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JU. JA. LIVŠIC

Palaeogene deposits and the platform structure of Svalbard

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OSLO 1974

DET KONGELIGE DEPARTEMENT FOR INDUSTRI OG HÅNDVERK

NORSK POLARINSTITUTT

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Transcriptional variants of the author's name (Лившиц) used in previous papers and in geological literature are:

LIVSHITS, LIVSHITZ, LIWSCHITZ.

Abstract

A local stratigraphical scheme for the Paleogene deposits of the whole archipelago is proposed. In the central part of the island of Spitsbergen, presence of Palaeogene, Eocene, and Oligocene (total thickness exceeding 2.5 km) is assumed, while on the west coast, only that of Eocene and Oligocene (thickness sometimes exceeding 3.5 km). It is concluded that Svalbard was an archipelago during the Palaeogene. The stratigraphical section of Svalbard is proposed to be used as a standard for the Central Arctic coal-bearing province of the entire Polar Basin.

Tectonic division of the epi-Caledonian platform mantle into a block structure is proposed, and structures of three ranks with local structures among them are distinguished in the axial part of the Spitsbergen trough. Four main stages of platform structure development are recognized: late Palaeozoic, Mesozoic, early Cenozoic, and late Cenozoic.

Besides the Mesozoic and possibly the Palaeozoic deposits, oil and gas possibilities are also suggested for the basal Palaeogene. Analysis of different criteria for oil and gas content testifies to prospects for oil and gas not only in the archipelago, but also in the adjacent areas of the Barents Sea Shelf.

Аннотация

Палеогеновые отложения и платформенная структура Свальбарда.

Работа представляет собой первое комплексное описание палеогеновых отложений и платформенной структуры Свальбарда в целом. Разработана местная стратиграфическая схема палеогеновой толщи, привязанная к международной шкале. Указывается, что на Свальбарде представлены палеоцен, эоцен и олигоцен, которые совместно встречаются лишь в пределах основной области развития толщи (Центральный бассейн), где суммарная мощность их превышает 2,5 км. Более грубозернистые образования западного побережья архипелага суммарной мощностью более 3,5 км относятся к эоцену и олигоцену. На основании палеогеографического анализа делается вывод, что Свальбард в палеогене представлял собой архипелаг, причем климат в этот период был теплее современного более чем на 12—13°. Выделяются три крупные меридиональные провинции полярной области в палеогене: Западная вулканогенная (базальты Туле), Центральная угленосная и Восточная вулканогенная (в пределах Тихоокеанского подвижного пояса). Разрез Свальбарда можно использовать как опорный при разработке стратиграфии Центральной угленосной провинции. При этом палеогеновые породы отличаются от одновозрастных образований платформенных областей необычно высокой плотнос-

тью и даже включают каменные угли газовой стадии углефикации, что безусловно связано с постседиментационными процессами.

Платформенный чехол Свальбарда имеет четкое блоковое строение. В составе чехла фиксируется ряд разнопорядковых пликативных структур, разделенных крупными зонами разломов, в том числе шесть структур первого порядка: горстообразное поднятие западного побережья, Западно-Шпицбергенский грабенообразный прогиб, Сассендаленская моноклиналь, Восточно-Шпицбергенское поднятие, прогиб пролива Ольги, поднятие Земли Короля Карла. В формировании платформенной структуры выделяется четыре основных этапа: позднепалеозойский, мезозойский, раннекайнозойский и позднекайнозойский, которые оцениваются не только качественно, но и количественно. Установлена различная мобильность платформенного чехла Свальбарда: более мобильная западная часть связана с областью наиболее интенсивного проявления каледонской складчатости и приближена к рифтовой зоне Срединно-Океанического хребта. Комплексный анализ различных критериев нефтегазоносности свидетельствует о перспективности архипелага и близрасположенных акваторий Баренцева моря на нефть и газ. Месторождения могут быть обнаружены не только в мезозойских и палеозойских образованиях, с которыми в настоящее время связываются основные перспективы, но и в базальных горизонтах палеогена.

Работа рассчитана на широкий круг геологов. Материалы о палеогеновых отложениях и платформенной структуре Свальдбарда позволяют правильнее представить альпийскую историю Полярного бассейна и перспективы нефтегазоносности шельфа Баренцева моря.

Introduction

Because of the key position of the Svalbard archipelago in the Atlantic sector of the Arctic, the Palaeogene deposits of this comparatively small land area are of special interest. It is clear that the archipelago's position on the north-western corner of the Eurasian continent makes an interpretation of its platform structure valuable.

The archipelago is composed of sedimentary, metamorphic, and igneous rocks of Precambrian to Quaternary age. The modern block structure of the archipelago is a result of a complex and long development in the history of which three main periods are distinguished: a geosynclinal, a post-geosynclinal, and a platform period (SOKOLOV et al. 1968). During each of these periods a certain structural complex was formed. In present exposures, formations of the geosynclinal structural complex (Hecla Hoek — Precambrian to Ordovician) are developed in northern Svalbard and along its west coast, and formations of the post-geosynclinal complex (the Devonian variegated sequence) are developed in the centre of northern Spitsbergen (the so-called Devonian graben). Platform formations (beginning with the Lower Carboniferous) occupy the entire southern and south-eastern part of the archipelago. They occur also in southern Nordaustlandet and in Kong Karls Land.

Svalbard has attracted the attention of geologists of different countries for a long time, but until recently all industrial prospecting of the archipelago was connected with coal, mainly of Palaeogene age. Special oil prospecting was started only in 1960 by geologists of different nations: American, French, Norwegian, Soviet, etc.

The Palaeogene deposits are of great importance for the determination of oil and gas prospects in Svalbard. These deposits outcrop in the main part of the Spitsbergen graben-like trough (Fig. 1), within which oil and gas occurrences seem most probable, especially as indications of them are already known there. These formations are also very important for interpreting the Alpine history of the archipelago and of the whole northern Atlantic, and also for the correlation of the still poorly investigated Palaeogene deposits of the entire Polar Basin. Nevertheless, the investigation of Svalbard Palaeogene deposits until recently was carried out mainly in connection with their industrial coal content or as a subsidiary to the study of other geological problems. Therefore the stratigraphical scheme for these formations proposed by NATHORST (1910) for the southern half of Spitsbergen (Central Basin) with lithological names for the separate formations (Table 1), has been reproduced almost without changes in subsequent, mainly summary papers (HAGERMAN 1925; HOEL 1929; KOTLUKOV 1936; LJUTKEVIČ 1937;

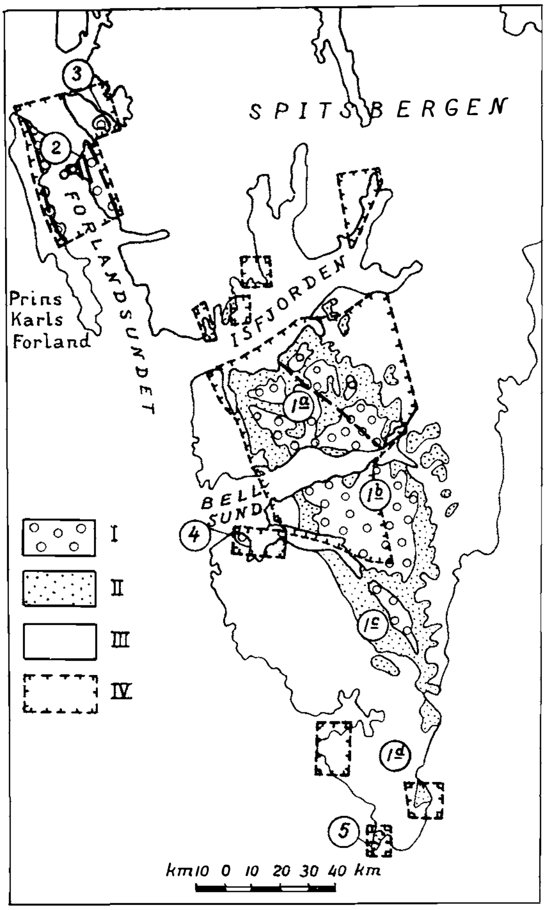


Fig. 1. *Areas of Palaeogene deposits in Svalbard. 1. Central Basin: 1ª Nordenskiöld Land, 1ᵇ Nathorst Land, 1ᶜ Torell Land, 1ᵈ Sørkapp Land. 2. Forlandsundet. 3. Kongsfjorden (Ny-Ålesund). 4. Renardodden. 5. Øyrlandet. I. Eocene-Oligocene deposits. II. Palaeocene-Eocene deposits. III. Pre-Palaeogene deposits. IV. Areas investigated by the author in 1962—1968.*

ORVIN 1940; HARLAND 1961; ATKINSON 1963). However, in contrast to NATHORST (1910) the rock age is considered to be not Miocene, but Palaeocene and Eocene, on the basis of faunal determinations (RAVN 1922)[1].

The deposits have been correlated according to the results of flora determination, carried out by HEER (1866, 1870, 1876) and NATHORST (1910). All investigators have regarded the Palaeogene deposits developed within small isolated sectors on the west coast of Svalbard (except the Kongsfjorden area) — Forlandsundet, Renardodden — as either contemporaneous with the upper formation of the Central Basin or even younger than these, but no definite dating has been done. Information on Palaeogene deposits of these areas is given in HOLTEDAHL (1913), TYRRELL (1924), ORVIN (1934, 1940), SCHLOEMER-JÄGER (1958), MANUM (1960), ATKINSON (1962, 1963), CHALLINOR (1967), and BARBAROUX (1967).

This paper had already been prepared for printing, when the author became acquainted with a paper published by VONDERBANK (1970), who

[1] A description of the fauna from the different horizons of the Palaeogene succession has also been given by GRIPP (1927) and by HÄGG (1927), while spores and pollen have been described by MANUM (1962).

Table 1
Stratigraphical schemes of Palaeogene deposits of the Central Basin

NATHORST 1910		ORVIN 1940	MAJOR (printed 1964, published 1972) (HARLAND 1969, FLOOD et al. 1971)		VONDERBANK 1970		LIVŠIC 1965	LIVŠIC 1967	This paper			macrorhythm
MIOCENE	Upper Coal-bearing Series	EOCENE	Aspelintoppen Formation	OLIGOCENE-MIOCENE (?)	Nordenskiöldfjellet-schichten	?	Upper Coal-bearing Formation	OLIGOCENE-MIOCENE (?)	Storvola Formation		OLIGOCENE	II
	Fissile Sandstone Series		Battfjellet Formation	EOCENE-OLIGOCENE	Fardalen-schichten			EOCENE-OLIGOCENE	Collinderodden Formation	Upper Member	EOCENE	
							Upper Transitional Formation			Lower Member		
	Upper Black Shale Series		Gilsonryggen Formation				Upper Argillite Formation		Frysjaodden Formation			
	Green Sandstone Series	PALAEOCENE	Sarkofagen Formation	EOCENE	Grumantdalen-schichten	DANO-MONTIAN	Lower Transitional Formation	EOCENE	Hollendardalen Formation	Upper Member		I
										Lower Member		
							Green Sandstones Formation		Grumantbyen Formation			
	Lower Dark Shale Series		Basilika Formation	PALAEOCENE			Lower Argillite Formation	PALAEOCENE	Colesbukta Formation		PALAEOCENE	
	Lower Coal-bearing Series		Firkanten Formation		Adventfjorden-schichten		Lower Coal-bearing Formation		Barentsburg Formation			

considers the age both of the lower part of the Palaeogene sequence in the Central Basin and of the succession from the Renardodden area (Kapp Lyell area) as Dano-Montian. His view is based on ROSENKRANTZ's (1942) suggested similarities between the Palaeogene fauna of Svalbard and that of Greenland.

In my opinion, the analysis of fauna, plant fossils, microfossils, spores, and pollen does not permit us at present to consider the age of Palaeogene basal horizons in the Central Basin to be older than Palaeocene. The Renardodden Formation is undoubtedly younger, as shown by plant remains, spores, pollen assemblages, and data on mineral rock composition. The classification according to large rhythms proposed by VONDERBANK, is undoubtedly progressive. However, the rhythm boundaries (and hence the formation boundaries) proposed by him are open to objection, especially as these boundaries are difficult to trace in the field and cannot be used to the full in compiling geological maps. Besides, VONDERBANK's scheme is even less detailed than that of NATHORST, as Table 1 shows.

In accordance with a contract with the organization «Arktikugol'», the Institute of the Geology of the Arctic organized in 1962 the Spitsbergen Complex Geological-Geophysical Expedition under the leadership of Dr. V. N. SOKOLOV. Being a member of this expedition, the author studied the Palaeogene formations and structures of the platform mantle from 1962 to 1968[1], first by carrying out geological mapping of Nordenskiöld Land and Nathorst Land with special structural investigations and measurement of key horizons, and afterwards in the course of thematic investigations. At this period the author managed to visit all the main outcrop areas of Palaeogene deposits. Besides the main area of their development (Central Basin), five separate areas on the west coast of the archipelago were also studied; these are, from north to south: the Kongsfjorden area, both sides of Forlandsundet (as well as the eastern side of Prins Karls Forland), near Renardodden, Bellsund, and Øyrlandet, Sørkapp Land (Fig. 1). During these investigations many fossils were collected and determined afterwards by Professor I. A. KOROBKOV (fauna, molluscs), Dr. T. N. BAJKOVSKAJA, Dr. L. JU. BUDANCEV, Dr. N. D. VASILEVSKAJA, Dr. Ė. N. KARA-MURZA, Dr. I. N. SVEŠNIKOVA (plant fossils), Dr. N. N. SUBBOTINA (foraminifera), and Mrs. A. S. VAKULENKO (spores and pollen).

Stratigraphy

Recent investigations have shown that the lithological names given by NATHORST (1910) to the formations of the Central Basin cannot be used for the correlation of Palaeogene formations throughout Svalbard. The formations, many of which have been distinguished for the first time, have, therefore, been given geographical names (LIVŠIC 1967)[2]. It is presumed that

[1] Besides this, the author made investigations on Bjørnøya in 1970, and in northern Torell Land, on Erdmannflya, and on Edgeøya in 1972.

[2] At present a geological map of Adventdalen on the scale 1:100,000 has been compiled at Norsk Polarinstitutt by H. MAJOR and J. NAGY, where geographical names are also proposed for the formations (Table 1). These same names have also been adopted for the south-western sheet of the geological map of Svalbard on the scale of 1:500,000 (FLOOD et al. 1971), even though the Palaeogene succession has not been differentiated on this map.

the Palaeogene system is represented by Palaeocene, Eocene, and Oligocene deposits, which occur together only in the Central Basin, the main area of development of the sequence (Fig. 2, Appendix 4)[1]. It is necessary to note, however, that a complete monographic treatment of the palaeontological and palaeobotanical data is still not finished. Therefore the accepted dating of some formations is essentially provisional. Thus, according to L. JU. BUDANCEV and I. N. SVEŠNIKOVA, the age of the youngest Palaeogene formations of Svalbard is not Oligocene but Upper Eocene. Some investigators have doubts about the possibility of ascribing the Palaeogene basal horizons in the Central Basin to the Thanetian stage.

