CHAPTER I

GEOGRAPHICAL SETTING OF ANTARCTICA

1. INTRODUCTION

Dominated by rigorous cold and characterised by months of continuous daylight alternating with equal periods of darkness, the Antarctica is a high continent, perennially ice-covered (13.918 million km²) completely surrounded and isolated from the world's six other continents by broad expanses of the Atlantic, the Pacific, and the Indian Oceans. It is a vast frozen desert. Secluded in high, thick ice-sheets and dominated by fierce cold, moreover its interior, and strongest winds along its coasts, it is the most lifeless of all continents. Man has, however, set foot on this continent but has never been a permanent inhabitant, although some of his scientific settlements have now gained signs of permanancy. Plant life consists, barring two flowering species, principally of lichens, mosses and algae. The ice-free areas comprise only about 2.5 per cent¹ of the land, but there are too dry and cold to support vegetation. Antarctic animal life is essentially marine, including the birds that crowd Antarctic coastal area during the breeding season and spend most of their time at sea.

Despite the distinctive environment of Antarctica, there is no single definition used to delineate its limits. To some observers the totality of the Antarctic is the continent of Antarctica, while others consider the Antarctic treaty line (60°S parallel) to be a satisfactory boundary. However, the Antarctic convergence, a relatively narrow zone that extends all around...
Antarctic sea ice extent in winter/summer
this polar continent, is generally regarded as the best natural definition of the Antarctica. This is an unbroken, well-defined, circumpolar oceanic boundary roughly paralleling the February 10°C surface air isotherm\(^2\). Caused by the northward flowing Antarctic cold surface water impinging on the warmer subantarctic surface waters, it is identified by an abrupt change in sea and air temperature as well as a marked transformation in the character of the plankton and the sea birds.

This distinctive Antarctica environment is governed by a number of geographical factors such as topography, tectonics, structure, marine system, climate, glacial system and periglacial system etc. These factors have profound implications on all other life systems of the Antarctic environment. Extensive cover of ice is probably the single most distinctive feature of Antarctica. It makes the continent an ideal laboratory for studying the influence of ice in modulating global climate, and in modifying oceanographic processes.

**PHYSIOGRAPHY**

(a) **Topography**

The main physiographic features of Antarctica is shown in figure. The continent measures 13.918 x 10\(^6\) Km\(^2\) in area and is roughly the equivalent in size of the USA and Mexico together.\(^3\) The average surface elevation of Antarctica is a little more than 1850 meter\(^4\) compared to Asia, which has a second highest surface elevation measuring only 800 meters in average. It is covered by
Fig. The main natural regions and constraints on human activity in Antarctica.
Fig. The location and approximate extents of rocky coast around the Antarctic continent.
an ice sheet which rises relatively steeply near its periphery and reaches an altitude of 4000 m in East Antarctica and at several summits over 2000 m in West Antarctica. The high plateau of East Antarctica has about $3.5 \times 10^6$ Km$^2$ surface area above 3000 m, plus a central area of above 4000 m covered by perpetual snow. In sharp contrast to the overall gentle grades of the East Antarctica plateau, sometimes less than 1/500, the point of greatest elevation has been found in the Ellsworth mountains of the West Antarctica, the highest peak being Vinson Massif (5140 m). In west Antarctica there is archipelago with three main upland centres, namely the Antarctic peninsula, the Ellsworth and Marie Byrd Land massifs. The Transantarctic mountains transverse the continent spanning more than 2200 Kms, and provide a magnificent scenic backdrop with peaks above 4000 m high overlooking the Ross sea. Much of the chain is buried in ice and acts as a dam to the world's largest body of fresh water, the East Antarctica ice sheet.

(b) Dry Valleys

On the eastern side of McMurdo Sound, opposite Ross islands, lies Antarctica's most intriguing areas - the dry valley covering an area of 3000 sq.km. Amidst all the snow and ice, this strange desert landscape has remained virtually unaltered for million of years. The valleys are the dryest places on the earth - no rain has fallen there for at least 2 million years. Valleys are generally 5-10 Kms wide (between ridge crests) and 10-50kms long. From south to north, the principal ice free valleys include the Taylor, Wright, Victoria, Barvic valleys etc. Only the Taylor
and upper Wright valleys have glaciers at their heads which connect with the ice of the polar plateau. The other valleys either have barren upper reaches or small alpine glaciers. Valleys also exist in the Bunger Hills, Wilkes Land, Vestfold Hills, Princess Elizabeth Land and also on the Peninsula portion of Antarctica. Bull pass is a broad glacier carved depression across the Olympus range that connects the MacKinley valley to the lower Wright Valley. The Pass affords spectacular views of peaks and valleys. Throughout Bull pass the ground is littered with other beautifully shaped rock fragments called 'ventifacts' - the wind faceted stones.

