarctica has a number of well pronounced features. The key distinctive feature of the thermal field of Antarctica's troposphere is the slope of isotherm levels which contact the continent's ice cap. This feature, as is the presence of a surface cold cap, is most clearly pronounced in the winter.

Changes in thermal fields in the first half of the fall period are most pronounced in the stratosphere, where the drop from January to April equals 33°. The temperature drop at Earth's surface reaches 30°, and in the troposphere four degrees maximum. As the result of these changes by April a region of cold forms at altitudes of about 25 to 30 km. There is pronounced intensification of this region of cold in the area of the tropopause and in the surface layer. All three of these cold centers, positioned one above the other, are localized within the boundaries of the mainland, which apparently points toward the growing role of radiation cooling and toward the cooling influence of the mainland.

The form of isotherms in April creates the impression that in the lower stratosphere there exists a warm ring surrounding a column of cold air. This ring of warm air, which has been traced at altitudes of 10 to 16 km, and beginning at about 55° latitude south, at altitudes of 12 to 15 km, is located approximately over the continent's coastline.

By mid-winter, over Antarctica at altitudes of 20 to 25 km is located a stratospheric region of cold with a mean monthly temperature of about -90°. In addition to this region, over East Antarctica there is a well pronounced surface region of cold with a mean temperature in July of -68° (Vostok station). The subsequent seasonal temperature changes are highly noteworthy in terms of the annual cycle. The temperature rise process (from July to November) is most observed (approximately -50°) at altitudes of 20 to 25 km and (approximately -20°) in the surface layer on the glacial dome. The slightest changes (4 to 7°) are observed in the middle and upper troposphere.

In the summer the stratospheric warm-air region is situated above 30 km, and the lowest-temperature region at the level of the tropopause (-54°). To determine periods of seasonal transformations in thermal fields in the lower stratosphere, we have analyzed the annual behavior of temperature at constant-pressure levels of 200, 100 and 50 mb at the Mirnyy station (fig 4). At these levels, in the annual thermal cycle are found periods representing intraseasonal and interseasonal transformations, i.e., the appearance of a winter minimum, a spring rise in temperature, conversion of lapse rates to inversions, the appearance of a spring-summer maximum, a period of summer high temperature, and a fall-winter drop, in the course of which a reverse takes place in temperature lapse rates from summer inversion to winter.

Usually in the annual cycle appearances of an extreme temperature are separated by a period of a half a year, but this is not observed here. According to the mean data the appearance of a minimum temperature at all equal-pressure levels occurs at very brief intervals--between 5 and 18 August, i.e., about the middle of the astronomical winter.

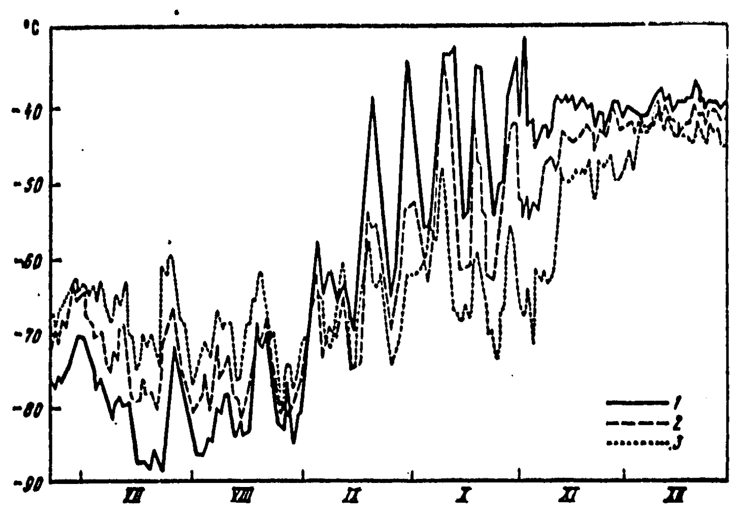

Figure 4. Annual Behavior of Air Temperature at Constant-Pressure Levels of 50 mb (1), 100 mb (2) and 200 mb (3) at Mirnyy in 1967

The length of the period from the winter minimum to the spring temperature maximum in the 100 to 50 mb layer equals on average 108 to 114 days, which amounts to somewhat less than one third of the year. At the 200 mb level the average length of this period equals 158 days. It is necessary to note the significant differences in the thermal cycle between the 200 mb constant-pressure level and the 100 and 50 mb levels. It is obvious from comparing the behavior of the temperature in these layers that during the warm season the 200 mb level proves to be the coldest, whereas in the cold half of the year it is the warmest. In addition, the period of appearance of a temperature maximum at the 200 mb level comes about 50 days later than at the 50 mb level. This agrees with the known seasonal features of temperature distribution in the upper troposphere and lower stratosphere.

Especially prominent in the annual cycle is the spring rearrangement of temperature fields in the lower stratosphere, which we will discuss in very great detail. This can be considered the key period for the appearance of nonperiodic disturbances of the annual temperature cycle. A characteristic feature of this period is a very rapid rise in temperature in the lower stratosphere. The rise in temperature in these layers is such that by the end of the spring rearrangement the temperature here reaches values which are maximum values at these levels for the entire year, although they occur in the second half of the astronomical spring season, and not in the summer.

The appearance of a maximum temperature is observed at the 100 and 50 mb constant-pressure levels at middle periods--from 5 November to 21 December, i.e., in the second half of the astronomical spring season, and at the 200 mb level between 16 and 25 January, which approximately corresponds to the middle of the astronomical summer season.

A change of sign in temperature lapse rates (reversal) always accompanies seasonal rearrangements of stratospheric temperature and pressure fields. Periods of reversal of temperature lapse rates quite clearly reflect seasonal changes in atmospheric circulation taking place at these levels.

The process of spring reversal of lapse rates must be associated with lowering of the warm-air region, which, having formed in the higher layers of the stratosphere, is spread downward, causing deformation of the stratospheric portion of the cyclonic vortex.

A determination was made of spring dates of the reversal of temperature lapse rates in the layer between the 200 and 50 mb constant-pressure levels for nine antarctic stations, from radiosonde observation data for 1961-1970 (the length of periods for some stations equaled from six to 10 years). Mean dates were determined from specially plotted curves.

As the result of an analysis of these curves, the following mean dates were arrived at for the reversal of temperature lapse rates in the spring period in the layer between the 200 and 50 mb levels:

Mirnyy	14 Sep	Amundsen-Scott	8 Oct
Vostok	30 "	Halley Bay	14 "
Molodezhnaya	25 Sep	Argentine Islands	20 "
Novolazarevskaya	4 Oct	Hallett	23 "
Byrd	6 Oct		

Consequently, the period during which spring reversal of temperature lapse rates takes place over Antarctica in the 200 to 50 mb layer on average equals the period from 14 September to 20 October, i.e., corresponds to the first half of the astronomical spring season.

It can be assumed that there can be well pronounced seasonal reversals in temperature lapse rates only at the higher latitudes. This assumption is based on the fact that, if the reversal of lapse rates is associated with seasonal rearrangements of stratospheric circulation, then the spatial spreading of this phenomenon must be limited to those latitudes at which a seasonal change in sign in stratospheric temperature and pressure fields takes place.

To verify these ideas, consideration was given to data for Howe Island for seven years (1962-1963, 1965-1969). It was determined that no seasonal reversal of temperature lapse rates is observed on Howe Island.

Similar temperature data were considered for the Macquarie Islands (approx. 54° latitude south) for the period 1963-1969. The temperature cycle on the Macquarie Islands proved to be more disturbed than on Howe Island, but considerably smoothed out as compared with antarctic stations. During periods of spring stratospheric rearrangements, which were recorded at higher latitudes, on the Macquarie Islands there was a moderate rise in temperature, but no reversal took place in lapse rates in the 200 to 80 mb layer.

In comparing the data presented it is obvious that in the range layers considered the temperature rises along the line from low latitudes to high.

The earliest dates of the reversal are recorded in the Indian-Australian sector, and the latest in the Atlantic sector. We know that during periods of spring rearrangement of temperature and pressure fields in the stratosphere of Antarctica the center of the stratospheric portion of a cyclone shifts into the Atlantic sector. If this pattern does occur, then applying it to the phenomenon discussed can explain the position of isochrones for the reversal of temperature lapse rates in the lower stratosphere.

In spite of the fact that the spring periods of a rise in temperature comprise a portion of seasonal transformations of thermal fields, they are usually considered stratospheric warmup periods. Therefore, the above-mentioned periods of a rapid spring rise in temperature and the appearance of a temperature maximum must be considered the consequence of stratospheric warming, observed during spring rearrangement of stratospheric temperature and pressure fields.

During the period 1961-1969, at the Mirnyy, Vostok, Molodezhnaya and Novolazarevskaya stations this warming was observed each spring season. Since this warming (like the reversal of lapse rates) is observed each year, this provides an opportunity to represent it by certain mean characteristics. Taken as the beginning of this warming is the end of the period of level temperature lapse rate reversal, and as the end, the time when the temperature reaches a maximum.

The spring stratospheric warming period exhibits differences from winter warming. In this connection it is possible for a certain vagueness to arise in explaining the time limits for the phenomenon, since during this period the rise in temperature more often does not take place smoothly, but consists of certain fluctuations over a considerable range. For example, very typical is the year 1967 (cf. fig 4), when at Mirnyy at the 50 mb level from 20 September through 31 October (42 days) were observed five fluctuations with an average range of about 28°. Usually in one of these concluding fluctuations the annual temperature maximum is recorded, after which the temperature drops somewhat and during the period of the warm season no longer reaches values of this sort. The impression is created that the temperature of these layers, in addition to the seasonal cycle brought about by radiational causes, experiences the influence of certain aperiodic surges which create fluctuations over a wide range against the backdrop of the seasonal rise in temperature. These surges must be related to the influence of dynamic factors which arise during the spring disturbance of the stratospheric portion of the cyclonic vortex. The influence of dynamic factors during this period has been acknowledged by many investigators, although they sometimes attach a different significance to it.

The manifestation of the annual temperature maximum in the lower stratosphere over Antarctica has a rather broad range of variation in terms of space and time. For example, whereas the maximum is most often observed at the 50 mb level in November, at the 100 mb level it is observed in December, and at the 200 mb level in January. It is obvious from this that with a reduction in altitude the time for appearance of the maximum shifts to later periods, i.e., is extended from up to down. This has been verified by the mean and extreme dates of appearance of the temperature maximum.

The mean length of the period from reversal of lapse rates in the 200 to 50 mb layer to the appearance of the maximum temperature at the 200 mb level is 107 days, at the 100 mb level 75 days, and at the 50 mb level 55 days. During this period in 76 percent of the cases the temperature at the 50 mb level rises from 31 to 40°.

The spring temperature maximum in the lower stratosphere is observed first in the Indian-Australian sector, and then moves in the direction of the Atlantic sector. It is possible that these characteristic features of the spring temperature cycle in the lower stratosphere are determined by the features of atmospheric circulation in the Indian-Australian sector.

It is obvious that all this is the result of a rise in baroclinicity here, which establishes this sector as the place for the earliest spring disturbance of the cycle of the stratospheric portion of the cyclonic vortex.

Antarctica's Hydrological Cycle

As the result of existing climatic conditions, about 90 percent of the fresh water of rivers, lakes and glaciers on the globe is concentrated in Antarctica. The dynamics of these resources is of extraordinarily great importance to the entire globe (Voskresenskiy, 1967; "The World's Hydrological Cycle...," 1974). Antarctica does not have considerable sources for humidifying the atmosphere for the purpose of maintaining the cycle within the range of the region; therefore, the key role in snow accumulation belongs to the advection of water vapor from ocean regions.

In the table are given the characteristics of the hydrological cycle for three regions of Antarctica typical of the major geographical zones of the continent (Voskresenskiy, 1976). Taking into account the relative stability of atmospheric processes in Antarctica, the assumption was made that each aerological station characterizes a region 280,000 km^2 in area (effective radius of station, 300 km).

A characteristic feature of the ice shelf zone is, in addition to high evaporation in the summer season (10 km^3), the considerable sublimation of water vapor on the surface of the ice during the winter period, which totals 18 km^3. The hydrological cycle coefficients for all zones are not too high (1.00 to 1.04), which is indicative of the advective source of precipitation. The atmospheric drain of moisture caused by evaporation equals from zero in the ice shelf zone to 49 km^3 in the coastal zone and reflects the circulation features of these regions. The ratio of the total atmospheric removal of moisture from the region to the occurrence of precipitation points toward mild precipitation forming processes. In the ice shelf zone P_a/P factors equal 1.00 to 0.98 at the Vostok station, and 0.97 at the Mirnyy station.

Characteristics of the Hydrological Cycle in the Atmosphere Over Antarctica for the Year

Characteristic	Ice Shelf Zone (Lazarev station)	Intra-continental region (Vostok station)	Coastal zone (Mirnyy station)
Area, km^2	280,000	280,000	280,000
Precipitation, P, km^3	80.1	10.4	119.6
Atmospheric moisture content in 0-7 km layer, W, km^3	0.8	0.1	1.0
Total annual moisture transport, A, km^3	444	25	605
Advective precipitation, P_a, km^3	80.1	10.2	114.4
Precipitation from evaporation from continent, P_e, km^3	0	0.2	5.2
Transit of moisture across continent, $C = A - P_a$, km^3	361	15	491
Atmospheric runoff of moisture caused by evaporation from continent, $C^2 = E - P$, km^3	0	0.92	48.8
Total removal of moisture in the atmosphere from continent, $C = C^1 + C^2$, km^3	361	16	540
Hydrological cycle coefficient	1.0	0.98	0.97

Note: The concept "precipitation" includes accumulating (sublimation) precipitation, $P = P + P_{accum}$.

Since the zones selected are typical, the advective origin of the precipitation does not cause doubt. The mechanism for the advection of moisture remains in need of explanation. In fig 5 is shown the total meridional moisture transport averaged from daily data for a period of many years from the Mirnyy - - Vostok - Amundsen-Scott - Byrd - Argentine Islands stations in an atmospheric column extending from the underlying surface to 5 km, inclusive. The moisture transport figures given here agree well with the existing pattern of circulation over Antarctica. In the winter in the troposphere the moisture transport is directed from the Indian Ocean toward Antarctica (Mirnyy station), with a maximum at the 3 km level (-1.5 g/kg/m·s). In the area of the Vostok station the transport figure equals zero. From the direction of the Antarctic Peninsula is directed a large-scale transport of moisture, which at the 3 km level equals 3.0 g/kg/m·s and reaches the South Pole.

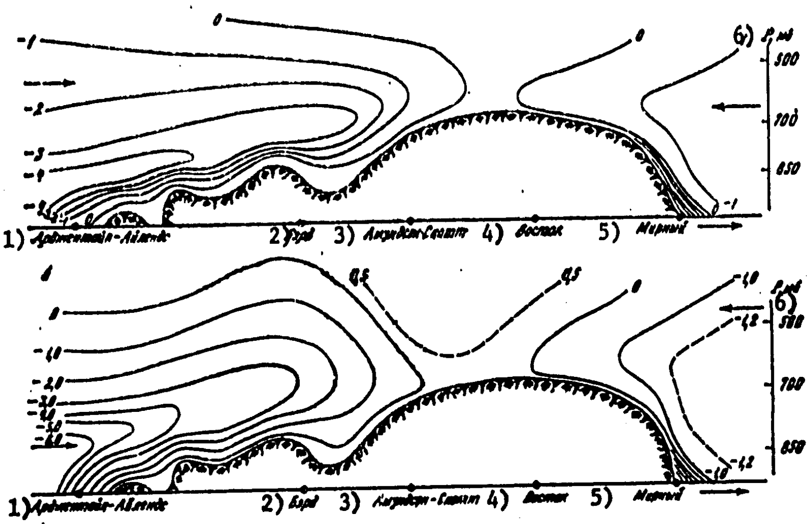

Figure 5. Total Meridional Moisture Transport Over Antarctica (kg/m·s) in January (a) and July (b)

Key:

1. Argentine Islands	4. Vostok
2. Byrd	5. Mirnyy
3. Amundsen-Scott	6. P, mb

In the distribution of moisture there is a distinctly pronounced influence of orography on the depth of penetration of air masses into the continent. On the West Antarctica side, which is mildly sloping and narrow, moist masses from the ocean penetrate into the interior of the continent in cyclonic formations two times further than in East Antarctica. In East Antarctica, by virtue of the considerable height above sea level and great steepness of the slope, cyclones usually cannot penetrate far into the interior of the continent, and those that do are without the lower most moisture bearing section.

In the summertime the distribution of meridional transport is practically maintained completely. But there is a change in the proportion of components in the transport. With a twofold increase in the atmospheric moisture content the meridional component of the wind velocity is reduced, and on the whole the transport of moisture in the troposphere remains the same as in winter.

Zonal transport of moisture evidences a distinctly pronounced annual cycle and is reduced drastically from coastal regions into the interior of the continent.

It is of specific interest to estimate the amount of outside-cloud precipitation, a phenomenon widespread in Antarctica. The existing mechanism for meridional circulation continuously supplies relatively warm and moist ocean air to the upper troposphere and lower stratosphere. The moisture content near the underlying surface is exceptionally low because of the low temperature. Thus, humidity inversion is created, which is observed practically all year. Because of descending movements, "moist" air masses reach saturation, and the crystals formed fall to the surface. This phenomenon is widespread in terms of time and space, and, in spite of negligibly low 24-hour figures (less than 0.1 mm), about 60 km^3 of water falls over Antarctica annually.

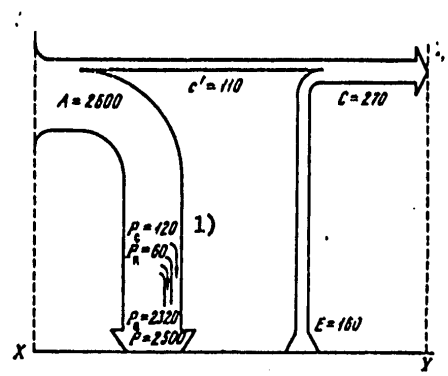

Figure 6. Diagram of Hydrological Cycle in Antarctica (km^3): A--advection of water vapor; P_s--precipitation in the form of sublimation of water vapor at the surface; P_k--precipitation on account of crystals; P_a--precipitation from advective water vapor; P--total amount of precipitation per year; c'--transit advection of water vapor; C--annual extent of evaporation

Key:

1. P_s

In fig 6 is shown a diagram of the hydrological cycle in Antarctica. We have set total annual advection at 2600 km^3, 2500 km^3 of which goes toward precipitation. Water vapor from evaporation (160 m^3) is apparently removed by runoff, and cloud formation processes (descending movements) have evolved but slightly in Antarctica. Thus, climatic runoff equals about 270 km^3 of water per year, which equals one tenth of the entire total of advection plus evaporation. Twenty-three hundred cubic kilometers are withdrawn from the global hydrological cycle to maintain the 2500 km^3 of precipitation which falls on Antarctica. The problem of the return of this water to the global ocean has not yet been treated fully. On the whole, Antarctica, which comprises about 2.5 percent of the total area of Earth, annually consumes about six percent of the surplus moisture delivered into the atmosphere by the global ocean.

The Cooling Role of Antarctica

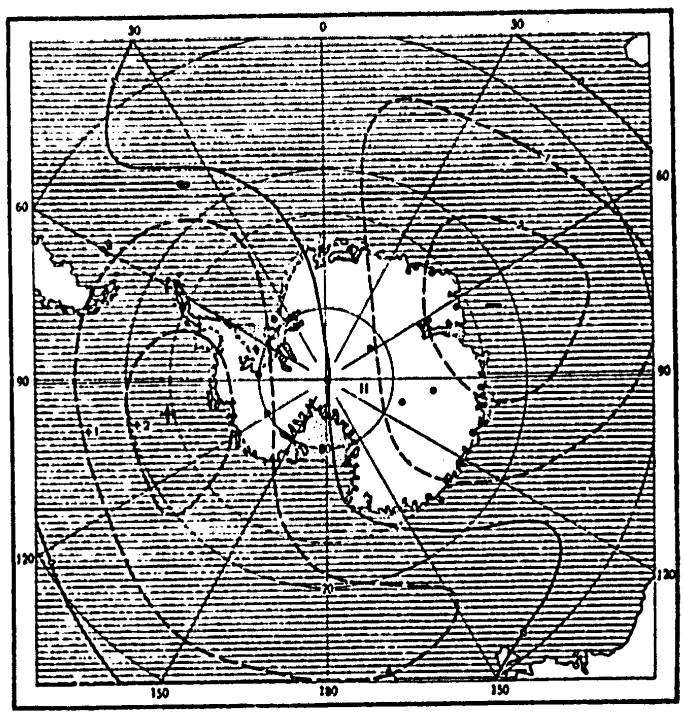

Figure 7. Deviations of Mean Annual Values of Air Temperature in the 1-5 km Layer at Points on the Coordinate System, From Mid-Latitude Values

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In studying the thermal cycle of the atmosphere at high latitudes in the southern hemisphere, the question arises of the thermal influence of Antarctica on the atmosphere and ocean. V.A. Bugayev (1967) stated that this question is of great interest from the viewpoint of both knowledge and practicality.

Let us discuss this problem, utilizing data on deviations of air temperature figures at points on the geographical system of coordinates from the mid-latitude value in the 1-5 km layer (fig 7). The spatial distribution of air temperature deviation figures makes it possible to point out well pronounced areas of deviation with different signs, positioned symmetrically in relation to the Antarctic Continent. It has turned out that for the lower troposphere at moderate and high latitudes in the Atlantic-Indian sector negative deviations are characteristic, and positive for the Pacific Ocean sector. From this it is possible to see that the lower troposphere is shown to be considerably colder in the Atlantic-Indian sector that at the same latitudes in the Pacific Ocean sector.

It is possible to arrive at an explanation for this distribution of centers of deviation by comparing the relative position of latitude circles and isohypses of the 700 mb constant-pressure level, which can be considered the midpoint of this layer. Isohypses on the mean annual AT-700 chart deviate from latitude circles in such a way that in the Pacific Ocean sector the advection of air takes place from low latitudes to higher (heat transport), and in the Atlantic-Indian sector there is a well pronounced meridional component running from high latitudes to lower (cold transport). Consequently, the position of centers of deviation in temperature with different signs in terms of the mid-latitude temperature is found to agree with the predominating forms of transport in this layer. On this basis it can be said that the influence of Antarctica as a source of cold is most pronounced in the Indian sector. The position of zones with the thickest ice cap in Antarctica and with the maximum extent of ice during the year agrees completely with the position of cold advection zones. Attention should be paid to the great ruggedness of the coastline of Antarctica in areas of location of heat centers and to the comparatively mild features of the coast of East Antarctica where the cold center is located.

Another estimate of the cooling influence of Antarctica is represented by the expenditure of heat in the equatorial zone to compensate radiational cooling. This figure has been estimated at approximately $5.25 \cdot 10^{22}$ J. In addition, as indicated above, about $9 \cdot 10^{9}$ tons of snow are removed from the continent's coastline into the sea, for the thawing of which it takes $1.93 \cdot 10^{11}$ J. Of course, these are just rough estimates which will be refined in the future, but they indicate Antarctica's significant role in the atmospheric energy balance.

Conclusion

Since Antarctica is a key heat sink region in the Earth-atmosphere system, meteorological conditions in this region will become more intelligible in relation to a consideration of the thermal, moisture and energy balance and of those physical processes which they determine. Starting from these premises, the main objectives in the area of the meteorology of this region can be formulated in the following manner:

1. Research on the radiation balance and development of a model of a standard actinometric atmosphere. The solution to this problem involves an extensive combination of studies in the free atmosphere which is also of independent scientific and applied significance (temperature profiles, water vapor, carbon dioxide, ozone, cloudiness, aerosols).

2. Research on the statistical structure of meteorological fields and development of climatological "standards" for the purpose of forecasting and studying contemporary climatic trends.

3. Research on the mechanism for circulation (vertical movements and horizontal flows) of pressure formations and on the quantitative characteristics of the atmosphere's mass balance.

4. Research on thermal and energy transport, both within the scope of the region itself, and at its outer limits, for the purpose of a quantitative estimate of the role of Antarctica as a heat and energy sink, and on the role of descending winds, atmospheric fronts, cyclones, anticyclones and jet streams in the energy balance.

5. Research on the atmospheric hydrological cycle, and determination of the role of Antarctica as a region for the runoff of atmospheric moisture. The influence of the cryosphere on the climate and weather of various regions. Research on continental ice and snow as climate indicators.

6. Development of models of climate and atmospheric circulation as means of forecasting climate changes on a longterm basis.

Accomplishment of this program will enable us to come considerably closer to a quantitative estimate of the role of Antarctica in overall atmospheric circulation. The results of recent research presented briefly here have demonstrated the possibility of new quantitative estimates of conditions and processes in the atmosphere of Antarctica and of its influence on adjacent territories.

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RESULTS OF SOVIET RESEARCH IN THE SOUTHERN OCEAN

Moscow ANTARKTIKA: OSNOVNYYE ITOGI IZUCHENIYA ANTARKTIKI ZA 20 LET. DOKLADY KOMISSII in Russian No 17, 1978 pp 82-95

[Article by A.F. Treshnikov]

[Text] Research in keeping with the program for the International Geophysical Year (MGG), in terms of its scale and exceedingly important scientific value, has laid the foundation for a new period in studying our planet. In keeping with a unified and predeveloped program, research has been begun on phenomena in Earth's crust, the atmosphere, space, and the seas and oceans. Sixty-five countries have taken part in this research. An important position in the MGG's plans has been assigned to studying Antarctica, as the least studied area of Earth. In the Soviet Union the organization of research in Antarctica and its accomplishment have been entrusted to the Combined Antarctic Expedition, specially created in 1955 under the auspices of the USSR Academy of Sciences.

The interest of Soviet scientists in studying the southern polar region was understandable, since many natural phenomena on the globe cannot be understood without observations in Antarctica. Information on hydrometeorological and geophysical processes in this region was quite scanty, and on geographical maps a considerable part of Antarctica was a white spot. Ships sailing in the waters of Antarctica made hydrometeorological observations far from the continent's shores, being afraid to call for an extended period at the sea ice zone surrounding the continent.

An important place in the plans of Soviet antarctic expeditions, in addition to research in Antarctica, has been occupied by observations in the waters of the Southern Ocean.

Unlike research conducted on English vessels of the Discovery Committee, research during the time of voyages by vessels of the Soviet antarctic expedition, the expeditionary vessels "Ob'," "Lena," and others, covered not only the northern, but also the southern regions of antarctic waters, including the floating sea ice zone.

The following have been the main objectives of Soviet antarctic expeditions in research on waters of the Southern Ocean:

1. Discovering the nature of the thermal and dynamic cycle of southern polar waters, and of water and heat exchange with adjacent regions of the global ocean and the atmosphere.

2. Studying the hydrological cycle of Antarctica's shelf seas.

3. Studying ice conditions and features of the distribution of icebergs, as well as the physical-mechanical properties of antarctic ice.

4. Studying the circulation of surface and deep waters.

5. Gathering instrument data on elements of waves in waters of the Southern Ocean, and studying their relationship to wind and ice conditions.

6. Studying the geological and morphological structure of the ocean floor, and making a hydrographic survey of coastal regions of Antarctica.

7. Studying the zonal distribution of fauna in waters of the Southern Ocean.

8. Studying features of geophysical phenomena in the Southern Ocean.

Thus, in the program for antarctic marine expeditions were concentrated all the most important and least studied questions relating to the hydrology of the Southern Ocean. Also paid attention to was the uneven distribution of observations of the Southern Ocean water area made prior to the start of the MGG.

Before the mid-50's a picture of the hydrological cycle could be drawn only for certain regions of the Southern Ocean. The Indian and Pacific Ocean sectors remained poorly studied. The region located south of 60° latitude south was almost not covered by hydrological observations.

The results of oceanographic research done during the voyages of the expeditionary vessel "Ob'" and other vessels of SAE's [Soviet anarctic expeditions] begun in 1956 and continuing every year thereafter have been a great contribution to the oceanography of the Southern Ocean.

The main area for Soviet hydrological research has become the Indian sector of the Southern Ocean, where observations have covered both coastal and ocean areas, and this research has been conducted from ships and airplanes (aerial ice surveys) and at antarctic stations. Most studied in the hydrological respect, as the result of the work of Soviet antarctic expeditions, are Davis Sea and Prydz, Alasheyeva and Leningradskiy bays.

Deepwater observations on the open sea have most frequently been made by making hydrological profiles, the majority of which intersect the Southern Ocean in a meridional or near meridional direction.

Fifteen times hydrological studies have been made on the cross section along 20° longitude east from Africa to Antartica. Observations have been made four times each on the Fremantle (Western Australia) - Mirnyy and New Zealand - Antarctica cross sections. Deserving of attention are two hydrological cross sections made by the expeditionary vessel "Ob'" in the Indian sector on the first two voyages. One of them intersects the Indian Ocean from the Antarctic coast to the Gulf of Aden, and the other from Antarctica to the Bay of Bengal.

SAE vessels have made a somewhat lesser number of observations in the Atlantic and Pacific Ocean sectors of the Southern Ocean. In the Pacific Ocean sector, in addition to the cross section between New Zealand and Antarctica already mentioned, observations have also been made on cross sections along 160° and 109° longitude west, on a cross section from Easter Island to South America, and in the region of the South American coast. In the Atlantic sector studies have been made on cross sections in Drake Passage, from Drake Passage to Montevideo, and along 30° longitude west.

The greatest amount of oceanographic observations was made by SAE vessels--the expeditionary vessels "Ob'" and "Lena"--during the first three expeditions, i.e., right during the time the International Geophysical Year was held, the Year of International Cooperation, and the International Year of the Quiet Sun. During this time, in addition to hydrological observations, research was conducted on marine biology and geology and studies were made of wave activity, currents, sea ice and icebergs, the topography of the ocean floor, optical hydrological characteristics, etc. Trips were made to the little-studied shores of Antarctica and they were described.

After the end of the MGG the amount of physical oceanographic observations in the Southern Ocean was considerably reduced. Major attention was paid to studying the hydrological cycle and ice conditions of coastal regions of Antarctica. With the slightest opportunity studies were also made on standard meridional cross sections. Beginning in 1968, in addition to the expeditionary vessel "Ob'," the scientific research vessels "Professor Zubov" and "Professor Vize" began to take part in Southern Ocean research.

During the past 20 years SAE vessels have set up in waters of the Southern Ocean about 1500 hydrological stations, of which about 1200 were from on board the expeditionary vessel "Ob'." On each voyage to Antarctica en-route measurements were made of the temperature and salinity of the ocean's surface layer.

While SAE vessels have been sailing in the Southern Ocean hundreds of thousands of miles have been traveled while making sonic depth finding measurements, and dozens of thousands of hydrometeorological observations have been made. Measurements of ocean currents by means of EMIT [electromechanical measuring equipment] have been made for a distance of 35,000 nautical miles. At 26 hydrological stations, by means of BPV [expansion unknown], measurements have been made of currents at deep levels, while recording current elements for as long as 30 24-hour periods. Elements of waves have been measured at 140 stations, and 155 wave records and 980 stereoscopic images of waves (stereo photographs of waves) have been made. At more than 500 stations samples of ocean floor sediment have been gathered; more than 200 measurements have been made of the thickness of marine sediment by the seismo-acoustical method; and more than 300 geographical stations have been set up. Expedition biologists have collected more than 4000 plankton and about 400 bottom sampler and trawl samples; 7300 specimens of fish have been recorded. On the 11th SAE for the first time in Antarctica biological studies were made by using an aqualung. On many journeys of the expeditionary vessel "Ob'" a cartographic survey was made of the coastline, covering more than one third of the perimeter of Antarctica. It must be stressed that research conducted in the Southern Ocean on SAE vessels has been performed at a very high methodological level.

