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Lithostratigraphy and provenance of the Early-Pleistocene deposits in the southern Netherlands and northern Belgium

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Abstract

An almost complete Early-Pleistocene sequence of the Tegelen and Kedichem Formation has been studied in the southern Netherlands and northern Belgium. Former Dutch and Belgian lithostratigraphic units are correlated and a new, more detailed lithostratigraphic framework is proposed. The provenance of the sediments was established by heavy mineral and gravel analysis. Rhine, Meuse and rivers from the Scheldt basin contributed their sediments to the southern North Sea basin during different stages of the Early-Pleistocene. The major importance of the rivers from the Scheldt basin in the upbuilding of the sedimentary sequence is emphasized.

Introduction

The study area is situated in the southern Netherlands (province of Noord-Brabant) and northern Belgium (province of Antwerpen) (Fig. 1). During the Early-Pleistocene tidal and fluviatile deposition occurred in this region, which was part of the southern North Sea basin (Kasse 1988, Zagwijn 1989). Due to uplift of the Belgian hinterland and subsidence of the Netherlands, the Early-Pleistocene deposits are found close to the surface in the Dutch-Belgian border area. They are covered by a thin layer of Weichselian coversands only.

The Early-Pleistocene deposits have been studied for almost a century (Lorié 1907, Doppert & Zonneveld 1955, Van Dorsser 1956, De Ploey 1961, Paepe & Vanhoorne 1970, Geys 1978). In Belgium they have been incorporated in the Campine Clay and Sand Formation (Paepe & Vanhoorne 1976). In the Netherlands they are part of the Tegelen and Kedichem Formations (Zagwijn & Van Staalduinen 1975). However, the correlation of these separate Dutch and Belgian lithostratigraphic units was still a matter of debate, since the investigations had often been performed on a local base. Furthermore, the sediment-petrographical results were often contradictory. Rhine (Doppert & Zonneveld 1955), Meuse (Van Dorsser 1956) and a Fennoscandian provenance (Dricot 1961) of the Early-Pleistocene deposits have been proposed.

In this study these former lithostratigraphic units in the Netherlands and Belgium are correlated. The lithostratigraphy of the Early-Pleistocene deposits is reinvestigated by lithological and sediment-petrographical analysis. Two cross-sections are presented, parallel and perpendicular to the depth contours of the Quaternary basin. Heavy mineral diagrams visualize the provenance of the various Early-Pleistocene units.

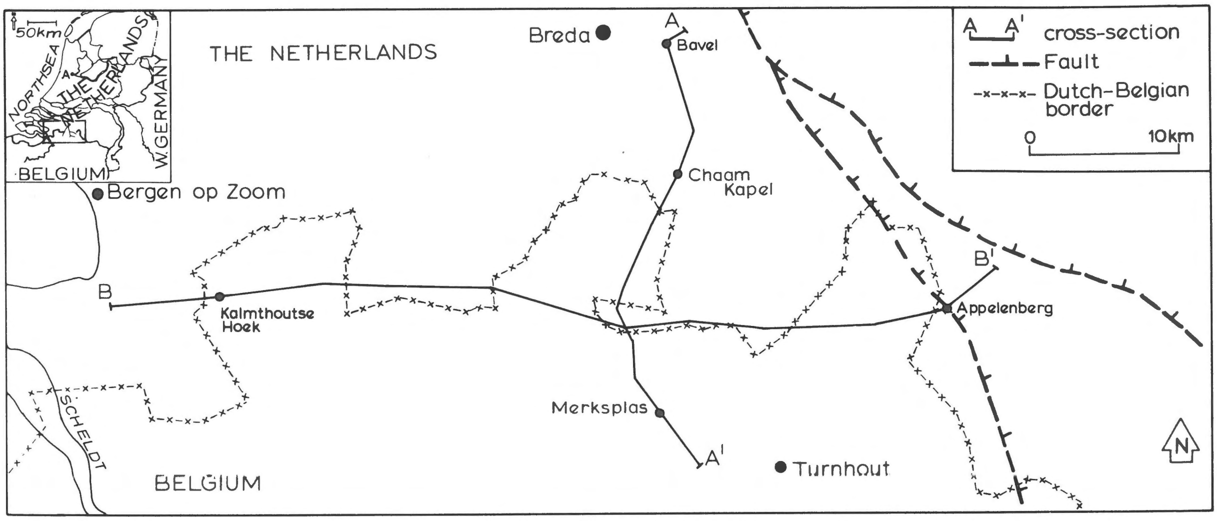

Fig. 1. Location map of the study area.

Lithostratigraphy

The lithostratigraphic upbuilding of the Dutch-Belgian border area is illustrated by two cross-sections (Figs 2 and 3).

Cross-section AA' (Fig. 2) is situated between Merksplas in Belgium and Bavel in the Netherlands (Fig. 1), at right angles to the depth contours of the Quaternary basin. The lithostratigraphic units dip to the north, indicating more pronounced subsidence in that direction. The inclination of the top of the units diminishes from 0.22% for the Late-Tertiary Kieseloölite Formation (unit 3) to 0.11% for the Late-Tiglian Turnhout Member (unit 6).

Cross-section BB' (Fig. 3) is situated between the villages Woensdrecht (Kalmthoutse Hoek) and Lage Mierde (Appelenberg) (Fig. 1) and is oriented parallel to the depth contours of the Quaternary North Sea basin. Therefore, the units reveal a more or less horizontal upbuilding. West of Woensdrecht the Early-Pleistocene deposits have been eroded by the Scheldt river during the Middle- and Late-Pleistocene, resulting in a 20 m high escarpment. East of Appelenberg the most western fault of the Central Graben is present in the cross-section. In the Central Graben the Early-Pleistocene units are covered by younger deposits reaching up to 90 m in thickness some 20 km more to the east (Bisschops et al. 1985).

The two cross-sections have been divided in 11 lithostratigraphic units, based on lithological and sediment-petrographical properties. The units 1, 2 and 3 are probably of Late-Tertiary age. The units 4 up to and including 8 belong to the Early-Pleistocene. Units 9, 10 and 11 were formed during the Middle- and Late-Pleistocene (Kasse 1988). In Table 1 the local lithostratigraphic units in the study area have been correlated with the formal units in Belgium (Paepe & Vanhoorne 1976) and the Netherlands (Zagwijn & Van Staalduinen 1975, Zagwijn 1985).

Unit 1 consists of glauconiferous, shell-bearing sands of the Oosterhout Formation. Unit 2 is a medium (250–500 μm), shell-bearing sand, which is indicative of the nearshore Maassluis Formation in the Netherlands (Zagwijn & Van Staalduinen 1975). It is overlain by and probably laterally equivalent to fine (100–250 μm) and medium (250–500 μm), non-calcareous sand of unit 3, which is part of the Merksplas Sands in Belgium (Paepe & Vanhoorne 1976) and the Kieseloölite Formation in the Netherlands (Zagwijn & Van Staalduinen 1975). Locally, a thin peat-bed of Late-Tertiary age (Vanhoorne 1962) dates the end of the sedimentation of unit 3.

