Sedimentary Rocks Associated with the Oslo Region Lavas

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Layers of sedimentary rocks are associated with the Late Palaeozoic (and Triassic?) basalts, rhomb porphyries and other lavas in the Oslo Region. With some exceptions the sedimentary units are thin and have a restricted areal distribution; *all appear to be non-marine.*

When relating the sedimentary units to the lavas, it should be noted that eruptions did not begin and end simultaneously in all parts of the region. The main sedimentary units are as follows:

Above and between the lavas	BRUMUND SANDSTONE (>400 m, mainly above the Brumunddal lavas, northern part of the Oslo Region). ALNSJØ SEDIMENTARY SUCCESSION (>100 m, above the main lava complex, Oslo). RHOMB PORPHYRY CONGLOMERATE (>1000 m, along main fault, southeastern part of the Oslo Region). Sedimentary deposits between lavas (predominantly <10 m thick or missing, locally up to 200 m thick).
Below the lavas	ASKER GROUP (from below) *Kolsås Formation, Tanum Formation* and *Skaugum Formation.* (Up to 50 m thick in central parts, 110–120 m in the southern part (Skien area) of the Oslo Region). Locally, the basal lava rests directly on the peneplaned Cambro–Silurian sedimentary rocks or on a very thin layer of reworked bedrock.

Palaeontological evidence of age

The discovery of fossils in 1931 (Holtedahl 1931) showed that the eruption of lavas commenced in the Early Permian, and not in the Devonian as generally believed previously. Fossiliferous horizons occur below the basal basalt (B_1) in both the Oslo – Asker and the Skien areas and between the early lava flows of the basal Holmestrand basalt (B_1) in Vestfold. The greatest number of species, and also the best preserved fossils, are from the Tanum Formation (see below) in Asker. The fossils comprise land plants (Høeg 1936, 1937 a & b), fresh water fishes (Heintz 1934), fresh water bivalves (Dix & Trueman 1935) and conchostracans (J. F. Bockelie, pers. comm. 1965). Both flora and fauna indicate an Early Permian age. The flora is richest in species, and according to Høeg (1936) it is probably of middle Early Permian age.

After his discovery of fossils, Holtedahl (1931) assigned the lavas and associated sedimentary strata to the Permian, and referred to the underlying peneplain as the sub-Permian peneplain. This practice is also followed here, although we cannot quite rule out the possibility that some of the unfossiliferous beds immediately above the peneplain are late Carboniferous in age. Furthermore, as no fossils have been found above the B_1 basalts, there is no palaeontological evidence for the age of the younger sedimentary layers associated with the lavas; an Early Triassic age has been hinted at for the youngest deposits.

Late Palaeozoic faulting pre-dating the lavas

Features observed in a road-cut along Dronningveien in the hillside above Sundvollen, Ringerike area, indicate that some faulting and erosion took place prior to the formation of the basal lava flow, (B_1) Kolsås basalt Member. (See Larsen, this volume, stop 1 in the description of the Krokskogen excursion). Even earlier faulting may well be reflected by the coarse-grained and widespread Tanum Formation (Dons & Győry 1967).

Underlying rocks

The Permian strata rest on a peneplaned and more or less weathered surface of Early Palaeozoic sedimentary rocks that display Caledonian folding in the northern and central parts of the Oslo Region, but not in the southern parts (e.g. Holmestrand, Jeløya and Skien areas).

The Lower Palaeozoic sequence, generally referred to as the Cambro-Silurian, consists of up to 1000 m of marine, richly fossiliferous Cambrian, Ordovician and Silurian sediments, predominantly shales and limestones (Oslo Region Stages 1–9), succeeded by up to 1250 m of the Late Silurian (Ludlovian – Downtonian) Ringerike Group (Stage 10), consisting mainly of non-marine red and grey sandstones and siltstones (cf. Turner 1974).

The latter rocks are comparable with the Old Red Sandstone in Britain and contain fossils of ostracoderms, eurypterids and phyllocarids. Ripple marks, mud cracks, shale flakes and trace fossils are common. The Ringerike Group is missing north of the Ringerike area.

In the southern parts of the Oslo Region, the Permian beds lie unconformably upon the Ringerike Group. In the central parts they rest on folded Ordovician and Silurian strata, including the Ringerike Group; in these areas the Ringerike Group is preserved in broad, shallow synclines and its strata are locally sub-parallel to the Permian beds (see Dons, this volume, Fig. 1). To the north (Brumunddal area), the Permian sequence overlies Silurian limestone.

