A 150-kyr. record of surface faulting from new trench site across the Bree fault escarpment, Roer Valley Graben

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ABSTRACT

A fourth trench excavated in 1998 across a segment of the southwestern border fault of the Roer Valley Graben in Belgium has recovered the longest and most complete record of surface faulting so far. A shallow fault located at the base of the frontal morphological escarpment displaces middle Pleistocene gravely sands of the Maas river Main Terrace, as well as overlying cover sands of Saalian to late Weichselian age. Different amounts of displacement for the bases of the two upper cover sand units provide direct evidence for the most recent two events, dating to the late Holocene and Last Glacial Maximum, respectively. In addition, four older faulting events are inferred from four elongated wedges of reworked Main Terrace deposits interbedded between lower-lying cover sand units in the hanging wall. These wedges are interpreted as colluvial wedges, produced by accelerated soil creep, most probably under periglacial conditions, following the creation of a new fault scarp. Over the entire 150 kyr. interval, the amount of fault displacement averages 50 cm, the return period 25 kyr., and the fault slip rate 0.02 mm/yr.

KEYWORDS

Colluvial wedge, Feldbiss Fault, Late Pleistocene, paleoearthquake, periglacial.

Introduction

Since 1996 paleoseismological investigations have been carried out along the Bree fault escarpment, which is the morphological expression of a segment of the southwestern border fault of the Roer Valley Graben, the Feldbiss Fault Zone (FFZ), in northeast Belgium. The long-term slip rate along the FFZ is in the order of 0.05 mm/yr. since the middle Pleistocene, as estimated from scattered borings reported by Beerten et al. (1999). The first excavations across the escarpment (Camelbeeck et al., 1996) have demonstrated the existence of a frontal escarpment, corresponding to the trace of a surface fault. Evidence was found for up to three coseismic fault displacements since about 40 kyr., the most recent event probably dating between 1000 and 1350 years BP. Summer 1998 a fourth trench site was excavated near the opposite end of the escarpment, 3.5 to 5 km southeast of the previous sites, in order to examine the validity of these results for the entire escarpment.

Trench stratigraphy

Following the positive identification of a shallow anomaly below the morphological escarpment using various geophysical prospecting methods (Demanet et al., subm.), a 3.5-m-deep and 90-m-long trench was excavated perpendicular to the escarpment. Additional hand borings extended the observations 2 - 5.5 m below the trench bottom. The log in Fig. 1 summarizes all stratigraphical information obtained from NW trench wall and borings. It shows a clear difference in stratigraphy between upslope and downslope portions of the trench, punctuated by a normal fault at the foot of the morphological escarpment.

The upper slope or footwall is dominated by the red-brownish, clay-coated, coarse, gravely sands of unit Tr4-1, characterised by distinct cross-bedding and erosional channels. These sediments can be correlated to the Zutendaal Gravel member of the Maas river Main Terrace, deposited during the “Cromerian” (770 - 350 kyr. BP). Below the trench bottom, hand borings could not penetrate more than 2 m into the unit Tr4-1 gravels. The top of unit Tr4-1 is transected by slanting sand wedges, filled with fine yellow sand, that are related to periods of periglacial activity. Close to the fault zone, the internal stratification of Tr4-1 becomes blurred.

