Reports

Ellsworth Mountains: Position in West Antarctica due to Sea-Floor Spreading

Abstract. *Similarities of middle and upper Paleozoic deposits of the Ellsworth Mountains with those of the Pensacola, Horlick, and other Transantarctic mountains indicate that all these ranges may have had a related geologic history. A tentative explanation is now suggested which involves sea-floor spreading and translocation of the Ellsworth crustal block from its original location adjacent to the East Antarctic Shield. Accordingly, the islands of West Antarctica may differ in origin and the Transantarctic Mountains of East Antarctica may represent one margin of an ancient rift.*

In many ways the Ellsworth Mountains of West Antarctica represent the greatest geographic and tectonic enigma in the Antarctic, a continent approximately meridionally divided (according to east or west longtitude) into an elevated East Antarctic Shield area and West Antarctica, with generally lower elevations and a peninsula extending north toward Tierra del Fuego. Nevertheless, these mountains are the highest on the continent and are isolated from the high Transantarctic Mountains that form the interior margin of the Antarctic Shield. The Ellsworth Mountains include a thick sedimentary section, but are divorced from any evident source of sediments. Cambrian and Devonian rocks are present very consistently along the Transantarctic Mountains, but the only record of these fossiliferous rocks in West Antarctica is in the Ellsworth Mountains (*1*). Although rocks of the latter mountains are folded like those of the Pensacola Mountains, located opposite them in East Antarctica, the trends of structure in the two systems diverge about 90°. The types of upper Paleozoic folds and deformed sediments dated by Permian plant fossils in the two mountain systems are so similar that the folds must be about the same age. The locations of the mountains on the map (Fig. 1) show that it is mechanically impossible for contemporary folds to form in these positions by thrust from a single direction. Since the Pensacola Mountains seem naturally related to a craton and to other Transantarctic Mountains, these observations lead to the conclusion that the Ellsworth Mountains probably have been displaced. If this is true, it suggests further that other parts of West Antarctica may have had a largely independent geologic history.

