volcanics and volcanic derived rocks that closely resemble the strata of the Phelan Creek formation. These modern volcanic islands are mostly inactive and have subsided. Thick limestone-black shale caps are now being formed on top of the subsiding volcanic platforms. The resulting stratigraphic succession is nearly identical with the stratigraphic sequence that characterizes upper Paleozoic deposits throughout the eastern Alaska Range.

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Ordovician of Soviet Arctic

Ordovician deposits are widely represented within the Soviet Arctic. They are known in Novaya Zemlya, Vaygach Island, Pay-Khoy, Severnaya Zemlya, northern Siberian platform, New Siberian Islands, and northeastern USSR. In the western Arctic (Polar Urals-Novaya Zemlya) Ordovician deposits formed the base of the Caledonian-Hercynian cycle, and consist of a very thick variable complex of clastic and carbonate rocks.

In the central Soviet Arctic, the Ordovician is at the base of the stratigraphic column in Severnaya Zemlya, whereas on Taimyr Peninsula and the Siberian platform, it comprises a single depositional cycle with the Cambrian. The Ordovician in the region is represented by predominantly carbonate rocks reaching a thickness of 2,000 m in depressions; in the northern part of the Taimyr Peninsula it consists of graptolite-bearing clastic and carbonate rocks up to 1,000 m thick. The Ordovician of Severnaya Zemlya is represented by variegated clastic and carbonate rocks about 2,000 m thick.

Within the eastern Arctic, Ordovician deposits are a part of the fold fringe of the Kolyma massif and of the Mesozoides of northeastern Chukotsk Peninsula. Ordovician strata in the northeastern USSR consist of carbonate, clastic and carbonate, and wholly terrigenous clastic sequences. The relations with underlying rocks are uncertain there. Ordovician rock thicknesses differ markedly from place to place and reach 5,500 m in some places.

Ordovician deposits have been studied in more detail in southern Novaya Zemlya, Vaygach Island, northern Pay-Khoy, central Taimyr, in the Norilsk district, and within the limits of the folded margin of the Kolyma massif. The Ordovician of northern Novaya Zemlya, Severnaya Zemlya, and the New Siberian Islands is less well known.

However, even where Ordovician sections have been investigated comprehensively and are richly fossiliferous, the Lower-Middle Ordovician and Ordovician-Silurian boundaries are uncertain because of geologic pecularities of the region. There is no definite solution to the Cambrian-Ordovician boundary problem. Variable sedimentary facies and diverse zoogeographic provinces make regional and interregional correlations difficult.

Nevertheless, recognition of transitional sequences in fold areas of the Soviet Arctic and the wide interregional distribution of some faunal elements during climaxes of marine transgression (late Tremadocian and middle Caradocian) permit rather definite correlations for the solution of practical biostratigraphic problems and correlation with standard sequences elsewhere.

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Geologic Structure and History of Polar Urals, Pay-Khoy, Novaya Zemlya, and Northern Pechora Depression

1. The late Paleozoic–early Mesozoic fold system of the Urals-Novaya Zemlya and the Paleozoic-Cenozoic strata of the Pechora depression formed on a folded basement.

2. Structures within the fold system may be divided into (a) the Polar Urals and Pay-Khoy anticlinoria and (b) the structures of Novaya Zemlya. In the mainland part of the Urals system, a set of foredeep basins is recognized at the junction of the fold system and the depression on the western sides.

3. The Urals-Novaya Zemlya fold system includes a complex of Precambrian, Paleozoic, and early Mesozoic (within a foredeep) sedimentary and volcanic rocks. The Precambrian thickness exceeds 3,000 m, and that of the Paleozoic, 10,000 m.

The Paleozoic (Ordovician and younger strata) transgressively and unconformably overlies the older formations. Important hiatuses in the Paleozoic are established in pre-Late Devonian (Novaya Zemlya), and in the Late Carboniferous (Pay-Khoy, Novaya Zemlya).

4. Volcanic strata of predominantly basic composition occupy much of the Precambrian (Polar Urals, Novaya Zemlya, Pay-Khoy) and Late Devonian sections. Volcanic rocks of late Paleozoic and early Mesozoic ages are found in northeastern Pay-Khoy.

An ancient pre-Ordovician and partly pre-Silurian ultrabasic to acid intrusive complex (Polar Urals, Pay-Khoy, Novaya Zemlya), a Caledonian (Silurian-Devonian) complex of ultrabasic, basic, and acid intrusions (Polar Urals and Novaya Zemlya), and Hercynian basic and acid intrusions (Novaya Zemlya, Polar Urals) are present in this area.

5. Within the fold system the following structural elements are clearly distinguished: (a) the Polar Urals with an adjacent foredeep of the Urals type; and the Pay-Khoy anticlinorium, an early Mesozoic structure, the strike of which is the same as that of the Baikalides and Novaya Zemlya. The Pay-Khoy and Novaya Zemlya areas thus have characteristics of both the Ural geosyncline proper and of the Scotland-Scandinavia Grampian geosyncline joining the Novaya Zemlya trough on the west.

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Origin of Manganese-Rich Layers in Arctic Sediments

A sediment core from the Wrangel abyssal plain (T3 69–12, lat. 80°21.9′N, long. 173°33′W, water depth: 2,867 m; core length: 374 cm) was analyzed for $CaCo_3$, Mn, P_2O_5, Al, Fe, and trace elements; in total, 15 samples from the interval 0–350 cm were used for these analyses. Three carbonate layers were found (5–16% $CaCO_3$), interspaced by carbonate free strata (0–2% $CaCO_3$), resembling lithologic variations described by Herman in other Arctic cores.