(c) Lakes

Strange lakes, perennially ice covered, and partially bounded by glacier ice are common in some Antarctic coastal region, but very rarely inside the continent. The largest fresh water lake of interior Antarctica, lake Untersee (71°20'S/13°30'E) arose from a melt water pond during climatic optimum periods in the Holocene. Several lakes occupy parts of some valley floors. Some lakes are over 30 meters deep. Lake Vanda, which is typical, has 10% dissolved salt contents in its lower few meters - three times as saline as sea-water while the upper 50 m has only 0.1% salinity.

(d) Sub Antarctic Islands

Of all the continents, Antarctica is the most isolated from other lands. Pressed down by weight of its ice caps, its
Map of Antarctica showing the locations of inland water bodies. Those names which are underlined are the sites of lakes described in the text. Modified from Priddle and Heywood (1980).
continental shelves are both narrowed and deeper than those of the other continents. It, therefore, has few offshore islands having a total area of \(38000 \text{ Km}^2\), which have not been submerged or over-ridden by the outward flowing ice sheets from the continental landmass itself. This loop extends for some 1500 km eastward into the south Atlantic basin. It is locally emergent, forming small, but extremely rugged and heavily glaciated islands. Continental rocks of southernmost of South America and Antarctica Peninsula does show a direct correlation in composition. Active volcanoes occur at the end of the South Scotia Ridge. Particularly the South Sandwich volcanic arch developed after being bent, disrupted and fragmented in the late Cenozoic. The distribution of sub-Antarctic Islands on the basis of their origin is as follows:

(1) **Islands on Scotia Arc**: Between the eastern tip of Tierra de Fuego and Northern tip of Antarctic Peninsula:
   
   (a) Falkland Islands
   (b) South Georgia
   (c) South Sandwich Island
   (d) South Orkey Islands
   (e) South Shetland Island.

(2) **Islands on Seismically Active Ridges of the Southern Atlantic, Indian and Pacific Ocean**:

   Except for Macquarie Island, all the Islands of the sub-Antarctic Islands are situated on mid-oceanic ridges, thus mostly consisting of Cenozoic volcanic rocks.
FIGURE 2. Scotia Arc.
Fig. Location and geotectonic setting of the sub Antarctic islands.
(a) Tristan da Cunha Group
(i) Inaccessible Island; (ii) Nigtiangle Island.
(b) Gough Island
(c) Bouvet Island
(d) Marion Island
(e) Prince Edward Island
(f) Amterdum Island
(g) St. Paul
(h) Macquaire Island

(3) **Islands on Aseismic Ridges in the Southern Indian and Pacific Oceans:**

(a) Crozet Islands : I. Ile Aux Cochons

Ile aux Pingouins
Les Aportnes

II. Ile de l'Est
Ile de la Possession

(b) Kerguelen Islands

(c) Heard Islands

(4) **Islands on the Continental Shelf of Antarctica:**

(a) Balleny Islands

(b) Scott Island

(c) Peter I Islands

The coasts of all these islands are ice free and more or less surrounded by kelp.
(e) **Glaciers and Ice-Streams**

Antarctica is drained by vast system of glaciers and ice streams. Studies in Antarctic ice movements, i.e. frozen cataracts draining the polar ice cap, reveal that most Antarctic glaciers occur around the edges of the ice-sheet when they drain the interior of the continent. There are also a number of small glaciers originating on the exposed mountain and islands around the coast. The world's largest glacier is in Antarctic, a 40 km wide Lambert Glacier which flows through Prince Charles mountains, draining one million sq.km of east Antarctica. More than 35 km$^3$ of ice are discharged through this vast glacial system per year. Other glaciers and ice streams merge with this system as it flows to the sea. In Antarctica, floating ice shelves are capable of building distinctive moraines such moraines are characterically horizontal and may be deposited along a coastline where the ice shelf runs around. An identified example is from George Island of Antarctica where the ice sweeps across the ground on the Alexander island.

