Måde Group

new group

History. The succession defined here as the Måde Group was referred by L.B. Rasmussen (1961) to the 'Måde serien'; this encompassed the marine, clay-dominated younger Miocene deposits. As described by L.B. Rasmussen (1961), the succession is characterised by a basal gravel layer which is overlain by black, mica-rich mud followed by a thin greenish, glaucony-rich clay, grey clay and finally by fine- to medium-grained sand. Relative to the North Sea lithostratigraphy, the Måde Group correlates with the Nordland Group (Deegan & Scull 1977; Hardt *et al.* 1989; Schiøler *et al.* 2007).

Name. After a local area west of Esbjerg (Fig. 1) that was renowned for its brickworks based on Upper Miocene clays; the last brick factories were closed in the 1970s.

Type area. The type area of the Måde Group is south-west Jylland. The group is exposed at the Gram clay-pit (Fig. 1) where both the Gram and Marbæk Formations can be seen. At Ørnhøj (Lille Spåbæk), the Hodde and Ørnhøj Formations are exposed and the Marbæk Formation crops out in coastal cliffs at Sjelborg and Marbæk, north-west of Esbjerg (Fig. 1). The full development of the group is illustrated by the cored borehole Sdr. Vium (DGU no. 102.948; 51–24 m, Fig. 63) and the Tinglev borehole (DGU no. 168.1378) from 197 to 50 m (197– 49 m MD; Fig. 63).

Thickness. The group is typically about 25 m thick in the western part of Jylland, but in southernmost Jylland, for example in the Tinglev borehole, nearly 150 m has been penetrated (Fig. 63; Plate 9).

Lithology. The Måde Group is dominated by dark brown, organic-rich mud (Fig. 64). The lower part is composed of alternating fine-grained sand and silty clay with a basal gravel layer (Hodde Formation). Upwards, the succession becomes more fine-grained with scattered incursions of glaucony. This is succeeded by greenish brown, glaucony-rich clay, typically 3 m thick (Ørnhøj Formation). In the upper part of the glaucony-rich section, goethification of glaucony grains is common (Dinesen 1976). This is overlain by a succession of brown clays rich in pyrite that becomes siltier upwards with thin (*c.* 5 cm thick), fine-grained storm sand beds occurring in the upper part. The uppermost Måde Group consists of fine- to medium-grained sand.

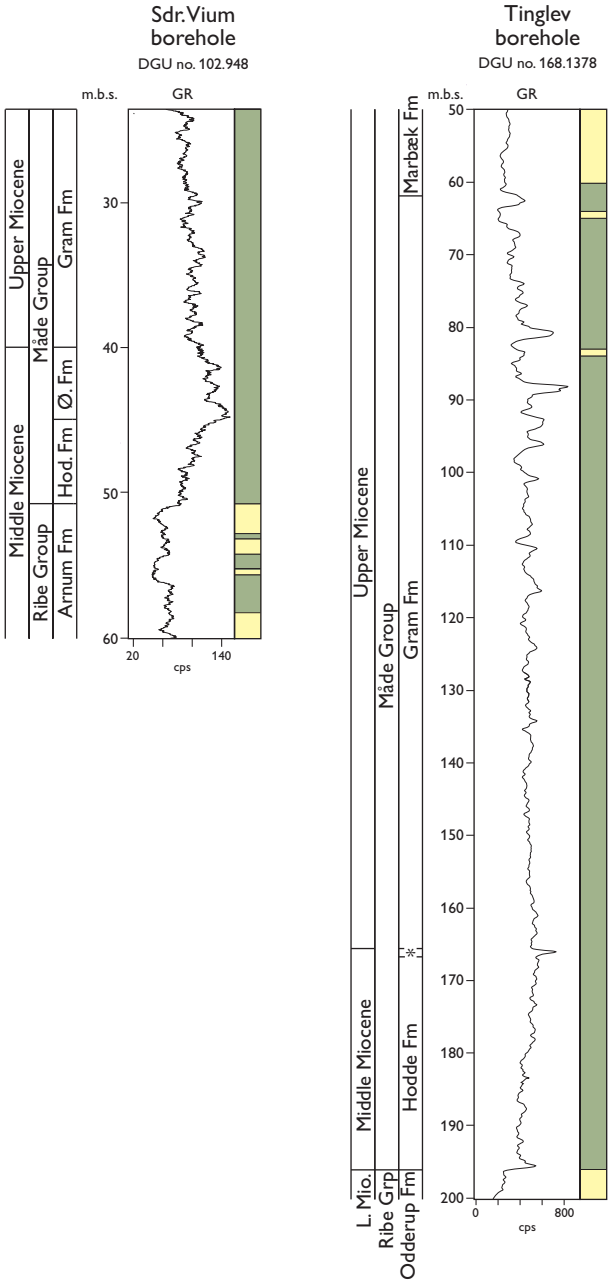

Fig. 63. The full development of the Måde Group is illustrated by the interval from 51 to 24 m in the cored Sdr. Vium borehole and the interval from 197 to 50 m in the Tinglev borehole; for legend, see Fig. 8, p. 17. **Hod.**: Hodde. **L. Mio.**: Lower Miocene. **Ø** and *: Ørnhøj Fm.