In contrast to the units 1, 2 and 3, the overlying units are predominantly fine-grained. Unit 4 consists of non-calcareous, micaceous, very fine (50–

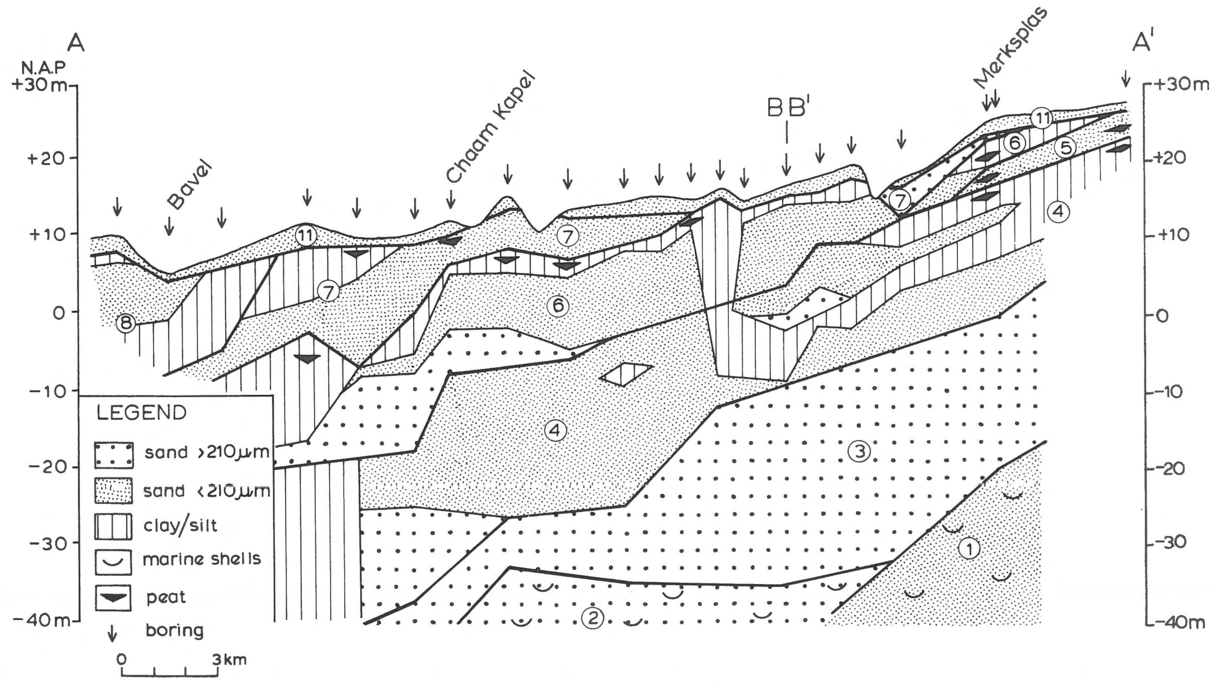

Fig. 2. Lithostratigraphic cross-section AA' between Merksplas and Bavel. (1) Oosterhout Formation, (2) Maassluis Formation, (3) Merksplas Member-Kieseloölite Formation, (4) Rijkevorsel Member, (5) Beerse Member, (6) Turnhout Member, (7) Gilze Member, (8) Bavel Member, (9) Sterksel Formation, (10) Eindhoven/Twente Formation, (11) Twente Formation (location Fig. 1) (modified after Kasse 1988).

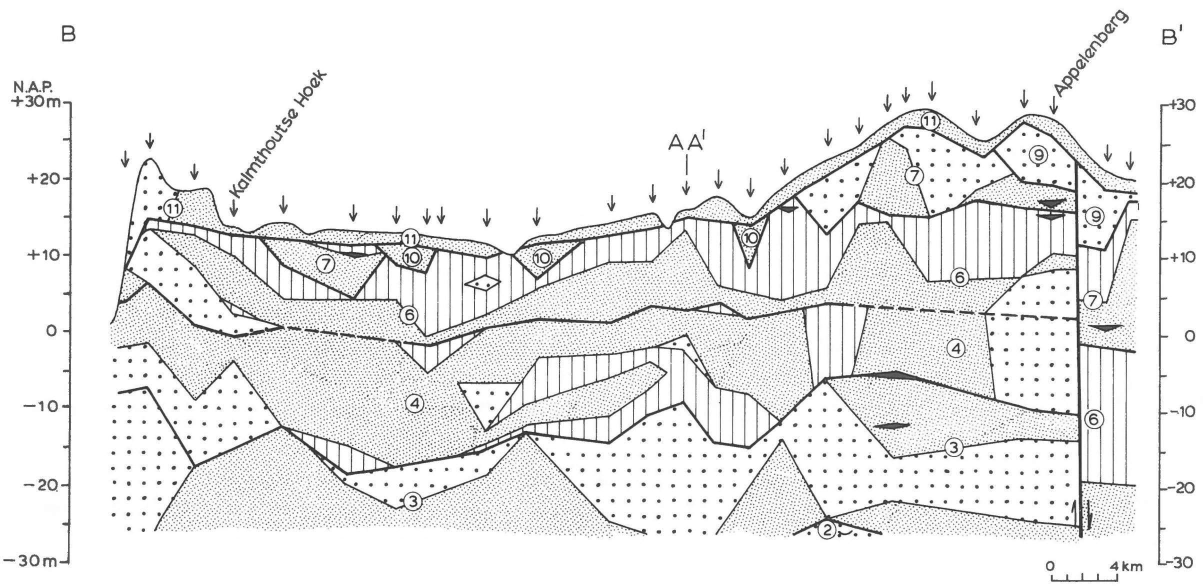

Fig. 3. Lithostratigraphic cross-section BB' between Kalmthoutse Hoek and Appelenberg (location Fig. 1, legend Fig. 2; modified after Kasse 1988).

100 μm) and fine (100–250 μm) sand and clay. Extensive clay-layers commonly occur in Belgium (Fig. 2). Grain-size increases to the north (Fig. 2) and west (Fig. 3) where fine to medium sands are found. In Belgium these inshore tidal deposits have been described previously as the Rijkevorsel Member (Paepe & Vanhoorne 1970, 1976). This local unit can be extended into the Netherlands, where these fine-grained deposits are incorporated in the lower part of the Tegelen Formation (Zagwijn & Van Staalduinen 1975). The clay-layer at the base of unit 4 (Fig. 3) represents the start of the sedimentation during the Tiglian C (Kasse 1988). Therefore, a major break is present between the Kieseloölite Formation and the overlying Rijkevorsel Member representing a hiatus caused by non-deposition or erosion after the Late-Tertiary and before the Tiglian C period.

The Rijkevorsel Member (unit 4) is concordantly overlain by eolian and fluviatile sands with intercalated, cryoturbated peat-beds of the Beerse Member (Fig. 2: unit 5). The Beerse Member has been preserved only along the southern rim of the sedimentary basin (Fig. 2; Kasse 1988). To the north the Beerse Member (unit 5) has been eroded completely during the formation of the Turnhout Member and the Turnhout Member (unit 6) directly overlies the Rijkevorsel Member (unit 4; Fig. 2: Chaam Kapel). Unfortunately, the boundary between the units 4 and 6 is not always clear (Fig. 3: dashed line), as the lithological and sediment-petrographical composition of the two members resemble each other.