A. INTERPRETATION OF SECTIONS ACCORDING TO AREAS

The Central Basin

The Palaeogene deposits accumulated during the formation of two macrorhythms containing a number of rhythms of first and second rank (rhythmicity has been analysed according to the method of IVANOV 1967). The first macrorhythm began with the deposition of the Upper Palaeocene (Thanetian stage) *Barentsburg Formation* on the eroded surface of Albian deposits. Basal conglomerates (0.2 to 3.6 m) are widespread only in western Nordenskiöld Land. In other areas the Albian rocks are immediately overlain by siltstones, argillites, and sandstones of the productive member (5 to 53 m) with coal seams of mineable thickness (up to 2.8 m, usually 1 m thick) such as those exploited in the Barentsburg (USSR) and Longyearbyen (Norway) fields. The rocks contain a great number of the fossil plants *Ginkgo spitsbergensis, Metasequoia occidentalis, Trochodendroides arctica, T. richardsonii, Platanus* sp. *Quercus juglandina* etc., and spores and pollen; molluscs and insect remains also occur[2]. The main part of the formation consists of feldspathic/quartzose sandstones and sandy siltstones with the marine bivalves *Callista nathorsti, Cyprina ex gr. lunulata, Dosiniopsis ex gr. orbicularis,* etc., as well as the foraminifera *Cyclammina coksuvorovae* and *Saccamina* sp. The total thickness of the formation is 80 to 230 m. (Fig. 3). The rocks exposed in Øyrlandet (Sørkapp Land) in extreme south-western Svalbard may

[1] In a number of previous papers, the author (LIVŠIC 1965b, 1967) has provisionally considered the age of the upper part of the sequence as Oligocene-Miocene (?). However, supplementary study of fossils has led to the conclusion that it is necessary to limit the upper boundary to the Oligocene.

[2] Detailed lists of preliminary determinations of fauna and flora, as well as of spores and pollen, found in 1962—1968 in the Palaeogene deposits of Svalbard have already been published (LIVŠIC 1965b, 1967; VAKULENKO and LIVŠIC 1971). Preliminary determinations of the flora have been made by T. N. BAJKOVSKAJA, N. D. VASILEVSKAJA, and Ė. N. KARA-MURZA. These lists are presented here in appendices 1, 2, and 3. Palaeobotanical determinations have been made by L. JU. BUDANCEV and I. N. SVEŠNIKOVA.

apparently also be related to the Barentsburg Formation. Above, the black argillites and siltstones of the *Colesbukta Formation* follow conformably; these rocks contain calcareous lenses with a marine fauna: *Thyasira* sp., *Tkredo* sp., and others; according to I. A. KOROBKOV these fossils are characteristic of the Thanetian stage. The thickness of the formation is highly variable (Fig. 3). In the main part of the area it usually fluctuates from 200 to 350 m, while in the centre of Torell Land it reaches 650 m (BIRKENMAJER and NAREBSKI 1963)[1]. Within the north-eastern part of the Central Basin (in the eastern part of Nordenskiöld Land and Nathorst Land, to the east of the Colesbukta fault) the thickness of the formation does not exceed 20 to 100 m, and the rocks are represented by sandstones and siltstones. The homogeneous greenish-gray feldspathic/quartzose sandstones of the 160 to 240 m thick *Grumantbyen Formation* with rare remains of *Cyrena altissima* are provinsionally ascribed to the Lower Eocene, while the conformably overlying rocks of the *Hollendardalen Formation* are also regarded as Eocene. The lower member of this formation (up to 60 m thick) is composed of argillites and siltstones with the foraminifer *Cyclammina* sp. and spores and pollen, while the upper member (up to 80 m) is composed mainly of feldspathic/quartzose sandstones, siltstones, and argillities with numerous bivalves *(Cyrena hoeli, «Solenocurtus» spitsbergensis)* and rare leaves of *Tilia malmgrenii, Viburnum* sp. etc. Intercalations of gritstones, conglomerates, and a coal seam (up to 1 m thick) have also been recorded.

The argillites of the *Frysjaodden Formation* (200 to 400 m) with the foraminifera *Cyclammina coksuvorovae* and *Cyclammina* sp., and spores and pollen rest unconformably on the rocks of the Hollendardalen and, locally, of the Grumantbyen Formations. They indicate the beginning of the next macrorhythm. The age of this formation as well as that of the conformably overlying *Collinderodden Formation* (100 to 500 m) is considered to be Eocene. The rocks of the lower member of the Collinderodden Formation (50 to 390 m) are characterized by considerable variability along the strike. The member is composed of rhythmically alternating beds of gray and greenish-gray often calcareous siltstones and polymict sandstones. The bivalve *Cyrena altissima* and others, the foraminifer *Cribroelphidium risthanicum,* remains of the plants *Ginkgo spitsbergensis, Metasequoia occidentalis, Credneria spectabilis* etc., spores, and pollen are recorded. The upper member (40 to 110 m) is represented mainly by polymict sandstones with the bivalves *Cyrena (Corbicula) angustidens,* cf. *Solenotellina brevisinuata,* etc. The upper macrorhythm is concluded by the Oligocene (?) *Storvola Formation* (more than 700 m) composed of polymict sandstones, rhythmically alternating with argillites and siltstones (usually calcareous), thin coal beds (5 to 20 cm thick), and rare intercalations of gritstones and conglomerates. The following shells have been found near the base of the formation: *Cyrena aff. convexa, Congeria* sp., *Valvata* sp., *Hydrobia* sp., etc. Numerous well preserved plant remains occur throughout the section: *Osmunda spetsbergensis, Sphenop-*

[1] According to Professor K. BIRKENMAJER (pers. comm. when this manuscript was already in press) this thickness is incorrect and much higher than the true value.

teris blomstrandii, Metasequoia occidentalis, Cercidiphyllum nathorstii, Ulmus pseudobraunii, Aesculus antiquorum. Tilia malmgrenii, Macclintockia lyellii, etc.

The Forlandsundet area.

Exposures of Palaeogene deposits extend for more than 45 km in a north-westerly direction on both sides of Forlandsundet, particularly on the east side of Prins Karls Forland. The Palaeogene formations belong to one macrorhythm, in which a number of rhythms of first and second rank have been formed. The basal horizons are represented by the characteristic rudaceous and clumpy variegated conglomerates of the *Selvågen Formation* (30 to more than 1,000 m — Fig. 2), which transgress with a sharp angular unconformity over different horizons of the Hecla Hoek succession. The overlying *Sesshøgda Formation*[1] (120 to more than 300 m) is composed of rhythmically alternating conglomerates and gritstones, polymict sandstones, siltstones, argillites, and three to ten cm thick coal beds. The following fossils have been discovered in the rocks: numerous small specimens of the bivalves *Elliptotellina tellinella, Sportella* sp. (? sp. *corbulina),* etc. as well as a number of plant remains of *Metasequoia occidentalis, Cercidiphyllum elegans, Tilia malmgrenii, Vitis olrikii,* etc. Besides these MANUM (1960) has noticed, apparently in the same deposits, the dinoflagellate *Svalbardella cooksonia* and spores and pollen. The overlying *Reinhardpynten Formation* (210 m) is represented by greenish-gray calcareous siltstones (110 m) with shells of *Chlamys ex gr. sublaevisatus, Gari ex gr. effusa,* etc. (lower part of the formation) and by compact black siltstones more than 100 m thick (upper part). This formation is conformably overlain by thick (60 to 80 m) beds of black siltstones and argillites of the *Krokodillen Formation,* which rhythmically alternate with compact polymict to quartzitic sandstones (total thickness of this formation is approximately 400 m). The age of all these formations is provisionally ascribed to the Upper Eocene. The overlying *Marchaislaguna Formation* is provisionally considered as Oligocene (?) and has a disconformable lower junction. This formation is represented by rhythmically alternating polymict sandstones, siltstones, argillites, conglomerates, and gritstones with plant detritus. Rhythms of two ranks are very distinctly marked. The rhythms of first rank (the larger ones) begin with rhythmically alternating rocks, usually sandstones, conglomerates, and gritstones with a total thickness of

[1] The Selvågen and the Sesshøgda Formations are exposed on both sides of Forlandsundet, while overlying formations occur only on Prins Karls Forland, mainly in the Selvågen area (Fig. 2). The most widespread Marchaislaguna Formation is found in the northern parts of the island. The fauna in the Sesshøgda Formation has been found only on the east coast of Forlandsundet near Sarsbukta, while plant remains occur on both sides of the strait (both near Sarsbukta and near Selvågen).

Formerly only two formations were distinguished within the Palaeogene deposits of Prins Karls Forland (TYRRELL 1924, ATKINSON 1962): the Selvågen Formation and the McVitie Formation. The latter formation corresponds to the combined Sesshøgda, Reinhardpynten, Krokodillen, and Marchaislaguna Formations.

55 to 400 m[1], and are completed by units of black siltstones and argillites with a thickness of 20 to 180 m (Fig. 2). These are disconformably overlain by coarse-grained rocks of the next rhythm. The total thickness of the formation exceeds 2,000 m.

The Kongsfjorden area.

Palaeogene deposits are exposed on the southern coast of Kongsfjorden (Brøggerhalvøya), and occur within an isolated small area (about 4 to 5 sq. km), known as the «Ny-Ålesund field». Two formations of Oligocene (?) age are distinguished (one of gray and one of green sandstone, after ORVIN 1934). The lower *Kongsfjorden Formation* (110 to 120 m) is represented mainly by polymict sandstones and rests unconformably on Lower Triassic (?) (CHALLINOR 1967) and Upper Permian rocks. Lowermost occur basal conglomerates with a maximum thickness of 4 m. These are followed by a 28 to 30 m succession of rhythmically alternating siltstones, argillites, and coals (with three seams of mineable thickness — up to 4 m). A great number of plant remains of *Taiwania schaeferii, Betula frigida, Acer* sp. have been found. In the upper part of the formation, a coal seam up to 2.3 m thick is recorded. The *Ny-Ålesund Formation* (more than 120 m) overlaps the basal formation and is composed mainly of more coarse-grained rocks: polymict sandstones, alternating with conglomerates and gritstones. Three coal seams have been found, the thicknesses of which decrease upwards in the succession (maximum 0.5 to 3.0 m, minimum 10 cm). Plant remains of *Metasequoia occidentalis, Tilia malmgrenii,* etc. have been found.

The Renardodden area.

The rocks are exposed at the base of a marine terrace on the southern side of Skilvika by Renardodden (southern part of Bellsund) and in a submeridional coastal plain sector of 4 to 5 sq. km. Two Oligocene (?) formations are distinguished. At the base of the lower one, the *Skilvika Formation* (112 m), 4.3 m thick conglomerates unconformably overlie the Hecla Hoek succession. Above follow rhythmically alternating black argillites and siltstones, polymict sandstones and thin (usually 2 to 20 cm, rarely 28 to 66 cm) coal beds. Throughout the whole section occur numerous remains of *Metasequoia occidentalis, Cercidiphyllum lyellii, Tilia malmgrenii, Acer arcticum,* etc., as well as spores and pollen. *The Renardodden Formation* (more than 300 m thick) overlaps the lower formation and is represented by quartzitic to polymict sandstones rhythmically alternating with argillites, siltstones, and 2 to 50 cm thick coal beds. Remains of *Metasequoia occidentalis, Corylus scottii, Alnus* sp., *Acer arcticum,* etc., and spores and pollen are found.

[1] The lower part of one of the rhythms of first rank, apparently 270 m thick, near McVitiepynten, was adopted by ATKINSON (1962) as the basis for his description of the whole McVitie Formation.

B. CORRELATION OF SECTIONS

A correlation of the Palaeogene deposits of Svalbard is here made for the first time using both palaeontological, lithological, and structural evidence. The most complete and best studied Central Basin section is used as a standard section.

It has been established that the lower part of the Palaeogene sequence of the Central Basin (the lower macrorhythm — the Upper Palaeocene Barentsburg and Colesbukta Formations and the Eocene Grumantbyen and Hollendardalen Formations) has no analogue on the west coast. The accumulation of Palaeogene sediments in the extreme west of the archipelago apparently did not start before the end of the Eocene. The Frysjaodden Formation of the Central Basin (Upper ? Eocene) most probably corresponds to the Selvågen, the Sesshøgda, and the Reinhardpynten Formations of the Forlandsundet area (Fig. 2). Of these the rudaceous Selvågen and Sesshøgda Formations should be correlated with only the basal horizon of the Frysjaodden Formation. The Upper (?) Eocene Collinderodden Formation apparently corresponds to the Krokodillen Formation on the west coast. Finally, the Oligocene (?) Storvola Formation of the Central Basin should be correlated with the Marchaislaguna Formation (Forlandsundet), the combined Kongsfjorden and Ny-Ålesund Formations (Kongsfjorden), and the combined Skilvika and Renardodden Formations (Renardodden).[1]

C. SVALBARD PALAEOGENE DEPOSITS AS PART OF THE PALAEOGENE DEPOSITS OF THE POLAR BASIN

The Palaeogene deposits of Svalbard are similar to the contemporaneous terrigenous coal-bearing formations of comparable thickness in the Canadian Arctic Archipelago, the New Siberian Islands, the adjacent part of the Soviet Arctic coast, and probably even of Northern Alaska (Table 2). Thus, an enormous coal-bearing province existed within the main part of the present Polar Basin in the Palaeogene; this was bordered by the plateau basalts of the British-Arctic Province to the west of Svalbard and by the volcanic formations of the Pacific mobile zone of the New Siberian Islands to the east. It is characteristic that the three zones distinguished have meridional strike and thereby emphasize the peculiar segmental zonality of the Palaeogene formations of the Arctic.

The several kilometers thick succession of the Svalbard Palaeogene deposits, which is now sufficiently thoroughly studied, may serve as a standard section for establishing the stratigraphy of this Arctic coal-bearing

[1] The correlation of the separate formations produced in this paper is not absolutely certain. At present one can with sufficient certainty correlate only the three upper formations of the Central Basin jointly with the whole Palaeogene sequence of the west coast.

province. However, before this, a monographic treatment of the fossils now collected is needed, and is also necessary for producing a detailed scheme for the biogeographic zonation of the Arctic Palaeogene.

It is noteworthy that the Palaeogene deposits in Svalbard are considerably denser (average density 2.61 gm/cm^3, KURININ 1965) than the poorly lithified contemporaneous formations of the adjacent regions, and they include hard coal of the gasseous stage of coalification. Rocks of such density are unknown even in Greenland, where they underwent an intense contact metamorphism during the formation of Cenozoic plateau basalts. In this respect they may be correlated only with Palaeogene deposits of the Northern Pacific mobile zone. There is no doubt that these features are connected with post-depositional processes caused essentially by the great mobility of Spitsbergen.