Log characteristics. The group is characterised by moderate to high gamma-ray readings (Fig. 63). Extremely high gamma-ray values may be recorded in the lower levels of the group, the upper part showing a gradual decrease in gamma-ray readings (see Fig. 63).

Fig. 64. The open pit at Lille Spåbæk, Ørnhøj (Fig. 1) where the Hodde, Ørnhøj and Gram Formations were exposed in the late 1970s. These three formations, together with the Marbæk Formation, constitute the Måde Group. The cliff is *c.* 10 m high.

Fossils. The Måde Group contains rich and diverse mollusc faunas, crustaceans and vertebrates. Shark teeth are common. Foraminifers and dinocysts are abundant (see details below in the description of the individual formations).

Depositional environment. The Måde Group was deposited on a marine shelf. When the flooding of the land was at its maximum, during the deposition of the glaucony-rich Ørnhøj Formation and the lower part of the Gram Formation, the water depth was over 100 m (Laursen & Kristoffersen 1999). The upper part of the group was deposited in front of a prograding coastline in an offshore to shoreface setting.

Boundaries. The lower boundary is sharp, being marked by a thin gravel layer separating the white, fine-grained sand of the Ribe Group from the dark brown mud of the Måde Group. The upper boundary is a sharp erosional boundary separating mud and fine-grained sand of the Måde Group from Quaternary deposits, the boundary commonly being characterised by a distinct change in lithology and colour of the deposits.

Distribution. The Måde Group is restricted to the western and southern part of Jylland (Fig. 10H) and is found locally around Herning and in the Brande–Give area (Fig. 1).

Geological age. The Måde Group is of early Langhian to latest Tortonian (early Middle to Late Miocene) age.

Subdivision. The Måde Group is divided into four formations: the Hodde, Ørnhøj, Gram and Marbæk Formations.

Hodde Formation

History. The Hodde Formation was defined by L.B. Rasmussen (1961) from the Hodde-1 borehole; it was exposed during the construction (1941–43) of the

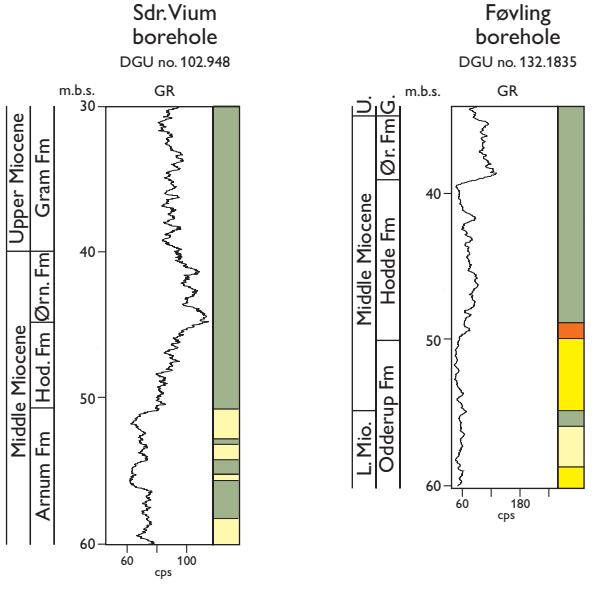

Fig. 65. Reference sections of the Hodde Formation; for legend, see Fig. 8, p. 17. The primary reference section is the interval from 51 to 44.9 m in the cored Sdr. Vium borehole. The secondary reference section is the interval from 50 to 39 m in the Føvling borehole. **G.**: Gram Fm. **Hod.**: Hodde. **L. Mio.**: Lower Miocene. **U.**: Upper Miocene. **Ør.** and **Ørn.**: Ørnhøj.

Fig. 66. The upper part of the Hodde Formation at Lille Spåbæk, Ørnhøj, dominated by dark brown silty clay.

Fig. 67. Close-up of the Hodde Formation at Lille Spåbæk, Ørnhøj. The Hodde Formation is composed of dark brown silty clay; the yellowish stripes are due to weathering of pyrite. The illustrated section is 0.5 m high.

