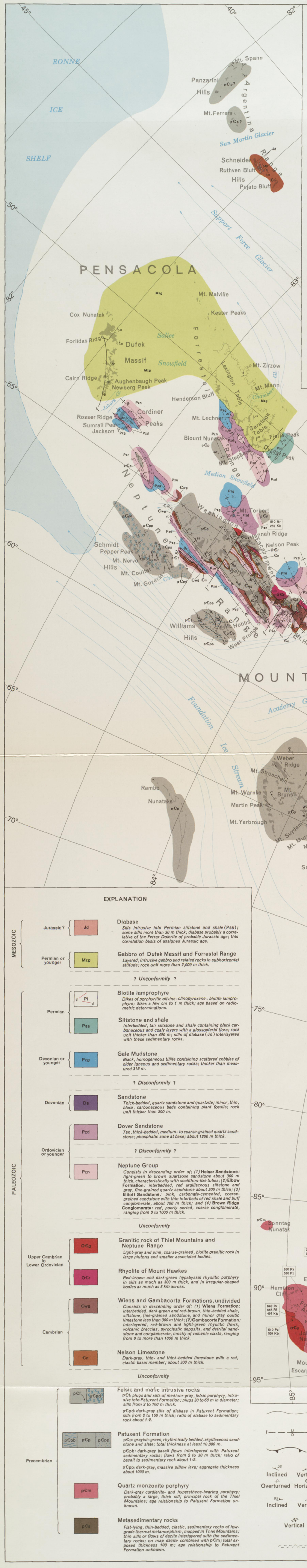

TABLE 2. RADIOMETRIC AGE DETERMINATIONS

Location	Lithology	Method and Material	Age (m.y.)	Ref.
85°17′S, 89°20′W	Granodiorite	Pb-Zircon	720±90	1
		K-Ar Biotite	500*	1
85°20′S, 88°05′W	Hypersthene-quartz monzonite porphyry	Pb-Zircon	670±50	3
85°02′S, 91°37′W	Granodiorite	Rb-Sr Whole Rock	648±85	1
		Rb-Sr K-feldspar	646±85	1
		K-Ar Biotite	491*	1
85°04′S, 90°10′W	Hypersthene-quartz monzonite porphyry	Pb-Zircon (nonmag.)	630±70	2
		Pb-Zircon (mag.)	530±60	2
85°09′S, 90°40′W	Hypersthene-quartz monzonite porphyry	Pb-Zircon	620±70	2
85°27′S, 87°00′W	Granodiorite	Rb-Sr Whole Rock	570±70	1
		K-Ar Biotite	484*	1
		Pb-Zircon	470±50	3
85°17′S, 89°30′W	Granodiorite	Pb-Zircon	560±60	3
		K-Ar Biotite	511*	1
85°02′S, 91°45′W	Granodiorite	Pb-Zircon	510±50	1
		K-Ar Biotite	504*	1
83°35′S, 54°40′W	Granite	Rb-Sr Whole rock	510±30	1
		K-Ar Biotite	265*	1
85°25′S, 86°44′W	Adamellitic pegmatite (glacial erratic)	Rb-Sr Muscovite	510±20	4
84°53′S, 62°10′W	Biotite lamprophyre	K-Ar Biotite	244*, 219*	1
84°52′S, 63°34′W	Biotite lamprophyre	K-Ar Biotite	233*	1

* Over-all analytical error is about ±5 percent of age value.

1. Unpublished. Analytical data may be obtained by writing to the authors, U.S. Geological Survey, Menlo Park, California.
2. Ford *et al.*, 1963
3. Ford, 1964
4. Craddock *et al.*, 1964

Geology of the Pensacola and Thiel Mountains[1]

D.L. Schmidt[2] and A.B. Ford[3]

The Pensacola and Thiel Mountains are part of the Transantarctic Mountain chain and extend for a distance of 650 km between 45°W and 90°W longitude. The Pensacola Mountains consist of the Patuxent, Neptune, and Forrestal Ranges and the Dufek Massif. These mountains were first sighted on U.S. Navy reconnaissance flights during preparation for the International Geophysical Year. Subsequent expeditions with their principal participants are listed in Table 1. Geological studies, on which the accompanying map is based, were made by the U.S. Geological Survey as part of a continuing program of geological research supported by the National Science Foundation. Radiometric age determinations were made in the laboratories of the U.S. Geological Survey.

