

Geology of the Ellsworth Mountains

Campbell Craddock¹

The Ellsworth Mountains were discovered in November 1935 by Lincoln Ellsworth during his flight across West Antarctica (Ellsworth, 1936, 1937; Joerg, 1936a, 1936b, 1937). This slightly arcuate mountain chain extends about 350 km in a north-northwest direction and is bordered by the polar plateau on the west and the Ronne Ice Shelf on the east. Because these mountains lie between Marie Byrd Land, the Antarctic Peninsula, and the Transantarctic Mountains, they are critical in determining the geologic evolution of the continent (Craddock, 1966).

The Ellsworth Mountains are divided by the eastflowing Minnesota Glacier into the Sentinel Range to the north and the Heritage Range to the south. The Sentinel Range contains one major, markedly asymmetric block with its summit ridge near the western edge of the mountains. Peak elevations diminish gradually on the eastern side, and heavily crevassed glaciers descend from the crest line to the ice shelf; the western side of the range, however, is marked by a steep and towering escarpment. The Vinson Massif in the Sentinel Range is believed to be the highest peak in Antarctica. In contrast, the Heritage Range consists of numerous dispersed massifs, hills, and nunataks. Outcrops are abundant in both ranges, but rock slopes are commonly steep or sheer. Most of the Heritage Range is easily accessible by motor toboggan, but surface travel is difficult and dangerous in much of the Sentinel Range.

The first visit to the Ellsworth Mountains was in 1958, when an oversnow traverse from Byrd Station reached two nunataks about 17 km west of the main Sentinel Range; large crevasse fields prevented their entry into the mountains proper (V. Anderson, 1960, 1961). In 1959 a party consisting of Edward C. Thiel, Edwin S. Robinson, and the writer conducted an aerial reconnaissance of the central and southern Ellsworth Mountains, landed in the northwestern part of the Heritage Range, and briefly studied the geology of a nunatak there (Thiel, 1961). Beginning in November 1961, University of Minnesota expeditions spent three successive field seasons mapping the geology of the

¹University of Minnesota at the time this text was prepared; now at University of Wisconsin.

Ellsworth Mountains. Geologists in these expeditions were: 1961-1962, John J. Anderson, leader, Thomas W. Bastien, Paul G. Schmidt, and John F. Splettstoesser; 1962-1963, Campbell Craddock, leader, Gerald F. Webers, deputy leader, Peter J. Barrett, J. Dolence, Ben Drake, Harvey J. Meyer, and Donald E. Soholt; 1963-1964, Robert H. Rutford, leader, Thomas W. Bastien, deputy leader, John P. Evans, Barton Gross, W. D. M. Hall, and Bernhard Spörli. The first two Minnesota expeditions used motor toboggans for travel (Craddock and Soholt, 1964), but the last expedition had the support of turbine helicopters.

Sedimentary and Volcanic Rocks

Almost all of the bedrock of the Ellsworth Mountains consists of strongly folded, slightly to moderately metamorphosed sedimentary or volcanic rocks (J. Anderson et al., 1962; Craddock et al., 1964; J. Anderson, 1965). The minimum thickness of this stratigraphic sequence is about 13,160 m, and no definite unconformities have been found. The oldest beds are probably of late Precambrian age, and the youngest formation is Permian. Available evidence suggests that most or all of these rocks accumulated under marine conditions. The sequence has been divided into the following five units, in ascending order: the Minaret Group, the Heritage Group, the Crashsite Quartzite, the Whiteout Conglomerate, and the Polarstar Formation.

The Minaret Group consists of tightly folded, recrystallized, thick-bedded, light-gray carbonate rocks. A few beds are oolitic or pisolitic, and some are distinctly silty. The base of the group does not crop out, but the thickness of the exposed sequence is estimated at 975 m. A probable contact with the overlying Heritage Group is known in only one locality, where it appears to be conformable. The Minaret Group comprises the oldest rocks exposed in the Ellsworth Mountains; on the basis of stratigraphic position it is considered probably late Precambrian in age.

The Heritage Group is composed of a thick sequence of varicolored, mainly clastic rocks such as argillite, slate, phyllite, sandstone, quartzite, and con-

glomerate. Some carbonate units occur in the upper part of the group, including one 275-m light-gray marble. Mafic lava flows have been found at three localities, and pillow structure is present in some of these eruptive rocks. No single complete section is exposed, but correlation of several measured sections indicates a total thickness for the group of about 6700 m. Both lower and upper contacts are considered conformable, and the latter records a gradual transition from dark-gray pelite to the overlying Crashsite Quartzite. A prolific fossil site occurs at the north end of Webers Peaks in a limestone bed about 120 m below the top of the Heritage Group. The Late Cambrian fauna found here includes trilobites, mollusks, brachiopods, an archaeocyathid, and pelmatozoan columnals (Craddock and Webers, 1964; Webers, 1966). Three other trilobite or brachiopod collections have been obtained from beds in the upper third of the Heritage Group, and some of these fossils are probably as old as Middle Cambrian. Thus the upper Heritage Group is Cambrian, but the lower part may include some beds of Precambrian age.