In recent years more and more extensive use has been made of computer technology in oceanographic research. "Minsk-22" and "Minsk-32" computers have been installed on the AANII [Arctic and Antarctic Scientific Research Institute] vessels "Professor Zubov" and "Professor Vize," which have been at work every year in the waters of the Southern Ocean. Because of this there has been an increase in volume, quality has improved, and the time required has been shortened for estimating oceanographic characteristics.

It is hard to overestimate the scientific importance of the observation data which has been gathered and of the research done. Without exaggeration it can be said that during the last 20 years we have learned about the nature of Antarctica immeasurably more than during the entire preceding history of studies on it. Soviet researchers on the Southern Ocean have published dozens of scientific reports, monographs and articles on natural phenomena in the southern polar region. The majority of these have been published in TRUDY SOVETSKOY ANTARKTICHESKOY EXPEDITSII [Proceedings of the Soviet Antarctic Expedition], in the collection PROBLEMY ARKTIKI I ANTARKTIKI [Problems of the Arctic and Antarctica], in the INFORMATSIONNYY BYULLETEN' SOVETSKOY ANTARKTICHESKOY EKSPEDITSII [Information Bulletin of the Soviet Antarctic Expedition], in the journal OKEANOLOGICHESKIYE ISSLEDOVANIYA [Physical Oceanographic Research] of the Interdepartmental Committee on Proceedings of the MGG, in the collection ANTARKTIKA [Antarctica], and in other publications. But the fullest reflection of the results of comprehensive study of Antarctica is found in the two-volume Soviet "Atlas Antarktiki" [Atlas of Antarctica]. In it is presented a long section on the oceanography, meteorology and biology of the Southern Ocean ("Atlas Antarktiki," 1966, 1969).

In "Atlas Antarktiki" are presented the results of many years of research on Antarctica conducted by scientists of different countries, and especially by Soviet scientists. This atlas marks the end of the stage of elementary study of the nature of Antarctica.

Below are presented the main scientific results obtained by Soviet researchers in the Southern Ocean.

Regarding the Boundaries of the Southern Ocean

Characteristic of the Southern Ocean is the absence of any distinctive morphological or orographic boundaries with the southern sections of adjacent oceans, and therefore the question of isolating the vast ocean area surrounding Antarctica as an independent ocean has for a long time remained moot.

Observations made in recent years in antarctic waters have demonstrated that the southern halves of the Atlantic, Indian and Pacific oceans (south of 40 to 45° latitude south) represent a unified independent physical geographical region of the global ocean, distinguished by unity and peculiarity of natural processes. Therefore, the isolation of the Southern Ocean as an independent ocean does not raise doubts now. Research conducted in the Southern Ocean has not only proved the correctness of isolating it as an independent ocean, but has also made it possible to precisely define its natural northern boundaries. Previously many researchers took the zone of antarctic convergence as the boundary of the Southern Ocean. But, as research has shown, the choice of this zone as the boundary of the Southern Ocean is an unfortunate one, since it runs through the southern half of the Antarctic Circumpolar Current (ATsT). And it is precisely the Antarctic Circumpolar Current, extending from the antarctic divergence in the south to the subtropical convergence in the north, which in essence forms all the key features of the hydrological cycle of the Southern Ocean. Thus, only the subtropical convergence, representing the northern boundary of the ATsT, can be considered the natural boundary of the Southern Ocean.

However taking into account the fact that the position of subtropical convergence varies over time and is not always sufficiently distinctly marked, in determining the boundaries of the Southern Ocean used in the Soviet "Atlas Antarktiki" use was made of a principle making it possible to draw boundaries conventionally by taking into account local orographic features, but with a maximum approximation of the position of subtropical convergence (Kort et al., 1964; Treshnikov, 1968).

Hydrography

In the cartographic and hydrographic respect, the least studied up to recent times has been the coast of East Antarctica. Here coastal regions abounded in "white spots." Based on a cartographic photographic survey of the antarctic coastline, the depiction of the coastline has been considerably refined for a distance of more than one third of the perimeter of Antarctica. Dozens of new geographic points have been discovered (mountains, glaciers, islands, bays, and the like). From the results of this research new nautical charts have been created for the Indian sector of the Southern Ocean.

Sonic depth finding measurements have made it possible to refine considerably the relief of the ocean floor and to find a number of previously unknown troughs and prominences. The continental shelf of Antarctica has been outlined and a study has been made of its morphology. In certain regions of Antarctica ice shelves shut off the greater part of the continental shelf. A characteristic feature of Antarctica's continental shelf is the fact that it is sunk deeper (as much as 500 m) than around other continents (200 m maximum). This is occasioned by the total submersion of Antarctica under the influence of the gigantic ice load.

In many areas of Antarctica's shelf Soviet researchers have found narrow intrashelf channels with depths as great as 2000 m. As explained by Soviet geologists, their formation has taken place on account of the cracking of Earth's crust during vertical tectonic movements of the Antarctic Continent under the influence of a change in the thickness of the ice cap in the Quaternary Period (Treshnikov, 1963a).

Study by Soviet researchers in the coastal area of Antarctica of the configuration of the coastline, the relief of the ocean floor, currents, water masses, and ice conditions has revealed the individuality and isolated nature of a number of regions of Antarctica. As the result of a thorough analysis of data obtained, at the present time on the map of Antarctica on a section of the coast from 0 to 113° longitude west have appeared new land-locked seas, answering all the requirements made for the concept "land-locked sea." These are the Lazarev, Riiser-Larsen, Kosmonavty, Sodruzhestvo and Mawson seas ("Atlas Antarktiki," 1969). Just recently the suggestion was made of singling out a new independent sea--Somov Sea, so named in honor of the famous Soviet polar researcher M.M. Somov.

Marine Geology

From data of research on the underwater topography of the Southern Ocean charts have been made of the types of topography of the floor of the Indian and Pacific Ocean sectors. Based on a study of the composition of soil samples it has been established that in the region of the antarctic continental shelf, the continental slope and the peripheral section of the ocean bed iceberg deposits predominate, forming around the continent a belt from 500 to 1000 km wide, and in the deepwater section of the Southern Ocean, biogenic deposits.

In long soil cores was discovered a recurring alternation of sediment associated with fluctuations in climatic conditions. The analysis of data has made it possible to study the history of the climate and glaciation of Antarctica, as well as to at the present time come near to solving the problem of genetic classification of the topography of the floor and of sediments over a vast area of the Southern Ocean.

Oceanography

Physical oceanographic research in the Southern Ocean in the last 20 years has made it possible to a considerable extent to refine and elaborate existing ideas regarding the circulation of waters and to reveal the system of currents at deep and floor levels, and also in little studied coastal regions. Based on new patterns of water circulation constructed by Soviet scientists, it has been determined that the key circulation system of the Southern Ocean is the Antarctic Circumpolar Current, which governs the hydrological cycle of waters of the southern polar region (Kort, 1963; Treshnikov, 1964, 1966).

This current is remarkably stable and is well evolved in terms of depth and width. The width of the ATsT varies from region to region from 300 to 1500 miles, and its depth of immersion from 1500 to 3000 m. A characteristic feature of the ATsT is its asymmetry, i.e., its configuration, which is irregular and does not fall in line with the trend of parallels. The furthest distance of its current from the shores of Antarctica is observed in the Atlantic sector of the Southern Ocean, and the shortest in the eastern half of the Pacific Ocean sector.

The results of dynamic analysis of observation data, as well as instrument measurements of currents, show that the velocities of the Antarctic Circumpolar Current are relatively not too high; even in the narrowest section of the Southern Ocean--in Drake Passage, where velocities are maximal--they do not exceed 100 cm/s.

The structure of the ATsT is rather complex. As a rule, the current is a multiple one. It is interesting that the wider the ATsT is in a specific region of the Southern Ocean, the more multiflow it is and the slower are the velocities of currents observed in its streams.

As the result of recent research, the hypothesis has arisen regarding the existence in the Southern Ocean of a floor-level countercurrent, which has been followed at almost all longitudes of the ocean beneath the mainstream of the ATsT (Treshnikov et al., 1966).

A determination has been made of the key features of water circulation in coastal regions of Antarctica. Around the Antarctic Continent have been discovered some instances of stationary water circulation located in areas of cyclone localization. It has been hypothesized that the coastal antarctic current consists of the southern peripheries of these instances of circulation. Branches of this circulation directed northward from the continent remove floating ice and icebergs to northern latitudes. This explains the relatively rapid washing away of sea ice from a number of regions along the coast and the formation of evacuation zones, which makes it possible for vessels to penetrate into coastal waters relatively easily.

The first estimates have been obtained of water exchange and heat exchange between the Southern Ocean and the Atlantic, Indian and Pacific oceans. It has been established, in particular, that the Atlantic zone is a zone for warming and replenishing waters of the Southern Ocean. The Indian Ocean is a neutral ocean in relation to the Southern, while the Pacific Ocean zone represents a zone for the discharge by the Southern Ocean of part of its water (Treshnikov et al., 1966).

Data on water transport in the Southern Ocean testify to the fact that the Antarctic Circumpolar Current represents a very powerful ocean current of the global ocean. In terms of the amount of water transported by it (about 500 km^3/h), this current surpasses six- to eightfold such a powerful current as the Gulf Stream.

Physical oceanographic studies of recent years have shown that the velocities of the ATsT and, consequently, the transport of water by this current, undergo seasonal and longterm variations. Changes in the rate of flow of the ATsT in time can reach 40 percent. High variability in the velocities of currents and water transport figures is observed in the northern half of the Antarctic Circumpolar Current, while in the southern half this variability appears chiefly because of changes taking place in the structure of the currents themselves (Treshnikov et al., 1970, 1972).

In the last 20 years, simultaneously with research on currents, studies have been made of water masses of the Southern Ocean. The key water masses of Antarctica and their interaction were revealed long before the beginning of the MGG (Makerov, 1956; Deacon, 1937; Swerdrup et al., 1957). It was established that the entire depth of the waters is divided into three types: surface antarctic, warm deep and floor-level antarctic waters. Observations of recent years have verified this division and have made it possible to add to, refine, and in some cases to shed new light on the structure of water masses and the key patterns of space and time distribution of hydrological characteristics and the factors causing them. These data have also made it possible to determine the reasons for and areas of formation of different water masses and the routes along which they spread, which is exceedingly important in studying the thermal influence of waters of the Southern Ocean on waters of neighboring oceans (Maksimov, 1961; Klepikov, 1963; Fomichev, 1965; "Atlas Antarktiki," 1969; Grigor'yev, 1972).

Before the start of the MGG, because of the lack of the necessary observation data, charts of the distribution of hydrological characteristics in the Southern Ocean were constructed according to the principle of smooth interpolation of isolines between the zone of antarctic convergence and the coastline of Antarctica. New charts constructed from the data of observations at a rather dense network of oceanographic stations have shown that clearly marked zonality in the distribution of hydrological characteristics in surface waters is observed not in the entire Southern Ocean, but only in its northern regions. In the coastal regions of Antarctica the distribution of hydrological characteristics has been shown to be exceedingly complex--azonal. Here are observed large tongues of cold waters which extend far northward, and relatively warm waters heading toward the shores of Antarctica ("Atlas Antarktiki," 1966, 1969).

The main factors responsible for the complex azonal distribution of hydrological characteristics in coastal regions of the Southern Ocean are the processes of atmospheric circulation and water circulation and the distribution of drifting ice.

In recent years, with the accumulation of hydrological data in the coastal zone and a deeper analysis of it, the question has arisen regarding the distinction within the boundaries of the antarctic region of one more water type--shelf waters. These waters are located on the continental shelf, in regions directly abutting the coast of Antarctica. In terms of their origin shelf waters represent modified antarctic surface waters from the wintertime and are distinguished by very low temperatures and very high salinity.

Extreme values of these characteristics (temperature below -2.0°, salinity about 35.00 percent) can be observed within the range of the antarctic region only in shelf waters. They are caused by supercooling of waters in regions of stationary ice clearings, and also by the influence of ice shelves.

A careful and thorough study of shelf waters is the key to discovering the secret of the genesis of floor-level antarctic waters. It is precisely shelf waters, and not surface antarctic waters, as was thought earlier, which together with warm deep waters participate in the formation of floor-level antarctic waters. And if the mechanism for the formation of these waters is still not completely clear at the present time, then the fact has already become indisputable that these waters form not only in Weddell Sea, as has been assumed for a long time, but also in the Ross and Davis seas, in Prydz Bay, and in a number of other coastal regions.

In connection with the "widening" of the boundaries of the Southern Ocean northward to the zone of subtropical convergence, the efforts of scientists have been directed toward investigating two more water masses of the Southern Ocean located within the boundaries of the subantarctic region: subantarctic surface and antarctic intermediate waters. Special attention has been paid to studying this, since it has been established that these waters, as do antarctic floor-level waters, extend far beyond the boundaries of the Southern Ocean northward (right up to 60° latitude north) and exert a great influence on thermal conditions of waters of the global ocean.

A thorough investigation of the circulation of waters and water masses of the Southern Ocean has made it possible to consider from a new viewpoint the mechanism for the formation of frontal zones and their structure and geographical location. Besides refinement of the boundaries and structure of the earlier known subtropical and antarctic convergences, as well as of the antarctic divergence, the subantarctic divergence and a number of other intermediate frontal zones have been discovered. Seasonal and longterm variations in the position of frontal zones have been revealed. At the present time in research on frontal zones there is still a whole series of unsolved questions concerning primarily their formation and structure (Ivanov, 1961; Botnikov, 1963, 1969; Kort, 1967; Buynitskiy, 1974).

There is the opinion that the origin of frontal zones in the Southern Ocean and their geographical position are due chiefly to atmospheric circulation. Recent research has shown that atmospheric circulation plays a definite role in the formation of this frontal zone, but by no means a major one. Its existence, as the majority of scientists think, is related to the movement of deep and floor-level waters.

The zone of antarctic divergence is of a distinctive nature. According to the data of observations by Soviet antarctic expeditions it has been determined that this frontal zone does not represent a continuous region for the ascent of waters, but is detected in the form of spots at the centers of cyclonic cycles. This conclusion has been verified also by the results of hydrobiological observations.

Sea Disturbance

On the basis of instrument and visual observations of sea disturbance, ideas have been arrived at regarding the features of wave formation in different climate zones of the Southern Ocean, along with information on the possible values of wave elements ("Atlas Antarktiki," 1969).

It has been determined that the key feature of Southern Ocean waves is their great height and steepness. In some areas the height of waves reaches 25 to 30 m. This feature of sea disturbance is explained by the relatively not too great wind acceleration caused by the horizontal dimensions of pressure formations passing over the ocean. The main areas of steady generation of storm waves are located in the zone of western transport of air masses, more precisely, within the range of 40 to 60° latitude south. In this zone have been found five climate regions with highly intense storm seas. These areas are directly associated with regions of heavily developed cyclone activity.

It is interesting that in the Southern Ocean a region of highly violent storm seas is found in the Indian sector with its center around Kerguelen Island. To the east is found a New Zealand area of intense storm activity with its center between New Zealand and Antarctica. In the Pacific Ocean sector such a region is found approximately between 100 and 130 to 140° longitude west. Two more regions of heightened storm activity are found in Drake Passage.

Observation data have revealed seasonal variability in the intensity of sea disturbance in the Southern Ocean.

Ocean Tides

Ebb and flow phenomena have been studied relatively little in the Southern Ocean because of the widely spaced network of observation points.

Because of this we have only a very general idea of the nature of tides in this ocean ("Atlas Antarktiki," 1969). Near the coast of the Antarctic Continent is observed the predominance of irregular diurnal or purely diurnal tides. In some regions the nature of tides changes to irregular semidiurnal. On the open sea the diurnal components are few and tides are of a semidiurnal or irregular semidiurnal nature. The maximum values of high tides vary near the antarctic coast from 1.4 to 3.5 m. The high tide figure is somewhat lower in the open section of the Southern Ocean.

New data on tides obtained at the time of the MGG and in subsequent years have made it possible to refine considerably the cotidal charts for the

Southern Ocean, to make important adjustments to our idea of the nature of propagation of tidal waves, and to explain a number of features of tides in the coastal area of Antarctica.

Sea Ice

During the period of work done by the Soviet antarctic expedition an immense group of observations of sea ice has been made. Ice observations are made regularly on expeditionary vessels, at coastal antarctic stations and from ice surveying aircraft. From observations made prior to 1962 summaries have been made in which information is given on ice conditions, along with charts of the seasonal variability of antarctic ice (Treshnikov, 1963b; "Atlas Antarktiki," 1966, 1969).

Further observations have made it possible to establish that the drifting of ice in the antarctic region is in keeping with the fundamental patterns of travel of surface waters and atmospheric circulation and is chiefly of a zonal nature (Yeskin, 1969; Buynitskiy, 1973). But the circulation of ice has a number of distinctive features (Romanov, 1976). Along the shores of Antarctica ice drifts in a general westward direction; north of this zone there takes place the removal of ice in the north and northeasterly directions, and then the ice is drawn into the easterly drift system. Several strong cyclonic drift systems have been distinguished, whose positions match the points where climatic cyclones station themselves. A precise determination has been made of the reasons for and the areas of formation of stable accumulations of drifting ice--ice massifs.

It has also been observed that ebb and flow phenomena and sea disturbance influence the formation of channels and open water patches in the ice zone of the Southern Ocean. During the period of three to five days after an astronomical syzygy (a full moon or new moon), in the ice cap are formed long channels up to 40 to 50 m wide extending approximately in the latitudinal direction parallel to the general coastline.

In recent years in the practice of Soviet antarctic research more and more extensive use has been made of satellite information, which makes it possible to obtain information on the distribution of sea ice in hard-to-reach and little studied areas.

It has been learned from satellite observation data that the ice content of the Southern Ocean, as an indicator of which has been used the area of the expansion of the ice cap in August-September, is related to forms of atmospheric circulation. The predominance of a zonal form of atmospheric circulation is accompanied by a low ice content, and the high recurrence of a meridional form is associated with a high ice content in the Southern Ocean. And in only one instance has the predominance of the meridional form been accompanied by a low ice content.

Against the backdrop of an overall increase or decrease in the ice content of the Southern Ocean in some sectors of Antarctica is observed opposition in alteration of the state of the ice. The greatest interannual changes in the position of the edge of antarctic ice in August-September are observed in the eastern half of Ross Sea and in Amundsen Sea, the Scotia Sea, in sectors of 0 to 50° longitude east (the Lazarev, Riiser-Larsen and Kosmonavty seas), and 100 to 160° longitude east (the Mawson and d'Urville seas). The position of the ice edge in these areas varies from year to year from 100 to 250 miles, and the ice content changes in synchronism and accounts for a major percentage of interannual variations in the ice content of the Southern Ocean.

Slight variations (0 to 100 miles) in the position of the ice edge in August-September are observed in sections where opposition in a change in ice content is characteristic. These sections vary in terms of length from year to year, and their position can shift to the east or west. On average they are located in the following sectors: 15° longitude west to 20° longitude east, 60 to 100° longitude east (the Sodruzhestvo and Davis seas), 160° longitude east to 170° longitude west, and sporadically in the area of the Scotia Sea.

V.Yu. Vize (1944) advanced a hypothesis regarding the unidirectionality in fluctuations in the amount of arctic and antarctic ice. It was demonstrated that the change in distance along the meridian from the Mirnyy station to the edge of the ice in August-September correlates with the ice content of the Greenland and Chukchi seas. The shape of the curves asserts that definite agreement in these changes is observed only in the Indian-Atlantic sector and in the Greenland Sea, but in general they are out of synchronism with variations in the ice content of the Chukchi Sea. The features revealed testify to the complexity of the dynamics of the ice cap.

Preliminary research has shown that elements of an association are found in changes in the state of the ocean ice cap in the Arctic and Antarctica. But the mechanism of this association, to the same degree as the interaction of ice caps with overall circulation of the atmosphere and ocean, is to a great extent unclear and requires further research.

Icebergs

Icebergs exert a considerable influence on the hydrological cycle and ice conditions of the coastal zone of Antarctica. The distribution of icebergs probably does not undergo considerable changes from year to year. It is set under the influence of steady factors, among which must be placed the stationary location of key areas for the production of icebergs, the general patterns of the circulation of the atmosphere, surface waters and ice, and also the configuration of the coastline and the relief of the ocean floor.

The boundary for the dispersal of icebergs almost agrees with the front of antarctic convergence. The distribution of icebergs takes place in conformity with the fundamental rules characteristic of the distribution of ice. The density of icebergs is reduced with distance from the shore and on the open sea it does not exceed three. A reduction in the number of icebergs takes place on account of intense melting and disintegration, as well as of their dispersal as they advance into northern regions.

A comparison has been made between the size of icebergs and their geographical location, and curves have been plotted for the probabilities of iceberg lengths and heights south and north of 65° latitude south.

Marine Biology

Extensive observation data gathered by Soviet antarctic expeditions have made it possible to make great strides in the development of a number of big problems relating to the marine biology of the Southern Ocean. Included under this heading in particular are such problems as that of biopolarity, latitude by latitude changes in fauna, patterns of vertical zonality for fauna, biological types of fauna, etc.

Quantitative and qualitative characteristics have been obtained for the zonal distribution of plankton. For the first time in Antarctica a quantitative study has been made of ocean-floor fauna from bottom sampler specimens. It has been learned that one of the most characteristic biological features is the high variegation of its ocean-floor classifications with relative monotony of underwater topography at depths from 100 to 500 m, resulting in the absence of distinctly marked vertical zonality. The main background of fauna on the antarctic shelf is made up primarily of organisms which do not serve as food for fish (more than 60 percent).

In the collections which have been assembled there is a number of new species and even genera of animals. The many subtropical species found among antarctic fauna testify to the connection between deep waters of these regions. It has been established that near the shores of Antarctica there is rather abundant water plant vegetation--more than 100 varieties.

Ichthyological research has also made important contributions to our knowledge of the species composition, ecology and distribution of antarctic ichthyofauna: New previously unknown species, genera and families of fish have been discovered. Leukemia has been determined in nine species of fish. It was found that the greatest variety of ichthyofauna species is observed in the northern seas within the range of the upper 100 m of the shelf, and near the shores of Antarctica it shifts to a depth of 300 to 500 m.

The ocean-depth routes for the penetration of certain northern groups of fish into the southern hemisphere have been discovered and verified. Among these have been identified fish which come to the surface in the zone of antarctic convergence. So, specific species of fish can be indicators of different water masses. Systematic observations of the distribution of sea birds, pinnipeds and whales have made it possible to give a zoogeographic description of waters of the Southern Ocean.

In summary it must be said that the scientific development of oceanographic observations made in the Southern Ocean during the past 20 years has brought many important, interesting and valuable results and has to a considerable extent enriched our knowledge of the nature of this section of the global ocean.

In addition, the processing and analysis of available observation data have made it possible to point out new problems which must be solved in future scientific and expeditionary research in the Southern Ocean.

At the present time there has been exceptionally little study of questions relating to the interaction between ice shelves and the waters flowing around them, to the reasons and conditions for the formation of cold ocean-floor waters, to the thermal influence of the Southern Ocean on waters of adjacent oceans, and to the influence of the ocean on atmospheric circulation. There has been little study of the variability of hydrological characteristics over time. There is still no clear idea of many processes originating in waters of the Southern Ocean and of the factors causing them.

At the same time it has become obvious that many processes originating in waters of the Southern Ocean are directly related to atmospheric circulation, and therefore can be explained only on the basis of a thorough study of the interaction between the atmosphere and ocean. It was for this purpose that the Polar Experiment (POLEKS) scientific program was developed. Its aim is to study the large-scale interaction between the atmosphere and ocean in the polar regions and their role in the formation of the energy balance of the atmosphere-ocean system, and to reveal the mechanism forming longterm changes in hydrometeorological processes in the Arctic and Antarctica.

A study of the hydrological cycle of the Southern Ocean and of the circulation of waters and of their influence on changes in weather and climate conditions on the global scale is called for in the "POLEKS-Yug" [Polar Experiment South] program (Treshnikov et al., 1973).

In keeping with this program, research in the Southern Ocean is aimed at solving the following problems: 1) the dynamics of the Antarctic Circumpolar Current (ATsT) as a component of overall circulation of the global ocean; 2) balances of energy and mass and other elements of the Southern Ocean; 3) the mechanism for the formation of antarctic ocean-floor waters and its role in global circulation of the ocean.

Expeditionary research for enacting this program was begun in 1975 on the scientific research vessel "Professor Zubov" and was continued in 1976 on the scientific research vessel "Professor Vize" (Treshnikov et al., 1975).

Of course, expeditionary studies carried out in keeping with the "POLEKS-Yug" program by utilizing a single scientific research vessel could not embrace with their research both the entire set of goals set and the entire water area of the Southern Ocean. Therefore, all efforts on these expeditions were concentrated on carrying out one of the key experiments of this program--"Dynamics of the Antarctic Circumpolar Current." The area for research selected was Drake Passage, since this region is one of the most interesting from the viewpoint of the dynamics of the ATsT.

In keeping with the main objective of the experiment, the expeditionary operation program included a number of divisions, the major ones of which were a study of the space-time structure of the ATsT and disclosal of the main causes governing its dynamics; obtaining data for verifying existing models for circulation of waters in the research area; a quantitative estimate of water and heat exchange in Drake Passage and of their variations over time; a study of small- and medium-scale space-time variability of physical oceanographic fields in the passage; and a number of other problems.

Setting aside a division for verifying existing models for circulation of waters in Drake Passage as an independent division was dictated by the difference formed at the present time in views on the structure of currents vertically.

The question is that among researchers on the Southern Ocean for a long time the opinion has existed that the Antarctic Circumpolar Current--the strongest current in the global ocean--has evolved vertically to very great depths, and in certain regions down to the ocean floor. But in recent years, based on data of estimates of currents by utilizing hydrodynamical models, the hypothesis has been advanced that in the Southern Ocean beneath the Antarctic Circumpolar Current there exists a strong circumpolar countercurrent, which equals the ATsT in its rate of flow (Treshnikov et al., 1974). The same thing has been indicated by an analysis of the distribution of water masses in the research area. The nature of the distribution of velocities with depth contradicts the conclusion regarding the equivalence of rates of flow of the ATsT and of the countercurrent underlying it.

To disclose the actual pattern of currents in the Southern Ocean, longterm instrument measurements of currents are required, by means of recorders installed in self-contained buoy stations (ABS's). The taking of instrument measurements of currents, as well as the performance of a hydrological survey in Drake Passage, have been a component part of the plan for full-scale research on the "POLEKS-Yug-75" and "POLEKS-Yug-76" expeditions.

An analysis of the space and time structure of currents in Drake Passage has indicated its complexity. In the passage it is possible to distinguish three current streams, the central of which is the mainstream of the Antarctic Circumpolar Current; this can also be divided. The northern stream represents the currents of Cape Horn, and the southern, the currents of Bellingshausen Sea.

The central stream of the ATsT falls in line with the position of the Antarctic Polar Front (APF), in the area of which are observed marked temperature lapse rates, salinity and other physical oceanographic elements to considerable depths. In this region can be formed meanders and vortices. Meandering of the stream and the formation of vortices are associated with high horizontal lapse rates in the density and velocity of currents and with the influence on the ATsT of the complex topography of the ocean floor in the region of the passage.

The general direction of currents in the entire 0-2500 m top layer is northeasterly. The origin of vortices and meanders results in complication of the actual pattern and the presence in certain areas of streams with a reverse direction, which have more than once been taken for countercurrents in making individual cross sections or instrument observations.

In the lower 3000-3500 m layer is observed a relatively weak ocean-floor current directed westerly, which has been verified both by calculations and instrument observations.

The opinion has existed among scientists that the Antarctic Circumpolar Current is of wind origin. But the nature of the Antarctic Circumpolar Current is closely related to the zonal thermal inhomogeneity of the southern hemisphere, which is intensified by temperature contrasts between Antarctica and the oceans surrounding it. The good alignment of the axes of the ATsT and APF is explained by the common thermodynamical reason for their origin and is supported by dynamic interaction between meridional and zonal atmospheric circulation in the area of the maximum of ATsT velocities, which is responsible for the relative intensification of both phenomena.

As calculations have shown, the major shift in the mean climate position of the ATsT and APF from strict zonality is associated with the asymmetry of the position of Antarctica in relation to the pole, with the geometry of the shores, and with the topography of the floor of the Southern Ocean.

The results of the expedition's observations were taken into account in drawing up the Soviet variant of the program for joint Soviet-American research in the Southern Ocean for the next few years. Agreement on the need to carry out this research was achieved at the second session of the Soviet-American United Commission for Cooperation in the Area of Research on the Global Ocean, held in Moscow from 27 through 30 May 1975.

Soviet proposals call for carrying out an international combined expedition with a force of 10 to 15 vessels in the entire water area of the Southern Ocean, placing anchored current meters and temperature gauges in a number of areas of the Southern Ocean, including in Drake Passage, and making oceanographic studies in Davis Sea and Weddell Sea, relating to the problem "Formation of Antarctic Ocean-Floor Waters," including a hydrological survey and the placing of buoy stations.

Successful accomplishment of these measures will be conducive to a deeper understanding of the processes of interaction between the ocean and atmosphere and will create the prerequisites for developing numerical methods of forecasting the variability of hydrometeorological elements for different periods in advance.

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SOVIET ANTARCTIC GEOLOGICAL RESEARCH ACCOMPLISHMENTS SUMMARIZED

Moscow ANTARKTIKA: OSNOVNYYE ITOGI IZUCHENIYA ANTARKTIKI ZA 20 LET. DOKLADY KOMISSII in Russian No 17, 1978 pp 132-143

[Article by M.G. Ravich: "Soviet Geological Research in Antarctica"]

[Text] Geological and geophysical studies in Antarctica have been carried out since the beginning of 1956 by associates of the Scientific Research Institute of Arctic Geology and the Sevmorgeo Scientific Production Geological-Geophysical Association of the USSR Ministry of Geology. The subject of these studies has been primarily territories of the continent (Antarctica) free from ice, making up about 800,000 km^2 (together with glaciers separating rock structures), since the total area of rock outcrops per se does not exceed 6000 km^2. Over the past 20 years geological-geophysical teams of the Soviet antarctic expedition have made the following major studies:

1. Geological mapping of Dronning Maud Land (central section) on a scale of 1 : 1,000,000, covering an area of 60,000 km^2, and of Enderby Land on the same scale, covering an area of 50,000 km^2.

2. Geological mapping of the mountain settings of the Lambert Glacier and Amery Ice Shelf (Prince Charles Mountains) on a scale of 1 : 2,000,000, covering an area of almost 250,000 km^2.

3. Geological exploration of the Yamato and Sør Rondane mountains (eastern half of Dronning Maud Land), covering an area of more than 70,000 km^2.

4. Geological mapping of the Humboldt Mountains on a scale of 1 : 200,000, covering an area of 2000 km^2.

5. Geological mapping of Bunger's Oasis on a scale of 1 : 100,000, covering an area of 400 km^2.

6. Seismic depth sounding of the crust of the crystalline basement of the Antarctic Platform, along the following cross sections: a) 425 km in the area of the Novolazarevskaya station, and b) 550 km on Ingrid Christensen Coast (from the Vestfold Hills to Beaver Lake).

7. An aeromagnetic survey of various territories of East Antarctica on scales of 1 : 1,000,000 and 1 : 2,000,000, covering an area of more than 1.2 million km^2, and, accompanying it, air-landing seismogravimetric studies and radar sounding of the ice shell.

8. Reconnaissance studies of certain regions of West Antarctica, on the staff of American and English antarctic expeditions.