Mineral composition and conditions of deposition

For the study of the mineral composition more than 2,000 petrographic thin sections have been investigated, and 120 complete mineralogical, 960 semi-quantitative spectrographic (for 40 elements), 250 thermal, 25 X-ray diffractometer, and 20 phase analyses have been carried out. Fifteen complete technical coal analyses have been accomplished, and 100 thin sections and polished sections of coal have been described. For the study of geochemical properties of the sequence, 33 ammonium chloride, 63 acetic acid, and 34 hydrochloric acid extractions have been analysed. Such a detailed study of mineral composition has not been carried out on Svalbard Palaeogene rocks before. The results have been of importance not only in rock correlation but, together with data from stratigraphic investigations, have made it possible to reconstruct conditions of deposition in the Palaeogene.

A. MINERAL COMPOSITION[1]

The Palaeogene deposits of Svalbard include practically all varieties of terrigenous sediments as well as hard coals. One of the main features of the sequence (particularly in the Central Basin) is the monotonous composition of the individual formations. Similar rock types show little compositional variation throughout the different formations.

The conglomerates are represented by five types which differ not only in the nature of their pebbles but also in their matrix composition. Fine-pebbled conglomerates with a sandy matrix often occur in the Central Basin, while on the west coast more massive coarse-pebbled conglomerates with an argillo-micaceous matrix are found.

[1] Data on mineral composition are presented only in a general form. The mineral composition of Svalbard's Palaeogene rocks will be dealt with by the author in a separate paper.

The sandstones of the Central Basin are mainly fine-grained, while on the west coast they are medium- to coarse-grained. Feldspathic/quartzose and polymict varieties can be distinguished. The former are assigned to the lower part of the Palaeogene sequence of the Central Basin, and are absent on the west coast. The latter occur in the upper part of the sequence and have been found in both regions. Leucoxene and titanium minerals dominate the heavy minerals in both types of sandstones; although chloritoid sometimes dominates in the polymict sandstones, this mineral occurs in only very small amounts in the feldspathic/quartzose sandstones. Iron hydroxides and pyrite are the most common authigenic minerals.

The argillaceous material in the argillites and siltstones is represented mainly by illite with kaolinite admixtures.

The Palaeogene coals are at present the main natural resources of Svalbard. The chief coal-bearing area in the Central Basin is Nordenskiöld Land, while deposits on the west coast are known from the Kongsfjorden area. The coals are humic, clarainous (frequently with a considerable amount of lipoid components), and clarain-durainous. The most ash-rich coals (up to 19 to 20 % of dry mass) are the clarain-durainous varieties of the western part of the Central Basin. In the eastern part, where clarainous coals are dominant, the ash content decreases to 5 to 10 %. The calorific power is usually 8100 to 8400 kcal. According to grade of coalification, the coals are gas coals (bottle coals) — combustible volatile component = 31.2 to 42.8 % — (according to Soviet classification). In the Kongsfjorden area they are similar to long-flame coals, and in all other areas they are usually more like fat steam coals.

B. CONDITIONS OF DEPOSITION

The nature of the Palaeogene sediments was determined in the first place by the high mobility of the humid and relatively small sedimentary basins. During the Palaeogene, Svalbard was probably an archipelago as it is now (Fig. 4). Sedimentation apparently occurred within comparatively shallow trough-like depressions, surrounded by land areas (large islands) and connected with the open sea by straits. Besides the main Central Basin, the contours of which were similar to those of the present day, small isolated basins existed on the west coast of Svalbard. These were commonly situated inside the islands and were not connected with the open sea; this was also the case with the Central Basin during its final stages of development.

The insular land surrounding the Palaeogene basin was probably an uplifted plateau-like plain with isolated mountain massifs. It was composed of formations of different age and apparently similar to those now surrounding the outcrop area of the Palaeogene sediments. The palaeogeography of the islands surrounding the basin changed repeatedly, and thus the main sedimentary source area also changed. It is worth noting that for short periods at the very beginning of the Thanetian age and again at the beginning of the

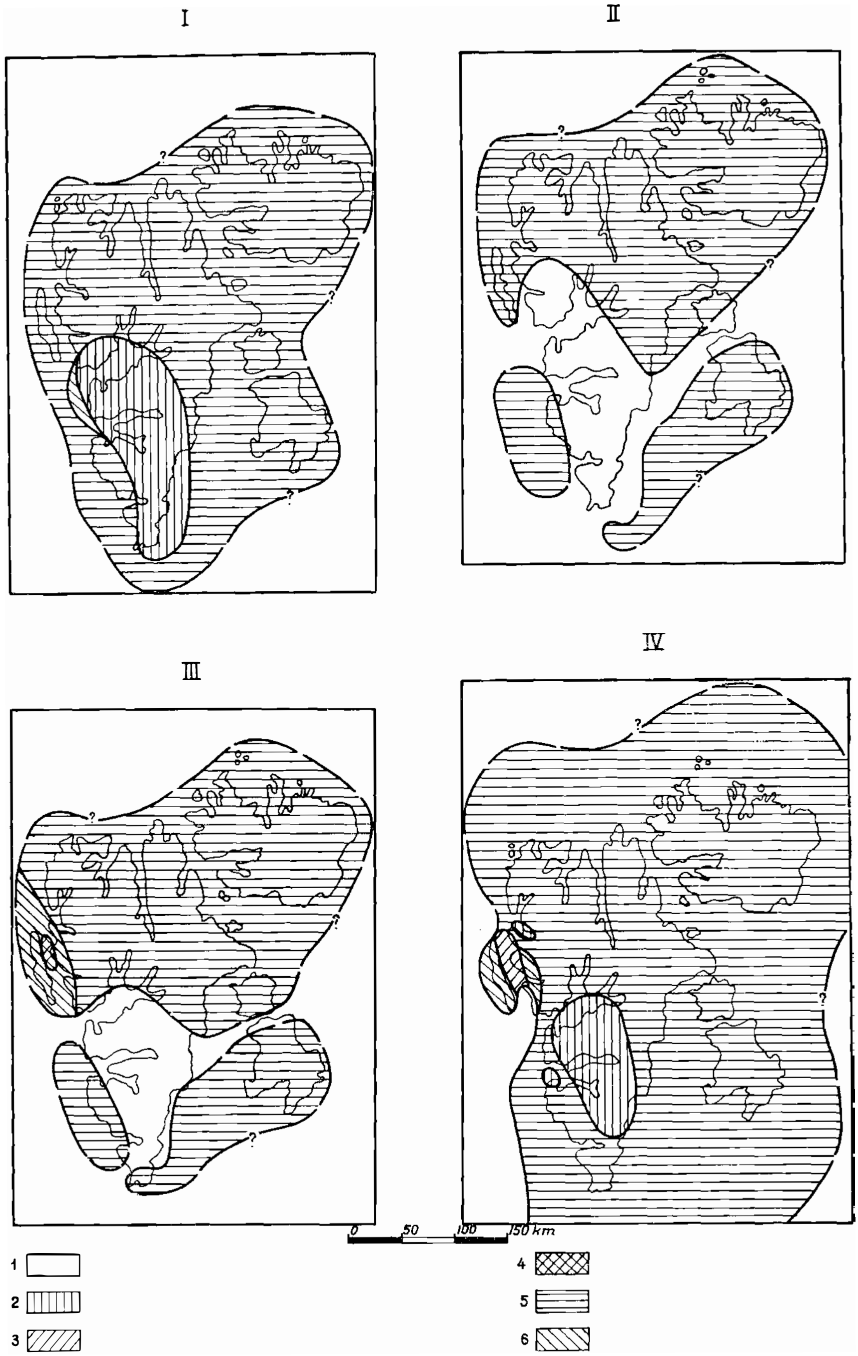


Fig. 4. *Palaeogeographical maps of Svalbard in the Palaeogene.* I. *Beginning of Thanetian age — period of deposition of the productive (coal-bearing) member of the Barentsburg Formation.* II. *End of Thanetian age — period of deposition of the Colesbukta Formation.* III. *Beginning of late Eocene — period of deposition of the Frysjaodden and Selvågen formations.* IV. *Beginning of Oligocene — period of deposition of the Storvola, Marchaislaguna, Kongsfjorden, and Skilvika formations.* 1. *The epicontinental sea (shallow part of the shelf).* 2. *Low-lying depositional plains with numerous swamps and lakes.* 3. *Intermontane depressions intermittently submerged by sea.* 4. *Intermontane depression.* 5. *Upland plain, plateau.* 6. *Mountain areas.*

Oligocene, the Central Basin consisted of one single island with isolated lacustrine and lacustrine-swampy hollows and even small basins. The period of the Oligocene regression in Svalbard emphasizes the extensive retreat of the sea in the Oligocene in northern Eurasia.

Although Pre-Quaternary deposits younger than Oligocene are not known in the archipelago, it is most probable that deposition continued after this period. An indication of this is the grade of coalification in Oligocene deposits, for the formation of which a pressure equivalent to that produced by a 2 to 2.5 km thick sedimentary sequence would be required. Taking for granted the average rate of Palaeogene sedimentation in the Central Basin (72 m/million years) and the data on the length of the Oligocene and Miocene (25 million years after AFANAS'EV et al. 1964), it is possible to assume that the sedimentation in Svalbard continued up to the Pliocene.

Judging from the complex of palaeontological and lithological evidence, the climate in Svalbard was much warmer in the Palaeogene than now (probably by more than 12 to 13 degrees C), and was more like the present climate of Central Europe.

Structure of the platform mantle of Svalbard

The epi-Caledonian platform mantle has a clear block structure, and the following major elements are distinguished from west to east (structures of first rank): the west coast horst-like uplift, the Spitsbergen graben-like trough, the Sassendalen monocline, the east Svalbard horst-like uplift, the Olgastretet trough, and the Kong Karls Land uplift. The structures enumerated mainly reflect the peculiarities of structure of the platform basement and are divided by major faults (Fig. 5). The structures of the western part of the archipelago (west of the east Svalbard uplift, in the areas of Palaeogene exposures) have been studied most thoroughly.

THE WEST COAST HORST-LIKE UPLIFT

This platform structure (visible width 50 km) coincides spatially with the Caledonian horst-anticlinorium of the same name. Its main part is composed of intensely dislocated and metamorphosed Hecla Hoek rocks. The platform formations, mostly Palaeogene, but also Palaeozoic and Mesozoic, are usually preserved in graben-like troughs. These have a north-western strike and occur along the whole west coast of Svalbard in the central part of the uplift. From north to south the Forlandsundet, Renardodden, Hornsundneset, and Øyrlandet troughs have been recognized. The largest of them — the asymmetrical Forlandsundet trough, more than 45 km long and 12 to 20 km wide, with a steeper western limb — is filled with Eocene-Oligocene deposits and is bordered on both sides by submeridional fault zones with

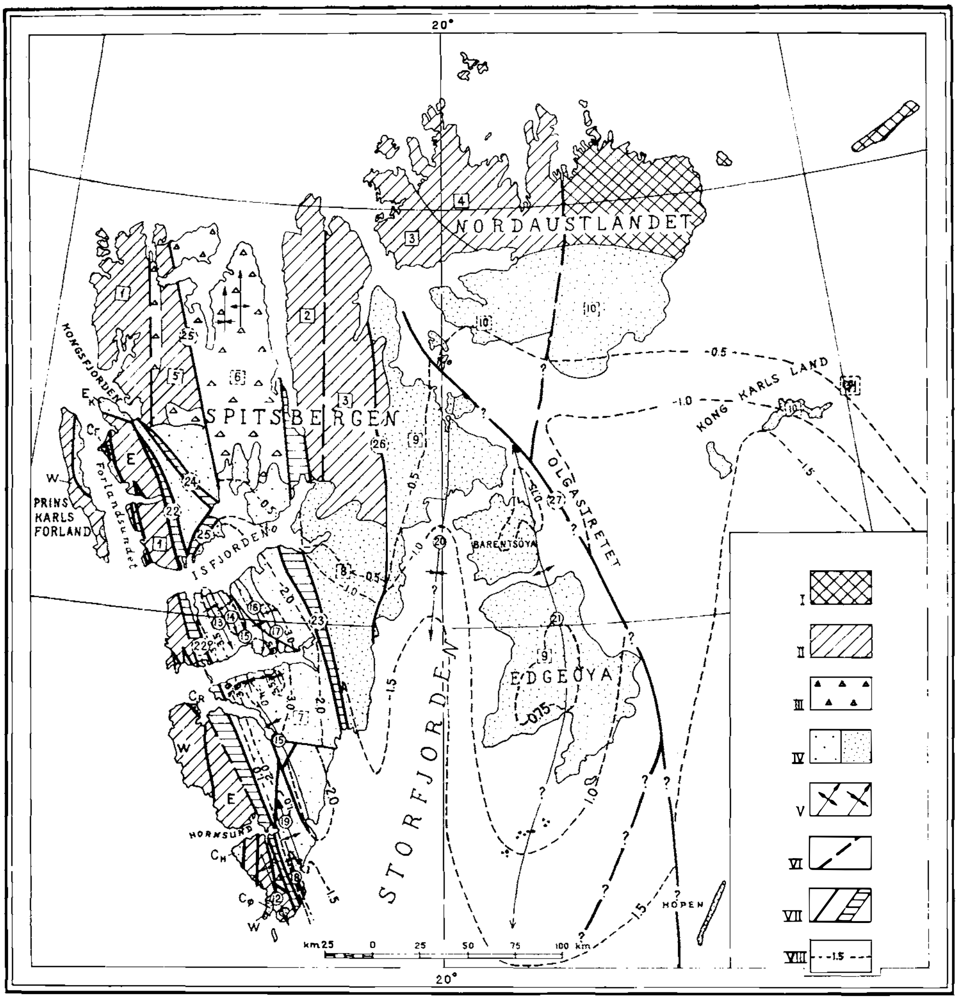


Fig. 5. *Structural scheme of the Svalbard archipelago devised by the author on the principles of the scheme proposed by* Sokolov *et al. (1968).* I. *Rejuvenated block of the pre-Riphean crystalline basement.* II. *Caledonian fold systems:* 1. *west coast horst-anticlinorium,* 2. *western Ny-Friesland anticlinorium,* 3. *Hinlopenstretet synclinorium,* 4. *Nordaustlandet anticlinorium.* III. *Devonian graben on the Caledonian fold basement:* 5. *inner horst,* 6. *Andrée Land monocline.* IV. *Platform mantle:* a) *area of increased mobility (on the Caledonian fold basement),* b) *area of reduced mobility (on the Caledonian and more ancient basement).* Major structures (first rank). *West coast horst-like uplift, spatially coinciding with the Caledonian horst-anticlinorium of the same name (1) and its parts: W — western block, C — central zone of graben-like troughs* (C_f *— Forlandsundet,* C_r *— Renardodden,* C_h *— Hornsund,* $C_ø$ *— Øyrlandet),* E *— eastern block* (E_k *— Kongsfjorden graben-like trough),* 7. *Spitsbergen graben-like trough,* 8. *Sassendalen monocline,* 9. *East Svalbard horst-like uplift,* 10. *Olgastretet trough,* 11. *Kong Karls Land uplift.* Intermediate structures (second rank). *In the west coast horst-like uplift:* 12. *Olsokbreen swell; in the Spitsbergen graben-like trough:* 13. *Iradalen depression,* 14. *Holmsenfjellet swell,* 15. *Skiferdalen depression,* 16. *Reindalen swell,* 17. *Tverrdalen depression,* 18. *Bettybukta depression,* 19. *Isbukta swell; east Svalbard uplift:* 20. *East Svalbard depression,* 21. *Barentsøya-Edgeøya swell.* V. *Axes of the middle structures with directions of plunge:* a) *in swells,* b) *in depressions.* VI. *Major fault zones not manifested in post-Devonian time.* VII. *Major fault zones manifested in post-Devonian time:* 22. *western marginal zone,* 23. *eastern marginal zone,* 24. *Pretender zone,* 25. *Bockfjorden-Erdmannflya zone,* 26. *Lomfjorden—Agardhbukta,* 27. *Hinlopenstretet —Olgastretet.* VIII. *Depth of the occurrence of the base of the platform mantle in km.*

throws of 2,200 m in the west and 1,400 m in the east. The trough is dissected by a number of faults which result from a strong dislocation of the rocks and the formation of fault folds. A narrow internal horst occurs to the north of Sarsbukta within the eastern limb of the trough. Hecla Hoek rocks are exposed by the structure, which although less than 1 km wide, is more than 30 km long and is also seen on Hermansenøya. The relative uplift of this structure is almost 1,000 m. The axis of the Forlandsundet trough rises on the whole to the north and to the south, and the dip angles in these directions are flattened out to 10° to 20° as compared to the more usual 30° to 40°.