Physiography

The Pensacola and Thiel Mountains form a bedrock block between the polar plateau ice at altitudes above 2400 m and the Ronne Ice Shelf at altitudes of a few tens of meters. Within the map area the plateau ice flows seaward against this mountain block and passes through it in two large outlet glaciers: one, about 145 km wide, between the Thiel Mountains and the Patuxent Range, and the other, about 122 km wide, between the Forrestal Range and Mt. Ferrara. Large, flat-topped masses, standing more than 1000 m above the surface of the two outlet glaciers, form central highlands of the ranges. The highland of the Thiel Mountains is highest, with a summit plain at about 2800 m. In all the ranges ragged ridges of rock and intramontane valleys of ice extend outward and downward from the central masses.

Within each mountain range snow and ice accumulate in the intramontane valleys and basins and have made miniature ice caps on the central highlands. This local ice cascades from the central ice caps down 1500-m rock escarpments and flows over a series of less impressive escarpments between the central highland and the outlet glaciers. Some of this ice flows into the outlet glaciers, but much of it is ablated on large, blue-ice fields in the lower parts of the valleys and in basins within the individual mountain ranges (W.W. Boyd, Jr., written communication, 1964).

The Patuxent and Neptune Ranges, and the Thiel Mountains were once completely covered by ice flowing from the polar plateau. This is indicated by striated bedrock surfaces that occur throughout the ranges, even at their highest parts, and by thick moraines on the highest parts of the Patuxent Range. These moraines contain sandstone and diabase that could only have been transported by ice from upglacier, from beneath the polar plateau ice.

Geologic History

General statement. The Pensacola and Thiel Mountains are part of an ancient orogenic belt that nearly coincides with the present Transantarctic Mountains. The geologic history of the Pensacola Mountains includes much of the sequence of events that has made the Transantarctic Mountains one of the great mountain belts of the world. At least three episodes of mountain building during late Precambrian and Paleozoic times occurred in the Pensacola Mountains (Schmidt *et al.*, 1964, 1965). The geologic history of the Thiel Mountains is different (Ford, 1964; Ford and Aaron, 1962) and is summarized separately below. The stratigraphy of both mountain areas is briefly described in the explanation of the geologic map. Radiometric age determinations and sites of dated rocks are shown on the geologic map and are tabulated in Table 2. The geology of the Forrestal Range, Dufek Massif, and Cordiner Peaks is subject to slight revision since only preliminary results were available at the time the map was being compiled.

Pensacola Mountains. During late Precambrian time large quantities of terrigenous turbidite sediment (p€p, Patuxent Formation) were deposited in a large geosynclinal basin in the Pensacola Mountains region. Interbedded pillow lavas (p€pp) and basalt flows (p€pb) indicate that volcanism occurred at various times during the deposition of the sediments and that large volumes of diabase (p€pd) and minor amounts of felsic magma (p€f) were injected into them. Prior to the Cambrian, these sediments were intensely folded and transformd into slates and well-indurated graywackes. The rocks were uplifted and exposed to subaerial erosion, forming perhaps the first ancestral Transantarctic Mountains.

Early during the Cambrian the mountains were well eroded. Marine transgression followed, with deposition of limestone (€n, Nelson Limestone) containing brachiopods and trilobites of Middle Cambrian age (A.H. Palmer, written communication, 1964). Archaeocyathids are abundant in the limestone at Ruthven Bluff but are poorly preserved elsewhere. Subsequent volcanism in the central Pensacola Mountains area resulted in the accumulation of a thick pile of felsic flows and pyroclastic rocks (€wg, Gambacorta Formation). Silt and mud beds (€wg, Wiens Formation) were in part interlayered with, and in part overlie, the volcanic deposits.