9. Studies on the geology of shelves in East Antarctica.

In the years which have passed 10 subject areas have been developed, of which the major are the following: 1) the Pre-Cambrian of East Antarctica; 2) the crystalline basement of the Antarctic Platform; 3) the Reeves and Lower Paleozoic of the Antarctic Platform: 4) geology and petrology of Marie Byrd Land and Eights Coast; 5) processes of sediment accumulation in the Indian sector of the Southern Ocean in the Upper Pleistocene and Holocene; 6) a geological map of Antarctica on a scale of 1 : 5,000,000; 7) geology and deep structure of MacRobertson Land and Princess Elizabeth Land; 8) metamorphic and magmatic complexes of West Antarctica (development work of this type is continuing).

As the result of the studies carried out, more than 250 articles have been published on different aspects of the geology of Antarctica, and five monographs have been published (Ravich, M.G., Klimov, L.V. and Solov'yev, D.S., "The Pre-Cambrian of East Antarctica," 1965; Ravich, M.G. and Solov'yev, D.S., "The Geology and Petrology of the Central Section of the Mountains of Dronning Maud Land," 1966; Ravich, M.G. and Kamenev, Ye.N., "The Crystalline Basement of the Antarctic Platform," 1972; Grikurov, G.E., "The Geology of the Antarctic Peninsula," 1975; Lopatin, B.G. and Polyakov, M.M., "The Geology and Petrology of Marie Byrd Land and Eights Coast," 1976). In addition, 21 geological maps have been made for the "Atlas Antarktiki" [Atlas of Antarctica] on scales of 1 : 100,000 to 1 : 20,000,000, which were published in 1966 and 1970. In 1969 was published a tectonic chart of Earth's polar regions, on a scale of 1 : 10,000,000.

Major Results of Research

Topography

The subglacial topography of Antarctica is quite varied and is characterized by a combination of differently oriented mountain ranges and vast lowlands and depression basins separating them. This topographical contrast is caused by alternating tectonic movements of blocks of the mainland which are transformed in addition by agents of physical erosion characteristic of the glacial wasteland.

East Antarctica represents a continent which for the most part bulges up steadily: Its mean height above sea level is about 400 m. In the eastern half of this continent there are two lowlands separated by a relatively moderate-size rise. The base of these lowlands is sunk about 100 to 300 m below sea level, and certain sections represent depression basins as much as 1500 m deep. The rise in the form of a ridge is from 200 to 500 m high, and certain peaks on it are as much as 1500 m high. The rise, extending, with breaks, almost 2000 km, is broken up by faults, along which is formed a feathering series of grabens, which gives the ridge a scalloped character.

In the very center of East Antarctica is subglacial mountainous country occupying an area of not less than 500,000 km^2 (fig 1). The largest are the Gamburtsev Mountains. They are formed by two individual blocks whose peaks are covered with a relatively thin layer of ice with a total thickness of 900 to 1000 m, while the thickness of the ice cap here, in the center of the continent, not infrequently reaches 4000 m. The largest block consists of the radial systems of the range, which merge at their roots and form a gigantic figure reminiscent in shape of the foot of a gigantic prehistoric animal. The surface of the Gamburtsev Mountains is strongly disjointed and is similar to young mountains of the alpine type. Peaks reaching 3000 m in height above sea level could not rise above the continent's ice cap and have been forged by the powerful glacial waste. The other, smaller, block is made up of parallel ridgelike plateaus with a smooth and mildly sloping peak type of relief. Their height does not exceed 1000 to 1200 m, and therefore the ice cap above them reaches a thickness of two to 2.5 km.

The western section of East Antarctica is a vast plain, raised slightly above sea level and divided by relatively narrow troughs. Only at its frontiers--on the continent's coast--do craggy mountains rise, "piercing through" the thin ice cap 300 to 500 m thick.

In contradistinction to East Antarctica [Greater Antarctica], more than 65 percent of the territory of West Antarctica [Lesser Antarctica] is sunk below sea level. Actually it is a gigantic ice shelf with large archipelagos sealed into it. The largest of these is the Antarctic Peninsula, whose mountain chains extend more than 1000 km. In the center of West Antarctica there is a rocky upland about 400 km long, which abutts an even longer ridgelike broken range. And, finally, in the coastal areas of Marie Byrd Land there is a rather extensive plateau occupying an area of 500,000 km^2, with peaks more than 3000 m high.

Like the horn of a rhinoceros, crowning Antarctica in the northwest, extends among the glaciers the mountainous archipelago of the Antarctic Peninsula. Its northern half is a narrow cut ridge with heights of 500 to 1000 m, bordered by countless coastal islands. Its southern half is a wide mountain range 500 km long with heights form 1200 to 2500 m. Some peaks reach 3000 m, and the highest peak of the Antarctic Peninsula--Jackson Mountain--is 4200 m high. The majority of peaks rise above the ice cap. On the Antarctic Peninsula rock massifs free from ice make up about eight percent of the land, i.e., considerably more than in remaining sections of the continent.

The central massif includes the Ellsworth and Whitmore mountains and smaller uplands. Its absolute heights do not exceed 2500 m and are usually covered with ice. Only certain peaks rise above the glacial shell hundreds of meters and even kilometers, including a mountain with an absolute height of 5140 m, representing the highest point in Antarctica. Typical of the higher mountains is an alpine type of relief, and of subglacial mountains, a mildly sloping peak type.

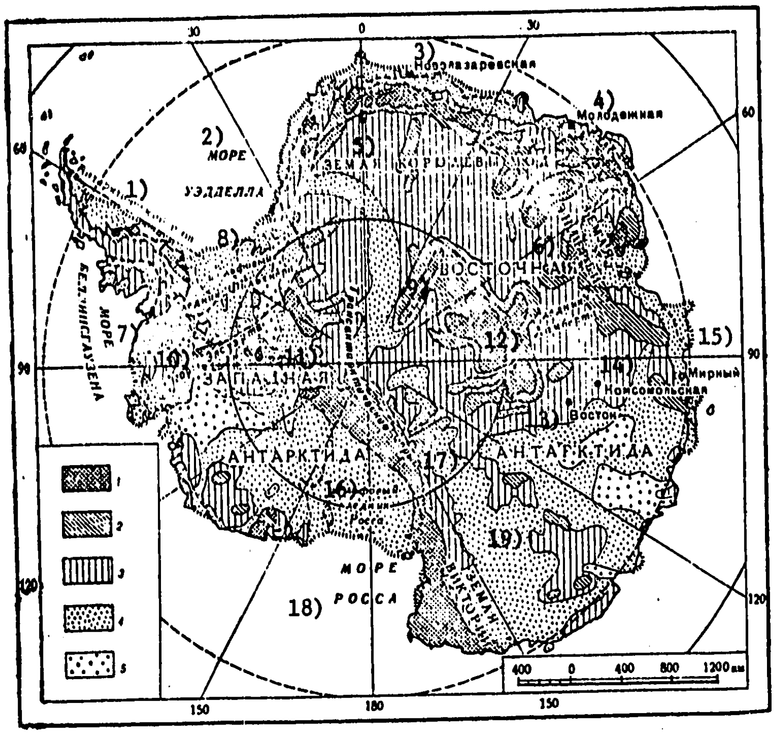

Figure 1. Diagram of Subglacial Relief of Antarctica. Made by G.A. Znachko-Yarovskiy. Height above sea level: 1--greater than 1000 m; 2--500 to 1000 m; 3--0 to 500 m; below sea level: 4--0 to 1000 m; 5--more than 1000 m

Key:

1. Antarctic Peninsula
2. Weddell Sea
3. Novolazarevskaya
4. Molodezhnaya
5. Dronning Maud Land
6. Enderby Land
7. Bellingshausen Sea
8. Filchner Ice Shelf
9. East Antarctica
10. Ellsworth Mountains
11. West Antarctica
12. Lambert Glacier
13. Vostok
14. Komsomol'skaya
15. Mirnyy
16. Ross Ice Shelf
17. Transantarctic Mountains
18. Ross Sea
19. Victoria Land

The coastal massif is a vast volcanic plateau with heights of a few hundred meters, covered with a glacial shell. Only the conical peaks of extinct volcanoes, reaching heights of 4000 m above sea level, rise many hundreds of meters above glacial fields.

As a whole, West Antarctica is a slightly wavy plain lying 500 to 1000 m below sea level. Between its rocky archipelagos there are deep depression basins whose floor is sunk 1000 to 2000 m below sea level. Therefore, West Antarctica cannot be considered, as East Antarctica is, a continent, but represents a gigantic shelf region covered by thick strata of ice; furthermore, it is not possible to exclude the existence of an intermediate water bed between the floor of depression basins and the ice cap.

And so, the antarctic glacial waste, if the glacial shell were to be removed from it, would look to the researcher's eyes like a heavily disjointed continent with numerous mountain ridges and plains, deep depression basins and plateaus. This continent is sunk below sea level at its frontiers and is pressed down by dozens of millions of tons of ice. It is surrounded by the gigantic ice shelves of the Ross and Weddell seas, which occupy about two million square meters, and the ice fields, close to them in structure, in West Antarctica, occupying an area of more than three million square meters.

Stratigraphy

For the first time a stratigraphic diagram has been made of the early Pre-Cambrian, which makes up the crystalline basement of the Antarctic Platform, whose thickness, according to geological observations and GSZ [seismic depth sounding] data, is about 40 km. The crystalline basement consists of 11 series of metamorphic rocks, which can be correlated for the entire continent. The most ancient Raggatt and Thule series, whose thickness exceeds 12 to 15 km, are made up of rocks with an absolute age on the order of four billion years (determined by the lead-isochrone method). These are the oldest rocks of the globe. They form exceptionally stable blocks of the crystalline basement, of the granite-gneiss dome type, and are represented by quite distinctive ultrametagenic mesoperthite granitoids (enderbytes, charnockites and granites per se), formed under conditions of high degrees of a granulite environment.

Strictly Lower Archean rocks make up two other series of the same age--Condon and Hay (thickness of 10 to 12 km each), encountered also only in stable blocks, where they clothe domes of the most ancient rocks. They are represented by standard vestigial granitoids of charnockite and granite composition, which alternate with abundant fields of migmatites. In these series for the first time have appeared carbonate rocks--granulite-environment calcifers. Along with numerous stacks of basic-composition dipyroxene crystalline schists, characteristic also of the two preceding series, there has been some development of garnet-sillimanite-cordierite crystalline schists with an acidic alumina composition. On the whole, raw vulcanites of average and basic composition make up more than 60 percent, and sedimentary terrigenous rocks not more than 20 percent, while carbonate deposits make up five to 10 percent of the total volume or Archean strata. The age of charnockites of these series, determined by the lead-isochrone method, is three to 3.3 billion years.

Upper Archean deposits are spread to a maximum over the boundaries of the crystalline basement of the Antarctic Platform. They form exceptionally mobile blocks of the basement which participate in tectonic and metamorphic processes, not only those having formed them, but also later processes having taken place in the Lower and even in part in the Middle Proterozoic. Therefore, quite characteristic of them are polymetamorphic rocks of an original granulite and superposed amphibolite facies, represented by crystalline schists of both a basic and acidic alumina composition, through which there has been intense development of migmatites and less vestigial granitoids of charnockite composition. Among these strata appear thick stacks of calcifers and quartzites and zones of typical granulites. Numerous determinations of the absolute age of these rocks by the potassium-argon method have given 500 to 550 million years; infrequent deviations go back 2 to 2.5 billion years. The most representative Humboldt series in Dronning Maud Land reaches a thickness of eight to 10 km, while the Larsemann and Reinbolt series, probably of the same age, in the Prince Charles Mountains have a thickness of as much as seven to nine kilometers each.

The higher-lying Lower Proterozoic deposits differ radically from the Archean. They make up geosyncline-like zones which formed by that period among Archean interdomal structures and are distinguished by the following features: a) the structure of original volcanogenic-terrigenous deposits (sedimentary deposits predominate over vulcanites), among which can be distinguished eugeosynclinal and miogeosynclinal formations; b) exceptionally extensive development of metamorphism of the amphibolite facies, as the result of which culmination of the processes of migmatization and granitization has been achieved; c) total shift in intrusive formations, when intrusions of gabbroids and granitoids developed extensively in place of anorthosite and charnockite massifs. The main rocks of the Lower Proterozoic series (the Insel in Dronning Maud Land and the Lambert in the Prince Charles Mountains) are biotite-garnet-sillimanite crystalline schists with an acidic alumina composition, plagiogneisses and amphibolites, as well as migmatites, developed extensively through them, and less developed vestigial granites. The thickness of Lower Proterozoic deposits does not exceed seven to eight kilometers.

Local development in grabens of the crystalline basement or in structures of the non-volcanogenic type is evidenced by quite distinctive sedimentary strata, most frequently transformed into various schists and phyllites of a green shale facies (Rooker series). Only in spots are they probably repeatedly metamorphized and changed into garnet-containing double mica schists with large-crystal staurolite, cyanite and other minerals of a low-temperature amphibolite facies (Menzies series). Very characteristic of the lower portion of the Rooker series are thick strata of ferruginous quartzites and jaspilites and, in addition to phyllites, quartz carbonate schists and quartzites. In the upper half of the Rooker series are found abundant dikes and sills of metabasites, whose age, determined by the not very reliable potassium-argon method, is one to 1.2 billion years. The location of this series is determined by its occurrence in the crystalline basement, represented by vestigial granitoids, whose age, established by the rubidium-strontium method, is 2.5 billion years and more, which corresponds to the lower limit of the Lower Proterozoic. But the presence in these deposits of jaspilites and relatively young metabasites makes it possible to believe that the upper half of the series can belong to the Middle Proterozoic. Their total thickness is four to five kilometers.

Magmatism

Three highly characteristic intrusive formations of Antarctica's early Pre-Cambrian discovered by Soviet geologists--an anorthosite, metagabbroid and charnockite--have been studied thoroughly with respect to composition and genesis. The largest anorthosite massif in Dronning Maud Land, with an area in outcrops of up to 900 km^2, has been shown to be indistinctly stratified. Peripheral sections are made up of leucocratic gabbro-norites, which have been considerably recrystallized and metamorphized under conditions of the amphibolite facies, as the result of which new formations have appeared, of garnet, hornblende and orthoclase. The rocks of the central portion of the massif are rather new; they consist of labradorite with an insignificant admixture of hypersthene and augite. The nature of the form of the massif and of its primary structural elements testifies to the magmatic origin of the anorthosites, which are the most ancient intrusive rocks on the continent.

Intrusions of metagabbroids are quite numerous and have highly varying dimensions, from single numbers to many hundreds of square kilometers, and the largest of them are considerably differentiated. They have all been subjected to metamorphism under conditions of granulite and superposed amphibolite facies, but most frequently under conditions of the latter alone. These intrusions are made up of various rocks, beginning with metagabbroids and metadiorites right up to typical amphibolites, and even to basic crystalline schists, which will be talked about below; in spots they have been converted into apogabbroid charnockitoids, whose primordial magmatic origin is highly probable.

The formation of intrusive and apointrusive charnockitoids is extremely widespread in the crystalline basement of the Antarctic Platform and is sharply distinguished from the formation of ultrametagenic enderbyte-charnockites, which in the majority of cases make up the most ancient series of the crystalline basement. These intrusions have been primarily confined to mobile blocks of the crystalline basement. Their dimensions vary from a few dozen to a few thousand square kilometers. The smallest of them most frequently are of the nature of domes or ridges, and the largest (up to 4000 km^2) intrusion in Dronning Maud Land is in the form of a complexly constructed plate of a pseudo-batholithic nature. While the smaller intrusions were formed in the process of metasomatism of gabbroid domes, the larger are of rheomorphic genesis. They were formed on the eve of cratonization of the crystalline basement, under conditions of heightened tectonic activity, when there occurred fusion of the most fusible elements from the crystalline basement, partial transition of the latter into the plastic state, and the preservation of high-melting components, such as pyroxenes and olivines. From the interaction of all three media charnockitoids formed, in which, in various quantitative ratios, are combined mineral associations of acidic and basic rocks, because of which the series described here begins with orthoclase-containing norites and ends with eulyte-fayalitic grancsyenites, having as transient varieties pyroxene and olivine dioritosyenites and syenites. More infrequent are charnockitoids of magmatic gensis, in which are clearly observed several stages of formation (under various physical-chemical conditions), distinctly placed on one another.

Tectonics

The continent's structural geology is characterized by the interaction of three global structures: 1) an ancient--an extremely early Pre-Cambrian--platform formed on the crystalline basement and located in East Antarctica, probably covering an area of eight to 10 million km^2; 2) a young extremely early Paleozoic platform on the folded basement of Ross (late Baykal) age, located in the Transantarctic Mountains, covering a probable area of not less than two million km^2; 3) Paleozoic-Mesozoic fold systems included in the Pacific migratory zone and located in West Antarctica, with an area of as much as two million km^2.

Of the major elements of the ancient Antarctic Platform, on the coast of East Antarctica for a distance of almost 8000 km, on block mountains and in rocky oases is revealed the crystalline basement, in whose structure are distinctly isolated two structural complexes (fig 2): 1) stable regions cratonized in the Archean and representing typical plates such as, for example, in Enderby Land and Terre Adélie; 2) mobile regions cratonized in the Proterozoic, but more than once subjected to tectonic-magmatic activation in later epochs, such as, for example, Dronning Maud Land. The internal structure of stable regions is determined by a combination of very ancient domes of granulite facies crystalline rocks and linear folded syncline systems. Characteristic of these are stable and persistent rises, but not especially intense ones. Within their boundaries deep faults and block tectonics have developed relatively slightly. These plates have reacted little to the latest stages of tectogenesis.

Mobile regions, on the other hand, have been subjected to tectonic rearrangement, not only in the Proterozoic, but also in the early Paleozoic, because of which characteristic of them is a block structure with an abundance of deep faults. Typical of mobile regions are intense differentiated block movements; therefore, their internal structure is determined by a combination of large short folds (former domes) with, superposed on them, linear folds of several orders of magnitude. In connection with this, in mobile blocks are rarely preserved the most ancient granulite facies rocks, but more often there is a predominance of polymetamorphic rocks, when an amphibolite facies has been superposed on the primary granulite facies. Mobile blocks of the crystalline basement contain numerous intrusions, not only of early Pre-Cambrian anorthosites, gabbroids and charnockitoids, but also later intrusions of granites, syenites, and even nepheline syenites of Paleozoic age.

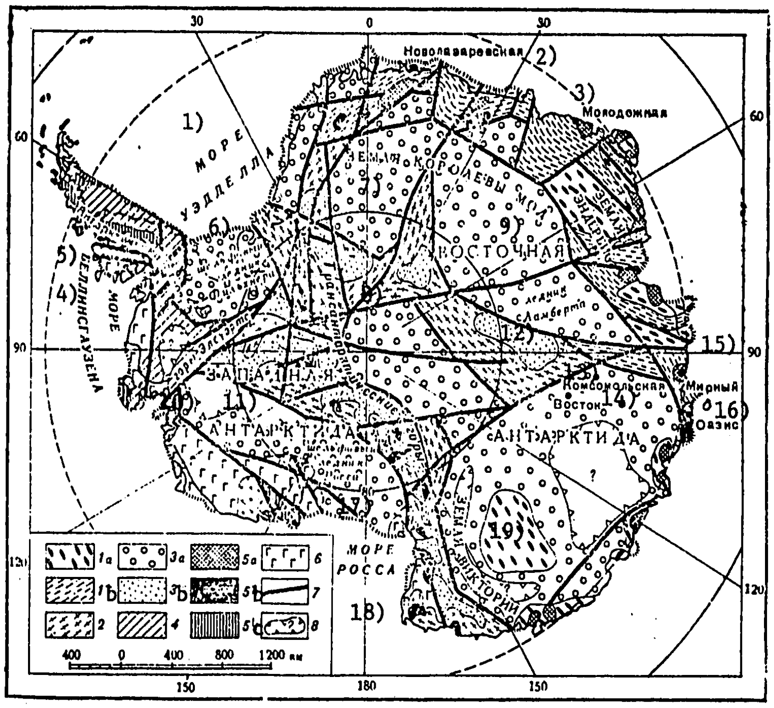

Figure 2. Tectonic Chart of Antarctica. Made by M.G. Ravich and G.E. Grikurov. 1--crystalline basement of Antarctic Platform (age, two to three billion years): a--very ancient plates; b--regions of activated basement; 2--relatively ancient rock structures (age, 500 to 600 million years)--folded basement of Antarctic Platform; 3--cover of Antarctic Platform (age, 200 to 400 million years): a--beneath ice cap; b--on block mountains; 4--young rock structures of Antarctica (age less than 200 million years); 5--intrusive massifs: a--charnockites in crystalline basement; b--granites and gabbro in folded basement; c--granites and diorites in antarctands; 6--lavas and tuffs of the Antarctic volcanic area (age, a half to 10 million years); 7--deep faults; 8--deep depression basins with an unknown combination of rocks

[Key on following page]

Key:

1. Weddell Sea
2. Novolazarevskaya
3. Molodezhnaya
4. Bellingshausen Sea
5. Antarctic Peninsula
6. Filchner Ice Shelf
7. Dronning Maud Land
8. Transantarctic Mountains
9. East Antarctica
10. Ellsworth Mountains
11. West Antarctica
12. Lambert Glacier
13. Komsomol'skaya
14. Vostok
15. Mirnyy
16. Oazis
17. Ross Ice Shelf
18. Ross Sea
19. Victoria Land

The cover of the ancient platform is of a dual nature: On the one hand it represents slightly metamorphized and subhorizontally bedded terrigenous rocks of pre-Reeves age (they are broken up by traprocks having an age of 1.7 billion years) with a thickness of up to 2000 m, and on the other, Permian carboniferous deposits with a thickness of a few hun red meters and rarely up to 1300 m.

The young extremely early Paleozoic platform (plate) was formed at the location of early Paleozoic Reeves geosynclinal fold systems, which are customarily called Ross systems. The Ross geosynclinal formations in the Transantarctic Mountains reach a thickness of 10 to 12 km. The most widespread is a schist-greywacke formation metamorphized under conditions of a green shale facies. Below it lies a terrigenous carbonate formation, and above it a volcanogenic rhyolite formation. At certain sections have been found deposits with fragments of Cambrian fauna, which are also included in the folded basement of the Ross Plate. All these formations have been intensely dislocated into narrow linear, often isoclinal, folds. Some blocks of intensely metamorphized amphibolite facies rocks are probably ledges of a pre-Ross folded geosynclincal basement, since their absolute age reaches two billion years. The cover of this young platform, with a maximum thickness of 4 km, contains Devonian to middle Jurassic deposits, usually called the "bicon group." The full cross-section of the cover includes four formations: 1) a basal Devonian made up of seacoast and subcontinental quartz sands; 2) a carboniferous Lower Permian teallite; 3) a Permian-Triassic carboniferous; 4) an early to middle Jurassic traprock.

To the Pacific fold zone of West Antarctica certainly belong the Antarctic Peninsula and the lands adjacent to it. The most widespread representatives of the mesozoid basement are primarily Ross complexes, lying in the form of numerous blocks among geosynclinal complexes of middle to late Paleozoic age, consisting of greywacke-schist and volcanogenic siliceous formations with a total thickness of six to seven kilometers. Linear fold structures of this basement were formed not later than the Triassic on the border of 220 to 180 million years ago. An extremely early kimmeridgean orogenic complex with a maximum thickness of 3 km, made up of vulcanites of a dacite-liparite structure with layers of seacoast deposits and cut through by gabbro-granite intrusions, was formed on the border of 120 to 100 million years ago. A Cretaceous molasse complex 2 to 3 km thick is represented by non-dislocated clay and sand deposits with conglomerates of more ancient rocks at its base. Late Cenozoic formations are represented by a basalt plateau complex up to 3 to 4 km thick, which covers not only fold deposits of the Pacific zone, but also formations of the epi-Ross plate, forming the so-called antarctic volcano area, which probably extends over an area of 2 to 2.5 million km^2.

Comparing the tectonic stages in the formation of Antarctica with the nature of the metamorphism of its major formations, it is possible to draw the following conclusions:

1. The early Archean stage (concluded on the border of 3.3 to 3.5 billion years ago) is characterized first by the formation of the very ancient continental crust, consisting of vulcanites with an andesite-basalt structure, converted into specific mesoperthite enderbytes and charnockites and crystalline pyroxene schists. At the concluding step in this stage were formed normal enderbytes and charnockites, interstratified with the former sedimentary rocks, converted into granite-sillimanite-cordierite crystalline schists, their migmatites and vestigial granites.

2. The late Archean stage (concluded on the border of 2.6 to 2.8 billion years ago) is characterized by further growth of the continental crust, primarily on account of a considerable heightening of the role of sedimentary rocks (pelite-psammite and carbonate), which, under conditions of metamorphism of comparatively lower-temperature subfacies of the granulite facies, have been converted not only into crystalline schists, quartzites and calcifers, but also to an even greater extent into migmatites and vestigial granites. At this stage has occurred cratonization of the most ancient sections of the crust formed in the early Archean, and their transformation into stable domes, representing typical crystalline plates.

3. The early Proterozoic stage (concluded on the border of 2 to 2.2 billion years ago) is characterized by the termination of cratonization of the entire crystalline basement, with the separation in its structure of mobile massifs (domes). Later these massifs were more than once subjected to tectonic-magmatic activation, the last stage of which concurred with the Ross orogeny, on the borderline of 500 to 550 million years ago. At the stage considered here there took place intense accumulation of volcanogenic sedimentary rocks in wide protogeosynclinal zones, metamorphized, as a rule, under conditions of high levels of the amphibolite facies, because of which, along with plagiogneisses and amphibolites, extensively developed were migmatites and, to a lesser extent, vestigial granites. It is very characteristic that, in the process of cratonization of the crystalline basement, during this period there took place metamorphic reprocessing of Archean rocks of the granulite facies under conditions of the amphibolite facies, with the extensive development of polymetamorphic rocks, especially developed in mobile domes of the crystalline basement.

4. The middle Proterozoic stage (concluded on the borderline of 1.5 to 1.6 billion years ago) of tectogenesis is manifested, apparently, but slightly, and is far from universal, since by this time the rigid crystalline basement

(the East Antarctica craton) had been completely formed. Within its limits there probably appeared along zones of deep faults structures of the graben and non-volcanogenic type, filled with terrigenous and carbonate deposits, metamorphized under conditions of the green shale facies, with the formation of strata of phyllites, green shale, quartz carbonate schists and various quartzites, including magnetite-containing varieties. All these were gathered into steep isoclinal folds, often horizontal and tilted and in places cut through and complicated by thrust faults.

5. The late Proterozoic to early Paleozoic stage (on the borderline of 500 to 600 million years ago) was the concluding stage in formation of fold systems at the location of geosynclines in the Transantarctica Mountains and West Antarctica. Associated with it is the so-called Ross orogeny, which formed the folded basement of the young antarctic platform (plate) and caused its saturation with various granitoid intrusions. Associated also with the Ross orogeny are activation of mobile blocks of the crystalline basement and the appearance within their boundaries of intrusions of quite different composition, from granites to syenites.

6. The middle Paleozoic to early Mesozoic stage (on the borderline of 280 to 220 million years ago) is the important one for the formation of the "bicon" cover, both in the Transantarctica Mountains and in the interior regions of West Antarctica, where it is not infrequently folded and is of increased thickness (e.g., the Ellsworth Mountains). At the end of this period there took place the formation of fold systems and inversion of the Paleozoic geosyncline of the Pacific zone.

7. The late Mesozoic to Cenozoic stage is characterized by the development of platformed depression basins and domelike rises within the boundaries of the crystalline basement. At the same time there occurred the powerful bulging up of Pacific fold systems, ending with their peneplanization. At the concluding stage the antarctic volcano area was formed and heavy continental glaciation occurred, probably having begun about (or more than) 20 million years ago.

Minerals

Direct discoveries of minerals in East Antarctica, where Soviet geologists have been at work, have been relatively rare. In the majority, there have been only signs of deposits, with the exception of iron ore, which even at this stage in studies of the continent can be classified under large deposits. This situation is explained by two main causes: 1) the small-scale nature of research on the continent's geology, where the objective has not been set of prospecting for minerals; 2) the quite scanty exposure of the continent (only in coastal regions). However, on the basis of the identity of the geological structure of Antarctica with other continents of the southern hemisphere and with Hindustan, which made up probably even 200 million years ago the single supercontinent of Gondwanaland, the prospects of the icy continent with regard to mineral resources must be considered quite considerable.

This refers primarily to deposits of iron ore, which have been discovered in the Prince Charles Mountains in MacRobertson Land. Here have been encountered bedrock outcrops of magnetite quartzites (jaspilites), which can be traced 2.5 km, with a visible thickness of 100 to 150 m. The content of iron in heavily weathered specimens reaches 30 percent. In addition to bedrock outcrops, in the region have been discovered two subglacial magnetic anomalies with a strength of as much as 6000 gamma, extending 120 and 140 km each, which, without doubt, have been formed by levels of jaspilites lying at a depth of 300 to 500 m beneath the ice. With respect to the nature of the iron ore and enclosing rocks, they are close to the Krivoy Rog type of deposit.

In calcifers and diopside rocks close to them, which are widespread in the crystalline basement, accumulations of phlogopite are constantly encountered. Phlogopite pockets reach 1 m in diameter, and some crystals in them measure up to 10 cm across. The degree of saturation of enclosing rocks with phlogopite is two to four percent. This type of phlogopitization is promising, since the majority of deposits of this mineral come under this heading. Similar accumulations of phlogopite have been encountered in an entire series of locations in Enderby Land and Dronning Maud Land.

The abundance of pegamatite veins, especially in mobile blocks of the crystalline basement, has made it possible to find (in differentiated veins) muscovite, rock crystal and beryllium at many points on the coast of East Antarctica. Some veins contain crystals of muscovite measuring 10 X 10 X 5 cm, and their mica content reaches three to six percent. In greisenized veins abundant in places are crystals of beryllium 5 to 10 cm long, forming pockets of up to 0.5 to 0.7 m across. Rock crystal is concentrated in axial bulges of wider pegmatite veins. In these there are not infrequently crystals of rock crystal 0.2 to 0.7 m long, most often lying in distinctive troughs. In collapses of these veins are found semitransparent crystals of rock crystal, colored in places smoked and violet. In an entire group of veins crystals of rock crystal make up as much as four to five percent of the vein. Especially many veins with rock crystal have been encountered in the central area of Dronning Maud Land.

Copper and molybdenum occurrences have been found in the Prince Charles Mountains and on Prince Olav Coast. Molybdenite, chalcocite and chalcopyrite have been encountered in migmatites of the amphibolite facies, making up a total of one to five percent. Areas inoculated with ore minerals are measured in hundreds of square meters; they are confined to narrow zones near faults, extending as much as 1 km. This type of copper and molybdenum mineralization in the Pre-Cambrian is of industrial significance.

The list of mineral occurrences can be concluded with graphite, which, in the form of flakes measuring 2 to 3 cm, is found in strata of marble, where its amount reaches 10 percent. The thickness of graphite-bearing strata is 5 to 7 m.

As is obvious from this list, the overwhelming majority of minerals is confined to various strata of the crystalline basement of the Antarctic Platform.

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Besides iron ore, it is as yet possible to speak only of signs of deposits. But in a whole series of sections these signs are so reliable that, if necessary, it is possible to recommend carrying out exploratory and prospecting operations there for the purpose of uncovering deposits.

Objectives of Future Research

Taking into account the fact that Antarctica is covered with a thick glacial shell, priority in studying its geological structure has gone to methods of exploratory geophysics--aerogravimagnetic and seismic. The regional nature of the studies has determined their two major scales: 1 : 1,000,000 and 1 : 2,000,000. Using these scales, the entire continent and the shelves surrounding it (an area of approximately 16 million km^2) can be surveyed in 10 to 12 years with the active work of all 12 countries taking part in studying Antarctica. This research should be conducted in keeping with a unified international program coordinated with all countries which are parties in the Antarctic Treaty.