Karlsgårde channel, near Hodde, but this exposure does not exist today.

Name. After the village of Hodde in south-west Jylland (Fig. 1).

Type and reference sections. The type section was defined by L.B. Rasmussen (1961) as the interval from 23.4 to 13.8 m in the Hodde-1 borehole (DGU no. 113.33; 55°41´04.11´´N, 8°40´14.27´´E). The formation is exposed at Lille Spåbæk near Ørnhøj, south of Holstebro (Fig. 1). The primary reference section is the interval from 51 to 44.90 m in the cored borehole at Sdr. Vium (DGU no. 102.948; Fig. 65). A secondary reference section is the Føvling borehole (DGU no. 132.1835) from 50 to 39 m (Fig. 65).

Thickness. The formation is 9.6 m thick (23.4–13.8 m) in the type section and is typically 5–10 m thick where present, but thickens in southernmost Jylland; more than 40 m was penetrated in the Rømø borehole (Plate 9).

Lithology. The Hodde Formation consists of dark brown, organic-rich, bioturbated silty clay with thin sand lenses (Figs 66, 67); the pyrite content is high. The basal part of the formation is composed of a thin gravel layer. In the upper part of the formation, laminated, silty clay is common and glaucony may occur. Trace fossils are common in the Hodde Formation (Asgaard & Bromley 1974).

Log characteristics. The formation is typified by moderate to high gamma-ray values (Fig. 65); a gradual upward increase in gamma-ray response is characteristic. Locally, the upper part shows low gamma-ray readings, for example in the Føvling borehole (Plate 8).

Fossils. The Hodde Formation typically contains a limited fauna of marine molluscs (L.B. Rasmussen 1966) but a

richer fauna occurs locally in shell-beds associated with the basal gravel bed. Marine microfossils, such as foraminifers and dinocysts, occur abundantly (Laursen & Kristoffersen 1999; Piasecki 1980, 2005; Dybkjær & Piasecki 2010).

Depositional environment. The depositional environment is interpreted as fully marine (L.B. Rasmussen 1961). The basal coarse-grained transgressive lag indicates deposition on a marine shoreface during the initial transgressive phase. The increase in glaucony in the upper part indicates a near cessation of sediment influx to this part of the North Sea in the Serravallian.

Boundaries. There is a marked change in lithology from the white, fine- to medium-grained sand of the Odderup Formation to the overlying dark brown, clayey silt of the Hodde Formation. The boundary is sharp and is commonly characterised by a gravel layer, the base of which (where present) defines the boundary. The gamma-ray log shows a prominent shift to high values at the lower boundary.

The upper boundary is defined by an abrupt change from dark brown, clayey silt of the Hodde Formation to greenish brown clay of the Ørnhøj Formation. On the gamma-ray log, this is reflected by a distinct shift towards higher gamma-ray values.

Distribution. The Hodde Formation is recognised in southern and western Jylland (Fig. 10H). The formation occurs locally as far east as Bording and Give in central Jylland in depressions associated with salt structures.

Biostratigraphy. The upper part of the *Labyrinthodinium truncatum* Dinocyst Zone and the *Unipontidinium aquaeductum* Dinocyst Zone (Dybkjær & Piasecki 2010) are recorded in the Hodde Formation.

Geological age. The Hodde Formation is of early Langhian to mid-Serravallian (Middle Miocene) age.