(f) **Coastline and Continental Shelves**

The Antarctica continent has a coastline of just over 30,000 Km. Of this 44% is ice shelf margin, 38% ice wall, 13% glacier snouts and only 5% rock beaches. Besides the broadly circular, little indented coastline of East Antarctica, it comprises of two large iceshelf of the Weddell Sea and the Ross Sea and the long projection of the Antarctic Peninsula. Antarctic ice shelves have formed largely by seaward movements of the ice and formed
### Present-day Glacier Extent in the Polar-Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Area (km$^2$)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>South polar region</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antarctic ice sheet (excluding shelves)</td>
<td>1,25,35,000</td>
<td>1,25,88,000</td>
</tr>
<tr>
<td>Other antarctic glaciers</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Sub-antarctic glaciers</td>
<td>3,000</td>
<td></td>
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<tr>
<td>North Polar Region</td>
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<tr>
<td>Greenland ice sheet</td>
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<td>Other Greenland glaciers</td>
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<td>Canadian Archipelago</td>
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<td>Svalbard</td>
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<td>Polar Total</td>
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<tr>
<td>World Total</td>
<td>1,48,98,320</td>
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</table>

Source: Flint (1971)
over the land rather than by confined thickening of sea ice bordering the shore. The Continent as a whole is fringed by continental shelf usually less than 100 km wide, which attains its maximum width of 1000 Km in the vicinity of the Weddell and Ross seas. According to Zirago and Evteev (1969), the Antarctic continental shelf has an area of about 4 m sq.km and out of it some 60% (2.4 m sq.km) is ice free. The shelf has a mean depth of 350 m, twice that of other continental shelves. Maximum width occur in the Weddell sea is 611 m and 1127 km in the Ross sea. The Ross sea shelf is the largest with an area of $7 \times 10^5$ sq.km. characterised by many small and occasionally giant icebergs of the size of upto $5 \times 10^3$ sq.km. These characteristics together with the problems posed by stormy seas drifting ice pack and icebergs with an average speed of 500 to 1500 m per year, pose constraints on the presently intensifying search for exploitable Antarctic resources particularly offshore oil and gas reserves. Thus, the Antarctic continental shelf exhibits typical high latitude morphology. It has been deeply incised by the glacial activity.

(g) Antarctic Beaches:

Antarctic beaches differ from those of temperate latitude chiefly due to seasonal effects of ice on land and sea. Because beaches are commonly the nesting sites of large number of Penguins, they are devoid of pebbles. Pebbles are used as nesting materials. Extensive beach-ridge complexes occur around the Ross sea, Antarctic peninsula and several other offshore
islands. Raised beaches, wave-cut platforms, sea caves and sea stacks are common on the Antarctic peninsula and its islands. The ground moraine is thought to be the most important source of beach materials. In contrast, Bird (1984) has found that talus, eolian action and the products of cliff abrasion are by far the predominant sources of beach material; though ground moraine is locally important in higher latitudes. Raised beaches up to 20 m of emergence has taken place over the last 6000 years. Raised beaches therefore present interesting problems concerning glacio-isostacy and glacio-eustacy and their operation at appreciable altitudes on most section of the Antarctic coast suggest that in the recent past the rate of isostatic uplift has exceeded the rate of sea-level rise that resulted from retreat of the ice sheets.

(h) The Deep Sea

The Deep ocean outside the continental shelf is usually more than 4000 m deep which surrounded the continent and is transversed by oceanic ridges running roughly parallel to the continental edge, except in the Scotia sea area. The mid-ocean ridge is offset by numerous transform faults which allow the complex differential motions of the continental plate during ocean-floor spreading. Unlike most other major plateau, the Antarctic is almost totally surrounded by passive margins; only in the Scotia sea region there is significant compressive motion and subduction. Here an accurate submarine ridge, doted with island groups such as the South Shetland Island and South Orkney islands and South Georgia, links the Antarctica peninsula with
south America. The floors of the deep ocean basins are generally very flat, minor irregularities being smoothed over by sand and mud brought by the bottom currents from the neighbouring continents and remains of plant and animal life raining down from above. Ice rafting is presently an important sedimentary process only within a few tens of kms of the coast where outlet glaciers drain.