The sub-Permian hiatus and peneplain

We know of no sedimentary rocks in the Oslo Region of an age between that of the Late Silurian Ringerike Group (Stage 10) and that of the strata above the sub-Permian peneplain, i.e. from an interval corresponding more or less to the

Devonian and Carboniferous periods. During this interval the Cambro-Silurian strata in the northern and central parts of the Oslo Region were folded, most probably during a late phase of the Caledonian orogeny in Devonian time, and peneplanation followed. Apparently, the sub-Permian peneplain sloped very gently southwards (Holtedahl 1953) and, as indicated by the immediately overlying sediments, also westwards, possibly with a low east-west 'ridge' between the central and southernmost parts of the Oslo Region.

The surface below the Permian strata shows distinct signs of weathering. This is especially evident where marine Cambro-Silurian strata form the old surface; beds which elsewhere are greyish, then display a reddish colour and are commonly brecciated. Unfortunately, natural exposures are rare. East of Semsvatn in Asker, Middle Ordovician shales and limestones have a red colour for several metres below the contact. A core from Bærum (see below) shows that Silurian limestone below the contact is brecciated at the top and has a red colour (diminishing in strength downwards) down to fully 3 m below the contact, where the drilling terminated. According to Elder & Kanes (1966), the brecciated limestone may be a solution or collapse breccia; they further suggested that the lowermost metre of the overlying Kolsås Formation represents a redeposited or residual soil. In an excavation in the Brumunddal area, Silurian limestone showed weathering to a depth of 1 metre below the sub-Permian peneplanation surface (Rosendahl 1929: 386). Where Ringerike Group rocks occur directly beneath this surface, the weathering appears less conspicuous – especially when the beds are red, although they may then show a different shade of red.

Both the youngest sediments below the sub-Permian peneplain and the beds immediately above the peneplain are indicative of non-marine conditions. This, the considerable pre-Permian erosion and the palaeo-geographical position of the Oslo Region suggest that the region was part of a land mass, the 'Old Red Continent' and its dwindling, gradually peneplaned successor, during the entire interval represented by the hiatus, or at least for a major part of it.

Sedimentary rocks below the basal lava
The Asker Group (Fig. 1)

The name Asker Group (Dons & Györy 1967) was established for the sedimentary succession occurring between the basal lava and the underlying peneplain in the central parts of the Oslo Region. Taken in a wide sense, the unit occurs throughout most of the region, but is locally very thin or even missing. The thickest successions known are located in the Skien area to the south (110–120 m, Segalstad 1976), and along the southern part of the Krokskogen lava plateau in Asker (40–50 m). Thin successions (<50 m), locally missing, are characteristic in northern and eastern parts of the Oslo Region, in the Skrim area to the west (Rohr–Torp 1973) and at Holmestrand in Vestfold.