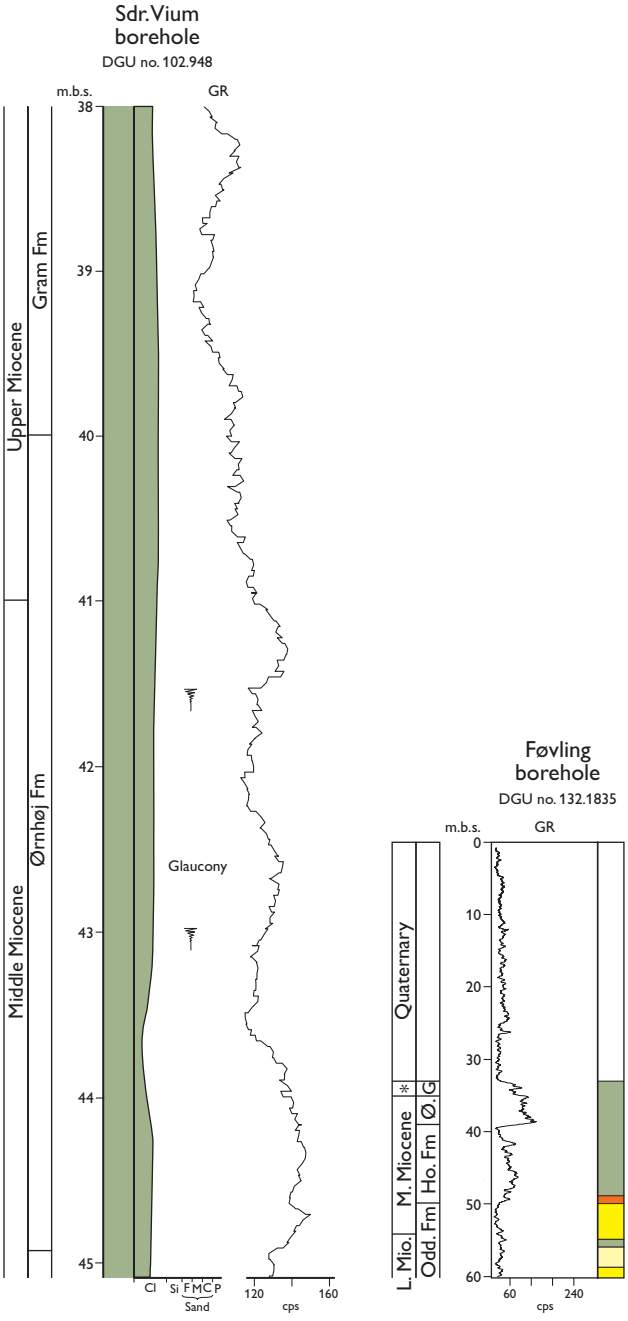

Fig. 68. The type and reference sections of the Ørnhøj Formation; for legend, see Fig. 8, p. 17. The type section is the interval from 44.9 to 40 m in the cored Sdr. Vium borehole. The reference section is the interval from 39 to 36 m in the Føvling borehole. **G:** Gram Fm. **Ho.**: Hodde. **L. Mio.**: Lower Miocene. **M.**: Middle. **Odd.**: Odderup. **Ø.**: Ørnhøj Fm. *: Upper Miocene.

Ørnhøj Formation

new formation

History. Formerly referred to as the 'Glauconitic Clay member' of the lower Gram Formation of previous usage (L.B. Rasmussen 1956, 1961).

Name. After the village of Ørnhøj (Fig. 1) where the formation is still exposed in some of the old brown-coal pits in the neighbourhood.

Type and reference sections. The formation is partly exposed at Lille Spåbæk, west of Ørnhøj (Figs 1, 64). The type section is the interval from 44.90 to 40 m in the cored borehole at Sdr. Vium (DGU no. 102.948; 55°49′04.02′′N, 8°24′46.52′′E; Fig. 68). The reference section is the inter-

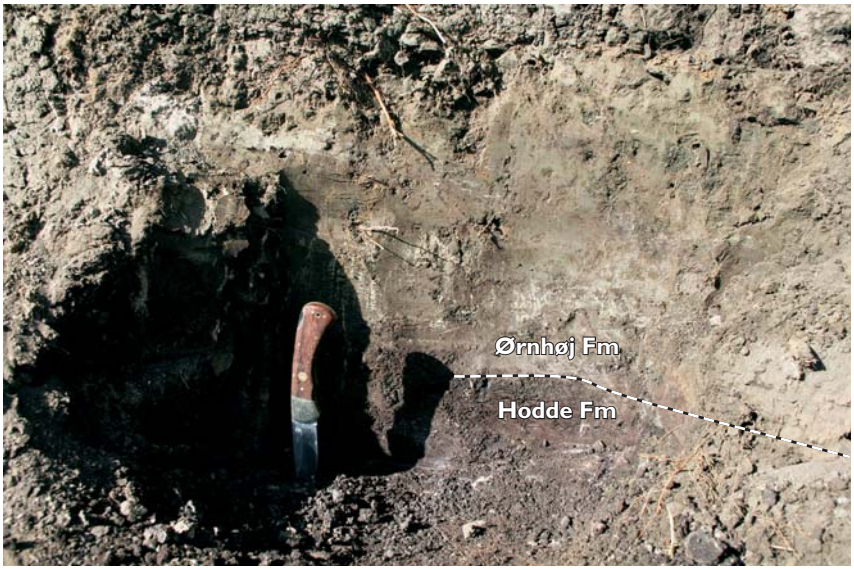

Fig. 69. The Ørnhøj Formation at Lille Spåbæk, Ørnhøj. The lower boundary with the Hodde Formation beneath is seen in the lower part of the section. Knife for scale, *c.* 20 cm long.

val from 39 to 36 m (39–36 m MD) in the Føvling borehole (DGU no. 132.1835; Fig. 68).

