Stratigraphy of the Layered Gabbroic Dufek Intrusion, Antarctica

GEOLOGICAL SURVEY BULLETIN 1405-D

Work done in cooperation with the National Science Foundation

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By ARTHUR B. FORD

CONTRIBUTIONS TO STRATIGRAPHY

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Description of newly named units in a differentiated stratiform mafic intrusion in the northern Pensacola Mountains of Antarctica

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CONTENTS

ILLUSTRATIONS

METRIC-ENGLISH EQUIVALENTS

Metric unit		*English equivalent*
metre (m)	=	3.28 feet
kilometre (km)	=	.62 mile
square kilometre (km^2)	=	.386 square mile
gram per cubic centimetre (g/cm^3)	=	62.43 pounds per cubic foot

CONTRIBUTIONS TO STRATIGRAPHY

STRATIGRAPHY OF THE LAYERED GABBROIC DUFEK INTRUSION, ANTARCTICA

By ARTHUR B. FORD

ABSTRACT

The Dufek intrusion in the northern Pensacola Mountains of Antarctica is a differentiated stratiform mafic igneous complex of unusually large areal dimension, probably at least 24,000–34,000 km^2, and a thickness estimated to be 8–9 km. It is Jurassic in age and presumably correlative with the Ferrar Group of basalt and diabase elsewhere in the Transantarctic Mountains. The body consists chiefly of well-layered pyroxene gabbro that contains abundant magnetite in higher levels. Minor lithologies of layers range from pyroxenite, leucogabbro, and anorthosite to magnetitite. The sequence is capped concordantly by a 300-m-thick layer of granophyre. Textures and structures indicate that most rocks are cumulates made up of variable amounts of settled plagioclase and two pyroxenes, one rich in calcium, in the series augite-ferroaugite, and the other poor in calcium, in the series bronzite-inverted pigeonite. Magnetite is a mjaor cumulus phase in many rocks. Cumulus apatite occurs at highest levels. The rocks form a stratigraphic succession that is similar in many respects to a sequence of sedimentary strata.

The Forrestal Gabbro Group consists of all the layered rocks, of which about a 3.5-km thickness is exposed. The group is made up of four mappable formations, in ascending order the Walker Anorthosite, Aughenbaugh Gabbro, Saratoga Gabbro, and Lexington Granophyre. The Walker and Aughenbaugh form a 1.8-km-thick section in Dufek Massif, and the Saratoga and Lexington form a 1.7-km-thick section in the Forrestal Range.

Major conspicuous layers mapped within the gabbroic units are recognized as members. Two of these, the Neuberg Pyroxenite Member and the Frost Pyroxenite Member, are key marker units in the Aughenbaugh Gabbro that are widely mappable in the area of Dufek Massif. Two other members of the Aughenbaugh are an unnamed lower anorthosite member, near the base of the formation, and the Spear Anorthosite Member, at the top. Three members are recognized in the Saratoga Gabbro: the Stephens Anorthosite Member at the base and two unnamed members characterized by conspicuous, rounded, and embayed inclusions of leucogabbro and anorthosite.

INTRODUCTION

Mafic igneous rocks of an unusually large differentiated stratiform intrusion make up two of the northern ranges of the Pensacola Mountains near the southeastern edge of Ronne Ice Shelf, Antarctica (fig. 1). The gabbroic and related rocks are exposed throughout Dufek Massif and the Forrestal Range and in many nearby nunataks. They form the principal outcrops in the Cordiner Peaks, Davis Valley, and Saratoga Table quadrangles of the U.S. Geological Survey's

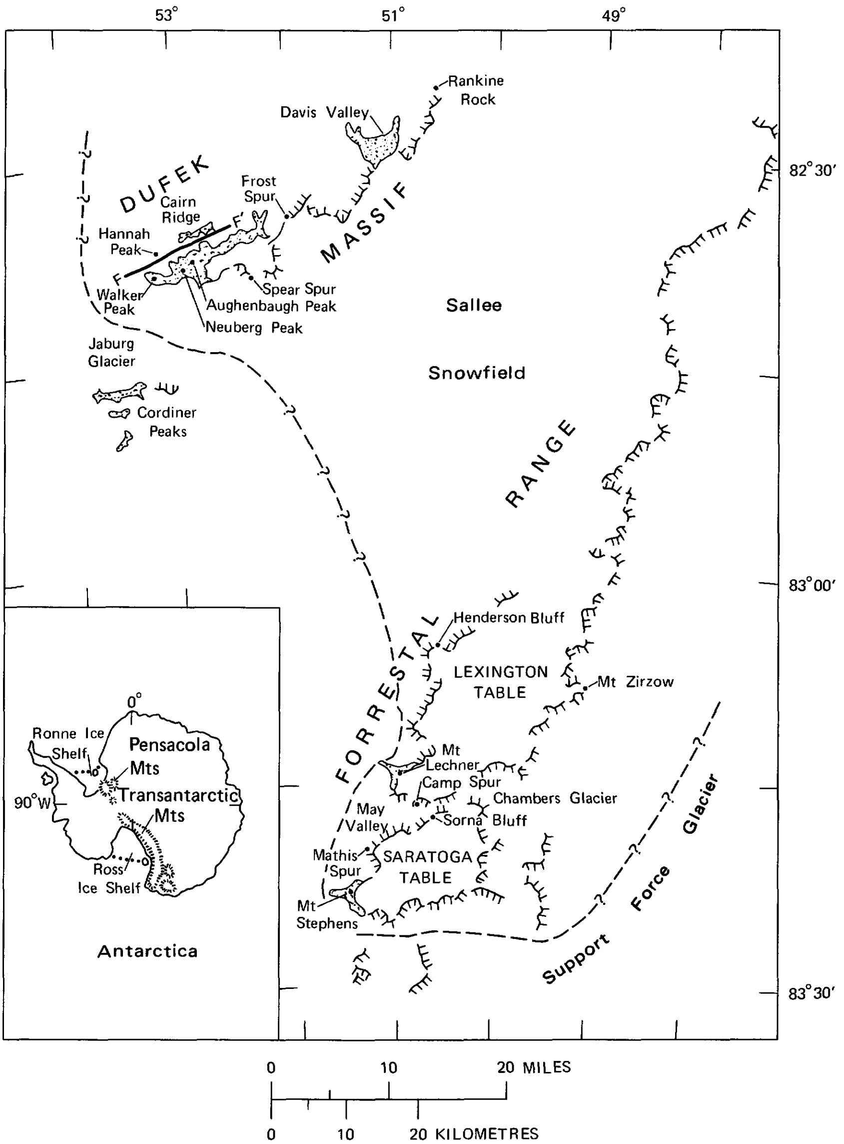


FIGURE 1.—Index map of the northern Pensacola Mountains showing major outcrops (stippled), mentioned localities, and southern limit of the Dufek intrusion (heavy dashed line). Line F–F′ shows the Enchanted Valley fault.

1:250,000-scale Antarctica reconnaissance series of topographic maps. The body was named the Dufek intrusion by Ford and Boyd (1968) after Dufek Massif (fig. 2), where a major part of its stratigraphy is well exposed.

The intrusion was discovered December 9, 1957, during mainly geographical and geophysical explorations by oversnow vehicle of inner reaches of the Ronne Ice Shelf and adjoining regions. The expedition was part of the International Geophysical Year (IGY) program at Ellsworth Station (Neuberg and others, 1959). An approximately 380-m-thick partial stratigraphic section was measured in the lowest exposed layers of the body during a 6-day visit by the IGY party. The similarity of the rocks to those of other stratiform mafic complexes was recognized at that time (Aughenbaugh, 1961; Walker, 1961).

The intrusion was mapped and sampled in detail by the U.S. Geological Survey in the austral summer 1965–66. The study was part of the final phase in completing geologic mapping of the entire Pensacola Mountains (Schmidt and Ford, 1969), a project begun in the southernmost range of the mountains in 1962–63. All major outcrops of the intrusion were either visited or viewed closely from the air by helicopter. This work was carried out from a base camp in the central Neptune Range where the party was placed by U.S. Navy LC–130F aircraft from McMurdo Station (Huffman and Schmidt, 1966). The Cordiner Peaks and the area of exposure of the contact zone, near Mount Lechner, were briefly revisited in January 1974 (Ford, 1974; Cameron and Ford, 1974).

Geophysical surveys carried out simultaneously with the geologic work show that the body extends for great distances under ice sheets adjoining Dufek Massif and the Forrestal Range. Geophysical anomalies that extend beyond the surveyed area indicate an areal distribution of at least 24,000–34,000 km^2 (Behrendt and others, 1974).

Except for dike rocks and rocks of the border zone, the intrusion consists of generally well layered mafic rocks mostly of gabbroic composition. Less common lithologies include leucogabbro, anorthosite, granophyre, and minor pyroxenite and magnetitite. This report describes the general stratigraphic features of the layered rocks and defines the nomenclature of rock-stratigraphic units used in the geologic mapping of the body.

Acknowledgments.—This work was carried out under auspices of the U.S. Antarctic Research Program of the Office of Polar Programs, National Science Foundation (NSF). Most of the logistic support was provided by the U.S. Navy Air Development Squadron Six and by NSF. UH–1B turbine helicopters, without which this work could not have been accomplished in a single field season, were provided by the U.S.

FIGURE 2.—Physiographic sketch of north face of Dufek Massif; view south from Cairn Ridge, showing some of the localities and features named in text. AP, Aughenbaugh Peak; NP, Neuberg Peak; WP, Walker Peak; EV, Enchanted Valley; FPM, Frost Pyroxenite Member; NPM, Neuberg Pyroxenite Member. Horizontal distance seen is about 18 km. Sketch by Tau Rho Alpha.

Army Aviation Detachment. Skillful piloting in the generally difficult terrain was a major factor in the safety and success of the project. Coordination, under difficult circumstances, of the field logistics support by Jerry Huffman, NSF, is gratefully acknowledged. The careful work of Walter W. Boyd, Jr., who carried out a major part of the geologic field study of the Dufek intrusion, is particularly acknowledged. Dwight L. Schmidt and Willis H. Nelson assisted in some of the field work during their principal work on sedimentary rocks of the region. Laboratory investigations were greatly helped by S. W. Nelson. The report benefited from reviews of the manuscript by E. D. Jackson, P. D. Rowley, and D. L. Schmidt.