A second episode of mountain building occurred by the end of the Cambrian. The Cambrian sedimentary and volcanic rocks were folded, the older Precambrian rocks were further deformed, and granitic magma was intruded as sills and shallow bodies of rhyolite porphyry (O€r) and as a deep-seated granitic pluton (O€g of Neptune Range). The radiometric age of the granite, based on a Rb-Sr whole-rock analysis, indicates that the granite cooled during Early Ordovician time (Z.E. Peterman, written communication, 1964).

A conspicuous, coarse, and poorly sorted gravel (Pzn, Brown Ridge Conglomerate), locally as thick as a thousand meters, was deposited in places in the Pensacola region during the initial intensive erosion of the mountains. Sand and silt with interbeds of gravel (Pzn, Elliott Sandstone) were deposited and were succeeded by red silt and clay (Pzn, Elbow Formation) and, in turn, by beds of quartz-rich sand (Pzn, Heiser Sandstone) containing abundant worm tubes, perpendicular to the bedding. This sequence of sedimentary rocks probably represents a succession of erosion of local mountains, a marine transgression, and a marine regression.

The name, Neptune Group (Pzn), is proposed here for the rock-stratigraphic unit consisting of the Brown Ridge Conglomerate, Elliott Sandstone, Elbow Formation, and Heiser Sandstone. The Neptune Group is named for the Neptune Range, where the individual type sections of the four formations are located (Schmidt *et al.*, 1965). The base of the Neptune Group is the unconformity at the base of the Brown Ridge Conglomerate, and the top is a probable disconformity at the base of the overlying Dover Sandstone.

A pause in sedimentation or an interval of moderate erosion before deposition of a basal quartz-pebble gravel and the quartz sand of the Dover Sandstone (Pzd) is marked by a disconformity. Sparse, black phosphate pebbles in the basal conglomerate are additional evidence of the disconformity.

In the southernmost Patuxent Range a coarse-grained tan sandstone (Ds) has a few interbeds of carbonaceous sandstone and siltstone containing plant fossils of probable Late Devonian age (J. M. Schopf, written communication, 1963). This unit is lithologically similar to the Dover Sandstone of the Neptune Range, but the two units cannot be correlated other than by lithology.

A massive, black, pebbly mudstone (Pzg, Gale Mudstone) containing scattered pebbles and cobbles of granite, gneiss, and rocks from underlying sedimentary strata was deposited on top of the Dover Sandstone. The unit is probably more than a thousand meters thick and occurs without apparent lithologic change throughout an area of more than 12,000 km² in the Pensacola Mountains. The rock has many characteristics of tillite. Very likely, the pebbly mudstone was deposited during the period of late Paleozoic glaciation when tillite was deposited in the Horlick Mountains (Long, 1964) and elsewhere in the Transantarctic Mountains.

On the Pecora Escarpment south of the Patuxent Range and in the southern Forrestal Range, well-bedded, light-tan quartzose sandstone, siltstone, and shale (Pss) occur with many conspicuous interbeds of carbonaceous and coaly sediments that locally contain abundant fossil leaves of a glossopterid flora of Permian age (Schopf, 1964). These rocks are similar to those of the Beacon Group found elsewhere in the Transantarctic Mountains (for example, Gunn and Warren, 1962).

Sometime after the deposition of the Permian sedimentary rock, mountain-building forces acted for a third time forming broad and locally tight to overturned folds in the sedimentary rocks of the Neptune Group, the Dover Sandstone, and the Gale Mudstone of the Neptune and Forrestal Ranges, as well as in the Permian rocks of the Forrestal Range. At the same time, the older rocks were further deformed and uplifted, and again a chain of mountains came into existence. The third mountain-building episode is of Permian or younger age but is probably older than the intrusion of the stratiform gabbro of the Dufek Massif and Forrestal Range.

The Permian rocks on the Pecora Escarpment are not deformed, thus suggesting that the effects of the third mountain-building episode did not extend that far south. These undeformed sedimentary rocks, however, were intruded by diabase (Jd) in the form of thick sills. The diabase may be equivalent to the Ferrar Dolerite of probable Jurassic age (McDougall, 1963) that is commonly intrusive into the Beacon Group elsewhere in the Transantarctic Mountains.