Thickness. The formation is 4–5 m thick in the type and reference boreholes, but in general it rarely exceeds more than 2 m in thickness (Plates 4, 8, 9).

Lithology. The Ørnhøj Formation is composed of green and brown clay (Fig. 69). High concentrations of green glaucony pellets of fine sand grade occur commonly. In the upper part of the formation, goethification of glaucony is common.

Log characteristics. The formation is characterised by high gamma-ray values.

Fossils. The Ørnhøj Formation is barren of macro- and microscopic calcareous fossils but a diverse assemblage of dinocysts is present (Piasecki 1980, 2005; Dybkjær & Piasecki 2010).

Depositional environment. The Ørnhøj Formation was deposited in a fully marine, sediment-starved depositional setting that favoured the formation of glaucony. The water depth was probably more than 100 m, based on the estimates of water depth during deposition of the Gram Formation (see below). The Ørnhøj Formation represents the most widespread transgression during the Miocene (E.S. Rasmussen 2004b; Knox *et al.* 2010). The goethification of glaucony in the upper part is interpreted as a result of a sea-level fall (Dinesen 1976; Eder *et al.* 2007) with associated wave action at the sea floor. Concentration of glaucony in depositional bars at Ørnhøj (J. Frederiksen, personal communication 2009) supports the interpretation of wave action at the sea floor.

Boundaries. The lower boundary is characterised by an abrupt change from the dark brown, clayey silts of the Hodde Formation to greenish brown clays of the Ørnhøj Formation (Fig. 69). The gamma-ray log shows a prominent shift in gamma-ray response towards high values.

The upper boundary is defined by the change from greenish brown or brown, glaucony-rich clay to dark brown clay. At the boundary there is an abrupt change from glaucony-impregnated pellets and shells to pyritised pellets. On the gamma-ray log, the upper boundary is defined at a decrease in gamma-ray values; locally a very prominent decrease is observed, for example in the Stensig borehole (Plate 4).

Distribution. The Ørnhøj Formation is recognised in southern and western Jylland. The formation is locally recognised in the subsurface as far east as Bording and Give in central Jylland, where it occurs in depressions associated with salt structures (Fig. 10H).

Biostratigraphy. The *Achomosphaera andalousiense* and *Gramocysta verricula* Dinocyst Zones of Dybkjær & Piasecki (2010) are recorded in the Ørnhøj Formation.

Geological age. The Ørnhøj Formation is of late Serravallian (late Middle Miocene) age.

Gram Formation

redefined formation

History. The Gram Formation was defined by L.B. Rasmussen (1956). In the original definition of the Gram Formation, three members were recognised: the Glauconite Clay, Gram Clay and Gram Sand members (L.B. Rasmussen 1956). The Glauconite Clay member of previous usage is herein redefined as the new Ørnhøj Formation and the Gram Sand member as the Marbæk Formation; the redefined Gram Formation thus equates to the Gram Clay member of L.B. Rasmussen (1956).

Name. After the town of Gram (Fig. 1).

Type and reference sections. The type section is at the disused pit of the Gram brickworks (55°18´24.90´´N, 9°03´31.26´´E; Fig. 1), now the Midtsønderjyllands Museum of Gram, where a 13.1 m thick section of the Gram Formation is exposed (Figs 70, 71). The reference section is the interval from 40 to 24 m in the cored borehole Sdr. Vium (DGU no. 102.948; Fig. 71).

Thickness. A 13.1 m section is seen at the type section, but neither the base nor the top is exposed. In the reference section, the formation is about 16 m thick. The formation thickens south-westward and 105 m was penetrated in the Tinglev borehole (Plate 1).

Lithology. The Gram Formation consists of dark brown clay, which becomes more silty upwards. In the upper part, a few, fine-grained, wave-rippled sand beds, *c.* 5 cm thick, are intercalated with the clays (Figs 70, 71). Siderite concretions are common in the lower part of the formation. Pyrite is common both as pyritised pellets and in trace fossils; the latter include common *Trichichnus* ispp. (Rasmussen & Larsen 1989; Bromley 1996).

Log characteristics. The formation is characterised by moderate gamma-ray values (Fig. 71). The log pattern is serrated and shows a general decreasing-upward trend in gamma-ray values through the succession (Fig. 63).

Fossils. The Gram Formation is characterised by abundant and diverse mollusc faunas, in association with marine vertebrates (whales and sharks) and crustaceans (crabs), the latter in concretionary nodules (L.B. Rasmussen 1966, 1968; Bendix-Almgreen 1983; Hoch 2008; Schnetler 2005; Steeman, 2009). Foraminifers and dinocysts are abundant (Laursen & Kristoffersen 1999; Piasecki 1980, 2005).