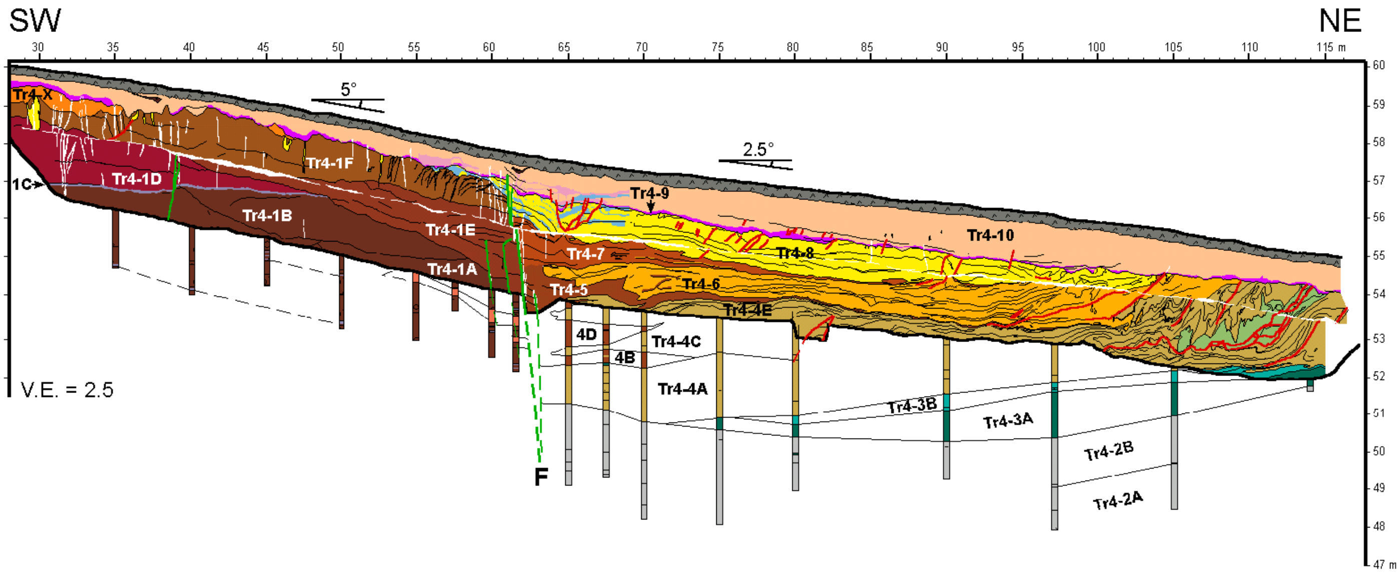


Figure 1 – Stratigraphic log of trench 4 drawn from NW trench wall and hand borings.

The stratigraphy of the lower slope or hanging wall is mainly composed of light-coloured, silty, fine to medium sands with varying amounts of fine gravel (units Tr4-4, Tr4-6, Tr4-8 and Tr4-10). These sediments show mostly parallel stratification with some minor erosional gullies, and correspond to eolian sands ("cover sands"), deposited during the Weichselian and Saalian glaciations, and partly reworked by slope wash and small creeks. Hand borings all easily penetrated 4 to 5.5 m below the trench bottom, into a grey-red-banded, more clayey unit of medium to coarse sands (Tr4-3), and a more than 2-m-thick unit of grey-coloured, slightly clayey, medium to coarse sands (Tr4-2). Both Tr4-2 and Tr4-3 are clearly dipping towards the fault zone, which was also indicated by the geophysical profiles.

The reworked eolian units are interbedded with two tongue-like units (Tr4-5 and Tr4-7) of dark-brown, clayey coarse sand unmistakably derived from the Main Terrace unit Tr4-1 on the footwall. These tongues merge into a more-than-2-m-thick unit towards the fault zone. The hand borings indicate the existence of two similar tongue-shaped units of identical composition (Tr4-4B and Tr4-4D) below the trench bottom, close to the fault zone.

Towards the base of the slope, units Tr4-4 up to Tr4-8 are severely disturbed by a set of low-angle thrust faults that probably developed at the toe of a detachment slide; the master detachment plane is probably seated at the clay-rich top of unit Tr4-3. The top of this structure is truncated by unit Tr4-9, a striking gravel bed only 5 - 10 cm thick, which can be traced with a small displacement onto the footwall block, where it covers unit Tr4-1 and some patches of Tr4-8. This unit is traditionally correlated to the Beuningen gravel bed, a lag horizon which developed at the end of the Last Glacial Maximum. Finally, the overlying, youngest cover sand unit Tr4-10 is draping the entire profile.

Faulting evidence

Faulting within trench 4 is confined to a single normal fault plane oriented N 124°E, dipping 76° NE, and located at the foot of the morphological escarpment. The continuation at depth of the fault plane is confirmed by hand borings, radar and electric tomography, arguing for the tectonic nature of the investigated feature.

