The Lower Oligocene-Lower Pliocene Molo Formation on the inner Norwegian Sea continental shelf

(Extent and thickness, age from fossil and Sr isotope correlations, lithology, paleobathymetry and regional correlation)

Tor Eidvin & Fridtjof Riis

Norwegian Petroleum Directorate (NPD), Stavanger, Norway
Professor Olav Hanssens vei 10, P. O. Box 600, N-4003 Stavanger, www.npd.no,
tor.eidvin@lyse.net, fridtjof.riis@lyse.net

The Molo Formation is a sand-dominated unit on the middle/inner part of the shelf extending from the coast off Møre (63°15'N) to Lofoten (67°50'N). It has a unique seismic signature, and represents a prograding system comprising fairly steep clinoforms (Fig. 5, Profiles 1 - 4). Eidvin et al. (1998a) investigated sidewall cores of the Molo Formation in well 6610/3-1 (in its northern part) and gave an Early Oligocene age for the unit based on benthic foraminiferal and dinoflagellate cysts correlations and strontium isotope analyses. At a later date T. Eidvin and M. Smelror investigated sidewall cores of the same formation in well 6510/2-1 (in the middle part of the formation). Based on the same kind of analyses they suggested an Early Miocene age for the formation in that well. Eidvin et al. (2007) investigated ditch cutting samples of the Molo Formation in well 6407/9-5, 6407/9-2 and 6407/9-1 (in its southern part) and based on the same kind of analyses they suggested a Late Miocene to Early Pliocene age for the unit in those wells.

Eidvin et al. (2007) interpreted the Oligocene fossils in well 6610/3-1 (Fig. 6) and the Early Miocene fossils in well 6510/2-1 (Fig. 8) to be reworked and suggested a post mid Miocene age for the whole of the Molo Formation. They interpreted the Molo Formation to be the proximal equivalent to the deeper marine Kai Formation. However, interpretation of new seismic data, for the current presentation, indicates the northern proximal part of the Molo Formation is as old as Early Oligocene and that the formation contains younger sediments towards west and south (Fig. 5, Profile 1-4). We now believe that the recorded index fossils in well 6610/3-1 (Fig. 6) and 6510/2-1 (Fig. 8) are not reworked, and that the Molo Formation is the proximal equivalent to both the Brygge and Kai formations (Profiles 1-4, Fig. 10). Eidvin et al. (2007) suggested 6610/3-1 from 555 to approximately 349 m (Fig. 6, the top is not sampled and logged) as the well type section and 6407/9-5 from 787 to 670 m as well reference section (Fig. 3). For the current presentation we suggest well 6510/2-1 from 480 to 441 m (Fig. 8, the top is not sampled and logged) also as well reference section.

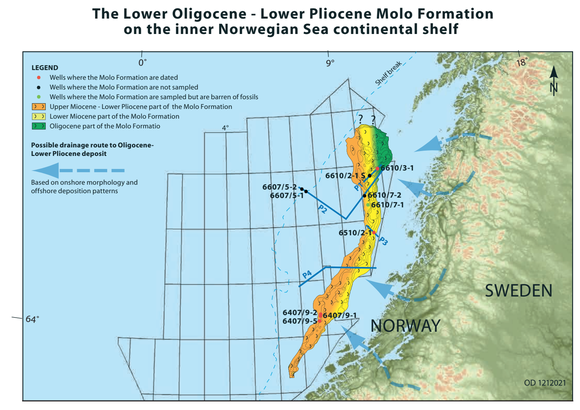
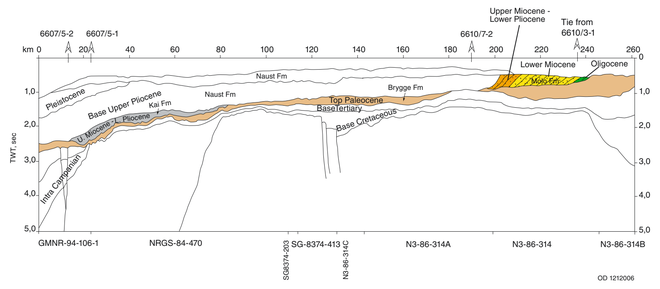
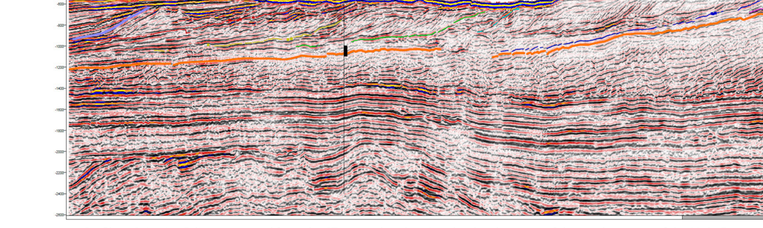