A special study by direct geological and geophysical methods is being made of the exposed areas of the continent, which make up about 750,000 to 800,000 km^2, including mountain glaciers separating mountain rock outcrops. Two scales have been proposed for these areas: 1) 1 : 1,000,000 for the more homogeneous areas of the crystalline basement, equaling approximately 400,000 km^2; 2) 1 : 250,000 (or 1 : 200,000) for all remaining exposed areas of the continent, equaling approximately 350,000 km^2.

Aeromagnetic and aerogravimetric surveys on a scale of 1 : 2,000,000 accompanied by radar sounding of the ice cap should cover the entire mainland and the surrounding shelves, for an area of 16 million km^2. Of these 3.5 million km^2 of exposed lands and surrounding shelves should be detailed on a scale of 1 : 1,000,000.

Air landing seismic (reflected wave method) and gravimetric studies on a scale of 1 : 1,000,000 should be made in shelf and coastal areas, representing a total area of about 4 million km^2.

Seismic depth sounding should be performed on shelves and coastal areas of the continent, as well as in the Transantarctic Mountains and on the Antarctic Peninsula, using cross sections intersecting regions with the most complex geological structure. It is suggested that roughly 25 to 30 GSZ cross sections be made, for a distance of 15,000 km.

After the performance of geophysical studies it is necessary to select areas for drilling five or six reference wells, which are needed to study the sedimentary cover, primarily in shelf areas.

Geological surveys, especially on a scale of 1 : 250,000, should be accompanied by a detailed study of reference cross sections of various formations of rocks, and by electronic exploration, magnetic and other geophysical land operations.

Of the above-listed group of regional geological and geophysical operations, as of the present time the antarctic expeditions of the 12 countries (especially of the USA and USSR) have already accomplished about 20 to 25 percent of the total, covering the most easily accessible regions of the continent.

As a result of accomplishment of the proposed international program, it is possible to study the deep structure of the continent and surrounding shelves; to give a general mineral forecast; to reveal in shelves and coastal areas structures of the first order of magnitude which are promising in terms of oil and gas; to reveal in mountain regions sections which are promising in terms of ore and non-ore minerals; to obtain unique data for the purpose of correlating the geological structure of Antarctica and other continents of the southern hemisphere in light of the Gondwanaland hypothesis; to obtain data on the structure of the crust and on the relationship between ocean structures and continental; and to make an important contribution to the geological mapping of Earth.

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FEATURES OF ATMOSPHERIC CIRCULATION IN ANTARCTICA AND OF THE CIRCULATION OF SOUTHERN OCEAN WATERS

Moscow ANTARKTIKA: OSNOVNYYE ITOGI IZUCHENIYA ANTARKTIKI ZA 20 LET. DOKLADY KOMISSII in Russian No 17, 1978 pp 96-110

[Article by A.M. Gusev]

[Text] Antarctica and the entire Southern Ocean represent regions of our planet where processes distinctive and of grandiose proportions have developed in the atmosphere and hydrosphere. The latitudinal temperature contrast, accentuated by the temperature contrast between Antarctica's ice cap and the relatively warm waters of the Southern Ocean surrounding the continent, has been responsible for the immense strength and intensity of these processes, and the symmetrical position of the continent and of the ocean surrounding it in relation to geographical coordinates, the geometrical regularity of large-scale circulation phenomena in the atmosphere and ocean. This fact has also made it possible to attempt to create physical and mathematical models of phenomena, and to discuss these regions of the globe as a distinctive natural model of phenomena, of a similar physical nature, in the atmosphere and hydrosphere of the northern hemisphere, where they have developed under incomparably more complex geographical conditions, and, consequently are more complex in terms of configuration and are less accessible for a precise mathematical description.

As we know, typical of Antarctica's atmosphere is the movement of continuous circular loops of cyclones around the mainland. This phenomenon is not observed in the atmosphere of the northern hemisphere. But in the most severe half of the year from the Atlantic to the European mainland come, as a rule, not individual cyclones, but series of them, representing, as it were, bits of a broken circular loop which is powerless to exist as a whole under the complex geographical conditions of the northern hemisphere.

General Pattern of Atmospheric Circulation in Antarctica

Numerous observations made in Antarctica have made it possible to construct the general patterns of atmospheric circulation and of the circulation of ocean waters in this area of the globe. The pattern of atmospheric circulation is shown in fig 1 (Gusev, 1967). In constructing it cnly the troposphere was considered, since there is reason to believe that the mass balance of this circulation forms a closed circuit there. Horizontally was considered the area from the South Pole to the center line connecting the centers of elevated pressure regions encircling the southern hemisphere at a latitude of 20 to 30°. This choice of boundary was a natural one, since it separates circulation systems in the atmosphere of the southern hemisphere which, although related, are fairly independent.

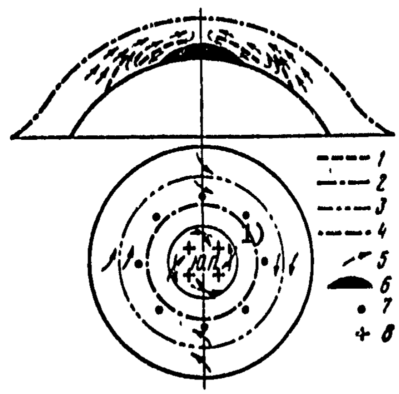

Figure 1. Pattern of Air Circulation Over Antarctica: 1--interface; 2--tropopause; 3--polar front; 4--antarctic front; 5--air currents; 6--Antarctica; 7--ascending air currents; 8--same, descending

Key:
1. South Pole

The basis for constructing this circulation diagram was charts of atmospheric pressure at sea level and at an altitude of about 10 km, as well as vertical cross sections of the atmosphere with data on wind velocity and temperature, taken from S.S. Gaygerov's study (1962).

The pattern constructed characterizes a certain mean annual circulation cycle. Observation data have made it possible to discover different kinds of deviations in the circulation cycle from the mean. These are seasonal deviations and deviations in the weather's time scale. The former are detected as a growth and reduction in the intensity of general circulation from the winter season to the summer with a corresponding shift in the mean position of the lines of the polar and antarctic front.

On mean monthly charts of pressure in the region studied have been detected loops of not too large stationary cyclones located directly near the shores of Antarctica (fig 2, insert [figure not reproduced]). On synoptic charts to this stationary loop are added two more loops of larger cyclones located successively north of the former over the Southern Ocean (fig 3, insert [figure not reproduced]). The cyclones of these loops, unlike the stationary, are separated by meteorological fronts and move continuously from west to east. These formations are responsible for changes in circulation on a yearly scale.

Synoptic charts made for different days and periods record not infrequent changes in the radius of these loops over a period close to 24 hours, a change in the number of cyclones in loops, and shortterm shifts northward and southward in some sections of circular loops. The latter temporarily disturb the symmetry of the pressure field in this region.

Seasonal shifts in front lines and periodic changes in the radius of loops of moving cyclones were related by A.M. Gusev (1967) to transverse waves at the domeshaped interface between the cold cotinental and warm ocean air. These waves were studied by N.Ye. Kochin (1949) for an infinite flat interface inclined by the effect of the Coriolis force. Changes in the intensity of circulation, according to the Margules equation, should result in bulging or flattening of the domeshaped interface and, accordingly, to a shift in its edge--the line of the front along the surface of the ocean. Slow seasonal changes in the shape of the interface are explained by a gradual seasonal change in the intensity of circulation, and shortterm changes by random disturbance of it and by subsequent variations in keeping with the natural cycle of the system.

The loops of cyclones moving around Antarctica are explained by A.M. Gusev (1967) by longitudinal internal gravitational waves at the interface, which develop and break down under the conditions of the system's rotary motion. They arise as the result of the relative motion of two layers of air. There has still been no strict solution to the problem of the origin and development of these waves. N.Ye. Kochin (1949) in his study investigates the conditions for the stability of these waves with different lengths, propagated along an inclined interface of infinite length, and relates the origin of cyclones in the atmosphere to the instability of long waves. In A.M. Gusev's study (1967) an investigation is made of the conditions for the stability of these waves at different distances from the center of the interface, and their rate of propagation is discussed, along with the number of waves originating at circular interfaces. The possible number of cyclone-waves has been estimated on the basis of the results of a number of experiments using circular and annular tanks (Shuleykin, 1968; Gusev, 1962).

General Pattern of Circulation of Waters of the Southern Ocean

The cycle of the waters of the Southern Ocean has been studied to a lesser extent than has the atmosphere over this region. Observation results were derived by us chiefly from studies by V.G. Kort (1963) and V.G. Neyman (1961) and from "Atlas Antarktiki" [Atlas of Antarctica] (1969). It should be mentioned that information on currents in waters of the Southern Ocean was obtained chiefly by indirect methods. Instrument observations are quite rare in this region of the global ocean. Diagrams of the circulation of surface and deep waters of the Southern Ocean were constructed by V.G. Neyman by the dynamical method. The first of these is shown in fig 4. The northern boundary of the Southern Ocean and the lines of divergences and convergences observed on its surface can be seen in fig 5. In fig 6 is shown the distribution by meridian of the mean annual wind velocity, averaged in terms of longitude, with a maximum value of about 6 m/s. There also are shown the mean position, in terms of longitude, of lines of convergences and divergences, as well as zones of the ocean covered by different currents. In fig 7 we see the distribution of velocity through the entire depth of ocean waters in a section extending along the 20° longitude east meridian, from the shores of Antarctica to Africa. In zones of convergence and divergence is observed a marked vertical displacement of water masses, since when they converge at the surface an increase in level occurs, causing the appearance of a vertical motion component pointing downward, and when they diverge, a vertical component pointing upward. This movement of water masses results in the appearance of interfaces--frontal zones extending from the surface to the depths of the ocean. The existence of vertical displacements of water has been detected by observation and by the respective rising and dipping of isotherms.

The most typical and important stream of Southern Ocean waters is the Antarctic Circular Current. Sometimes it is called the West Wind Drift. This current is found between the zones of subtropical convergence and antarctic convergence, located around Antarctica within the range of 36 to 52° latitude south.

The West Wind Drift is almost universally divided into two parallel streams. These streams are located at its edges, and the maximum velocity in them varies from 20 to 40 cm/s. Between these streams is found a region of weak currents and closed-circle circulation. It is precisely as the result of this distribution in velocities in the effective zone of the West Wind Drift that, approximately at the center of this current, there arises a line of divergence of waters--the line of subantarctic divergence, which runs along the circle of latitudes within the boundaries of 40 to 45° latitude south.

Observations have shown that the line of antarctic convergence is the northern boundary for the spread of antarctic surface waters directly interacting with the atmosphere. Therefore, the region from the shores of Antarctica to this boundary is customarily called the Antarctic Region of the Southern Ocean, which conforms well with the definition of the boundary of Antarctica as a geographical region of the globe. The water space between the antarctic and subantarctic convergences is called the Subantarctic Region of the Southern Ocean.

The next zone of general circulation of the waters of the Southern Ocean is the zone located south of the antarctic convergence to the antarctic divergence, surrounding the mainland within the boundaries of 63 to 64° latitude south. Typical of this region of the ocean are weak currents directed easterly, with a mean velocity of 5 cm/s.

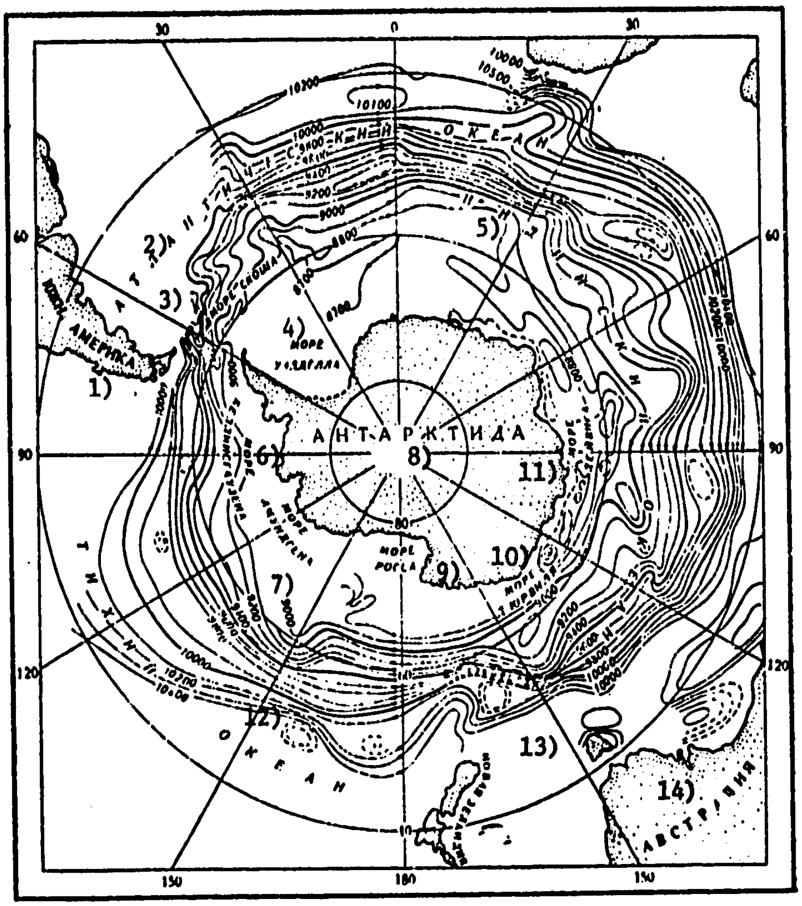

Figure 4. Dynamical Chart of Surface of the Ocean in Relation to 3000 dbar

Key:

1. South America
2. Atlantic Ocean
3. Scotia Sea
4. Weddell Sea
5. Indian Ocean
6. Bellingshausen Sea
7. Amundsen Sea
8. Antarctica
9. Ross Sea
10. d'Urville Sea
11. Davis Sea
12. Pacific Ocean
13. New Zealand
14. Australia

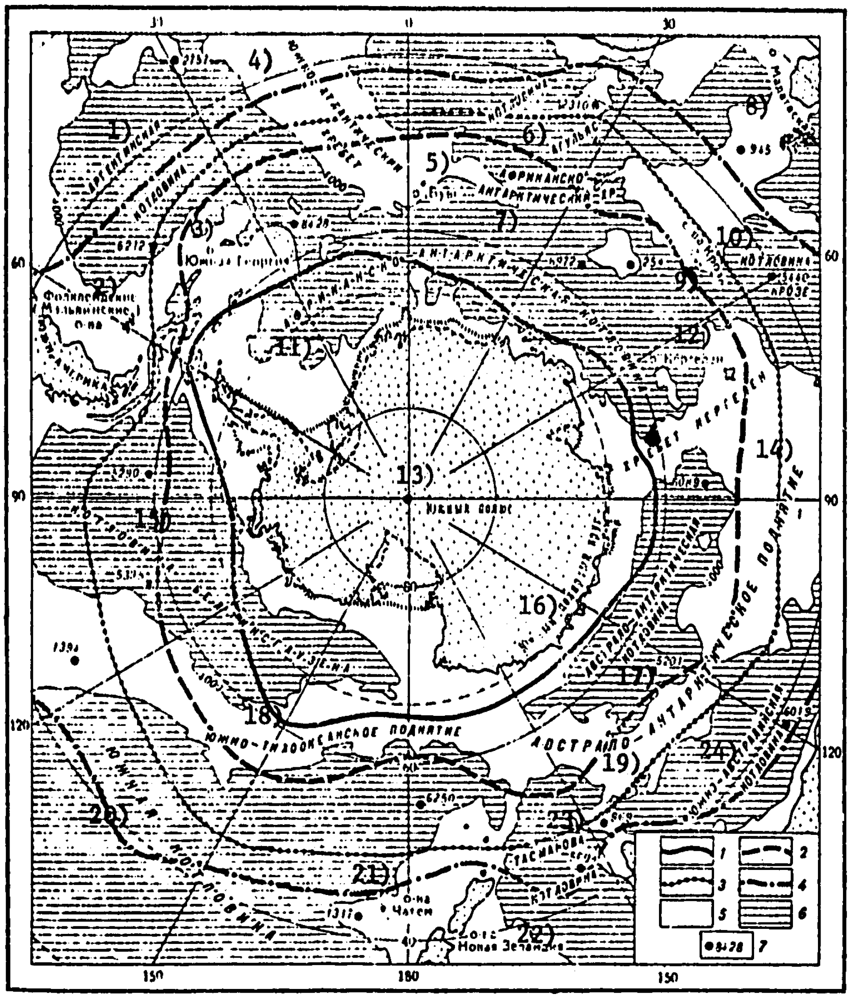

Figure 5. Location of Lines of Divergence and Convergence: 1--antarctic divergence; 2--antarctic convergence; 3--subantarctic divergence; 4--subtropical convergence, northern boundary of Southern Ocean; Depths: 5--from 0 to 4000 m; 6--deeper than 4000 m; 7--depth points and markers

Key:

1. Argentine Basin
2. Falkland (Malvinas) Islands
3. South Georgia
4. South Atlantic Ridge
5. Bouvet Island
6. Agulhas Basin
7. African-Antarctic Ridge
8. Madagascar

[Key continued on following page]

9. Crozet Islands
10. Crozet Basin
11. African-Antarctic Basin
12. Kerguelen Island
13. South Pole
14. Kerguelen Ridge
15. Bellingshausen Basin
16. Antarctic Circle
17. Australian-Antarctic Basin
18. South Pacific Rise
19. Australian-Antarctic Rise
20. Southern Basin
21. Chatham Islands
22. New Zealand Islands
23. Tasmania Basin
24. South Australian Basin

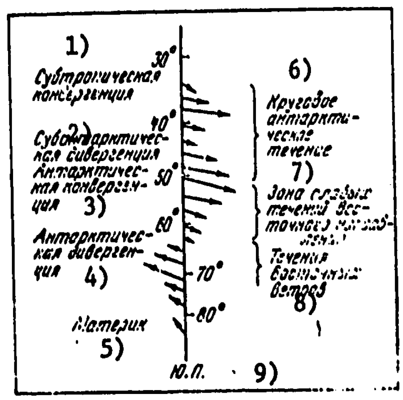

Figure 6. Diagram of Distribution of Wind by Meridian Over the Southern Ocean

Key:

1. Subtropical convergence
2. Subantarctic divergence
3. Antarctic convergence
4. Antarctic divergence
5. Mainland
6. Antarctic Circular Current
7. Zone of weak easterly currents
8. East Wind Drifts
9. South Pole

The positions of zones of convergence and divergence of surface waters, and, consequently, the widths of the rings between them, are not identical at different longitudes in the Pacific Ocean, Atlantic and Indian sectors of the Southern Ocean. Nor are their position and width identical in terms of time. They vary both from season to season and from year to year for the same seasons (cf. figs 5 and 6).

For investigations of the temperature cycle of levels of Southern Ocean waters it is very important to know its water exchange and water balance, and, in particular, the water balance of the strongest ocean stream, which is the Antarctic Circular Current. Utilizing the data of all observations, and supported by special observations made for different meridional cross sections connecting the shores of Antarctica with the extremities of other continents, Soviet researchers have been able to determine the rate of flow of water in the zone of the Antarctic Circular Current in several areas of it. It has been shown that the transport of water by this current, for a cross section running through its entire depth from the surface to the floor at 20° longitude east, equals 19.8 million m^3/s. For a cross section at 165° longitude east, the amount of water transported per second equals 18.9 million m^3, and for a cross section across Drake Passage, 16.5 million m^3.

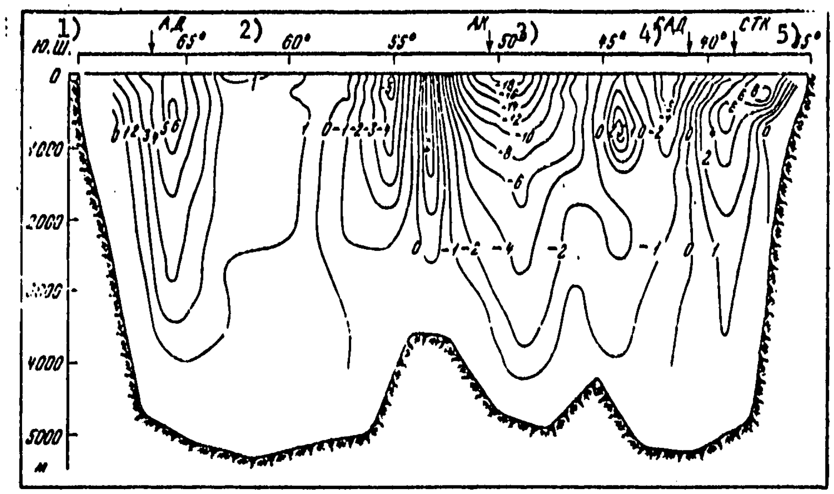

Figure 7. Values of Velocities of Currents (cm/s) in a Section Along 20° Longitude East, From the Coast of Antarctica to Africa

Key:
1. Latitude south
2. AD [antarctic divergence]
3. AK [antarctic convergence]
4. SAD [subantarctic divergence]
5. STK [subtropical convergence]

The inequality in the amount of water transported by the current at different sections is totally explainable. The boundaries of the Antarctic Circular Current are by no means isolated, and across them takes place the exchange of waters of the Southern Ocean with waters of other oceans, which is accomplished by currents having a meridional or close to meridional direction. Such currents, for example, are the Cape Point Current, carrying the waters of the Indian Ocean to the south, and the Peruan Current, representing the discharge item in the balance of Southern Ocean waters, and other currents.

From these cross sections and V.G. Neyman's chart for the 600-dbar level (cf. figs 4-7) we are convinced that the streams of easterly currents cover the entire depth of Southern Ocean waters, which testifies not only to their drift, but also to their gradient origin. But as soon as a current extends to the floor, of course, the contour of the floor will influence the direction of flow. And in fact the lines of flow are not circles. They are deflected first to the right and then to the left, and now to the south and then to the north of latitude circles. This well-known phenomenon was studied by Yu.A. Ivanov and V.M. Kamenkovich (1959) for the Antarctic Circulation Current.

The most complicated is the pattern of currents at the approaches to the shores of Antarctica where winds with an easterly component begin to blow. These regions of the ocean have been studied less because of the complexity of sailing in sea ice and among icebergs. Here are observed vortex-type currents differing in scale, rotating primarily clockwise. These vortices can be seen on the diagram of coastal surface water currents made for this section of the ocean (fig 8). It is hard to talk of the degree of precision of this diagram. We do not know whether these vortices do move around the continent. But it is clear that vortex-type currents do exist. Many researchers in Antarctica have observed them.

Directly near the coast is observed a current with a westerly direction, caused by the effect of a southeast wind blowing from the icy continent. This current must surround the continent in a continuous ring. The considerable changes in its cycle near the shore itself can be related to the complicated configuration of the coastline in certain places.

Let us now discuss how the Antarctic Circular Current originates (fig 9). Northwest winds acting in a wide belt along the latitude ring in the Southern Ocean create a strong drift current flow. This flow, encountering the flow of subtropical waters, forms a line of convergence--the subtropical convergence. It is precisely for this reason that the level of the ocean along it is raised somewhat as the result of the two-way surge of waters. This also determines the pressure gradient of current sets, in particular southward. The vector of the gradient current encompassing the entire depth of waters points eastward. The vector of the total surface current on average agrees well with reality. But the current flow is non-uniform with respect to breadth. There are observed intensification of it along its edges and weakening in the center, which is related to the features of wind distribution along meridians (cf. fig 6). This same cause results in the origin of other lines typical of the Southern Ocean: the subtropical divergence, the antarctic convergence and the antarctic divergence. Consequently, the overall slope of the surface of the ocean from its northern boundary--the subtropical convergence--to the south is non-uniform; rises and dips occur.

Let us turn now to coastal circulation. Southeast winds blowing along the entire extent of Antarctica's coastline create a surge of water, since here the Coriolis force deflects the current to the left of the direction of the effect of the wind (fig 10). The pressure gradient originating as the result of this inclination in level, as well as the Coriolis force, force coastal waters throughout the entire depth to move westward around the mainland. The overall gradient drift current on the surface will also have a westerly direction with northern components which differ in magnitude depending on the features of the position of the coastline, but are not too great.

Hydrological cross sections perpendicular to the coastline graphically show the surge-type nature of circulation near the coast of Antarctica. Of course, the cycle described here is an average one. At each specific section of the coastline it depends on its position in relation to the wind, on the distribution of sea ice (shore ice) and on the depth of the sea.

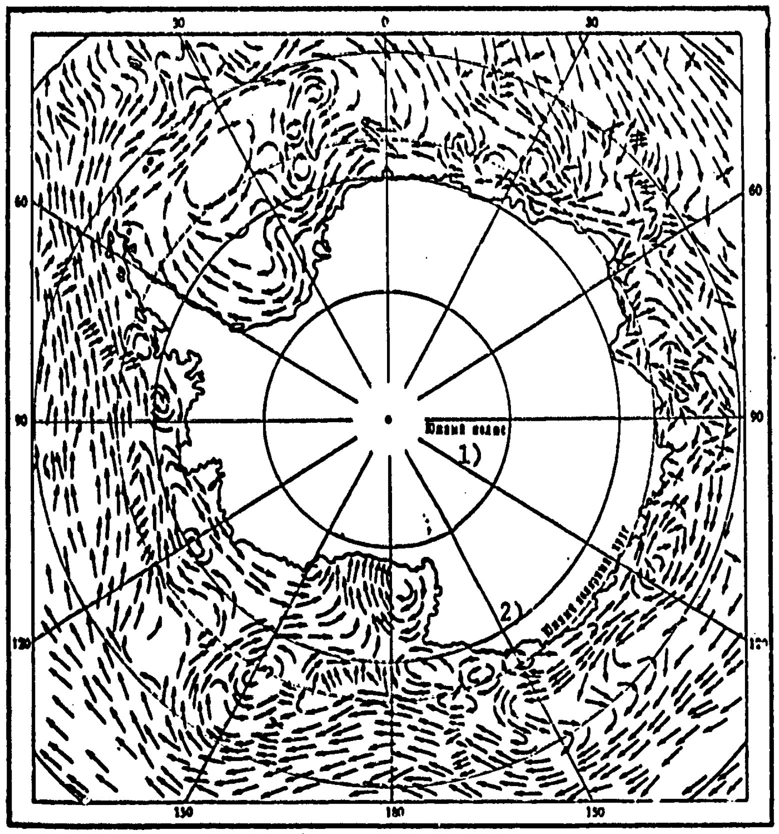

Figure 8. Vortex-Type Currents in the Southern Ocean

Key:
1. South Pole
2. Antarctic Circle

The vortex circulation loop is the most difficult to explain and estimate. Here we have to tu... to atmospheric vortices--cyclone loops, since the reasons for their origin can be shown to be the same from the formal standpoint.

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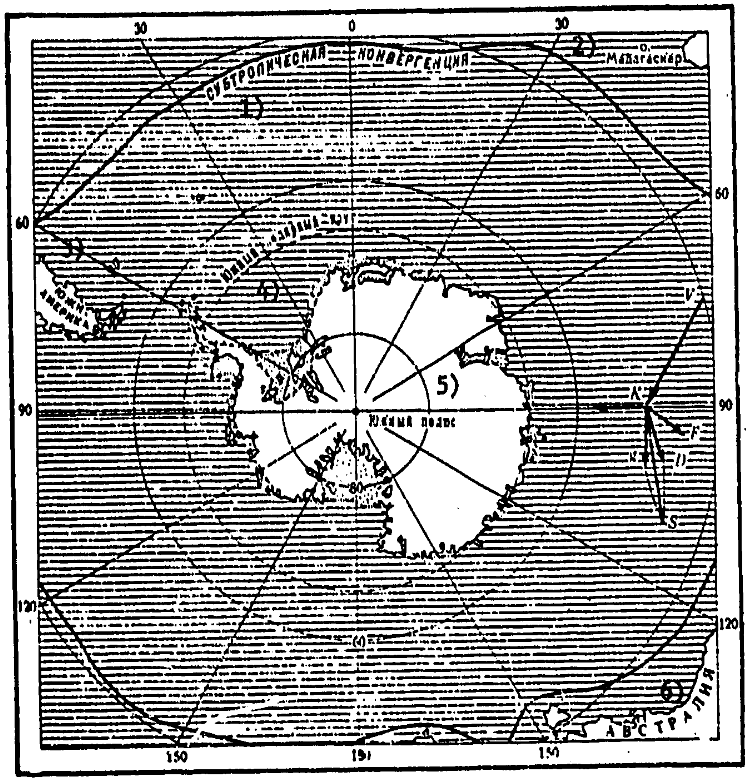

Figure 9. Diagram of the Formation of the West Wind Drift Current (Antarctic Circumpolar Current): V--wind; D--surface drift current; F--total drift current flow; K--slope of ocean level; g--gradient current; S--total surface current

Key:

1. Subtropical convergence
2. Madagascar
3. South America
4. Antarctic Circle
5. South Pole
6. Australia

We recall that cyclone vortices in the atmosphere were regarded above as internal gravitational waves breaking down under conditions of rotation at the interface of layers of air of different density. Obviously, vortex currents can originate in this manner in the ocean, too, if there exist there interfaces between layers of water of different density and relative movement of these layers. It is also obvious that, as the result of the greater density of water as compared with air and the lower relative velocities as compared with in the atmosphere, vortex waves in the water will be smaller than atmospheric waves. Lines of convergence and divergence on the surface of the ocean represent the beginning of interfaces between different water masses. These interfaces are then traced at different depths. In the case of the antarctic divergence is observed an extreme sudden change in the density and relative velocity of two different water masses. Incidentally it is precisely in this area that vortex currents are concentrated in the Southern Ocean.

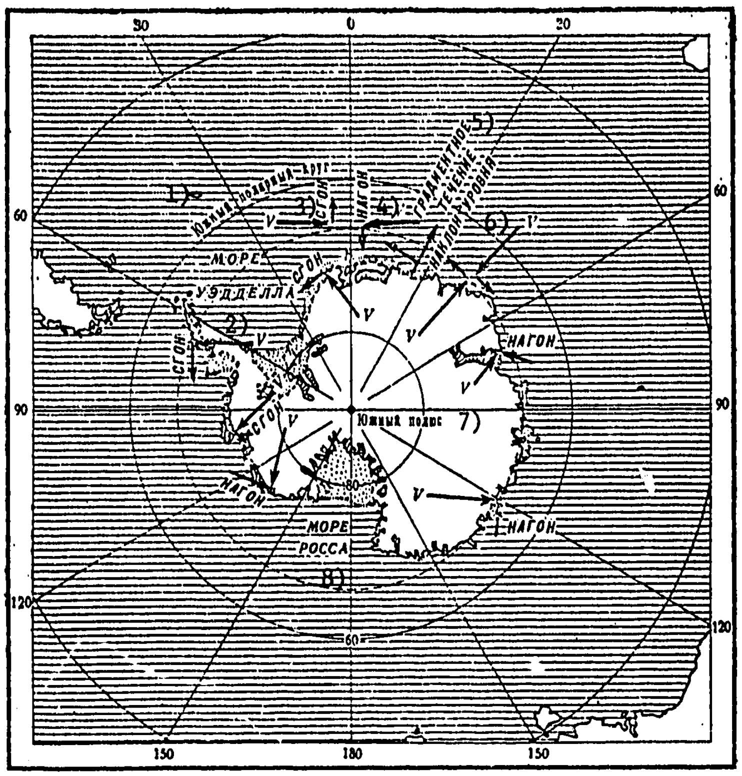

Figure 10. Diagram of the Formation of Coastal Circulation of Waters Around Antarctica

Key:

1. Antarctic Circle
2. Weddell Sea
3. Surge
4. Surge
5. Gradient current
6. Slope of level
7. South Pole
8. Ross Sea

Let us talk some more about the cycle of internal waves under different conditions. With a great difference in the density of two layers of fluid, the waves will be more stable, and very high relative velocities are required for them to reach high ranges and begin to break down. In the other extreme case when the difference in density approaches zero and a relative velocity exists, all waves will break down at the very start of their formation, creating small-scale turbulence. Consequently, large waves and large vortices corresponding to them can form only with definite relatively not too high differences in density and values for the relative velocity, corresponding to them, of the two layers of air or water. But such a purely wave-type pattern will arise only upon the condition of homogeneity, in terms of density, of the two contacting layers of fluid and of their interfacing horizontally. If the interface is inclined, then this inclination must be counterbalanced by some other type of force. In the case of the absence of this force, density convection will originate.