The stratigraphic similarity (*2*) of

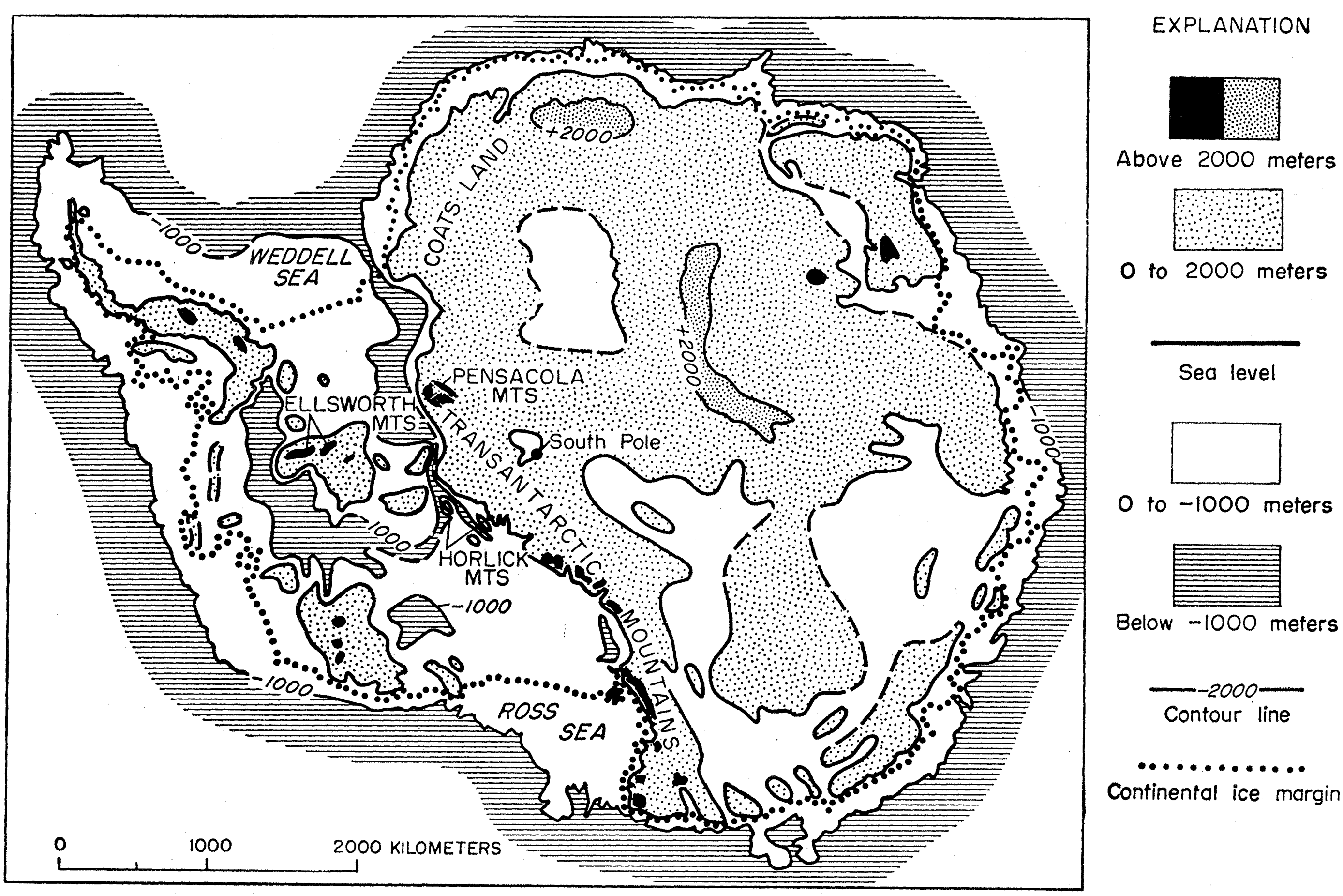

Fig. 1. Rock surface (sub-ice) map of Antarctica showing sea level outline and −1000-m and +2000-m contours. Location of Ellsworth, Pensacola, and Horlick mountains is indicated. The usual ice-front outline of Antarctica is shown by the dotted line. [Sketched from Avsyuk *et al.* in the Soviet subglacial relief map of Antarctica (*10*)]

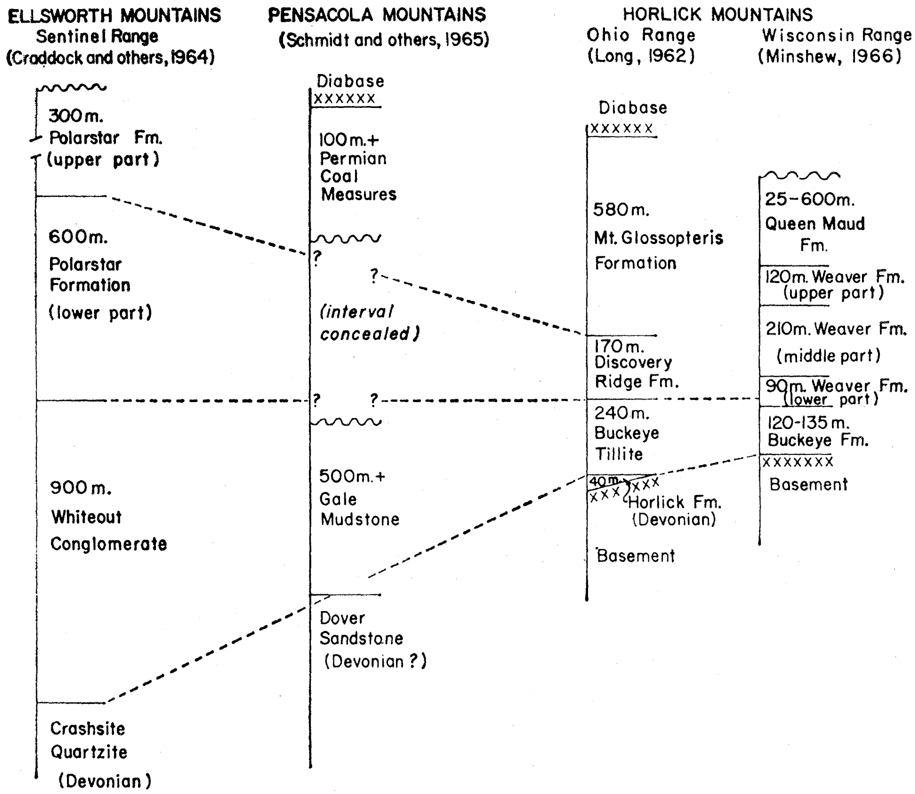

Fig. 2. Suggested correlation of middle and upper Paleozoic formations in the Ellsworth, Pensacola, and Horlick mountains, Antarctica.

the upper Paleozoic succession of both folded and flat-lying beds in the Horlick (*3*) and Pensacola (*4*) mountains is shown in Fig. 2, in comparison with that of the Ellsworth Mountains (*5*). The three areas are separated nearly equidistant from each other [about 500 miles (about 800 km)], but the trend of systematic increase does not fit present locations. The movement of Ellsworth Mountains which I am suggesting would lead to consistency in thickening approximately as indicated in Fig. 2.