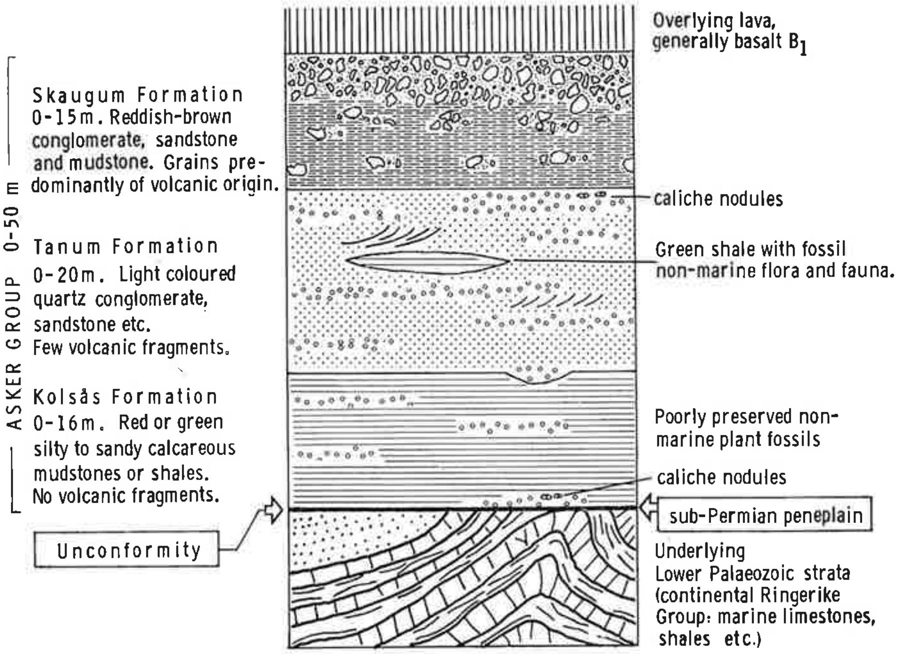

Fig. 1. Stratigraphic subdivision of the Asker Group in the vicinity of Oslo.

The overlying lava is the basal basalt (B_1) except where this is missing, i.e. in the Brumunddal area to the north and in isolated localities elsewhere. The basal flow in B_1 apparently is progressively older southwards (Ramberg & Larsen, this volume). At Brumunddal, the basal lava is a rhomb porphyry, which overlies 0–0.3 m of a sedimentary breccia (Rosendahl 1929).

As a rule, the Asker Group is heavily covered by scree from the steep escarpment of the capping lavas. Exceptions are partial outcrops in some crevices and on steep slopes (e.g. at Kolsås) and in a few road-cuts (e.g. along Billingstadveien and Tanumveien in Bærum, Dronningveien above Sundvollen in the Ringerike area and at Ryggen in the Skien area). Furthermore, resistant benches of sandstone and conglomerate tend to protrude through the scree.

The Asker Group is best known in the Oslo–Asker area, where it is thickest to the west and comprises 3 formations (Fig. 1); from below: Kolsås, Tanum and Skaugum (Dons & Györy 1967). The only continuous profile through all 3 formations is from the Staverhagen drill-core, from No. 3 Staverhagen road in Bærum, 0.8 km NW of Billingstad railway station in Asker. The core is described in an unpublished report by Elder and Kanes (1966). All 3 formations appear to be continental deposits. Their principal differences relate to environmental changes which are largely a reflection of increasing volcanic and tectonic activity.

The Kolsås Formation, named after the Kolsås hill in Bærum, consists mainly of red, less commonly green, silty and sandy calcareous mudstones or shales.

Calcareous nodules, commonly pigmented by hematite or with hematite rinds, occur especially in its upper part which also contains more sandy material. Anhydrite has been identified in the Staverhagen drill-core (Elder & Kanes 1966). The core lithologies show a gradational contact between the basal beds and the underlying 1.5 m-thick breccia of Silurian limestone. The Kolsås Formation is 10–16 m thick in Bærum and Asker west of Oslo, but appears to be missing east of Oslo. Sections at Kolsås in Bærum are described by Dons & Györy (1967). Two poorly preserved plant fossils of *Cordaites* and *Neuropteris* type have been found in the hillside of Kolsås. The formation is also present in the Ringerike area. Brownish-red, fine-grained sandstone, etc., with some plant fossils (*Cordaites principalis*) in the Skien area may belong to the same formation or, possibly, to an unnamed, local formation.

Lithologically, the Kolsås Formation resembles the continental Rotliegendes of Central Europe (Holtedahl 1953:492). It appears that the Kolsås Formation predates the lava eruptions; according to Elder & Kanes (1966), no volcanic fragments were observed in this formation in the Staverhagen drill-core. They suggest that the material was derived from a terra rossa type of soil mantling the Cambro–Silurian bedrock, and interpret the Kolsås Formation to be a fluvial deposit, the environment of which changed from flood plain to braided stream. An arid climate is suggested.

The Tanum Formation, named after Tanum in Asker, comprises mainly light-coloured conglomerates and calcareous sandstones, with or without thin shale partings. Up to about 5.5 m of fossiliferous, greenish or reddish shales with arenaceous intercalations occur within the upper half of the formation in the hillside above Semsvatn in Asker. The fragments in the conglomerates are usually less than 10 cm in diameter, but some exceeding 20 cm have been found. The fragments are subrounded to rounded with a medium to high sphericity and consist mainly of quartz and quartzite (commonly coated or pigmented throughout by hematite) and to a small extent also of quartz-mica schist, limestone and shale (Dons & Györy 1967). Current bedding, graded bedding, scouring surfaces and channel fillings are common. Volcanic rock fragments have been identified in the Staverhaugen drill-core (Elder & Kanes 1966). The Tanum Formation is the most widespread of the 3 formations and is up to 20 m thick in Asker.