SEDIMENTARY NATURE OF THE LAYERED IGNEOUS ROCKS

The Dufek intrusion is characterized by an abundance of conspicuous subhorizontal layering caused by compositional differences of the rocks. The layered structure and locally well developed cliff-and-slope topography led Aughenbaugh (1961, p. 166) to note the similarity from a distance of these igneous rocks with a thick sequence of undisturbed sedimentary rocks. Wager and Deer (1939, p. 5), in their original work on the Skaergaard intrusion of east Greenland, similarly state that "The stratification in the layered series is so marked that, when these rocks (of the Skaergaard) were first distantly seen from the deck of the ship in 1930, they were mistaken for well bedded red sandstones." The resemblance also of rocks of the Stillwater Complex of Montana to sedimentary rocks was noted by Jones, Peoples, and Howland (1960, p. 286).

The layered igneous rocks of the Dufek intrusion formed by the accumulation of crystals by settling. Rocks of this origin are termed "cumulates"; their textures and structures reflect sedimentary processes controlled by gravity, hydraulic parameters of the magma, and the presence or absence of currents (Jackson, 1971). According to Jackson (1967), who follows usage in sedimentary petrology by distinguishing between grains and cement, cumulates are divisible into two components: (1) the cumulus phases that settled and packed together to make the framework of the rock and (2) the postcumulus material which is primary material that formed in the place it now occupies in the magmatic sediment. The cumulus textures are characterized by the alinement of platy minerals, chiefly plagioclase, in the plane of layering—a feature termed igneous lamination by Wager and Deer (1939, p. 37). Jackson (1967, p. 22) distinguishes planar and lineate lamination depending upon whether the cumulus-mineral parallelism is planar or linear. Noncumulus rocks are those such as the granophyre of the Dufek intrusion in which crystal settling was negligible, as indicated by absence of layering and lamination.

Cumulates are named by prefixing names of the settled minerals in order of decreasing abundance (Wager and others, 1960, p. 85), in an analogous fashion to the naming of sedimentary rocks (Jackson, 1967, p. 23). Many rocks of the Dufek intrusion are thus plagioclase-augite-inverted pigeonite-opaque oxide cumulates that may more simply be referred to as gabbroic cumulates where proportions of cumulus phases are not known or are not otherwise indicated. Anorthositic cumulate and pyroxenitic cumulate consist, respectively, of settled plagioclase and of settled pyroxene but generally contain minor amounts of other phases, including postcumulus minerals. Although most minerals occur as either cumulus or postcumulus phases in different rocks of this intrusion, quartz and K-feldspar are only postcumulus, and apatite is only cumulus in cumulates at a high stratigraphic level.

Layering is the most pronounced primary structure of the Dufek intrusion and is analogous to bedding in a sedimentary sequence. According to Wager and Brown (1968, p. 5), the term bedding "could have been used equally well for the sheet-like structures of igneous rocks." They opt to use the term layering, however, and to restrict bedding for sedimentary rocks. This usage is followed in this report.

Layers in the Dufek body range in thickness from a few millimetres to many tens of metres. Terminology of layers in this report generally follows Jackson (1967, p. 22). Some layers, termed "mineral graded," show gradual stratigraphic change in proportions of cumulus minerals; others, termed "isomodal," are characterized by uniform proportions of cumulus minerals. Mineral-graded layers are much more common than isomodal layers in the Dufek intrusion. A few conspicuous mineral-graded layers of pyroxenitic cumulate are traceable with little change in thickness for tens of kilometres along strike lines in Dufek Massif. Many layers have sharply defined bases and gradational tops, thus resembling graded bedding of sedimentary rocks. Trough layering (Ford, 1970, fig. 6), similar to that described in the Skaergaard intrusion (Wager and Deer, 1939, p. 45), occurs at several stratigraphic levels and is analogous to cut-and-fill channels in water-deposited sediments. The truncation of thin layering in cumulates beneath the troughs clearly indicates that magma-current erosion was involved in the origin of the trough-layered structures in the Dufek intrusion.

Although magma currents were operative, there is little evidence for them in the fabric of the rocks. Most rocks of the intrusion show well-developed planar lamination, but lineate lamination was not observed. Lack of linear fabric indicates that the lamination was imparted by crystal settling after cessation of lateral current flow. The currents were probably of convective origin, as described in detail by

Hess (1960, p. 134) and by Wager and Brown (1968, p. 210) for other layered intrusions. Like turbidity currents in aqueous environments, they were bottom-flowing currents laden with suspended crystals, and in places they scoured the floor beneath them. At times the currents were canalized, eroding deep channels, as indicated by the occurrence of trough layering at several levels in the layered sequence.

Although all major mineral-graded layers (as well as size-graded layers, if they are found in future study) are probably related to turbiditylike current activity, other types of layering may have a different origin. Cumulus textures in rocks of thick stratigraphic sections (fig. 7) that are free of major mineral-graded layers indicate that crystals continued to settle during lengthy quiescent intervals. Fine-scale mineral-graded layering on the order of a few millimetres to about 1 cm in thickness, however, is generally present in these rocks. The fine-scale layering, which is similar to that described as "rhythmic layering" by Wager and Deer (1939, p. 41), is believed to have formed by the differential settling mechanism of Coats (1936).

Stratification in the Dufek intrusion thus formed, crystal on crystal and layer on layer, in a manner similar to stratification in sedimentary rocks; as noted by Jackson (1971, p. 145), "the law of superposition is as rigorously obeyed as it is in sedimentary rocks." Minor disconformities can be recognized where scour channels cut layering in underlying cumulates. Diastemlike breaks, representing intervals of nondeposition, may be present, but none have been recognized in the measured sections. The disconformities possibly mark bases of cyclic units such as those recognized in other layered intrusions (Jackson, 1971, p. 150). The cyclic units, according to Jackson, are regularly repetitive sequences of layers formed from repetitive influxes of small batches of magma, perhaps brought in by convection currents. Compositional changes in pyroxene strongly suggest the presence of cyclic units in the column (Himmelberg and Ford, 1976), but the stratigraphy of these units has not been studied in detail.

Separation of crystals from the originally basaltic Dufek magma led to progressive chemical changes, including notably an increase in the ratio of iron to magnesium and an increase in silica and alkalies in late stages. Granophyric residue of granodioritic composition (Ford, 1970) was eventually produced. The granophyre forms a layer, probably about 300 m thick, that concordantly caps the layered mafic sequence. It is noncumulus and apparently formed essentially in place, perhaps analogously to evaporites of the final desiccation stage in a sedimentary cycle.

GENERAL FEATURES OF THE STRATIGRAPHY

Owing to their stratigraphic characteristics, the layered igneous rocks were studied largely by using techniques as in the study of a stratified sedimentary sequence. Ten partial stratigraphic sections were measured in the area of Dufek Massif, and 11 in the Forrestal Range.[1] Most sections are intercorrelated within each range by using one or more key marker layers or horizons. The composite Dufek Massif section is about 1,800 m thick, and the composite Forrestal Range section is about 1,700 m thick. No markers in Dufek Massif can be correlated with the Forrestal Range. Chemical and mineralogic differences and geometry of the layered structure indicate that the two composite sections constitute different stratigraphic parts of one intrusion—the Dufek Massif section being a lower part and the Forrestal Range section an upper part.

Rocks of Dufek Massif form a gentle homocline dipping 5°–10° southeastward beneath Sallee Snowfield. Projecting the average dip southeastward from Dufek Massif suggests that a 2–3-km-thick section of unexposed rock lies beneath the ice cover of Sallee Snowfield. The approximate chemical and mineralogic characteristics of this inferred hidden middle section, here called the "Sallee Snowfield section," can be estimated by projecting trends from the exposed sections (figs. 3, 4).

A second hidden section, here called simply the "basal section," is inferred to lie beneath the lowest exposed rock layers of Dufek Massif. Reconnaissance geophysical surveys by Behrendt, Henderson, Meister, and Rambo (1974, p. 14) suggest that this section is 1.8–3.5 km thick. Part of the basal section presumably consists of early ultramafic cumulates similar to those of other major layered intrusions (Jackson, 1961; Wager and Brown, 1968). Comparison of plagioclase composition and of pyroxene occurrence and composition between the Dufek and other layered complexes, such as the Stillwater and Bushveld, suggests that mafic cumulates on the order of at least 1 km in thickness may lie between the lowest exposed Dufek layers and the possible ultramafic cumulates.

The roof of the intrusion is presumably eroded. The missing section, here called the "eroded section," probably included an upper part of the granophyre layer as well as mafic rock similar to that of the upper border group of the Skaergaard intrusion described by Wager and Brown (1968, p. 17). The thickness of the eroded section is unknown but by comparison with the Skaergaard is inferred to be less than 1 km.

Though differing in detail, the igneous stratigraphy shows a differentiation trend broadly similar to those of other major layered intrusions. The Dufek Massif section consists of early, but not earliest, differentiates, and the Forrestal Range section consists of late differentiates, including granophyre. The unexposed basal and Sallee

[1]The sections measured in Dufek Massif were designated D–A to D–J, and those in the Forrestal Range F–A to F–K. These designations are used in stratigraphic descriptions in this report.

Snowfield sections are inferred to contain, respectively, earliest and middle-stage differentiates. The composition of bulk rocks and minerals shows progressive changes with stratigraphic height within each of the exposed sections. The most conspicuous changes are in the relative amounts of iron and magnesium, as indicated by the mafic index of bulk rocks (fig. 3*A*) and by Fe/Mg ratios in pyroxenes (fig. 3*B*). The offsets in figure 3 between trends in each of the exposed sections suggest that similar changes occur in the intervening Sallee Snowfield section. Projection of trend lines downward beneath the Dufek Massif section implies downward decrease in the Fe/Mg ratio, but the magnitude is unknown.