The graben-like Renardodden trough is composed of Oligocene rocks and has a northwesterly plunge of 12° to 25°. Only its western part is accessible to observation (visible length 5 to 6 km, width 2.5 to 3 km). A western border fault is seen, which dips steeply to the east.

The graben-like Hornsundneset trough (visible length 15 km, width 10 km) is filled with Lower Carboniferous rocks, which in its axial part are covered by Triassic rocks. The eastern limb dips to the south-west, and the western limb to the south-east (10° to 12°). The axis of the structure plunges towards the south. The vertical amplitude of the eastern border fault is 100 to 200 m.

The graben-like Øyrlandet trough (visible length and width 10 km) is composed of Palaeocene formations which cover an Aptian-Albian succession. The rocks have southwesterly dip of 3° to 4°. The vertical amplitude is more than 300 m along the eastern border fault and more than 1,500 m along the western border fault. On the whole, the dips of the rocks within the chain of troughs discussed become more gentle southwards.

The structure of the western and eastern blocks of the horst-like uplift is generally similar. However, the platform formations are somewhat more developed within the eastern block, and they have been preserved not only in small grabens and graben-like troughs, but also within positive structures (e. g. the Olsokbreen swell in Sørkapp Land, Fig. 5, 6). The largest of the troughs, the Kongsfjorden trough with a north-westerly strike axis, is filled by Upper Palaeozoic, Triassic (?), and Palaeogene formations. Its present structure is very complicated and results from movements of the western marginal fault zone. The Palaeogene deposits are bordered by faults in a small sector of the eastern limb of the main trough; they dip principally monoclinally south-west by 10° to 35° and are dissected into five blocks by submeridional faults (Orvin 1934).

THE WESTERN MARGINAL FAULT ZONE

This name has been given by the author (Livšic 1965a) to a zone of intensely dislocated rocks principally of Middle — Upper Palaeozoic, Mesozoic, and Palaeogene age; this zone is up to 10 to 15 km wide and stretches for more than 300 km along the eastern edge of the west coast horst-like uplift. This zone changes its strike to the west and north-west and probably

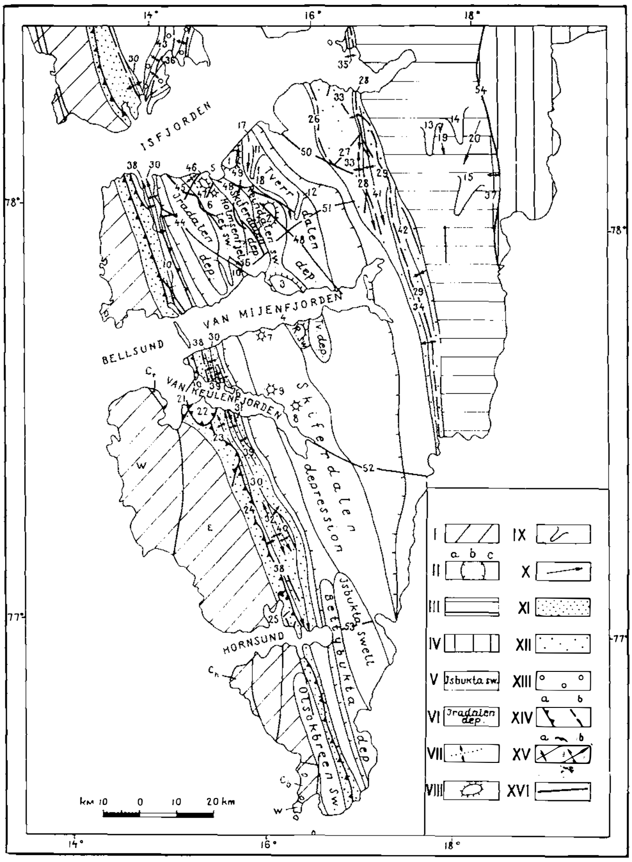


Fig. 6. *Scheme of the platform structures of the southern part of Spitsbergen.* PLICATE STRUCTURES. Major structures (of first rank) — I. *West coast horst-like uplift and its parts: W — western block, C — central zone of graben-like troughs (C_r — Renardodden, C_h — Hornsund, $C_ø$ — Øyrlandet), E — eastern block.* II. *Spitsbergen graben-like trough and its parts: a) western slope, b) axial part, c) eastern slope.* III. *Sassendalen monocline.* IV. *East Svalbard horst-like uplift.* Middle structures (second rank) — V. *Swells: Olsokbreen, Holmsenfjellet, Reindalen, Isbukta.* VI. *Depressions: Iradalen, Skiferdalen, Tverrdalen, Bettybukta.* VII. *The buried Nordhallet swell (to the west of Kapp Laila).* Minor structures (third rank) — VIII. *Domes:* 1. *Grumantbyen,* 2. *Bromdalen,* 3. *Ishøgda,* 4. *Blixodden,* 5. *Kapp Laila,* 6. *Lailadalen,* 7. *Collinderodden,* 8. *Storvola,* 9. *Davisdalen.* IX. *Hemianticlines:* 10. *Kalvdalen,* 11. *Bjørndalen,* 12. *Fardalen,* 13. *Vendomdalen,* 14. *Fulmardalen,* 15. *Svenfjellet.* X. *Hemisynclines:* 16. *Kalvdalen,* 17. *Bjørndalen,* 18. *Fardalen,* 19. *Moskusdalen,* 20. *Storfjellet.* DISJUNCTIVE STRUCTURES. Major Pre-Carboniferous fault zones — XI. *Western marginal zone.* XII. *Eastern marginal zone.* XIII. *Bockfjorden—Erdmannflya zone.* XIV. *Main faults within the major zones, a) faults of thrust type with general dip direction of the dislocation plane:* 21. *Midterhuken,* 22. *Berzeliustinden,* 23. *Saussureberget,* 24. *Supanberget,* 25. *Hyrnefjellet; b) faults:* 26. *Janssondalen,* 27. *Arctowskifjellet,* 28. *Arnicadalen,* 29. *Brentskardhaugen.* Near-fault and over-fault linear folds in marginal zones — XV. *Fold axes with direction of the plunge,* a) *of anticlines:* 30. *Grønfjorden,* 31. *Annaberget,* 32. *Engadinerberget,* 33. *Arnicadalen,* 34. *Brentskardhaugen,* 35. *Gipshuken,* 36. *Bohemanflya,* 37. *Roslagenfjellet; b) of synclines:* 38. *Grønfjorden,* 39. *Annaberget,* 40. *Engadinerberget,* 41. *Arnicadalen,* 42. *Brentskardhaugen,* 43. *Bohemanflya.* XVI. *Post-Carboniferous faults:* 44. *Grøndalen,* 45. *Hollendardalen,* 46. *Vestalaksla,* 47. *Ravndalen,* 48. *Colesdalen,* 49. *Grumantbyen,* 50. *Adventdalen,* 51. *Reindalen,* 52. *Van Keulenfjorden,* 53. *Hornsund,* 54. *Lomfjorden—Agardhbukta.*

extends through the northern part of Greenland to the Canadian Arctic Archipelago. Beyond Svalbard the eastern and western marginal fault zones are apparently adjacent, and it is possible that the same zones can also be traced to the south, being the northern continuation of the Rhine-Scandinavian lineament, distinguished by BELJAEVSKIJ (1963).

This zone represents a complex but single unit of tectonic dislocations connected with crustal block movements. A number of thrust sheets have been assigned to the 2 to 10 km wide *subzone of major thrusts* (western zone) (Fig. 6); these sheets overlap each other and are often curved (RÓŻYCKI 1959, CHALLINOR 1967). The blocks have moved north-eastwards in the southern part of the zone, and north-westwards in the northern part (up to 6 to 7 km in Brøggerhalvøya).

The subzone of linear folds (1 to 10 km wide) is situated in front of the main thrusts. The Grønfjorden anticline and the *overturned* Grønfjorden syncline, linked with the former to the west, are distinguished (Fig. 6). The formation of both structures has been influenced by the thrusts; they are asymmetrical and dissected by a number of faults. The dips of the western limbs are 5° to 10°, and those of the eastern limbs 15° to 35°. Their general strike is 330 to 340 degrees. The anticline is complicated by the minor (1 to 1.5 km wide) linked Annaberget and Engadinerberget anticlines and synclines (RÓŻYCKI 1959, LIVŠIC 1965a).

THE SPITSBERGEN GRABEN-LIKE TROUGH

The trough is filled with all the formations of the platform structural complex: mainly Palaeogene deposits are exposed, and the trough has a north-western strike. The total width is 50 to 60 km, the length exceeds 250 km (elongation 1:4 to 1:5), the growth intensity — the relationship between the amplitude of the structure and its area (after NALIVKIN et al. 1965) — is 0.24 m/sq. km.

The trough is asymmetrical — its western limb is considerably steeper and narrower than its eastern one (4° to 17° and 2.5 to 5 km against 2° to 5° and 9 to 12 km). The axial part is 20 to 45 km wide and is complicated by a number of intermediate (second rank) and minor (third rank) platform structures (LIVŠIC 1965a) (Fig. 6). These structures are classified in accordance with the resolution of the Conference on Platform Structure Classification (1963). According to terrestrial and marine seismic survey investigations, these structures are well defined in all the horizons of the platform mantle down to a depth of 3 to 4 km, i. e. they are transverse. The most typical are the linked swells and depressions (medium structures) which are usually subparallel to the general strike of the trough. The only buried structure recorded by seismic survey is the Nordhallet swell (situated to the west of Kapp Laila), which is recorded only at 2,000 m below sea level on the south coast of Isfjorden.

The axial part of the trough is divided into two almost equal parts in a meridional direction by the Skiferdalen depression. Bilaterally linked to this depression in Nordenskiöld Land are first swells (the Holmsenfjellet swell in the west and the Reindalen swell in the east) and so depressions (the Iradalen and Tverrdalen depressions). The same relation is preserved further south, but the structures west and east of the Skiferdalen depression are displaced relative to each other submeridionally by 60 km. As a result of this, these structures occur only to the east of the Skiferdalen depression in Nathorst Land; in Sørkapp Land and Torell Land, the Isbukta swell and the Bettybukta depression are situated to the west of the Skiferdalen depression. The total length of the intermediate structures is 40 to 150 km, their width 2 to 16 km, and their area is 240 to 2 250 sq. km; their amplitude (beginning from the core of the depression and up to the swell arch) is 150 to 800 m, while their growth intensity is 0.1 to 1.3 m/sq. km (total) and 0.6 to 1.8 m/sq. km (in a certain horizon)[1]. The largest structures are the Skiferdalen and Tverrdalen depressions and the Reindalen swell. The highest growth intensity is observed in the Holmsenfjellet swell, and the lowest in the Tverrdalen depression. The structures are asymmetrical. Although the dip angles are not large — usually 2° to 5°, and rarely up to 8° — the swells usually have steeper eastern limbs, whereas the depressions have steeper western limbs.

The minor structures of third rank (domes, hemianticlines, hemisynclines) are best represented in the eastern part of the trough. Thus in the northern part of the Holmsenfjellet swell, the small Kapp Laila and Lailadalen domes (respective widths 2 and 1 km and lengths 4 and 1.8 km) are distinguished. Four domes are distinguished from north to south in the Reindalen swell, viz. the Grumantbyen, Bromdalen, Ishøgda, and Blixodden domes. Their width is 3 to 6 km, their length 8 to 12 km, and their amplitude (measured from the lower closed structure contour to the arch of the swell) is 60 to 150 m. The dip angles are usually 2° to 4°. The Bromdalen dome is the highest, and has the highest growth intensity (37 m/sq. km). Among the hemianticlines, the Kalvdalen hemianticline, which complicates the southern pericline of the Holmsenfjellet swell, is noteworthy. Its length is 3 to 14 km, its width 1 km, its height 50 to 100 m, and the limbs dip by 2° to 5°.

The trough is dissected by numerous steep-angled faults, with associated drag folds. Faults first initiated prior to the Carboniferous are distinguished from Carboniferous and later faults, although all were highly active in the Palaeogene and post-Palaeogene. Pre-Carboniferous faults include: a) the western and eastern marginal zones, b) the Bockfjorden-Erdmannflya fault zone (NNE and submeridional strike), and c) possibly the Pretender zone (ORVIN 1940, CUTBILL and CHALLINOR 1965). Carboniferous and later faults include: a) steeply dipping faults, strike WNW, vertical throw 50 to 200 m (e. g. the Grøndalen, Hollendardalen, Colesdalen, and Adventdalen faults),

[1] Data on amplitude, intensity, increase, and other peculiarities of the northern part of the Isbukta swell in the centre of Torell Land (FLOOD et al. 1970) have not been taken into account.

b) those faults with both NE and sublatitudinal strike and vertical throws of 30 to 300 m (e. g. Vestalaksla, Ravndalen, Grumantbyen, Reindalen, Isfjorden, Van Mijenfjorden, Van Keulenfjorden, Hornsund, etc.).

The latter faults regulate the strikes of the corresponding bays and fjords.

THE EASTERN MARGINAL FAULT ZONE

This zone is 2 to 12 km wide and extends in a meridional direction across the whole of Svalbard from Wijdefjorden to Kvalvågen. It represents a totality of dislocations which have affected both the deposits of the platform mantle and older formations. The most intense dislocations took place in the Upper Devonian, the Middle Carboniferous, the Palaeogene, and in the post-Palaeogene. Steep submeridional faults with throws of up to 500 m and sometimes even 3 to 4 km (Upper Devonian movements) are dominant (McWhae 1953; Livšic 1965a, 1966). Their downthrow is usually to the east. The formation of asymmetrical anticlines with fractured crests and linked synclines is typical. Examples are seen at Pyramiden, Arnicadalen, and Brentskardhaugen. These structures here are 1 to 5 km wide and 200 to 600 m high; the steeper western limbs dip by 10° to 35°, the eastern limbs by 8° to 12° (Livšic 1965a, 1966; Parker 1966) (Fig. 6). The products of basic magmatism are restricted to this zone.

