ANTARCTICA
The 7th Continent
John Gunton
Mar 27, 2021

OUTLINE

• Why is Antarctica the 7th continent and so different from the Arctic?
• How Antarctica came to be.
• Is Antarctica melting?
• Antarctic Treaty
• Research
• Ice dynamics
• Drilling
Why the 7th Continent?

What defines a continent?

Convention: World’s main continuous expanses of land?
Historical: Last to be discovered
Geological: “Lands accreted to a core of ancient cratonic rock (2.4 Gya)”
Subducting/collision plate margin

Spreading ridge plate margin

Plates and Plate Margins

Heated material expands and rises.
THE INTERNATIONAL BATHYMETRIC CHART OF THE ARCTIC OCEAN (IBCAO)

Compiled by
Martin Jakobsson, U of New Hampshire, USA
Ron Macnab, Geological Survey of Canada (Ret)
Norman Cherkis, Five Oceans Consultants, USA

Distribution of year-round LAND Ice
SEA ICE removed from map

Lomonov Ridge (spreading centre)
Extension of Mid Atlantic Ridge
Continental Drift:
A precursor concept to Plate Tectonics

- 1912 Alfred Wegener proposed “Continental Drift”.
- His drift mechanism was the spinning earth
- The mechanism was rejected by geologists
- He died in 1930.
- His idea was taken up by Wilson and others.
- In 1966 Wilson published a landmark paper.
  John Tuzo Wilson, Nature 1966, v. 211
- This led to Plate Tectonic Theory and the “Wilson Cycle” was introduced in 1974

J. Tuzo Wilson CC OBE FRS FRSE FRSC (1908-1993)
Wilson Stages A to F – Tectonic Rock Cycle
300 Mya
Pangaeanean Glaciation
200 Mya
50 Mya
MAP COURTESY OF CR SCOTSESE,
PALEOMAP PROJECT
Present Day

MAP COURTESY OF CR SCOTESE, PALEOMAP PROJECT: NATIONAL GEOGRAPHIC
In 300 Ma

- 10 minutes

2nd
- c. 380 Ma: First vertebrate land animals

3rd
- c. 540 Ma: Cambrian explosion
- c. 650–635 Ma: Marinoan Glaciation (Snowball Earth event)
- c. 716–660 Ma: Sturtian Glaciation (Snowball Earth event)

4th
- c. 4000 Ma: End of the Late Heavy Bombardment; first life

5th
- c. 3200 Ma: Earliest start of photosynthesis
- c. 2300 Ma: First major increase in atmospheric oxygen levels; first Snowball Earth event (Huronian glaciation)

1st
- 4527 Ma: Formation of the Moon
- 4550 Ma: Hominins, Mammals, Land plants, Animals, Multicellular life, Eukaryotes, Prokaryotes, Formation of the Earth
- 2 Ma: First Hominins
- 230-66 Ma: Non-avian dinosaurs
- 4.6 Ga
- 4 Ga
- 3 Ga
- 2.5 Ga
- 2 Ga
- 1 Ga
- 1 Ga
300 My of Temperature Fluctuation
Global Average

Temperature of Planet Earth

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- East Antarctica Ice Sheet
- West Antarctica Ice Sheet
- North Hemisphere Ice

**Snowball Earth #4**

Drake Passage Forms & Antarctica is isolated in polar position 40 mya

**Snowball Earth #5**

TODAY's Temp
TODAY Time zero
1. Geographic South Pole
2. Geomagnetic Pole 2007
3. Magnetic Pole 2005
4. South Pole of Inaccessibility
**Geomagnetic and Magnetic Poles**

(kyoto-u.ac.jp)

**North Magnetic Pole**
- Drifting NW @55 - 60 kms per yr

**South Magnetic Pole**
- Drifting NW @10-15 kms per yr
- Currently located Sth of Antarctic Circle
- 2860 kms from Geographic South Pole
ANTARCTICA

First sighted 1820 (Russians - Lazarev)
First landing 1821 (Americans - Davis)
7th Continent 1839 (Americans – Wilkes)
5th largest continent
Twice size of Australia
Coldest, driest, windiest, highest continent
Highest Point 4,892 m (16,050 ft) Vinson Massif
98% covered by a continuous ice sheet called land ice to distinguish it from sea ice
The land ice holds approx. 70% of world`s fresh water
Predicted sea level rise of 60 m if melted
No permanent human residents
Why is “Being a Continent” Relevant to Polar Opposites?
• 1959 - Founding member countries (12)

  territorial claimants (7):
  Argentina, Australia, UK, Chile, France, New Zealand, Norway,

  non-claimants consulting members (5):
  Belgium, Japan, Sth. Africa, USSR, USA.