We will not be concerned here with cases of wave motion taking rotation into account and developing all the more under conditions of density convection. A strict solution to such problems is exceedingly difficult.

Mathematical Model of Large-Scale Vortex Circulation in the Atmosphere of Antarctica and in the Waters of the Southern Ocean

The above suggests that vortex winds and currents can be related also to another cause--horizontal large-scale convection in the atmosphere and ocean, developing under conditions of Earth's rotation. We will attempt to clarify this question, employing experimental data and theoretically. Let us imagine an annular vessel whose vertical walls are formed by two coaxial cylindrical surfaces of different radius. If the inside wall is cooled and the outside heated, then in the annular space filled with fluid will originate convection with closed lines of flow in terms of radii. At a certain depth of the fluid an interface will occur. Gravitational waves cannot arise at this interface on account of convective motion, since the relative velocities of the two layers are not great and are directed along the radii, along which there is no space for "acceleration" of a wave. If this vessel begins to rotate, then the interface is twisted and the lines of flow deviate from the radial direction and take on a periodic wave nature. It is precisely traces of such lines of flow which have been detected in experiments by R. Hide (Hide, 1958) and D. Fultz (Fultz, 1951) at the interface. The transformation of wave lines into closed cells with a vertical axis, which ensues with a certain Rossby number, testifies to the fact that the circulation becomes close to two-dimensional in the now level plane; in this plane, consequently, the equation of discontinuity is also closed. Strictly speaking, this pattern of circulation should arise in a vessel of infinite height, when the influence of the bottom disappears. Thus, gravitational waves can arise in annular tanks, rotating and not rotating, only with a sufficiently intense relative velocity of the two layers along the circumference of the tank, not caused by means of convection. It should also be mentioned that gravitational waves and vortices corresponding to them must as a rule be shifted in relation to the circumference, and the convection cells must remain stationary if there is no circular motion caused by another reason.

For the purpose of constructing a mathematical model of this process, it is possible to use the system of equations of thermohydrodynamics in the Boussinesq approximation. In studies by V.V. Alekseyev, T.G. Akimova and A.M. Gusev (Akimova et al., 1974, 1975; Alekseyev et al., 1975), this non-linear system was studied analytically for the purpose of determining the number of vortices and was solved numerically for the purpose of studying the process of their development in the atmosphere. A solution was found to the plane problem, corresponding to a certain cross section of a cylindrical vessel of infinite height. It was verified by the insignificant influence of the vertical component of the large-scale convection studied on its overall vortex nature and the number of vortices. But fundamental difficulties do not arise in solving the three-dimensional problem numerically, either.

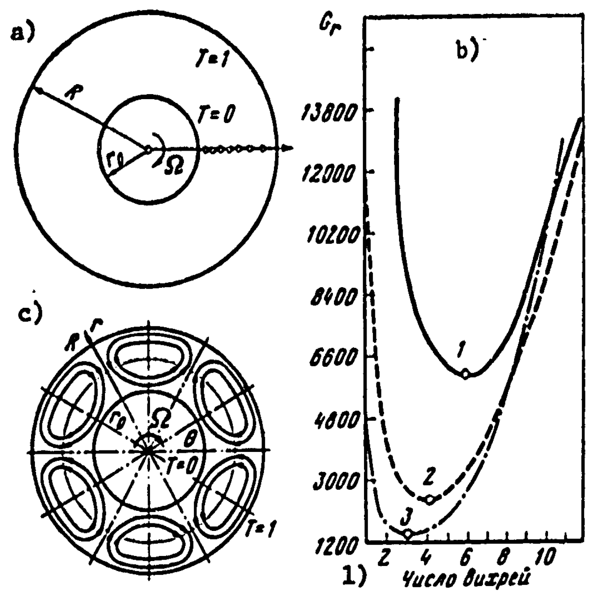

Figure 11. Mathematical Model of Atmospheric Circulation: a—cross section of vessel formed by two coaxial cylinders; b—dependence of number of vortices on Grashof number: 1—r_0 = 1; R = 1.5; 2—r_0 = 0.85; R = 1.5; 3—r_0 = 0.75; R = 1.5; c—vortices with steady-state convection conditions. Cf. text for letter symbols.

Key:

1. Number of vortices

It is possible to write in the following manner the system of equations in dimensionless form in polar coordinates, describing the steady-state motion of a viscous incompressible fluid between two coaxial cylinders of infinite height with radii of r_0 and R (fig 11a), rotating with a constant identical angular velocity of Ω :

$$\nabla p = \Delta v - GrT; \quad \mathrm{div}\, v = 0; \quad \frac{1}{Pr}\Delta T = \gamma v_r \qquad (1)$$

where
$$\gamma = \frac{1}{r \ln \frac{R}{r_0}}, \quad Gr = \frac{\beta\Omega^2 (R - r_0)^4 (T_2 - T_1)}{\nu^2}$$

is the Grashof number, where $T_2 = 1$, $T_1 = 0$ are the temperature of the outside large cylinder and the inside smaller cylinder, respectively, written in certain dimensionless units. As we see, the temperature of the surface of the inside cylinder is lower than the temperature of the surface of the outside. The same conditions were imposed also in the experiments of R. Hide (Hide, 1958) and D. Fultz (Fultz, 1951). Similar conditions occur in nature, too: The atmosphere near the shores of Antarctica is colder than the atmosphere of more northern latitudes near the boundary of the outer loop of cyclones. $Pr = \nu/\chi$ is the Prandtl number (ν represents the kinematic modulus of viscosity; χ is the coefficient of thermal conductivity); $v_2(r,\theta)$ and $v_0(r,\theta)$ are the radial and zonal components of the velocity, respectively; $T(r,\theta)$ is the deviation in temperature from a certain equilibrium value; $p(r,\theta)$ is the overpressure of the fluid (the deviation from its static value); and ∇ and Δ are individual operators. Used as boundary conditions were the conditions of impermeability and adhesion, and for the temperature, its constancy at boundaries. An added condition is the condition of continuity of all functions with respect to angle.

The integral characteristics of the system studied are the numbers of convection cells--the number of vortices. For the purpose of determining their dependence on the Grashof number it was shown to be convenient to utilize the principle of least effect. In general, the variation principle for these problems was suggested by V.V. Alekseyev (Alekseyev and Aleksandrov, 1973). The dependence of the number of vortices on the Grashof number for three variants of the ratio of radii r_0 and R is shown in fig 11b. In fig 11c is shown the ring of vortices arising in the convection system studied. There also is shown the system of coordinates chosen. In fig 11b are plotted three curves corresponding to the values of radii r_0 and R , given in dimensionless values.

The minimum value of the Grashof number on each curve corresponding to the range of the dimension selected, and, more precisely, to the width of the ring where convection develops, corresponds to the most probable number of vortices for the conditions imposed. It is obvious that the value of Gr_{min} grows and the number of cylcones increases with a reduction in the width of the convection ring. These results accord well with reality. Let us compare them with the number of cyclones originating in the atmosphere around Antarctica. From data given in METEOROLOGICHESKIY BYULLETEN' [Meteorological Bulletin] (1958), in January (the summer) the latitude difference between the inside and outside radii of the cyclone region equals approximately 22°, and the difference in air temperature at its boundaries equals approximately 22°C. Here the number of cyclones equals six. In July (the winter) the cyclone ring region is narrowed down to 18° in latitude, and the temperature difference at the boundaries reaches 40°C. The number of cyclones observed equals seven. In spring, when the cyclone region expands to 26°, and the temperature contrast is reduced to 32°C, the number of cyclones is reduced to five. Of course, this is a question only of the agreement of the order of magnitude of numbers calculated and observed, as well as of agreement in the overall trend. But this does testify to the fact that the model suggested correctly reflects the key features of the phenomenon studied.

Let us dwell now on one discrepancy between the theory and reality. The theory indicates that, under steady-state conditions, the number of vortices must be even and equal 2n. In nature, however, are observed both an even and odd number of cyclone vortices around Antarctica. But this discrepancy is only an apparent one. We become convinced of this in a short while below, when we give the results of calculations of the development of convection over time with different modes of it characterized by different Grashof numbers. The number of vortices depends essentially on $R - r_0$, since this parameter enters the equation for Gr to the fourth power.

For the purpose of studying changes in the mode of convection in cylindrical vessels, taking place over time and under different conditions, consideration was given to non-steady-state equations written for a rotating system of polar coordinates:

$$\left.\begin{aligned} &\frac{\partial v}{\partial t} + (v\nabla)v = -\frac{\nabla p}{\rho_0} + \nu\Delta v - 2(\Omega v) + \beta T[\Omega(\Omega r)], \\ &\frac{\partial T}{\partial t} + (v\nabla)T = \chi\Delta T, \quad \operatorname{div} v = 0. \end{aligned}\right\} \quad (2)$$

The symbols used here are the former; in addition, ρ_0 represents density, β is the coefficient of thermal expansion, and Ω is the vector of the angular velocity of rotation.

Applying the rot operation to the first equation of system (2), introducing the flow function, ψ, and its total temperature, it will be possible to write it in dimensionless form in the following manner:

$$\left.\begin{aligned}&\frac{\partial\Delta\psi}{\partial t}+\frac{1}{r}\left(\frac{\partial\psi}{\partial\theta}\cdot\frac{\partial\Delta\psi}{\partial r}-\frac{\partial\psi}{\partial r}\cdot\frac{\partial\Delta\psi}{\partial\theta}\right)=\Delta\Delta\psi+Gr\frac{\partial T}{\partial\theta},\\&\frac{\partial T}{\partial t}+\frac{1}{r}\left(\frac{\partial\psi}{\partial\theta}\cdot\frac{\partial T}{\partial r}-\frac{\partial\psi}{\partial r}\cdot\frac{\partial T}{\partial\theta}\right)=\frac{1}{Pr}\Delta T+\frac{T_2-T_1}{r^2\ln(R/r_0)}\cdot\frac{\partial\psi}{\partial\theta}.\end{aligned}\right\}\quad(3)$$

Here the transition to dimensionless variables is executed by means of the following relationships:

$$T=(T_2-T_1)T';\quad t=\frac{(R-r_0)^2}{\nu}\,t';\quad r=(R-r_0)r';\quad \psi=\nu\psi';\quad \theta=\theta',$$

where values with primes represent dimensionless variables. Primes after the respective transforms of equation (3) are omitted. Gr and Pr in system (3) are the Grashof and Prandtl numbers already familiar to us, the expressions for which are written above.

For the convenience of solution, introduced into system (3) is also the symbol $\Delta\psi = -\phi$, where ϕ represents vorticity on axis z. Thus, the solution to the problem boils down to solving a system of two quasilinear second-order partial differential equations with boundary conditions of the first kind, and to the Dirichlet problem. At the boundaries are maintained the previous conditions of impermeability, adhesion and constancy of temperature. This system has no analytical solution. We will not dwell here on the process of its numerical solution. We will just present its results. In fig 12 are shown lines of flow and isotherms at different moments of time. In the first numerical experiment with Gr = 6000, the artificially imposed insignificant disturbance first, increasing, results in succession in the appearance of two, three and, finally, four vortices. This state, as demonstrated by further calculations, proves to be stable. In the second experiment, conducted with Gr = 8000, precisely this state (four vortices) was used as the initial. Further calculations showed that over a specific period of time one vortex is split in two, and via a mode with five vortices the system gradually passes into a steady state with six vortices. Thus, an odd number of vortices in the atmosphere of Antarctica should testify to instability in the synoptic conditions of the atmosphere. This phenomenon was also noted in experiments by T.V. Bonchkovskaya (1962), conducted by using rotating physical models of the atmosphere of the southern hemisphere.

Numerous synoptic charts made from observations in Antarctica demonstrate that the number of cyclones observed around the continent at different times of the year varies from five to 12. In T.V. Bonchkovskaya's model were observed five to eight vortices. The Grashof numbers, representing similitude criteria, computed for different natural conditions and conditions of the physical experiment varied from 5000 to 12000, i.e., were close to those with which a calculation was made by using the mathematical model. All this confirms their similarity to nature.

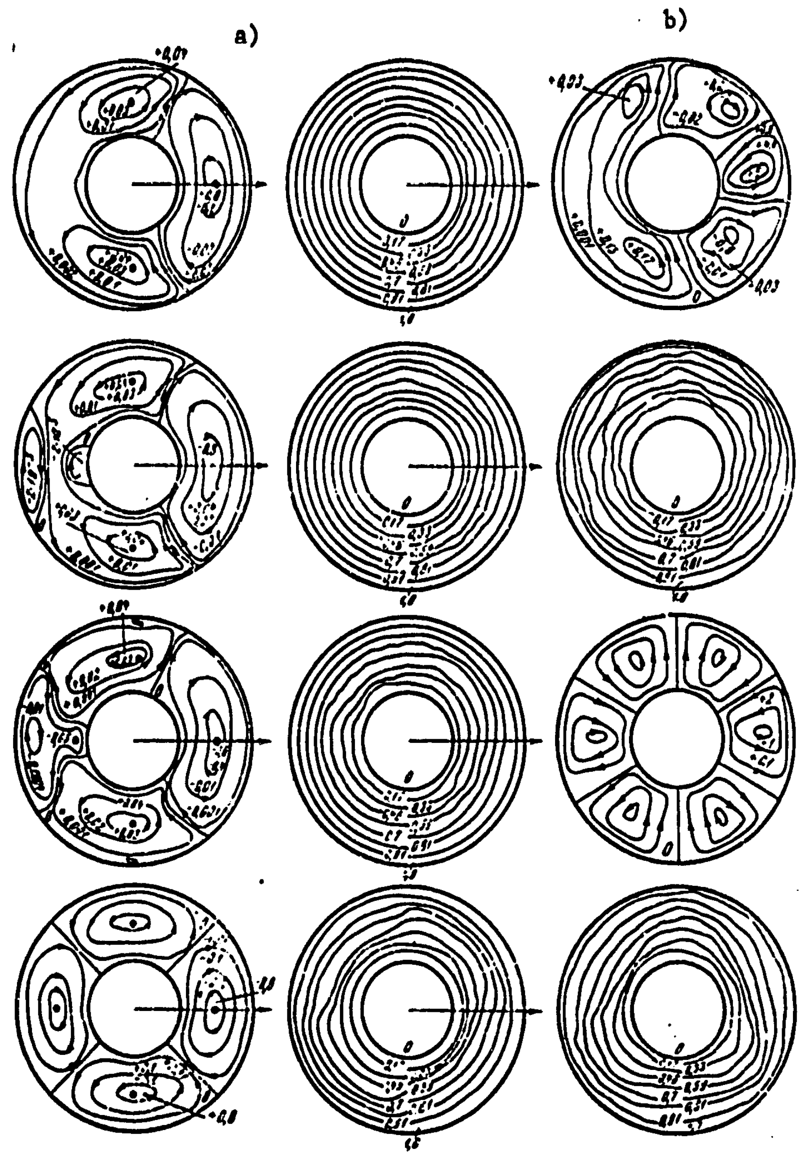

Figure 12. Process of Establishing Mode of Convection at Various Moments of Time (from Top to Bottom): a—with Gr = 6000; b—with Gr = 8000

The model described here can be used with total justification also for studying vortex currents in the ocean. What in this case will the results be of the different physical characteristics and constants of water? The considerably greater viscosity of the water, for example, which enters the equation for determining the Grashof number as a square, will reduce its value with other conditions being equal. This will characterize a more stable mode of convection with a correspondingly smaller number of vortices. Unfortunately, we do not yet have for the ocean the same data as for the atmosphere. The diagrams constructed for the movement of its waters have been averaged and are not very accurate. But in the ocean, too, (cf. fig 8) it is possible to count six to eight large vortices.

And so, as the result of research on vortex currents in the atmosphere of Antarctica and in the waters of the Southern Ocean, it can be asserted that their cause can be both wave processes at interfaces, and convective processes. Just as in studying the overall dynamics of ocean waters, in determining the causes of vortex currents it is impossible to leave completely out of consideration the role of cyclone winds in the creation of similar drift currents of water.

The more distinctly pronounced the interface, and the higher the relative velocity of layers of different density, the more probable the occurrence of vortex waves. With a slight difference in the density and velocity of currents the more probable is the occurrence of vortex convection cells. But purely convective currents cannot cause large internal waves. For this are required high relative velocities of the layers, caused by other reasons.

An interesting but insufficiently studied question is that of the agreement of the order of magnitude of the number of convection-type vortices and wave vortices. Under conditions when the probability of the occurrence of vortices because of both reasons is identical, waves can turn out to be the primary disturbances for the development of convection cells. The reason for the agreement of the order of magnitude of the number of waves and cells under purely convective conditions and purely wave-type conditions is still not clear.

If the movement of loops of cylcones of wave origin around Antarctica can be explained by the relationship between the rate of wave propagation at the interface and the velocity of the lower current, then the rotation of convection cells can be related only to the total transport velocity in relation to latitude circles, caused by another non-convection-type reason--overall atmospheric circulation, or a gradient or drift current in the ocean.

In the atmosphere of Antarctica and in the waters of the Southern Ocean temperature and dynamic conditions are caused by the entire group of factors enumerated. Therefore, for an estimate and forecast of these conditions it is necessary to go from fragments to the problem as a whole. This problem is not easy, but it is very important. It is necessary to begin to construct a full model just for Antarctica, for the southern hemisphere.

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STUDY OF THE BIOLOGICAL RESOURCES OF THE SOUTHERN OCEAN

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[Article by A.S. Bogdanov and T.G. Lyubimoba]

[Text] Fishing industry research in the Southern Ocean was begun in 1961 by the Atlantic Scientific Research Institute of Marine Fishing and Oceanography (AtlantNIRO) on the SRTM [fishing and merchant motor ship] "Muksun" in the southern half of the Atlantic Ocean. The results of research done during this voyage clearly demonstrated the need to arrange for combined fishery research studies in the Falkland-Patagonia region and in the Scotia Sea.

Systematic combined fishing industry research was begun in 1964 by the All-Union Scientific Research Institute of Marine Fishing and Oceanography (VNIRO) in the Atlantic sector of Antarctica, on the NPS [fishery research vessel] "Akademik Knipovich," the flagship of the scientific research fleet of the USSR Ministry of the Fish Industry.

The NPS "Akademik Knipovich" is the first and best outfitted ship of a series of Soviet scientific fishery research vessels constructed on the basis of a large freezer trawler and designed for extensive combined research on the ocean. Accommodations have been made on this ship for physical oceanographic and biological laboratories, five winches with the necessary equipment, and deepwater sonic depth finders. This makes it possible to gather and process data thoroughly characterizing hydrological and hydrochemical features, the relief of the ocean floor, soil, plankton, ichthyoplankton, and benthos of regions being studied. Studies of ichthyofauna are made not only by special gathering of material, but also, what is especially important, by fishing with different commercial gear, followed by an analysis of the needed portion of the commercial catch.

The "Akademik Knipovich" has at its disposal in addition great opportunities for doing research work relating to improving fishing gear and developing technological processes for processing commercial goods. On the ship there are well equipped technological laboratories, mechanized lines for processing fish and antarctic krill, a waste recovery unit, and refrigeration compartments with a 300-ton capacity. The ship delivers from expeditions considerable batches of finished products whose value is especially high since in the majority of cases they are made from new goods of the industry (Gershanovich and Lyubimova, 1971).

Research over many years by VNIRO on the NPS "Akademik Knipovich," which has completed nine extended antarctic expeditions (1964-1976), has not only made a very valuable contribution to the job of studying the biological resources of the Southern Ocean, but has also served for the further development of domestic research on the technique of finding and evaluating the ocean's raw material resources. A combination of large-scale regional research in keeping with an extensive comprehensive program and a detailed study of regions of promise to the industry as applies to different seasons and stages in the life cycle of commercially-suited organisms has been the basis of the fishery research expeditions of VNIRO. Furthermore, to the maximum degree oceanographic and biological data have been compared, determinations have been made of the feasibility of mastering specific regions and products from the commercial viewpoint, and an evaluation has been made of the commercial utilization of biological raw material resources. The reality of setting up an industry has as a rule been substantiated by the experimental operation of the vessel in a commercial situation.

This methodological principle has proved itself on all expeditions of VNIRO and has been utilized successfully in the industry's system of ocean fishery institutes doing research in subantarctic and antarctic waters on vessels equipped similary to the NPS "Akademik Knipovich" (the NPS's "Atlant," "Evrika," "Skif," "Gerakl," "Professor Deryugin," etc.).

In 1967 research was begun in the Pacific and Indian sectors of Antarctica (the New Zealand region, Bellingshausen, Amundsen, Ross and d'Urville seas, and the water area south of 40° latitude south between 20 and 90° longitude east) by the Pacific and Azov - Black Sea scientific research institutes of marine fishing and oceanography. An important role in antarctic research was played by commercial basin explorations, such as the Zaprybpromrazvedka (Kaliningrad), the Yugrybpromrazvedka (Kerch' and Sevastopol') and the TURNIF [expansion unknown] (Vladivostok), by whose efforts were made a considerable number of expeditionary voyages on vessels of different types, from BMRT's [long-range commercial fishing vessels] to SRTM's, and a great amount of exploratory work was done.

Of great importance to the intensification of fishery research studies in subantarctic and antarctic regions was the organization in 1971 of the Antarctic Combined Permanent Fishing Industry Expedition of the USSR Ministry of the Fish Industry. Whereas during the period of 1961-1971 a total of 27 scientific research and exploratory voyages were made in the Southern Ocean, from the moment of organization of this expedition through 1975 the number of voyages made reached 60.

This large industrial expedition combined the forces of all ocean fishery institutes and commercial exploratory groups and to a considerable extent activated and intensified research on the biological raw material resources of the Southern Ocean.

As the result of the fishing industry research which has been done, very important theoretical and practical results have been obtained. The greatest successes in studying biological resources and in determining their commercial value have been achieved in the Atlantic sector of Antarctica, where research began earlier than in the Pacific and Indian sectors and was carried out by the efforts of two institutes. Systematic research over many years conducted by VNIRO in the Scotia Sea and waters adjacent to it has shown that certain of its regions can serve in a number of instances as a distinctive proving ground for studying the fundamental patterns of distribution of antarctic marine organisms and, primarily, of those spread in circumpolar fashion through the Southern Ocean.

Based on the results of basic research performed by Soviet antarctic expeditions during the period 1956-1966 in the area of studying geomorphology, atmospheric circulation, oceanography, plankton, and ichthyofauna of the Southern Ocean, on the data of the thorough summaries of the Discovery Committee expedition (Deacon, 1937; Hart, 1942; Foxton, 1956; Marr, 1962), and on an analysis of the data of detailed regional fishing industry research in Antarctica, a determination was made of high-output regions and of the key patterns in the formation of biological productivity for many of them.

It has been established that the nature of biologically productive processes in the waters of the Southern Ocean is determined chiefly by the Antarctic Circumpolar Current (ATsT), which exerts a multilateral influence on the distribution of biogenic elements, hydrological and hydrochemical characteristics, phytoplankton and antarctic fauna.

The Antarctic Circumpolar Current, which passes around Antarctica from west to east, is the most important circulation system in the global ocean and is exceptionally stable in terms of time and space. Its effect has been traced to a depth of 300 m, and its range of extent stretches almost from the shores of Antarctica to the subtropical zone of the southern hemisphere. The mainstream of the ATsT passes between 50 and 55° latitude south (Moroshkin, 1960; Kort, 1961, 1963; Neyman, 1961; Maksimov, 1962).

Changes in the direction and strength of the ATsT's flow are closely related to changes in the nature of the relief of the ocean floor (Ivanov and Kamenkovich, 1959; Kort, 1963; Treshnikov, 1964).

Because of deviations of the current's mainstream under the influence of the relief of the ocean floor, in a number of regions of the Southern Ocean a system of powerful cyclonic forms of circulation forms. The largest circulation systems are created in the Weddell, Ross, Bellingshausen and Amundsen seas. Circulation processes close to the mainland are intensified as the result of the influence of the West Coast Current (Maksimov, 1958; Treshnikov, 1964).

As was discovered during the time of regional fishing industry studies, complex and distinctive hydrodynamic processes take place because of disturbance of the zonal transport of the ATsT near islands, underwater prominences and banks located on the path of the current's track. Here, above the island shelf and the central section of submerged banks are formed local closed-circuit circulation systems, as well as secondary forms of circulation in the area of the outer edge of the shelf and continental slope. Especially intense vorticity is aroused from the leeward side in relation to prevailing winds and the current (Yelizarov, 1969; Maslennikov, 1969; Maslennikov et al., 1971). The coastal merger which forms is responsible in the majority of instances for high productivity of waters, especially in regions of subantarctic and antarctic islands and prominences.

An important influence on the formation of productivity in open areas of the Southern Ocean is exerted by the meridional circulation of waters created in the effective area of the Antarctic Circumpolar Current. As the result of meridional circulation in the region between 40 and 70° latitude south are formed the frontal zones of the subantarctic divergence, the antarctic convergence, and the antarctic divergence (Ivanov, 1961; Maksimov, 1961; Botnikov, 1964; Neyman, 1966).

The nature of the distribution of biogenic elements over the water area of the Southern Ocean correlates with the position of frontal zones and regions of strong cyclonic circulation formed in the ATsT system. Analysis of the quantitative distribution of biogenic elements testifies to their pronounced increased concentration in circulation systems of the southern half of the Scotia Sea and of the Weddell, Ross, Bellingshausen and Amundsen seas, as well as near islands and underwater prominences located in the effective area of the ATsT. During periods of vegetation the concentration of major biogenic elements in these areas is reduced because of their consumption by living organisms, which is testified to by the increase in the supply of nitrites, which are indicators of the decomposition of a great amount of organic matter (Volkovinskiy, 1969, 1971).

The highest values of the zooplankton biomass are observed primarily in the areas of fronts. Some plankton-rich spots are observed in the areas of circulation of waters near subantarctic and antarctic islands and underwater prominences, the main ones being the islands of South Georgia, Crozet, Kerguelen, and Bouvet, the Balleny Islands, the Macquarie Islands, the Ob', Lena and Bairdwood banks, and prominences located in the water area of the Kerguelen Ridge. It has been determined that the biomass of copepod plankton in these regions equals 400 to 600 mg/m^3 (Vinogradov and Naumov, 1961; Voronina and Naumov, 1968; Kanayeva, 1969; Pervushin and Naumov, 1970).

Distinguished by especially high productivity is the epipelagic zone near the antarctic divergence, because of the intense development of macrozooplankton, among which Euphasia superba D. predominates in terms of biomass. Mass concentrations of individuals of this species are known by the name of antarctic krill. E. superba is one of the most typical representatives of antarctic macrozooplankton, living in the Southern Ocean south of the antarctic convergence. In certain regions of the Southern Ocean are formed dense clusters of E. superba, considerably surpassing in biomass the concentration of mesoplankton. Whereas the maximum biomass of mesoplankton in the areas of its highest concentration equals 20 to 30 g/m^3 (1 g/m^3 is the highest figure for mesoplankton), the biomass of antarctic krill reaches 10 to 15 kg/mg^3. The formation of mass concentrations of E. superba in the Southern Ocean is caused by a number of factors of a biotic and abiotic nature. It has been established that the largest clusters of crayfish originate in the spring, summer and part of the fall period (November-May) and are associated with their breeding and feeding (Naumov, 1963; Makarov and Shevtsov, 1969, 1971; Makarov et al., 1972).

Combined fishing industry studies over many years in the Scotia Sea have provided an opportunity to determine not only areas of mass concentration of crayfish, but also the conditions under which the formation of dense clusters takes place, as well as to determine the reasons for and the length of preservation of these clusters and their disintegration. It should be mentioned that main patterns of the distribution and formation of clusters of krill discovered by using the Scotia Sea as an example are common to the entire water area of the Southern Ocean, since this was confirmed later by the results of research in the Pacific and Indian sectors of Antarctica.

On the basis of features of the distribution of physical and chemical characteristics in the southern half of the Scotia Sea, VNIRO physical oceanographers as early as the first year of research discovered the existence of a secondary frontal zone (VFZ) separating the waters of Weddell Sea and the Antarctic Circumpolar Current (Bogdanov et al., 1969; Yelizarov, 1969; Maslennikov, 1969). Later the location of the VFZ was verified by detailed research on geostrophic currents of the Scotia Sea and the adjacent water area. The general direction of this secondary frontal zone runs from the southwest to northeast, parallel to the Scotia Arch, in relation to the water transport predominant in the Scotia Sea, and its meandering nature matches the kinks in dynamic lines of flow (Maslennikov et al., 1971). The latter fact is especially important, since concentrations of antarctic krill are related to vortical formations of the VFZ.

Every year during the summer within the range of the frontal zone are concentrated sexually mature crayfish, where they spawn at the end of the summer. Fry during this period are distributed south of the Scotia Arch, so the separate occurrence of generations of crayfish is observed (Makarov, 1970). With the approach of the fall-winter period, the areas of habitation of the fry and sexually mature crayfish in this section of the sea gradually overlap. At the same time in another section of the sea, in the area of South Georgia Island, every year a significant quantity of fry accumulate.

But this region represents an anomaly from the viewpoint of the habitation and reproduction of this species and is characterized as a sterile zone for eviction of the Euphasia superba population (Makarov and Shevtsov, 1971).

The occurrence of E. superba and its spatial and quantitative distribution are closely associated with plankton. Phytoplankton and some forms of zooplankton are a steady source of food for krill. The rather even distribution of phytoplankton and zooplankton, whose areas of mass development during the period of vegetation surround the continent in an almost continuous ring, provides antarctic krill with a large food base in all regions of its geographic range (Vinogradov and Naumov, 1961). Consequently, the food base cannot be the decisive factor of the conditions for formation of their mass concentrations. The distribution and the biomass of food organisms apparently exert a decisive influence on the behavior of crayfish in clusters, on their concentration at the surface or in the depth of the water, on their submersion depth, the nature of vertical migrations, etc. (Pavlov, 1969; Makarov and Shevtsov, 1971).

By research by VNIRO in the Scotia Sea it was established that the formation of mass dense concentrations of krill in regions of distribution of crayfish (the area of the VFZ, the waters of South Georgia Island) is determined by specific features of the dynamics of the waters. An analysis of the vertical circulation of waters in regions of mass concentrations of krill has demonstrated the confinement of clusters to sections where waters sink, adjacent to areas of a rise. Furthermore, areas of descent where concentrations of krill are found can be related both to the center of an anticyclonic form of circulation, to the periphery of a cyclonic form, and to straight-line movement of a flow along a shore or underwater prominence, but is certainly to the left of horizontal currents. The velocity of the horizontal flow in this case is not of essential significance to clusters of krill. An important condition for the formation of concentrations of crayfish is, as it were, restriction of the section for descent of waters by distinctive "walls." This restriction can be either of a dynamic nature (for the open sea), when waters flow from both flanks to the section of descent, or of an orographic (for coastal regions), where the role of one of the "walls" is played by the shore. These patterns have been revealed both in the open section of the Scotia Sea and in the coastal waters of the South Orkney Islands and South Georgia Island. It has also been determined that, in the absence of a distinctly pronounced region of descent of waters, concentrations of krill do not form even in regions of distribution in which this is normal, e.g., in the secondary frontal zone where the waters of Weddell Sea and the ATsT mix (Bogdanov and Solyankin, 1970; Yelizarov, 1971).