The rather rich fossil flora and fauna in the section above Semsvatn consist of land plants (i.a. fern-like leaves, *Calamites* spp., mostly *C. undulatus*, *Asterophyllites equisetiformis*, *Cordaites principalis*, *Samaropsis holtedahli*, *Lebachia piniformis*, *Ernestiodendron filiciforme*, *E. arnhardtii*), fresh water fishes (i.a. *Pleuracanthus* sp., *Megalichtys* sp., *Amblypterus* sp.) and fresh water bivalves (*Palaeanodonta* spp.) and conchostracans. (For references to fossil descriptions, see first page of this article). The fossil assemblage indicates a middle Early Permian age. Less well preserved fossils have been found elsewhere in Asker. About 0.5 km north of Holmestrand railway in Vestfold, poorly preserved plant fossils (*Cordaites* sp., *Calamites* sp.) occur *between* the earliest lava flows of the basal basalt (B_1), but could be of the same age as those in the Tanum Formation.

The remarkable change in lithology from the Kolsås Formation to the Tanum Formation may reflect a change in topography, and as assumed by Dons & Györy (1967) this may have been caused by fault movements connected with the initiation of volcanic activity. These authors suggest that certain pebbles in the conglomerates came from the Precambrian Telemark area to the west, perhaps by a stepwise transport. Considerable precipitation, possibly intermittent, must have occurred in the source areas and possibly in the Oslo Region itself — again perhaps related to the volcanic activity. According to Elder and Kanes (1966), the Tanum Formation lithology in the Staverhagen core suggests deposition in a point-bar environment.

The Skaugum Formation, named after Skaugum in Asker, is characterized by a predominance of grains of volcanic rocks. It consists of sandstones and conglomerates, generally with a reddish-brown calcareous matrix coloured by hematite (Elder & Kanes 1966). Low-angle cross-bedding and scour surfaces are common. Green shale from the NE side of Semsvatn shows a bentonitic composition and may represent tuff layers (unpublished report by E. Roaldset & J. A. Dons). A silificied fragment of a tree trunk (*Dadoxylon* sp.) was found close to the base of the formation at Tanum (Høeg 1937b). In the Oslo–Asker area the Skaugum Formation is 15 m thick above Semsvatn in Asker and decreases rapidly in thickness northeastwards. Thus, only a few patches of similar lithology overlie the Tanum Formation in Kolsås (Dons & Györy 1967). The Skaugum Formation is also known in the southernmost part of the western hillside of the Krokskogen lava plateau, and from the Skien area. Similar lithologies are common in sedimentary intercalations between the lavas.

The Skaugum Formation lithology reflects strong volcanic activity in the source area. According to Elder and Kanes (1966), the Skaugum Formation in the Staverhagen drill-core is a fluvial deposit, suggesting a change in environment from flood plain to braided stream.

Sedimentary rocks between and above the lavas

Sedimentary rocks commonly occur between the lava flows, in most cases as thin horizons rarely more than 10 m thick, or as infillings of depressions and fissures (see Larsen, this volume). Some thicker successions are known especially in the upper part of the lava series, indicating a decrease in volcanic activity and a rougher topography because of increased faulting. Thus, 150–200 m of sediments occur between lava flows of the late basalt (B_3) in the Krokskogen area and the Bærum–Sørkedal cauldron (Sæther 1962). The sediments (conglomerates, sandstones, greywackes, tuffs) predominantly contain material derived from basalt and rhomb porphyry lava, together with clastic quartz — never felsite porphyry and associated rocks. At Gyrihaugen in the northern part of Krokskogen, about 150 m of a coarse rhomb porphyry conglomerate, the *Migartjern Conglomerate*, fills an erosional trough in the lava sequence (see Larsen, this volume).

The following three successions of sedimentary rocks are not capped by lavas; the *Brumund Sandstone* to the north, the *Alnsjø sedimentary succession* (still with some lava) in the vicinity of Oslo, and the *Rhomb Porphyry Conglomerate* along the southern part of the Oslofjord.