On the upper trench wall, the bases of the two youngest cover sand units (Tr4-8 and 10) are displaced by different amounts (12 cm and 45 cm, respectively, Fig. 2), witnessing the two most recent fault movements at the trench site. The latest movement is also evidenced by the sharp displacement of a thin Bt soil horizon. The affected Bt-band developed within the E-horizon associated with an older, early Holocene Bt-banded horizon, and may thus have a fairly recent, possibly even historical, age.

Colluvial wedges associated with these two latest fault movements have not been observed, probably because of unfavorable preservation conditions: the colluvial wedge associated with the penultimate event may have been wiped away by the strongly erosional gravel bed Tr4-9, while the most recent one was almost certainly too small. There are, however, several other indications for the coseismic nature of these fault movements: [1] the youngest Bt-band is cleanly faulted along a sharp fault plane, suggesting instant rupture; [2] linear, subvertical fissures parallel to the main fault (Fig. 2) are interpreted as extensional cracks induced by sudden fault movement; and [3] cover sands adjacent to the fault zone are affected by a peculiar intraformational deformation structure (Fig. 2), consisting of a set of small-offset faults, both syn- and antithetic, and folded lamination, suggesting an origin by seismically induced liquefaction.

Below unit Tr4-8, direct evidence of fault displacements is limited due to the general lack of correlative horizons in sediments that have an identical aspect on both sides of the fault (merged "tongues" Tr4-5 and 7 in the hanging wall are composed of the same material as the Main Terrace deposits of unit Tr4-1 in the footwall, Fig. 2). There are several lines of evidence, however, that these tongues are not the stratigraphical equivalent of Tr4-1, interdigitating with and partly eroded by reworked cover sands, but are instead derived from Tr4-1 by slope controlled processes that were most likely initiated by fault movements: [1] although both tongues are slightly eroded by the base of the overlying fluvially reworked cover sands, their wedge-like shape is mostly original; [2] the tongues lack the cross-bedding typical of unit Tr4-1; [3] dating results (Fig. 2) indicate that the reworked cover sands below and in between them are younger (Saalian at the oldest) than the Main Terrace deposits of Cromerian age; [4] hand borings (Fig. 1) as well as geophysical data indicate that footwall and hanging wall stratigraphy below the trench bottom are very different.

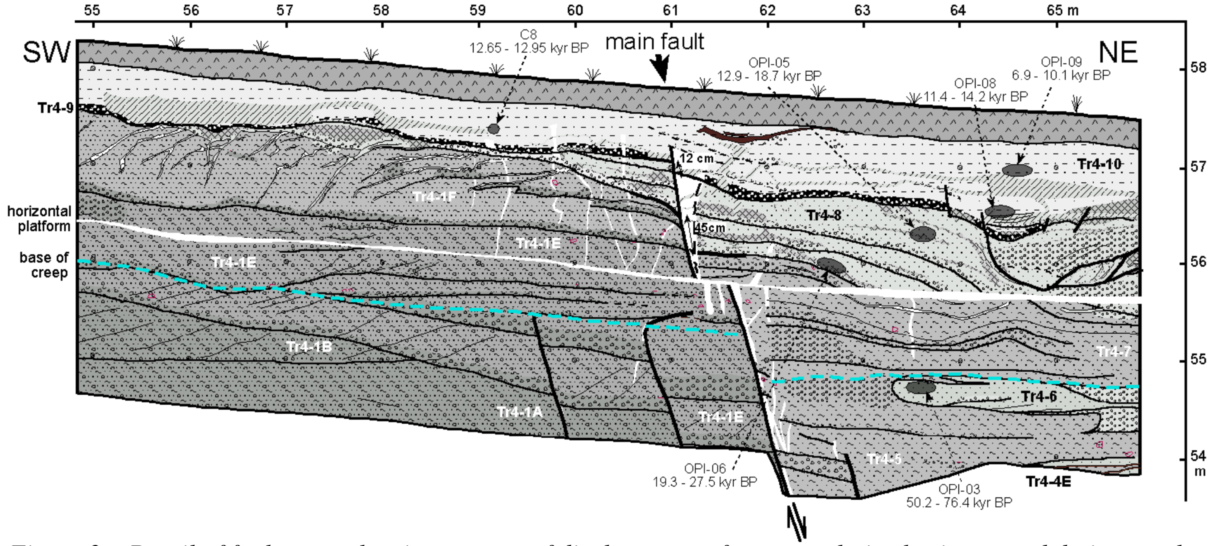
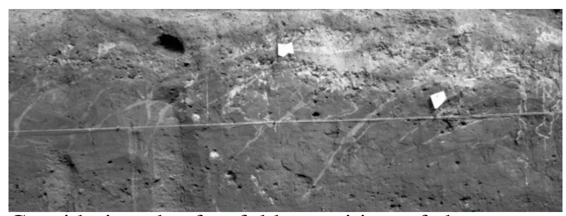


Figure 2 – Detail of fault zone, showing amount of displacement of two correlative horizons, and dating results.