GEOLOGY

It is widely believed that Antarctica was at one time a part of an ancient, considerably larger landmass, referred by Geologists as Gondwanaland. The supercontinent began breaking up during the Triassic period (205-240 million years ago) and its several major segments are south America, Africa, India, Australia and Antarctica. It might be said that the later got "the short end of the draw" and ended up at the bottom of the world. But the present outlines of these continents - along with the similarity of their geology and fossil finds - strongly suggest that they had fitted together and that Antarctica was not always a cold and inhospitable place.

(a) Geological Setting

Antarctica can be divided into eastern and western parts. East Antarctica consists of a pre cambrian craton and, along its boundary with West Antarctica, occurs the trans-Antarctic mountains. By analogy with most other Gondwana craton, the East Antarctica cration probably consists of Archaean crystalline
Fig. Schematic tectonic map of Antarctica based, in part, upon Craddock (1972), and Cameron (1978). Key: 1. East Antarctic shield; 2. Late Pre-Cambrian and Early Palaeozoic orogenic zones of Transantarctic Mountains (Beardmore and Ross); 3. Mid-Palaeozoic orogenic zone of Northern Victoria Land (Borchgrevink); 4. Early Mesozoic orogenic zone of Ellsworth Mountains (Gondwanian); 5. Late Mesozoic to early Cenozoic orogenic zone of Antarctic Peninsula and Byrd Land (Andean); 6. Subglacial sedimentary basins of Ross Sea, Byrd Basin and Weddell Sea; 7. East Antarctic intracratonic sedimentary basins; 8. Cenozoic volcanics. The dotted line is the approximate edge of the Continental Shelf.
"nuclei" welded together during Proterozoic and early Paleozoic time. Rock exposures, however, are limited mostly to narrow strips along the coastline; thus Archaean nuclei blocks are not well defined except in the Prince Charles mountains - Enderby land area.17

In contrast to the craton, the Trans-Antarctic mountains form a linear fold belt (the Ross belt) underlain mostly by Proterozoic and lower Palaeozoic rocks folded chiefly during a late Proterozoic Beardmore deformational event and an early Palaeozoic Ross deformational event. The controversial Middle Palaeozoic Berchgrevink event (Tingey, 1982) in northern Victoria land and the late Palaeozoic to early Mesozoic Weddell event in the Pensacola mountains also have affected the Trans-Antarctic mountains. The deformed rocks of the trans-Antarctic are uniformly overlain by mostly flat-lying non-metamorphosed lower Palaeozoic to lower Mesozoic sedimentary rocks of the Beacon Supergroup.

The Rocks of the West Antarctica are generally younger than those of East Antarctica and the area is topographically lower than east Antarctica. Continental lithosphere is also much thinner in west Antarctica. West Antarctica consists of at least four microplates of continental lithosphere that differ from each other in rocks and structural trends18. Precambrian rocks have been confirmed only at Hagg Nunataks; north of Ellsworth mountains. Palaeozoic rock occurs in the Ellsworth mountains and in widely scattered places in Marie Byrd land and western Ellsworth land. Mesozoic and Cenozoic rocks dominate in West
Fig. position of Antarctic structural belts in relation to those of adjacent Gondwana land masses.
Antarctica. Most belong to a Pacific-margin magmatic and deformational belt formed by subduction prior to and during break up of Gondwana land. This tectonic feature is the Andean belt. It is best exposed in Antarctic Peninsula and eastern Ellsworth land, but Andean deformation also overprinted older rocks in the Western Ellsworth land and Marie Byrd land until subduction ceased in these two areas in late cretaceous time. The Andean belt consists mostly of scattered magmatic arcs and adjacent associated sedimentary rocks deposited in fore-arc and back-arc basins. Most magmatic arcs formed on continental lithosphere of western Gondwanaland by repeated igneous activity starting in late Triassic or perhaps earlier time and continuing until late tertiary time. Deformational and magmatic events occurred locally at various times in this broad span. The Gondwana wide deformational event of late Triassic and early Jurassic age may be the most widespread (Dalzie, 1982). Other deformational events in the belt are more local and have not been named. Different pulses of plutonium are indicated by isotopic ages and their products may warrant names.

By the end of the Mesozoic (65 Ma Bp) much of the present configuration of Antarctica and its near polar position had been established. The opening of the southern ocean by sea-floor spreading led to the progressive isolation of Antarctica from the other southern continents and development. Volcanic activity in Antarctica is limited to only a few places, the most notable being Mount Erebus on Ross Island. The island is entirely
Antarctic Basin's Distribution
volcanic in origin, as are White and Black islands, Brown peninsula and Mina Bluff, and the massif of mount Discovery and Morning. These are products of erruptions - from Pliocene through the present - of basaltic lavas from central cones and fissures at various locations. Mount Erebus is the largest and by far the most active of the few volcanoes on the continent. In Cenozoic times, the latest chapter of Antarctica geological history has been characterized by the occurrence, principally, in West Antarctica, of abundant basaltic volcanism.