Depositional environment. The Gram Formation was deposited in a fully marine environment with water depths of more than 100 m (Laursen & Kristoffersen 1999; C. Morigi, personal communication 2010). The incoming of storm beds in the upper part is interpreted to reflect progradation of the shoreline (Rasmussen & Larsen 1989).

Boundaries. The lower boundary is defined at the change from greenish brown or brown, glaucony-rich clay to dark brown clay, associated with an abrupt change from glaucony-impregnated pellets and shells to pyritised pellets. On the gamma-ray log, this is reflected by a decrease in gamma-ray values.

Fig. 70. Fine-grained, partly bioturbated sand interbeds in the upper part of the Gram Formation, Gram clay pit. The sand beds are commonly wave-rippled. The illustrated section is 0.30 m high.

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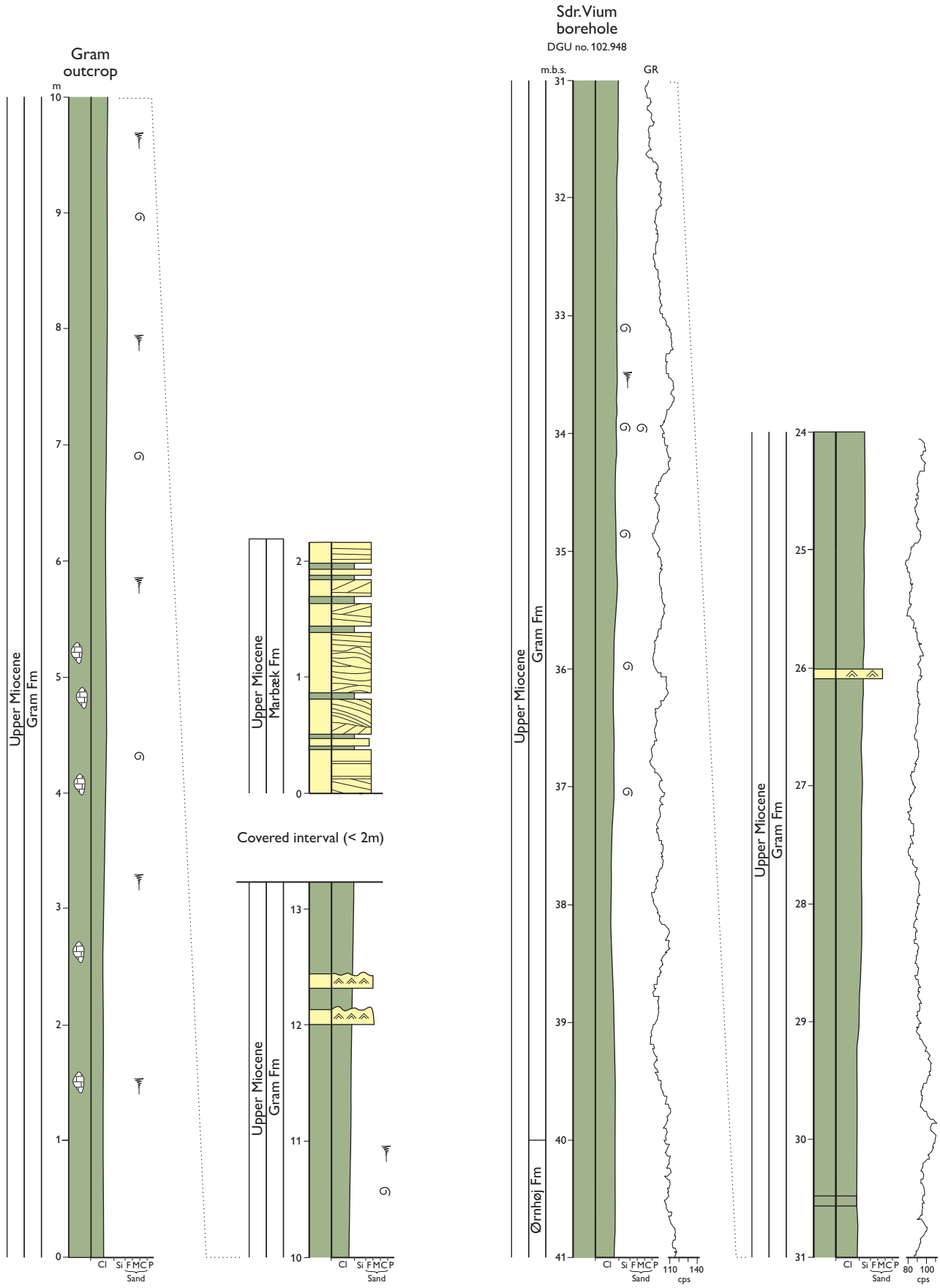
Fig. 71. Type and reference sections of the Gram Formation; for legend, see Fig. 8, p. 17. The type section is at the Gram clay pit near Gram, where 13.1 m of the formation is exposed. The reference section is the interval from 40 to 24 m in the cored Sdr. Vium borehole.