Like the Rijkevorsel Member (unit 4) the Turnhout Member (Figs 2 and 3: unit 6) consists of non-calcareous, micaceous, fine and very fine sand and clay, deposited in an inshore tidal environment (Kasse 1988). Grain-size increases to the north and west, where fine to medium sand is present locally at the base of the Turnhout Member (Fig. 2: Chaam Kapel; Fig. 3: Kalmthoutse Hoek). An almost continuous clay-layer with intercalated peat-beds is present at the top of the Turnhout Member (fining-upward sequence). The top of the Turnhout Member is descending from 23 m + N.A.P. (Dutch Ordenance Level) at Merksplas to 6 m + N.A.P. at Chaam Kapel (0.11%), because of the post-sedimentary subsidence in the north. At Bavel the top is found at approximately 10 m − N.A.P. (Zagwijn & De Jong 1984).

The Turnhout Member is covered by the Gilze Member (Figs 2 and 3: unit 7). The deposits are restricted mainly to the Netherlands and increase in thickness to the north (Fig. 2: unit 7). In the eastern part of the study area the Gilze Member is present as a continuous deposit, while isolated occurrences are found in the west (Fig. 3). The discontinuous character of the fluvial deposits of the Gilze Member in Belgium (Fig. 2) and western Noord-Brabant (Fig. 3) is due to Middle- and Late-Pleistocene erosion. The lower part of the Gilze Member consists of non-calcareous, fluviatile, fine sand and clay (Kasse 1988: Appelenberg Sand, Gilze Clay; Fig. 2). The upper part is characterized by fine and medium sand (Vandenberghe et al. 1986: Alphen Sand), which partly erodes the underlying fine deposits (Fig. 3). East of the fault (Fig. 3) the Gilze Member is capped by a sandy clay-layer (Spruitenstroom Clay).

The generally fine-grained character of the Gilze Member (Fig. 2: unit 7) in combination with its sediment-petrographical characteristics (see below) are indicative of the Kedichem Formation in the Netherlands (Zagwijn & Van Staalduinen 1975). Although the Alphen Sand is often coarser grained, it has also been incorporated in the Kedichem Formation because of its stable heavy mineral assemblage (see below). In Belgium sediments corresponding with the Gilze Member have been included in the Scheldt and Meuse gravel Formation (Paepe & Vanhoorne 1976) and the St. Lenaarts Formation (De Ploey 1961).

A few kilometres south of Bavel the Gilze Member (unit 7) is overlain erosively by the Bavel Member (Fig. 2: unit 8). Although the erosional boundary between the members has not been observed in the borings, it is assumed that large-scale erosion has occurred between Chaam Kapel and Bavel, since the lithology and sediment-petrography of the Bavel Member are very different from the Gilze Member. The Bavel Member consists of very calcareous (up to 33% carbonates), fine sand and up to 10 m thick, plastic clay, deposited in fluvial channels and meander cut-offs (Kasse 1988). Fresh

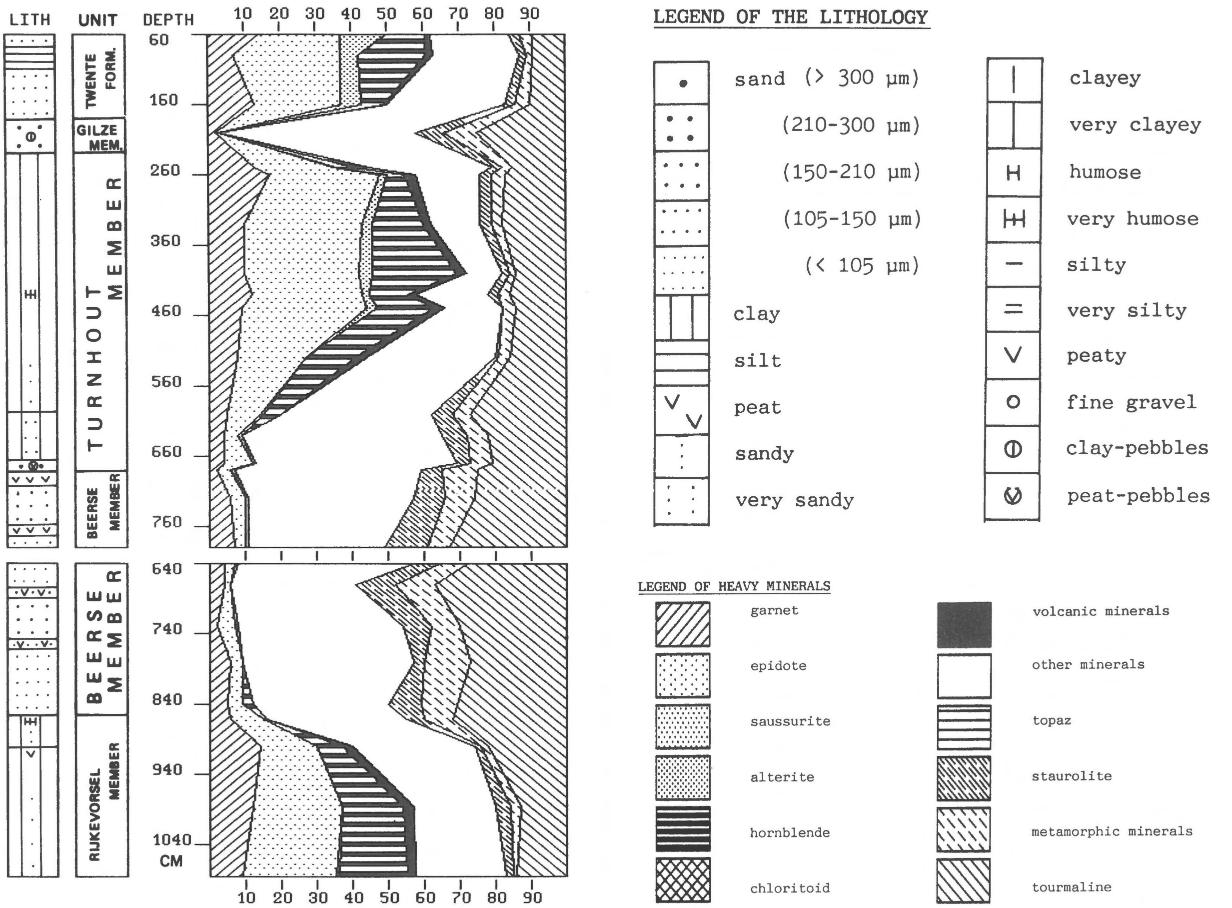

Fig. 4. Heavy mineral diagram of the Rijkevorsel Member, Beerse Member and Turnhout Member at Merksplas (location Fig. 1, depth below surface in cm).

water shells were found occasionally in intraformational lag deposits. Comparable deep erosion has been found approximately 30 km southeast of Bavel (at Eindhoven) by Bisschops et al. (1985). The 10 to 20 m deep valley, eroded in the Kedichem Formation, was filled there with sediment containing the Sterksel heavy mineral zone. The erosional contact at Bavel and Eindhoven is interpreted as the southwestern bank of the former Rhine flowing to the northwest during the Bavelian (Kasse 1988). Since the fluvial sediments of the Bavel Member are fine-grained, they are included in the upper part of the Kedichem Formation. In the upstream, southeastern direction sediments of the same period (Bavel Interglacial) become medium to coarse-grained and are therefore incorporated in the base of the Sterksel Formation by Zagwijn & De Jong (1984).

