An Early Oligocene oil seepage at the southern rim of the North Sea Basin, near Leuven (Belgium)

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Abstract

A prominent chocolate-coloured horizon at the top of the Kerkom Sand (Oligocene, Tongeren Group) near Pellenberg in the Leuven area (Belgium), has traditionally been interpreted as the illuvial zone of a podsol type soil. Observed features however are equally compatible with an origin as an oil-saturated reservoir sand. In fact, organic geochemical analyses indicate strongly that a fossil oil seepage is the most likely interpretation. The time of oil impregnation may be related to an important tectonic re-arrangement, which started at the very end of the Eocene, and probably triggered the leakage and migration of oil from traps in the southwest of the Netherlands. The oil migrated through porous sands up the gentle northern flank of the Brabant Massif, guided by clayey seals till it reached the surface. The presence of a fossil oil seepage in the Leuven area, means that possible traps, downdip of the Pellenberg outcrop, may contain accumulations of oil.

Introduction

The fossil oil seepage described in this paper occurs in the Roelants sand pit near Pellenberg, some 10 km to the east of Leuven (Fig. 1). It occurs in the Oligocene Kerkom Sand, which forms part of a gently north to northeast dipping series of sands and clays of Tertiary age, overlying chalks of Late Cretaceous to Danian age. The total thickness of the Tertiary and Cretaceous sediments in the area of Leuven and Tienen is about 150 m. Towards the north the sediment thickness increases rapidly (Fig. 2). The base of the Upper Cretaceous is an important regional unconformity. Upper Cretaceous chalks overlie Paleozoic rocks of the Brabant Massif: Caledonian rocks near Leuven, and Hercynian ones further north.

The section observed in the sand pit is a temporary outcrop. It is situated, however, in the flank of an elongated hill, in which over the years many similar sections have been visible in several temporary sand pits. Therefore, the local geological succession in the hill has been described in a number of field guides (Gullentops 1963; Gullentops et al. 1988), and

excellent regional geological descriptions have been available for over a century (Van den Broeck 1893). Glibert & de Heinzelin (1954) published a representative classical section for one of the former pits in the hill, the Aardebrug pit. The present paper deals with the paleosol and 'sables chocolatés' found in this section (Fig. 3).

Field description

The geological profile

Several sections can be observed today in the extensive Roelants sand pit (Fig.1). The estuarine Kerkom Sand forms the basal part of the section. These sands are cross-bedded at the base and are parallel-laminated towards the top, indicating a beach facies. In the upper part of these sands a black to purple-coloured organic impregnation is present. The base of the overlying Heide Sand is erosional. The Heide Sand consists of coarse- to medium-grained white sands, about a metre thick and generally cross-bedded, with at the base in
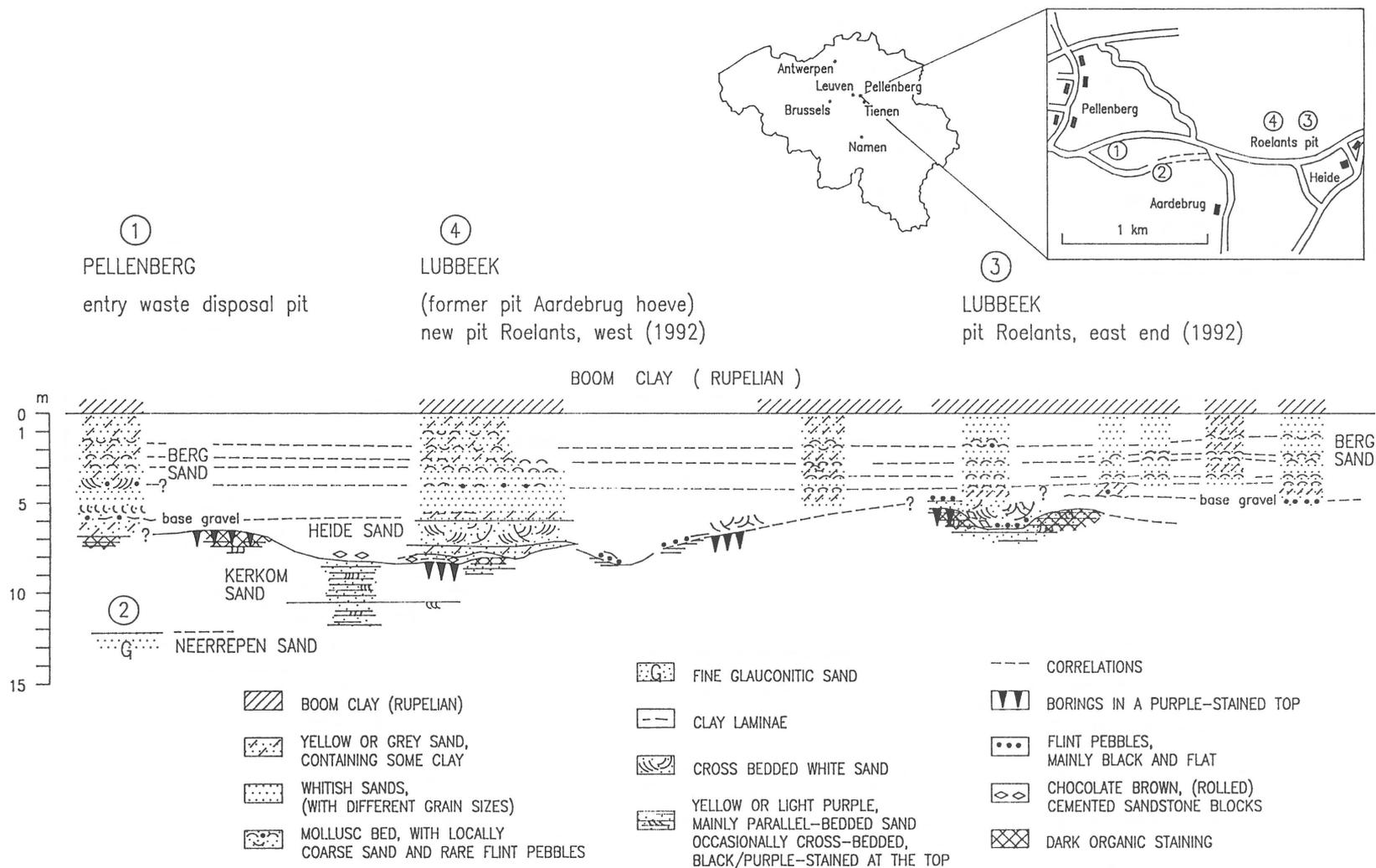
Antwerpen
Leuven Pellenberg
Brussels Tienen
Namen