Gram
outcrop
m
Upper Miocene
Gram Fm
Cl Si F M C P
Sand
Upper Miocene
Marbæk Fm
Covered interval (< 2m)
Upper Miocene
Gram Fm
Sdr.Vium
borehole
DGU no. 102.948
m.b.s.
GR
Upper Miocene
Gram Fm
Ørnhøj Fm
110 140
cps
Upper Miocene
Gram Fm
80 100
cps

The upper boundary is placed where interbedded clay and thin sand layers are succeeded by amalgamated sand beds. On the gamma-ray log, the upper boundary is identified by a marked shift to consistently low gamma-ray values.

Distribution. The Gram Formation is recognised in the subsurface of southern and western Jylland (Fig. 10H). The formation occurs locally as far east as Bording and Give in central Jylland in depressions associated with salt structures.

Biostratigraphy. The *Amiculasphaera umbracula* and *Hystrichosphaeropsis obscura* Dinocyst Zones of Dybkjær & Piasecki (2010) are recorded in the Gram Formation.

Geological age. The Gram Formation is of Tortonian (Late Miocene) age.

Marbæk Formation

new formation

History. Sands exposed in the cliffs at Sjelborg and Marbæk, north-west of Esbjerg (Fig. 1), and sandy sediments in the upper part of the Sæd borehole (DGU no. 167.445) were tentatively referred to the Pliocene by Jørgensen (1945). New studies of these sections (Piasecki *et al.* 2003), however, indicated that these deposits are Tortonian in age. The sand was informally named the Gram Sand member (Gram Formation of previous usage) by L.B. Rasmussen (1956).

Name. After the coastal cliff at Marbæk, north-west of Esbjerg (Fig. 1).

Type and reference sections. The type section is the exposure at Marbæk cliff (55°32´56.49´´N, 8°18´57.49´´E; Figs 1, 72). The reference section is the interval from 62 to 50 m (62–49 m MD) in the Tinglev borehole (DGU no.168.1378; Fig. 73).

Thickness. The Marbæk Formation is *c.* 16 m thick in the Marbæk cliff (Fig. 72); neither the base nor the top is exposed. In the pit at the Gram brickworks, 1.5 m of the formation is exposed in the bank of a stream (Fig. 71). In

