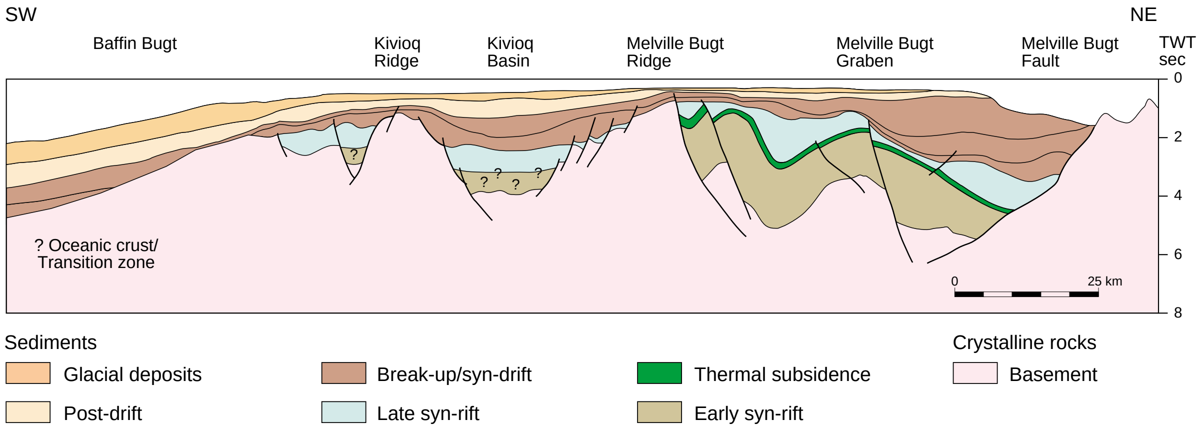

Fig. 51. Representative cross-section compiled from seismic reflection data from offshore North-West Greenland at *c.* 75°N, south-west of Melville Bugt / Qimusseriarsuaq. Vertical exaggeration × 2.5. From Whittaker *et al.* (1997).

usually cannot be interpreted and there are seldom distinct reflections from the underlying formations. Locally, however, as for example at *c.* 69°30′N, the basalts are thinner, and reflections from underlying sediments can be seen. In this area the basalts are only about 1300 m thick, and the thickness of underlying sediments may be as much as 5 km (Fig. 50; Whittaker 1996).

North-West Greenland (73°–77°N)

North of 73°N the new seismic data acquired as part of the KANUMAS project have confirmed the existence of a very deep graben or half-graben in the west and south-west part of Melville Bugt (Fig. 51; Whittaker *et al.* 1997). This had earlier been outlined from aeromagnetic and gravity data acquired in the late 1960s and early 1970s. The new data have also revealed several other graben and half-graben structures extending to the northern limit of the survey at 76°30′N. In the Melville Bugt graben the thickness of sediments exceeds 13 km. By analogy with the onshore geology of West Greenland and north-east Canada, the main phase of rifting is thought to have taken place in the Cretaceous, prior to sea-floor spreading in Baffin Bugt. Later, parts of the area were subjected to marked inversion.

Mineral deposits

Mining activities have been carried out in Greenland since the middle of the 19th century, with the cryolite mine at Ivittuut as the only long-term mine; it was in operation for a period of 130 years. The cryolite deposit was associated with a granite intrusion in the late Proterozoic Gardar Province of South Greenland (p. 26; Fig. 52, locality 5), and represents an example of a very rare type of mineralisation; there are only very few equivalent deposits in the world (Pauly & Bailey 1999). Other mining activities in Greenland have exploited more common types of mineralisation. The two most important were both lead-zinc deposits – one at Mestersvig in East Greenland was associated with quartz veins of probably Tertiary age, and the other at Maarmorilik in central West Greenland was a stratabound mineralisation in the Proterozoic Mârmorilik Formation (p. 20).

Mining activities have so far been very limited in view of the expected potential of such a large country. However, systematic exploration did not commence until the late 1950s and 1960s when new legislation governing the mineral sector was introduced to encourage the mining industry to undertake exploration. This was intensified with the introduction of Home Rule status for Greenland in 1979.