Pellenberg
④ ③ Roelants pit
① Heide
② Aardebrug
1 km

① PELLENBERG

entry waste disposal pit

④ LUBBEEK

(former pit Aardebrug hoeve)
new pit Roelants, west (1992)

③ LUBBEEK

pit Roelants, east end (1992)

BOOM CLAY (RUPELIAN)

m
0
1

BERG SAND
?
base gravel
HEIDE SAND

BERG SAND
base gravel

5

KERKOM SAND

10

② G NEERREPEN SAND

15

BOOM CLAY (RUPELIAN)

YELLOW OR GREY SAND, CONTAINING SOME CLAY

WHITISH SANDS, (WITH DIFFERENT GRAIN SIZES)

MOLLUSC BED, WITH LOCALLY COARSE SAND AND RARE FLINT PEBBLES

G FINE GLAUCONITIC SAND

CLAY LAMINAE

CROSS BEDDED WHITE SAND

YELLOW OR LIGHT PURPLE, MAINLY PARALLEL-BEDDED SAND OCCASIONALLY CROSS-BEDDED, BLACK/PURPLE-STAINED AT THE TOP

CORRELATIONS

BORINGS IN A PURPLE-STAINED TOP

FLINT PEBBLES, MAINLY BLACK AND FLAT

CHOCOLATE BROWN, (ROLLED) CEMENTED SANDSTONE BLOCKS

DARK ORGANIC STAINING

Fig. 1. Location of the Pellenberg-Lubbeek sand pits, north of the N3 Leuven-Tienen road, and description and correlation of sections outcropping in the hill flank. The Neerrepen Sand (upper member of the marine Sint-Huibrechts-Hern Formation, Tongeren Group), Kerkom Sand (member of the continental Borgloon Formation, Tongeren Group), Heide Sand (a thin white sand member between the Kerkom Sand and the Berg Sand), Berg Sand (member of the Bilzen Formation, Rupel Group) and the Boom Clay Formation (Rupel Group), are the lithostratigraphic units identified in the sections. The organic impregnation occurs at the eroded top of the Kerkom Sand.
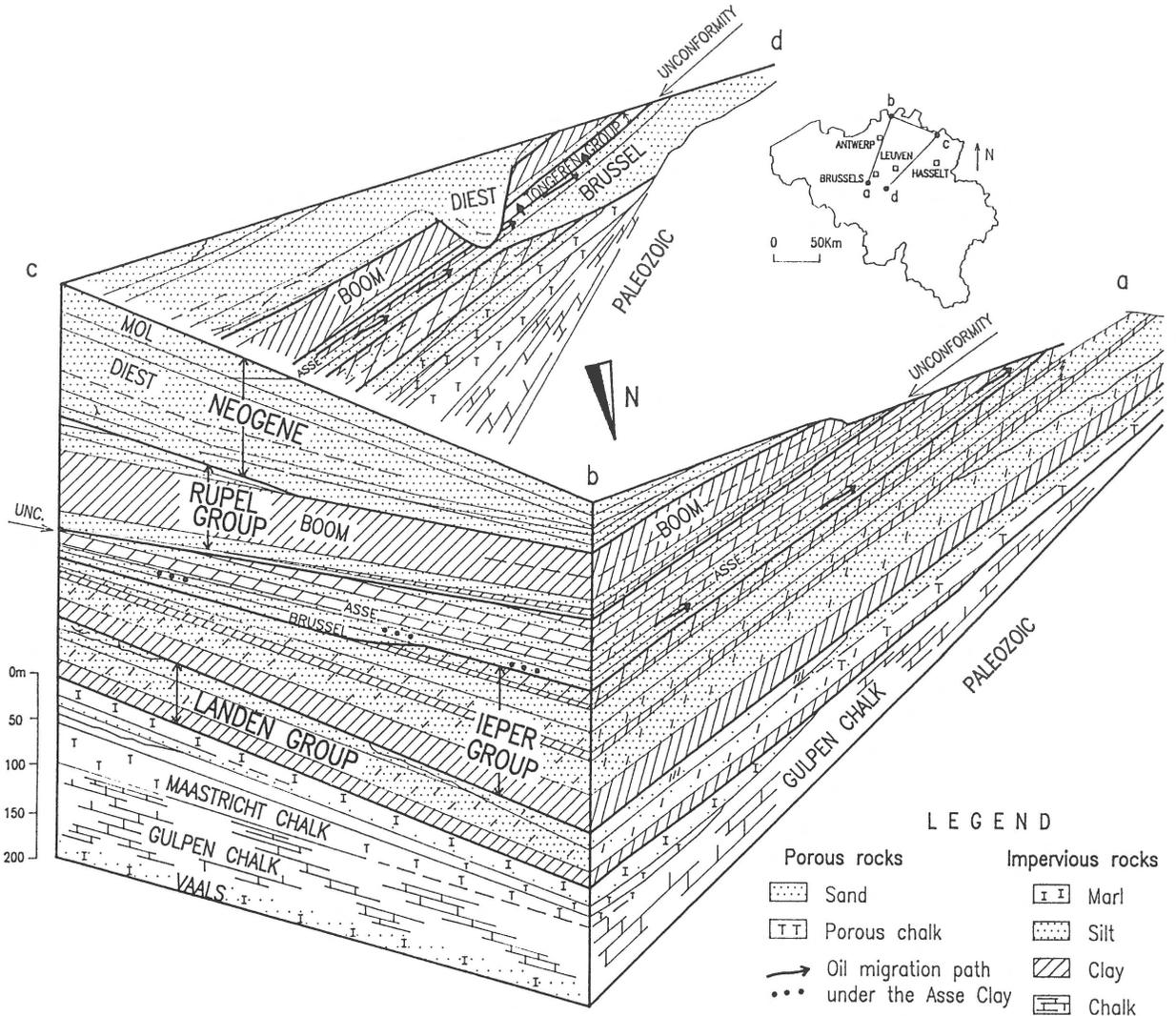
Figure 2. Panel diagram of the post-Paleozoic strata in north and central Belgium, indicating permeable and impermeable units. Note in particular the unconformity underlying the Rupel (and Tongeren) Group (see also Fig. 4). The oil migration took place before deposition of the Rupel Group.