  Unclaimed (Marie Byrd Land)
  Nowhere else in the world is there unclaimed territory

• Now 54 states party to treaty

• 1988 Canada joins by ratifying treaty along with 40 countries & the original 12 claimants
Antarctic Treaty System

International Council of Science (ICSU)
  Responsible for Antarctic Research

Scientific Committee on Antarctic Research (SCAR)

Canadian Polar Commission (CPC)
  Since 1991 www.polarcom.gc.ca

Canadian Committee on Antarctic Research (CCAR)
  14 member body of scientists to review Antarctic research proposals
The Antarctic Treaty
1959

ONLY TWO REASONS TO VISIT ANTARCTICA

RESEARCH
1000 to 5000 researchers
~60 stations - (28 permanent year-round, 30 summer only)

TOURISM
80,000+ tourists annually governed by IAATO
International Association of Tour Operators
Research Stations
Information & Data Gathering
- Surface mapping
- Drilling
- Telescopes
- Remote surveys (land, sea, airborne & satellites)
  - acoustic (seismic)
  - radioglaciology (Ice penetrating radar)
  - gravity
  - magnetics

Research Topics
- Isostasy and sea level change – ice dynamics
- Microbial life in permafrost environments
- Solar wind – Magnetosphere – Ionosphere (SW-M-I) System
- Bioremediation of pollution (spills)
- Atmosphere – ocean fluxes of climate active gases (CO$_2$, DMS, CH$_4$, N$_2$O, O$_3$)

**Effects of UVB radiation**
- Ecology of marine plankton: physical-biological coupling processes and dynamics
- Meteorite & space debris
- Muon & Neutrino Detector Array – IceCube Neutrino observatory

![Australia Airbus A319 supplying research station](image)
![Ken Borek Air Twin otter](image)
Penguins

Adelie

Chinstrap

Gentoo

Magellanic

Emperor

King
Penguin Highways
Research Stations

- 19 countries involved in year round research in permanent stations
- Approx 28 permanent stations
- Staffing grows from 1000 to 5000 (summer)
- Over wintering means no supplies and 24 hour darkness for 6+ months
- Researchers must have appendix and wisdom teeth removed
Permanent Research Stations

Main Research Stations
Bernardo O’Higgins - Chile

Oldest station in continuous use: Opened in 1948
Winter 16 staff, summer 60
Operated by Chilean Navy
36 COVID-19 case were reported on December 22, 2020
South Pole – USA
Amundsen Scott

50 Staff winter: 200 staff summer
Keeps moving & is being buried
Geodesic dome decommissioned 2008
And new elevated station opened

@SPTelescope
@NSF
photo taken in July 2020 by Danny Hampton
South Pole Facts:

Elevation  2835 m ASL
Ice thickness Approx 2850 m
Distance to open sea 1600 kms (Snow rd to McMurdo)
Ice sheet movement 10 m/yr  to 37°W of Nth (to Weddell Sea)
1956    Established US South Pole Station –continuously manned
South Pole Attempts

1901-02  Scott, Shackleton, Wilson
          FAILED (Discovery Expedition)

1909    Shackleton
          FAILED (Nimrod Expedition)

1911    Amundsen
          SUCCESSFUL - Norwegian

1912    Scott + 4 companions
          SUCCESSFUL but died on return

1914    Shackleton
          Imperial Transantarctic Expedition

1928    Byrd & Balchen
          First Flight over South Pole
The 2021 South Pole marker!
McMurdo - USA

- Main base and supplier to Amundsen -Scott Sth Pole Station (1600 kms by snow road)
- Access by air from New Zealand through Williams Field: snow-ice runway on 500m of water
- Main supply by ship Operation Deep Freeze
- 1200+ residents
Rothera & Halley – Britain
BAS (British Antarctic Survey) Research Stations