According to Hamilton (*6*), the Scotia Arc may be attributed to an overriding surficial tongue of oceanic crust formed by a short segment of the East Pacific Rise (Fig. 3). Displacement along the northern and southern margins of this tongue must be transcurrent. The Antarctic Peninsula forms the southwestern continuation of the Scotia Arc; the Ellsworth Mountains are west of the embayment occupied by the Weddell Sea, an arm of the South Atlantic or Southern Ocean, that lies just south of the Scotia Arc.

If one considers the mountain-trend configurations of the Scotia Arc and the Antarctic Peninsula in relation to ocean-floor spreading (*7*) and considers continental drift in the light of plate tectonics (*8*), displacement of the Ellsworth Mountains can readily be explained. The geologic features of the Pensacola and Ellsworth mountains suggest that the Ellsworth Mountains are a crustal fragment that has been transported in post-Jurassic time into its present position from a former location at the margin of East Antarctica north of the Pensacola Mountains. The relations seem complementary to those that apply farther north to the Scotia Arc.

According to the view advocated here, the Weddell Sea can be accounted for as a result of spreading from a crustal tongue (now quiescent) that emanated from the South Atlantic midocean ridge, essentially a counterpart of the Scotia Arc. On a global projection, the eastern side of the Weddell Sea tends to line up with the trend of the Mozambique, Prince Edward, and associated parallel fracture zones that displace the midoceanic ridge southeast of the Agulhas Basin. According to Heezen and Tharp's map [physiographic provinces, Fig. 4 in (*9*)] of the Indian Ocean floor, the lineations of the Mozambique fracture zone cross the midoceanic ridge obliquely, and the offset continues to the southwest. This aggregate displacement seems to be transcurrent (see dashed line, Fig. 3). Probably a tongue of sea-floor crust similar to, but broader than, that of the Scotia Arc is involved.

The movement could be responsible for sweeping the Ellsworth fragment from the corner of the Antarctic Shield and displacing it southward. According to the Soviet subglacial map

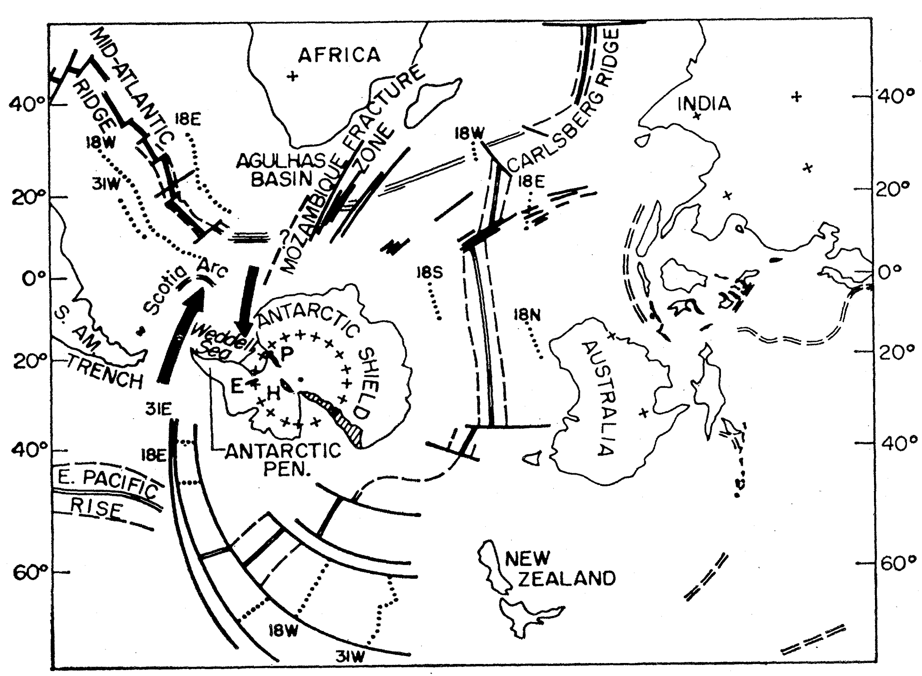

Fig. 3. Antarctic and Indian Ocean region showing continent outlines, ridge crests, fracture zone locations, and correlation of magnetic anomalies *18* and *31*. Arrows indicate directions of postulated crustal shift that tend to explain attitude of the Ellsworth Mountains (*E*), Pensacola Mountains (*P*), Horlick Mountains (*H*); other Transantarctic Mountains, cross-lined. [After Le Pichon (*8*), modified]