some instances laminae of pure clay of a few centimetres thickness, and also black, flat flint pebbles. Similar pebbles occur above the Heide Sand at the base of the Berg Sand: yellowish strongly bioturbated sands, with several shell beds. The regionally occurring Berg Sand is about 5m thick. It was deposited in very shallow coastal waters. The sand units are separated by a sharp, flat contact from the Rupelian Boom Clay, which forms the top of the section in the sand pit. The Boom Clay is several metres thick. More towards the centre of the hill the clay is overlain by coarse-grained glauconitic sands, the Diest Sand.

Figure 4 shows the regional stratigraphic setting as well as the sequence-stratigraphic context (Haq et al. 1987). The Kerkom Sand occurs at the very base of the Oligocene. The Boom Clay Formation to the north forms the Rupelian stratotype. The glauconitic Diest Sand is Late Miocene in age.
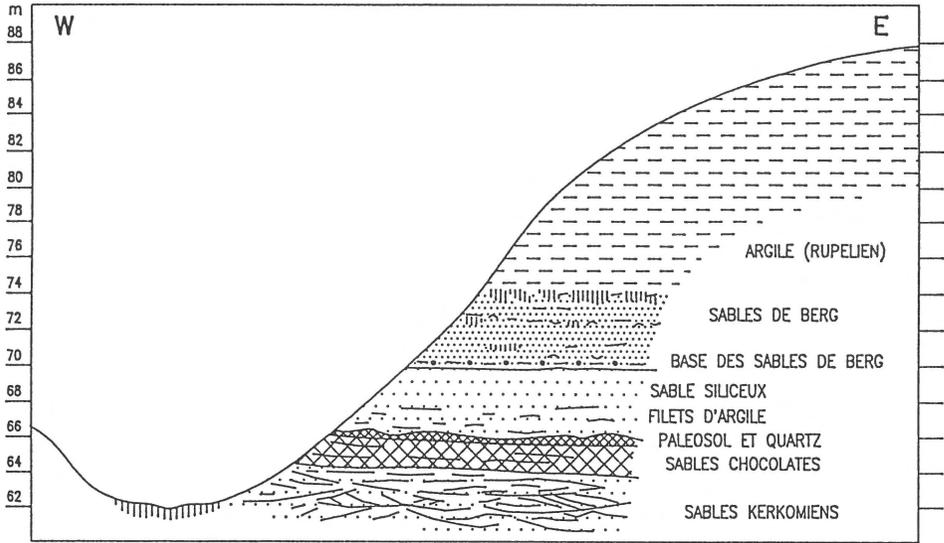
Figure 3. The section in the Aardebrughoef hill near Pellenberg as described by Glibert & de Heinzelin (1954: fig. 5). Translations: argile = clay, filet = streak, sable = sand.
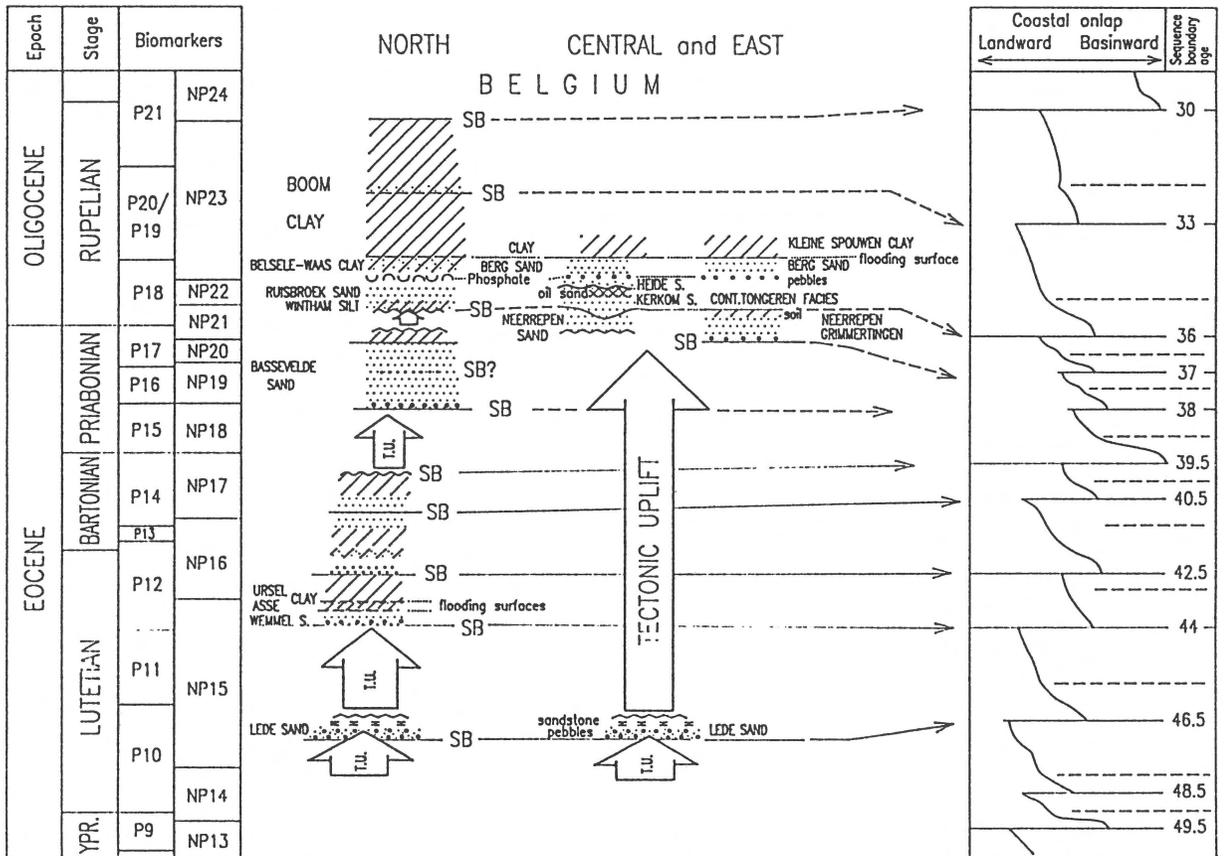