A key element for establishing the nature of units Tr4-5 and 7 is the presence of several subhorizontal and parallel horizons of fine yellow sand only a few mm. Thick within them (Fig. 3a). These horizons are very similar in color and grain size to the slanting sand wedges that are found in the top part of footwall unit Tr4-1F, particularly adjacent to the fault zone (Fig. 3b). The latter are also filled with yellow fine sand, laminated parallel to the edges; these are interpreted as periglacial frost wedges, formed by desiccation of clay-containing sediments, and filled in by windblown sand. Frost wedges are usually subvertical, as reflected by those at some distance from the fault zone (Fig. 1). Closer to the main fault, however, the dip angle of the wedges progressively decreases to almost horizontal at the fault contact. This deformation is not likely to be tectonic in origin (an underlying gravel bed remains horizontal and continuous), but is thought to result from slow, creep-like movement of surface sediments, most likely under the influence of frost creep and solifluction in a periglacial environment. Thus, the thin horizons of yellow sand in the tongue-shaped hanging wall units are interpreted as originally vertical sand wedges that have been completely stretched out to almost horizontal beds, and the tongue-shaped units of coarse sand in which these horizons are embedded, as slope deposits that were entirely derived from the Main Terrace deposits in the footwall.



Considering the fourfold repetition of the tongue-shaped units of Main Terrace derived sands in the hanging wall, their position adjacent to the fault zone, and the accommodation space needed for their emplacement, we infer that these units are directly related to activity of the fault itself, each of them created in response to slope modification by a surface rupturing event. They thus represent a periglacial equivalent of the colluvial wedges that are typically associated with degradation of surface fault scarps in more arid climates (Fig. 4). Assuming that the creep process went on until the free face of the fault scarp was completely leveled, the thickness of the tongues adjacent to the fault plane can be taken as a proxy to the amount of fault displacement that induced their generation. Thus, four additional fault movements can be identified, with displacements of ± 100 cm (youngest event), 55 cm, 70 cm, and 30 cm (oldest event). A geometric reconstruction of these events indicates at least 1.2 m of earlier fault slip, which cannot be resolved into individual events, however.

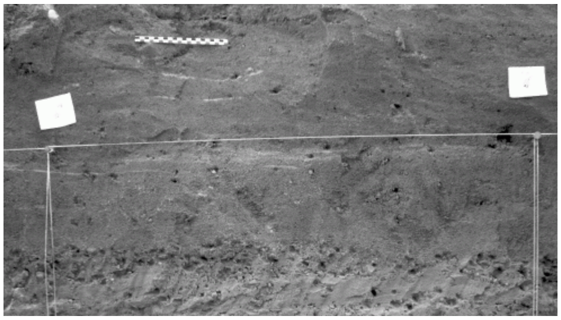


Figure 3 – [a, left] Slanting sand wedges at top of Tr4-1E; [b, top] Thin horizontal beds of fine sand embedded within coarse-grained tongue Tr4-7.