THE SASSENDALEN MONOCLINE

This monocline, which is separated from the Spitsbergen trough by the eastern marginal zone, extends from south to north for more than 120 km, and has a width of 30 to 40 km. It is composed of Upper Palaeozoic rocks in the north; Mesozoic rocks in the south dip SSW by 1° to 5°. According to A. I. Panov and V. F. Nepomiluev (unpublished data), the monocline is complicated in Sabine Land and in eastern Nordenskiöld Land by gentle submeridional hemianticlines and hemisynclines (lengths 10 to 15 km, widths 3 to 5 km) (Fig. 6).

THE EAST SVALBARD HORST-LIKE UPLIFT

This uplift extends for more than 250 km, with a width of 160 km, and is separated from the Sassendalen monocline by the Lomfjorden — Agardhbukta fault. It is formed mainly of Triassic and, to a lesser extent, of Jurassic and Upper Palaeozoic rocks dipping very gently (maximum 1° to 1.5°).

The total thickness of the Triassic rocks is less than that of the contemporaneous formations in western Svalbard (Klubov 1965a, 1965b; Pčelina 1965, 1967; Buchan et al. 1965). Very gentle submeridional structures of second rank are noticed: first of all the Barentsøya-Edgeøya swell and the east Svalbard depression (KLUBOV 1965b). The swell is complicated by a number of smaller structures with an east-north-eastern strike, and by isolated dome-shaped structures, where Upper Permian rocks outcrop (eastern coast of Barentsøya, the Krokå and Veidebreen areas on Edgeøya).

THE OLGASTRETET TROUGH

This trough is separated from the east Svalbard uplift by the Hinlopenstretet — Olgastretet fault which, as with the main part of the structure, is almost completely under sea level. Unlike the more westerly structures, the basement of the trough is composed, as the basement of the eastern part of the east Svalbard horst-like uplift, mainly of Precambrian crystalline rocks which outcrop in the eastern part of Nordaustlandet (KRASIL'ŠČIKOV 1965).

THE KONG KARLS LAND UPLIFT

This uplift is provisionally identified to the east of the Olgastretet trough. As with the previous structure, it is situated on the ancient Barents Sea massif and is almost completely under sea level.

The differences between the platform structures to the east and west of the eastern marginal fracture zone, are notable:

1. The major structures (troughs and uplifts) in the west are smaller in dimension, but the values of their linearity and growth intensity are much higher than those of the eastern structures. At the same time, the rocks dip more steeply than in the east.
2. Intermediate structures (swells and depressions) occur more frequently in the west of the archipelago, and the values of their linearity and growth intensity are much higher than in the east.
3. In the east of the archipelago, disjunctive dislocations occur more rarely in the platform sedimentary mantle.

Thus, all the dislocations are much more strongly developed in the western part of Svalbard.

The main stages of formation of the platform structure of the archipelago

All platform history of Svalbard is the history of block movements. Four stages of platform development are distinguished: late Palaeozoic (including also the early Carboniferous epoch), Mesozoic, early Cenozoic, and late Cenozoic (LIVŠIC 1970). These stages coincide with the main depositional cycles and are separated by periods of general uplift of the area and subsequent levelling (Fig. 7). Block movements in different directions have determined the partial structural reorganization of the archipelago between

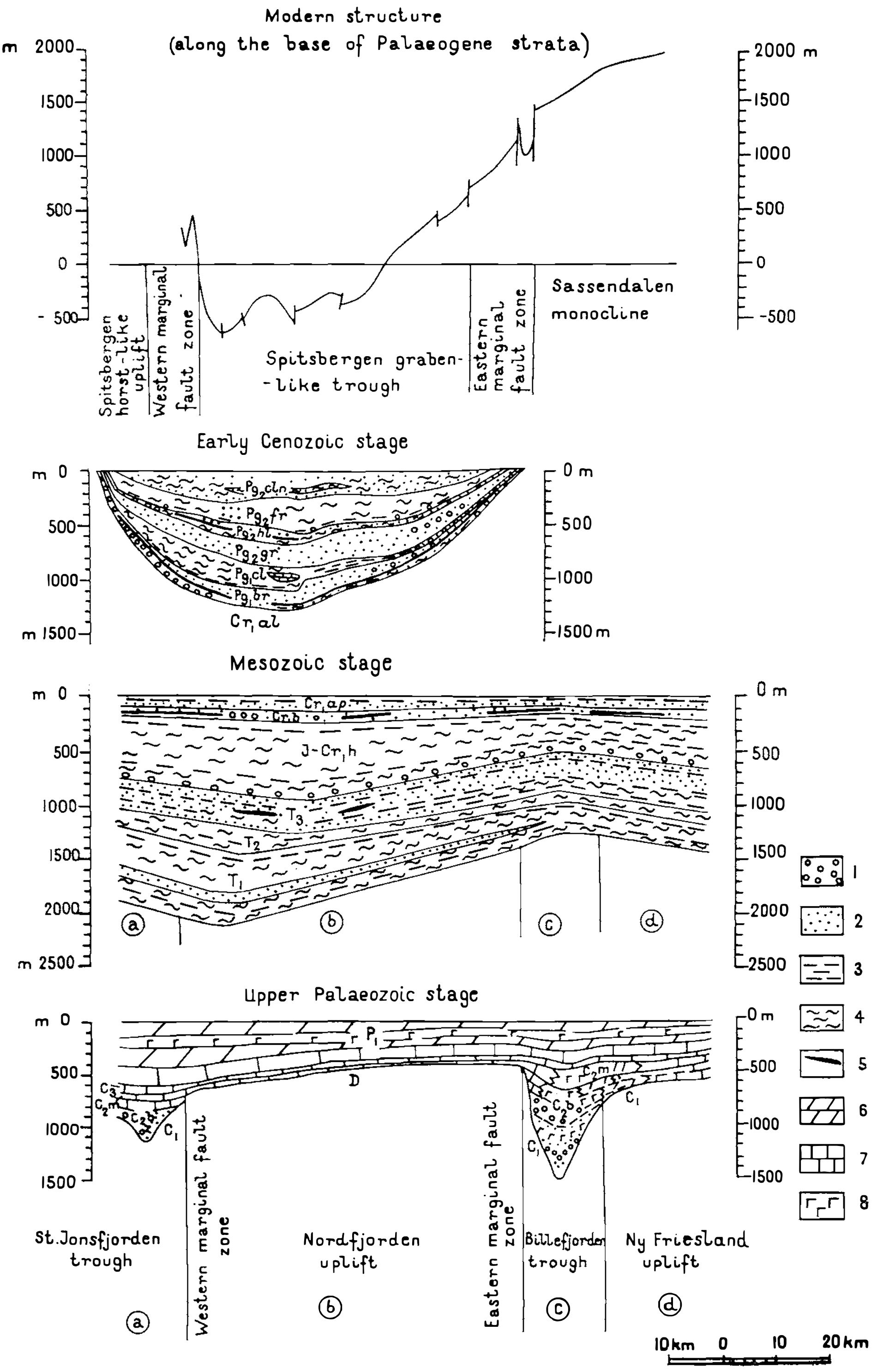


Fig. 7. *Main formation stages of the epi-Caledonian platform mantle in Spitsbergen (lithological-facial profiles across the Isfjorden area).* 1. *Conglomerates.* 2. *Sandstones.* 3. *Siltstones.* 4. *Argillites.* 5. *Coals.* 6. *Dolomites.* 7. *Limestones.* 8. *Gypsums.*

the different epochs. Therefore, each stage of development has apparently a certain corresponding structural stage.

The origin of the largest dislocations, which have played the main part in the development of the region, dates back to the initial phases of Caledonian tectogenesis or even to earlier periods of geological history. These are primarily the submeridional faults, bordering the Spitsbergen graben-like trough (western and eastern marginal zone), and controlling the large Devonian graben in northern Svalbard.

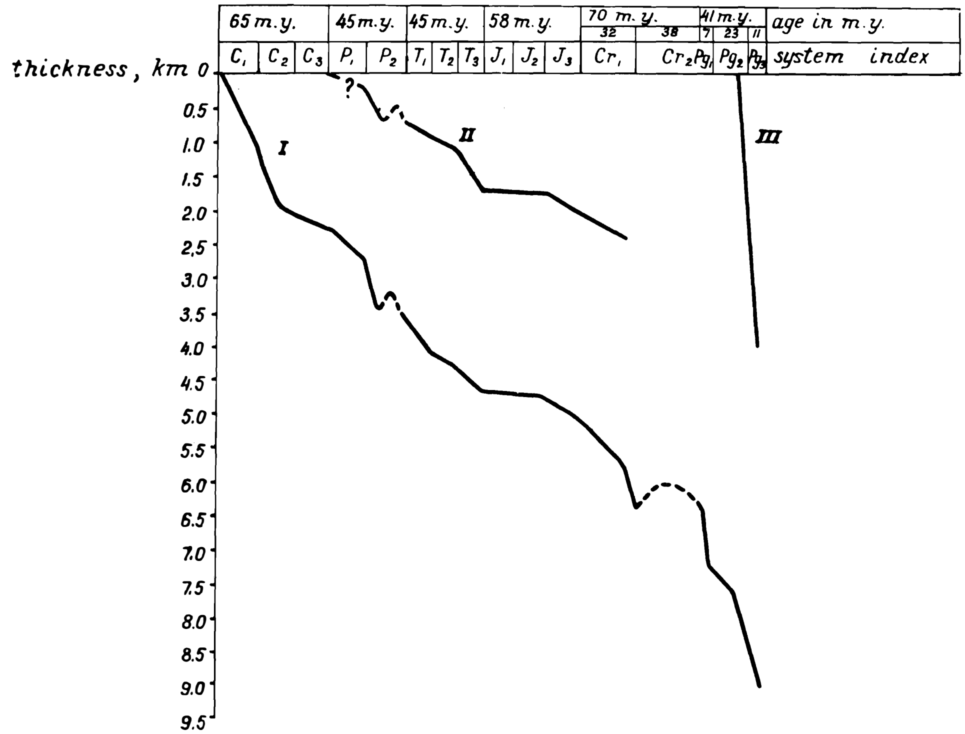
Svalbard first developed as a mobile platform in the early Carboniferous. Extensive faulting in the early Bashkirian produced for the first time a block structure with a series of horst-like uplifts and graben-like troughs (CUTBILL and CHALLINOR 1965; USTRICKIJ 1967). Block movements were again manifest at the Upper Carboniferous/Lower Permian junction, and a single trough was formed in place of the uplifts and troughs. This still existed in the late Permian. The average rate of sedimentation during this stage was 35 metres per million years (Fig. 8, all values given are for the central part of Spitsbergen). The stage of general uplift was completed at the end of the Upper Permian.

The Mesozoic stage began with the accumulation of Lower Triassic rocks on a considerably peneplaned surface. Movements along the faults were not very intense at this stage, and the general contours of the Permian trough were preserved, although its axis migrated eastwards. The average rate of sediment accumulation during this stage was 16 m/million years. The stage was completed in the late Cretaceous by an uplift which continued into the beginning of the Palaeocene. The main phase of basic magmatism apparently dates to the middle of the Cretaceous (100 million years), whereas dolerite intrusions are usually localized near the major faults (FIRSOV and LIVŠIC 1967).

At the beginning of the early Cenozoic (in late Palaeocene) the importance of block movements greatly increased, the Palaeogene troughs were reduced in size and had a character of near-fault position and aulacogen shape. The average rate of sediment accumulation increased to 72 metres per million years. Only the general contours of the present Spitsbergen trough were determined between the late Palaeocene and Middle Eocene. The intermediate structures (of second rank) did not originate before the beginning of the Upper Eocene (Fig. 3). The main graben-like troughs of the west coast were formed in the Upper Eocene and Oligocene. The most intense movements took place in the Pliocene, when the present structure of the archipelago was mainly formed. The stage was completed with a general uplift at the end of the Pliocene.

It is of interest to note that the formation of each of the stages indicated took place in three phases: first an intense accumulation of sediments, then a period of less intense sedimentation, and finally a new increase in the rate of deposition (Fig. 8). The highest rates correspond to periods of intensification of block movements.

The late Cenozoic was characterized by an irregular uplift, which has



In metres/million years.

		Region west of the eastern marginal fault zone			Region east of the Lomfjorden—Agardhbukta fault	Forlandsundet region
		Stage				
		Upper Palaeozoic	Mesozoic	Early Cenozoic	Mesozoic	Early Cenozoic
First stage (increased rate)		C_1-C_2b 59	T_1-T_3 24	Pg_1br-Pg_1cl 193	T_1-T_3 20	—
Second stage (decreased rate)		C_2m-C_3 10	J_1-J_2 0.2	Pg_2gr-Pg_2hl 24	J_1-J_2 0.4	—
Third stage (increased rate)	Not including thickness of eroded strata	—	J_3-Cr_1b 43	—	J_3-Cr_1b 26	—
		P_1-P_2st 38	J_3-Cr_1ap 38	Pg_2fr-Pg_2cln 112	—	—
	Including thickness of eroded strata	P_1-P_2sl 47	J_3-Cr_1al 50	Pg_2fr-Pg_3st 116	—	—
Average rate for the stage	Not including thickness of eroded strata	35	16	72	—	Pg_2sl-Pg_2kr 247
	Including thickness of eroded strata	38	20	76	—	Pg_1sl-Pg_3mr 292

Fig. 8. *Rate of deposition of the epi-Caledonian platform mantle.* I. *West of the eastern marginal fault zone (western part of the archipelago);* II. *East of the Lomfjorden-Agardhbukta fault (eastern part of the archipelago);* III. *Forlandsundet.*

continued until the present time. Connected with this stage was the formation in the Holocene of olivine basalt sheets, trachybasalts, and tuffs, composing the Quaternary volcanos of northern Spitsbergen.

It has already been pointed out that both disjunctive and plicative dislocations are more common in the western part of Svalbard than in the east of the archipelago. The higher mobility of the western part is seen throughout the whole platform history. The varying mobility of the epi-Caledonian platform in the late Palaeozoic and Mesozoic was apparently connected with the peculiarities of the basement structure, and in the early and late Cenozoic — with the influence of the rift zone of the mid-Atlantic ridge. It is worth noting that the increased mobility is restricted to Cenozoic time, during which the aulacogen-shaped structures were formed in the west of the archipelago.

The importance of Palaeogene deposits for oil and gas prospecting in Svalbard

Palaeogene deposits are exposed in the most downwarped areas of the epi-Caledonian platform mantle and, therefore, have limited importance for oil and gas prospects. Firstly, the basal Palaeogene horizons may contain oil and gas deposits. Secondly, good marker horizons in the Palaeogene permit us to trace out on the surface structures in the deep Mesozoic (and possibly Palaeozoic) sediments which are of prime interest for oil and gas prospecting.