Figure 4. The Pellenberg-Lubbeek section (central column) in the regional tectono-stratigraphic framework. Biostratigraphic zonations and coastal onlap curve from Haq et al. (1987). SB = sequence boundary. Large vertical arrows represent times and locations with evidence of tectonic uplift, often accompanied by erosion.
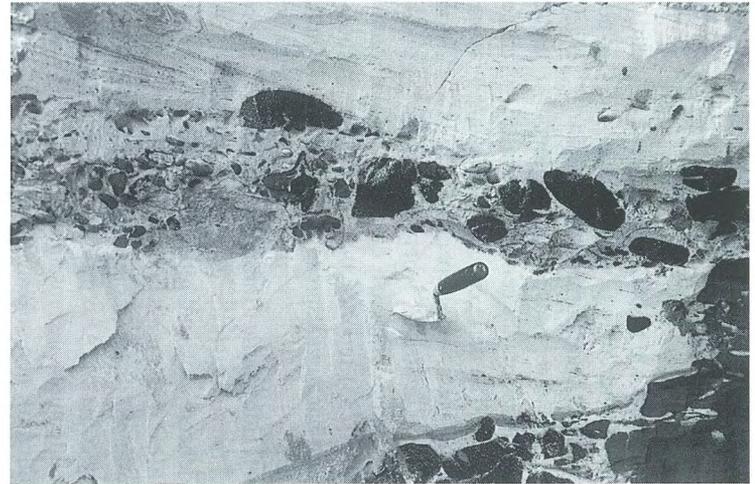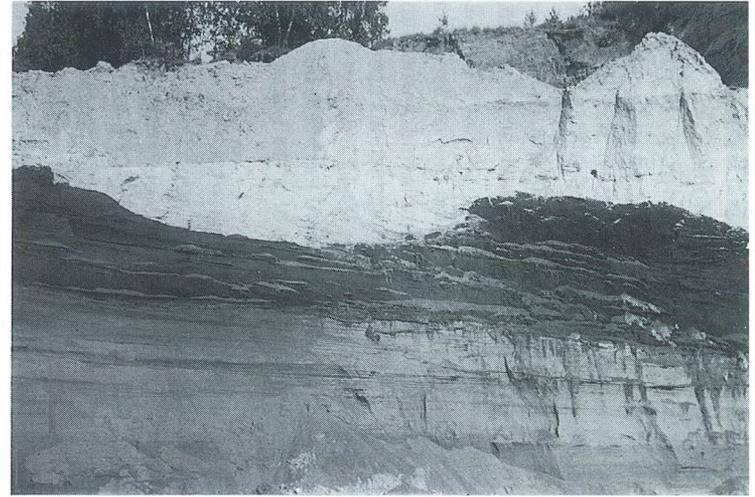
Fig. 5. Roelants sand pit, Pellenberg. a) A general view of the section in the pit: the lower sand unit is the Kerkom Sand, of which the top is impregnated by black to brown oil. This top is clearly eroded and overlain by the white Heide Sand. The Heide Sand, of varying thickness, is levelled off at the top by the transgressive surface at the base of the darker, grey Berg Sand. On top of the Berg Sand, in the background, the Boom Clay occurs. b) A view of the erosional top and oil-impregnated upper part of the Kerkom Sand. Note the differences in oil staining along stratification planes in the lower part. c) Detail of the eroded top of the oil-impregnated zone. Note the borings in the top and in particular the very delicate features of the eroded top, testifying to the cementation of the sand prior to the erosion. Flint pebbles are present at the top of the white Heide sand. d) Black, rounded pebbles and angular blocks eroded from the oil-impregnated horizon, and deposited in the overlying white Heide Sand.

The organic impregnation at the top of the Kerkom Sand

The impregnated zone at the top of the Kerkom Sand has a thickness of a metre or more (Fig. 5a). The underlying sands are irregularly stained purple over a thickness of several metres; still lower beds are pale yellow. The colouration is most intense at the centre of the hill, but it disappears laterally. The dark, chocolate-brown to black horizon is only preserved deeper in the hill (which is presently being quarried), where it is still covered by several metres of Rupelian clay (Fig.3). Van den Broeck (1893: 235) reported that the characteristic black horizon has a widespread, but spotty occurrence in the region.

Distinct erosional features point to an almost immediate consolidation of the stained layer after its deposition (Fig. 5c). This delicate erosional relief as well as the animal borings, filled with pure white sand, could never have been preserved if the impregnated sands had not been strongly cohesive. Also prominent cliff- or gully-like erosional features are present, which are clearly too steeply sided for non-cohesive sands. The best proof for an almost immediate consolidation after the deposition of the sands is the presence of chocolate-coloured sand pebbles and angular, larger impregnated blocks of sand at the base of the overlying white sands (Fig. 5d). No pollen were found in the black, impregnated sand. The original sedimentary stratification in the black sands is still preserved (Fig. 5b). Additionally, in the part of the section directly below the upper, very dark layer, the staining locally differs in intensity in the finer or coarser-grained laminae. The less permeable layers appear to be most intensely stained, with the coarser laminae being lighter in colour. Along small fault zones the staining is often absent.