Fig. 5: Oligocene to Lower Pliocene Molo Formation with investigated wells and seismic profiles. The extent and thickness of the Molo Formation are according to Bullimore et al. (2005).

Profile 1: Seismic 3D line generated from the ST9404 cube, showing the development of the northern part of the Molo Formation in a profile through exploration wells 6610/2-1S and 6610/3-1. The seismic data are consistent with the biostratigraphy indicating that early Oligocene sediments are distal and fine-grained in 6610/2-1 S whereas they belong to a sandy progradational unit in 6610/3-1. In both profiles, the orange horizon marks the base of the Oligocene whereas the blue horizon indicates the boundary between the Molo and the Naust formation. Some undated internal boundaries within the Molo progradation have also been marked. Black rectangles show the studied, Eocene and Early Oligocene intervals.

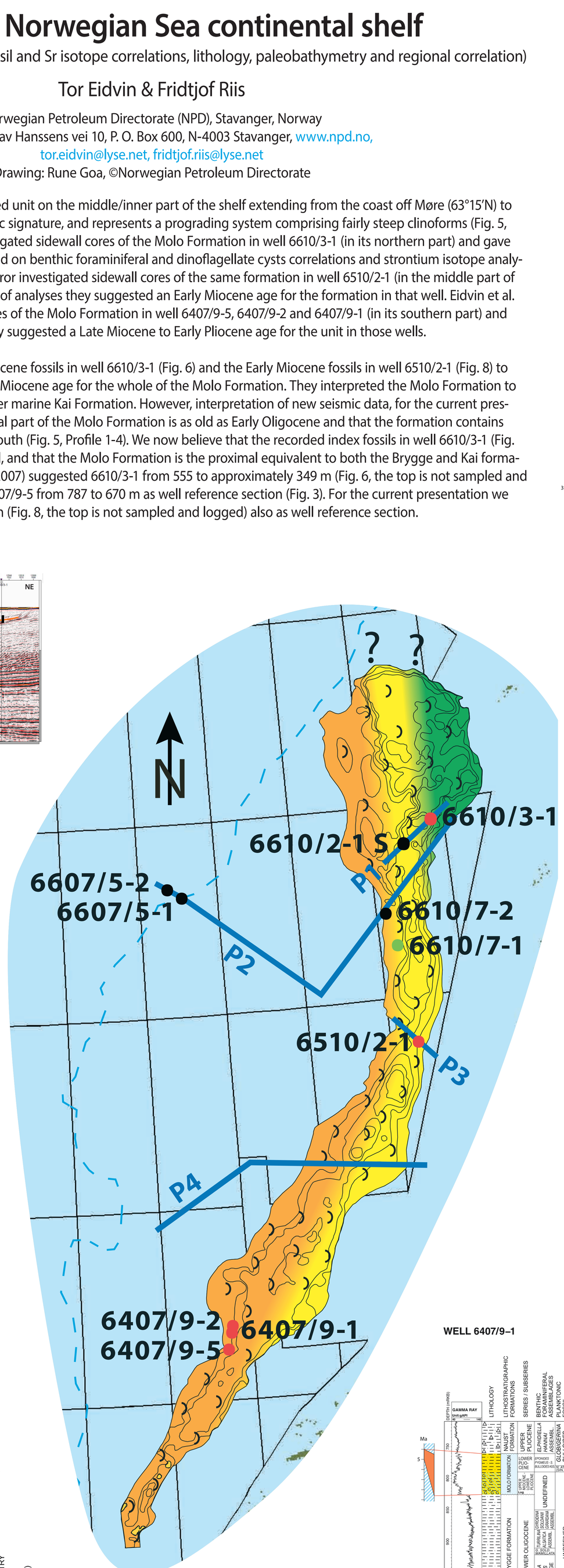


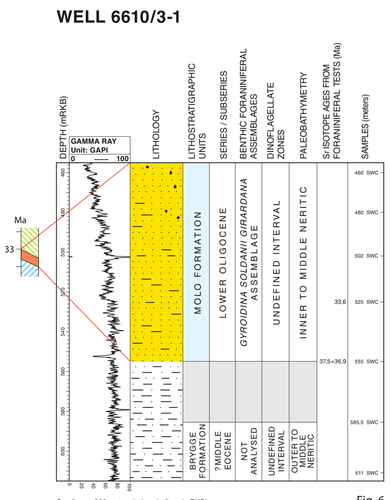
Profile 2: Regional geoseismic line across the Utgaard High and along the Nordland Ridge through well 6607/5-1 and 6607/5-2 (modified after Eidvin et al. 2000). The boundaries between the Oligocene, Lower Miocene and Upper Miocene - Lower Pliocene parts of the Molo Formation are tentative and after F. Riis (work in progress).