The Crashsite Quartzite consists mainly of wellsorted, medium- to coarse-grained, thick-bedded quartzite; rock colors include greenish-gray, gray, tan, buff, and white. Cross-bedding is abundant, and current ripple marks are common. A few scour-and-fill structures and oscillation ripple marks are present. The quartzites consist predominantly of quartz with minor plagioclase and potash feldspar, and some volcanic rock fragments occur in the upper part of the formation. Thin units of argillite, slate, and pebble conglomerate are locally interbedded with the quartzite. The minimum thickness is estimated at 3200 m. The formation resists degradation effectively, and it underlies all the high peaks of the central Sentinel Range. Fossils are rare in the Crashsite Quartzite, but fragmental inarticulate brachiopods were found near the base of the formation at three localities. A brachiopod fauna of probable Devonian age has been collected from the upper part of the formation in the northern Heritage Range. The Crashsite Quartzite has been divided into three units in the Sentinel Range: a lower dark member, a light member, and an upper dark

The Whiteout Conglomerate is a massive, dark gray formation about 915 m thick. Sorting is very poor, and the rock consists of angular to rounded rock and mineral fragments ranging from clay-size particles to 5-m boulders. These fragments are composed of quartzite, vein quartz, granite, gneiss, schist, phyllite, argillite, chert, sandstone, conglomerate, and limestone. Shale and sandstone lenses occur at two locali-

ties, but bedding in the formation is rare. Both the lower and upper contacts appear conformable, although some evidence suggests the latter may be a disconformity. The only known fossils are some unidentified forms in limestone boulders.

The Polarstar Formation consists of interbedded, dark-gray, silty argillite and arenaceous rocks, mainly graywackes. Bedding is distinct and ranges from one millimeter to one meter in thickness. Graded bedding, cross-bedding, current ripple marks, and slump structures occur in the graywacke beds. Coal beds as much as 30 cm thick are present in the upper quarter of the formation. The top of the formation does not crop out, but the thickness of the exposed sequence is about 1370 m. Glossopterid leaves have been collected from six units in the upper third of the Polarstar Formation. This flora includes species of Glossopteris and Gangamopteris, and it is considered Permian in age (Craddock et al., 1965).

Intrusive Igneous Rocks

Tabular, mafic, intrusive bodies crop out at four localities in the Heritage Range; these occurrences are too small to plot on this map. All these igneous rocks are altered, but they probably belong to the gabbro-basalt clan. At three localities the intrusives are sills, and it is not clear whether their emplacement preceded or followed the folding of the sedimentary rocks. At one locality near the southern end of the Heritage Range, however, the Minaret Group is cut by a dike which appears to be post-tectonic.

Structural Geology

The entire stratigraphic sequence of the Ellsworth Mountains has been strongly deformed and subjected to low-grade regional metamorphism. The tectonic grain parallels the axis of the mountains; it strikes about N 50°W in the south and changes gradually to about N 15°W in the north. Rock cleavage and folds are abundant structural elements, and joints and minor faults are common. The cleavage typically dips steeply southwestward and lies about parallel to the axial planes of the folds. It is best developed in the slates, but even such rocks as marble, quartzite, graywacke, and conglomerate exhibit fair to good fracture cleavage. The Minaret Group is cut by numerous white calcite veins; and quartz-epidote-chlorite veins are common in the younger strata.

Most sizeable outcrops display folds; types present include symmetric, asymmetric, overturned, recumbent, chevron, and isoclinal. Common wave lengths range from 15 m in the medium- to thick-bedded quartzites up to 3000 m in the massive Whiteout

Conglomerate. Most fold axes plunge northwest at angles less than 15°, but a few axes in the Minaret Group plunge as much as 70°.

Many joints and minor faults are present, but few faults of proven large slip have been discovered. Many of the small faults are oblique and result from shearing after tight folding; they commonly occur as conjugate sets. Two important strike faults are shown in the Heritage Range; their mechanical classification is indefinite, but they are probably reverse faults.

Dozens of irregularly shaped breccia bodies are widely distributed throughout the Minaret Group. One cylindrical body is 45 m wide and at least 75 m high; another mass extends about 245 m up the face of one peak. Angular blocks of carbonate rock up to 6 m long are set in a matrix of coarsely crystalline white calcite, locally deposited in distinct layers paralleling the edges of the block. These breccia bodies postdate the formation of both folds and cleavage in the Minaret Group, and they are interpreted as solution collapse structures.

Geologic History

The known geologic history of the Ellsworth Mountains began in late Precambrian or early Cambrian time with the deposition of carbonate sediments, probably in a shallow marine environment. Subsidence and deposition continued in this area, possibly without interruption, until Permian time; and a sedimentary section, at least 13,160 m thick, accumulated. The chemical sedimentary rocks in the lower part of the sequence yield to clastic varieties higher in the section. Volcanic activity was limited in the early history of this geosyncline, but volcanic rock fragments are a significant constituent of some of the upper units. Most or all of these strata probably accumulated under marine conditions, mainly in shallow to moderate depths. The Whiteout Conglomerate is considered a glaciomarine deposit of late Paleozoic age.

Sometime after the deposition of the Polarstar Formation (Permian), all strata in the geosyncline underwent orogeny, resulting in regional metamorphism and intense folding. Some of the tabular mafic intrusives were probably emplaced after this orogeny. Since Permian time the deformed rocks of this geosyncline have been elevated a minimum of 6000 m. Rolling upland surfaces of modest relief suggest that this uplift may have been in two stages separated by a stable interval of erosional gradation.

Continuing uplift and dissection formed the major outlines of the present ranges. Alpine glaciation may have begun in the ancestral Ellsworth Mountains as

early as Mesozoic time, and many features of the modern landscape result from local glacial processes. The mountains were engulfed by the continental ice sheet during middle or late Cenozoic time. At least 300 m of deglaciation has occurred since the ice sheet surface reached its maximum elevation adjacent to these mountains.

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