Hypotheses about the origin of the impregnation

Van den Broeck (1893: 241) summarised previous work and supported the interpretation of Raeymaekers & Van Ertborn (1883), that the chocolate colour is due to the decomposition of plant-derived organic matter dispersed in sands, interpreted to have been deposited in a lagoonal to littoral environment. Moreover, he specifically refers to abundant marine algae. In addition, he reports abundant terrestrial vegetation and a soil occurring in an onshore setting, laterally from the chocolate sands. Glibert & de Heinzelin (1954) note a paleosol above the chocolate-coloured sands (Fig.3).

In this interpretation the dark interval is considered to be an illuvial zone of a thick soil profile.

The absence of a clear eluviated zone, of rootlets and of mottles was explained by erosion. In this hypothesis the considerable thickness of the 'illuvial' black horizon is attributed to prolonged weathering under tropical to subtropical conditions. The paleoclimatic interpretation is based on analysis of pollen, spores (Roche 1982) and fish remains (Steurbaut & Herman 1978). Consolidation of the illuvial zone of a podsol can happen through the complexing of iron with humic acids, and hard humic impregnations can even form directly beneath peat layers (Dekker et al. 1991). Gullentops et al. (1988) considered the black horizon to be a typical illuvial horizon of a well-developed podsol.

Although the field observations as such allow interpretion of the black impregnation as part of a soil, all these macroscopic features are also compatible with a fossil oil accumulation in the sands. In particular in the upper part, the homogeneity of the impregnation is striking, whilst the predominantly layer-parallel lighter colouration in the lower part of the dark layer would reflect grain size differences, as is generally observed in cores of oil-bearing sands. The more porous sands are preferentially leached. The absence of staining along small faults indicates the occurrence of leaching. Leaching may also explain the purple staining of the sands below the impregnated zone.

Additional support for oil impregnation is given by an outcrop equivalent: similar albeit more rounded pebbles, comparable with the brown blocks and pebbles found at the base of the white Heide Sand, are present in the Lower Cretaceous of the Wessex Basin at Mupe Bay, Dorset, south England (Selley & Stoneley 1988). In this example the dark-stained pebbles have been proven to be derived from underlying tar-cemented sands.

There is no previous record of the Pellenberg outcrop having been interpreted as a fossil oil accumulation. This may be related to the known absence of mature oil source rocks north of the Brabant Massif in Belgium, the Palaeozoic being over-mature and the post-Palaeozoic not yet mature enough. Not being able to resolve the above questions from outcrop observations, the authors were prompted to check the hypothesis of a fossil oil by geochemical analysis.
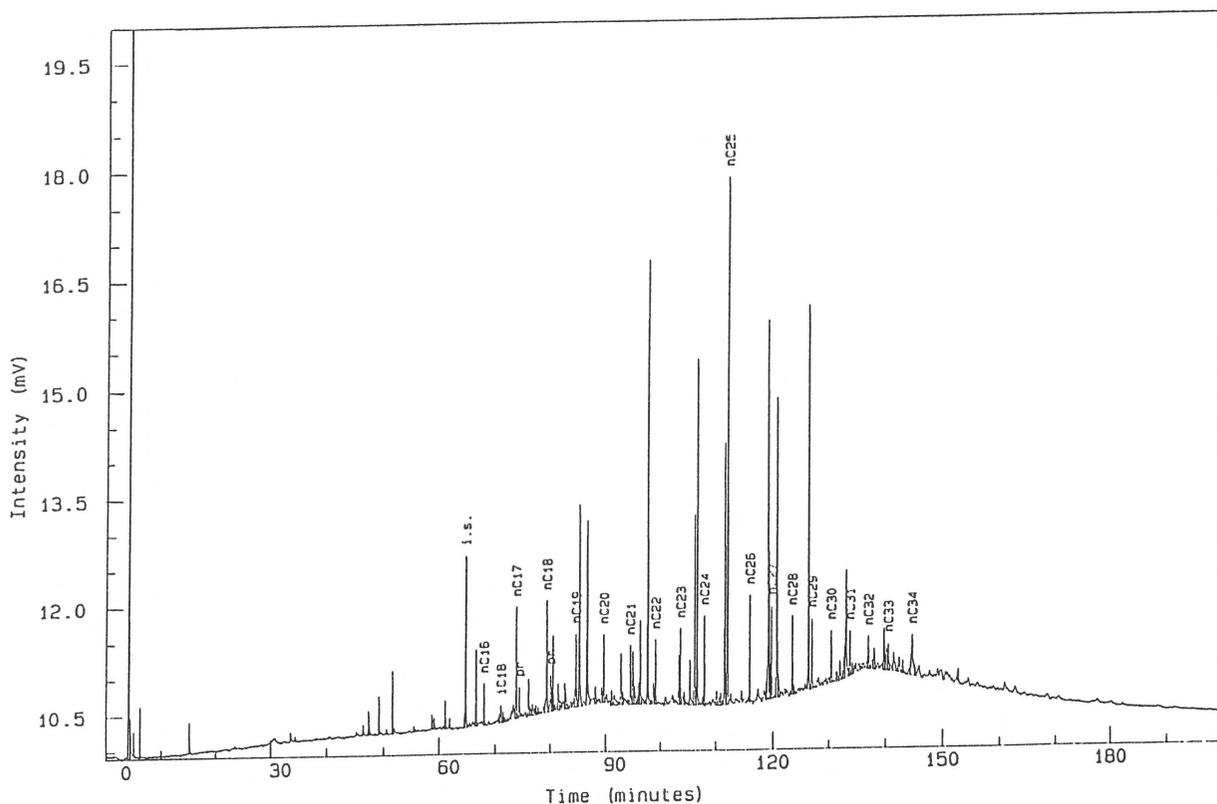
Figure 6. Kerkom Sand, Pellenberg. Gas chromatogram of the whole extract. On the vertical scale the relative measured mass spectrometre intensity of the fractions, on the horizontal scale the scan time. The high peaks, e.g. nC^{25} are probably due to the small volume of abstract, which required high amplification. These anomalously high values did not re-occur in the same places in the abstract of the second sample, but the overall result was very similar. i.s. = Iso sterane.