The only known indications of liquid oil in Svalbard have been discovered in the lower productive member of the Barentsburg formation in the Isfjorden area. Combustible gas of methane compisition with an admixture up to 3 % of higher hydrocarbon is contained in groundwater which rises along fissures in the same region. In addition to this, gas indications on the surface have been discovered in the field where Upper Palaeocene and Mesozoic rocks are developed in some areas on the west coast of Svalbard.

BITUMINOSITY AND RESERVOIR ROCK PROPERTIES IN PALAEOGENE DEPOSITS

470 determinations of organic carbon, 1150 luminiscence-capillary determinations of chloroform bitumen «A», and a number of special analyses of oil and bitumens (group composition, chromatographic division, etc.)[1] have been carried out. The results have been analysed statistically. Particularly it has been established that the content of bitumen «A» in sandstones and siltstones approximates to the Pirson curve of type III, and in argillites to the Pirson curve of type I; the distribution of organic carbon is subordinate to the normal law.

[1] All determinations of bituminological and reservoir properties of the rocks have been carried out in laboratories of the fuel mineral department of the Scientific Research Institute of the Geology of the Arctic.

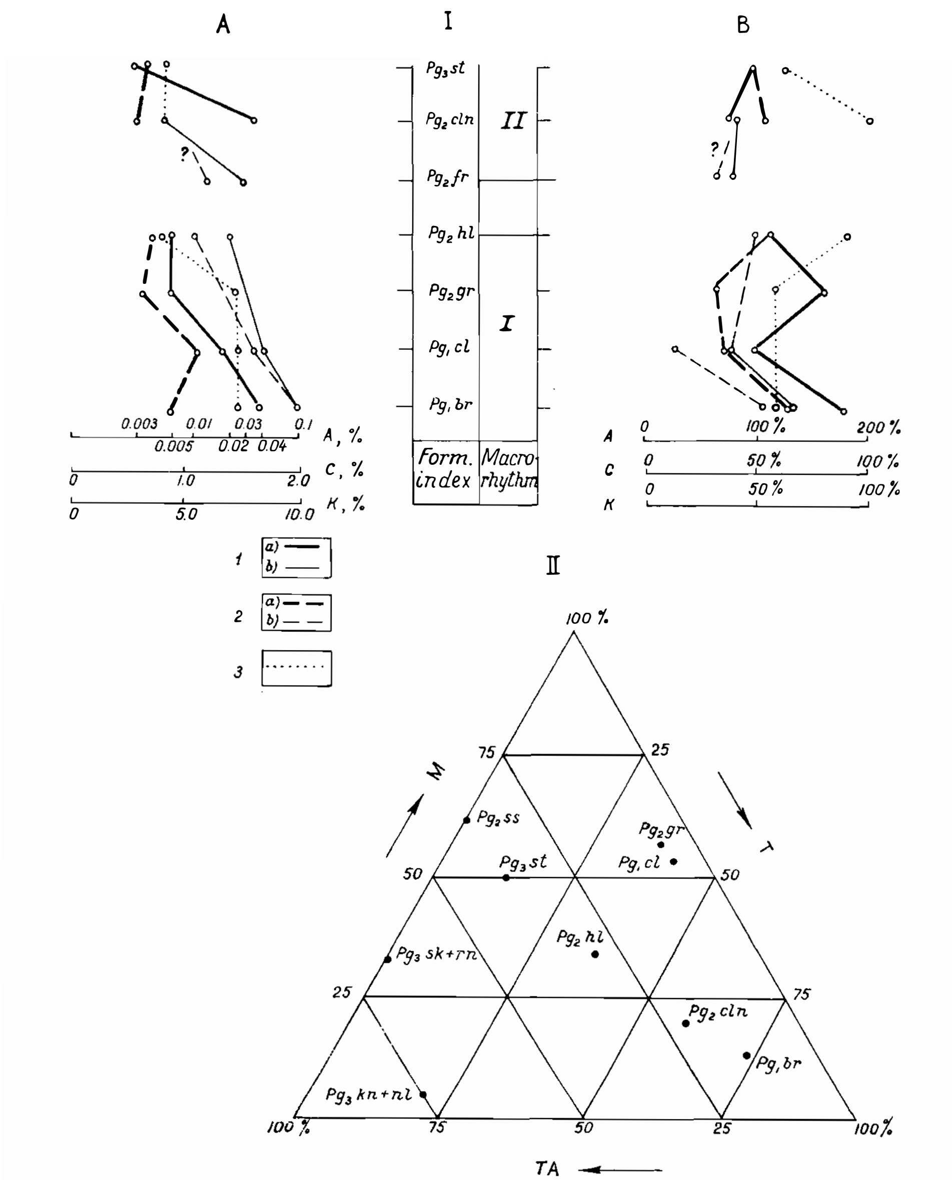


Fig. 9. *Diagrams of the bituminous and reservoir rock properties of the Palaeogene deposits of the Central Basin.* I. *Content of bitumen «A» (A), of organic carbon (C), and open porosity coefficients (K).* A. *Mean values in formations in %;* B. *Variation coefficients: —* 1. *bitumen «A» a) in sandstones and siltstones, b) in argillites, —* 2. *organic carbon a) in sandstones and siltstones, b) in argillites, —* 3. *open porosity coefficient in sandstones and siltstones.* II. *Types of bitumen «A» in sandstones and siltstones in % of the total number of samples from each formation: M — median bitumen «A», T — tarred bitumen «A», TA — tarred-asphaltene bitumen «A». The indicated types of bitumen «A» are distinguished according to the luminiscence colours of the chloroform extracts (yellow extract - median bitumen «A», orange extract — tarred bitumen «A», brown extract — tarred-asphaltene bitumen «A») and testify to the grade of oxidation of bitumen from median bitumen (least oxidized) to tarred-asphaltene bitumen (most oxidized).*

The bitumens are present mainly in a dispersed state. The average values of the content of chloroform bitumen «A» (mainly tarred and median) in certain formations (a few hundredths and thousandths of one per cent) usually do not exceed the Clark values (Uspenskij et al. 1949; Dvali 1963). The argillites are more bituminous than the sandstones. The most bituminous rocks are those of the Central Basin, among them the argillites of the productive member of the Barentsburg Formation (Fig. 9). The content of bitumen «A» in them sometimes reaches 0.3 to 0.6 %, with an average bitumen content of 0.09 %, C org. of 2.0 %, and the bitumen coefficient of 3.4 % $\left(\frac{\text{A bit.}}{\text{C org.} \times 1.3}\right.$ after Neručev 1962$\left.\right)$. In the Barentsburg Formation the values are respectively 0.04, 0.8, and 3.8 %. In composition the bitumens correspond to malthas and petroleum asphalts (according to the classification of Uspenskij et al. 1961), and in this respect are relatively similar to the oil from the Isfjorden area and to bitumens from the Triassic deposits and apparently correspond in composition to the naphthenic-aromatic oil, altered by supergenesis (according to the classification of Dobrjanskij 1948) (Fig. 10).

The content of bitumen in rocks of all the formations of the Palaeogene sequence (except the Barentsburg Formation) is directly dependent upon the amount of organic C in the same rocks. A direct connection in the content of bitumen «A» and that of organic C is observed with the rhythmicity of the deposits. The bituminosity of rocks increases in the lower part of each macrorhythm and decreases upwards in the section (Fig. 9). The main part of the dispersed bitumen in Palaeogene sequences has probably been formed in place by transformation of the organic matter in the rock. However, the bituminosity of the Barentsburg Formation (at least that of its basal horizons from where oil indications are known) is epigenetic and is connected with the migration of the hydrocarbons from the underlying deposits. The bituminosity of the Palaeogene deposits on the western coast is on the whole lower than in the Central Basin. In the Palaeogene rocks from Kongsfjorden and Renardodden, tarred-asphaltene bitumen «A» dominates, with an average abundance of 0.01 %. It is of interest that rocks of the Selvågen Formation and the Sesshøgda Formation in the Forlandsundet region of Spitsbergen contain chloroform bitumen «A», usually median bitumen, and more rarely tarred-asphaltene bitumen in a quantity of 0.0003 to 0.007 %, and only sometimes 0.01 %. On Prins Karls Forland only traces of bitumen have been discovered both in these and overlying formations. This increase in bituminosity in the eastern part of the region is apparently due to the influence of the western marginal fault zone, from where fluids have come. It is characteristic that the content of organic carbon in the rocks on the eastern coast of the strait, where seams of hard coal are known, is lower than on its western coast. Thus, in sandstones and siltstones of the Sesshøgda Formation in the region of Sarsbukta, the main content of organic carbon is 0.71 %, while it is 2 % on the opposite shore of the strait near Selvågen.

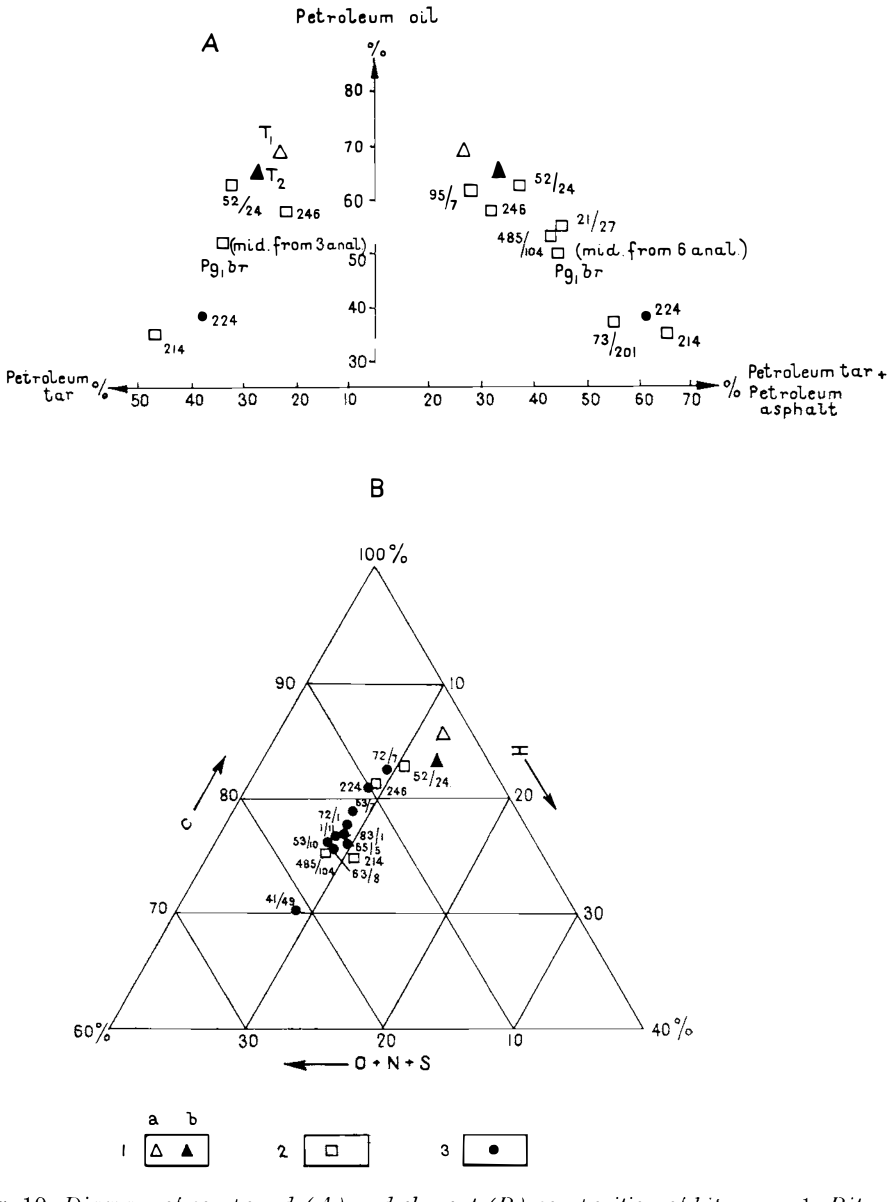


Fig. 10. *Diagram of compound (A) and element (B) composition of bitumens.* 1. *Bitumens from Triassic argillites, after* PČELINA *and* KLUBOV *(unpublished data) (mean values of four samples given): a) Lower Triassic argillites, b) Middle Triassic argillites.* 2. *Bitumens from the Barentsburg Formation: from the coal-bearing argillite member of the Grønfjorden area — 73/201, 485/104; of the Todalen area — 95/7; from argillites of the Richterelva area — 52/24; compound sample from the Neppeldalen area — 214; from borehole near Grønfjorden — 246.* 3. *Bitumens from argillites of other Palaeogene formations: Colesbukta Formation (Richterelva) — 53/10; Hollendardalen Formation — 1/11 (Oppkuvbekken), 63/7, 63/8 (Pallfjellet), 72/1 (Grøndalen); Frysjaodden Formation — 72/7 (Grøndalen); Collinderodden Formation — 83/1 (Storvola), 65/5 (Pallfjellet); Storvola Formation — 224 (Collinderodden); Skilvika Formation — 41/49 (Renardodden).*

To investigate the properties of the reservoir rocks, 430 open porosity determinations and 50 permeability determinations have been made. The distribution of the open porosity coefficients is subordinate to the normal law. The Palaeogene rocks are generally poor granular oil traps: their permeability is less than 0.3 millidarcy, and the values of the open porosity coefficients do not exceed 5 to 6 % (Fig. 9). However, in the lower member of the Barentsburg Formation some 3 to 10 m thick sandstones and conglomerates are observed with a porosity of 8 to 11 %. In view of the highly fractured rocks of the lower part of the formation (the volumetric density of the fractures for sandstones is 30 m/sq. m), they may apparently serve as fractured/porous oil and gas reservoirs (SMECHOV et al. 1963). All these considerations together with other evidence of oil and gas indications and bituminosity give us reason to assume that the lower member of the Barentsburg Formation may contain productive oil and gas accumulations in favourable structural conditions.

HYDROGEOLOGICAL CRITERIA TESTIFYING TO GAS AND OIL CONTENT OF THE ROCKS

These criteria are the presence of naphthenic acids in the underground waters of the Isfjorden area and a high content of higher hydrocarbons in the natural gas dissolved in the underground waters. Favourable indications for search of oil and gas are also the predominantly saline composition of the underground waters, high bromine content in some samples, comparatively low sulphate content, predominance of methane in the gaseous phase, and presence of hydrogen sulphide and carbonic acid as gas constituents.

TECTONIC CRITERIA OF OIL AND GAS CONTENT

Detailed investigations by the Spitsbergen Expedition of the Institute of Geology of the Arctic have shown that the most promising area for oil and gas search is the territory of the Spitsbergen trough, and most of all its most downwarped part (Nordenskiöld Land and Nathorst Land) where Palaeogene rocks are exposed. A number of tectonic features testify to the importance of this area:

1. Subsidence persisted from the Moscovian to the Oligocene; this resulted in the formation of a sedimentary sequence with a total thickness of more than 5.0 km.
2. Deposition occurred predominantly in marine and coastal-marine environments at shallow depths under conditions favourable for the accumulation of organic matter.
3. Traces of volcanic activity are rare.

4. Positive platform structures have been established in the central part of the trough; these are similar to oil-bearing structures of other platform areas.