RRS Sir David Attenborough Research Supply Vessel
Bellingshausen - Russia
Founded in 1968 by Soviets
Year round staffed
Site of first attempted murder in Antarctica October 2018
Eastern Orthodox Church

VOSTOK – Russia
Built 1957 by Soviets
Staffed summer 25 Winter 13
Elevation 3,488 m
Lowest recorded temp on earth -89.2°C July 1983
Site of ice core drilling
Mirny - Russia

Year round staffed winter 30 – 40: summer 200
Base for Vostok Station 1400 kms away

Progress - Russia

New base for Vostok Station
Completed 2013 following a fire of original
Base for Vostok Station 1400 kms away
SANAIE IV – Sth Africa
Built 1997
Staffed Summer 100, Winter 10
160 kms from edge of ice shelf
Supplied by S.A. Agulhas II & Over-winters
Class 5 ice hull: heated decks: research labs

MAWSON – Australia
Built 1954 oldest of 3 permanent Aus stations
One of oldest research stations in Antarctica
Staffed Summer 60, Winter 20
70% of power needs met from wind turbines
Concordia – French-Italian

- Built 2005
- 3,233 m elevation
- Site of Dome C drilling
- Winter staff 13 French; 2 Italian
- 9 months of darkness

Dumont d’Urville – French

- Built 1956
- 202 m elevation
- Supply base for Dome C drilling
- Winter staff 30, summer 120
- Research includes $O_3$, cosmic ray detection
KUNLUN – China
Summer Operations only
4087 m elevation
opened 2009
Several telescopes

- 3 Antarctica Schmidt telescopes (AST3)
- 1 Kunlun Dark Universe Survey Telescope (KDUST),

Zhongshan - China
60 summer, 25 winter
Opened 1989
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3 Running Races

Antarctic Marathon King George Island by ship Vavilov or Loffe from Punta Arenas (Buenos Aries) $9 000 10 days

Antarctic Ice Marathon and the Antarctic 100 Km fly – in Punta Arenas to Union Glacier 14,000 euros 4 days
The Geography of Antarctica

Continental Ice Sheet/Shelves vs Bedrock

Antarctic Circle 66.34°S

Which way is North?

Antarctic Peninsula

South Pole

Below Sea Level

Transantarctic Mts

Sea Ice Not Shown

With Snow and Ice Removed

Land = green & yellow

Continental shelf = pale blue
With Snow and Ice Removed
land = green & yellow
continental shelf = pale blue

South Pole below sea level

With Snow and Ice Removed
Isostatic Rebound
Crust Rises
Mt Erebus

1734 m high
Active
Air New Zealand Flight 901
Nov 1979
DC 10 Crashed on Mt Erebus – whiteout
257 sightseers killed
Cross-sectional profile of the Antarctic ice sheet based on BEDMAP bed topography

Fault Bounded Rifted Basin, below sea level punctured by 30+ volcanoes

West Antarctica Rift System 3000 km X 700 km
West Antarctic Rift System – Byrd Subglacial Basin.

http://www.largeigneousprovinces.org/13apr

Byrd Subglacial Basin: 2,870 meters below sea level
Denman Canyon - Lowest point on land

Amos, Jonathan (2020-03-23). "Climate change: Earth's deepest ice canyon vulnerable to melting"
Map of Antarctica showing Wilkes Land, with the asteroid impact crater conjectured by von Frese and team marked in red

- Ring structure detected by radar under 2km of ice
- Probable asteroid impact crater 480 km diameter
- 2.5 X Chicxulub Crater
- Speculative date P-T Boundary & Extinction

Bedmap2: improved ice bed, surface and thickness datasets for Antarctica

Coverage of datasets used in the construction of the ice thickness grids:
- Satellite gravity
- Outcrop
- Drilling
- Seismic
- Airborne Radar
- Aeromagnetics

Fretwell et al., 2013
The Cryosphere, 7, 375–393, 2013
https://doi.org/10.5194/tc-7-375-2013
Ice Sheets, Ice Streams, Ice Shelves, Sea Ice

