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Exploring the Belgian Maas valley between Neeroeteren and Bichterweert for evidence of active faulting

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ABSTRACT

In the framework of a project for the assessment of seismic risk in low-seismicity regions, we are conducting a paleoseismological study of the Feldbiss fault zone in the Belgian Maas valley. In a first phase, geomorphologic and geophysical investigation allowed us to identify and map an active fault, in some places coinciding with, but in other places significantly diverging from the previously known Bichterweert scarp. The surface expression of this fault has only been preserved at a few sites. We show for the first time that this fault has experienced post-late Weichselian activity, as it displaces the top of the Maasmechelen terrace by about 1 m. At a site close to the alluvial plain, Holocene deposits may be affected as well.

KEYWORDS

Active tectonics, electric tomography, fault scarp, geo-radar

Introduction

Since 1996, the Royal Observatory of Belgium is investigating active faulting in the area of the Roer Valley graben (RVG). In previous years, we mainly focused on the Bree fault scarp in the framework of the EC-project PALEOSIS. The Bree fault scarp is a 10-km-long segment of the SW border fault of the RVG that is particularly well expressed in the morphology (Fig. 1). It juxtaposes middle Pleistocene gravel of the Campine Plateau against late Weichselian coversands of the Bocholt Plain. Using a combination of geomorphologic analysis, geophysical prospecting techniques and trenching it was established that the Bree fault scarp is the expression of an active fault that experienced several surface-rupturing earthquakes during the past 100,000 years, the most recent event during the Holocene (Camelbeeck & Meghraoui, 1998; Meghraoui et al., 2000; Vanneste et al., 2001).

Our contribution to the new EC-project SAFE ("Slow Active Faults in Europe"), which started in 2000, is aimed at the SE-ward extension of the Bree fault scarp in the Belgian Maas valley (Fig. 1). Between the villages of Neeroeteren and Bichterweert, the Feldbiss fault zone transects the younger terraces of the Maas river, covered by late Weichselian coversands, and the Holocene alluvium, joining with the Geleen and Feldbiss faults in the Netherlands (Fig. 2). The geomorphologic expression of these fault segments is much reduced compared to the Bree fault scarp. Considering the low slip rates of these faults (< 0.1 mm/yr.), it is clear that the fault scarp morphology in the Maas valley does generally not exceed that of other landforms such as land dunes, small local drainage features, terrace scarps, and artificial landforms. It is therefore difficult to determine the precise location of these faults, and thus also to evaluate their activity.

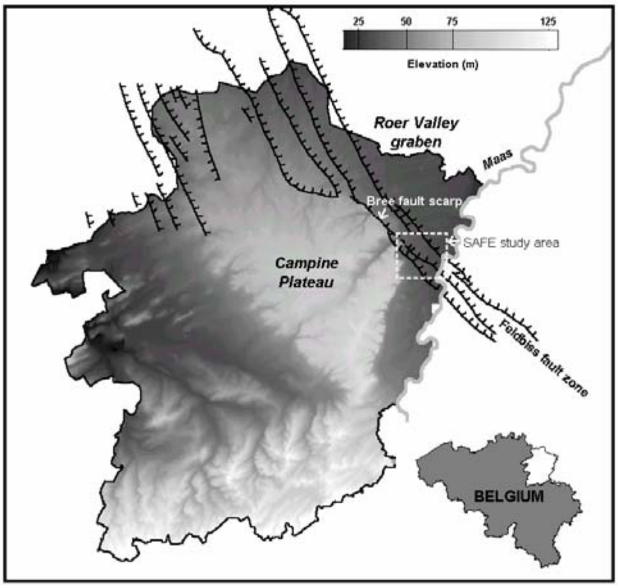

Fig. 1. Elevation map of NE Belgium, showing faults bounding Roer Valley graben and location of study area.

Morphologic and geophysical reconnaissance

The exact location of the SW border faults of the RVG in the Belgian Maas valley has been a source of debate for considerable time. Based on scattered geoelectric soundings and boreholes, Paulissen et al. (1985) were able to map the buried Bichterweert "scarp", corresponding to the Neeroeteren fault, and joining up with the Feldbiss fault in the Netherlands. More recently, Beerten et al. (1999) used new borehole data to redefine the SE end of the Bichterweert scarp, now connecting it with the Geleen fault in the Netherlands. This is supported by an intermediate-resolution seismic reflection profile of the Belgian Geological Survey (Dusar et al., 2001), which shows a major fault with large offset at this new location.