Profile 3: Seismic 2D line SH9601-409 showing the development of the Molo Formation in a profile through exploration well 6510/2-1 on the Vega High. The black rectangle shows the studied interval, dated to Eocene in the lower part and Early Miocene in the upper part. The Miocene section consists of a glauconite-rich, quartzose sand deposited in a neritic environment. In this area, only the outer parts of the Molo sand system, believed to be of a Late Miocene and Early Pliocene age, show a distinct progradation.

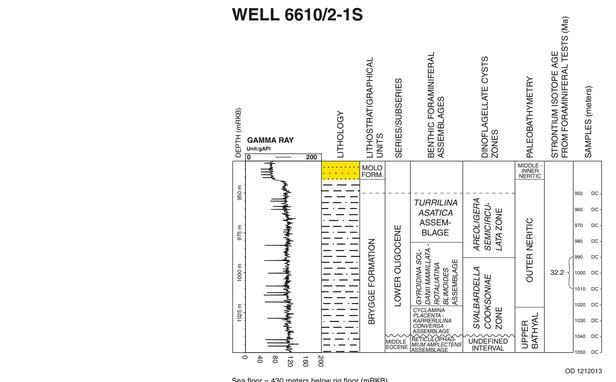
Profile 4: Geoseismic section showing that the Molo and Kai formations are proximal and distal equivalents with respect to each other. The mid Miocene unconformity separates the Kai and Molo formations from the underlying Brygge Formation (see also Map 1for location, modified after Eidvin et al. 2007). The boundery between the Lower Miocene and Upper Miocene-Lower Pliocene parts of the Moloformation are tentative and after F. Riis (work in progress).