The carbonate-free fractions of the carbonate layers show higher contents of Mn (0.4–0.9%) and P_2O_5 (0.215–0.237%) than the carbonate-poor layers in which the corresponding values range between 0.15–0.25% and 0.183–0.211%. The Al and Fe values show no major variations, ranging between 7.5–9.9 and 4.3–

5.5%, respectively, suggesting that most abiogenic constituents are terrigenous.

The stratigraphy by Herman suggests that the $CaCO_3$-Mn-P_2O_5-rich layers were deposited during glacial periods. Similar climatically related variations are described from the Caribbean by Wangersky and Hutchins, and by the writer. Analyses of pelagic sediments from the Coral Sea, the Black Sea, and western Pacific show that similar variations also occur in other oceanic regions; future dating of these cores will illuminate this problem further. The origin of these sediments is very poorly understood. A possible but unlikely explanation (proposed earlier by the writer) is that chemical weathering was more intense during glacial periods. It is characteristic, however, that all sediments with $CaCO_3$-Mn-P_2O_5 covariations, without exception, are found in basins with restricted entrances, but nowhere in the major oceanic basins. During the glacial maxima, sea level was considerably lower than at present, enhancing the isolation of many of these basins. As a result, oxygen-poor bottom waters were more likely to develop, enhancing the migration of manganese upward as has been described from the East Pacific by Lynn and Bonatti. The Mn-rich layers in the sediments thus could be "fossil top sediments" enriched in manganese. This mechanism may not explain the enrichment in P_2O_5. However, in more poorly vented basins, labil layering and overturn of water masses are known to occur under certain circumstances. This could explain the covariation between $CaCO_3$, Mn, and P_2O_5 in many of these cores.

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SILURIAN BIOGEOGRAPHY AND LITHOFACIES OF ARCTIC

Llandovery through early Wenlock marine faunas of the Arctic appear to be relatively cosmopolitan in their distribution. Those of the late Wenlock through Pridoli probably belong to the Uralian-Nevadan-Canadian Arctic province; this biogeographic unit developed during the Early Devonian into the Old World province (as opposed to the Appalachian and Malvinokaffric provinces).

Silurian lithofacies of the Arctic are dominated by platform carbonates on the northern edges of the Russian and Siberian platforms, and by geosynclinal facies of eastern and northeastern Novaya Zemlya and Arctic North America. Inferences may be drawn from these data for the existence of large blocks, location not known, of Silurian platform carbonates seaward of the Old World Silurian. Sources of clastic debris for the Arctic North American Silurian may be inferred to have existed in a seaward position as well, and the same is probably true for that area related to Novaya Zemlya and, possibly, the Taimyr Peninsula.

Lithofacies within the relatively uniform Siberian platform strata, from the Yenisey River all the way east to the Chegitun area (almost on Bering Strait), contrast with those known on the Seward Peninsula; both are of the carbonate type, however.

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REWARD AND UNCERTAINTY IN EXPLORATION PROGRAMS

The attractiveness of a petroleum exploration program depends on the expected return and the associated risk. Previous analyses of drilling programs have dealt with particular aspects of uncertainty. The variable—size of reservoirs—has received the most attention; various skewed probability density functions have proved to be consistent with empirical observation. Estimates of the expected value and variance of this variable have been interpreted casually as measures of the economic reward and the degree of risk, respectively, of specific exploration programs. The size of reservoir found, however, is only one aspect of the uncertainty in exploratory drilling. Among the other variables which have an important bearing on the economics of the program are the probability of making a discovery, the depth of the producing formation, and productivity of the wells. Possible stochastic descriptions of the most significant variables, and studies of their combined effects on the attractiveness of a particular venture, have proved to be very instructive.

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DEVELOPMENT OF PRECAMBRIAN SHIELD IN SOUTHWESTERN GREENLAND, LABRADOR, AND BAFFIN ISLAND

The Precambrian rocks on either side of Davis Strait show a similar pattern of events and can be interpreted as having formed part of a single shield. Eight major stages in the development of this shield are suggested. (1) Formation of an extensive early crust before 3,000 m.y. ago, relicts of which are now preserved as migmatite and high-grade gneiss in the Archean block of eastern Labrador and southwest Greenland. (2) Deposition of greenstone belts between 2,700 and 3,000 m.y. ago. (3) Plutonic activity in the period 2,500–2,900 m.y. ago, affecting both the greenstone belts and the major part of the basement on which they lie. (4) Intrusion of numerous basic dike swarms in the general period of 2,000–2,600 m.y. ago. (5) Lower Proterozoic (Aphebian) geosynclinal rocks were deposited on the consolidated Archean basement and were involved in an orogeny known in Canada as Hudsonian and in Greenland as Ketilidian and Nagssugtoquidian. (6) Post-orogenic magmatism, particularly prominent in areas affected by Hudsonian metamorphism, extends from southern Greenland through Labrador. This produced chiefly anorthosites, adamellitic granites, monzonites, and norites, that were probably emplaced between 1,400 and 1,700 m.y. ago although the areas in which they occur commonly remained thermally active to 1,200 m.y. ago or later. (7) Emplacement of the post-orogenic rocks was accompanied and followed, in southern Greenland and in parts of Baffin Island, by graben faulting, deposition of molasse sediments, and widespread intrusion of basic dikes. The majority of these dikes are tholeiitic; however, locally (for example, in the Gardar Province of southern Greenland), alkaline and peralkaline intrusions took place 1,100–1,300 m.y. ago. (8) The Archean and Proterozoic rocks in the southern part of the Canadian shield were metamorphosed and tectonically "worked" by the Grenville orogeny about 900–1,100 m.y. ago. The only effect of this orogeny in southern Greenland was a slight updating of earlier rocks from areas close to major faults so that they yield K/Ar ages of about 900–1,000 m.y.