The Bavel Member (unit 8) has not been found in cross-section BB' (Fig. 3). The Sterksel Formation (Fig. 3: unit 9) directly overlies the Gilze Member (unit 7), implying a considerable hiatus. West of the fault the Sterksel Formation has eroded locally 5 to 10 m of the Gilze Member (Fig. 3: Appelenberg). The Sterksel Formation is present predominantly east of the study area, in the Central Graben, where the formation attains a thickness of 70 m (Bisschops et al. 1985). The great thickness in the Central Graben in comparison with the thin occurrences of the Sterksel Formation west of the Central Graben implies synsedimentary subsid-

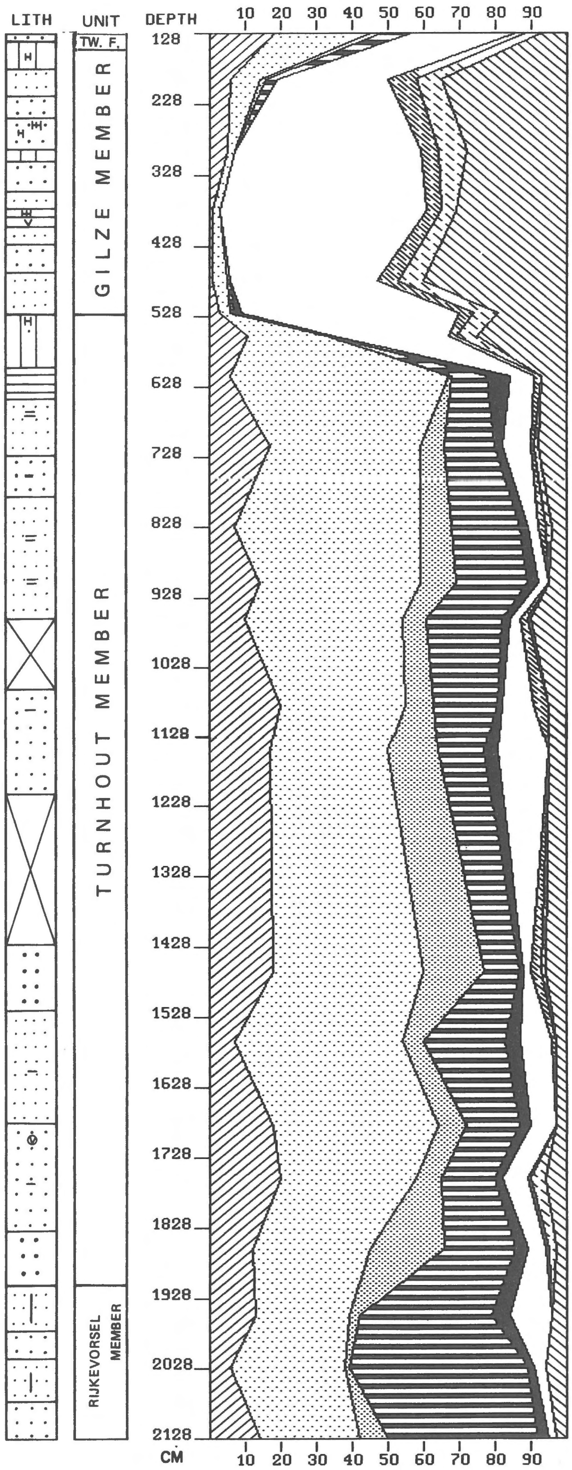

Fig. 5. Heavy mineral diagram of the Rijkevorsel Member, Turnhout Member and Gilze Member at Chaam Kapel (location Fig. 1, legend Fig. 4; Tw.F. = Twente Formation; depth below surface in cm).

ence during the deposition of the Sterksel Formation.

Unit 10 (Fig. 3) belongs to the Eindhoven and/or Twente Formations. It is found in local channels, eroded in the Early-Pleistocene formations, and filled with fluvial fine sand. The eolian fine sand of the Late-Pleistocene Twente Formation (unit 11) forms an almost continuous, thin cover (1–2 m) over the area, often resting directly on the Early-Pleistocene units. The larger thickness of the Twente Formation in the west is due to the formation of Weichselian Late-Glacial river dunes on the eastern bank of the Scheldt (Fig. 3).

Provenance

The various lithostratigraphic units have been analysed sediment-petrographically in order to establish the provenance of the sediments. The Late-Tertiary units 1 (Oosterhout Formation), 2 (Maassluis Formation) and 3 (Merksplas Member: Kieseloölite Formation) fell outside the scope of this investigation.

The Rijkevorsel Member (lower part of the Tegelen Formation) is characterized by a dominance of garnet, epidote and hornblende (Figs 4 and 5). This heavy mineral assemblage is indicative of a Rhine supply (Zonneveld 1948a). The presence of glaucophane (included in the hornblende group) points to an Alpine provenance (Sindowski 1949). In the southernmost occurrences of the Rijkevorsel Member in Belgium an admixture with stable heavy minerals such as zircon, rutile and tourmaline was established (Fig. 4). This admixture is explained by reworking of the underlying Merksplas Member or by an additional supply from Tertiary formations in the south, which are often dominated by stable heavy minerals (Mol Sands; Gullentops 1963).

In contrast to the Rijkevorsel Member, the Beerse Member is dominated by stable heavy minerals such as zircon, rutile, staurolite, andalusite, disthene and tourmaline (Fig. 4). Gravel was found occasionally in the Beerse Member at the base of a fluvial channel. The fine gravel (3–5 mm) is characterized by quartz (58%) and flint (29%). In the coarser gravel (>5 mm) flint is very dominant (71%), besides quartz (16%). The rest group in both fractions (13%) consists of predominantly quartzite and silification (Kasse 1988). These gravel assemblages resemble the Scheldt (SC) gravel association described by Zandstra (1969). Therefore, it is proposed that the sediments of the Beerse Member have been supplied by the Scheldt and associated rivers from Central Belgium (Dender, Zenne, Dijle, Gete). During the Early-Pleistocene these rivers eroded the Tertiary formations, which are often characterized by stable heavy minerals (Gullentops 1963) and flint and quartz gravel (Gulinck 1960).

The heavy mineral composition of the Turnhout Member (dominance of garnet, epidote, alterite and hornblende) is quite similar to that of the Rijkevorsel Member and thus points to a Rhine supply (Figs 4, 5 and 7). Alterite is best represented in the coarser sediments, due to grain-size and specific density effects (Van Andel 1950, Kasse 1988).