Geochemical analysis

Two samples were collected in 1993 and 1994 at two nearby locations in the Kerkom Sand in the Roelants pit. The first sample yielded so little extract that results were questionable, hence a second sample was taken to check the results. This sample was also tested against a blank (fully cleaned sand), to ensure that no laboratory artefacts, giving rise to inconclusive results, were present. Both the first and the second sample contain an organic substance, coating the grains, but no hydrocarbon smell is observed when rubbing the sample. Simple test-tube pyrolysis results in weak hydrocarbon indications: a light acrid odour and some release of tarry components. The brown staining is somewhat removed when the sample is vigorously shaken with water, which could also point to the presence of humic and/or fulvic acid type material, a feature usually associated with soils.

Gas chromatography (GC) was performed on whole extracts. Both GC traces demonstrate the absence of light compounds (Fig. 6), which points to the effect of strong evaporation, possibly combined with some biodegradation. Very strong biodegradation would have removed all normal alkanes, which is not the case. Although the GC traces differ somewhat, the pattern of the homologue alkanes can easily be recognised in both samples. This regular pattern, the high n-C^{17}/Pr and n-C^{18}/Ph ratios, and the roughly equal proportion of pristane (Pr) and phytane (Ph), all indicate an oil derived from a mature marine source rock, with organic matter of algal and/or bacterial origin (Engel & Macko 1993). For comparison, GC traces of Chinese soils, with and without hydrocarbon pollution (Shu Tao et al. 1993) are shown in Fig. 7.

GC-MS (Gas Chromatography-Mass Spectrometry) was carried out on the branched cyclic fraction
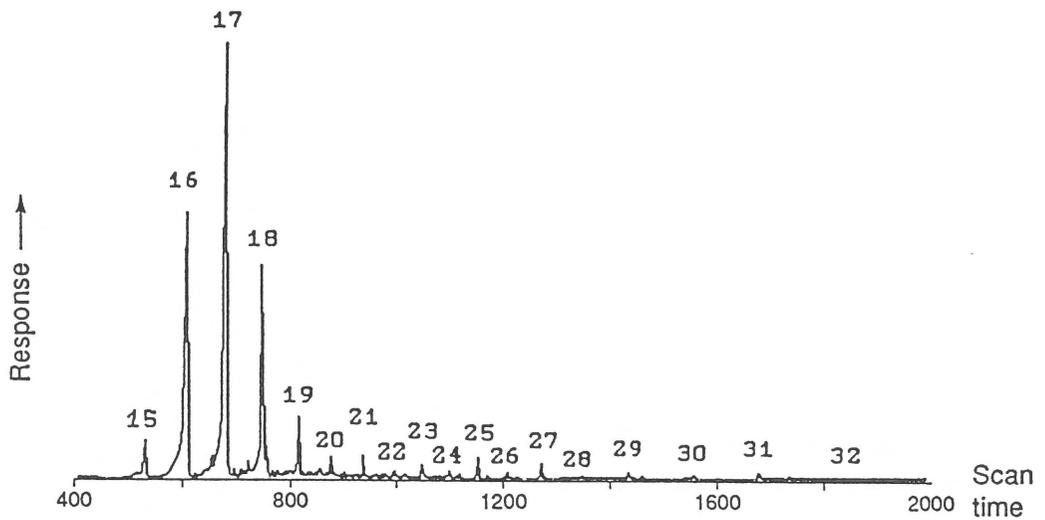
A. Typical soil
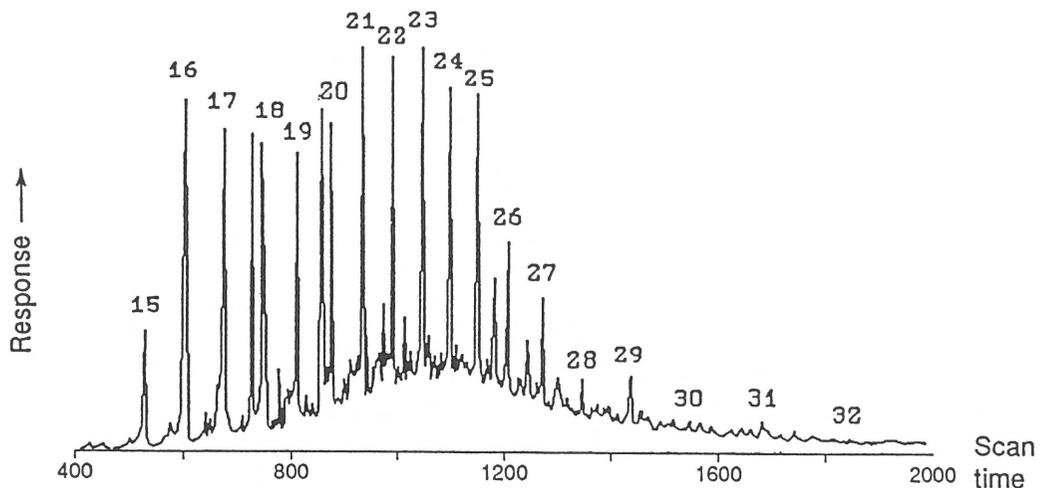
B. Soil polluted with Hydrocarbons

Figure 7. Gas chromatograms of a Chinese organic-rich soil, sampled at two nearby locations, one with and one without hydrocarbon pollution (after Shu Tao el al. 1993). The figure is included to illustrate the difference between GCs of soils with and without hydrocarbons.

of both samples. The sterane composition leads to the following conclusions (Fig. 8):

The ratio of Regular steranes over the Iso+Rearranged steranes points to a mature oil, which is consistent with the mature character of the *n*-alkane pattern. The slight dominance of Iso steranes over the Rearranged steranes would suggest a marly source rock, which fits with a Pr/Ph ratio roughly equal to one.