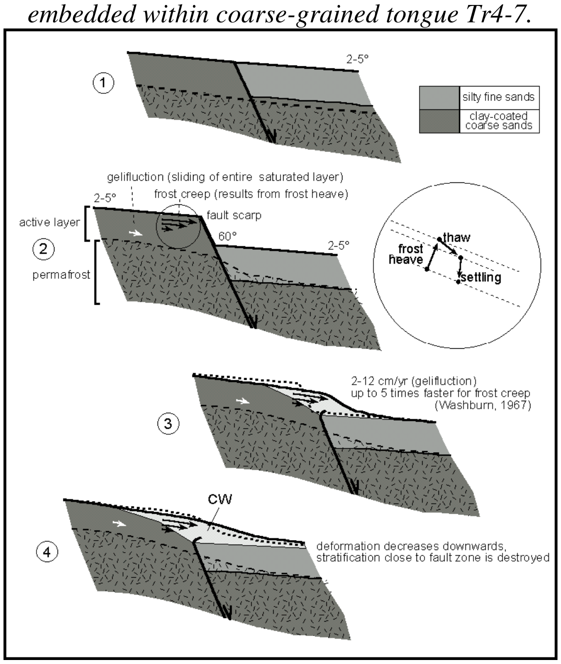


Figure 4 – Model of colluvial wedge development following surface rupture in a periglacial setting.

Conclusions

The paleoseismic record at trench site 4 is the longest and most complete record recovered so far along the Bree fault escarpment. Taking into account all information from trench walls and boreholes, evidence is provided for six individual, successive, surface fault displacements during the past 150 to 185 kyr. (Fig. 5), in addition to cumulative displacements resulting from an unknown number of earlier fault movements. Several arguments have been found for the coseismic nature of these displacements. The four oldest faulting events are associated with colluvial wedges resulting from the interplay between surface rupture and slope processes in a periglacial setting.

The results of the present study are in good agreement with the faulting history obtained from previous excavations along the fault scarp (Meghraoui et al., in press): the three most recent faulting events, consecutively of late Holocene age, and posterior and anterior to a cover sand unit corresponding to Older Coversand I (27 - 23 kyr. BP), are easily correlated with the three events identified in the other trenches. The three older events, early Weichselian to ± middle Saalian in age, are resolved for the first time.

The slip per event averages 50 cm, but significant departures are represented by the most recent event (only 12 cm, but larger in other trench sites) and by the third event back in time, which was double the average. Extrapolating the OSL datings downward, the oldest identified surface faulting event probably took place somewhat before 150 kyr. BP. This corresponds to an average fault slip rate slightly larger than 0.02 mm/yr. during the last 150 kyr. There is no evidence of a strong acceleration of the fault slip rate towards present times.

The return period of surface rupturing earthquakes at the trench site averages 25,000 yr. for the entire 150 kyr. interval. Correlation with the other trench sites suggests that it may be somewhat shorter for the three latest events, between 10,000 and 20,000 yr., taking into account a large error bar.

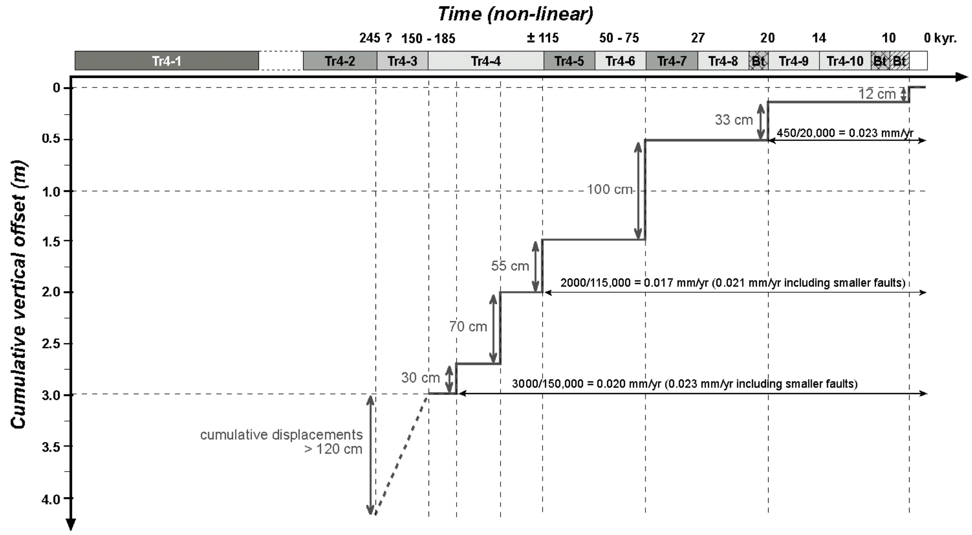


Figure 5 – Time/displacement plot derived from trench site 4 along the Bree fault escarpment.

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