In recent years exploration activities have concentrated on prospecting for gold, base metals and diamonds. Gold exploration has focused on the Archaean and early Proterozoic Precambrian shield of West Greenland and a layered Tertiary gabbro intrusion (Skaergaard p. 50) in southern East Greenland (Andersen *et al.* 1998). A major new gold province in the early Proterozoic Ketilidian mobile belt forming the southern tip of Greenland (MINEX 1997, 1998b) was first detected by panning of stream sediments, and in 1992 visible gold was found in quartz veins transecting mafic supracrustal rocks. At present (1999) investigations of a gold prospect are taking place in Kirkespirdalen (a valley north-east of Nanortalik, Fig. 52, locality 4). Another find substantiating the interpretation of the Ketilidian mobile belt as a gold province has been made in southernmost South-East Greenland, where gold mineralisation was found in a quartz-bearing shear zone cutting a sequence of mafic extrusives and intrusives and associated sediments. The promising gold mineralisations in southern Greenland are situated at the southern border of the Julianehåb batholith, which is interpreted as the root zone of a volcanic arc (Garde *et al.* 1998).

Exploration for base metals in recent years has focused on finds in the Lower Palaeozoic Franklinian Basin and Ellesmerian fold belt of North Greenland. A massive sulphide deposit with lead and zinc was discovered in 1993 at Citronen Fjord in Peary Land (Fig. 52, locality 7; van der Stijl & Mosher 1998). It occurs as stratiform sheets in a folded sequence of dark argillaceous rocks of the Upper Ordovician to Lower Silurian Amundsen Land Group. The Citronen Fjord deposit is located at the eastern end of the Franklinian Basin, which extends across North Greenland into Arctic Canada where it is known to be a prospective zone of wide significance, and includes the Polaris zinc-lead mine. A further new discovery of zinc-lead-silver mineralisation in the same mineralisation province has been made in Washington Land, western North Greenland, where the occurrence is hosted in evaporitic Lower Ordovician carbonates in the platform succession (Jensen 1998).

Diamond exploration has focused on the Archaean and early Proterozoic crystalline shield areas of West Greenland, where latest Proterozoic and middle Jurassic kimberlite intrusions have been known since the late 1960s. The first finds of microdiamonds in stream sediments led to intensive prospecting, and more than 500 occurrences of kimberlite, lamproite and ultramafic lamprophyres have now been found, mainly as dykes and sheets (MINEX 1998a). Diamonds and diamond indicator minerals have been recorded in stream sediments, boulders and *in situ* kimberlites. The recognised kimberlite province includes the Archaean block of West Greenland and areas of Archaean rocks farther north reworked during the early Proterozoic. Prospecting in the Precambrian crystalline complexes of West Greenland is expected to continue in the light of important diamond discoveries in the Lac de Gras area of the Northwest Territories of Canada.

Significant occurrences of a broad range of metallic and industrial minerals are present in all the principal geological provinces in Greenland, ranging in age from Archaean to Quaternary (Schønwandt & Dawes 1993). In broad terms these are related to five main groupings which are:

Precambrian crystalline shield (Archaean – early Proterozoic)
Middle Proterozoic intracratonic deposits
Palaeozoic orogenic belts
Upper Palaeozoic – Mesozoic sediments
Late Phanerozoic magmatic rocks.

The following description covers the principal former mines and some significant prospects (Fig. 52); at the present time (1999) there are no active mines. On the printed map sheet the locations of only four abandoned mines and one large Zn-Pb mineral occurrence are indicated. Information with respect to a large number of mineralised localities is available in the continually updated Greenland Mineralisation Data Bank at the Survey (Lind *et al.* 1994).

Precambrian crystalline shield

At Isukasia (Isua supracrustal sequence [69]; Fig. 52, locality 1) north-east of Nuuk/Godthåb, a major Archaean iron formation has been outlined which is composed of interlayered magnetite and chert (Fig. 5). The deposit, which is partly covered by the Inland Ice, has been drill tested and a minimum tonnage of 1900 million tons grading 32.9% Fe is estimated (Appel 1991).