The lithological and sediment-petrographical characteristics and paleobotanical results (presence of *Azolla tegeliensis*; Kasse 1988) indicate that the Turnhout Member is part of the Tegelen Formation of Tiglian age in the Netherlands (Zagwijn & Van Staalduinen 1975). The correlation of the Turnhout and Rijkevorsel Members with the Tegelen Formation leads to the conclusion that the intercalated Beerse Member is part of the Tegelen Formation as well. Although the Beerse Member differs from the rest of the Tegelen Formation by its lithology, sediment provenance and sedimentary environment, it is included in the Tegelen Formation because of its limited extent in the study area. In contrast to the ideas of Paepe & Vanhoorne (1970), who correlated the Rijkevorsel, Beerse and Turnhout Members with the Tiglian, Eburonian and Waalian respectively, it is concluded now that the three members (together forming the Campine Clay and Sand Formation in Belgium) are equivalent with the Tegelen Formation in the Netherlands and date from the Tiglian stage (Vandenberghe & Kasse 1989).

The heavy mineral composition of the Rijkevorsel and Turnhout Members reveals a change in a western direction (Fig. 6). The stable heavy minerals (zircon, rutile and tourmaline) are more important, especially in the coarser sand-beds. Garnet, epidote and to a lesser extent hornblende are dominant in the very fine sand and silt-beds. This higher stable heavy mineral content has been explained previously by a Meuse supply (Van Dorsser 1956). However, the deposition of the Rijkevorsel and Turnhout Members occurred during the Tiglian C period (Kasse 1988). According to Zagwijn (1986) the Meuse still flowed in a northeastern direction then through southern Limburg. Therefore, it is more likely that the stable heavy minerals have been eroded from Tertiary deposits in the Scheldt basin (Gullentops 1963). The dominance of unstable heavy minerals in the fine-grained beds indicates a Rhine supply. In the tidal environments of the Rijkevorsel and Turnhout Members this fine sediment was probably transported further to the west than the coarser Rhine sand, which was already deposited in the east (see Fig. 7). In western Noord-Brabant this fine, suspended sediment of the Rhine was mixed with medium sediment from the Scheldt basin.

Because of the fine-grained character and the dominance of unstable heavy minerals in the eastern part of the area (Figs 5 and 7), the Rijkevorsel and Turnhout Members are clearly part of the Tegelen Formation (Zagwijn & Van Staalduinen 1975). The top of the Turnhout Member (Fig. 3: unit 6) is situated generally between 10 and 17 m above N.A.P. West of the Central Graben this top is very continuous from east to west in cross-section BB' (Fig. 3). Therefore, it is concluded that the western occurrences of the Rijkevorsel (Fig. 3: unit 4) and Turnhout Member (unit 6) are part of the Tegelen Formation as well. The lithological and sediment-petrographical variations within the Tegelen Formation are caused by differences in sedimentary environment and sediment provenance (Kasse 1988).

Towards the top of the Turnhout Member the unstable heavy mineral content drops and the concurrent increase in stable heavy minerals points to a change in the sediment provenance, which culminates in the overlying Gilze Member (Fig. 7). The heavy mineral composition of the Gilze Member (Kedichem Formation) is dominated by zircon, ru-

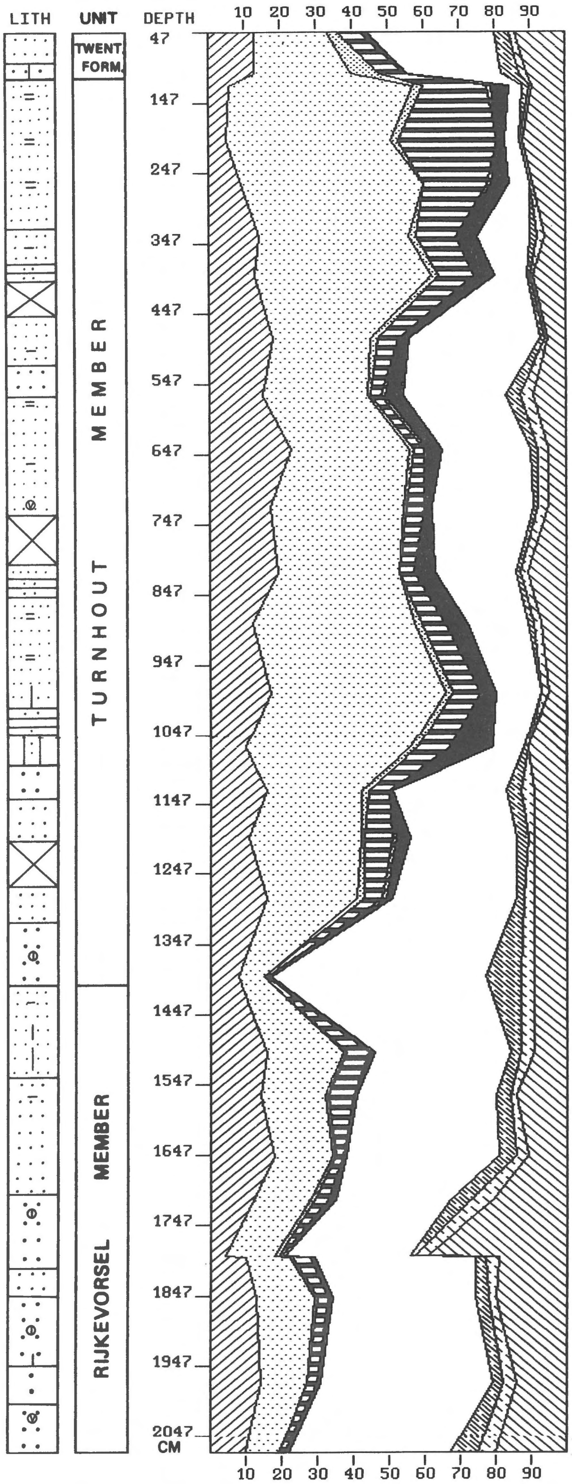

Fig. 6. Heavy mineral diagram of the Rijkevorsel Member and Turnhout Member at Kalmthoutse Hoek (location Fig. 1, legend Fig. 4; depth below surface in cm).