The Brumund Sandstone, described by Rosendahl (1929), crops out in a narrow, 6 km-long area in the valley Brumunddal in the northernmost part of the Oslo Region, 13 km NW of Hamar at the lake Mjøsa. The Brumund Sandstone, a continental formation at least 400 m thick, is bright red and rather massive, except for its middle part which is yellowish and well laminated. The fairly well rounded grains, chiefly of quartz, but with as much as 30–40% of feldspar (derived from rhomb porphyries), are loosely cemented by calcite. Mud cracks and ripple marks occur in a red-coloured layer within the yellow beds; reddish clay pellets are observed in both the red and the yellow beds. The Brumund Sandstone rests on the youngest of the four rhomb porphyry lavas in that area, called RP_{4br} (Ramberg & Larsen, this volume, Fig. 4). Similar sandstones occur between the lavas. According to Rosendahl (1929), larger sand grains are wind-corroded and the yellow beds are lacustrine or fluviatile deposits. The climate may have been arid.

The Alnsjø sedimentary succession, studied in the field by Dr. Sven Føyn and described by Holtedahl (1935, 1943), and later by Sæther (1962, 1977) and Naterstad (1971), crops out at and around the lake Alnsjø (8–9 km NE of Oslo centre) in the southern part of the Nittedal cauldron. (For further description and a stratigraphical scheme, see Naterstad, this volume). The succession is separated from the underlying sequence of basalt and rhomb porphyry lavas by welded and unwelded ignimbritic deposits, reworked at the top. The lower and greater part of the sedimentary succession is a fine-grained unit, 80–100 m thick. The unit consists predominantly of reddish and grey argillites, intercalated by siltstone horizons at some levels, and by a single layer of basalt with a scoracious surface and overlain by a conglomerate with pebbles of the same basalt. A layer of light-grey ashfall tuff above the unit is succeeded by a formation of coarse sandstones and conglomerates, the *Storhaug Conglomerate*, with subrounded pebbles of basalt and felsite porphyry. The conglomerate, about 30 m thick, forms the summit of the hill Storhaug, where the succession terminates.

According to Naterstad (this volume), the fine-grained unit was probably deposited in lakes inside the caldera, whereas the overlying tuff probably marks a volcanic episode leading to a change in relief and the formation of the conglomerate. Locally, other sedimentary rocks may represent parts of the talus formed along the caldera wall.

The Rhomb Porphyry Conglomerate, described by Brøgger (1900) and Størmer (1935), is a spectacular, more than 1000 m-thick formation with pebbles, boulders and blocks predominantly of rhomb porphyries. (For further description, see Larsen, Ramberg and Schou Jensen, this volume). The formation occurs on a number of islands along the eastern side of the Oslofjord, south of Jeløya. The islands are located just west of a channel along the main fault which separates the Oslo Region from the Precambrian terrain to the east, and in an area split into tectonic blocks.

The formation consists of poorly sorted conglomerates alternating with stratified, finer-grained beds. The conglomerates have angular to rounded, gravel- to boulder-sized rock fragments (maximum 5×3×3 m) in a reddish-brown, arkosic matrix. More than 90% of the rock fragments are of rhomb porphyries. The remainder are of basalts and other effusives, including their cavity fillings (calcite, chalcedony, jasper), but mainly of sandstones probably derived from the underlying, Late Silurian Ringerike Group of 'Old Red' facies (Stage 10). No blocks of older rocks have been recognized. Cross-bedding is rare (see Fig. 13 in Larsen, Ramberg & Schou Jensen, this volume), but an imbricate arrangement of pebbles suggests an east to west transport. Typical mudstones have not been found, but some of the stratified beds have a maximum grain-size of 0.1 and do, in several cases, show mud cracks and raindrop imprints (Holtedahl 1931).

The possible lower boundary of the Rhomb Porphyry Conglomreate is exposed only on Revlingen, the northernmost of the islands. The formation lies conformably upon the plane but weathered surface of a rhomb porphyry lava, perhaps RP_{4b} of the Vestfold series. No upper boundary is known, since the sequence is tilted on all the islands and either continues below sea-level or is cut by a fault. The thickest sequence can be seen on Rauøy, the largest island. No characteristic horizons have been found which would allow a safe correlation from island to island. Beds tend to be coarser the closer they are to the main fault to the east.

According to Størmer (1935), the Rhomb Porphyry Conglomerate most probably represents fanglomerates and arkoses deposited during sudden washes and mud flows in an arid climate. He, further, gave evidence for an east to west transport of material into the subsided area west of the main fault, supporting Holtedahl (1931) who suggested that the formation was formed in connection with the fault.