The length of time crayfish remain in clusters in various regions of the Scotia Sea is not the same. In the main geographic zone (the southern half of the sea) where the breeding of E. superba takes place, clusters of crayfish are stable right up to the end of the spawning period, after which, in February-March, is observed the process of disintegration of dense clusters (Makarov and Shevtsov, 1971). In the waters of South Georgia Island, where the accumulation of crayfish is observed during the summer-fall period, transported by the Weddell Sea current, the stability of concentrations is governed chiefly by the period concentrating forms of horizontal circulation continue, i.e., by the maintenance above the shelf of a system of powerful cyclonic and anticyclonic forms of circulation (Maslennikov, 1972, 1974).

The patterns which have been determined for the formation of clusters of antarctic krill, using the Scotia Sea as an example, are of very important theoretical and practical value, since the types of vertical circulation of waters described above are observed in many regions of the Southern Ocean. Consequently, concentrations of krill can be found in the open area of the ocean--in frontal zones, in forms of circulation originating on the periphery of horizontal currents, in the coastal waters of islands and underwater prominences, and to the left of a horizontal stream passing along the shore. From this viewpoint especially close attention is deserved by regions of cyclonic and anticyclonic circulation in the open seas of the Southern Ocean (the Bellingshausen, Amundsen, Ross, d'Urville, Sodruzhestvo, etc., seas), as well as the waters of antarctic islands and banks on the leeward side in relation to prevailing winds and currents (the islands Bouvet, Herd, Scott, Peter the First, the Balleny Islands, the Ob' and Lena banks, etc.). Mass concentrations of krill have already been found in many of these regions (Lubimov et al., 1973).

Antarctic krill are the central element in the ecosystem of the Southern Ocean, because of their high number and the influence they exert within the range of a specific trophic level on the distribution and number of antarctic marine organisms.

According to the estimates of various authors, based on data on the feeding of the whiskered whale and other consumers of krill, the total supply of antarctic krill in the Southern Ocean is reckoned in astronomical figures--from 800 million to five billion tons (Klumov, 1961; Pequegnat, 1958; McQuillan, 1962; etc.). It has been estimated approximately that the humpbacked whale, during the time it remains in Antarctica, consumes as much as 450 tons of krill (Ivashin, 1961). These figures characterize the extremely high level of the biomass of E. superba.

The vast supply and the formation of mass concentrations of antarctic krill through certain areas of the vast water area of the Southern Ocean testify to the extensive opportunities for commercial utilization of its raw material resources as an independent objective of the industry. In connection with the fact that individuals of commercial size among the E. superba population make up no more than 30 to 40 percent of the total supply, and that a considerable percentage of the crayfish output is eaten up by an enormous number of krill-consuming species, the total figure for possible commercial removal can equal not less than 25 to 50 million tons per year, without detriment to the supply.

The first experiments in trapping clusters of antarctic krill in the Scotia Sea and in obtaining human and animal food products from it, conducted by Soviet scientists, produced positive results and proved the feasibility of commercial adoption of this product (Lubimova et al., 1973).

As the result of a thorough study of ocean biocenoses by marine fishery institutes, many patterns have been discovered, relating to the biology, zoogeography and distribution of antarctic ichthyofauna in shelf waters and in the open area of the ocean, and a determination has been made of the population level of various groups and species, as well as of the position and significance of fish in the ecological systems of certain regions of the Southern Ocean.

The most detailed modern description of the distribution and general traits of the biology of antarctic ichthyofauna was made by A.P. Andriyashev (1962, 1964). The data of regional fishing industry research have substantially broadened the previously existing notion regarding the species composition of antarctic ichthyofauna and its distribution in the Southern Ocean, and the vertical distribution of fish in certain regions, and have deepened our knowledge of the biology of many species of fish with regard to the conditions of the environment in which they live. Species of fish new to science have been discovered, as well as certain species, genera and families previously unknown in antarctic waters. The fact of circumpolar geographic zones has been established for a number of antarctic species (Permitin, 1966, 1969).

The permanency in the existence of frontal zones in the Southern Ocean, where either an ascent or descent of waters occurs, is responsible for the high concentration of biogenic elements and the abundance of zooplankton, especially of antarctic krill (south of the antarctic convergence), which has provided the pelagic fish living here with optimal conditions for distribution over water levels, as well as for breeding and feeding and for the development of larvae and fry. In addition, the high availability of food practically universally determines the vastness of the geographic zones of many antarctic fish species and the significant level of their population in the effective range of the ATsT.

The waters in the area of the southern edge of the antarctic convergence are characterized by a high zooplankton biomass, not only during the summer maximum, but also throughout the year, as well as by intensity in the quantitative development of plankton vertically to depths of 500 m and more (Voronina, 1971). In connection with the deepwater distribution and high biomass of food-type zooplankton in waters of the southern edge of the antarctic convergence at depths of up to 600 m, bathypelagic plankton-eating fish are widespread. The most numerous are representatives of the "glowing anchovy" family (Myctophidae)--species of the genera Electrona and Gymnoscopelus. Among other mass bathypelagic fish can be mentioned Bathylagus antarcticum (family Bathylagidae) and Paralepis atlanticus prionosa (family Paralepididae). Pelagic clusters of these species can be found from surface level to a depth of 200 to 600 m.

Directly associated with antarctic krill are the distribution and formation of concentrations of epipelagic krill-eating fish in the area of the antarctic divergence and south of it. Among these fish mention should be made first of the two most numerous species--Micromesistius australis (family Gadidae) and the antarctic silverfish Pleuragramma antarcticum (family Nototheniidae).

Micromesistius australis forms pelagic clusters in the southern half of the Scotia Sea at the 0 to 100 m level and floor clusters in shelf waters and waters of the continental slope in the Falkland-Patagonia region, at depths of up to 400 m and more. Because of the wide distribution and assimilation of a highly productive krill zone, the population of this species has reached a high level (Shubnikov et al., 1969).

Distinguished by an even wider distribution in the Southern Ocean is the antarctic silverfish, which lives in circumpolar fashion near the edge of the ice and forms pelagic clusters in the level from the surface down to 100 m at points of concentration of antarctic krill (Lubimova et al., 1973).

The conditions of habitation and the spatial and quantitative distribution of ocean floor ichthyofauna in the waters of the subantarctic and antarctic islands and banks have been found to agree with the main patterns of the formation of biological productivity in these regions, which are located within the effective range of the Antarctic Circumpolar Current: One is near the highly productive zone of the antarctic convergence, and the others right in the zone of the antarctic divergence. Thus, the key patterns of the formation of productivity in the Southern Ocean are common to the waters of islands and banks. In addition, it should be mentioned that the features of horizontal and vertical circulation and the enrichment of waters with biocenoses and microelements because of continental runoff determine the unusually high productivity of many of them, the high biomass of food-type meso- and macroplankton and of nectobenthic organisms (Volkovinskiy, 1969; Kanayeva, 1969; Lyubimova et al., 1971).

The shelf waters of islands and banks are populated by ocean floor ichthyofauna of the families Nototheniidae, Chaenichthyidae, Muraenolepidae, Macruridae, Bothidae, etc. In spite of the isolation of their areas of habitation, among the ocean floor ichthyofauna of the Southern Ocean can be observed no small number of genera and species distinguished by wide distribution, and in some instances by a circumpolar geographic zone. These are chiefly representatives of the most numerous families Nototheniidae and Chaenichthyidae. For example, wide distribution around the continent has been established for Notothenia rossi (waters of the Antarctic Peninsula and of the South Shetland Islands, South Orkney Islands, South Georgia, the Macquarie Islands, and the islands Bouvet, Crozet and Kerguelen), Champsocephalus gunnari (waters of the Antarctic Peninsula, South Shetland Islands, South Georgia, and the islands Bouvet, Crozet and Kerguelen), and Notothenia larseni (waters of the Balleny Islands, South Shetland Islands, South Georgia, and Bouvet Island). Also with a circumpolar geographic zone are the species Dissostichus mawsoni, Trematomus hansoni, Notothenia coriiceps, and several others (Lubimova, 1974).

The most significant quantitative development has been achieved by those species of bottom fish of whom is characteristic a high degree of adaptation to utilization of the rich food base of the pelagic zone, i.e., those whose food base is made up of plankton organisms and antarctic krill, in particular. In their search for food some bottom fish are capable of making considerable vertical migrations, right up to the surface levels of the water. Under the heading of these species come first of all planktophagous, or, more accurately, krill-eating, fish, such as Notothenia rossi and Champsocephalus gunnari. Species of fish which do not complete such considerable migrations and feed on nectobenthic and benthic organisms, as, for example, N. gibberifrons. N. squamifrons, Chaenichthys rhinoceratus, etc., are notably inferior to planktophagous fish in terms of number (Lyubimova et al., 1971).

Features of the geomorphological structure of island shelves and the specifics of hydrodynamics and of the nature of bottom deposits (Avilov and Gershanovich, 1969) determine in the majority of instances the poverty of the benthos food base. It has been learned that characterized by the lowest population are bottom fish closely bound to the bottom throughout their entire life cycle and feeding exclusively on benthos (representatives of the families Muraenolepidae, Bothidae. Liparidae, etc.).

Based on the trophic relationships between bottom ichthyofauna of the shelf waters of subantarctic and antarctic islands, different ecological groups of fish have been distinguished, including different families, genera and species. It has been learned that between related species of fish in Antarctica, and sometimes even between different generations within the same species, there exists an ecological separation, which is of decisive importance to the formation of their number. As an example can be given two species of bottom fish living in the same region (near South Georgia Island--Notothenia rossii marmorata and N. gibberifrons). The specifics of the nature of how each of these species feeds, the first being a krill eater and the other a benthophagous fish, and ecological features respectively associated with this, determine the considerably lower population level of N. gibberifrons, in spite of the fact that its geographic zone within the boundaries of the same area of habitation is twice as large as that of N. rossii marmorata.

Of great importance in formation of the high population of N. rossii marmorata is the ecological individualization of the non-sexually-mature part of its population, which lives in open island fjords, from the sexually mature, which is distributed over the open area of the shelf. Because of this a certain extension of the geographic zone is achieved and the fry are removed from the constant influence of predators in open shelf waters. As the result of this intraspecies ecological individualization, the spawning part of the population of this species is guaranteed relatively steady replenishment every year.

The results obtained from many years of combined research in the shelf waters of the subantarctic and antarctic islands, beginning with the determination of the magnitude of primary production and ending with the discovery of abiotic and biotic factors in formation of the population of marine organisms of different trophic levels, and with an estimate of their biomass, has made it possible even now to approach a determination of the key elements of the structure of ecosystems in different regions of Antarctica. In the future, study of the features of energy metabolism at different trophic levels and of the patterns of the quantitative transformation of organic matter in ecosystems will make it possible with much higher accuracy to determine the magnitude of the end product in a specific region of the Southern Ocean (Lyubimova et al., 1971; Lubimova, 1974).

No doubt, the best prospects for the industrial utilization of antarctic ichthyofauna resources are represented by the highly productive subantarctic and antarctic epi- and bathypelagic zones, where the supply of fish is fairly large and has not been touched by industry. The industrial utilization of fish resources in the shelf waters of islands is of secondary importance because of the limitedness of the total area of island shelves in the Southern Ocean and of the locality of populations of species of bottom fish which live in these waters. In addition to the prospects for the industrial utilization of mass planktophagous and krill-eating fish in Antarctica, it is necessary not to forget about the utilization of the raw material resources represented by bathyal fish, in particular, by representatives of the families Macruridae, Merlucidae and Moridae, as well as the large fish of the family Nototheniidae. Of course the supply of these fish, which are on a higher trophic level, is not as great as the supply of planktophagous fish, but it is possible to set up an efficient controllable industry for them. Among these species it is possible to mention Dissostichus mawsoni, Coelorhynchus fasciatus, Macruronus magellanicus, etc. (Lubimova et al., 1973).

In conclusion it is necessary to mention that success in mastering the productive regions of the Southern Ocean will depend to a considerable extent on the organization of further extensive combined fishing industry research, utilizing high-efficiency exploratory and commercial equipment.

The vastness of the water area, the severity of hydrometeorological conditions, and the distinctive nature of the horizontal and vertical distribution of antarctic marine organisms make it necessary to use for fishery research operations in regions of Antarctica vessels of the ice class, with a high degree of self-sufficiency in sailing, and with improved acoustical equipment and underwater equipment for studying the behavior of organisms at water levels, and to create in some instances fundamentally new automatic controllable fishing gear with a wide catching range and devices for attracting and forming schools of commercially suited organisms.

Taking into account the increasing human demand for animal protein, in addition to conducting exploratory scientific and fishery research, it is necessary thoroughly to develop new methods for the technology of obtaining food products from fish and invertebrates which hitherto have not been traditional raw material but which in the not too distant future will become products for commercial use.

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HUMAN ADAPTATION AND HEALTH IN ANTARCTICA

Moscow ANTARKTIKA: OSNOVNYYE ITOGI IZUCHENIYA ANTARKTIKI ZA 20 LET. DOKLADY KOMISSII in Russian No 17, 1978 pp 237-248

[Article by N.R. Deryapa, A.L. Matusov and I.I. Tikhomirov]

[Text] Antarctica is of exceptional interest for conducting medical research, since on the Sixth Continent human vital activity takes place under extreme conditions of social and natural environment. Leading among medical biological problems are the different aspects of human adaptation and of polar health.

During the 20 years of research in Antarctica dozens of physicians have been at work on Soviet antarctic expeditions. The key objectives of medical research have been to study the process of adaptation of polar explorers in different regions of Antarctica, to study the influence of the natural environment and working and living conditions, and to develop measures for preventing misadaptation disorders and for the vital protection of polar explorers.

Unlike other disciplines, there was absolutely no kind of medical research on expeditions for a period of several years. The first medical research was performed by expedition physicians at times without sufficient scientific guidance and materials and equipment. But it was precisely the observations of these enthusiastic physicians which were a kind of "scientific exploration," which attracted the attention of the medical public at large to the problem of health care in Antarctica. It was only in 1962 that the subject area of medicine was included in the overall plan for research on Antarctica by the Interdepartmental Commission on Research on Antarctica under the auspices of the USSR Academy of Sciences, upon the initiative of Professor G.M. Danishevskiy.

The next important step was the creation in 1966, under the auspices of the USSR Academy of Medical Sciences, of the problem commission on human acclimatization in Antarctica, and the enlistment for this job of a number of scientific research institutes. At this time medical research conducted on Soviet antarctic expeditions began to enter the plans for scientific research work of the learned medical council of the USSR Ministry of Public Health and the USSR Academy of Medical Sciences. In connection with this, in addition to practicing physicians, scientific associates in different fields of specialization (physiologists, psychoneurologists, microbiologists and hygienists) began to be sent on antarctic expeditions.

In the beginning of 1966 in the Arctic and Antarctic Scientific Research Institute was created a medical group, which was reorganized in 1967 into the Division of Polar Medicine, which for a number of years has been an organizing center on the Union scale. Since this time scientific and medical research has finally acquired a systematic and orderly nature, and its methodological and technical level has been raised to the front ranks of modern medical science.

The creation in 1970 of the Siberian Branch of the Academy of Medical Sciences and the transfer to it of the functions of the head center for planning and coordinating scientific research work relating to the problems of the north, the Arctic and Antarctica made it possible for this line of medicine finally to take shape in an organized manner. The way had been paved toward the further improvement and longterm planning of medical research in Antarctica.

During the last decade some of the largest scientific research institutes in the country have taken an active part in working on the problem of human acclimatization under the conditions of Antartica: the USSR Ministry of Public Health Institute of Medical Biological Problems, the USSR AMN [Academy of Medical Sciences] Institute of Experimental Medicine, the USSR AMN Institute of General and Public Hygiene imeni A.N. Sysin, the USSR AMN Siberian Branch Institute of Clinical and Experimental Medicine, etc. A great contribution to working out the problem of human acclimatization in Antarctica has been made by scientists at the Military Medical Academy imeni S.M. Kirov.

There is no doubt that the enlistment of such scientific research institutions for studying human acclimatization in Antarctica must be regarded as the greatest contribution of Soviet medical science to solving problematic questions relating to further and thorough mastery of the Sixth Continent.

Conducive to success in studying the problem of adaptation in the polar regions of Earth have been the extensive development of research on medical geography and geographic pathology, the systematic holding of all-Union scientific conferences on the problems of medical geography, and the enlistment for work on this problem of many scientists of our country and countries of the socialist community.

During the 20 years of research by physicians participating in wintering sessions, considerable scientific data have been accumulated on human adaptation under specific conditions of habitation, and data have been obtained on clinical-biochemical, physiological and hygienic aspects of the adaptation of polar explorers in coastal and intracontinental regions of Antarctica.

During this period six monographs have been published (Deryapa, 1965; Tikhomirov, 1965, 1968; Matusov, 1972; Borinskiy, 1973; Deryapa et al., 1975), as well as three collections of scientific studies ("Acclimatization of Man...," 1969; INFORMATSIONNYY BYULLETEN' SAE [Soviet Antarctic Expedition Information Bulletin], 1969; TRUDY AANII [Proceedings of the Arctic and Antarctic Scientific Research Institute], 1971). More than 250 scientific articles written by SAE physicians have been published. Physicians G.A. Barashkov, V.V. Boriskin, P.V. Bundzen, N.R. Deryapa, I.F. Ryabinin, I.I. Tikhomirov, I.V. Shastin and A.L. Matusov have successfully defended doctoral dissertations, and A.F. Zavadovskiy, N.I. Makarov, N.R. Paleyev, O.I. Pal'yanov, A.A. Popov, Yu.A. Senkevich and A.Ya. Shamis and others, candidate dissertations, utilizing materials from their research in Antarctica. N.R. Deryapa has been elected a corresponding member of the USSR Academy of Medical Sciences.

International ties have been extended and will grow stronger. Soviet physicians participating in SAE's have been delivering papers and publishing studies as part of the proceedings of international conferences and symposia (Finland, the USA, England, Canada, the FRG). Soviet medical personnel are represented and are active associates in the SCAR [Scientific Council on Antarctic Research] study group on human biology and medicine.

Thus, the range of scientific medical institutions and individuals which have made an important contribution to studying human adaptation and health in Antarctica is quite vast. Soviet researchers have been occupied with studying various aspects of human adaptation in Antarctica.

Social and Hygienic Problems in Adaptation

Research on human acclimatization in Antarctica merges as a whole into the general problem of the adaptation of man to natural conditions. The problem of the longterm and complete adaptation of man to unusual and severe environmental conditions is especially topical in our country, with its varied natural conditions. At the same time the successful fulfillment of the goals set by the party and government concerning the broad national economic mastery of new little-populated regions of the country, in particular, regions of the extreme north, depends to a great deal on an intelligent solution to the problem of the acclimatization of people in their new habitat. In the future the same problems can originate with respect to Antarctica.

In Antarctica are combined the natural conditions of the Arctic and high mountains (Central Antarctica). The intense cooling resulting from the severe polar climate, the contrast of light conditions, the maximum degree of isolation from other continents, the lifelessness and monotony of the landscape--all this makes it necessary to work on the social and hygienic aspects of adaptation. In Central Antarctica an independent problem is the protection of man from the unfavorable influence of reduced atmospheric pressure (because of a reduction in the content of oxygen), typical of high-mountain regions of Earth.

In addition, the conditions of life at antarctic polar stations are quite distinctive by virtue of the fact that a number of social factors playing an enormous role in ordinary life are either absent here or, as it were, withdraw into the background. For example, questions of wages or spending money, family relationships and relationships between the sexes, different social pressures, etc. The role of different interrelationships in the team increases.

More distinctly pronounced also is the effect of natural environmental factors, the more so in that the intensity of many of them under local conditions exceeds ordinary parameters. These features made it possible for us even more than 10 years ago to characterize Antarctica as a natural laboratory where, as in a gigantic experimental chamber, biotropic environmental factors veiled in everyday life by social factors are most accessible to consideration and observation.

A distinctive feature of human acclimatization is the fact that it is not so much a physiological process as a social and hygienic one, in which the major role, unlike the acclimatization of animals and plants, is played by an active influence on the environment for the purpose of creating favorable conditions for human life and work, and not the development in the organism of various physiological adaptations. It is precisely this approach which has made it possible for people to penetrate habitats where biological life was considered impossible (Central Antarctica, space). And the achievements of the scientific and technical revolution taking place at the present time have created enormous opportunties in this respect.

The social and hygienic aspects of optimizing the living and working conditions of organized teams under extreme conditions are quite manifold and include such problems as the design of housing and clothing, arranging for food and water, and the work and rest routine (all these aspects are included in the range of interests of researchers). Recommendations have been drawn up and partly put into effect, which have made it possible to improve considerably working and living conditions at stations. In each specific situation (coastal or intracontinental stations, sled and tractor journeys, etc.) it is important to choose the most advisable form of vital protection and to avoid extremes in solving this problem. The best thing to do is to be concerned with a reasonable maximum level of convenience, ensuring a high level of efficiency and a high level of health for members of the team, but at the same time without pampering the body and requiring excessive expense.

It has been established by studies by Soviet physicians taking part in winter expeditions in Antarctica that the existing standard buildings of antarctic stations are capable of effectively protecting from the cold. Comfortable microclimate parameters are maintained in rooms, the air temperature, primarily (Tikhomirov, 1962, 1968; Deryapa, 1965; Deryapa et al., 1975; Makarov, 1969; Garshenin, 1971). At the Vostok station have been observed considerable temperature gradients, which has made it necessary to improve the ventilation system. Buildings made of aluminum panels best satisfy hygienic requirements.

The clothing of SAE participants satisfies practical requirements, including protection from supercooling at a superlow temperature (down to -80°C and below). But existing outfits require improvement, especially with regard to wind protection properties (Pal'yanov, 1972; etc.). New clothing designs are needed for polar explorers in Central Antarctica, as well as devices for effective protection from supercooling of the respiratory tracts (Tikhomirov, 1968; Makarov, 1969). Without denying the high qualities of the traditional clothing of peoples of the north, we suggest all the same that it is more promising to utilize the new synthetic materials and a self-contained electric warmer.

Many domestic writers have made profound studies of the problem of nutrition for polar explorers (Tikhomirov, 1965, 1968; Makarov, 1969; Shamis, 1969; Ryabinin, 1972). The contemporary food ration in Antarctica in terms of quantitative and qualitative structure is sufficiently close to a balanced diet and provides for the energy requirements of the body. On the contrary, under conditions of partial hypodynamia the diet for certain professional groups can be excessive. The most difficult thing is to ensure a high-quality diet structure for the duration of the entire winter period to conform to hygienic standards. As a result of the longterm storage of foodstuffs the vitamin content is especially reduced, thus requiring compensation with multivitamin additives. Under conditions of consumption of low-mineral water, it is necessary to test for the content of calcium and other minerals.

In connection with this, recommendations have been developed on the artificial mineralization of drinking water. Although scurvy and other avitaminoses are things of the past, the problem of adjusting the vitamin balance at polar stations continues. A solution is needed to the problem of utilizing specially prepared products (sublimation drying, etc.). In this connection, having become urgent are clinical and biochemical studies on nutrition for polar explorers in the future, too. Questions relating to the water supply, bathing and laundry facilities, and removing impurities and waste are being solved at the present time by taking into account the relatively shortterm existence of antarctic stations. Further work is required for the creation of stationary systems of this nature (water mains, a sewer system, and the like, taking into account the polar climate and the knowhow gained in mastery of the Arctic).

Modern communications facilities and means of providing polar explorers with leisure have made the life of polar station personnel sufficiently varied. But the effect of the monotony and relative sensory deprivation has not yet been completely compensated.

At the present time Antarctica is a "man's continent," which has facilitated the solution of social and hygienic problems here. But with complication of the social infrastructure and the appearance of bases with a mixed (male and female) population higher levels of vital protection systems are required.

On the whole it can be stated that because of the decisive influence of the social conditions of human life on the adaptation process constant attention is required to the social and hygienic aspects of adaptation, as well as further intense study of them. The social conditions which have been created at the present time at antarctic stations meet the requirements of general and public hygiene.

Clinical and Physiological Aspects of the Adaptation of Polar Explorers

In the most general sense adaptation is a complex social and biological process of adaptation of the human body to new environmental conditions, in which, together with social and hygienic aspects, a significant role belongs to strictly physiological mechanisms of bodily adaptation.

SAE physicians have obtained unique factual data characterizing the adaptive changes of various physiological systems of the body.

The major research results boil down to the following. Higher nervous activity (VND) has as a rule been characterized by adequate reactions of people with a normal psyche to the extreme conditions of polar stations. A considerable impression on the behavior of polar explorers has been made by life in isolated miniature collectives, where the problem of psychological and social compatibility is especially acute.

Characteristic is the relative frequency of subjective disorders of different natures (modification in sleeping, pains in different places, "polar dyspnea"). With the maintenance or even improvement of the major psychic functions (thinking, memory, attention), at polar stations attention has been drawn to neurotization in a percentage of associates to the point of clinically pronounced forms. Changes in the functional sphere have been more profound than in the associative (thinking). Various forms of adaptive changes in VNP have been studied by N.R. Derpaya (1965), Ye.A. Il'in (1969), P.V. Bundzen (1972), V.V. Boriskin (1973), etc.

Special studies have also shown great diversity in reactions of the vegetative nervous system, which in the majority of polar explorers have been of a normal physiological nature.

The problem of studying the state of the central nervous system of man in Antarctica remains quite topical in the long term. Especially needed are an intensive study of the question of the social and psychological compatibility of associates of isolated polar station teams and the development of methods of preventing nervous and psychic disorders.

The great homeostatic importance of the circulatory system is completely obvious, which explains the special interest in studying it under conditions in Antarctica. The data available can be evaluated as proof of the development in polar explorers of fairly pronounced seasonal changes in hemodynamic indicators in the process of adaptation. These changes have been of a normal adaptive nature, and pathological variants have been rare and most often have represented the aggravation of a previously existing cardiovascular pathology. The use of modern methods (tachooscillography, sphygmography, phase analysis, etc.) has made it possible to broaden and deepen our ideas on the range of changes in the circulatory system.

The state of other physiological systems (external respiration, digestion, urination) has been characterized by the predominance of physiological changes over pathological. But the existing factual data do not profoundly enough reveal the essence and ranges of adaptive changes in these systems.

A.Ya. Shamis (1969), I.P. Ryabinin (1972) and other researchers have obtained important facts on the biochemical aspects of the adaptation of polar explorers under conditions in the coastal and central sections of Antarctica. Various changes have been discovered in protein, fat and carbohydrate metabolism, as well as shifts in vitamin balance and water-and-salt homeostasis. With respect to some indicators (calcium) they have been of a (pre-) pathological nature; quite typical are biochemical signs of hypopolyvitaminoses, especially with regard to ascorbic acid and B vitamins. High extrarenal moisture loss has been determined, especially under conditions in Central Antarctica, on account of drying out of the mucosal respiratory tracts (Tikhomirov, 1962; Makarov, 1969). The increase in the content of cholesterol and lipoproteins discovered in Antarctica has confirmed the hypothesis regarding the change from a carbohydrate type of metabolism to a fat type upon moving to the Arctic, advanced by scientists of the USSR AMN Siberian Branch (Panin, Belova et al., 1976; Panin, Kovalenko et al., 1976).

At polar stations in Antarctica contradictory data have been obtained regarding the biochemical manifestations of human stress. The absence of distinct activation of functions of the hypophyseal adrenal system is explained by the majority of writers as an effective special defense for polar explorers, from supercooling and other extreme effects of Antarctica's natural phenomena on the human body.

Of special interest are data on changes in the biorhythms of physiological functions in polar explorers (circadian and seasonal). Under conditions of contrasting light conditions and a reverse in the seasons of the year, substantial biorhythmological changes have been found, up to the point of dysynchronoses, especially in the initial periods of adaptation.

Interesting data regarding bodily biorhythms, especially from the viewpoint of the effect on the body of global heliogeophysical factors (the geomagnetic field, etc.) have been obtained by the USSR AMN Siberian Branch in the course of two-year observations in Antarctica and the Taimyr Peninsula (Moshkin et al., 1976).

The understanding of the physiological mechanisms for the formation of disorders revealed in several bodily functions (meteolability, asthenization, polar dyspnea and other symptoms), originally designated by G.M. Danishevskiy as disadaptation meteoneuroses, has obtained a further explanation on the biological level from the positions of the hypothesis of USSR AMN Academician V.P. Kaznacheyev on the "polar stress syndrome."

Thus have been established distinct adaptational changes in the body's control and homeostatic systems, the definite phasal nature of the adaptation process, and the origin of a state of chronic stress on adaptation mechanisms. In polar station teams in Antarctica "failures" in adaptation are relatively rare. They most often testify to the aggravation of pre-existing chronic diseases under the influence of the extreme factors of Antarctica. Under conditions of the antarctic high-altitude zone, adaptive reactions occur more suddenly than on the coast, testifying to the difficulties of adaptation to hypoxia. On the other hand, facts have been obtained regarding the favorable (training) influence of chronic hypoxia on the after-effects of human hypodynamia in Central Antarctica (Zavadovskiy, 1973; etc.). There is no doubt that research on the physiology and pathology of mechanisms of human adaptation in the Arctic and Antarctica conducted in recent years by Soviet polar physicians under the methodological guidance of the USSR AMN Siberian Branch has hastened an understanding of the adaptation process and has facilitated the health care of the variable population of Antarctica by introducing into the practice of polar health care the results of basic research.

Morbidity Among Polar Explorers

The systematic study of morbidity among participants in Soviet antarctic expeditions was begun in 1964, after unified medical record and reporting documentation was introduced into the practical work of physicians working at polar stations, making it possible every year to obtain comparable and statistically reliable information on the state of health of polar explorers for the entire period of the expedition.

The specific features of the work of physicians on polar expeditions have made it possible to make active systematic prophylactic observations of the state of health of personnel at polar stations and to record in the medical record files of polar explorers all cases of disease and trauma revealed both when expedition participants have sought medical assistance, and in monthly medical examinations, which are conducted by expedition physicians at all antarctic stations.

Thus, we have had an opportunity to utilize data from all sources of disease detection: seeking assistance, medical examinations, statistics on disability, and records of causes of death among polar explorers.

A statistical analysis of our data has made it possible to determine that on Soviet antarctic expeditions 16.2 percent of personnel at polar stations in 1964-1973 did not have a single case of disease or trauma, and 72.2 percent of polar explorers did not lose time from work because of illness.

In the structure of overall morbidity among antarctic polar station personnel, a key place has been occupied by dental and oral cavity trauma and disease, acute purulent and other diseases of the skin and subcutaneous fatty tissue, muscular diseases, neuroses, and diseases of the peripheral nervous system. More than two thirds of the total number of primary treatment cases were for these diseases.

Participants in antarctic expeditions have had a rather low index for morbidity with temporary disability (on average, 28.9 cases and 256.9 days of disability per 100 participants in a single wintering expedition). Whereas the relatively high rate of treatment can be explained by the high access of polar explorers to skilled medical assistance, by systematic active prophylactic observation, by the recording in outpatient journals of the slightest changes in the state of health, which would not be recorded under ordinary conditions, and, finally, by the specific features of work and life at polar stations, then the insignificant percentage of morbidity with temporary disability among polar explorers and the high percentage of expedition participants who have not been disabled on account of disease testify to the good state of health of polar station teams and to a certain extent characterize the high quality of the work of physicians in Antarctica.

The highest number of requests for medical assistance is found among polar explorers whose main activity involves doing outside work. It is necessary to especially emphasize the tendency toward aggravation of previously noted chronic diseases among polar explorers. We have regarded this as proof of an imperfection in the system of medical selection of participants in arctic and antarctic expeditions, since people with an existing pathology are shown to be most vulnerable to the influence of various unfavorable environmental factors.