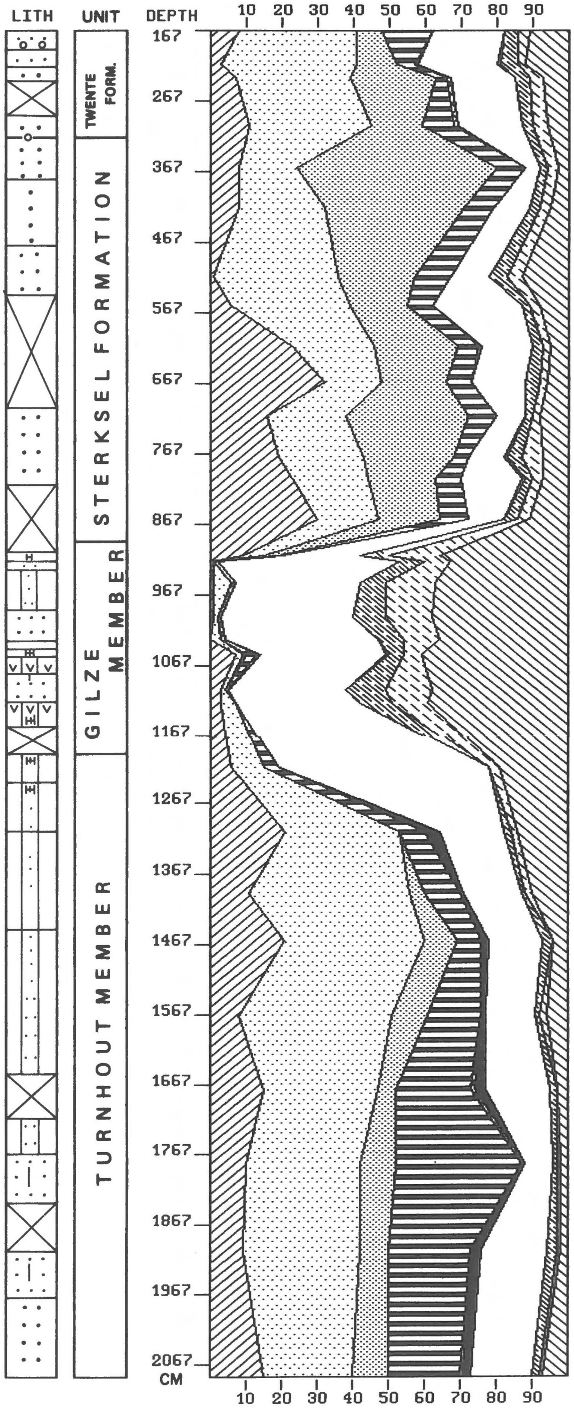

Fig. 7. Heavy mineral diagram of the Turnhout Member, Gilze Member and Sterksel Formation at Appelenberg (location Fig. 1, legend Fig. 4; depth below surface in cm).

tile, staurolite, disthene, andalusite and tourmaline (Figs 5 and 7). Gravel is commonly scarce in the Gilze Member. Only in the upper, coarser-grained part (Alphen Sand) gravel occurs in trough-shaped fluvial channels. According to Vandenberghe et al. (1986) the 3–5 mm gravel is dominated by flint (68%) and quartz (28%), which resembles the gravel composition of the Beerse Member (Kasse 1988). This assemblage is comparable to the Scheldt gravel association (Zandstra 1969) and points to a supply of Tertiary material from Central Belgium by rivers of the Scheldt basin. In the coarser gravel (8–23 mm, > 23 mm) the flint and quartz content is lower (together 80%). The cristalline components are more important (1–5%) and the rest group consisting of silification and quartzite is somewhat larger (15–19%). The presence of Revinian quartzite points to an additional supply from the Meuse basin. Therefore, it is concluded that the upper part of the Gilze Member (Alphen Sand) was supplied by both the Scheldt and Meuse. The Scheldt probably transported the major part of the sand and fine gravel. The Meuse contributed only to the coarse gravel, since typical Meuse heavy minerals like turbid chloritoid and green brown Vosges hornblende (Zonneveld 1948b) have never been found in the sand fraction.

North of the villages Chaam and Gilze an increase of unstable heavy minerals has been found in the Gilze Member (Kasse 1988), which points to an interaction of a Scheldt/Meuse and a Rhine supply. A comparable transition has been found at Veghel, 40 km east of the study area (Zagwijn 1960).

In the upper part of the Alphen Sand a change in the heavy mineral composition has been observed (Kasse 1988: heavy mineral diagram Weelde). The stable heavy minerals decrease, while garnet and epidote become more important (up to 30%). This tendency is even more pronounced in the Spruitenstroom Clay, overlying the Alphen Sand, in which garnet, epidote and hornblende amount to 60%. In comparison with the lower part of the Alphen Sand, supplied exclusively by the Scheldt and Meuse, the unstable heavy mineral increase in the upper part of the Alphen Sand reflects an increased supply of Rhine material.

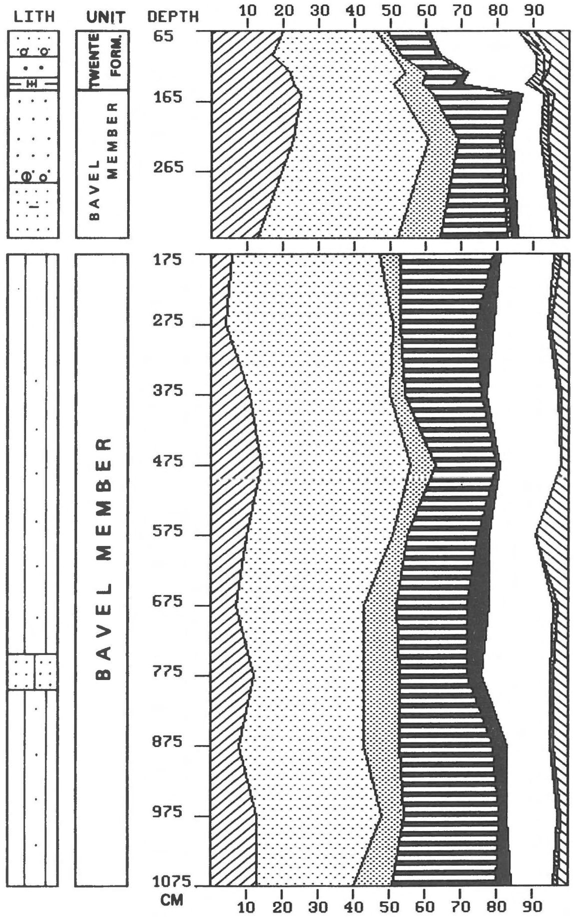

Fig. 8. Heavy mineral diagram of the Bavel Member at Bavel (location Fig. 1, legend Fig. 4; depth below surface in cm).

The original presence of the Gilze Member over the complete area is whitnessed by the high content of quartz and flint in the Eindhoven and Twente Formations (Fig. 3: units 10 and 11; Kasse 1988). This gravel was reworked from the Gilze Member during the Middle- and Late-Pleistocene.

The heavy mineral composition of the Bavel Member (Kedichem Formation) is characterized by garnet, epidote, alterite and hornblende (Fig. 8). The clay and overlying channel sands reveal a comparable heavy mineral assemblage indicating a common provenance. The higher garnet and alterite content in the channel deposits is due to grain-size effects. This heavy mineral composition is equivalent with the Sterksel heavy mineral zone formed by the Rhine (Zonneveld 1947) during the Bavel Interglacial (Zagwijn & De Jong 1984).

The gravel in an intraformational lag deposit in the channel sands of the Bavel Member is dominated by milky quartz (51%) and Paleozoic sandstone (43%) (Kasse 1988). This gravel assemblage is indicative of a Rhine/Meuse supply (Zandstra 1978). In contrast to the Gilze Member flint content is low (2%), even though the Bavel Member erosively overlies the Gilze Member. Therefore, it is concluded that the Scheldt supply had stopped in the study area and been replaced by a Rhine and Meuse supply.