Stratiform pyroxene gabbros and less abundant related rocks, at least 2000 m thick, make up the Dufek Massif and most of the Forrestal Range. The Dufek Massif forms a tilted fault block bordering the Ronne Ice Shelf (Aughenbaugh, 1961). If, as seems likely, the mafic rocks of both ranges form parts of a single intrusive mass, the body has a minimum areal extent of about 8000 km². Neither base nor top of the stratiform body is exposed, but fine-grained chilled phases locally border contact-metamorphosed Paleozoic quartzites. Pyroxenite layers, 1 to 3 m thick, occur at several horizons and are extremely widespread. Pyroxenites, which are characteristically feldspathic, generally lie with sharp contact on anorthosite or leucogabbro and grade upward into dark- or medium-gray gabbro. Foliation (igneous lamination) invariably parallels rhythmic layering. Channel-like structures, some filled with anorthosites and metallic-rich layers and lenses and others with layered pyroxenites, are interpreted to have been formed by currents—perhaps of convection origin—that moved across the partly consolidated floor of the magma chamber. The age of the body is uncertain, but a post-Permian one is indicated by the metamorphic effects in nearby carbonaceous Permian beds.

The historical relationship of dikes of black biotitic lamprophyre (Pl) is not yet clear. The dikes cut across the strike of the folded rocks of the Patuxent Formation in the Patuxent Range (Schmidt *et al.*, 1964). Three radiometric dates on biotite from the lamprophyre average 232 m.y., based on K-Ar analyses (S. S. Goldich, written communication, 1964). Intrusions of this type or of Late Permian age are not presently known elsewhere in the Transantarctic Mountains.

Structural deformation younger than the third episode includes warping and faulting over a broad region. A frontal fault of unknown, but probably large, displacement separates the Pensacola Mountains from the rocks beneath the Ronne Ice Shelf. Relatively recent movement along this and related faults probably accounts in part for the present height of the Pensacola Mountains as well as the Transantarctic Mountains in general.

Thiel Mountains. The oldest rocks are a 100-m thick series of low-grade, thermally metamorphosed, thin-bedded clastic sedimentary rocks (p€s) concordantly interlayered with thin sills or flows of dacite (combined on map with p€m). They have a nearly horizontal attitude. Stromatolites in a thin marble layer are the only fossils known (Campbell Craddock, written communication, 1964). A Precambrian age is probable since the sedimentary rocks are intruded by a large sill-like body of quartz-monzonite porphyry of late Precambrian or earliest Paleozoic age.

Fine- to medium-grained, dark-gray, cordierite-hypersthene, quartz-monzonite porphyry (p€m) is the most widely exposed rock throughout the approximately 2000-km² mountain area. The porphyry is homogeneous in most exposures, but at one place faint layering defines a broad anticlinal structure having a minimum amplitude of 500 m; at another place strongly gneissose structure is apparently due to magmatic flowage. Textures are typically igneous, and the body appears to form a large sill. Phenocrysts of plagioclase, quartz, potassium feldspar, hypersthene, and cordierite are set in a fine-grained matrix of quartz and feldspar. Hypersthene and a distinctive violet cordierite are uniformly scattered in small amounts throughout the body. Radiometric study of minerals from the porphyry indicates a late Precambrian to earliest Paleozoic age (Aaron and Ford, 1963; Ford *et al.*, 1963).

Discordant granitic masses (O€g) that belong to a single or perhaps several related plutons have intruded the sill-like porphyry body. Granitic, aplitic, and pegmatitic dikes, apparently related to the larger plutons, also cut the porphyry at several places. The granitic rock is mostly granodioritic to quartz monzonitic in chemical and modal composition. These rocks are clearly younger than the quartz-monzonite porphyry, and radiometric studies indicate an early Paleozoic, probably Late Cambrian to Early Ordovician, age (Aaron and Ford, 1963).