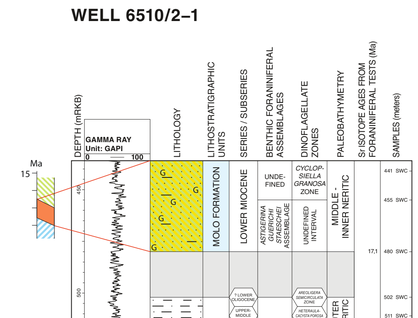
Sea floor = 332 meters below rig floor (mRKB)
gAPI = American Petroleum Institute gamma ray units
SWC = Side-wall core
● = Rounded or sub-angular pebbles
Unconformity
Not sampled
OD 1212011

Fig. 6



Sea floor = 430 meters below rig floor (mRKB)
gAPI = American Petroleum Institute gamma ray units
DC = Ditch cuttings
OD 1212013

Fig. 7

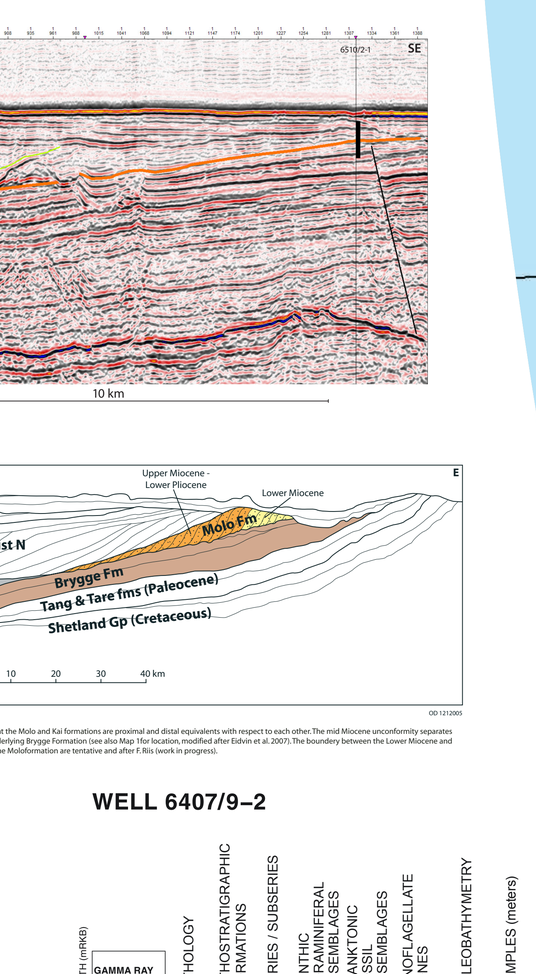


Sea floor = 348 meters below rig floor (mRKB)
gAPI = American Petroleum Institute gamma ray units
SWC = Side-wall core
G = Common glauconite
Unconformity
Not sampled
OD 1212010

Fig. 8

Sea floor = 263 meters below rig floor (mRKB)
DC = Ditch cuttings
gAPI = American Petroleum Institute gamma ray units
G = Abundant glauconite
△ = Ice rafted pebbles
Unconformity

Fig. 9



Sea floor = 272 meters below rig floor (mRKB)
DC = Ditch cuttings
gAPI = American Petroleum Institute gamma ray units
G = Abundant glauconite
△ = Ice rafted pebbles
Unconformity

Fig. 1

Sea floor = 319 meters below rig floor (mRKB)
DC = Ditch cuttings
gAPI = American Petroleum Institute gamma ray units
G = Abundant glauconite
△ = Ice rafted pebbles
Unconformity