The Middle-Pleistocene Sterksel Formation in the eastern part of the study area is dominated by garnet, epidote, alterite and hornblende (Fig. 7). The high garnet and alterite content are typical for the Woensel heavy mineral zone (Zonneveld 1947) within the Sterksel Formation. These unstable heavy minerals together with traces of glaucophane point to a Rhine supply, while the continuous presence of brown so-called Vosges hornblende indicates an additional supply by the Meuse. Although the Rhine minerals dominate the heavy mineral spectrum, the amount of sediment supplied by the Meuse may have been considerable, since the heavy mineral content in Meuse material is approximately 4 times less than in Rhine sediment (Kasse 1988).

The combined Rhine/Meuse supply is confirmed by the gravel composition, which is characterized by quartz (30%), Paleozoic sandstone (27–50%) and Revinian quartzite (Kasse 1988). This association resembles the Rhine/Meuse gravel associations of the Kedichem and Sterksel Formations described by Zandstra (1978). However, the relatively high flint content (circ. 20%) in the Sterksel Formation in boring Appelenberg has not been observed in Meuse terrace deposits in southern Limburg (Van Straaten 1946). It can be explained by reworking of flint-rich gravel from the Gilze Member or by an additional transport from the Scheldt basin, besides the Rhine and Meuse supply.

After the deposition of the Sterksel Formation western Noord-Brabant was outside the depositional area of the Rhine, Meuse and Scheldt. Erosion dominated and large volumes of the Sterksel Formation and especially the Kedichem Formation

Table 1. Lithostratigraphic units in the Netherlands and Belgium. R = Rhine, M = Meuse, S = Scheldt, L = Local provenance.

<table>
<tr><th colspan="3">UNIT / AGE</th><th colspan="2">BELGIUM (Paepe and Vanhoorne, 1970, 1976)</th><th colspan="2">NETHERLANDS (Zagwijn and Van Staalduinen, 1975; Zagwijn, 1985)</th><th colspan="3">DUTCH – BELGIAN BORDER (Kasse, 1988)</th><th></th></tr>
<tr><td colspan="3">LATE - PLEISTOCENE</td><td colspan="2" rowspan="2">Gent / Hainaut / Scheldt gravel Formation</td><td>Kreftenheye Formation</td><td>Twente Formation</td><td colspan="3">Twente Formation</td><td>L</td></tr>
<tr><td colspan="3">MIDDLE - PLEISTOCENE</td><td colspan="2">Veghel | Urk | Eindh. F.
Sterksel Formation</td><td colspan="3">Eindhoven Formation
Sterksel Formation</td><td>L
R+M (+S)</td></tr>
<tr><td rowspan="8">EARLY - PLEISTOCENE</td><td colspan="2">BAVELIAN</td><td colspan="2" rowspan="2">Scheldt and Meuse gravel Formation</td><td colspan="2" rowspan="4">Kedichem Formation</td><td rowspan="4">Kedichem Formation</td><td colspan="2">Bavel Member</td><td>R+M</td></tr>
<tr><td colspan="2">MENAPIAN</td><td rowspan="3">Gilze Member</td><td>Spruitenstroom Clay
Alphen Sand</td><td>S+M+R
S+M</td></tr>
<tr><td colspan="2">WAALIAN</td><td rowspan="5">Campine Clay and Sand Formation</td><td>Turnhout Member</td><td>Gilze Clay</td><td>S (+R)</td></tr>
<tr><td colspan="2">EBURONIAN</td><td>Beerse Member</td><td>Appelenberg Sand</td><td>S</td></tr>
<tr><td rowspan="3">TIGLIAN</td><td>C 5</td><td rowspan="3">Rijkevorsel Member</td><td rowspan="3">Tegelen Formation</td><td rowspan="4">Maassluis Formation</td><td rowspan="3">Tegelen Formation</td><td colspan="2">Turnhout Member</td><td>R (+S)</td></tr>
<tr><td>C 4</td><td colspan="2">Beerse Member</td><td>S</td></tr>
<tr><td>C 3</td><td colspan="2">Rijkevorsel Member</td><td>R (+S)</td></tr>
<tr><td colspan="2">PRETIGLIAN</td><td colspan="2" rowspan="2">Merksplas Sands</td><td rowspan="2">Kieseloölite Formation</td><td rowspan="2">Merksplas Member</td><td colspan="2">hiatus</td><td></td></tr>
<tr><td colspan="3">PLIOCENE</td><td>Oosterhout Formation</td><td colspan="2"></td><td></td></tr>
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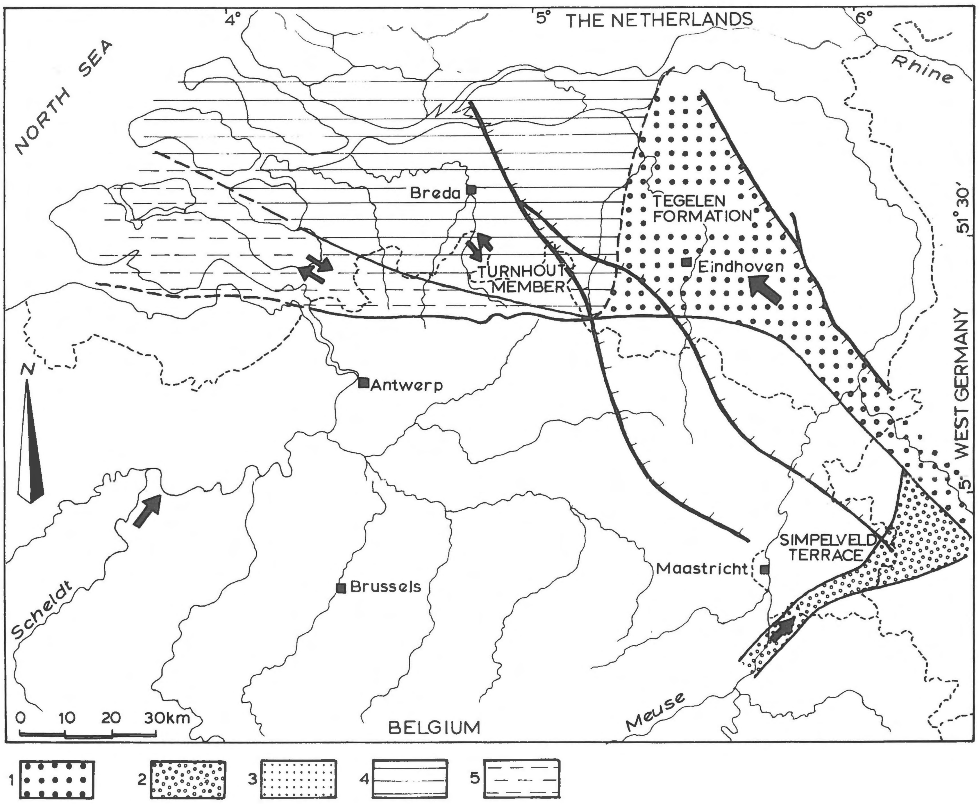

Fig. 9. Paleogeographic reconstruction of the Tiglian C5 period. 1 = fluvial deposition by the Rhine, 2 = fluvial deposition by the Meuse, 3 = fluvial deposition by the rivers of the Scheldt basin, 4 = tidal deposition of Rhine sediments, 5 = tidal deposition of Rhine and 'Scheldt' sediments.