In-hospital medical assistance to polar station personnel has its own characteristic features. For example, on average for a single wintering expedition, per 100 participants in Soviet antarctic expeditions there are 16.8 cases of hospitalization at coastal and intercontinental station hospitals. Of the total number of diseases among polar explorers during the period of a wintering session (with temporary disability), 42 percent have been accompanied by in-hospital treatment. This can be explained by the high access to in-hospital treatment and hospitalization (in infirmaries at home), even with comparative figures.

In SAE explorers, during all the years of operation of our stations in Antarctica, among diseases accompanied by in-hospital treatment, in first place are traumas (21.4 percent), in second, appendicitis (12.6 percent), in third, diseases of the peripheral nervous system (11.3 percent), in fourth, pneumonia (9.9 percent), and in fifth, acute respiratory diseases (8.8 percent). Under the heading of these five nosological forms come 64 percent of the total number of cases of disease requiring in-hospital treatment on wintering expeditions. To traumas, appendicitis, diseases of the peripheral nervous system, pneumonia and cardiovascular diseases are due 72.1 percent of the total number of days of in-hospital treatment at antarctic stations.

The data which we have obtained on in-hospital treatment of antarctic polar station personnel confirms the opinion which we and other physicians have expressed more than once, regarding the need to send on polar expeditions physicians with the highest skills, who have mastered modern methods of diagnosing and treating various diseases and traumas.

From the data given here it is possible to draw certain conclusions regarding the main causes of heightened morbidity in different nosological forms during the period of polar wintering expeditions. Knowing these causes, physicians taking part in expeditions, as well as directors of scientific research stations, can take specific preventive measures, for the purpose of reducing the unfavorable influence of the environment on the human body under severe natural conditions, and of improving the body's ability to adjust in the process of adaptation. These measures will make it possible to preserve to the maximum degree the health of polar station personnel and at the same time to increase labor productivity and improve the efficiency of the work of Soviet antarctic expeditions.

In the meantime, aspects of the course of some diseases under conditions in Antarctica have still been insufficiently studied. The little study there has been of the state of health of polar expedition participants after completing wintering expeditions and returning home has not made it possible to objectively estimate the remote consequences of human adaptation under the extreme conditions of the Arctic and Antarctica. This fact is of important value in determining optimal periods of stay for polar explorers at polar stations, their age for sending them to work in various regions of Antarctica, the period of rest between wintering expeditions, and areas for resting after an extended stay under conditions on the icy continent.

Medical Services for Antarctic Expeditions

During the period of work done by Soviet polar explorers in Antarctica highly valuable know-how has been gained in supplying medical services to expeditions and polar stations. A characteristic feature of this has been the presence among small teams of polar explorers of highly skilled physicians furnished with the necessary medical equipment. This has made it possible for them to carry out the active prevention of disadaptation disorders.

The considerable remoteness of polar stations from civilization and from one another, the low and superlow temperatures, the hurricane winds, the polar night, the difficulty and sometimes the impossibility of establishing communication between stations (this is basically done by radio), and often the lack of insurance of aviation because of the impossibility of making flights under so complex climatic conditions--all this requires special stipulations for arranging for medical aid at polar stations. Medical services for antarctic expeditions are typified by considerable specificity.

The "Statute" and "Instructions on the Work of Physicians on Arctic and Antarctic Expeditions" developed at AANII [Arctic and Antarctic Scientific Research Institute], as well as the new "List of Medical Contraindications for People to Be Sent on Arctic and Antarctic Expeditions" (approved by the USSR Ministry of Public Health in November 1972) and other documents have made it possible to improve the organizational forms and working methods of physicians in the medical service for participants in polar wintering expeditions, and to carry out in a better organized manner the medical selection of future expedition participants.

The division of polar medicine created at the Arctic and Antarctic Scientific Research Institute (1967) has become the main organization and methodological center for arranging for medical services for participants in polar and marine expeditions of the Central Administration of the Hydrometeorological Service under the auspices of the USSR Council of Ministers. Its work is based on a systematic study of the health of polar explorers under specific environmental conditions, for the purpose of developing a combination of measures which, on the one hand, will be able to reduce the unfavorable effect of the extreme factors of the Arctic and Antarctica on the body, and, on the other, to improve the compensatory functions of various homeostatic systems in the process of adaptation to special living conditions.

Thus, the final goal of studying the problem of adaptation and morbidity in the Arctic and Antarctica is to develop scientifically substantiated principles for medical services to polar explorers. In addition to taking into account the specifics of conditions, this service must be based on achievements in Soviet health care, especially with regard to confined teams.

Improvement in living, working and domestic conditions on Soviet polar expeditions, as well as in the quality of medical services, has resulted in a systematic reduction in morbidity (especially that accompanied by temporary disability among polar explorers because of illness).

Observations of human adaptation in different regions of Antarctica have made it possible to develop a number of important rules regarding the work of physicians under specific conditions of polar stations (medical selection of polar explorers, their toughening and training, transportation facilities, and other prevention and treatment measures). The practical application of these recommendations has been conducive to improving the living conditions of polar explorers and has had an influence on improving the labor productivity of participants in antarctic expeditions.

Prospects for Further Research

The medical research conducted in Antarctica by Soviet medical personnel over the 20-year period has made it possible to a great deal to reveal the specifics of human acclimatization under local conditions, to develop a number of practical recommendations, and to improve considerably the living conditions of polar explorers. But, in spite of the successes achieved, it is necessary to designate future longterm trends in this research. Guidance on this problem from the USSR AMN Siberian Branch will make it possible to make studies at new organizational and methodological levels. The realistic opportunity has appeared of making synchronous studies in keeping with unified programs and techniques in remote regions of the planet (e.g., the Antarctica - Novosibirsk - Taimyr Peninsula experiment).

For the purpose of developing scientific recommendations on the vital protection of the variable structure of Antarctica's population, it is necessary to solve a combination of problems, the first among which are the following:

1. An estimate of the level of the physical and mental working capacity of a human being during different periods of its life in Antarctica.

2. A determination of the optimal period for a wintering expedition from the viewpoint of health, on the basis of research on the remote after-effects of one-time or repeated participation in SAE's.

3. The development of means of preventing (pre-) pathological states of the organism of polar explorers originating as the result of the unfavorable influence of social, heliogeophysical and other ecological factors in Antarctica.

4. Finding methods and means of monitoring and adjusting social relationships in polar station miniature collectives.

These goals are based on methodological approaches developed by scientists of the USSR AMN Siberian Branch (Kaznacheyev, 1973; etc.), which provide for the need to solve the problem of adaptation on the social-hygienic, biological and bodily levels.

The social-hygienic aspects of adaptation remain topical. Needed is a scientific evaluation of new types of buildings and clotning and of methods of balanced diets and of organizing the work and leisure of polar explorers for optimization of the adaptation process in Antarctica. Extensive use should be made of modern methods of hygienic science. Deserving of special attention is the problem of the health of polar explorers ("failures" in adaptation, and morbidity in polar station teams), and especially needed is a study of the health of polar explorers from the viewpoint of the possible remote after-effects of one-time and repeated wintering expeditions in Antarctica.

It should be mentioned that as a successful solution is found to a number of the most important problems relating to medical and sanitation services for polar expeditionary personnel new problems come to the forefront. One of these is the psychological adaptation and compatibility of people under conditions of a small isolated team. Therefore, more and more attention is being paid to developing principles and criteria for a psychological evaluation of expedition candidates and for forecasting the functional structure of personal interrelations in formation of a miniature collective. In some countries not only physical status, but also psychological status is beginning to be taken into account in the process of medical selection of candidates. At the present time there has been shown a relationship between capacity for psychological adaptation and not only psychological aspects of the personality, but also the intellect and skills of the specialist. The most courteous and tolerant are individuals of the intellectual type with high professional skills, and an insufficient level of skills in a specialist generates lack of self-confidence and phenomena of neurotization. Consequently, questions of psychological adaptation should occupy an important place in the plan for further research.

A number of problems must be solved at the bodily level. Of great importance for an understanding of the adaptation process is an explanation of interaction between the body and a combination of heliogeophysical factors from the viewpoint of the "polar stress syndrome." Man under conditions of an antarctic wintering expedition has been a unique subject for research data.

Biochemical research along several lines is promising. Under conditions of the Arctic and Antarctica have been established important changes in carbohydrate and fat metabolism (Ryabinin, 1972; Panin et al., 1976). This research must be continued for the purpose of precisely determining the mechanisms for the readjustment of energy metabolism among inhabitants of the Arctic. Together with an evaluation of key oxidation substrates, it is necessary to study the state of key carbohydrate metabolism enzymes, taking into account the vitamin balance and neuroendocrinal regulation factors. This research was begun by the USSR AMN Siberian Branch on the 21st SAE.

On expeditions during the period up to 1980 has been planned research on bioenergetics, based on a study of oxygen transport systems (respiratory and cardiovascular). This will make it possible to estimate the physical working capacity of a human being under extreme conditions.

The specifics of infection processes in isolated groups of polar explorers and the role of the immunostructural homeostasis system in adaptational rearrangements have occasioned the obvious interest in conducting immunological research on SAE's, especially in conjuction with virology.

The specifics of the work done by SAE associates must be taken into account in estimating the tension of the adaptation process and its prognosis. Therefore, a research division has been assigned to studying the degree of working tension among the major professional groups of polar explorers (magnitudes of information and energy flow in relation to production and living conditions).

Accomplishment of the key trends in scientific research work indicated above, relating to the problem "Human Adaptation in Antarctica," will make it possible to introduce adjustments into the existing system for vital protection of SAE polar station teams. In particular, the following are possible: a) the development of means of preventing "failures" in adaptation; b) recommendations on preventing emotional stress and on adequate selection of polar explorers for not too large (low number of personnel) stations; c) optimal limits (periods) of a human being's stay in Antarctica, and intelligent methods of readaptation; d) review of the diet for polar explorers.

The unique scientific data on human adaptation in Antarctica accumulated up to now has been the basis for the creation of a new branch of medical science--polar medicine. The great services rendered by domestic scientists in establishing it are obvious.

The most important prerequisite for future successes is a broad combination of representatives of medical science and allied sciences involved in studying nature.

The various aspects of human adaptation under the severe conditions of Antarctica should become the subject of systematic intensified research, based on the State combined scientific program "Human Adaptation" (on the social-hygienic, biological and bodily levels) developed by the USSR Academy of Medical Sciences Siberian Branch.

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STATE OF HUMAN IMMUNITY UNDER THE EXTREME CONDITIONS OF ANTARCTICA

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[Article by R.Yu. Tashpulatov, Ye.V. Guseva, V.V. Yevdokimov and V.V. Petrosov]

[Text] Antarctica, with its severe climatic conditions and practically abacterial environment, places strict requirements on the adaptive abilities of the human body. Obviously, in the process of adaptation its immune system will also be affected, the indicators of which can change in the higher or lower direction.

Up to the present time there has been practically no direct immunological research on representatives of the continent's animal world, concerning cellular and humoral factors of the immune response. Therefore, it is difficult to compare indicators of the immunity of the animal world of an abacterial continent with indicators of the immunity of animals in regions with a moderate climate. In research on seals and penguins (Bruden and Lim, 1969; Mejia and Pinto, 1970) it was established that the amount of circulating blood in adult southern seals equals 16 percent of body weight, whereas the hemoglobin concentration was the same as in man, in spite of the smaller number of erythrocytes, which on average have greater dimensions. In penguins the blood volume, in scaling per unit of weight, is greater than in domestic birds and white rats. The increased blood volume in penguins is also explained by a greater size of erythrocytes with the same volume of plasma.

Investigations of plasma proteins, glycoproteins, lipoproteins, lipids and immunoglobulins (Ig) in Weddell's seals (Margni et al., 1971) showed that there are no marked differences between plasma proteins and whole and fractionated glycoproteins and the same indicators in other mammals. Just a considerable increase in lipids and lipoproteins was observed. Classes of immunoglobulins in seals were similar to immunoglobulins in other verterbrates: A determination was made of four main immunoglobulins, two of which corresponded to Ig(G_1 and G_2), the third to IgM and the fourth to IgA.

The great importance was established of serum glycoproteins, which play the role of antifreeze in antarctic fish. The blood serum of antarctic fish freezes at -2°C. This temperature is approximately one degree below the melting point of their sera. The freezing and melting points of aqueous solutions of purified glycoproteins make it possible to hypothesize that this temperature lag in freezing of the serum is the result of adsorption of a molecule of glycoprotein on the surface of crystalline particles of ice (DeVries, 1971).

Thus, the incomplete information on immunological indicators available in the published data makes it possible to think that a material for the appearance of humoral factors of immunity in animals exists (immunoglobulins). But remaining unstudied are indicators of cellular immunity, and the specificity of humoral factors of immunity in response to stimuli in the form of bacterial and other antigens. From the data available it is impossible to estimate the influence of extreme factors of the environment with its practically abacterial nature on the immune system of the animal world and the correlative changes in this system in relationship to the influence of bacterial antigens and microbial associations. For the same reason it is difficult to predict possible changes in microbial flora and in the immunity of a human being staying in Antarctica. It is natural to assume that the prolonged stay in Antarctica of a human being adapted to existing in other regions of Earth with its abundant microbial flora, with the diversity of his own microflora and the indicators of the immunity of his body, should be reflected essentially in the many quantitative and qualitative indicators of his microbial flora and immunity.

The results of research have shown that under the extreme conditions of Antarctica there takes place a "simplification" of the specific structure of microbial flora in people, which should be reflected in the level of immunity of a human being during the period he is on an expedition, and, probably, in particular after his return home, when he "plunges" into the environment customary for him, with its abundant microflora. It is possible to assume that the practically abacterial environment of the Antarctic Continent and the elimination of certain kinds of micro-organisms of human flora will be accompanied by a reduction in the level of non-specific resistance in the human body. In a similarly formed situation representatives of conventional pathogenic flora can begin to manifest their biological activity, which is indicated by the origin of infections of endogenous etiology.

Evidence of the changes taking place in the human body during a period of stay under the extreme conditions of Antarctica is changes in the peripheral blood pattern of polar explorers. We know that the peripheral blood pattern in many instances reflects the state of the body when it is under the influence of various physical, chemical and biological factors. Under conditions of the icy contintent the human body is influenced by at least two of these three factors: physical (insolation and the total absence of it for an extended period, low temperature, magnetic and corpuscular disturbances, and the like), and biological (practical absence of a microbial environment).

Of course, changes in the peripheral blood in response to the effect of extreme environmental factors are of an adaptive nature. From the viewpoint of red blood cells these changes are reflected in seasonal fluctuations in the level of hemoglobin, erythrocytes, the chromatic index, and the erythrocyte sedimentation rate. For example, A. Merwe (Merwe, 1962) observed a reduction in the amount of hemoglobin and erythrocytes in the first five months of a wintering period in Antarctica. K. Rodahl (Rodahl, 1954) showed that in the winter the content of hemoglobin in eskimoes is higher than in the summer, while the erythrocyte sedimentation rate did not reveal seasonal variations. A. Merwe (Merwe, 1962) thinks that a further reduction in the content of hemoglobin and erythrocytes can be prevented by prescribing 0.025 g per day of ascorbic acid. These data indicate that environmental conditions govern physiological reactions of the body in response to stimuli of a physical nature--the cold. Serving as a confirmation of this are data obtained with animals subjected to chilling (Savchenko and Maksimova, 1974). In some of them were observed reticulocytosis, increasing on average 60 percent in the peripheral blood, and elevation of the acid resistance of erythrocytes. Reticulocytosis and an increase in erythrocytes with improved resistance serve as proof of heightening of the erythropoietic function of the bone marrow under the influence of cold. Similar data--reticulocytosis, elevated resistance in erythrocytes and some increase in hemoglobin content under the influence of cold--have been obtained with animals (Shchupak and Ugrilovich, 1959; Hannon and Young, 1959; Orme and Beaton, 1962). It is probably possible to explain by the influence of cold similar changes in the red blood of polar explorers at the Mirnyy and Molodezhnaya coastal antarctic stations (Garshenin, 1969), when in the middle of the polar night, i.e., in the most intense freezing weather, was observed a definite increase in the number of erythrocytes. At the same time similar investigations of red blood at the Mirnyy station carried out two years later (Ventsenostsev, 1969), on the other hand, showed a reduction in the amount of erythrocytes and hemoglobin, reaching its minimum in the coldest months (July-August). The varying nature of the data obtained at coastal antarctic stations is probably explained by changes taking place in the environment of Antarctica, under which heading can come cosmic rays, UV radiation, changes in the ionosphere and magnetic disturbances.

Of considerable interest are similar investigations at the Vostok intracontinental antarctic station, located at the South Geomagnetic Pole at an altitude of 3450 m above sea level and in Earth's cold zone (at the Vostok station in 1960 was recorded the lowest temperature on the globe, - 88.2°C.). The severe conditions of intracontinental Antarctica with pronounced hypoxia cause more important adaptive changes in the hemopoiesis of polar explorers, accompanied by a significant increase in hemoglobin content (from 13.6 $\pm$ 0.7 percent to 18.7 $\pm$ 1.4 percent) and erythrocyte count (from 4.43 to 6.2 million per mm^3) (Poggenpol', 1969).

I.I. Tikhomirov (1968) found a gradual increase in the amount of hemoglobin in the blood of polar station personnel at the Vostok station, which exceeded in the second half of the wintering session the original level by 73 percent.

A large role in the prevention of infections is played by leukocytes and granulocytes in particular, which have the ability to phagocytize bacteria, as well as by humoral factors of immunity of the blood serum and of different secretions of the human body (saliva, gastric and intestinal juices). It is natural to expect that in the practically abacterial environment of Antarctica with its extreme conditions considerable changes must take place in the leukocyte count of the blood, in the ability of granulocytes to phagocytize bacterial antigens, and in humoral factors of human immunity. If the cold factor is an inducer of erythropoiesis, then the environment's microbial deficiency can probably influence leukopoiesis activity, in addition to the cold factor's influence.

The last decade has been characterized by a progressive reduction in the leukocyte count with a simultaneous relative rise in the lymphocyte count in healthy people (Kochetova, 1960). Variations in the white blood cell count depend on the latitude of the locale, and as one goes northward there is a significant rise in the number of functional neutropenia and relative lymphocytosis cases. In zones with a tropical climate there are no changes in blood count. This phenomenon is explained by the fact that, the closer the area of research is to Earth's poles, the more significant are the effects of cosmic radiation and corpuscular and magnetic disturbances. Based on numerous observations made over the period of several solar cycles, N.A. Shul'ts (Kochetova, 1960) came to the conclusion of an indisputable relationship between quantitative changes in white blood cells and the state of solar activity.

Research in Antarctica has shown that the leukocyte count in the peripheral blood of polar explorers is reduced by the middle of a wintering expedition, and by the end of it it is somewhat increased, without reaching, however, the original level (Ventsenostsev, 1969; Fraizer, 1945; Wilson, 1962). Changes in leukocyte count probably indicate disturbance of the interrelationships of white blood form elements or indicate an increase or reduction in some single structural form of leukocyte.

Mention is made above of the leading role of neutrophilic granulocytes in processes of phagocytosis with bacterial infections. We know that phagocyte activity is one of the strong factors of the body's natural immunity in the prevention of infection and in combating it. The human body must produce a sufficient number of neutrophils, since they constantly leave the blood channel and can be found in the saliva, bronchial secretions, urine and contents of the intestine (Boggs et al., 1960). They also play a major role in preventing invasion of the "normal bacterial flora" of the host, which is the source of many endogenous infections encountered in neutropenia patients (Boggs et al., 1967). Of course, the human body's level of resistance depends to a considerable extent on the functional capabilities of neutrophils.

Studies on the ratio of white blood form elements in polar explorers over the period of a wintering session in Antarctica have shown a reduction in the absolute and relative number of segmented and stab neutrophils (from 3940 to 2950 kl/mm^3; from 60 percent prior to the expedition to 50.4 percent at the polar station) and an increase in the absolute and relative number of lymphocytes (from 1790 to 2455 kl/mm^3; from 27.3 to 41.8 percent, respectively).

The maximum reduction in the number of neutrophils and increase in lymphocytes have been recorded in July. Then the content of neutrophils began to increase, and of lymphocytes to decrease, but their number was considerably less than the original (Ventsenostsev, 1969). A. Barsoum (Barsoum, 1962) reports considerable lymphocytosis (at 10 to 48 percent of their initial level) in polar explorers under conditions of a wintering session in Antarctica. I.I. Tikhomirov (1968) detected lymphocytosis in polar explorers at the intracontinental Vostok station, increasing from 31.29 to 33.25 percent during the observation period.

It has been determined by several investigators that eosinophils do not vary in number (Ventsenostsev, 1969), others have observed eosinophilia (Wilson, 1962), and A. Barsoum (Barsoum, 1962), finding eosinophilia in polar explorers, explains the phenomenon he has detected by stimulation of the body's adrenal system.

Thus, the change in the ratio of white blood form elements in polar explorers requires further study, since these changes have been found in practically healthy young people in satisfactory living conditions with good nutrition. The changes detected are probably of an adaptive nature, and must be taken into account in practical work, since indicators which are normal under extreme conditions can prove to be pathological for Earth's mid-latitudes.

The change in the ratio of white blood form elements, in particular, of neutrophilic leukocytes, is probably actually an adaptation to the practically abacterial environment of Antarctica. This hypothesis can be confirmed by studies of granulocytopoiesis in abacterial and ordinary mice (Boggs et al., 1960), which have shown that granulocytopoiesis is not impaired in gnotobionts, and mature neutrophilic leukocytes, because of the absence of a bacterial stimulus and the products of their vital activity, are deposited in the spleen and bone marrow, and they are instantly expelled into the blood channel upon introducing bacterial antigens into the body of an abacterial mouse.

The increase in the content of lymphocytes in the bodies of polar explorers, responsible for the synthesis of specific and non-specific immunoglobulins, is probably caused by non-specific stimulation of the lymphoid system of a polar explorer's body by the extreme factors of Antarctica's environment.

It is natural to assume that a change in the quantitative ratio of white blood form elements can be accompanied by functional changes in them. A study of the functional activity of neutrophils conducted at the American antarctic station at the South Pole in 1973-1974 (Muchmore and Shurley, 1974) showed a considerable reduction in the phagocytosis function of staphylococcus aureus. We know that the capacity of neutrophils for phagocytosis depends also on the content of lysozyme in the blood serum and secretions of the body. So, the activity of phagocytosis is related to the effect of lysozyme on both bacteria and phagocytes. Lysozyme is adsorbed on them and promotes their coming together and phagocytosis of the bacterial cell

(Zhukovskaya and Likina, 1966). Unfortunately, the content of lysozyme in polar explorers in Antarctica was not studied previously, in spite of the fact that lysozyme, being one of the important indicators of natural immunity, increases the gamma globulin fraction of the blood serum, heightens the activity of the ACTH [adrenocorticotropic hormone] and raises the number of leukocytes and neutrophils in the first few hours after its introduction into the body (Zhukovskaya and Likina, 1966).

In combating infection, the first to come to the forefront are the cellular and humoral factors of the body's non-specific resistance, which begin to act with an agent two to five hours after injection, and only later (from a few days to a few weeks) do specific antibodies which have formed enter the battle. Specific and non-specific antibodies, which play an important role in infectious and non-infectious pathology, are represented by immunoglobulins, which are subdivided into five classes: M, A, D, E and G. Immunoglobulins, in addition to their physical-chemical differences, are distinguished by biological properties and functions performed in the human body. For example, IgM contains the main mass of antibodies against somatic antigens of intestinal bacteria; IgA is subdivided into secretory, contained in saliva, sputum, lacrimal fluid, bile, and intestinal juice, and serumal. It is assumed that secretory IgA plays an important role in micro-organism protection, from infections of the respiratory tracts and from intestinal infections; IgG contains the main mass of antibodies in the body.

Research on classes of immunoglobulins in the blood serum of polar explorers has been conducted in only one team (16 individuals) at the American station at the South Pole (Muchmore and Shurley, 1974); determinations were made of serumal immunoglobulins M, A and G by the method of radial immunodiffusion, at the beginning, in the middle and at the end of the expedition. A considerable reduction was shown in the content of IgG and IgM during the period of isolation; the authors explain this by the absence of new infections during a period of prolonged isolation of a not too large group of people.

Changes in human microbial flora under conditions in Antarctica, indicated by a reduction in the total number of micro-organisms, lower the antigen load on the body and influence human immunity, lowering the level of its intensity.

In view of the fact that the peripheral blood pattern in many instances reflects the physiological and immunological state of the human body, we made a study of peripheral blood indicators in polar explorers in action during the period of the 12th SAE at the Novolazarevskaya station and during the period of the 15th SAE at the Vostok intracontinental antarctic station. The research results obtained during the period of operation of antarctic expeditions were subjected to statistical analysis, and the importance level of the discrepancies obtained (P) was determined from a Student table (Oyvin, 1960).

The dynamics of hemopoiesis in polar explorers at the Novolazarevskaya station during the period of the 12th SAE showed that the variations in the erythrocyte count (fig 1) during the entire period of the expedition were statistically unreliable, while the hemoglobin content was found to be directly dependent on solar activity (solar activity was measured in kcal/cm^2 by the station's meteorologist, G.A. Khlopushin). For example, while during the period of the polar night solar activity equaled zero, then the content of hemoglobin in the blood was reduced from 15.0 $\pm$ 1.6 to 12.5 $\pm$ 1.4 g% ($P < 0.001$), and this reduction continued even in August to 12.0 $\pm$ 1.4 g% ($P < 0.001$), when solar activity increased to 0.5 kcal/cm^2. With a further increase in solar activity the content of hemoglobin grew, and, having reached its original level, produced statistically unreliable variations from $P <$ < 0.2 to > 0.5.

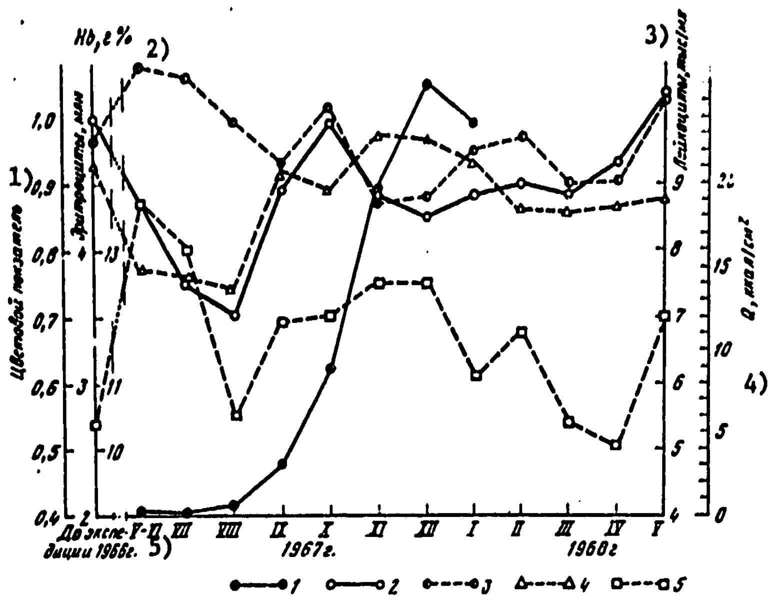

Figure 1. Dynamic Variations in Erythrocytes, Hemoglobin and Leukocytes in the Blood of Polar Explorers as a Function of Solar Activity: 1--solar activity, kcal/cm^2; 2--Hb, g%; 3--erythrocyte count, million; 4--chromatic index; 5--leukocyte count

Key:

1. Chromatic index
2. Erythrocytes, million
3. Leukocytes, thousand/ml
4. Q, kcal/cm^2
5. Prior to expedition, 1966

The chromatic index curve (cf. fig 1) practically imitates the hemoglobin content curve. During the period of the polar night in station associates was observed a drop in the chromatic index with an unchanged erythrocyte count from 0.93 ± 0.06 (before the expedition) to 0.74 ± 0.02 ($P < 0.05$) in August (the fifth month of the wintering session), i.e., hypochromic anemia was observed. The leukocyte count (cf. fig 1), having increased in the first two months of the study from 5.35 ± 1.34 thousand/ml in Leningrad to 8.7 ± 2.7 thousand/ml ($P < 0.001$), later fluctuated from 7.5 ± 1.9 thousand/ml ($P < 0.01$) in November (the eighth month of the wintering session) to 5.0 ± ± 2.4 thousand/ml in April when passing through the tropics after completing the expedition.

In four polar explorers (BPV, IAI, PNV and ShPN) leukopenia was observed, amounting respectively to 3.1 to 3.9, 4.3 to 3.2, 4.4 to 3.2 and 3.3 thousand/ /ml, but it was observed only for the period of one or two months in the second half of the expedition.

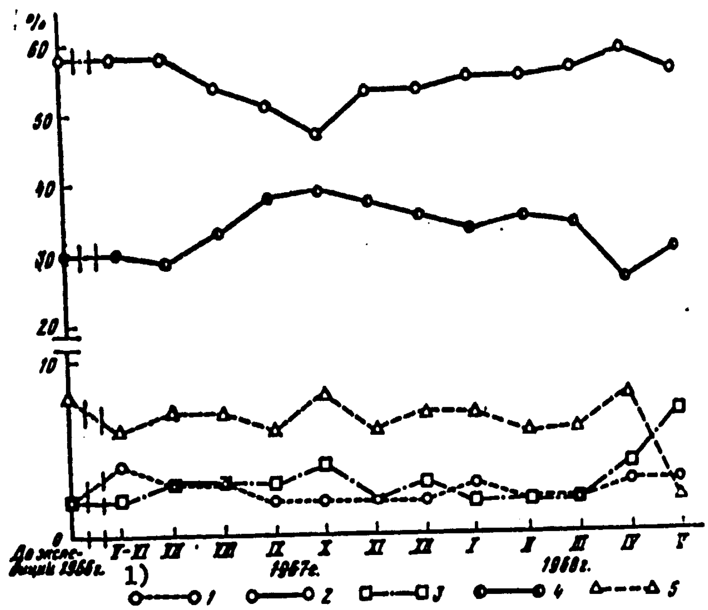

Figure 2. Dynamic Variations in the Quantitative Ratio of White Blood Form Elements in Polar Explorers: 1--stab neutrophils; 2--segmented neutrophils; 3--eosinophils; 4--lymphocytes; 5--monocytes

Key:
1. Prior to expedition, 1966

From the viewpoint of characteristics of the immunological state of the body of a polar explorer of considerable interest are data obtained from studying the leukocytic blood count (fig 2). In the first few months of the study was observed some shift in the leukocytic blood count to the left, i.e., there took place an increase in stab neutrophil leukocytes from 2.0 ± ± 1.6 percent to 4.0 ± 2.8 percent ($P < 0.01$). The number of segmented neutrophilic granulocytes, eosinophils and lymphocytes remained unchanged, and the number of monocytes was lowered only slightly, from 8.0 ± 3.4 percent to 6.0 ± 1.1 percent ($P < 0.01$). By October, i.e., in the second half of the expedition, the number of stab neutrophilic granulocytes returned to the original level, 2.0 ± 1.3 percent, whereas the number of segmented granulocytes was lowered to 47 ± 9.8 percent ($P < 0.05$) against a background of eosinophilia, 4.0 ± 2.2 percent ($P < 0.05$) and lymphocytosis, 39 ± 7.8 percent ($P < 0.05$). Relative lymphocytosis and moderate neutropenia were maintained to the end of the expedition and were normalized only after returning home.

It should be mentioned that in passing through the tropics after the expedition slight eosinophilia was observed (4.0 ± 2.1 percent, $P < 0.001$), and upon returning to Leningrad it reached 8.0 ± 2.4 percent, $P < 0.001$, whereas the number of monocytes dropped suddenly to 2.0 ± 1.2 percent, $P < 0.001$.