Sedimentary rock, coeval to the Beacon Group, and diabase, which is perhaps equivalent to the Ferrar Dolerite, probably underlies the ice-covered escarpments in the southern part of the Thiel Mountains. These rock types make up most of the recognizable morainal erratics on the southernmost nunataks (Ford, 1964).

Structure in the Thiel Mountains is not easily discernible in the chiefly massive types of rocks exposed there. High-angle faults cut the metasedimentary beds and the sill-like porphyry body on several nunataks. A faintly outlined anticline and a syncline indicate broad, open folding of the porphyry body, but where discernible elsewhere the porphyry and intruded metasedimentary rocks are nearly horizontal or form gently tilted fault blocks.

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TABLE 1. SURFACE AND AIRBORNE EXPLORATION OF THE PENSACOLA AND THIEL MOUNTAINS

Expedition	Area and Personnel
PENSACOLA MOUNTAINS	
U.S. Navy transpolar reconnaissance flight (Jan. 13, 1956)	From McMurdo to Filchner Ice Shelf; photographed Pensacola Mountains on flight path over the Forrestal Range; W. M. Hawkes, pilot.
IGY reconnaissance flight (U.S.) (Oct. 23, 1957)	From Ellsworth Station to the Dufek Massif; no landing; F. Ronne, E. Thiel, observers.
Ellsworth Station IGY traverse (U.S.) (Dec. 9-15, 1957)	Geological reconnaissance of the Dufek Massif (Aughenbaugh, 1961; Walker, 1961).
U.S. Air Force photographic flight (Jan. 28, 1958)	Aerial trimetrogon photographic strip of northern two-thirds of the Pensacola Mountains; J. W. Lassiter, pilot; W. H. Chapman, topographic engineer.
U.S. Geological Survey geologic reconnaissance (Field season, 1962-1963)	Patuxent Range motor-toboggan traverses; geologists, A. B. Ford, D. L. Schmidt, R. D. Brown, J. H. Dover; glaciologist, W. W. Boyd, Jr.; topographic engineer, T. E. Taylor (Schmidt and Ford, 1963).
U.S. Geological Survey geologic reconnaissance (Field season, 1963-1964)	Neptune Range motor-toboggan traverses; geologists, D. L. Schmidt, P. L. Williams, W. H. Nelson, J. R. Ege; glaciologist, W. W. Boyd, Jr.; topographic engineers, D. C. Barnett, J. R. Heiser (Schmidt, 1964).
U.S. Geological Survey geologic and geophysical reconnaissance (Field season, 1965-1966)	Pensacola Mountains, helicopter support; geologists, D. L. Schmidt, A. B. Ford, W. H. Nelson, W. W. Boyd, Jr.; geophysicists, J. C. Behrendt, J. R. Henderson, L. J. Meister, W. L. Rambo, R. E. Wanous; topographic engineers, E. R. Soza, J. R. Heiser, M. K. Weber, E. W. Rosser.
THIEL MOUNTAINS	
Horlick Mountains traverse (U.S.) (Dec. 1958)	Approached to within about 50 km of north end of the Thiel Mountains; obtained first geographic coordinates of area.
Airborne reconnaissance along 88° west longitude (U.S.) (Dec. 1959)	Geophysical and geological reconnaissance; visited southernmost nunatak group; geophysicists, E. C. Thiel and E. S. Robinson; geologist, C. Craddock (Thiel, 1961; Craddock *et. al.*, 1964).
U.S. Army tractor-train traverse (Dec. 1960)	Traverse from Byrd Station to Pole Station, about 10 km north of the Thiel Mountains; leader, A. Havola.
U.S. Geological Survey geologic reconnaissance (Jan. 1961)	Man-hauling traverses; geologists, A. B. Ford, J. M. Aaron, H. A. Hubbard; glaciologist, B. G. Andersen; topographic engineer, P. F. Bermel.
U.S. Geological Survey geologic reconnaissance (Field season, 1961-1962)	Motor-toboggan traverses; geologists, A. B. Ford, J. M. Aaron, R. W. Tabor, R. L. Elliott; glaciologist, B. G. Andersen; topographic engineer, P. F. Bermel (Aaron and Ford, 1963; Anderson, 1963; Ford, 1964; Ford and Aaron, 1962; Ford *et al.*, 1963).