It is important to note that so far, the fault corresponding to the Bichterweert scarp has not been identified in the field, in terms of locating it with a precision of a few meters and connecting it with a morphologic anomaly. To this end, we carried out a targeted geomorphologic and geophysical survey of the Maas valley, starting out from the published data. First we conducted a geomorphologic reconnaissance of the area, searching for subtle scarps (heights generally < 1 m) and aerial lineaments that have the proper orientation and location, and no obvious non-tectonic origin. Based on these observations, we selected 10 sites for detailed geophysical investigation, usually including electric tomography, geo-radar (100 MHz antenna), as well as shallow hand borings. At some sites, additional high-resolution seismic reflection profiles were acquired in co-operation with the university of Utrecht.

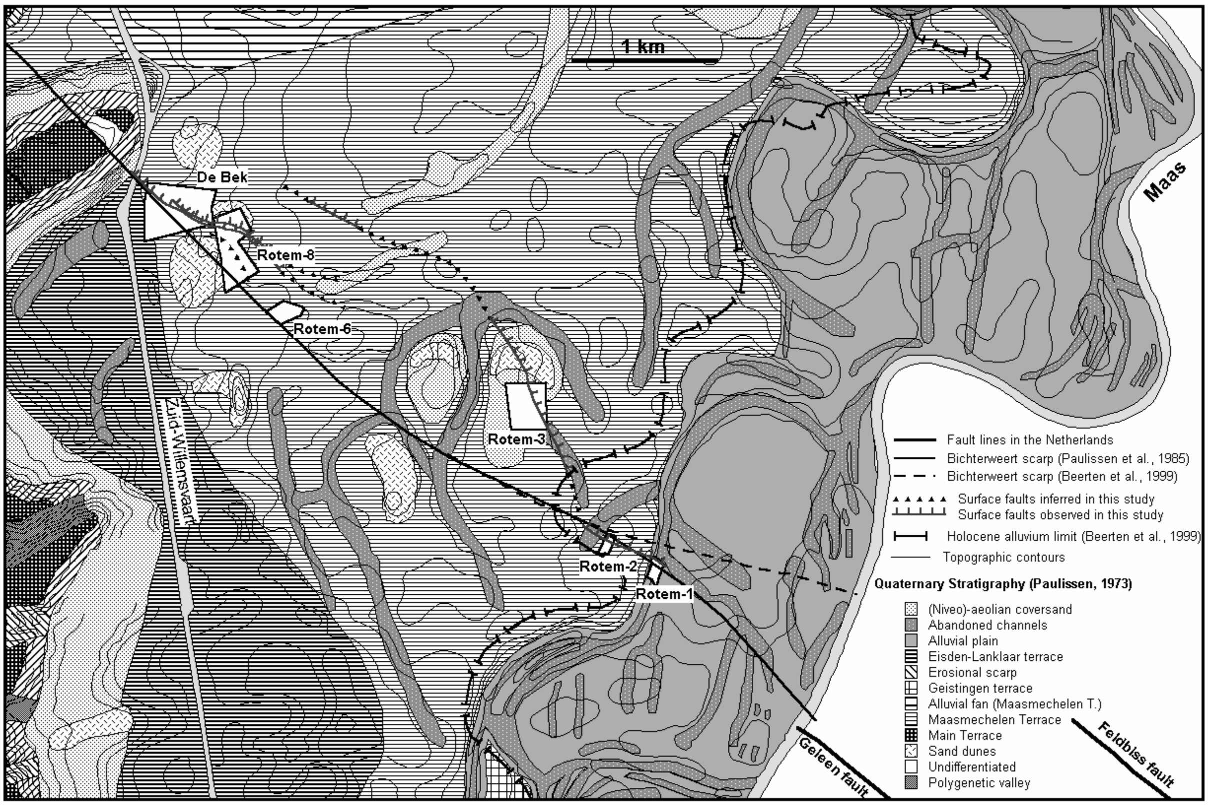

Fig. 2. Geomorphologic map of the study area, showing investigated sites and observed fault positions.

A few words about the methodology. With electric tomography, a 2-D profile of subsurface resistivity is obtained from 64 electrodes that are placed with a constant spacing along the survey line, and with which a sequence of measurements is carried out using different combinations of current and potential electrodes. We usually employ a Wenner-Schlumberger array, as it is the best compromise between horizontal and vertical resolution (Loke & Barker, 1996). Electrode spacing was 2 to 5 m, corresponding to a depth penetration of about 20 to 50 m, respectively. In addition to resistivity, we often measure induced polarisation (IP) as well, which in the time domain corresponds to a residual decay voltage after the current has been switched off, mostly caused by clay particles and conductive minerals. Electric tomography is much more reliable than electric soundings, which are merely point observations. It proved to be a powerful method for imaging base and top of the Maas river gravel terraces. Geo-radar is a relatively fast method for profiling shallow heterogeneities in non-conductive soils. With a 100 MHz antenna, we obtain a penetration of about 5 m in sandy substratum. In most cases, the top of the Maas river gravel is an excellent reflector of 100 MHz radio waves, making this method well suited for imaging this stratigraphic contact.