(*10*) (see Fig. 1), the deepest part of the Weddell Sea is a broad lateral trough in the marginal area near the Coats Land coast. This may mark the place from which the Ellsworth fragment has been transported. The Weddell tongue would also come in lateral contact with the crustal tongue of the Scotia Arc and with the Antarctic Peninsula. The reaction of counter movements of Pacific and Atlantic crustal tongues might readily account for reorientation of the Ellsworth Mountains, comparable to the orientation of the South Sandwich Islands at the tip of the Scotia Arc. The Coats Land trough continues as a frontal depression west of the Ellsworth Mountains (Bentley trough), in a position analogous to the South Sandwich trench distal to the front of the Scotia Arc. This movement could also account for the southern bend of the Antarctic Peninsula.

If the Ellsworth Mountains were located due north of the Pensacola Mountains during the early Mesozoic, the folding of both mountain systems could be explained as a common result of the same compressional stress. However, such folding must be older than the present regime of sea-floor spreading and probably took place before the Antarctic plate had developed its present configuration. Latest folding of the Ellsworth and Pensacola mountains was essentially completed before injection in the northwest part of the Pensacola Mountains of the Dufek layered gabbro (*11*).

The present lack of strong seismic events within the Antarctic Continent south of the Scotia Arc suggests that the Antarctic plate is now near a state of minimum mobility. Perhaps this condition has existed since about the middle of the Tertiary, but the sedimentary and fossil record of Tertiary events in Antarctica is poor. Active movement of the Weddell tongue may have stopped about this time. However, nothing about the stratigraphy and structure of the Antarctic continent indicates that through the earlier part of its history it was not just as tectonically and seismically active as any of the other southern continents.

The present configuration of Antarctica must be regarded as the result of an early Tertiary succession of crustal events, the latest of which may be as old as Paleogene and is probably responsible for (i) displacement of the Ellsworth Mountains block and (ii) the basal curve of the sigmoid trend of the Antarctic Peninsula. As Le Pichon (*8*) has indicated, the Scotia Arc seems to have grown throughout the Tertiary and its seismic activity still continues. The Weddell tongue, on the other hand, probably ceased to be extended as seismic activity decreased. A marked decline in late Tertiary movement also may be responsible for heavier sedimentary cover and poor definition of the magnetic reversal bands in the South Atlantic. The central position of the Antarctic plate (*12*) between dominant midoceanic ridges (Fig. 3), as well as the static load of ice, may have influenced the modern aseismicity of Antarctica (*13*).

The central position of Antarctica in a southern crustal plate may also be responsible for other perplexing features of Antarctic geology. Although the transantarctic front has been regarded as the frontal scarp of a horst by Priestley and David (*14*), and as a major anticlinal structure by Hamilton (*15*), my present conception is that it represents a rift margin that has been subjected to some fragmentation. Somewhat similar suggestions have previously been made by others (*16*), and even Du Toit's (*17*) famous Gondwana reconstruction shows West Antarctica separated from East Antarctica. If this is the correct interpretation of the geologic structure of the continent, much of the West Antarctic archipelago may be essentially accretionary in the course of organization of the present Antarctic plate.

West Antarctica may be composed of various crustal fragments of diverse origin which were distantly and separately located in late Paleozoic time. For example, the Antarctic Peninsula evidently has had a long relationship with South America, but this is not evident for the mountains of Marie Byrd Land or for the Ellsworth Mountains. Devonian deposits along the transantarctic front (*18*) represent marine and nearshore facies similar to the Bokkeveld of South Africa and those of Brazil. Fragments of the plant *Hostimella,* similar to those found in the Falkland Islands (*19*), occur in the Ohio Range of the Horlick Mountains in associated interbeds between the marine horizons. In West Antarctica, Devonian deposits are known only from the Ellsworth Mountains. This is awkward for Devonian paleogeography, but it might be more readily understood if the interposition of West Antarctic islands, now icebound, had occurred later during the Tertiary.

In further work, we should seek evidence in other southern continents of the other side of the transantarctic "rift" and other clues about the manner in which the modern Antarctic crustal plate has formed. The present configuration probably differs greatly from that of the Mesozoic, during which greater movement occurred. The Antarctic plate may occupy the position of a "keystone" in the modern configuration, and its further evaluation may demonstrate effects beyond the Southern Hemisphere. The problem of validly reconstructing a Paleozoic Gondwanaland would be simplified if West Antarctica is not regarded as part of the ancient Antarctic crustal unit.