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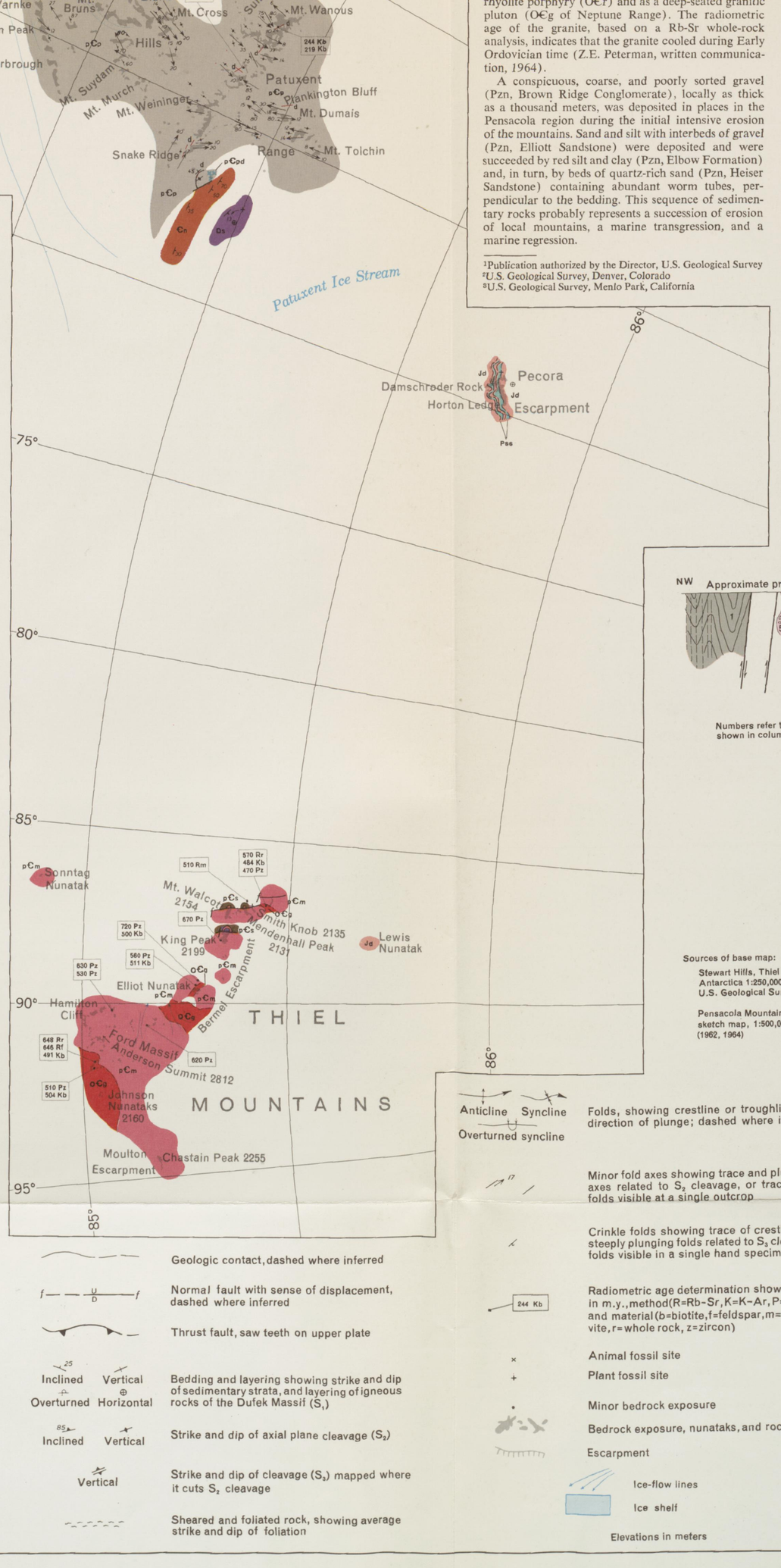