The location of Antarctica in Gondwanaland reconstructions has long been used for making predictions on what mineral deposits are likely in Antarctica. In these reconstructions, pre-Cambrian rocks in previously adjoining Gondwanaland countries are of special interest because many are metal-rich. The Antarctic craton undoubtedly contains undiscovered mineral deposits. Based on analogy with the formerly nearby Yilgaras nucleus of Australia, Wilkes Land appears to have a geologic environment favourable for nickel deposits in Archaean Ultramafic intrusions and gold deposits in Archaean mafic volcanic rocks. Based on analogy with eastern South Africa, Queen Mand Land may contain fossil placer Au-U deposits in proterozoic conglomerate and may contain magmatic Cr-Ni-Cu-Pt deposits in ultramafic intrusions.19

The possible occurrence of diamond-bearing Kimberlite pipes in Queen Mand Land cannot be ruled out. Hydrocarbons are typically found in relatively young sedimentary rocks in basins where characteristics have allowed adequate maturation, migration
and trapping. The thick ice cover (upto 4 km), however, must
limit their possible future exploitation. Permian coal i.e.
widely known from the Transantarctic Mountains and the Prince
Charles Mountains.

Meteorites provide the only samples of material outside the
Earth-moon system that are available for laboratory studies of
its composition and physical properties. In 1969, Japanese
ever exploration team first found meteorites in the Yamoto Mountains
of Antarctica. In fact, prior to 1969, only about 2100 distinct
meteorites were known world-wide. During 1979-80, Japanese
recovered about 3000 more meteorites from the Yamoto and Belgica
mountains. American investigators soon found even larger
concentration (specimen per sq.mile) in McMurdo area - nearly all
in the vicinity of the Allan Hills.

Antarctica is a unique collecting ground for the recovery
of large number of meteorites, where they can be easily
recognised. The location of Meteoric fragments have all been in
blue, snow-free ice areas of mountain barrier margins of the
polar plateau. The meteorites are believed to move downward
within the ice; following its flow lines toward the continental
margins, where they are either discharged unnoticed into the sea
or are captured in ice where they stagnant against a resistant
mountain barrier.

Meteorite studies are a significant part of space science
because the specimens include the oldest materials of the solar
system available for research. They provide identifiable records
Climatic zoning of Antarctica (after Bugaev and modified according to Antarctic Atlas, 1966).

1 - the zone of high Antarctic plateau; II - the zone of Antarctic slope; III - the zone of Antarctic coast; IIIa - the region of ice shelves. The drift ice zone: IVa - the subzone of Antarctic drift ice; IVb - the subzone of Subantarctic drift ice; V - the zone of open Antarctic water; 1 - Antarctic Divergence between the prevailing western and eastern winds; 2 - out at the time of maximum expansion; 3 - Antarctic water convergence.
of certain solar and glaciatic effects, and they yield data that are otherwise not obtainable - about the origin, evolution and composition of the Sun, the Earth and the other planets, satellites and asteroids.

CLIMATE

In the last 20 years, considerable research in meteorology, climatology and glaciology has developed understanding about broader climatic pattern of Antarctica. Perennial presence of ice and snow can be understood to be a major determinant of the climate of Antarctica. Minor variations of temperature regime in the coastal regions and the southern oceans are related to the varying abundance of ice.

a) Temperature

Antarctica is the coldest place on the earth, \(-17^\circ C\) colder than Arctic on an average. At the south pole, about 2800 meters altitude, monthly mean temperature ranges from \(-25^\circ C\) in summer (Dec.-March) to \(-63^\circ C\) in winter. Only in the coastal regions are temperatures occasionally above freezing in the summer. At McMurdo station the annual average temperature is \(-17.4^\circ C\). The average daily temperature ranges between about \(-2^\circ C\) and \(-7^\circ C\) during December-January, and between about \(-23^\circ C\) and \(-34^\circ C\) in August.\(^2\)