The C^{27}, C^{28}, C^{29} sterane relative abundance is typical for marine source rocks with algal/bacterial organic matter (Type II source rocks). The presence of gammacerane and the relatively low pristane/phytane ratio may indicate a hypersaline environment of deposition.

GC-MS-MS (Gas Chromatography-Mass Spectrometry-Mass Spectrometry) was used to crudely assess the age of the source rock from which the oil of the
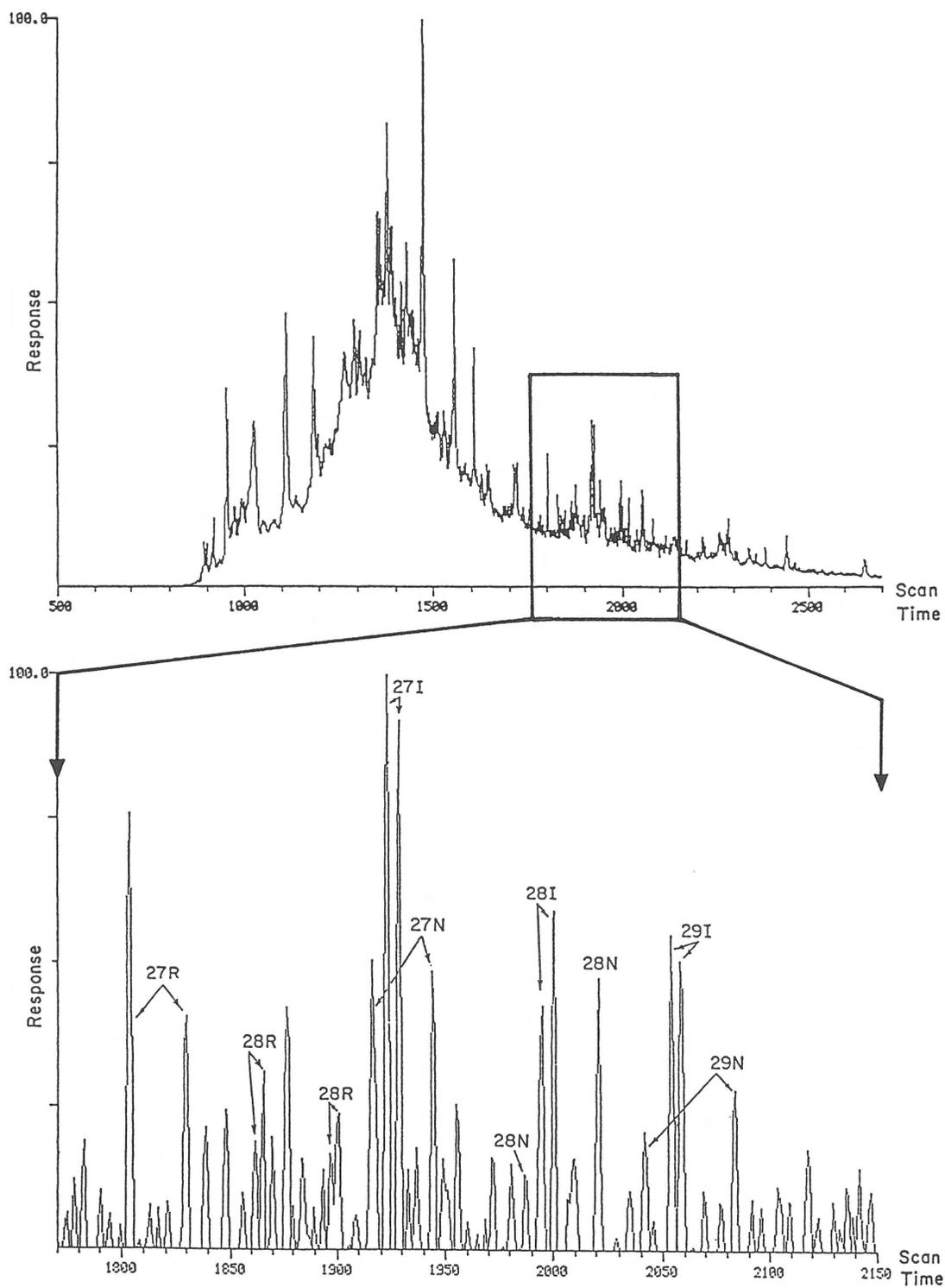
Figure 8. Kerkom Sand, Pellenberg. Enlarged segment of the sterane fragmentogram (of branched cyclic fraction of extract), of which the relative intensities provide information on the origin of the oil (see text).

seepage was derived. The presence of dinosterone could be demonstrated beyond doubt. Therefore, the source rock most likely contained dinoflagellates, a microfossil group, of which the presence suggests a Mesozoic or Tertiary age. The absence of oleananes, however, indicates the source rock to be older than latest Cretaceous (Peters & Moldoan 1993).

A problem in the interpretation of the geochemical data is the lack of evidence for strong biodegradation. The field relations between the black horizon, the purple-stained sands and the unstained sands (see 'Field description') suggest that the black horizon, containing the impregnation, is partly sealed off from water circulation by the Boom Clay, which has protected the impregnation against bacterial activity. Some recent leaching, however, may have occurred, as well as introduction of waxes out of the overlying present-day soil. The extent of this is minor, because the quarrying is intensive, and the exposure relatively fresh.

The combined geochemical evidence suggests the presence of a degraded oil, derived from a mature, marine, marly, Type II source rock of Mesozoic age. Therefore a Jurassic source rock (Posidonia = Toarcian, or Kimmeridge shales) is possible. However, the extract has a number of characteristics (e.g. gammacerane) never encountered in known Kimmeridge or Posidonia source rocks. Both shales are marly at the southern edge of the basin (Ziegler 1990), and conceivably could have been developed locally in a saline lagoonal environment at the northern edge of the London-Brabant Massif. At Lulworth Cove (Dorset, S England), the Purbeck limestones above the Kimmeridge Clay contain a thin source rock layer deposited in a hypersaline lagoonal environment. Such a Purbeck source rock could be a more likely candidate to consider.