Owing to variable amounts of several chief minerals in the rocks, including postcumulus minerals, the interpretation of bulk-rock data in terms of fractionation history is equivocal. Compositional variation of individual minerals is more significant (Wager and Brown, 1968, p. 150). Preliminary optical studies show that cumulus plagioclase ranges from An_{80-85} near the base of the Dufek Massif section to about An_{50} near the top of the Forrestal Range section (Ford and Boyd, 1968). Electron-microprobe studies show that pyroxene forms two coexisting cumulus phases through most of both sections. Both phases, one rich in

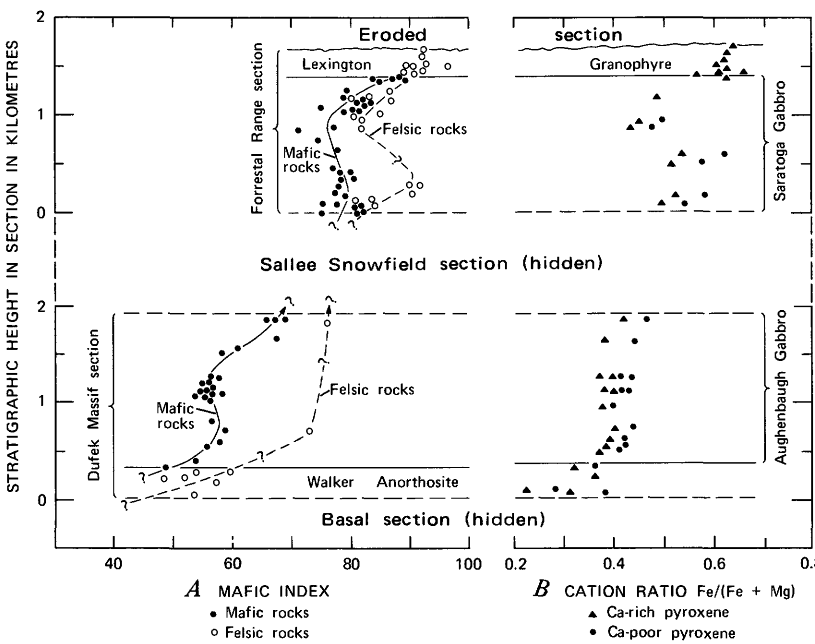


FIGURE 3.—Variation (*A*) of mafic index of bulk rocks [$(FeO+Fe_2O_3)\times100/(FeO+Fe_2O_3+MgO)$] and (*B*) of cation ratio Fe/(Fe+Mg) in pyroxenes with height in the Dufek intrusion. *A*, after Ford (1970); *B*, after Himmelberg and Ford (1976).

calcium in the series augite-ferroaugite, and the other poor in calcium in the series bronzite-inverted pigeonite, show a general upward increase in the ratio Fe/(Fe+Mg), as shown in figure 2*B*. Calcium rich pyroxene ranges from $Ca_{36.4}Mg_{48.7}Fe_{14.9}$ to $Ca_{30.0}Mg_{23.5}Fe_{46.5}$, and calcium poor pyroxene ranges from $Ca_{3.5}Mg_{69.1}Fe_{27.4}$ to $Ca_{11.4}Mg_{34.0}Fe_{54.6}$ (Himmelberg and Ford, 1976).

Iron enrichment of the magma during early fractionation led to later crystallization of opaque iron-bearing oxides. Only a preliminary study has been made of the mineralogy of opaque oxides (Himmelberg and Ford, 1975); for brevity, they are henceforth referred to simply as magnetite, a mineral that appears to be the predominant among several phases of iron- and titanium-bearing oxides. Magnetite first appears as a cumulus phase at about 1,600 m above base of the Dufek Massif section. It occurs in minor amounts from there to the top of the section and increases in amount upward to become a major component in many rocks of the Forrestal Range section. Upward increase in modal magnetite is reflected in a general upward increase in rock densities, which average about 2.95 g/cm^3 in the lower section and about 3.05 in the upper one (Ford and Nelson, 1972). Stratigraphic difference in modal magnetite is also reflected in wide variations in aeromagnetic intensities over the region (Behrendt and others, 1974).

ZONAL NOMENCLATURE

The term "zone" has been used in a variety of ways in studies of layered intrusions of the Dufek type. Jackson (1967, p. 22) defines zone as "an informal, mappable, rock-stratigraphic unit in a layered intrusion, characterized by lithologic homogeneity or distinctive lithologic features." He obviously considers this usage as parallel to the use of "formation" in sedimentary rocks, and he further defines "member" as an informal subdivision of a zone. Jones, Peoples, and Howland (1960) subdivide the Stillwater Complex into four such zones on the basis of their mappability, and their subdivisions are retained in more recent work (Jackson, 1961; Page and Nokleberg, 1974). Hess (1960) recognizes different subdivisions, in part, and employs capitalized terminology such as "Ultramafic Zone" and "Upper Gabbro Zone." Hess's "Anorthosite Zone" is further subdivided into several "Anorthosite subzones." His named units are not formal rock-stratigraphic units, however, in the absence of designated type sections and geographic features after which they should be named (American Commission on Stratigraphic Nomenclature, 1970, Art. 13). In his study of the Duke Island ultramafic complex of southeastern Alaska, Irvine (1974, p. 5) uses the term zone "in only an informal way for physically or geometrically distinct units of rock* * *", without necessarily a stratigraphic connotation.

Others use the term "zone" in a different sense, analogous to biostratigraphic zones in sedimentary rocks. For subdividing cumulate sequences, Wager and Brown (1968, p. 30) point out the analogy between cumulus mineral phases in layered intrusions and fossils in sedimentary sequences. The appearance and disappearance of mineral phases, and their changing compositions, are suggestive of an evolutionary sequence of a fossil assemblage. The mineral assemblages define a relative age sequence in a cumulate pile related ultimately to progressive cooling of the magma. As in sediments, the sequence may be disturbed by factors both internal and external to the system, such as erosion by convection currents, influxes of new magma, and loss of material by volcanism. Wager and Brown (1968, p. 30) subdivide igneous sequences of layered intrusions on the basis of mineral zones and subzones that they define as being "the thickness of layered rocks developed while a specific cumulus mineral or assemblage of cumulus minerals was forming." Mappability is not inherent in their definition. They do, however, use zones named "lower," "middle," and "upper" as informal units in mapping the Skaergaard intrusion. Morse (1969) uses units termed "Upper Zone" and "Lower Zone" in subdividing and mapping the Kiglapait intrusion of Labrador.

The layered rocks of the Dufek intrusion were originally subdivided into informal mappable rock-stratigraphic units termed "zones" (Ford and Boyd, 1968), following usage of that term by workers on the Stillwater Complex. That scheme is herein abandoned, and the units are given formal names of group, formation, and member rank. The term "zone" is retained but used in the sense of Wager and Brown (1968, p. 30). Zones here recognized are mineral zones based on the appearance and disappearance of cumulus minerals in the sequence. Although mappability is not required for recognition of this type of zone, mineral-zone boundaries may correspond to boundaries of rock-stratigraphic map units, as they apparently do in the Kiglapait (Morse, 1969) and Skaergaard (Wager and Brown, 1968) intrusions.

Mineral-zone subdivisions of other layered intrusions (as the Skaergaard) have been given names such as "lower," "middle," and "upper." However, stratigraphic comparison between intrusions is obscured by use of different definitions for these terms. Whereas the "upper zone" of the Skaergaard is defined by the lowest occurrence of iron-rich cumulus olivine and that of the Bushveld by appearance of cumulus magnetite (Wager and Brown, 1968), the "Upper Zone" of the Kiglapait intrusion is defined by the lowest occurrence of cumulus clinopyroxene (Morse, 1969).

From the analogy made earlier of cumulus-mineral assemblages to fossil assemblages in sedimentary rocks, zones (and subzones) of layered intrusions might better be named after characteristic cumulus minerals in a similar fashion to the naming of biostratigraphic zones after characteristic fossils in the assemblage (American Commission on Stratigraphic Nomenclature, 1970, Art. 24). The naming of mineral zones after key cumulus minerals also follows the standard practice of naming metamorphic zones after an index mineral (Turner, 1968, p. 25).

Preliminary petrographic studies indicate that cumulus minerals of the Dufek intrusion have a stratigraphic distribution as shown in figure 4. Names of major cumulus minerals may be used for naming

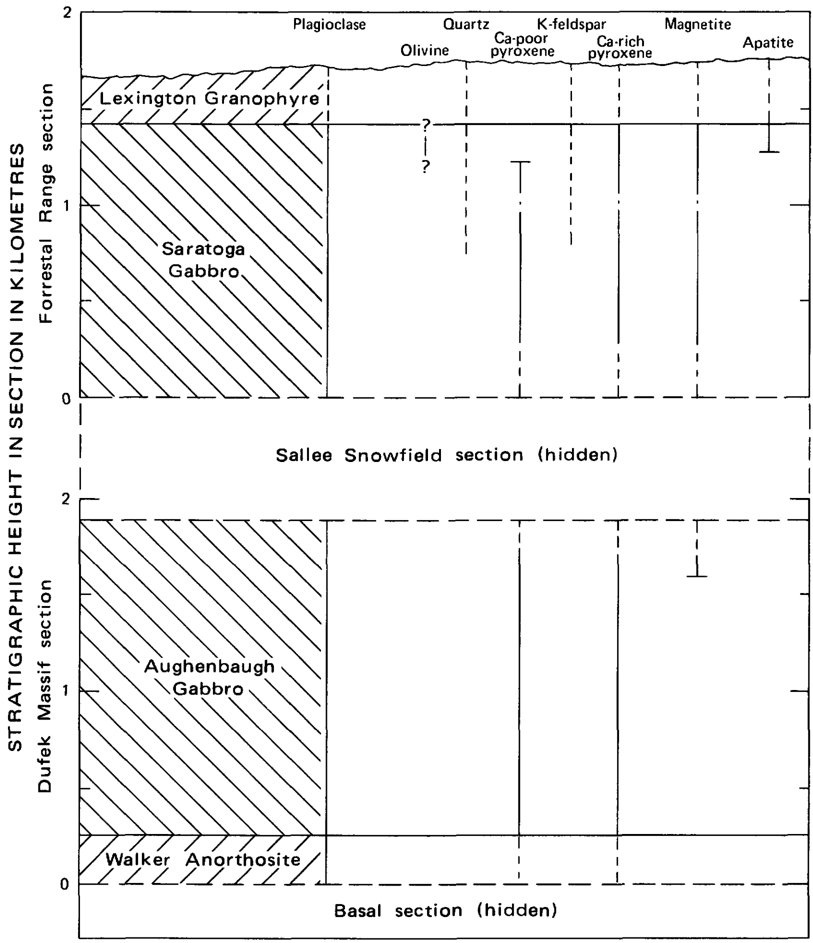


FIGURE 4.—Stratigraphic distribution of minerals in the Dufek intrusion. Cumulus minerals shown by solid line; postcumulus minerals and, in granophyre, noncumulus minerals shown by dashed line. After Himmelberg and Ford (1976).