A folded and metamorphosed Archaean anorthosite complex [85] at Qeqertarsuatsiaat/Fiskenæsset, southern West Greenland (the Fiskenæsset complex; Fig. 52, locality 2) hosts widespread chromite mineralisation (Ghisler 1976). The complex, which has a strike length of more than 200 km and an average thickness of 400 m, has a potential estimated at 100 million tons of low-grade

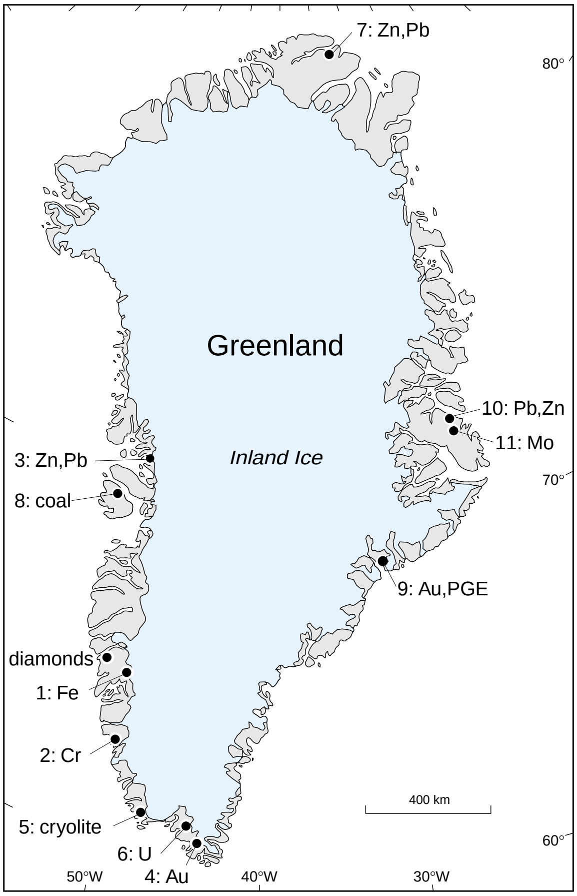

Fig. 52. Major mineral deposits of Greenland described in the text: **1**: Isukasia; **2**: Fiskenæsset; **3**: Maarmorilik; **4**: Kirkespirdalen; **5**: Ivittuut; **6**: Ilímaussaq; **7**: Citronen Fjord; **8**: Qullissat; **9**: Skaergaard; **10**: Mestersvig; **11**: Malmbjerg. **Au**: gold; **Cr**: cromium; **Fe**: iron; **Mo**: molybdenum; **Pb**: lead; **PGE**: platinum group elements; **U**: uranium; **Zn**: zinc.

chromium ore with a chromium/iron ratio of 0.9–1.0. Enhanced precious metal values have been reported from the ultramafic parts of the complex (Appel 1992).

At Maarmorilik, central West Greenland, the Black Angel (Fig. 52, locality 3; Fig. 53) lead-zinc ore bodies hosted in lower Proterozoic marble (p. 20; lower part of [62]) were mined in the period 1973–1990. Production totalled *c.* 11 million tons ore grading 4.0% Pb, 12.6% Zn and 29 ppm Ag. The deposits are now exhausted, but other marble-hosted lead-zinc prospects exist in the area (Thomassen 1991). Prior to the Pb-Zn mining, some 8000 tons of marble were quarried at Maarmorilik.

The Nalunaq gold deposit in Kirkespirdalen, northeast of Nanortalik, South Greenland (Fig. 52, locality 4) displays visible gold in quartz veins within a lower Proterozoic mafic volcanic sequence. Drilling and an exploration adit have revealed the presence of a high-grade, small tonnage gold deposit (MINEX 1998b).

Middle Proterozoic intracratonic deposits

Cryolite hosted in a Gardar granite stock (part of [56])at Ivittuut, South-West Greenland (Fig. 52, locality 5) was worked from 1858 until 1987 and a total of 3.7 million tons ore grading 58% cryolite were quarried from an open pit. In addition to cryolite, galena and sphalerite were extracted as by-products from the ore. The main ore body is now exhausted, but there are indications of deep-seated reserves in the area (Bondam 1991).