The results are consistent with the hypothesis of the oil having been generated at the southern edge of the West Netherlands Basin, where in some areas a Purbeck source rock would have reached maturity some 50 million years ago.

Discussion

The presence of an oil-impregnated layer at the top of the Kerkom Sand near Leuven-Tienen may be related to the tectono-sedimentary history of the area (Fig. 4):

Due to the uplift of central and east Belgium, the area shows a major hiatus between the Middle Eocene Lede Sands, and the marine latest Eocene to Oligocene Tongeren beds. During that time however, overall subsidence continued in north and west Belgium, but even there a hiatus due to some uplift is conspicuous in the sedimentary record. The renewed general subsidence at the end of the Eocene reflects an important tectonic change: from that time onwards central and east Belgium and the Ardennes area were both subsiding, and transgressed by the sea. We suspect this tectonic pulse to be related to the Pyrenean tectonic phase. It is possible that this tectonic rearrangement broke or weakened the sealing of oil-filled traps in the central Netherlands, e.g. the IJsselmonde-Ridderkerk field, some 100 km to the north. Consequently a thin oil film started to move up-dip towards the Brabant Massif in the south along the top of a sand aquifer. This carrier bed would have been sealed by the Eocene Asse-Ursel Clay, which extended southwards as far as the Pellenberg-Lubbeek area, as has been demonstrated by recent mapping (Schiltz et al. 1993).

Possibly, oil migrating in deeper sand layers also seeped out, and formed tar sands in areas to the south of Pellenberg-Lubbeek. Such tar sands, however, would have been removed by later erosion.

The geochemical mis-match with the present-day oils in the central Netherlands forms an apparent contradiction with the theory of breached traps, which can presently not be explained. Charge from a Purbeck source rock or changes in oil characteristics over the long migration path are options that may be considered.

The following sequence of events is envisaged:

1. In the Early Oligocene the sea regressed northwards, and a soil could develop on the incised relief at the top of the marine Tongeren deposits. This incised relief at the base of the Kerkom Sand corresponds with the lowest sea level and represents the 36 Ma sequence boundary (Fig. 4).

2. The subsequent slow rise in sea-level caused filling of the incised valley and the deposition of brackish coastal Kerkom deposits on top of the soil-covered relief. In the Belgian stratigraphy these strata are traditionally known as the continental Tongeren deposits. At the base of the Kerkom Sand occur estuarine sands, influenced by tidal currents; towards the top a more parallel lamination prevails, indicating a beach facies.

3. The parallel-laminated beach sands became impregnated by oil. Since the overlying Heide Sand is also very porous and permeable, and the impregnated sands are already reworked as blocks and pebbles at the base of this overlying sand, the impregnation must have happened before the

sea fully transgressed the area again. Clearly, oil impregnated the very shallow-marine to beach-like sands, that filled the Kerkom incised valley, before the next regional transgression. It is assumed that oil was actually seeping out into the estuary and along the beaches. The lighter and more volatile components evaporated during the expulsion, and the remaining heavier components cemented the sand together as a tar sand.

4. Upon the subsequent sea-level rise, a new beach-slope equilibrium was established, and consequently the cemented sand was partly eroded, as indicated by the blocks and pebbles of oil-cemented sand found in small gullies and along beach cliffs. The cemented sands were also colonised by boring organisms (Figs. 1 and 5c). Some laminae of pure clay of a few centimetres thickness were deposited, probably under tidal influence. The rising sea-level caused deposition of the transgressive, white bioturbated sands with black pebbles at the base (Fig. 5d). The transgressing sea did not completely level the underlying sands, as the oil-cemented sand preserved a significant relief. The next step of the sea-level rise was clearly more important, as the sea transgressed considerably further southwards. It formed a regional, flat abrasion surface marked by the common occurrence of flat black flint pebbles (Fig. 5c), streaks of purple-stained sand, and occasionally even small purple sand pebbles, derived by abrasion of the highest cliffs of the tar sand relief. This abrasion surface is the main, regionally important transgressive surface within the sequence that overlies the unconformity at the base of the Kerkom Sand.

5. Above the abrasion surface, shallow-marine shore-facies sands (Berg Sand) were deposited, followed by the Rupelian Boom Clay.

6. During the long period of time after its deposition, the tar cement lost its cohesive power and the black sand, as well as the pebbles and angular blocks derived from it, are nowadays again soft due to leaching. The overlying Boom Clay has possibly protected the tar sand from being completely leached, and hence caused it to be preserved at its present position.

The inference that oil has migrated from the southwestern Netherlands up the flank of the Brabant Massif, means that possible traps on its path could have been filled, also in areas where, since the end of the Mesosoic, no mature source rocks are present. In future wells in the Brabant area, the Eocene should be investigated on the presence of oil migration paths and/or accumulations.

Conclusions

Geochemical analysis has shown the presence of a residue of a mature oil, that cemented a sand horizon at the very base of the Rupelian. The oil source rock is probably of Jurassic age. The geological history of the area precludes the local formation of oil because of the very shallow burial history. Although somewhat greater burial depths were reached in north Belgium, even there temperatures in Mesozoic and Cenozoic sediments never exceeded 40° C. Therefore the oil must have migrated updip from the central or southwestern Netherlands, where oil is known to have accumulated. A remaining problem is the geochemical mis-match with the known West-Netherlands oils, although the long migration path of over 100 km may account for this. The migration was probably triggered by a major tectonic rearrangement at the end of the Eocene. The oil reached the Leuven-Tienen area in Early Rupelian time where it seeped out in coastal deposits, and the tar residue subsequently cemented the sands. The tar cementation gave sufficient cohesion to the sand to allow erosion in blocks and pebbles, and to support a small but steep relief. Afterwards the sands were never deeply buried and the cementation lost its cohesiveness due to prolonged leaching in the vadose zone. The inference that oil has migrated from the southwestern Netherlands up the flank of the Brabant Massif, means that possible traps on its path could have been filled.

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