zones, and names of minor minerals for naming subzones. Although zonal terminology is not formalized in this report, an example is figure 4, which shows that the "magnetite zone" extends from about 1.6 km in the Dufek Massif section, probably continuing through the concealed Sallee Snowfield section, to the top of the mafic rocks in the Forrestal Range section. The "apatite subzone" makes up the highest part of the zone. Postcumulus minerals are not considered in the zonal nomenclature.

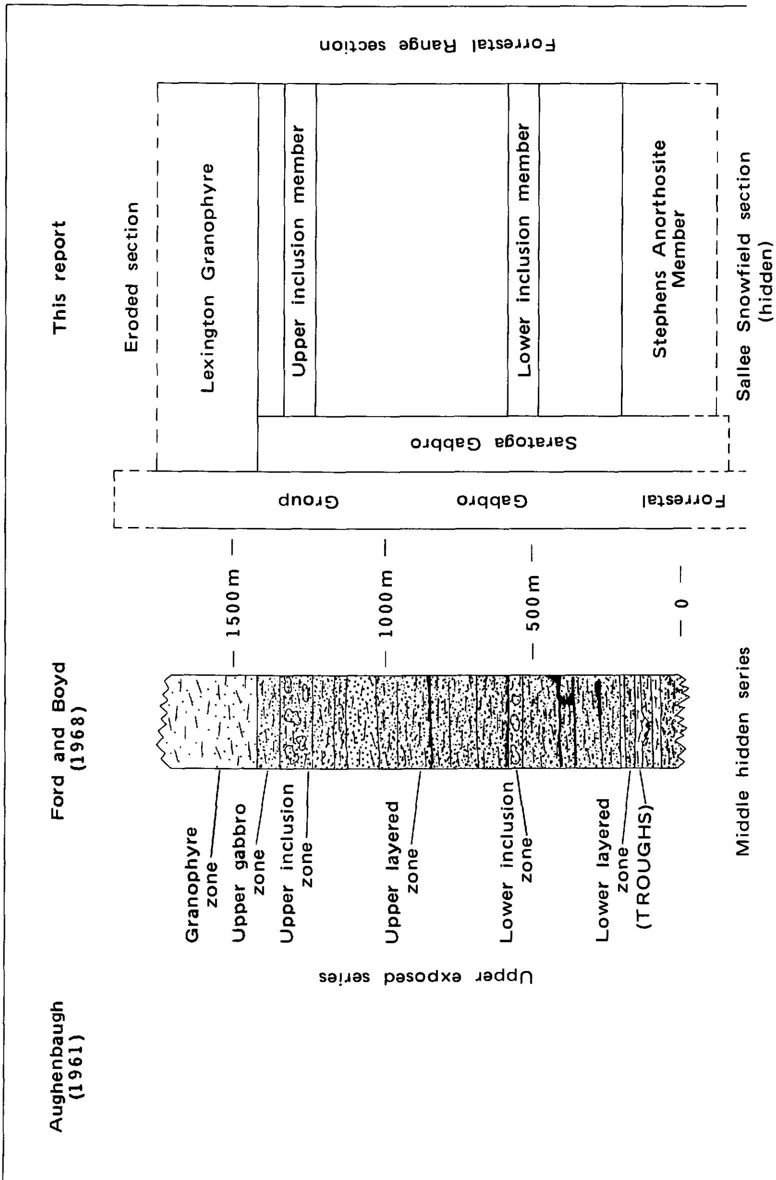
PREVIOUS NOMENCLATURE

Previous nomenclature of the Dufek intrusion by Aughenbaugh (1961), Walker (1961), and Ford and Boyd (1968) was informal. Aughenbaugh, who did not map his units, subdivided the rocks of his partial stratigraphic section into a "normal and leucocratic series" (Aughenbaugh, 1961, p. 160). The characteristic rock of his normal series is described, on field appearance, as a "medium-grained diorite which grades locally into gabbro, anorthosite, or a gneissic-looking rock." Owing to different usage of petrographic terminology and to the location of his stations only on an uncontrolled sketch map, the correlation of his units with those of Ford and Boyd (1968, p. 221) and those of this report is uncertain but is believed to be as shown in figure 5. Aughenbaugh's leucocratic series and the anorthosite zone of Ford and Boyd (1968) are probably equivalents. Aughenbaugh shows a 6-m-thick layer of brown melagabbro that is probably equivalent to pyroxenitic cumulate of the lower brown zone of Ford's and Boyd.

Ford and Boyd (1968) subdivided the layered rocks into numerous mappable rock-stratigraphic units that were called zones (fig. 5). The term "zone" is discontinued in this sense for reasons discussed earlier. Their zones were subunits of larger divisions that they called series, a term that has been used for other layered intrusions, but that is a misusage of the term according to the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1970, Art. 9f).

PRESENT NOMENCLATURE

Continued and more detailed study of the intrusion and the preparation of geologic maps now require a formal rock-stratigraphic nomenclature to be established. This nomenclature is compared with previous nomenclature in figure 5. Whereas cumulate terminology is generally used for rock description in this report, the formal names herein defined use common igneous-rock names of the characteristic lithology of the unit. Cumulate names, though generally preferable to describe rocks such as these, would require lengthy compound terms


Forrestal Range section
This report
Eroded section
Lexington Granophyre
Upper inclusion member
Lower inclusion member
Stephens Anorthosite Member
Sallee Snowfield section (hidden)
Saratoga Gabbro
Forrestal Gabbro Group
1500 m
1000 m
500 m
0
Ford and Boyd (1968)
Granophyre zone
Upper gabbro zone
Upper inclusion zone
Upper layered zone
Lower inclusion zone
Lower layered zone (TROUGHS)
Middle hidden series
Upper exposed series
Aughenbaugh (1961)

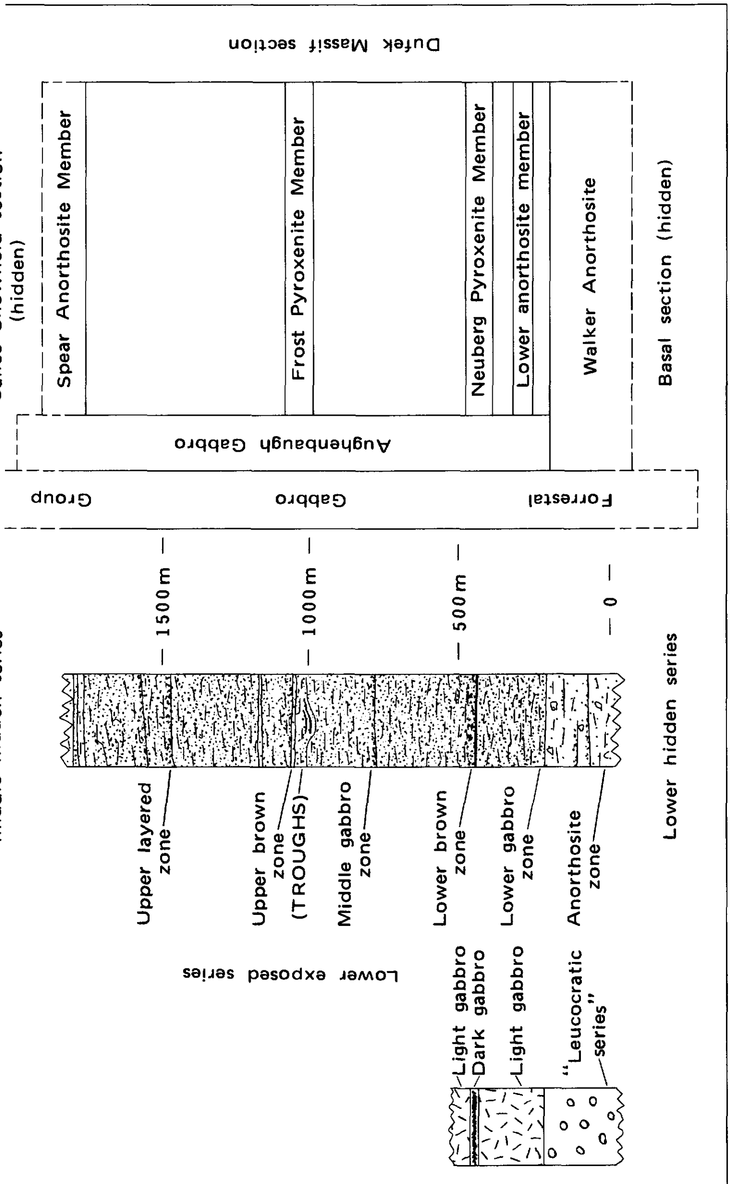


FIGURE 5.—Stratigraphic nomenclature of the Dufek intrusion. Dashed lines of present-nomenclature diagram indicate inferred, hidden, or eroded parts of the stratigraphy.

such as "plagioclase-inverted pigeonite-augite-magnetite cumulate," which should be avoided in naming formal rock-stratigraphic units (American Commission on Stratigraphic Nomenclature, 1970, Art. 10c). Rock names used in this report therefore are of two types based on (1) total mode and (2) types and proportions of cumulus minerals. As previously stated, a common igneous-rock name may be combined with the term "cumulate" for referring to rocks whose settled phases are not specifically indicated.