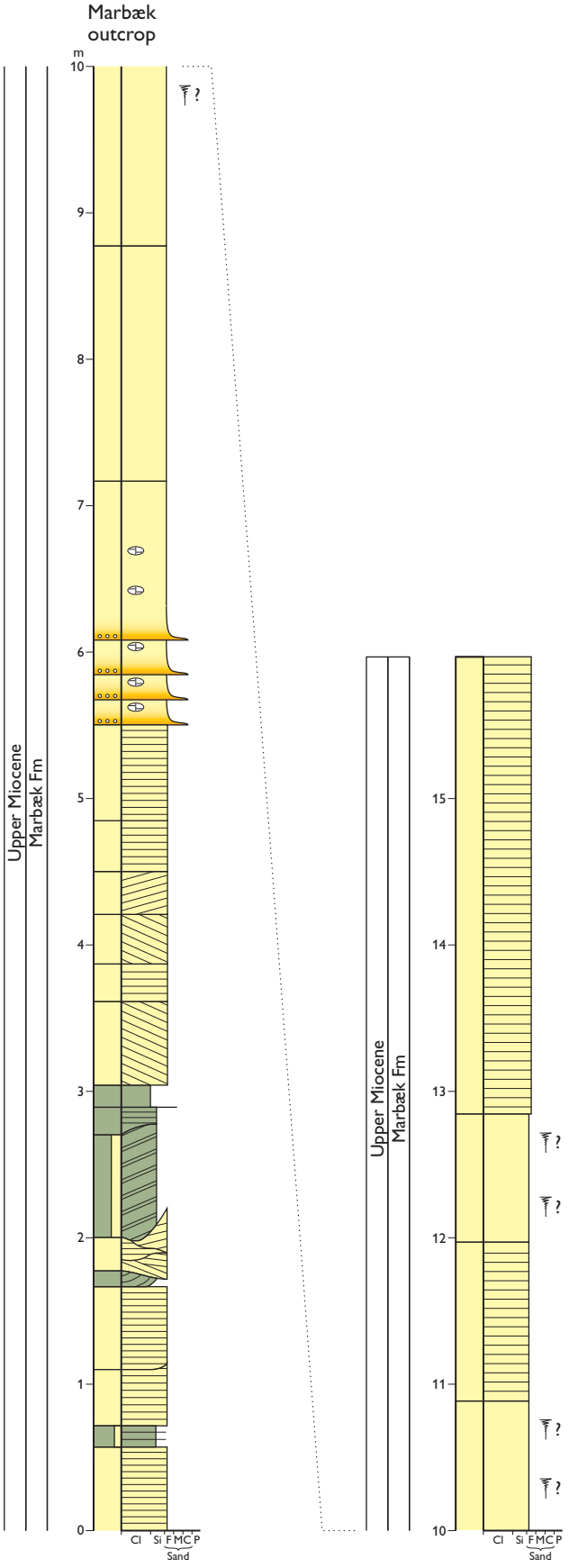


Fig. 72. Type section of the Marbæk Formation in the coastal cliff at Marbæk, north-west of Esbjerg, where *c.* 16 m of the formation are exposed; for legend, see Fig. 8, p. 17. Iron-stained fractures are conspicuous at 7–9 m in this section.

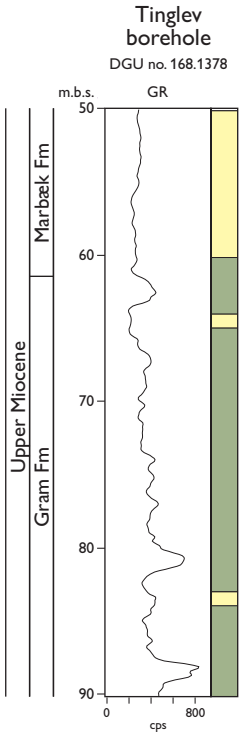


Fig. 73. Reference section for the Marbæk Formation is the interval from 62 to 50 m in the Tinglev borehole; for legend, see Fig. 8, p. 17.

the Tinglev borehole, the formation is 10 m thick (Fig. 73, Plate 1), though the top is an unconformity with Quaternary sediments.

Lithology. In the type section, the formation is dominated by white, often reddish, fine- to medium-grained, mica-rich sand with a few thin intercalated coarse-grained sand or gravel layers and, in the lower part, subordinate silt-rich intervals (Figs 72, 74). The sand beds show parallel lamination with subordinate cross-bedding; hummocky cross-stratification is common (Fig. 75). A silt-rich interval shows double clay layers. The uppermost white sand at Sjelborg consists of homogenous sand capped by wave-ripples (Fig. 76). The pyrite content is very high in the Marbæk Formation (Olivarius 2009) and the distinctive red colour of the succession at the Marbæk outcrop is due to oxidation of the pyrite.

Fossils. Rare, poorly preserved molluscs have been found in the Marbæk Formation (Jørgensen 1945). Dinocysts occur in the lower part of the formation but become scarce upwards (Piasecki *et al.* 2003).

Depositional environment. The formation was deposited in a storm-dominated environment within the upper and

Fig. 74. Oblique view of the Marbæk Formation at Marbæk, north-west of Esbjerg. Two persons (upper right) for scale.

Fig. 75. Hummocky cross-stratified sand of the Marbæk Formation at Marbæk; the illustrated section is 50 cm high.

Fig. 76. Although deformed by glacial tectonics, the Marbæk Formation sands display homogenous and wave-rippled facies typical of upper shoreface deposits. The illustrated section is 0.4 m high; Sjelborg.

lower shoreface. Double clay layers indicate some tidal influence.

Boundaries. The lower boundary is defined where alternating thin clay and sand layers are overlain by amalgamated sand beds; this boundary is not observed at outcrop. On the gamma-ray log, this boundary is identified by a marked shift to steady low gamma-ray values.

The upper boundary is placed at a distinct, erosional unconformity separating the mica-rich sands from tills and yellowish, coarse-grained sands and gravels of Quaternary age.

Distribution. The formation is limited to the far west and south of Jylland.

Biostratigraphy. The *Hystrichosphaeropsis obscura* Dinocyst Zone of Dybkjær & Piasecki (2010) is recorded in the lower part of the Marbæk Formation.

Geological age. The lower part of the Marbæk Formation is of Tortonian (Late Miocene) age, equivalent to the uppermost part of the Gram Formation. The absence of fossils in the upper levels of the formation precludes precise dating of this part.