In the Gardar Ilímaussaq alkaline intrusion (part of [56]; see Fig. 17; Fig. 52, locality 6) east of Narsaq in South Greenland, a low-grade uranium deposit has been outlined by diamond drilling, indicating a reserve of 56 million tons of U with a grade of 365 ppm (Nyegaard 1979). In addition, the intrusion has a potential for zirconium, beryllium, rare earth elements and sodalite (Bondam 1995).

Late Proterozoic kimberlites, lamproite and ultramafic lamprophyres are widespread as dykes and sheets in the Archaean block of West Greenland; small pipes have also been found. Diamonds and diamond indicator minerals have been found especially in the Maniitsoq/Sukkertoppen region (65°N), in stream sediments, in boulders and *in situ* kimberlites (MINEX 1998).

Palaeozoic orogenic belts

South of Citronen Fjord (Fig. 52, locality 7) in Peary Land, North Greenland, a large gossan zone hosts a major lead-zinc bearing Sedex-type massive sulphide deposit in Ordovician black shales (part of [24]) (Kragh *et al.* 1997). Diamond drilling up to 1997, totalling 32 km of core, indicated a resource of more than 20 million tons grading 7% Zn and 1% Pb (van der Stijl & Mosher 1998). The deposit is located north of a prominent palaeo-escarpment separating carbonate shelf sediments to the south from deep-water trough sediments to the north.

Upper Palaeozoic – Mesozoic sediments

At Qullissat (Fig. 52, locality 8) on Disko, central West Greenland, Cretaceous sub-bituminous coal (part of [8])

Fig. 53. Sorte Engel (Black Angel), the locality which hosted the Maarmorilik lead-zinc deposit at *c.* 71°N in central West Greenland. The two small black spots just beneath the left wing of the angel-like figure (marked by the arrow) are cable car entrances to the mine *c.* 500 m a.s.l. Photo: B. Thomassen.

was mined during the period 1924–1972. A total of about 570 000 tons of coal was shipped before the mine was closed because it was unprofitable (Schiener 1976). On nearby Nuussuaq, more than 180 million tons of sub-bituminous coal distributed in layers more than 0.8 m thick have been indicated by surface investigations and limited drilling (Shekhar *et al.* 1982).

Late Phanerozoic magmatic rocks

The 55 Ma old Skaergaard layered gabbro intrusion [57] (Fig. 52, locality 9) at Kangerlussuaq, north-east of Ammassalik in southern East Greenland, hosts a major deposit of palladium, platinum and gold (Bird *et al.* 1991). Initial diamond drilling has indicated a resource of more than 43 million tons grading 2.4 ppm Au and minor platinum group elements. Similar mineralisation is known in other nearby intrusions.

Lead-zinc-bearing quartz veins (Fig. 52, locality 10) are hosted in Lower Permian sediments near Mestersvig in East Greenland. One of these, the Blyklippen deposit, was mined in the period 1956–1962. After production of 545 000 tons ore grading 9.3% Pb and 9.9% Zn the deposit was exhausted (Harpøth *et al.* 1986).

A large porphyry-molybdenum deposit of Miocene age occurs at Malmbjerg (Fig. 52, locality 11) south of Mestersvig, East Greenland, hosted in an intrusive complex [53]. Ore resource calculations based on 22 000 m diamond drilling indicate a tonnage of 150 million tons grading 0.23% MoS_2 and 0.02% WO_3 (Harpøth *et al.* 1986). Other less well investigated porphyry-molybdenum occurrences exist in the East Greenland Tertiary province (Geyti & Thomassen 1984).

Petroleum potential of Greenland

The petroleum potential of Greenland is confined to the sedimentary basins of Phanerozoic age. Onshore, such basins occur in North Greenland, North-East and central East Greenland, and central West Greenland. Offshore, large sedimentary basins are known to occur off both East and West Greenland (Fig. 54). No proven commercial reserves of oil or gas have been found to date (1999), but so far only six exploration wells have been drilled, five offshore southern West Greenland between latitudes 65°30′ and 68°N, and one onshore, on Nuussuaq at 70°28′N in central West Greenland (Pulvertaft 1997). The untested areas of Greenland are still very large. A brief summary of the petroleum-geological features of the main sedimentary basins is given below.