FORRESTAL GABBRO GROUP

The new name Forrestal Gabbro Group is here applied to all the layered rocks of the Dufek intrusion. The name is taken from the Forrestal Range, a lengthy mountain mass containing nearly half the exposed stratigraphy of the group. Its type locality is in the southern part of the range. As its name implies, the group consists chiefly of rocks of gabbroic composition. It includes rocks of wide range in total-mode composition, from pyroxenite and magnetitite to felsic rocks such as leucogabbro, anorthosite, and granophyre.

Most rocks are well-laminated pyroxene-plagioclase cumulates, and many in the upper part of the group also contain a large proportion of cumulus magnetite. Single-mineral cumulates or cumulates with only minor amounts of a second cumulus phase form thin layers, lenses, and tongues at many levels in the layered sequence of mostly gabbroic cumulates. The thin units include pyroxene cumulate (pyroxenite), magnetite cumulate (magnetitite), and plagioclase cumulate (anorthosite), which also makes up a major unit of formation rank at the lowest exposed part of the group. The group includes a noncumulus layer of granophyre that forms the top of the layered sequence.

In addition to pyroxene and plagioclase, which occur through the entire stratigraphy of the group, and magnetite, which is abundant in the upper part, the cumulus mineralogy includes minor amounts of iron-rich olivine and apatite in high stratigraphic levels, as shown in figure 4. Quartz and K-feldspar are minor postcumulus minerals in higher gabbroic cumulates and are major constituents of the granophyre. Amphibole and mica are locally present, chiefly in the uppermost part, and probably formed by alteration or as postcumulus phases.

Neither the base nor top of the Forrestal Gabbro Group is exposed. The group is believed to be on the order of 8–9 km thick, which includes the measured thicknesses of the Dufek Massif and Forrestal Range sections and the estimated thicknesses of the concealed basal section and Sallee Snowfield section. The top of the group is probably eroded, as discussed earlier.

The Forrestal Gabbro Group is subdivided into four formations as shown in figure 5. Two of the formations are partly subdivided into members, some formal and others informal. All formally named units were mapped at a scale of 1:40,000 in the 1965–66 fieldwork.

WALKER ANORTHOSITE

Layered anorthositic cumulates form a thick and conspicuously light colored unit on lower slopes above Enchanted Valley at the west end of Dufek Massif. This unit is here named the Walker Anorthosite after Walker Peak. The type section (D–C) of the formation is on the western spur of Walker Peak (figs. 9, 10) where a thickness of about 230 m is exposed. The base of the formation is not exposed, and the unit presumably constitutes an upper part of the hidden basal section of the intrusion. It is unknown whether this or some unit of mafic rock lies on the inferred basal ultramafic rocks. The top of the formation is exposed over a distance of about 8 km on the north side of the western Dufek Massif and for about 5 km on the south side.

The Walker Anorthosite is cut off on the northwest by the Enchanted Valley fault, a near-vertical fault set composed of three individual faults mapped locally on the north side of Dufek Massif (fig. 1). Rocks from higher in the section are successively downdropped to the north along at least the two southern of the three faults and probably also along the northern one. Toward the southeast, the Walker presumably extends beneath Sallee Snowfield.

The formation is predominantly composed of medium-grained plagioclase cumulates. Plagioclase, generally poorly zoned, is mostly in the compositional range An_{75-85}. Except locally, layering is less conspicuous than in other parts of the Dufek Massif and Forrestal Range sections. Layering is generally indistinct and gradational and only pronounced where cumulus pyroxenes are present (fig. 6). Most rocks are well laminated. They are white to cream or light gray owing to their high feldspar content, and they commonly have a spotted appearance because of the presence of coarse poikilitic postcumulus pyroxene crystals, as seen in figure 6.

AUGHENBAUGH GABBRO

A sequence of mostly mafic cumulates overlies the Walker Anorthosite and makes up the main part of Dufek Massif and most nearby nunataks. This unit is here named the Aughenbaugh Gabbro after Aughenbaugh Peak, where, though poorly accessible, it is well exposed on cliff walls and spurs. It is a widespread formation that extends for a distance of nearly 50 km from Walker Peak, its most westerly exposures, to Rankine Rock, the most northeasterly nunatak of the Dufek Massif area. Section D–D, measured on the main

FIGURE 6.—Plagioclase cumulate of the Walker Anorthosite at the base of the main northwest spur of Neuberg Peak. Shows typical spotted appearance of the postcumulus pyroxene. Indistinct gradational layers about 40 cm above hammer contain cumulus pyroxene. Hammer 42 cm long.

northwest spur of Neuberg Peak (fig. 7), is the type section of the Aughenbaugh. This section is more complete and more accessible than that on Aughenbaugh Peak, about 1.6 km to the east. The type section contains the lowest occurring 775-m thickness of the formation, the total minimum thickness of which is about 1,600 m. The upper part is eroded at Neuberg Peak. Stratigraphically higher rocks are exposed on the southern side of Dufek Massif owing to the southeastward dip of the layering. Thus, a 760-m-thick section, D–J, measured on Spear Spur (fig. 8) is here designated a reference section for the upper part of the formation.

FIGURE 7.—Neuberg Peak (right-center skyline) showing gabbroic cumulates in upper part of type section D–D of the Aughenbaugh Gabbro on spur leading to foreground. Layering poorly developed in this part of section. About 520 m of section exposed from foreground saddle (near helicopter) to Frost Pyroxenite Member (dark layers marked FPM).

The base of the Aughenbaugh Gabbro is exposed at the base of the type section where the formation sharply and concordantly overlies the Walker Anorthosite, as it also does at Walker Peak (fig. 10). The top is not exposed; the highest rocks visible, at the top of reference section D–J, have an eroded surface. The Aughenbaugh presumably extends under cover of ice to the southeast where it forms a lower part of the Sallee Snowfield section. On the north, the formation is faulted and downdropped, along with the Walker Anorthosite, by the Enchanted Valley fault.

The Aughenbaugh Gabbro consists predominantly of light- to medium-gray medium-grained plagioclase-augite-inverted pigeonite cumulate, with minor amounts of cumulus magnetite in the uppermost

200 m of the formation. Plagioclase is generally in the compositional range An_{60-70}. Most rocks are well laminated and show millimetre- and centimetre-scale mineral-graded layering. A 600-m-thick lower middle part of the formation (fig. 7), between the two conspicuous pyroxenitic units, is generally free of major layers. Sections of the formation above (fig. 8) and below this fairly homogeneous appearing midsection contain conspicuous mineral-graded and rare isomodal layers one to tens of metres thick.

Although many of the major layered units might be recognized as subdivisions of the formation, only four that are especially conspicuous are designated as members (fig. 5). Two of these, given formal names, are dark mineral-graded units of pyroxenitic cumulate that have been

FIGURE 8.—Spear Spur (right center) showing reference section D–J and the well-developed layering in upper cumulates of the Aughenbaugh Gabbro above the Frost Pyroxenite Member (FPM). Arrows mark trough-layered tongue-shaped body of pyroxenitic cumulate about 30 m below the Frost. About 670 m of section exposed in cliffs above the Frost.

mapped over large distances in Dufek Massif (fig. 9). They are key markers used in correlating measured sections in the region. The other two, one formally and the other informally named, are anorthositic cumulates that are of more local distribution.

LOWER ANORTHOSITE MEMBER

A conspicuous layer of white to cream plagioclase cumulate, about 12 m thick, near the base of the Aughenbaugh Gabbro is designated by the informal name "lower anorthosite member." It lies, in the type section of the Aughenbaugh, about 40 m above the formation base. The unit is an isomodal layer with sharply defined basal and top contacts. The rocks are similar in appearance to plagioclase cumulates of the Walker Anorthosite. As in the Walker, they are characterized by the presence of coarse poikilitic postcumulus pyroxenes that give them a spotted appearance. The extent of the unit is unknown, as it is mostly covered by snow and ice. It is not present at some localities (fig. 10) where a similar stratigraphic interval is exposed, which suggests that it has a limited lateral distribution compared with other major layers.

NEUBERG PYROXENITE MEMBER

A conspicuous dark layer, about 5 m thick, of pyroxene-rich cumulate lies about 200 m above the base of the Aughenbaugh Gabbro in the western part of Dufek Massif (figs. 9, 10). This unit is here named the Neuberg Pyroxenite Member after Neuberg Peak, on the main northwest spur of which it is well exposed. Its type section is at an elevation of about 1,075 m in the type section D–D of the Aughenbaugh.

The Neuberg Pyroxenite Member is a mineral-graded layer showing a sharp basal contact and gradational upper contact with adjacent plagioclase-rich gabbroic cumulates (fig. 11). The Neuberg is a feldspar-bearing pyroxenitic cumulate, as are some of the upper pyroxenites of the Bushveld intrustion (Wager and Brown, 1968, p. 365). Postcumulus and cumulus plagioclase are minor constituents, in general, and cumulus plagioclase gradually increases in amount upward in the member.