b) Precipitation

Precipitation, nearly all as snow, occurs frequently over much of Antarctica, but is light; the total fall varies from year
Figure 5.5 Same as Figure 5.4 (upper frame) for steady-state doubling of CO₂ (Washington and Meehl, 1984), except showing winter and summer of surface air temperature change in °C.
Fig. Map of Antarctica, showing the water equivalent mean annual precipitation in cm (from Budd et al. 1971) and the principal iceshelves.
Fig. Accumulation (isolines and underlined numbers) in gram cm$^{-2}$ year$^{-1}$. Average annual precipitation values in the same units, marked by the line above the numbers, have been added for a few stations.
to year. The scantiness of the snowfall is evident on the Polar plateau, where over large areas annual amounts are less than 3 centimeters (water-equivalent). Annual snow accumulation on Ross Island averages 17.6 cm in water-equivalent, but accumulation over the polar plateau to the west of the dry valleys is considerably less. Within the dry valleys most of the snowfall is associated with hurried easterly winds blowing off the Ross sea. In October 1961, 8 to 10 cms of snow covered the eastern end of Victoria Valley; most of this disappeared by mid-November.

c) Radiation:

Surprisingly, during the summer more solar radiation reaches the surface of the South Pole, than is received at the equator in the equivalent period. Even the total annual radiation at the South Pole is about equal to that received in equatorial regions, despite there being 6 months of "night". This is largely explained by the continent's high elevation, and therefore, its thin atmosphere, and by the air's unusual clarity (transparency). However, the incoming solar radiation does not afford much surface heat, as most is reflected back into the atmosphere by the snow-covered ice sheet and greater expanse of the sea. The combination of high elevation with a high albedo gives rise to a negative annual heat budget. Antarctica is a true major global heat-sink. This fact has widespread importance since the difference in solar warming between the tropical and the polar regions establish transfer of energy which drive the global atmospheric circulation and establish such critical features on
the intertropical convergence zone (ITCZ), polar trough and high-pressure belts (Allison, 1983).

d) Pressure and Winds

The Antarctic continent experiences relatively high barometric pressures (in the range 1030-1040 mb) and there is only an infrequent occurrence of depressions. On the Antarctic continent cold surface air layers lead to the widespread development of strong, stable inversions in the lower few hundred metres of the atmosphere. This phenomena is probably one of the most distinctive elements of the Antarctic climate. This inversions are often 10° - 15° "deep" and favour development of katabatic air drainage. Winds in dry valleys range widely in direction and velocity, being controlled by the local topography, the proximity of the polar plateau and McMurdo sound, and the season of the year. Onshore winds from the east dominate during the summer with mean speeds of 10-15 Kms per hour. During the winter, katabatic winds, which originate on the polar plateau, sweep through the valleys. Effects of the winter winds are found in the orientation of the ventifacts and occurrence of pebble ridges. In all the dry valleys, ventifacts are commonly positioned with their cut and polished facets facing west. Pebble ridges with lee slopes facing east are prominently in the upper Victoria and Barbick valleys. Pebbles along the west are as large as 6 cms in diameter. Velocities necessary to transport such large particles have been calculated to be 200 kms/hour. In the areas of high winds, blizzards frequently fill the air with powdery snow that reduces visibility to zero. Blowing snow is
Atmospheric pressure at sea level, averages for January (above) and July. Units: millibars; 1 mb = 100 Pascal.
especially troublesome in west Antarctica and along the edge of the ice sheet. August is the stormiest month in Antarctica.

It is important to stress that polar climates result from the operation of two sets of processes. At a world scale basic geometric considerations imply a cooler climate at the poles than elsewhere and a westerly circumpolar air circulation. The interaction between these features and distribution of land, sea and high topography introduces a second set of processes which determine the climate at any given point within the polar regions.