(Hannes Grobe, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany)
ICE FLOW
Ice sheet Dynamics – Rate of Flow
Up to 1.5 Kms/year
Map showing the rates of mass changes
From ICESat 2003-2008 over Antarctica. Credits: Jay Zwally/ Journal of Glaciology

All Antarctica; +82 GT/yr

East Antarctica (EA, 2-17); +136 GT/yr

Interior West Antarctica (WA2, 1, 18, 19, and 23); +72 GT/yr

Coastal West Antarctica (WA1, 20-21); -97 GT/yr

Antarctic Peninsula (24-27). -29 GT/yr

1 gigaton (Gt) = 1 billion metric tons
ICE SHELF THICKNESS CHANGES

Paolo et al. (2015)
Note volcanos are shown as white circles.
Ablation in action: polished hard blue ice, glazed by persistent katabatic winds, which remove (ablate) and vaporize (sublimate) snow. A wind scour at Mt Henderson, East Antarctica

(photo by Matt Williams in May @AusAntarctic)
Iceberg Monitoring

Worldwide by (NIC) US National Ice Center
Names and tracks Antarctic icebergs
Larger than 10 Nm long
A, B, C, D according to Longitude quadrant + running number
Largest recorded B15 – Calved 2000 – Ross Ice Shelf – 295 kms long
Ross Ice Shelf is 330 m thick and twice the area of Spain
Iceberg A-68A

- July 2017 broke from Larsen Ice Shelf
- Broke off (spawned) A 68B and A 68C
- Skirted by Sth Georgia Island (Dec 2020)
- Half the size of B 15
Drinking Water from Tabular Icebergs

Towing an Iceberg: One Captain’s Plan to Bring Drinking Water to 4 Million People - Bloomberg

Towing a Berg

Iceberg density per 20,000 square miles in 2017: Most Antarctic icebergs are 1,300 feet to 4,000 feet long

1. Encircle an iceberg in a giant plastic net.
2. Use tankers and tugboats to maneuver the skyscraper-size iceberg into a helpful current...
3. ...and park it off the coast of South Africa three months later. Container ships take the water ashore.
Tabular Iceberg in Bransfield Straits; 2015
Ferrar Glacier

Line of Section

Elevation (m above sealevel)

Ferrar Glacier Profile
Present day

Ferrar Glacier Profile
MIS 2 (LGM)

Ferrar Glacier Profile
Quaternary Maximum

Ferrar Glacier Profile
Pliocene Maximum

Distance from Terminus (km)

Temperature (°C)

Taylor Dome

Taylor Valley

Koettlitz Glacier

Cathedral Rocks

Basal Melting

Blue Ice

Wright Valley

Earth and Planetary Science Letters
Volume 243, Issues 3–4, 30 March 2006, Pages 489-503
Taylor Glacier – Blood Falls: McMurdo Dry Valleys
Taylor Glacier – Blood Falls: McMurdo Dry Valleys
Subglacial Microbial Communities in McMurdo Dry Valleys, Antarctica

Taylor Glacier

Surface Glacier Ice Conditions:
- Exposed to light
- Highly oxygenated
- Low salinity
- Low chloride
- Low sulfate
- Very low temps

Subglacial ecosystem (Blood Falls source water)

Bedrock

Lake Bonney

Conditions:
- Isolated marine system
- No light
- No oxygen
- High salinity
- High chloride
- High sulfate
- Rich in reduced iron (Fe^{2+})
- Very low temps

Resident Bacteria:
- Persist without photosynthesis
- Can use organic or inorganic carbon for growth
- Actively cycle iron, sulfur & carbon
- A few dominant species
- Low diversity

Thiomicrospira sp., Desulfocapsa sp., and others

Blood Falls intrusion into L. Bonney

DRILLING

- Historical record of temperatures (proxy) and chemistry
- Thickest ice selected (oldest and slow moving)
- Measurement of ice flow behavior
- Capable of sampling bedrock for geological purposes
- Investigate subglacial meltwater system
- Downhole imaging to observe ice properties
- Time consuming and expensive

- 2 Projects have been developed over the last 10 years:
  - The Goal: Drilling to bedrock in one season (2-3 months)
    - RAID (USA & UK)...Rapid Antarctic Ice Drilling
    - Subglacier (French)...uses combination cutter & meltprobe
- DOME C
- EPICA
- VOSTOK
- Corrected
Locations of known Antarctic subglacial lakes and predicted major drainage routings.