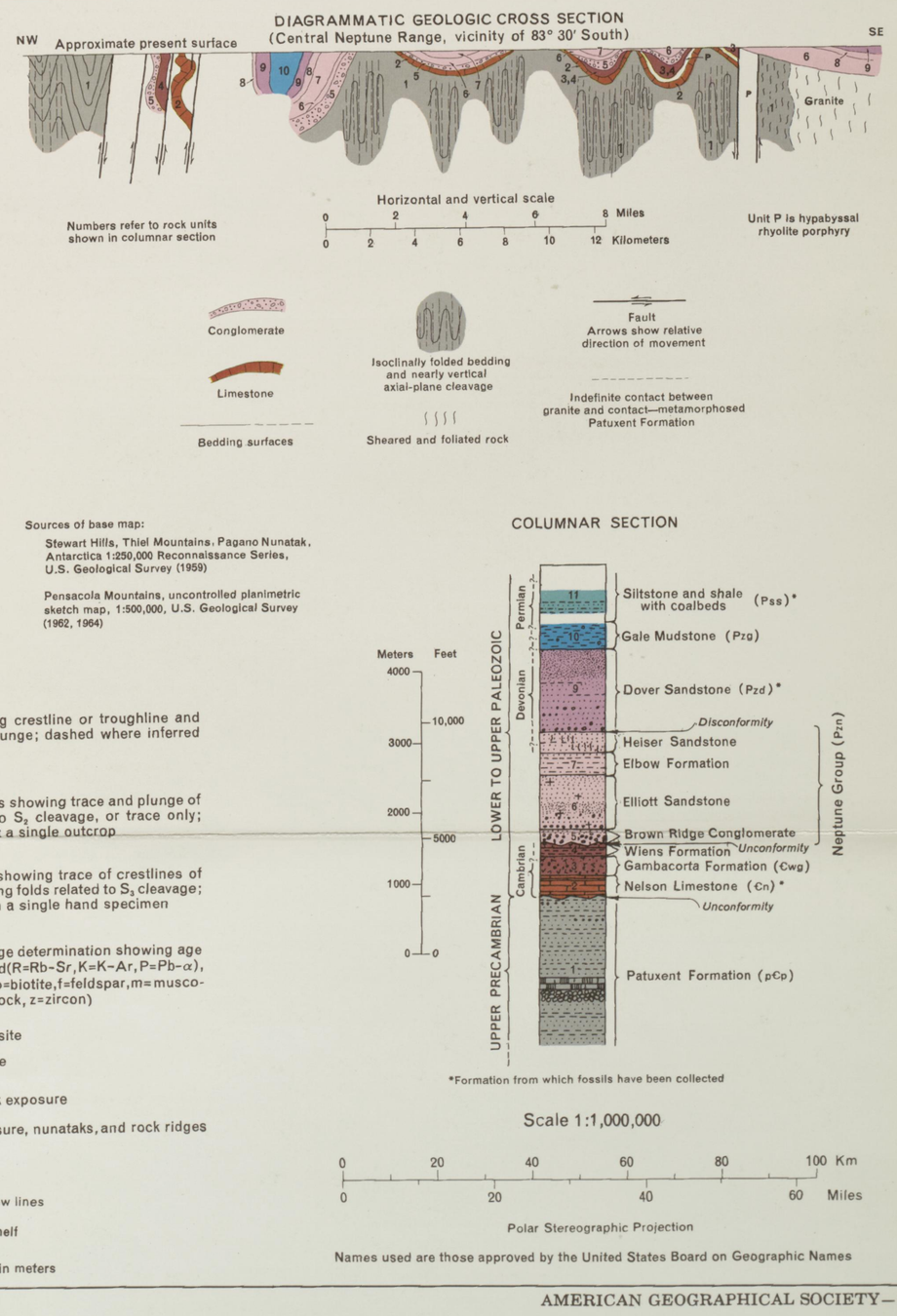
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