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Antarctic Atmospheric Chemistry: Preliminary Exploration

Abstract. *The particulate and trace gas content of polar air is very similar to that of tropical air despite differences in climatology and biotic activity.*

Results of the examination of field data obtained on a trip to Antarctica in November and December 1966 have included (*1*) details of methods, equipment, locations, and interpretation. However, consideration of the data as a whole and comparison with data from other locations have not been reported.

Data on the monthly mean antarctic turbidity of periods 16 years apart (Table 1) indicate that no pronounced change in the turbidity in the antarctic atmosphere has occurred over the intervening 16 years (*2*). Any changes in the northern temperate regions (*3*) must be local and are not yet reflected in antarctic data.

Data on atmospheric turbidity in Antarctica reveal a concentration of 5 to 50 particle/cm^3 with radii between 0.1 and 1.0 μ in a 10-km column. Examination by optical and electron microscopy of the particles collected with an impactor indicate 0.1 to 1.0 particle/cm^3 in the radius interval between 0.1 and 1.0 μ. This latter finding is lower than the concentration derived from measurements of atmospheric turbidity, a common characteristic in this type of comparison probably due to the contribution to the turbidity from the stratospheric aerosol layer of sulfate near 20 km.

Table 1. Antarctic turbidity.

Month	Atmospheric turbidity *B*	S.D.
November 1950	0.016	0.007
December 1950	.026	.006
November 1966	.022	.006
December 1966	.024	.004

Although many studies have been made of airborne particles in temperate regions, little is known about the nature and concentration of such particles near the poles. Using an impactor, Fenn *et al.* (*4*) found that about 40 percent of the mass of aerosol particles in the air above the Greenland ice cap consists of sulfate particles. The relative concentration of sulfate is much higher than that commonly found in tropospheric air particles, except near localized sources, in most parts of the world (*5*). Numerically, concentrations of collected particles in the air of Antarctica varied from about 0.01 particle/cm^3 in the upper Taylor Valley and on the Ross Ice Shelf to 1.0 particle/cm^3 at 5000 feet on Mount Discovery. In McMurdo Station the air contained much greater concentrations of particles, mostly dark-colored, that almost certainly consisted mainly of powdered lava from the ground in that area.

Morphology (*6*), electron diffraction patterns, and melting points indicate that the range of particles from nearly pure sulfuric acid to nearly pure ammonium sulfate accounts for more than 50 percent of all particles. Particle shapes and a few electron diffraction patterns also indicate that some (less than 10 percent) of the particles collected may consist of sodium chloride. There is an indication of some mineral content, probably calcium aluminum silicates, particularly in those samples collected around McMurdo Station, which is built on lava and has a fair amount of vehicular traffic.

The high relative concentrations of sulfate agree with results obtained in the Arctic from the Greenland ice cap (*4*). The low chloride-sulfate ratio agrees with previous arctic data.

Electron diffraction patterns indicate that persulfate, $S_2O_8^{2-}$, may be present. If so, the persulfate is evidence for the stratospheric origin of the particles, since Friend (*7*) found this highly oxidized form of sulfur in stratospheric particles. Because downward mixing by subsidence is greatest in winter, measurement of sulfate concentrations in winter might indicate still higher concentrations.

Studies of trace substances in the air of remote tropical locations (*8*) have revealed a wide variety of organic and inorganic compounds. Conditions in Antarctica are such that temperature and biotic activity are much reduced as compared with the tropics, and these trace gases would be expected to be correspondingly reduced, especially if they are short-lived. On the other hand, gases whose lifetimes exceed average tropospheric mixing times should be present in comparable amounts in tropical, temperate, and polar regions; this is true for ozone and carbon dioxide, each of which occurs in comparable amounts throughout the world (*5*).

Table 2 summarizes data on trace gases and particles from several locations. The higher value for formaldehyde from Antarctica is somewhat in doubt as the analytical reagent releases gas bubbles which are very difficult to remove from the surface of the cuvettes. In Antarctica, concentrations of formaldehyde and nitrogen dioxide were highest at McMurdo Station; sulfur dioxide concentrations were highest on the Ross Ice Shelf, at the upper stations on Mount Discovery, and in the aircraft sample at 10,000 feet over Mount Discovery, thus indicating that this gas is not related to any human activity in Antarctica.

Table 2. Trace gases and particulates.

Locality	HCHO (ppb)	NO_2 (ppb)	SO_2 (ppb)	Particle/cm^3 with radius between 0.1 and 1.0 μ (No.)
Antarctica (*1*)	0–10(?)	0–3	0–2	~1
Panama (*8*)	0–3	0.5–1.5 (dry); 2.5–5 (rainy)	1–5	<1
Continental (*5, 10*)	0–10	0–20	0–100	10^3
Urban (*11*)	~100	~200	~500	~10^4