Fig. 3

Late Paleogene and Neogene lithostratgraphy

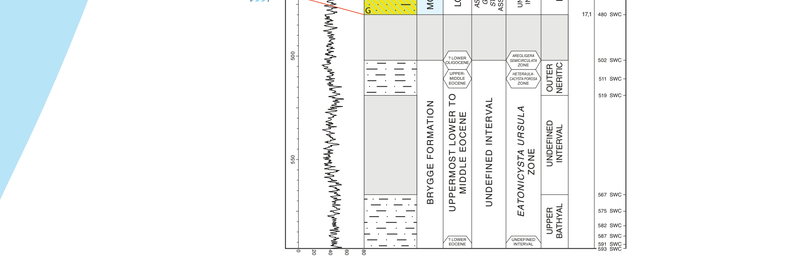


Fig. 10: General view of the Late Paleogene and Neogene lithostratigraphy in the investigated areas modified after Rasmussen et al. (2008) and Rundberg & Eidvin (2005). On the right hand side of the diagram there is added some paleoclimatic data including a global deep-sea oxygen curve, bottom-water paleo-temperatures in the world's oceans and periods with ice-sheets in the Antarctica and northern hemisphere (after Zachos et al. 2001). Periods with deposition of IRD at ODP Site 913 (off East Greenland) are also indicated (Eldrett et al. 2007).

Geochronology of studied wells, boreholes and outcrops

(The Molo Formation in dark red)

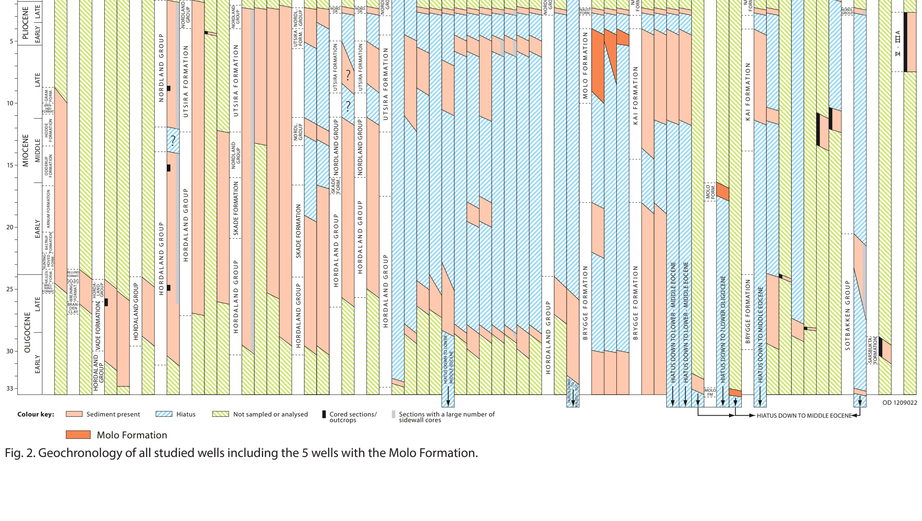
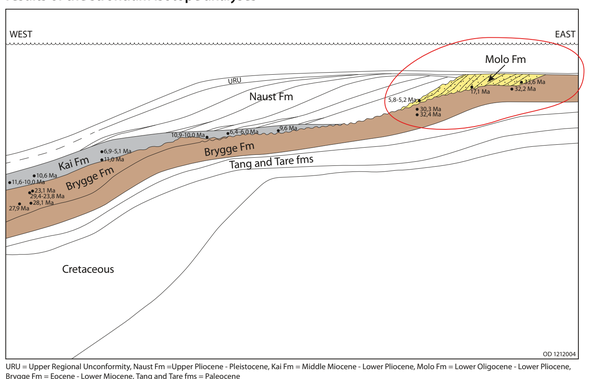


Fig. 2. Geochronology of all studied wells including the 5 wells with the Molo Formation.

Scematic and generalised cross-section of the Norwegian Sea shelf including the main results of the strontium isotope analyses



URU = Upper Regional Unconformity, Naust Fm =Upper Pliocene - Pleistocene, Kai Fm = Middle Miocene - Lower Pliocene, Molo Fm = Lower Oligocene - Lower Pliocene, Brygge Fm = Eocene - Lower Miocene, Tang and Tare fms = Paleocene

Fig. 4: Schematic and generalised cross-section of the Norwegian Sea shelf (modified after Henriksen et al., 2005) including main results of the strontium isotope analyses based on fossil tests interpreted to be in situ (after Eidvin et al., work in progress).

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If not stated otherwise all figures and text are according to:

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