**OCEANOLOGY**

Oceanic circulation around the Antarctica is zonal and relatively consistent from place to place. There are three main water masses. Antarctic surface water consists of a layer 100-150 m thick which has a fairly low salinity and a temperature close to the freezing point. At its northern extent near the Antarctic convergence, it is about 1-2°C in winter and 3-5°C in summer, while in the south temperatures of -1.0 to 1.9°C are common. The Antarctica convergence itself is a shallow frontal feature where Antarctic surface water meets and sinks below warmer waters of the southern oceans. Beneath this thin cap of Antarctic surface water is a zone of warm deep water at 0.5-2°C which is a continuation of the deep ocean water of the Atlantic, Pacific and Indian oceans respectively. Beneath this is a layer of cold Antarctic bottom water which flows down the Antarctic continental shelf.
Fig. Circumpolar wind/water boundaries
Fig. Surface currents and the position of the Antarctic Convergence and the Antarctic Divergence. Various sources.
The circulation pattern closely reflects average wind directions. North of 63°S the water is driven by the dominant westerly winds and is called the west wind drift. With a coriolis component which deflects winds and currents to the left in the southern hemisphere, the dominant direction is out from the continent in a north-easterly direction. Close to the continent itself the dominant wind direction reflecting outflow of katabatic winds from the ice sheets is from the east. This encourages an east wind drift. There is a zone of divergence between the two currents which is associated with upwelling from underlying deep water. Antarctic bottom water probably forms where water comes into contact with ice shelves and is cooled sufficiently for its density to increase and for it to flow down the continental slope.23

Although the main features of the Antarctic water circulation readily explained in terms of atmospheric circulation, there are several important features imparted by the topography of the continent and the seafloor. The Antarctic peninsula juts out into the southern ocean and causes the east wind drift to circle around the Weddell sea and to join the west wind drift in the lee of the tip of the peninsula. This circuit is called the Weddell drift. Bottom topography is also important in affecting the main currents, especially in the constricted Scotia sea between the Antarctic peninsula and South America. Here it is believed that localised zones of upwelling and the position of such features as the Antarctic convergence itself are influenced by the bathymetry of the sea floor.
Circumpolar salinity distribution at maximum salinity depth (parts per thousand)
Ice Shelves and Bergs

About one third of the Antarctic coastline is comprised of ice shelves - floating ice fed by glaciers emanating from the vast polar plateau and by snow fall upon their surfaces. The ice shelves are as much as 300 meters thick at their seaward edges and they thicken toward the land. Ross ice shelf is the largest covering about 520,000 sq.km and measuring about 650 kms across.\(^{24}\) It moves northward to Ross sea, flowing about 1.4 kms a year. The movement of the ice shelf against and past various land masses such as Ross island, is marked by ice pressure ridges. These are characterised by undulating ridges and troughs and crevicesed areas.

Sea ice originates on or at the edge of the polar landmass and is dispersed by strong winds blowing northward into the surrounding oceans. Annually the ice pack grows from an average minimum of 2.9 sq.Kms in March to about 18.8 sq.Kms in September. The average thickness of the sea ice is about 1.5 meters and about 85% of the ice pack melts each year. The pack moves quickly with winds - as much as 65 kms in a single day - and ships can easily be caught in some of the thicker, more complex multilayer ice that is trapped within indentation of the Ross sea coastline.\(^{25}\) The melting of the sea ice and its surface snow cover in the summer release considerable fresh water to the near-surface layers of the southern ocean. In winter, salinity is increased by fractionation as the surface freezes over and later as brine drains downwards out of the developing sea ice canopy.
Fig. Locations of Antarctic icebergs sighted from 1773 to 1960 as compiled by Nazarov (1962).
Thus, it can be concluded from the description of fundamental natural systems associated with land, atmosphere and ocean that Antarctic is a unique continent indeed. Natural constraints really pose a great task to the scientific community for maintenance of its uniqueness along with Antarctic development programmes and activities. More specifically, the geographical or natural constraints include inaccessibility of bed rock through the ice; low temperatures; high altitude of the interior which induces mountain sickness; net snow accumulation, which buries any buildings; a coast with access seasonally or permanently impeded by pack ice; a deeper than average continental shelf; and remoteness from the developed human settlements. These constraints have a distinct environmental and spatial expressions which require deep scholastic, scientific, economic and political probing and analysis.
Fig. Major flow directions of the Antarctic ice-sheets (modified after Drewry 1983). Because the rock layers of Antarctica have been systematically sampled by erosion of these ice-flows, sediment dispersal patterns of resource-index minerals around Antarctica can reveal much about the sub-ice mineral potential of this continent. Scientific investigations of this nature may provide a future test for more theoretical resource evaluations of Antarctica.
NOTES

1. Dr. L.U. Joshi, Dr. S.Z. Qasim and Dr. S. A. Abidi: Geography of Antarctica; Nuclear India, vol.20/No.11 & 12, 1982, Bombay, pp.2-3.


9. Ibid.


12. Ibid.


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24. Ibid.


26. Ibid.