According to T. M. PČELINA, V. N. SOKOLOV, and B. A. KLUBOV, oil and gas deposits may have formed and been preserved principally in the Mesozoic (Upper Triassic and Barremian-Aptian) and to a lesser degree in the Palaeozoic rocks (LIVŠIC and SOKOLOV 1965). The basal horizons of the Palaeogene may also be considered to be oil-bearing. Impermeable Palaeogene sequences, mainly of argillaceous composition (beginning with the Colesbukta Formation) may serve as cap rock for these deposits; such accumulations are most probably of a structural type (though lithological ones are also possible) and are to be found principally within the positive structures observed in the axial part of the trough.

Besides this, the sea areas situated to the east and south-east of Svalbard are undoubtedly of interest in connection with oil and gas prospecting — principally the Olgastretet trough area, the western and southern area of the east Svalbard uplift, and the southern extension of the Spitsbergen trough. The sea areas to the west of Svalbard may also be interesting in this respect; the presence of a considerable thickness of sedimentary formations of the platform mantle is also possible here.

As is known, the first exploration well (3.0 km deep) was bored by American geologists in the northern part of Van Mijenfjorden, Central Basin, in 1965 (NAGY 1967). Neither this, nor the rotor well bored by French geologists on Edgeøya in 1972, gave any direct positive results. However, this does not exclude the expediency of deep boring in the future, particularly taking into account the enormous significance of Svalbard for the investigation of a sea area so promising in respect of oil and gas as is the Barents Sea Shelf.

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Appendix 1

Preliminary list of fossil plants from Palaeogene deposits of Svalbard. Collections of JU. JA. LIVŠIC (1962—1968), L. JU. BUDANCEV and I. N. SVEŠNIKOVA (1959, 1967) (Fig. 11). Determinations made by L. JU. BUDANCEV and I. N. SVEŠNIKOVA.

Central Basin

Barentsburg Formation

Osmunda spetsbergensis NATH.
Hemitelites torellii HEER
Sphenopteris blomstrandii HEER
Ginkgo spitsbergensis MANUM
Pitiophyllum sp.
Picea sp.
Metasequoia occidentalis (NEWB.) CHANEY
Taxodium dubium (STERNB.) HEER
Glyptostrobus sp.
Thuites ehrenswærdii HEER
Moriconia cyclotaxon DEB. et ETT.
Trochodendroides arctica (HEER) BERRY
T. richardsonii (HEER) KRYSHT.
Nordenskiöldia borealis HEER
Trochodendrocarpus arcticus (HEER) KRYSHT.
Platanus rectinervis HOLLICK
P. basicordata BUDANTS.
Quercus juglandina HEER
Q. groenlandica HEER
Corylus scottii HEER
C. carpinifolia BUDANTS.

The most complete collections were made in the lower coal-bearing part of the section in the Barentsburg mines. Similar specimens from the same part of the succession were also found in the Grumantbyen and Sveagruva mines, near Camp Morton (north coast of Van Mijenfjorden), in Neppeldalen (south coast of Van Mijenfjorden), and on Erdmannflya.

Hollendardalen Formation

Isolated remains of *Platanus* sp., *Quercus* sp., *Tilia malmgrenii* HEER, *Viburnum* sp. were collected on the west side of Vassdalen (north coast of Van Mijenfjorden) in the uppermost part of the formation.

Collinderodden Formation

Ginkgo spitsbergensis MANUM, *Metasequoia occidentalis* (NEWB.) CHANEY, *Trochodendroides arctica* (HEER) BERRY, *Credneria spectabilis* (HEER) KOCH were found west of Collinderodden on the south coast of Van Mijenfjorden 120—140 m above the base of the formation.

Storvola Formation

Osmunda spetsbergensis NATH.
Sphenopteris blomstrandii HEER
Metasequoia occidentalis (NEWB.) CHANEY
Taxodium dubium (STERNB.) HEER
Taiwania sp.
Thuja sp.

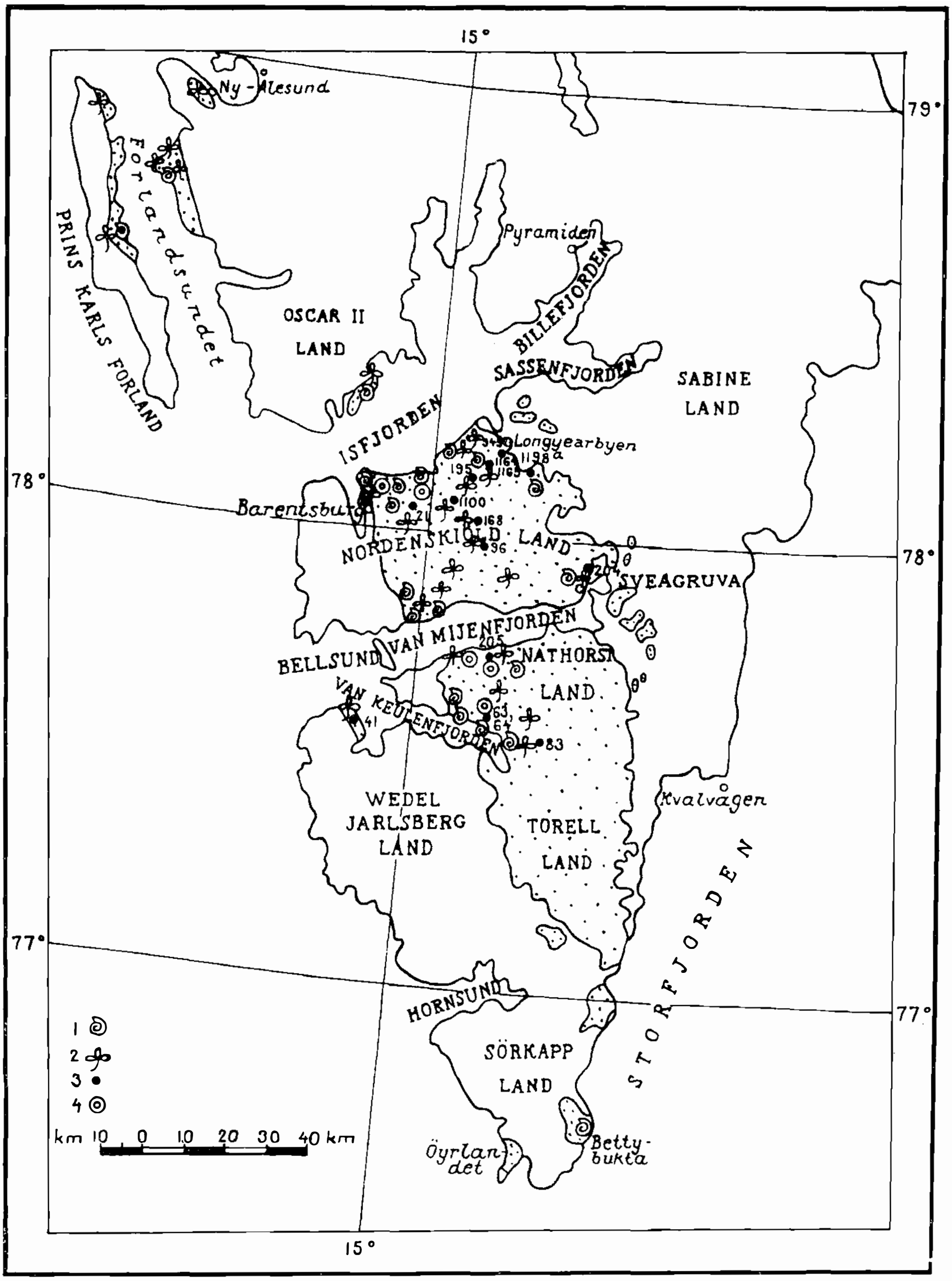


Fig. 11. *Locations of fossils in Palaeogene deposits of Svalbard (collections of 1962—1968).* 1. *Fauna.* 2. *Flora.* 3. *Spores and pollen (with number of specimen).* 4. *Foraminifera.*

Cercidiphyllum nathorstii BUDANTS.
C. heerii BUDANTS.
Credneria spectabilis (HEER) KOCK
Ulmus pseudobraunii HOLLICK
Betula nansenii BUDANTS.

B. spitsbergensis BUDANTS.
Carpinus nathorstii BUDANTS.
Tilia malmgrenii HEER
Aesculus antiquorum (NEWB.) ILJINSK.
Macclintockia lyellii HEER

Numerous plant remains were found throughout the section in all the outcrops in Nordenskiöld Land and Nathorst Land. The most complete locations are Sandsteinfjellet, Lindströmfjellet, Mefjellet, Høgsnyta (Nordenskiöld Land), Collinderodden, Storvola (Nathorst Land) as well as Bingtoppen, Nordenskiöldfjellet, Kalvdalen, Gramryggen (Nordenskiöld Land), Synshovden, Wahlenbergfjellet, Marlowfjellet, Brongniartfjella, Hisingerfjellet (Nathorst Land), etc.

Forlandsundet

Sesshøgda Formation

A. Prins Karls Forland

The flora was collected 30 to 40 m above the base of the formation.

1. The north coast of Selvågen

Sequoia langsdorfii (BRONGN.) HEER
Metasequoia occidentalis (NEWB.) CHANEY
Glyptostrobus sp.
Cercidiphyllum elegans BUDANTS.
Vitis olrikii HEER

2. Sesshøgda, 409 m

Equisetum arcticum HEER
Metasequoia occidentalis (NEWB.) CHANEY
Platanus sp.
Tilia malmgrenii HEER

B. East coast of Forlandsundet

Metasequoia occidentalis (NEWB.) CHANEY
Platanus sp.
Alnus sp.
Cornophyllum sp.

The fossils were found in six horizons near Sarsbukta in the north of Aavatsmarkbreen and in two horizons located 3 and 5 km south of Kapp Graarud. Better preserved flora was found in the upper part of the section.

Kongsfjorden

Kongsfjorden Formation

Taiwania schaeferii SCHLOEM.-JÄGER. *Betula frigida* BUDANTS. *Acer* sp., were found in the Advokat mine (the lower part of the section).

Ny-Ålesund Formation

Metasequoia occidentalis (NEWB.) CHANEY, *Tilia malmgrenii* HEER were found near the base of the Ragnhild seam in the upper part of the section.

Renardodden

Skilvika Formation

Metasequoia occidentalis (NEWB.) CHANEY
Trochodendroides spitsbergiana BUDANTS.
Cercidiphyllum lyellii BUDANTS.
Carpinus gracilis BUDANTS.
Tilia malmgrenii HEER
Acer arcticum HEER

Numerous plant remains are found throughout the section in coastal scarps along the south coast of Skilvika.

Renardodden Formation

Metasequoia occidentalis (NEWB.) CHANEY
Corylus scottii HEER
Alnus sp.
Acer arcticum HEER
Trochodendrocarpus arcticus (HEER) KRYSHT.

Plant fossils were found in the creek flowing from under the glacier 1 km south of Renardodden approximately in the middle of the section.

Appendix 2

Spores and pollen from Palaeogene deposits of Spitsbergen. Collection of JU. JA. LIVŠIC (1962—1968). Determinations by A. S. VAKULENKO. All contents in per cent.

	Palaeocene		Eocene								Oligocene				
	Barentsburg Formation		Hollendardalen Formation		Frysjaodden Formation			Collinderodden Formation		Storvola Formation			Skilvika Formation & Renardodden Formation	
	Nordenskiöld Land		Nathorst Land: Northern coast of Van Keulenfjorden, Pallfjellet		Nathorst Land: Southern coast of Van Mijenfjorden, Frysjaodden		Nordenskiöld Land, Hollendardalen	Nathorst Land, Storvola		Nordenskiöld Land, Southern coast of Isfjorden			Renardodden, Bellsund	
	Specimens Nos. 204/52, 204/55, 345, 1198		Specimens Nos. 63/6, 63/7, 63/8, 63/11		Specimens Nos. 205/4, 205/9, 205/17, 64/2, 64/3, 64/4		Specimen No. 21	Specimens Nos. 83/2, 83/4		Specimens Nos. 96, 1/68, 195, 1100, 1165a		Specimen No. 1164	Specimens Nos. 41/26, 41/29, 41/54, 41/95	
	from–to	average	from–to	average	from–to	average	%	from–to	average	from–to	average	%	from–to	average
Spores															
Sphagnum sp.	0,5–6	2,4	4–15	9,5	0–4	1,3	0,5	0–3	1,5	0–1	0,3	–	0–1	0,25
Bryales	–	–	–	–	0–0,5	0,1	–	–	–	–	–	–	–	–
Lycopodium sp.	0–0,5	0,1	0–1	0,2	0–4	2	–	0–3	1,5	0–0,5	0,2	–	0–0,5	0,1
Selaginella sp.	–	–	–	–	0–1	0,1	1	–	–	0–3	0,8	–	0–4	1
Osmunda sp.	0,5–3	1,9	0–0,5	0,1	0–4	0,8	3,0	–	–	1–48,5	10,9	–	1–2,5	1,8
Schizaea sp.	0–0,5	0,1	0–1	0,2	0–6	1,8	–	–	–	–	–	–	–	–
Lygodium sp.	–	–	–	–	–	–	–	–	–	0–0,5	0,2	–	0–0,5	0,1
Anemia sp.	–	–	–	–	0–2	0,6	–	0–1	1	–	–	–	–	–
Gleichenia sp.	–	–	4,0–10,6	7,6	0–10	2,2	0,5	0–2	1	1–1,5	0,8	–	0–3,5	1,4
Coniopteris sp.	–	–	–	–	–	–	–	0–1	0,5	0–0,5	0,1	–	0–0,5	0,1
Cyatheaceae	0–0,5	0,1	–	–	0–2	0,3	–	–	–	0–0,5	0,2	–	–	–
Polypodiaceae	7,5–32,5	13,3	1–3	1,8	●–6	1,7	12,5	7–20	13,5	0–9,5	4,7	1,5	0–22	18,1
Leiotriletes spp.	15–35	29,5	29–41	32–3	21–66	46,1	15	8–28	18	19,5–51	32,6	0,5	5–11,5	8,5
Lophotriletes sp.	2–14	5,8	1–7	4,2	0–10	5,2	2,5	3–4	3,5	2–7	4,6	–	0–2	0,8
Acanthotriletes sp.	–	–	0–1	0,2	0–0,5	0,1	–	–	–	–	–	–	–	–
Trachytriletes sp.	–	–	–	–	–	–	–	0–6	3	0–0,5	0,1	–	–	–
Stenozonotriletes sp.	0–2	1	0–1	0,2	0–5	2,3	–	–	–	0–3	0,8	–	0–0,5	0,25
Zonotriletes sp.	–	–	–	–	0–12	4,2	–	0–2	1	–	–	–	–	–
Pollen of Gymnospermae														
Coytoniales	–	–	–	–	–	–	–	–	–	–	–	–	0–1	0,2
Cycadales	–	–	–	–	0–2	0,3	3,5	–	–	–	–	–	0–1	0,2
Ginkgoaceae	0–0,5	0,3	0–1	0,2	–	–	–	–	–	–	–	–	0–1	0,2
Coniferales	12–20	17,5	8–18	12,5	1–14	8	4	24–36	30	2,5–11	6,4	–	6–14	10,6
Podocarpus sp.	–	–	–	–	–	–	0,5	3–4	3,5	0–1	0,3	–	0–1	0,4
Pinaceae	0–8,5	2,8	2–6	3,8	0–6	2,2	–	0–1	0,5	2–4,5	2,5	–	0–2	0,8