In September a reduction in the relative number of segmented neutrophilic granulocytes was observed in three associates: in BPV--42, in NAYu--44 and in SOK--44 percent (absolute numbers equaled, respectively, 1302, 2024 and 3433, i.e., in BPV and NAYu the absolute number of segmented neutrophilic granulocytes was also reduced). In two associates was determined an increase in the absolute number of lymphocytes (BPV-48 and SOK--43 percent), although their absolute number was within the limits of the norm. Absolute and relative monocytosis were observed in NAYu and SOK.

In October similar changes in the ratio of white blood form elements were observed in nine station associates, in November in five, and in December in three.

Table 1. Leukocyte Count in Polar Explorers at the Vostok Station During the 15th SAE [Soviet Antarctic Expedition]

Initials of explorers	Months III	IV	V	VI	VII	VIII	IX	X	XI	XII
VVF	8800	9500	10200	6050	12150	7050	10000	7550	8500	8800
LFN	10350	10350	11600	11400	10450	7750	9200	11400	13100	12600
SVI	7950	5950	9100	8100	8400	9350	9850	6700	9450	9050
FNN	7950	9550	10950	7950	6600	9450	11250	8500	9450	9100
VNI	4850	4750	4650	3555	4600	3450	3560	4600	5750	5650
SPA	5400	4000	6250	3400	5650	5200	4100	3400	4650	4650
UVA	4500	4900	2800	4500	4050	3550	6400	4750	4500	6700

From table 1 it is obvious that in polar explorers there occurs basically a redistribution of the ratio of relative values of leukocytes, while their absolute amounts remain within the limits of the accepted physiological norms (Denshchikov, 1969).

As already mentioned above, at the Vostok intracontinental antarctic station, located at a height of 3450 m above sea level, an additional factor influencing the human body is hypoxia (the atmospheric pressure equals 450 mm Hg); therefore, the body of a polar explorer, of course, responded to hypoxia by an increase in the hemoglobin content from 14.6 g% in Leningrad (reference point) to 20.4 g% in July (middle of the wintering session). However, at this station, just as at the Novolazarevskaya station, was observed a definite reduction in hemoglobin by the end of the four-month polar night--from 20.4 $\pm$ $\pm$ 0.33 g% in July to 19.5 $\pm$ 0.43 g% ($P < 0.001$) in August (eighth month of the wintering session).

In five station associates was observed a more pronounced reduction in hemoglobin content at the end of the polar night: in VVF--from 21.2 to 17.4 g percent; in GTKh--from 22.0 to 20.2 g percent; in LFN--from 22.4 to 19.2 g percent; in SPA--from 20.0 to 18.0 g percent; and in UNN--from 19.4 to 17.8 g percent.

The results obtained in studying the red blood have shown that the level of the content of hemoglobin in the red blood is found to be in direct relationship to solar activity, and that even at the Vostok station, where the key effective factor influencing the content of hemoglobin and erythrocytes is hypoxia, the absence of solar activity somewhat lowers the hemoglobin level.

Dynamic studies of the leukocyte count at the Vostok station have shown that, just as at the Novolazarevskaya station, in the first two months of the stay of polar explorers at the Vostok station the leukocyte count increased from 6026 (reference) to 8000 $\pm$ 48.3 ($P < 0.001$), then, lowered somewhat, varied within the range of 6210 to 7480. It was established in the process of observation that, of the 23 people of the station's team, in 16 no significant fluctuations in leukocyte count were detected for the entire period of the expedition, while in four polar explorers (VVF, LFN, SVI and FNN) leukocytosis was observed almost steadily. In three explorers (BNI, SPA and UVA), on the other hand, leukopenia was observed for the greater part of the expeditionary period (cf. table 1).

It should be mentioned that in not one of the groups of explorers mentioned, be it the group with leukocytosis or with leukopenia, was there any complaint of feeling bad. The pronounced leukocytosis and leukopenia in polar explorers at the Vostok station are probably the consequence of an adaptive reaction of their bodies to the influence of the extreme factors of Antarctica. In this case the changes in the leukocyte count probably indicate changes in the leukocytic blood count, which can be reflected either by a redistribution in the ratio of white blood form elements, or in an increase or decrease in any of the structural forms of leukocytes.

Studies of the leukocytic blood count at the Vostok station have shown that beginning in the first few months of the expedition there takes place a shift of the blood count to the left, accompanied by a significant increase in the number of stab neutrophilic leukocytes. Their increased content is maintained right up to the last month of the expedition, varying from 304.0 in the first month, to 191.7 in the middle, and to 292.0 in the last month of the expedition.

In the first two months of the expedition (January and February) was observed also an increase in the content of segmented neutrophils, to 4636.0 and 5040.0, respectively. In the remaining months this was reduced and kept at the same level with slight variations up to the end of the expedition.

In the first (January), fifth (May), seventh (July), 11th (November) and 12th (December) months of the expedition eosinophilia was observed, equaling, respectively, 228.0, 219.0, 299.2, 220.5 and 219.0. For the entire period of the expedition, in polar explorers at the Vostok station monocytosis was observed, varying within the range of 496.8 to 608.0. Insignificant changes were observed in polar explorers with regard to the lymphocyte count.

Attention is drawn by the fact that, against a background of intensified poiesis of stab neutrophilic leukocytes, the number of mature forms is reduced beginning with the third month of the expedition. Probably, mutual infection of station associates by representatives of their microbial flora is conducive to the maintenance in the peripheral blood of these explorers of a large number of segmented neutrophilic leukocytes, and upon termination of this mutual infection the need for their phagocytic function drops because of the absence of an attack by bacterial antigens, and they are either deposited in the spleen and bone marrow, as was demonstrated in gnotobionts (Boggs et al., 1960), or their intensified destruction takes place.

It is probable that the extreme factors of Antarctica exert an influence on leukocytosis. A demonstration was given above of the influence of the cold effect as an inducer of erythropoiesis (Savchenko and Maksimova, 1974). An analogy can be drawn with leukopoiesis, too. It has been shown that in a great number of polar explorers at the Vostok station increases have been observed (in absolute numbers) in the total number of leukocytes, and their stab and segmented neutrophils, eosinophils, monocytes and lymphocytes, over the accepted physiological norms (Denshchikov, 1969); these indicators have been shown to be very low in a smaller number of explorers.

The number of explorers at the Vostok station with deviations from the norms for the content of different forms of leukocytes to one side or another makes it possible to assert that under the extreme conditions of the Vostok station intensified poiesis of stab neutrophils is observed in the greater number of explorers, whereas there have been considerably fewer explorers with an increased number of segmented neutrophils.

But what can be the cause of the restructuring of the ratio of white blood form elements? It is probable that a human being, finding himself in the abacterial environment of Antarctica, in a new group of people in which each individual has his own microbial flora, is subjected to infection from representatives of the microflora of each member of the group. The body reacts to this infection via its immune system, in particular, by a shift in the blood count to the left, i.e., leuokopoiesis is intensified. But in the majority of expedition associates pronounced segmented neutrophilia is not observed, in spite of the fact that considerably more stab neutrophils are detected in the blood than the accepted physiological norms. The data obtained make it possible to suggest that under the influence of the extreme conditions of Antarctica leukopoiesis of the human body is intensified on account of an increase in the number of stab neutrophils, eosinophilia and monocytosis. Segmented neutrophils, whose number practically does not change or is reduced, serve as an indicator of a reduction in the bacterial antigen load on the macro-organism, and they either are deposited in the cells of the bone marrow and spleen, as was demonstrated in germ-free animals when they were subsequently infected with micro-organisms (Boggs et al., 1967), or they are destroyed.

One of the remarkable properties of neutrophilic leukocytes is their ability to phagocytize micro-organisms. This property is a leading one in the macro-organism's struggle against infection of bacterial origin and comes under the heading of the body's non-specific resistance factors, the level of this resistance being able to vary in relation to the effect of very different environmental factors and to the state of the macro-organism.

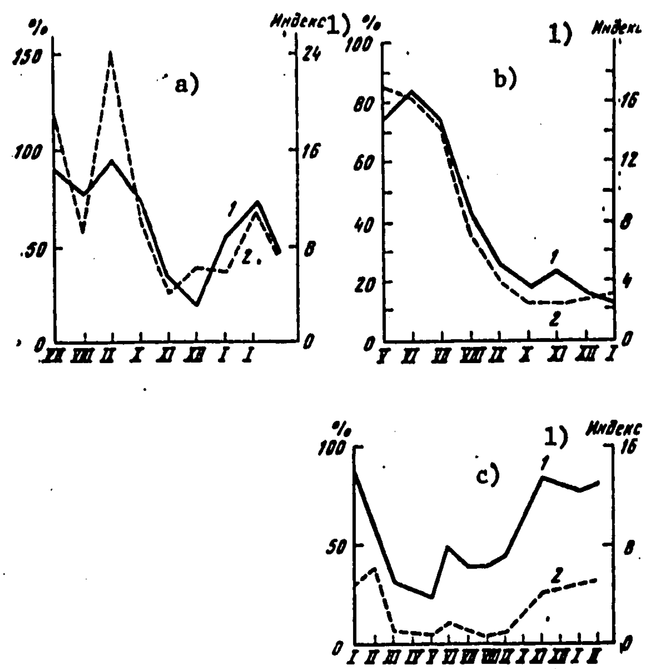

Figure 3. Phagocytic Activity of Granulocytes in the Blood of Polar Explorers: a--12th SAE, Novolazarevskaya station; b--13th SAE, Novolazarevskaya station; c--15th SAE, Vostok station; 1--phagocytosis; 2--index

Key:

1. Index

The dynamics of the phagocytic activity of the granulocytes of polar explorers during the period of the 12th SAE at the Novolazarevskaya station are shown in fig 3a. Whereas at the beginning of the study phagocytosis amounted to 86.6 percent, and the index to 19, then in August it was reduced to 13.3 percent, and the phagocytosis index to 5.6. In December four people arrived at the station from the staff of a new replacement group of explorers, who had the same reduced indicators of phagocytic activity (13 percent) and phagocytosis index (5.8). The low indicators of the phagocytic activity of blood granulocytes is probably explained by the fact that prior to arriving at the station the members of the new expedition had been on the diesel electric motorship "Ob'" for a period of four months (isolated group). A study of phagocytic activity and of its index in the next two months of the combined stay of the new minigroup (four people) and of the group who had already wintered there (12 people) revealed a new increase in phagocytic activity to 61.7 percent in the group who had already wintered there and to 60.0 percent in the newly arrived group (January), with indices of 6.0 and 5.7, respectively. In February the increase in phagocytic activity continued to 71.6 percent in the group already there and to 73.8 percent in the newly arrived group, with indices of 11.6 and 11.3, respectively. In March was observed a reduction in the activity of phagocytosis to 46.5 percent in the group already there and 45.7 percent in the newly arrived group, with indices of 7.6 and 7.0, respectively.

A study of the same indicators in action in 16 polar explorers of the 13th SAE at the Novolazarevskaya station indicated identical changes in activity and the phagocytosis index, consisting in a curve of the same nature. It is true that the distinguishing feature of this change is the absence of an increase in phagocytic activity and its index at the end of the expedition, as was observed in the preceding 12th SAE, in spite of the fact that at the end of the 13th SAE a new group arrived (35 people) (fig 3b).

The results of research on the phagocytic activity of blood granulocytes in polar explorers at the Novolazarevskaya station during the period of the 12th and 13th SAE's make it possible to form the opinion that in a single group staying for an extended time in isolation there occurs a reduction in the activity of this important indicator of the non-specific resistance of the human body. As demonstrated by the results of research conducted during the 12th SAE, upon contact between a newly arriving group and the group already there, in both groups an increase in the activity of phagocytosis can take place. It is probable that this phenomenon can be explained by mutual infection of the two groups by representatives of the microbial flora of the associates coming into contact, as the result of which an induction of immunity takes place in the explorers, which had been lowered from the prolonged stay in the practically abacterial environment of Antarctica. Apparently two months is sufficient for mutual infection by representatives of the individual microflora of each associate in the group, after which there again ensues a reduction in the level of resistance in the group. Based on the data obtained, it is possible to suggest that in a larger group of associates such a comparatively rapid reduction in the phagocytic activity of neutrophils can be absent, since, for mutual infection by representatives of the microbial flora of each of the associates of a large group, a longer time is required for the body to become immunologically "accustomed" to representatives of the microflora of station colleagues.

An example of the possibility of this hypothesis can be represented by studies on phagocytosis activity and index in blood granulocytes among the group of polar explorers at the Vostok intracontinental station during the period of the 15th SAE, made up of 23 people. The results of these studies are shown in fig 3c, where it is obvious that upon arrival at the Vostok station in January the phagocytosis activity and index equaled respectively 86.4 percent and 4.84. In the next month an increase in these indicators continued to 93.4 percent and 5.92. In March, i.e., in the third month of the stay of the explorers at the station, a reduction in the phagocytosis activity and index took place to 29.9 percent and 0.74, respectively. Such low indicators of phagocytosis, with a slight increase in June to 51.2 percent and 1.99, were maintained for the entire polar night, i.e., up to August, and beginning in September there occurred an increase in phagocytic activity and its index, reaching 83.3 percent and 3.92 in November. Phagocytic activity was not increased further, while the phagocytosis index continued to increase to 5.11.

As is obvious from the research results cited, phagocytic activity of blood granulocytes at the not too large Novolazarevskaya station and the intracontinental Vostok station are distinguished from one another by the nature of the dynamic curves. In the small group at the Novolazarevskaya station the phagocytic activity of neutrophils was reduced, probably as the result of the effect of the isolation factor and the practical absence of micro-organisms in the environment, while at the Vostok station, at which there was a relatively large group, the immune system of the explorers was influenced, in addition to the practically abacterial environment, apparently by high cosmic radiation, magnetic disturbances and a longer polar night. Remaining unclear is the reason for the increase in the phagocytic activity of leukocytes in the second half of the expedition beginning in August, if antigens of bacterial origin are considered the inducer of phagocytic activity.

An attempt has been made to explain the changes observed in the phagocytic activity of blood granulocytes by changes in the content of lysozyme in the blood serum of polar explorers. In addition to its antibacterial effect, lysozyme stimulates the protective powers of the macro-organism and under its influence the phagocytic activity of blood granulocytes is intensified. Studies of lysozyme in the blood serum of polar explorers were made at the intracontinental Vostok station during the time of the 15th and 17th SAE's.

The results of studies of the lysozyme activity of the blood serum of polar explorers during the period of the 15th SAE have shown that the content of lysozyme is subject to fluctuation and changes in a two-phase manner: The first phase is represented by a statistically reliable increase in it immediately upon arrival at the station in March, 2.92 ± 0.20 γ/ml, P = 1.4 percent, as compared with normal indicators of 2.35 ± 0.10 γ/ml, and a tendency toward a reduction in the accepted norms in April and May to 2.19 ± 0.10 γ/ml, P > > 5 percent and 2.03 ± 0.13 γ/ml, P = 5 percent, respectively. The second phase is represented by an increase in lysozyme activity from June through October, variations in the amount of lysozyme within the range of 2.67 ± 0.13 to 3.14 ± 0.25 γ/ml, P < 5 percent, and a reduction in its amount in the last few months of the stay at the station to 1.92 ± 0.15 γ/ml, P = 4 percent.

A study of the lysozyme activity of the blood serum of polar explorers made at the Vostok station during the period of the 17th SAE showed that the amount of lysozyme increased by the end of the wintering session, reaching 3.0 ± 0.3 γ/ml in December. In the first month of the wintering session its level equaled 2.0 ± 0.3 γ/ml (table 2).

Table 2. Indicators of the Immunological Reactivity of Polar Explorers at the Vostok Station During the Period of the 17th SAE

Indicator	Months			
	II	III	IV-V*	V-VI
Blood lysozyme, γ/ml	2.0±0.8	2.2±0.3	1.8±0.3	2.0±0.2
Bacterial activity of blood serum, titer	18±5	70±22	32±5	79±27
Staphylococcic α-antitoxin, AE/ml	0.97	1.17	1.00	0.81
logA, mg% (norm 90-450)	127.6±11.3	131.6±10.4	135.9±9.5	145.1±10.1
logG, mg% (norm 800-1800)	1228.0±121.0	1246.5±104.8	1202.7±118.6	1062.1±103.7
logM, mg% (norm 60-250)	95.5±8.3	88.0±9.4	87.6±8.3	89.5±8.3
	VI-VII	VII**	VIII	IX
Blood lysozyme	2.0±0.2	2.0±0.2	2.3±0.2	2.0±0.2
Bacterial activity of blood serum	56±14	57±22	100±45	116±36
Staphylococcic antitoxin	0.91	0.75	1.00	0.85
logA	137.7±9.9	132.3±10.5	127.6±10.6	122.1±10.1
logG	937.7±80.6	1120.9±126.7	1090.9±94.5	1233.8±127.9
logM	83.3±8.8	82.8±7.8	87.2±8.5	76.1±8.6

*Vaccination with staphylococcic anatoxin, three ampoules per day.
**Revaccination with anatoxin once, three ampoules, from 26 Jul to 10 Aug.

Table 2. [continued]

Indicator	Months			
	X	XI	XII	I
Blood lysozyme	1.8±0.2	2.4±0.3	3.0±0.3	2.8±0.3
Bacterial activity of blood serum	54±18	83±38	68	70±34
Staphylococcic antitoxin	1.05	1.00	0.95	0.85
logA	121.3±10.6	119.6±10.1	123.1±10.8	129.2±11.2
logG	1110.5±111.7	1049.5±84.1	983.8±73.7	993.0±82.9
logM	79.9±8.6	76.1±8.1	93.1±10.0	86.2±8.1

Unlike the data of other authors (Zhukovskaya and Likina, 1966), no correlation was observed between an increase in the content of lysozyme in the blood serum and an increase in the phagocytic activity of blood granulocytes, but, on the contrary, an inverse relationship was observed: With an increase in the content of lysozyme the phagocytic activity of neutrophils was reduced.

Lysozyme has a direct relationship to the bactericidal activity of human skin. The extent of bactericidal activity of the skin of polar explorers varied for the length of the stay on the expedition. For example, at the Vostok station during the period of the 15th SAE in the first month of the expedition the average number of deposited colon bacillus colonies equaled 32.4 per 30 min; then the bactericidal activity of the dermal integuments increased, corresponding to a reduction in the number of colonies to 3.2 to 3.4. A marked reduction in the bactericidal activity of dermal integuments was observed in November, when from the forearm were sown up to 110 colonies/cm^2. In fig 4 is shown the bactericidal activity of dermal integuments in polar explorers at the Novolazarevskaya station during the time of the 12th SAE. It is obvious that if the bactericidal activity of dermal integuments is determined by the content of lysozyme, then its quantity in the blood serum and dermal integuments must be intercorrelated.

Immunoglobulins are an important indicator of humoral immunity, which plays a major role in human infectious and non-infectious pathology (fig 5). A dynamic study of immunoglobulins A, M and G in the blood serum of polar explorers at the Vostok station during the period of the 15th SAE showed that in a group of associates consisting of 23 people variations in serumal IgA throughout the expedition were statistically unreliable. Prior to the expedition, in Leningrad (reference), IgA in them equaled 148.3 ± 10.2 mg percent. A tendency toward an increase in its content was observed beginning in the middle of the expedition (155.3 ± 12.2 mg percent). By the end of the explorers' stay at the station there occurred a drop in the level of IgA below the indicators obtained prior to the expedition (134.1 ± 7.7 mg percent), and below the indicators obtained in January and February of the following year (142.5 ± 21.7 mg percent).

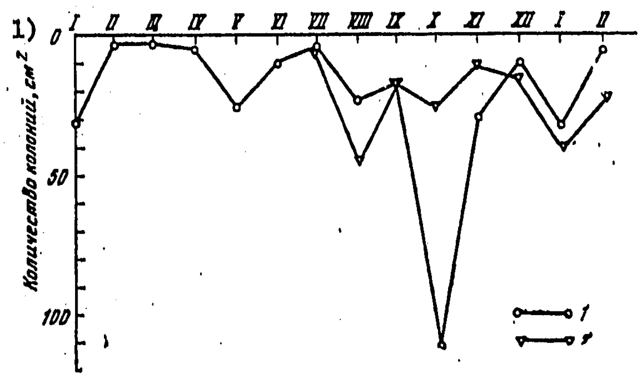

Figure 4. Change in Bactericidal Activity of the Skin of Polar Explorers During an Expedition: 1--at Vostok station; 2--at Novolazarevskaya station

Key:
1. Number of colonies, cm²

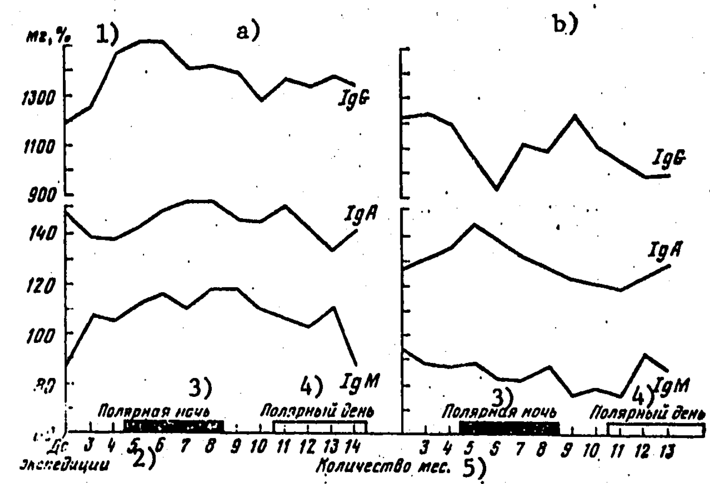

Figure 5. Content of Immunoglobulins in Blood Serum of Polar Explorers at Vostok Station: a--during 15th SAE; b--during 17th SAE

Key:
1. mg %
2. Prior to expedition
3. Polar night
4. Polar day
5. Number of months

The quantity of IgM began to increase immediately after arrival of the explorers at the station (108.6 ± 8.4 mg percent) as compared with the reference figure (86.8 ± 7.5 mg percent, P < 5 percent), reliably increased during May-September from 113.6 ± 9.7 to 118.9 ± 10.2 mg percent, P = 3 to 4 percent, and then gradually was reduced to the original figures, 87.0 ± 26.6 mg percent, P > 5 percent. The quantity of IgG, having reliably increased in May (the fifth month of the stay at the station), remained reliably high to the very end of the expedition, 1531.0 ± 160.1 mg percent, P = 5 percent, 1435.3 ± ± 103.6 mg percent, P = 4 percent, with a norm of 1202.6 ± 26.4 mg percent (cf. fig 5a).

Similar studies of Ig made during the 17th SAE at the Vostok station in a group of 27 people produced indicators differing from those obtained during the 15th SAE (cf. fig 5b). For example, the level of IgG was lowered during the period of the polar night (from April through August), from 1202.7 ± 118.6 to 1090.9 ± 94.5 mg percent, and toward the end of the explorers' stay at the station was observed the maximum drop in the level of this immunoglobulin to 993.0 ± 82.9 mg percent. The content of IgM during the period from February through July dropped gradually from 95.5 ± 8.3 to 82.2 ± 8.3 mg percent, and its maximum reduction was observed in September-November (76.1 ± 7.7 mg percent). The content of IgA on average was maintained at the normal physiological level (127.6 ± 11.3 mg percent); only a slight increase in it was observed during the period of the polar night (to 145.1 ± 10.1 mg percent).

An analysis of the nature of changes in the content of immunoglobulins in several associates at the Vostok station during the period of the 15th SAE showed that in the process of the human body's adaptation to the severe conditions of Antarctica the level of immunoglobulins in the blood serum is subject to considerable individual variations. For example, in four explorers the increase in the level of IgG, determined to one extent or another in all members of the group, went beyond the range of variation of the generally accepted physiological norms for this immunoglobulin. This rise ensued either immediately after arrival at the station (table 3) and was maintained for the extent of the entire expedition, or after several months of staying at the station. The high level of IgG agreed with an increase in the content of IgM (within the range of normal physiological indicators) and with the tendency toward an increase in the amount of IgA in these explorers.

But in some station associates a sporadic increase in the level of IgG in specific months of the wintering session was accompanied by an increase not only in IgM, but also in IgA.

A stay over the course of a year under conditions in Antarctica resulted in the manifestation of different, not infrequently opposite reactions with regard to a change in the level of immunoglobulins of different classes. For example, in UNN was observed a drop in IgA and IgG below the limits of the accepted physiological norms (table 4).

Table 3. Change in the Content of IgG in the Blood Serum of Polar Explorers at the Vostok Station During the 15th SAE, mg%

Инициалы полярников 1)	2) Месяцы									
	III	IV	V	VI	VII	VIII	IX	X	XI	XII
3) СВС	1872	2390	2246	2300	1872	2102	1392	1210	1227	1330
4) СКГ	1987	2880	1872	1555	1440	—	1987	—	2707	2390
5) УВА	1440	4066	2707	2880	2074	1786	1786	1901	1901	1440
6) ФГВ	1440	1498	1094	2246	2016	2160	2074	2074	2074	2074

Key:

1. Initials of explorer
2. Months
3. SVS
4. SKG
5. UVA
6. FGV

Table 4. Change in Content of Immunoglobulins in Blood Serum of UNN During the 15th SAE, mg%

Иммуноглобулин 1)	2) Месяцы							
	III	IV	V	VI	VII	VIII	IX	X	XI
IgA	78	67	67	59	78	85	82	72	82
IgG	360	432	432	432	605	490	432	662	576
IgM	109	127	120	65	78	78	84	109	72

Key:

1. Immunoglobulins
2. Months

Table 5. Change in Content of Immunoglobulins in Blood Serum of YeVI During 15th SAE, mg%

Иммуноглобулины 1)	2) Месяцы							
	III	IV	V	VI	VII	IX	X	XI	XII
IgA	69	67	79	69	69	69	58	51	56
IgG	1238	1526	1238	1238	1279	1152	1094	1411	1411
IgM	49	49	46	46	46	46	43	56	53

Key:

1. Immunoglobulins
2. Months

The results obtained have shown that in some associates of the station's team a non-identical adaptive reaction of the body's immunological state was observed: In some this involved an increase in one of the classes of immunoglobulins and a reduction in others, and vice-versa. It should be mentioned that in the station's group three associates had low IgM indicators even in the reference period in Leningrad (42.5, 42.5 and 51.0); hypoimmunoglobulinemia with regard to IgM can probably be explained by deficiency of the lymphoid system.

The question of the increase in the content of IgM and IgG during the period of the polar night requires an explanation, since it is not known what acts as an inducer of the synthesis of these immunoglobulins.

Division of the team of associates at the Vostok station during the 15th SAE (23 people) on the basis of frequency of participation in antarctic expeditions, into two groups--the first group consisting of 11 people taking part for the first time, and the second of 12 people taking part more than once--showed that no substantial differences in the extent and nature of the change in the level of immunoglobulins were observed. But in explorers of the first group the early period of adaptation (March) was accompanied by a slight drop in the levels of IgA and IgG, while in explorers of the second group was observed an increase in these immunoglobulins immediately after arrival at the station. In addition, before the expedition a reduced level of IgM was determined in some associates of the first group, and for the extent of the entire wintering session there was traced a tendency toward a change in this class of immunoglobulins at a lower physiological level as compared with analogous indicators in explorers of the second group. Apparently adaptation of the human body to changed climatic conditions is accompanied by an increase in the level of immunoglobulins and in the humoral defense mechanism index, and in people having repeatedly taken part in antarctic expeditions the process of restoring immunological reactivity begins earlier.

A well-known antigenic stimulus of lymphoid tissue is represented by micro-organisms of internal human microflora with the products of their vital activity. A study of the dynamics of the content of the staphylococcic alpha antitoxin in the blood serum of polar explorers (fig 6) during the period of the 15th SAE at the Vostok station showed that during the time of the expedition no important variations occurred in the alpha antitoxic activity of the blood serum of explorers; it equaled on average 1.0 to 1.5 AE/ml. A study of the level of the staphylococcic alpha antitoxin in polar explorers at the same station during the time of the 17th SAE showed that for the extent of the entire period its quanitative content was not changed, equaling on average 0.75 to 1.2 AE/ml, in spite of peroral vaccination and revaccination with staphylococcic anatoxin.

Thus, the conclusion can be drawn that the minimal content of micro-organisms in the coastal regions of Antarctica and their total absence within the continent result in a quantitative reduction in human microbial flora. This phenomenon is probably explained by the elimination of saprophytic forms of microbes. "Simplification" of the specific composition of microbial flora results in lowering of the level of resistance of the human body, the indicators of which are an increase in the amount of conventionally pathogenic flora, a tendency toward leoukopenia, and a reduction in the phagocytic activity of blood granulocytes. The reduction in the level of resistance of the human body obviously explains the "seeding" of human dermal integuments with representatives of conventionally pathogenic flora of the upper respiratory tracts and the manifestation of infectious diseases of endogenous etiology.

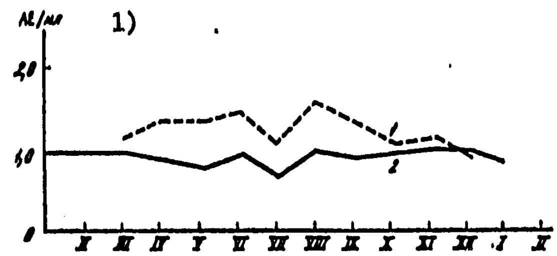

Figure 6. Staphylococcic Alpha Antitoxin in Polar Explorers at the Vostok Station: 1--during the 15th SAE; 2--during the 17th SAE

Key:
1. AE/ml

It is interesting to note that quantitative disturbances in the microbial flora of polar explorers are not accompanied by a change in the biological properties of the types of microbes studied, which remain practically at the level of the reference data (pathogenic properties, carbohydrate utilization, virulence).

It is obvious that from the environment micro-organisms constantly enter the human body and are destroyed by its immune powers, and only as the result of a drop in the level of immunity taking place under the influence of extreme environmental factors or disease can a change in the strain representation of human microbial flora take place.

The results of research in dynamics, on the non-specific and specific immunity of polar explorers during an expedition, have shown that the non-specific resistance of a polar explorer's body is lowered by the end of a wintering session in an isolated group, and in order for there to be an increase in some of its indicators it is necessary that a new antigenic stimulus enter this group, in the form of people from a new station replacement group with their own microbial flora.

In view of the fact that the alpha antitoxic activity of the serum, pertaining to specific antistaphylococcic immunity, reliably does not change, it can be assumed that the increase in the content of IgG and IgA on the 15th SAE and their periodic increases during the time of the 17th SAE are the consequence of non-specific stimulation of the human lymphoid system. But this increase can be caused also by bacterial antigens of other conventionally pathogenic microbes which have not been considered in this study.

The immunological reordering of the human body under extreme conditions is indicated both by a reduction of the level of non-specific resistance, and by the manifestation of specific immunological response reactions. The consequence of a reduction in the level of a human being's non-specific resistance is obviously seeding of his body with representatives of his own microflora, resulting in the origin of infectious diseases of endogenous etiology.

An analysis of the results of research conducted in Antarctica and on groups of testers in ground experiments while imitating the conditions of flight into space has made it possible for us to advance a hypothesis regarding the possibility of an endogenous etiology for postoperative purulent infections in surgical wards. This hypothesis has found verification in the practice of health care, in analyzing postoperative purulent infections in a group of neuro-oncological patients.

The active stimulation of the specific immunity of neuro-oncological patients with the staphylococcic anatoxin created powerful antistaphylococcic immunity and showed a pronounced clinical effect, reducing fourfold the number of postoperative complications.

Research on the state of the immune system of the human body under extreme conditions will help to reveal the pathogenesis of possible endogenous infections and to develop intelligent ways of preventing them.

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