The Neuberg is characterized by the presence of unusually coarse clusters of pyroxene grains showing uniform crystallographic orientation. These clusters, as much as 5–7 cm across, are visible in the field by their cleavage reflectance. Much of the pyroxene crystallized as pigeonite, which settled and later inverted to orthopyroxene (Himmelberg and Ford, 1976). Textural relations indicate that the individual settled grains initially had random orientation and that the development of uniform orientation in large clusters was a post-

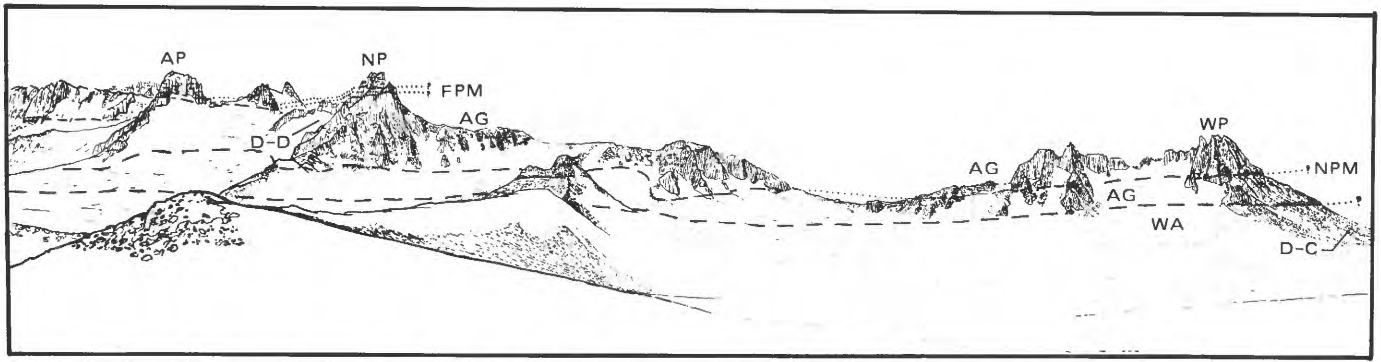


FIGURE 9.—Physiographic sketch of western Dufek Massif, view south from Hannah Peak, showing contact of the Walker Anorthosite (WA) with the Aughenbaugh Gabbro (AG) and the key marker units, the Neuberg Pyroxenite Member (NPM) and Frost Pyroxenite Member (FPM). Type section (D–C) of the Walker on far-right skyline and type section of the Aughenbaugh (D–D) below Neuberg Peak (NP). WP, Walker Peak; AP, Aughenbaugh Peak. Horizontal distance seen is about 10 km. Sketch by Tau Rho Alpha.

FIGURE 10.—Aerial view south of Walker Peak showing the light-colored layered cumulates of the Walker Anorthosite about 200 m below the thin dark layer of the Neuberg Pyroxenite Member (NPM). Compare figures 9 and 11. Type section D–C of the Walker on right skyline spur beyond photograph. Arrow marks contact of the Walker (WA) with the Aughenbaugh Gabbro (AG).

cumulus process. The clusters are similar to those described by von Gruenewaldt (1970, p. 70), who interprets the preferred orientation as having formed during inversion as a result of directed pressure by the

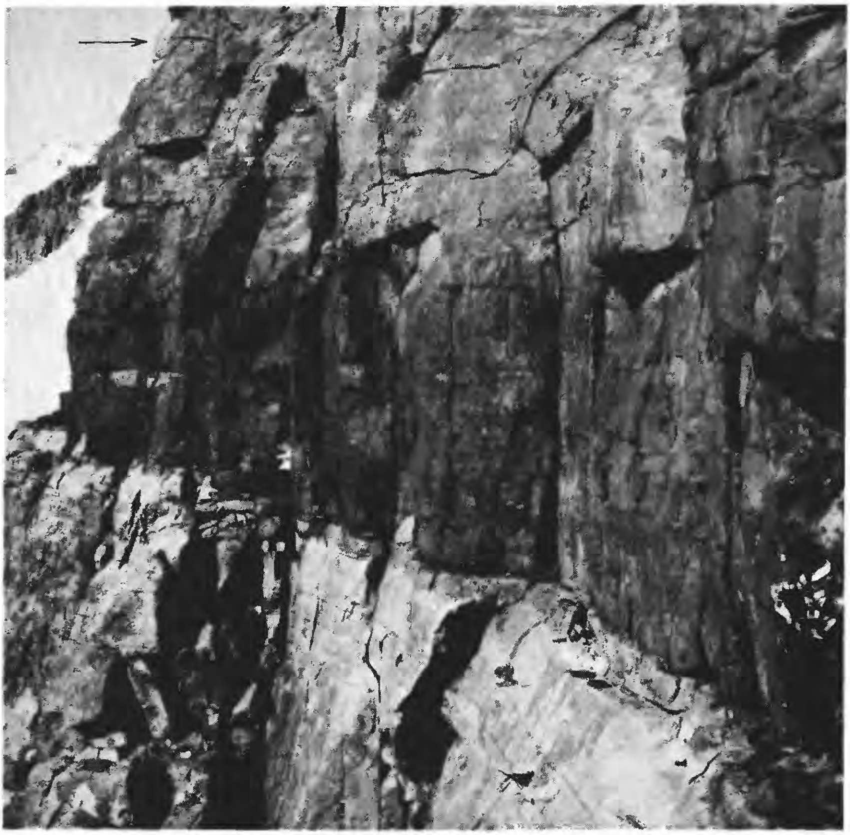


FIGURE 11.—Mineral-graded Neuberg Pyroxenite Member at its type section showing sharp basal contact. Gradational upper contact marked by arrow.

overlying crystal mass. This unusual texture is characteristic of the pyroxenitic cumulates of the Aughenbaugh Gabbro, and it is also present, though rarer and less conspicuous, in pyroxene-rich gabbroic cumulates of the formation.

The Neuberg Pyroxenite Member is exposed at a nearly constant thickness for distances of about 11 km on both the north and south sides of the west end of Dufek Massif. A thin dark pyroxene-rich cumulate layer near the top of Hanna Peak is believed to correlate with the Neuberg. However, it is at a considerably lower elevation on this nunatak than in Dufek Massif, probably as a result of downdropping along the Enchanted Valley fault. At both its northern and southern terminations of exposure, the Neuberg passes beneath snow- and ice-covered talus aprons.

FROST PYROXENITE MEMBER

A second conspicuously dark pyroxenitic unit occurs about 800 m above the base of the Aughenbaugh Gabbro. The unit is well exposed, though not easily accessible, near the top of Neuberg Peak (fig. 12) and

FIGURE 12.—Aerial view east of Neuberg Peak showing mineral-graded pyroxene-rich cumulate layers of the Frost Pyroxenite Member (FPM) in the upper cliffs. Upper part of type section D–D of the Aughenbaugh Gabbro on left-center spur.

in higher parts of the main north face of Dufek Massif. Its elevation gradually decreases eastward, owing to dip, and reaches the level of the lower ice plateau near Davis Valley at the east end of the massif where the unit is easily accessible. This unit is here named the Frost Pyroxenite Member for Frost Spur, its type locality, where it is part of a section (D–H) measured in the upper Aughenbaugh.

The Frost Pyroxenite Member can be seen on Neuberg Peak to consist of at least six thin mineral-graded layers, three of which have pyroxenitic cumulate bases and the others pyroxene-rich gabbroic cumulate bases. The dark pyroxene-rich bases have sharp contacts with underlying gabbroic cumulates. Upper contacts are gradational owing to gradual upward increase in amount of cumulus plagioclase. The sequence of layers totals about 43 m in thickness. Two of the pyroxene cumulate layers, each between 1 and 2 m thick, occur near the base of the Frost, and the third, about 4 m thick, marks the top of the member. Together, the three dark-brown pyroxenitic layers form a conspicuous unit (fig. 12) that is traceable with little variation in thickness for a distance of about 35 km along nearly the entire length of Dufek Massif. At the type locality and at Spear Spur (fig. 8), trough-layered cumulates of cut-and-fill channels occur about 30 m below the Frost.

SPEAR ANORTHOSITE MEMBER

A sequence of three layers of cream to light-gray anorthositic cumulates that are interlayered with medium- to dark-gray gabbroic cumulates lies within the upper part of the Aughenbaugh Gabbro. This well-layered sequence is here named the Spear Anorthosite Member after Spear Spur, above which lies its type section below the summit plateau of Dufek Massif. Elsewhere, in most places it has been removed by erosion. Its type section is at the top of the reference section (D–J) for the upper Aughenbaugh (fig. 8).

The Spear Anorthosite Member is about 105 m thick in its type section. Its base is at the sharp lower contact of the lowest layer of plagioclase cumulate; its top in the section is the erosional upper surface of the highest layer of plagioclase cumulate. From lowest to highest, the three plagioclase cumulate layers are about 46 m, about 12 m, and at least 5 m thick. They are separated by layers of pyroxene-plagioclase-magnetite cumulate, a lower one about 18 m thick and an upper one about 24 m thick. The plagioclase cumulates contain minor amounts of postcumulus pyroxene and magnetite. The coarse postcumulus pyroxenes give the anorthositic cumulates a spotted appearance similar to that of the lower anorthosite member and the Walker Anorthosite.

SARATOGA GABBRO

The name Saratoga Gabbro is here given to the generally well-layered mostly gabbroic cumulates that are exposed throughout the Forrestal Range. Most of the range is covered by snow and ice and thus exposures of the formation are generally small and widely scattered. The unit probably underlies most of the ice-covered Saratoga Table, for which it is named. The formation is chiefly exposed in west-facing escarpments of the Saratoga and Lexington Tables. Smaller exposures are seen in many nunataks on and near these two mesalike tablelands as well as in the widely scattered nunataks at the north end of the range. The unit thus extends for a distance of at least 100 km in a northeasterly direction and about 30 km in a southeasterly direction. Geophysical evidence (Behrendt and others, 1974) suggests that it continues, beneath ice, for at least another 100 km northeastward beyond the Forrestal Range.

Correlation of the 11 partial stratigraphic sections measured in the Forrestal Range is more uncertain than correlation of sections in Dufek Massif because layers are less continuous, conspicuous markers are scarcer, and outcrop areas are smaller and more isolated by snow and ice. On the basis of tentative correlation of these sections, the total exposed thickness of the Saratoga Gabbro is about 1,400 m. The partial section (F–B) measured on the western spur of Mount Stephens (fig. 13) is designated the type section of the formation. The type section contains about a 610-m thickness of well-layered rocks, chiefly pyroxene-plagioclase-magnetite cumulates locally with interlayers of plagioclase cumulates and minor thin magnetite cumulates. The upper part of the Saratoga is not present in the type section. Higher layers are exposed to the east owing to a gentle southeastward dip of layering. Accordingly, three partial sections, from lowest to highest, F–E, F–F, and F–G, measured at Sorna Bluff (fig. 14) are designated as reference sections to illustrate stratigraphic features in the upper 730 m of the formation. Rocks of the reference sections are generally similar in lithology to those of the type section. A snow-covered interval estimated to be 50–60 m thick separates the type section and the lowest reference section.