Pinus sp.	1,5–4	1,4	–	–	0–1,5	0,2	–	0–1	1	0–1	0,3	–	0–0,5	0,1
Picea sp.	–	–	0–3,5	0,9	–	–	–	–	–	0–0,5	0,1	–	–	–
Taxodiaceae	2–4,5	1,8	0–5	1,2	–	–	12	0–10	5	3–4	3,0	–	0–65,	3,7
Taxodium sp.	1–4	1,2	10–24	15,5	2–26	8,3	–	0–4	2	–	–	–	0–11,5	5,0
Glyptostrobus sp.	–	–	–	–	–	–	–	–	–	0–1	0,2	–	–	–
Pollen of Angiospermae														
Ulmus sp.	–	–	–	–	–	–	0,5	–	–	–	–	–	0–2	0,6
Castanea sp.	–	–	–	–	–	–	–	–	–	–	–	–	0–6	3
Nothofagus sp.	–	–	–	–	–	–	–	–	–	–	–	–	0–2	0,5
Betula sp.	–	–	–	–	0–2	0,3	1	–	–	0–10	2	32,5	0–4	1,2
Alnus sp.	0–4	1,2	–	–	0–2	0,3	1	–	–	–	–	–	3–16	11
Corylus sp.	–	–	–	–	–	–	–	–	–	–	–	–	0–1	0,2
Myrica sp.	0–0,5	0,1	0–1	0,6	–	–	2,5	–	–	1–2	0,5	1	0–1	0,9
Juglans sp.	–	–	–	–	–	–	–	–	–	–	–	–	0–2	0,2
Carya sp.	0,1	0,3	–	–	–	–	–	–	–	0–1	0,3	–	0–1	1,2
Pterocarya sp.	–	–	–	–	–	–	0,5	–	–	–	–	–	–	–
Salix sp.	–	–	–	–	–	–	1,5	–	–	–	–	–	0–3	1
Ericaceae	–	–	–	–	–	–	–	–	–	–	–	–	0–0,5	0–1
Tilia sp.	–	–	0–0,5	0,1	–	–	–	–	–	–	–	–	0–3,5	1,2
Acer tener Samoil.	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ptoteacidites sp.	–	–	–	–	–	–	–	–	–	–	–	–	0–1	0,5
Labiatae	–	–	–	–	–	–	–	–	–	–	–	–	0–2	0,9
Aquilapollenites sp.	0–2	1	–	–	0–2	0,5	–	0–2	1	0–1,5	0,5	–	–	–
A. regularis (Chlon.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–
A. asper N. Mteh.	–	–	0–1	0,2	–	–	–	–	–	1–3	1,2	–	–	–
Mancicorpus sp.	0–0,5	0,1	–	–	–	–	–	–	–	–	–	–	–	–
Krysthofoviana vera Samoil.	–	–	0–1	0,2	–	–	–	–	–	–	–	–	0–1	0,2
Gothanipollis gothanii N. Kr.	–	–	–	–	–	–	–	–	–	0–1	1,2	–	–	–
Duplosporis sp.	–	–	–	–	–	–	–	–	–	0–2	0,4	–	0–0,5	0,1
Trudopollis sp.	6–7,5	3,5	0–2	0,5	0–2	0,3	0,5	0–2	1	0–0,5	0,1	–	–	–
Oculopollis sp.	0–6	1,2	–	–	–	–	–	–	–	–	–	–	–	–
Orbiculapollis globosus Chlon.	–	–	0–1	0,2	–	–	–	–	–	–	–	–	–	–
Extratriporopollenites sp.	0–4	1,2	–	–	–	–	–	–	–	0–1	1,5	–	0–0,5	0,2
Triporites spp.	1,5–22	15,2	2–8	5,2	4–10	6	14	5–6	5,5	8–32	16,2	63,5	1,5–14	10,2
Tetraporites sp.	0–1	0,6	0,5–1	0,6	0–4	0,8	1	0–4	2	0–4	1,0	0,5	0–0,5	1,9
Pentaporites sp.	1–1,5	1,2	0–1	0,7	0–2	0,6	–	0–3	1,5	1–3	2,1	0,5	0–6	2,5
Hexoporites spp.	0–1	0,2	–	–	–	–	–	–	–	0,5–1,5	0,8	–	–	–
Tricolpites sp.	1–2	1,4	0,5–2	0,9	0–0,5	0,08	22,5	0–2	1	0–3,5	1,2	–	1–15	6,5
Tricolporites spp.	0–0,5	0,2	–	–	–	–	–	–	–	–	–	–	0–4	1,4
Spores	–	47,4	–	56,8	–	68,5	35	–	44	–	58,3	2,0	–	32,4
Pollen of Gymnospermae	–	25,3	–	34,1	–	19,1	20	–	12,8	–	12,8	0,0	–	21,1
Pollen of Angiospermae	–	27,3	–	9,1	–	12,2	45	–	14,5	–	28,9	98,0	–	46,5

Appendix 3

Preliminary list of fauna from Palaeogene deposits of Svalbard. Collections of JU. JA. LIVŠIC (Fig. 11). Determination made by I. A. KOROBKOV.

Central Basin

Barentsburg Formation

Callista nathorsti RAVN
Gari ex gr. edwardsi (MORRIS)
Gari (Psammocola) sp.
Gari sp. (? *Solenocurtus nordenskiöldi* RAVN)
Gari sp. (? *Solenocurtus spitsbergensis* RAVN)
Gari sp.
Cyprina ex gr. lunulata DESH.
Cyprina sp. nov.
Cyprina sp.
Dosiniopsis ex gr. orbicularis EDW.
Dosiniopsis sp.
Aporrhais sp.

The fauna was found in the Berzeliusdalen and Camp Morton areas (north coast of Van Mijenfjorden), on the east coast of Grønfjorden near the Grumantbyen and Sveagruva mines, in the Richterelva area, and in the Kapp Hesselman area (north coast of Van Keulenfjorden). At least four horizons were recognized; these were characterized by homogeneous assemblages. The most complete assemblage was found in the Richterelva area 27 m above the base of the formation:

large *Callista nathorsti* RAVN
Cyprina ex gr. lunulata DESH.
Dosiniopsis ex gr. orbicularis EDW.
Gari sp. (? *Solenocurtus nordenskiöldi* RAVN)
Gari sp.

Similar assemblages were found in the same section 90 and 145 m above the base of the formation. Abundant gastropods *(Aporrhais* sp.) as well as the bivalves *Cyprina* sp. and *Gari* sp. ex gr. *edwardsi* MORRIS were found 35 m above the base of the formation in the Berzeliusdalen — Camp Morton areas.

Colesdalen Formation

Large *Thyasira* sp. and *Tkredo* sp. were found in limestones in the upper part of the formation in the Colesbukta area, near Svartodden (north coast of Van Mijenfjorden), and in the Richterelva basin (Van Keulenfjorden). On Erdmannflya at the same horizon A. I. PANOV and V. F. NEPOMILUEV (unpublished data) found specimens of *Thyasira* sp., *Taras* sp. (= *Diplodonton)*, *Isognomon* (= *Perna Pedalion)*, *Ficus* sp. (= *Rurula)*, *Aporrhais* sp., and *Ranina*. *Dosiniopsis* sp. was found in argillites in the middle part of the formation in the Dumskolten area (Sørkapp Land).

Grumantbyen Formation

Cyrena altissima RAVN was found in the upper part of the formation in Foxdalen (Adventdalen area).

Hollendardalen Formation

Upper member

Numerous

Cyrena altissima RAVN
Cyrena hoeli RAVN
Cyrena sp. (? *C. acutangularis* DESH. RAVN)
Cyrena sp.
«*Solenocurtus*» *nordenskiöldi* RAVN
«*Solenocurtus*» *spitsbergensis* RAVN
«*Solenocurtus*» spp. RAVN

were found in sandstones overlying the coals between Isfjorden and Hollendardalen. Bivalves were found in the same member on Pallfjellet (Van Keulenfjorden).

Collinderodden Formation

Lower member

Cyrena altissima RAVN
Cyrena spp.

were found 120 to 140 m above the base of the formation at the head of Bromelldalen (south coast of Van Mijenfjorden).

Storvola Formation

Numerous

«*Solenocurtus*» sp.
Solenotellina brevisinuata COSSM. (after RAVN)
Cyrena aff. convexa BRONGN.
Cyrena sp.
Corbula sp.
Cyrtodaria sp.
Congeria sp.
Valvata sp.
Hydrobia sp. (= *Bayania* sp. ?)

were found in argillites 25 m above the base of the formation in the Storvola area.

Cyrena altissima RAVN
Cyrena hoeli RAVN
Cyrena aff. convexa BRONGN.
Corbula sp.
Valvata sp.

were found in the lower part of the formation on Bingtoppen (Fardalen, Nordenskiöld Land).

Forlandsundet

Sesshøgda Formation

Numerous small specimens of

Elliptotellina tellinella LAM.
Elliptotellina sp. (? *E. transversa* DESH.)
Sportella sp. (? sp. *corbulina)* DESH.

were found in calcareous argillites 60 m above the base of the formation in the Sarsbukta area (east coast of Forlandsundet).

Reinhardpynten Formation

Chlamys ex gr. sublaevisatus NYST.
Tellina sp.
Gari ex gr. effusa KON.
Solenocurtus cf. deshayesi DESM.
Angulus sp.

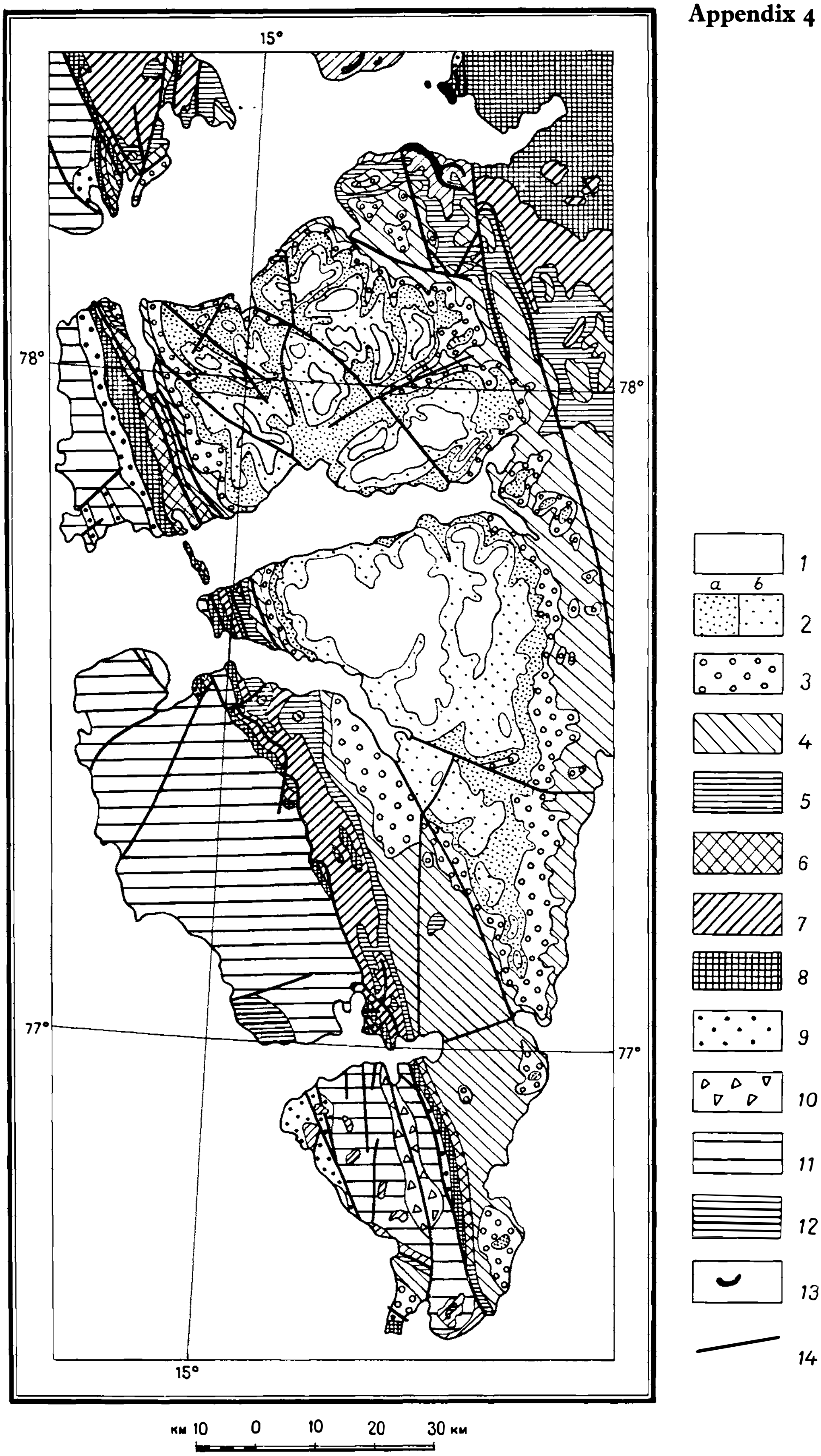
were found in calcareous argillites near the base of the formation on the north coast of Selvågen (Prins Karls Forland).

Appendix 4 →

Geological map of the southern part of Spitsbergen. Compiled by JU. JA. LIVŠIC from data obtained by BIRKENMAJER and NAREBSKI (1963), FIRSOV and LIVŠIC (1967), FLOOD et al. (1971), LIVŠIC (1965 a, 1965 b, 1967), NAGY (1966), ORVIN (1940), RÓŻYCKI (1959), and unpublished data by A. A. KRASIL'ŠČIKOV, JU. JA. LIVŠIC, V. F. NEPOMILUEV, A. V. PAVLOV, A. I. PANOV, V. N. SOKOLOV.

Palaeogene: 1. Oligocene (the Storvola Formation in the Central Basin, the Skilvika and the Renardodden Formation in the Renardodden area); 2. Eocene: a) the Grumantbyen Formation and the Hollendardalen Formation, b) the Frysjaodden Formation and the Collinderodden Formation; 3. Palaeocene: the Barentsburg Formation and the Colesbukta Formation; 4. Cretaceous/Barremian-Albian; 5. Jurassic and Cretaceous (Lower Jurassic — Hauterivian); 6. Triassic and Jurassic; 7. Triassic; 8. Middle to Upper Carboniferous; 9. Lower Carboniferous; 10. Devonian; Hecla Hoek rocks; 11. Upper Proterozoic and Lower Palaeozoic; 12. Lower and Middle Proterozoic; 13. Dolerite intrusions; 14. Fault and thrust fault.

Appendix 4



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