(Gilze Member) have been removed. Only the Scheldt gravel association in the Eindhoven and Twente Formations testifies the original presence of the Gilze Member (Kasse 1988).

Discussion and conclusions

Lithological and sediment-petrographical investigations in the Dutch-Belgian border area revealed new results concerning the stratigraphy and sediment provenance of the Quaternary deposits (see Table 1). During the Early-Pleistocene Noord-Brabant and northern Belgium were part of the southern North Sea basin in which the Rhine, Meuse and Scheldt deposited their sediments.

The Rijkevorsel Member, Beerse Member and Turnhout Member, which are part of the Campine Clay and Sand Formation in Belgium, have been dated previously as Tiglian, Eburonian and Waalian respectively by Paepe & Vanhoorne (1970). However, on lithological, sediment-petrographical and paleobotanical grounds it was established that these three members are part of the Tegelen Formation in the Netherlands dating from the Tiglian. In the Rijkevorsel and Turnhout Members predominantly Rhine sediment, characterized by garnet, epidote, alterite and hornblende, was redistributed by tidal processes (Fig. 9).

An admixture with stable heavy minerals was established in the western part of the area. Formerly this high stable heavy mineral content was interpreted as evidence for a Meuse supply (Van Dorsser 1956). However, according to Zagwijn (1986) the Meuse was still flowing in a northeastern direction through southern Limburg and formed

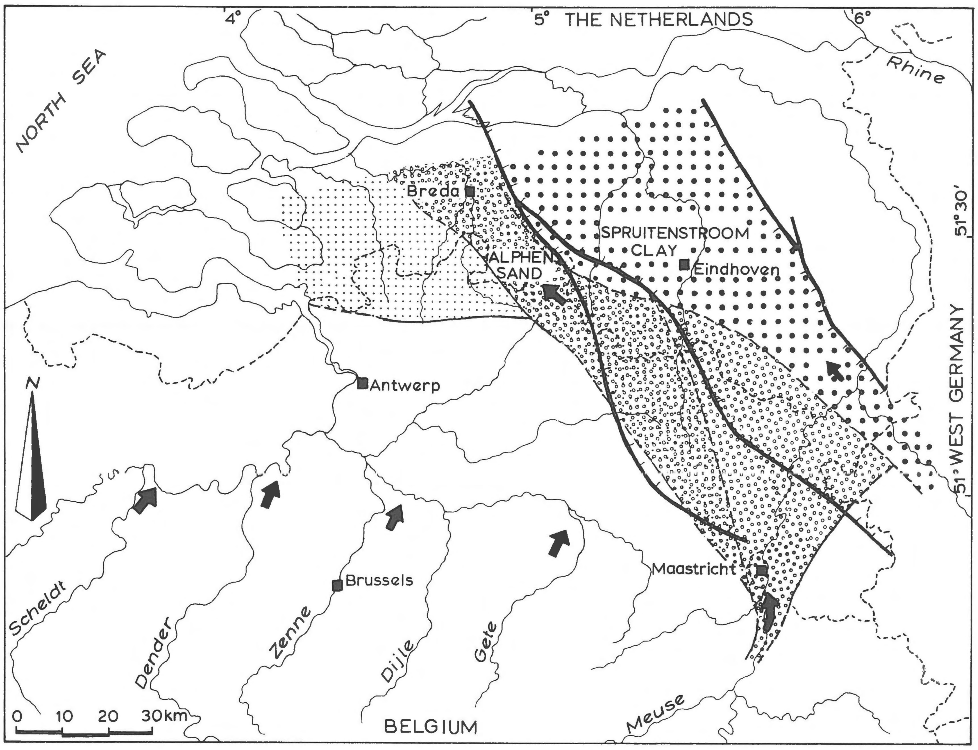

Fig. 10. Paleogeographic reconstruction of the Menapian stage (legend Fig. 9).

the Simpelveld terrace. It is therefore concluded that these stable heavy minerals were not supplied by the Meuse, but by rivers from the Scheldt basin who eroded Tertiary formations which are dominated by stable heavy minerals (Gullentops 1963). In the tidal environments of the Rijkevorsel and Turnhout Members in western Noord-Brabant these stable heavy minerals were mixed with suspended Rhine sediments (Fig. 9).

During a glacial phase in the Tiglian stage (Tiglian C4), sea level dropped. Tidal sedimentation by the Rhine stopped and the sediments supplied from the Scheldt basin expanded to the north (Beerse Member). The deposition of Rhine sediments during the Tiglian is related to interglacial periods with a high sea level (Tiglian C3, Tiglian C5).

The Gilze Member (Kedichem Formation) (Table 1) is restricted mainly to the Netherlands. Isolated occurrences of the Gilze Member in Belgium have been described previously as the St. Lenaarts Formation of Weichselian age (De Ploey 1961). The fine-grained lower part of the Gilze Member (Appelenberg Sand, Gilze Clay) was deposited by rivers from the Scheldt basin during the Eburonian and Waalian. In the coarser grained upper part (Alphen Sand) of Menapian age the Scheldt supply is still dominant, but the influence of the Meuse could be established in the gravel composition. The presence of the Meuse in the study area is restricted to the late Early-Pleistocene (Menapian, Bavelian) (Fig. 10). For the first time during the Quaternary the Meuse made a shortcut to the northwest, possibly caused by the onset of the subsidence of the Central Graben. During the Menapian Noord-Brabant and northern Belgium were situated in the confluence area of the Meuse and the rivers from the Scheldt basin (Fig. 10). At the top of the Gilze Member (Spruitenstroom Clay) a renewed influence of the Rhine is evident.

The fine-grained Bavel Member is included in the Kedichem Formation. It is found only in the northeast of the area, in a deep valley at the western side of the Central Graben. In contrast with the Gilze Member of predominantly Scheldt provenance, the Bavel Member was supplied by the Rhine and Meuse. The Rhine/Meuse supply continued during the deposition of the coarser-grained Sterksel Formation, which is found in the east of the study area and in the adjacent Central Graben. In contrast with the Tiglian interglacial stages when the Rhine deposition was due to a high sea level, the reappearance of the Rhine in the study area was determined by subsidence of the Central Graben during the Bavelian and Cromerian.

The supply by the rivers from the Scheldt basin has been very important during the Early-Pleistocene. The stable heavy mineral association and the Scheldt gravel assemblage, characterized by flint and transparent quartz, were eroded from the Tertiary formations in Central Belgium and transported to Noord-Brabant and northern Belgium from the Tiglian until at least the Menapian stage. Deposition of Scheldt material was favoured by low sea level during glacial phases and by uplift of the Central Belgian region.

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