The base of the Saratoga Gabbro is not exposed. The formation presumably makes up at least a higher part of the ice-covered Sallee Snowfield section of the intrusion. The top is well exposed in summit areas of Sorna Bluff, Mount Lechner, and Mount Zirzow where the unit is sharply and apparently concordantly overlain by granophyre.

The Saratoga differs from the Aughenbaugh Gabbro in several important respects. Although it is generally more conspicuously layered (fig. 15), its layers have far less lateral continuity. Layers

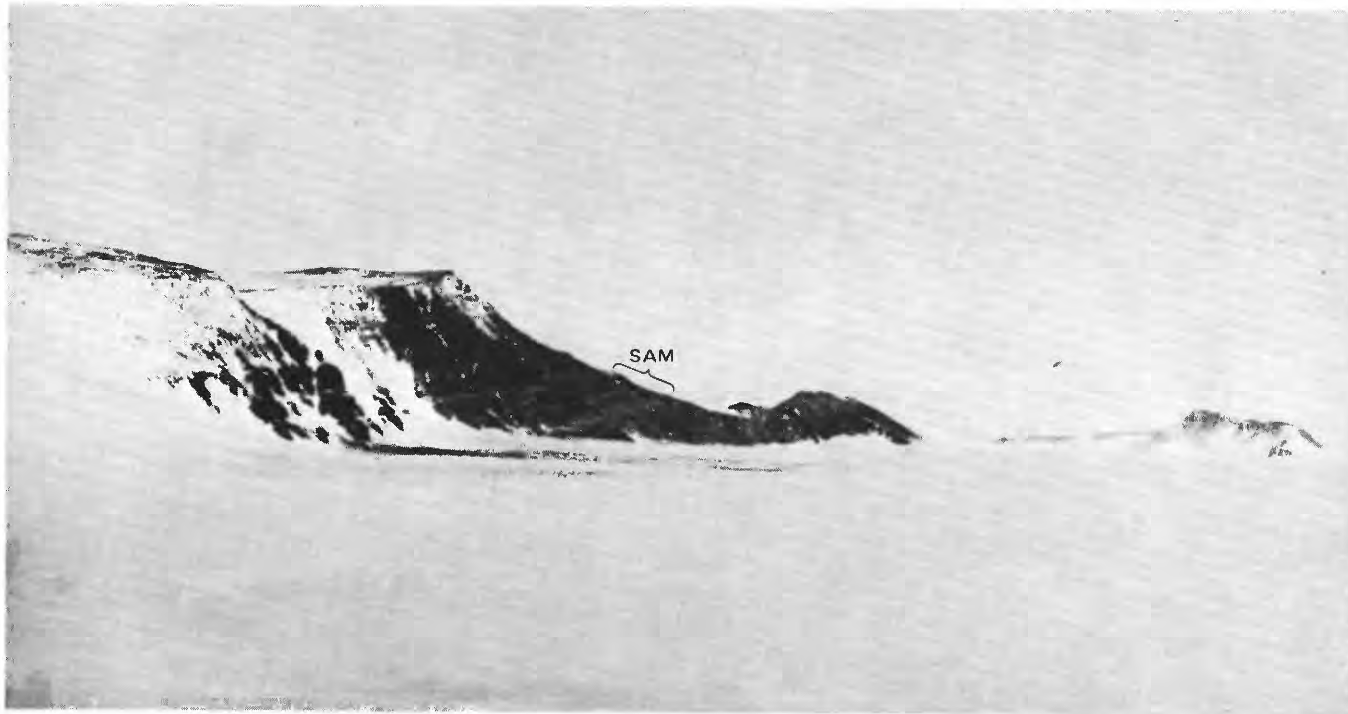


FIGURE 13.—Mount Stephens (left of center), view south, showing type section (F–B) of the Saratoga Gabbro. Stephens Anorthosite Member (SAM) seen in lower part of section on western spur of Mount Stephens. Contact of Dufek intrusion is in ice-filled valley to left of far-right nunatak, which consists of Dover Sandstone. Summit plateau to left of Mount Stephens is southwestern corner of Saratoga Table.

FIGURE 14.—Sorna Bluff, view east, showing reference sections, F–E, F–F, and F–G, for upper part of Saratoga Gabbro. Upper inclusion member (UIM) of the Saratoga lies about 107 m below contact, marked by arrow, of the Saratoga with the overlying Lexington Granophyre (LG). Photograph by D. L. Schmidt.

thicken and thin in relatively short distances. Mafic cumulates of the Saratoga are considerably richer in magnetite than those of the Aughenbaugh. Owing to a high magnetite content, rocks generally are darker, commonly a dark brownish gray, than those of the Aughenbaugh. Magnetite locally forms the sole or the greatly predominant cumulus phase in thin layers or lenses of magnetite cumulate (magnetitite) in the basal parts of some mineral-graded layers. Pyroxenes in both the calcium-rich and calcium-poor series are higher in Fe/(Fe+Mg) ratios than those in the Aughenbaugh (Himmelberg and Ford, 1976), and plagioclase compositions, generally

FIGURE 15.—Spur at west end of Sorna Bluff, view west, showing conspicuous layering typical of upper part of Saratoga Gabbro. Spur is reference section F–E. Compare figure 14.

in the range An_{50-60}, are more sodic than those in the Aughenbaugh. Apatite and rare fayalite, which are unknown in the Aughenbaugh, occur as cumulus phases in the upper part of the Saratoga Gabbro. Three of the more prominent mappable units of the Saratoga are designated below as members.

STEPHENS ANORTHOSITE MEMBER

A conspicuously layered sequence of alternating white to light-gray plagioclase-rich cumulates and dark-gray gabbroic cumulates makes up the lower 300 m of the Saratoga Gabbro. The unit is here named the Stephens Anorthosite Member for Mount Stephens. The type section, in the lower part of the type section F–B of the Saratoga, is on the lower end of the main western spur of Mount Stephens (fig. 13). The member consists of four conspicuous light-colored mineral-graded layers of mainly plagioclase cumulate that are interlayered with dark-gray pyroxene-plagioclase-magnetite cumulate. The plagioclase cumulate layers are 7–15 m thick. The layers have sharp bases, and the tops are gradational owing to a gradually upward increasing amount of cumulus pyroxene. Trough-layered structure is locally present. The base of the member is not exposed; the top is the gradational upper contact of the highest plagioclase cumulate layer. The member is exposed only in the vicinity of Mount Stephens, to the north and south of which it passes under adjoining ice sheets.

LOWER INCLUSION MEMBER

Two units of dark gabbroic cumulates are characterized by abundant rounded and embayed pillowy masses, 1–3 m across, of medium- to coarse-grained rock that is of noticeably lighter color than the surrounding rock (fig. 16). These inclusions are chiefly quartz-bearing leucogabbro with minor amounts of anorthosite and granophyre. They are locally so abundant that the layers have the appearance of a breccia. They are nonlaminated, indicating that they did not form by cumulus processes similar to those that formed the gabbroic cumulate host rock. Textures of the inclusions generally range from hypidiomorphic to xenomorphic granular. The inclusions are believed to be autoliths rafted in laterally by magma currents (Ford and Boyd, 1968, p. 224). The source of the autoliths may have been near the roof of the magma chamber where quartzofeldspathic materials were accumulating or crystallizing in late-stage differentiated magma. Their origin is believed to be similar to that of plagioclase "rafts" in the Kiglapait intrusion described by Morse (1969).

The lower of the two units is here designated by the informal name "lower inclusion member." Its base lies at a stratigraphic height of about 518 m in the type section of the Saratoga Gabbro and at an elevation of about 2,020 m on the western spur of Mount Stephens. The member is about 46 m thick in this section. It is exposed at several places near the top of the western escarpment of Saratoga Table and makes up the rim of the table above Mathis Spur. The member extends for a distance of about 10 km north of Mount Stephens; it was not seen to the south or east where the escarpment is mostly covered by ice. The upper and lower contacts at Mathis Spur and Mount Stephens are indistinct.

UPPER INCLUSION MEMBER

The upper of the two inclusion-bearing units, here informally designated the upper inclusion member, is best exposed at Sorna Bluff (fig. 16) in the upper middle part of reference section F–G of the Saratoga Gabbro. It is also exposed locally near the rim of Lexington Table at Mount Lechner and near May Valley. Similar anorthosite and

FIGURE 16.—Leucogabbro autoliths in dark cumulates of the upper inclusion member of the Saratoga Gabbro at Sorna Bluff. See location in figure 14. Lexington Granophyre (LG) lies about 100 m above the member. Ice axe, right center, is 90 cm long.

leucogabbro inclusions occur in dark gabbroic cumulates at Henderson Bluff, but in the absence of definitive markers, the section (F–K) measured at this isolated nunatak cannot be correlated with other sections of the Saratoga Gabbro. The upper inclusion member makes up a stratigraphic interval from about 1,195 m to about 1,295 m above the base of the Saratoga, in reference section F–G at Sorna Bluff. The lower and upper contacts, which generally are indistinct, are arbitrarily placed at the base of the lowest and top of the highest inclusion at each locality. On the basis of vertical distribution of inclusions, the thickness of the member ranges from about 100 m at Sorna Bluff to about 64 m at Camp Spur and to about 107 m at Mount Lechner.

LEXINGTON GRANOPHYRE

A layer of light-gray to cream granophyre makes up the highest formation of the Forrestal Gabbro Group. The unit, here named the Lexington Granophyre, is locally well exposed at a number of places on escarpments of Lexington Table, for which it is named, and on the north rim of Saratoga Table (fig. 14). It probably underlies much of the ice cover of Lexington Table. The thickest measured section of the Lexington is at Mount Zirzow. This section (F–J), about 238 m thick, is designated the type section of the formation. An additional 50–60 m is believed to underlie the ice cover of nearby highlands, and so the total thickness present is probably about 300 m. The unit is also well exposed at Mount Lechner and Sorna Bluff where sections respectively about 204 m and 116 m thick were measured. At these and all other localities where it was seen, the basal contact with underlying gabbroic rock is sharp and apparently concordant. An upper part of the Lexington and the inferred upper border rocks and roof rocks of the intrusion presumably were removed by erosion.