SOURCE: Siegert et al. 2007.

- Major clusters of subglacial lakes are located in Dome C and Ridge B areas.
- The majority of these environments are small (<20 km in length) with an average depth of 100 m.
- A few larger lakes may be up to 1000 m deep.
- Discovered by radio-echo sounding airborne surveys.
First drilling by Soviets took place in 1970’s with several holes:

- **Hole 3G**: 1984 2202 m
- **Hole 4G**: 1990 2546 m
- **Hole 5G**: 1993 2755 m
- 1996 3623 m usable data to 3310 m (414,000 yrs)
- 2003 3640 m
- 2012 3770 m reached lake

Lake Vostok:
- Biggest lake 250 kms x 50 kms
- 432 m deep
- 500 m subsea
Milankovich Cycles (Yrs)
100,000, eccentricity
41,000, obliquity
26,000, precession

Solar irradiance
Or insolation
Coincides with precession
26,000 yr cycle
Milankovitch Cycles
100,000, 41,000 & 26,000 yrs duration

EnvironmentCounts.org
Dome C Core (EPICA) 3260 m depth data to 740,000 yrs
Vostok V Core (drilled to 3770 m in 2012) 420,000 yrs
ICE SEARCH
An international effort is afoot to find the best site to drill for the world’s oldest ice.

- Probable areas of oldest ice

Dome F
- German team to send aeroplanes to map ice thickness, 2016–17.
- Possible site for US RAID drill to begin exploration, 2017–18.

Dome A
- Chinese researchers working to extract deep intact core.

Dome B
- Radar suggests attractive site, but no research infrastructure exists so no exploration is planned.

McMurdo Station

Dome C
- UK RAID drill begins exploration, 2016–17.
- French SUBGLACIOR drill tested, 2016–17.
- Possible site for US RAID and SUBGLACIOR drills to begin exploration, 2017–18.
- 740,000-year-old EPICA core obtained, 2004.
RAID (Rapid Access Ice Drill) Plan

The US team is a consortium of Scripps Institute, National Science Foundation and U of Minnesota

• Drill a 2500 to 3300 m borehole to the base of the Antarctic ice sheet as rapidly as possible. 2 to 3 months, 24/7, at high altitude (4000 m) and temperatures of -40°C.
• Drill through dry, frozen-bed conditions in the absence of liquid water at the basal glacial bed (ice-rock interface).
• Retrieve short ice cores (~50 cm long) of approximately 1.5 inches diameter at up to 2500 m depths.
• Retrieve 25-50 m of bedrock cores of approximately 1.5 inches diameter at up to 2500 m depths.
• Design a drilling rig that will fit on a skid-mounted mobile platform and be deployed as part of a stand-alone, traverse-capable system.
• Construct boreholes that will remain open for down-hole logging for up to 5 years.
March 2013 and November 2015. Consortium begins design, fabrication, construction, integration, and testing.

November 5, 2015. Verified and accepted by the University of Minnesota.

November 2015 shipped by truck to vessel facility at Port Hueneme, California.

January 28, 2016 RAID arrived at McMurdo Station in Antarctica.

2016-17, 2017-18 and 2018-19. Antarctic field trials and technical development completed.

2019-20 RAID will undergo further technical trials.
RAID System

A. Casing section
- auger bit
- steel casing
- sealed by inflatable packer

B. Ice borehole section
- non-coring rotating ice bit
- 3.5" borehole
- 2.4" O.D. drill rod
- reverse circulation
- ESTISOL 140 drilling fluid

C. Coring section
- wireline latching system
- 1.5"-1.9" O.D. cores
- normal circulation
- thin-kerf diamond bits
- retrievable core barrels
RAID Test Site McMurdo
2017

Dec 8, 2017

Dec 1 2017
Full Circle – 120 years earlier

The ship Discovery and Scott approaching McMurdo Sound with Mt Erebus in the background in 1901

https://www.coolantarctica.com