The rocks are characterized by fine-grained xenomorphic-granular textures showing mosaics and irregular myrmekitic intergrowths of quartz and K-feldspar. Micrographic textures are locally present. The rocks are commonly microporphyritic and contain anhedral to subhedral microphenocrysts of zoned andesine and of pale green commonly zoned augite. The pyroxene and its alteration products of green amphibole and mica generally make up 1–5 percent of the mode. Apatite needles are ubiquitous but less than 1 modal percent.

The granophyre formed at the end stage in differentiation of the Dufek magma (Ford, 1970). The rocks are uniform in appearance. They are apparently structureless and show no evidence of crystal settling. The layer is free of inclusions that might suggest an origin by contamination with silicic country rocks. It is volumetrically small in comparison to the rest of the igneous body; in fact, assuming that only a negligible part was eroded and that relative thicknesses of layers represent relative volumes, the granophyric differentiates make up only about 3–4 percent of the entire 8–9-km-thick body.

AGE AND CORRELATION

From field evidence the age of the Dufek intrusion can only be placed as Permian or younger. The mostly ice covered intrusive contact crops out in a single small area on the end of the west spur of Mount Lechner where recrystallized Dover Sandstone (Devonian) abuts fine-grained gabbro of a high-angle marginal border of the body. Elsewhere, on nunataks near the Saratoga Table, rocks as young as the Pecora Formation (Late Permian) lie in the thermal aureole.

Beck's (1972) south paleomagnetic pole position for the intrusion, at lat 56.5° S, long 168° W, is near but statistically distinct from the Antarctic Ferrar Dolerites' (Jurassic) composite pole. He concludes that the Dufek intrusion and Ferrar Dolerites probably should not be ascribed to a single brief pulse of magmatic activity. Although the slight difference in pole positions suggests a slight age difference between the Dufek and the Ferrar, the difference in pole locations might also be accounted for by differential rotations of blocks along faults such as the Enchanted Valley fault that is known to displace rocks of the Dufek intrusion. The paleomagnetic evidence, accordingly, is suggestive only of approximate age equivalence between the Dufek and the Ferrar Dolerites.

Radiometric dating supports the general correlation of the Forrestal Gabbro Group with the Ferrar Group, which includes the Ferrar Dolerites (Grindley, 1963, p. 339–340) and the Kirkpatrick Basalt (Elliot, 1970, p. 305). Potassium-argon dating of three mineral separates of plagioclase from the Dufek intrusion yielded an average age of 168.0±3.4 m.y. (million years) (R. W. Kistler, written commun., 1969), an age that is within the 163–179-m.y. range reported by Elliot (1970) for five basalts and one diabase within the Ferrar Group in the central Transantarctic Mountains. All three Dufek plagioclase ages, considered to represent a Jurassic intrusive event, are within the experimental error of the reported average. The Jurassic magmatism in the Transantarctic Mountains probably occurred in a number of pulses not presently discriminated by radiometric dating. Although most lie within a Middle Jurassic time span, reported ages of Ferrar-equivalent rocks in the entire Transantarctic Mountains range from 191 m.y. to 147 m.y. (Elliot, 1970). The apparent culmination of activity in the Middle Jurassic may have resulted in intrusive emplacement on a vast scale at one place, as in the northern Pensacola Mountains, and in outpourings of major flood basalts as the Kirkpatrick at another.

REFERENCES CITED

American Commission on Stratigraphic Nomenclature, 1970, Code of stratigraphic nomenclature: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 22 p.

Aughenbaugh, N. B., 1961, Preliminary report on the geology of the Dufek Massif: IGY World Data Center A, Glaciology, Glaciology Rept. 4, p. 155–193.

Beck, M. E., Jr., 1972, Palaeomagnetism and magnetic polarity zones in the Jurassic Dufek intrusion, Pensacola Mountains, Antarctica: Royal Astron. Soc. Geophys. Jour., v. 28, p. 49–63.

Behrendt, J. C., Henderson, J. R., Meister, Laurent, and Rambo, W. L., 1974, Geophysical investigations of the Pensacola Mountains and adjacent glacierized areas of Antarctica: U.S. Geol. Survey Prof. Paper 844, 28 p.

Cameron, R. E., and Ford, A. B., 1974, Baseline analyses of soils from Mount Lechner and Cordiner Peaks, Pensacola Mountains, Antarctica: Antarctic Jour. U.S., v. 9, p. 116–119.

Coats, R. R., 1936, Primary banding in basic plutonic rocks: Jour. Geology, v. 44, p. 407–419.

Elliot, D. H., 1970, Jurassic tholeiites of the central Transantarctic Mountains, Antarctica, *in* Gilmour, E. H. and Stradling, D., eds., Proceedings of the second Columbia River basalt symposium: Cheney, Wash., Eastern Washington State Coll. Press, p. 301–325.

Ford, A. B., 1970, Development of the layered series and capping granophyre of the Dufek intrusion of Antarctica, *in* Visser, D. J. L., and Von Gruenewaldt, G., eds., Symposium on the Bushveld igneous complex and other layered intrusions: Geol. Soc. South Africa Spec. Pub. no. 1, p. 492–510.

———1974, Basalt dikes of the Cordiner Peaks, Pensacola Mountains, Antarctica—satellitic bodies of the Dufek intrusion?: Antarctic Jour. U.S., v. 9, p. 149–153.

Ford, A. B., and Boyd, W. W., Jr., 1968, The Dufek intrusion, a major stratiform gabbroic body in the Pensacola Mountains, Antarctica: Internat. Geol. Cong., 23d, Prague 1968, Proc., v. 2, p. 213–228.

Ford, A. B., and Nelson, S. W., 1972, Density of the stratiform Dufek intrusion, Pensacola Mountains, Antarctica: Antarctic Jour. U.S., v. 7, no. 5, p. 147–149.

Grindley, G. W., 1963, The geology of the Queen Alexandra Range, Beardmore Glacier, Ross Dependency, Antarctica with notes on the correlation of Gondwana sequences: New Zealand Jour. Geology and Geophysics, v. 6, no. 3, p. 307–347.

Hess, H. H., 1960, Stillwater igneous complex, Montana: Geol. Soc. America Mem. 80, 230 p.

Himmelberg, G. R., and Ford, A. B., 1975, Petrologic studies of the Dufek intrusion—iron-titanium oxides: Antarctic Jour. U.S., v. 10, no. 5, p. 241–244.

Himmelberg, G. R., and Ford, A. B., 1976, Pyroxenes of the Dufek intrusion, Antarctica: Jour. Petrology, v. 17, no. 2, p. 219–243.

Huffman, J. W., and Schmidt, D. L., 1966, Pensacola Mountains project: Antarctic Jour. U.S., v. 1, no. 4, p. 123–124.

Irvine, T. N., 1974, Petrology of the Duke Island ultramafic complex, southeastern Alaska: Geol. Soc. America Mem. 138, 240 p.

Jackson, E. D., 1961, Primary textures and mineral associations in the ultramafic zone of the Stillwater complex, Montana: U.S. Geol. Survey Prof. Paper 358, 106 p.

———1967, Ultramafic cumulates in the Stillwater, Great Dyke, and Bushveld intrusions, *in* Wyllie, P. J., ed., Ultramafic and related rocks: New York, John Wiley and Sons, p. 20–38.

———1971, The origin of ultramafic rocks by cumulus processes: Fortschr. Mineralogie, v. 48, p. 128–174.

Jones, W. R., Peoples, J. W., and Howland, A. L., 1960, Igneous and tectonic structures of the Stillwater complex, Montana: U.S. Geol. Survey Bull. 1071–H, p. 281–340.

Morse, S. A., 1969, The Kiglapait layered intrusion, Labrador: Geol. Soc. America Mem. 112, 204 p.

Neuberg, H. A. G., Thiel, Edward, Walker, P. T., Behrendt, J. C., and Aughenbaugh, N. B., 1959, The Filchner Ice Shelf: Assoc. Am. Geographers Annals, v. 49, no. 2, p. 110–119.

Page, N. J, and Nokleberg, W. J., 1974, Geologic map of the Stillwater Complex, Montana: U.S. Geol. Survey Misc. Inv. Series Map I–797, scale 1:12,000.

Schmidt, D. L., and Ford, A. B., 1969, Geologic map, with accompanying text, of the Pensacola and Thiel Mountains; sheet 5, Geologic maps of Antarctica: New York, Am. Geog. Soc., scale 1:1,000,000.

Turner, F. J., 1968, Metamorphic petrology: New York, McGraw-Hill, 403 p.

Von Gruenewaldt, G., 1970, On the phase-change orthopyroxene-pigeonite and the resulting textures in the main and upper of the Bushveld complex in the eastern Transvaal, *in* Visser, D. J. L., and Von Gruenwaldt, G., eds., Symposium on the Bushveld igneous complex and other layered intrusions: Geol. Soc. South Africa Spec. Pub. no. 1, p. 67–73.

Wager, L. R., and Brown, G. M., 1968, Layered igneous rocks: Edinburgh, Oliver and Boyd, 588 p.

Wager, L. R., Brown, G. M., and Wadsworth, W. J., 1960, Types of igneous cumulates: Jour. Petrology, v. 1, p. 73–85.

Wager, L. R., and Deer, W. A., 1939, Geological investigations in East Greenland; Pt. 3, The petrology of the Skaergaard intrusion, Kangerdlugssuaq, East Greenland: Medd. Gronland, v. 105, no. 4, 335 p.

Walker, P. T., 1961, Study of some rocks and minerals from the Dufek Massif, Antarctica: IGY World Data Center A, Glaciology, Glaciology Rept. 4, p. 195–213.

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