Results

In the NW of the study area, the Neeroeteren fault has been identified on a very-high-resolution seismic reflection line on the Zuid-Willems canal (Vanneste et al., 1997). The main fault shows a displacement of more than 5 m of the top of the late Saalian Eisden-Lanklaar terrace. The faulting pattern is quite complex, however, with several syn- and antithetic faults distributed over a 400-m-wide zone NE of the main fault. We collected several electric and geo-radar profiles on a site ("De Bek", see Fig. 2) just east of the canal, over the Weichselian Maasmechelen terrace. The fault is particularly well visible on the 2-D resistivity profiles (Fig. 3), where it corresponds to a strong lateral contrast, extending between ± 2 and 15 m below the surface, and slightly dipping towards the NE. The resistivity contrast is thus mostly situated within the Maas gravels. In the footwall, Maas gravels are characterised by high resistivities (600-2000 Ω.m), whereas hanging wall gravels show rather low resistivities (50-200 Ω.m). We suggest that this resistivity variation reflects different water content (rather than gravel quality) on either side of the fault, which thus appears to represent an important hydrological barrier. Strikingly, the 2-D IP section shows an elongated anomaly of elevated IP values centred around the probable position of the fault, below a depth of 5 m, and dipping in the same direction. The nature of this anomaly is not yet fully understood, but it may be explained by a concentration of clay particles in the fault plane, which would also agree with the presence of a hydrological barrier. We also note that there is no clear resistivity contrast between the Maasmechelen and Eisden-Lanklaar terraces which should be in vertical succession at this site.

The elevation of the gravel base can easily be determined in the footwall, where a large contrast exists between high-resistivity gravel and underlying low-resistivity sediments (probably water-saturated Tertiary sands), and varies between 17.5 and 30 m. In the hanging wall, the gravel base is much harder to detect due to the reduced resistivity contrast between gravel and underlying deposits, and also because of the limited length of the profiles. A deeper profile on site Rotem-8 (see Fig. 2) shows the gravel base at an elevation of 0-10 m. At that site, fault offset of the gravel base is about 20 m, but this is at most other sites impossible to determine. It is important to note that, within the same tectonic block, the elevation of the gravel base may vary by up to 10 m. The Maas gravels are overlain by dry coversands showing higher resistivities over the entire profile. The gravel top is situated at an elevation of 35-36 m, but the resolution of the tomography profiles is not sufficient to determine any fault offset of this surface. Using geo-radar and hand borings, however, we were able to establish that (at least) the top of the Maasmechelen terrace is displaced at the very same location as the resistivity anomaly, from 37 m in the footwall to 36 m in the hanging wall. It is not clear if the overlying coversands have been faulted as well. The hand borings indicate the possible occurrence of gravelly colluvium within the coversands adjacent to the fault, but on the other hand the fault has no topographic expression at all at this site (though this may to a large extent be due to human landscape modification).

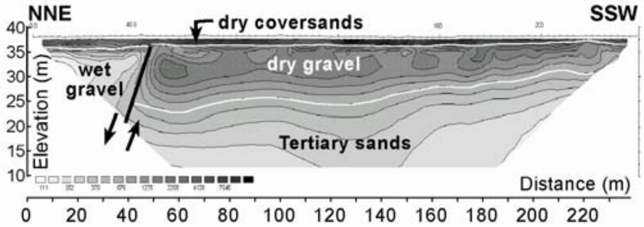

Fig. 3. 2-D resistivity profile at site De Bek.

The WNW-ESE orientation of the fault established from a series of 5 electric tomography profiles (Fig. 2) shows a significant divergence from the NW-SE orientation inferred by Paulissen et al. (1985) and Beerten et al. (1999). Close to the canal, our fault position is only 20 m away from the Bichterweert scarp, but only half a km eastward, the deviation is already 250 m. Initially, we assumed that the fault is bifurcating in this area. We therefore investigated an additional site (Rotem-6, see Fig. 2) where we observed a morphologic scarp very close to the position of the Bichterweert scarp. Neither electric tomography nor geo-radar profiles showed any indication of a fault at this site, however. The elevation of the gravel base (17.5-20 m) and the resistivity of the gravel suggests that this site is in footwall position. The incorrect position of the Bichterweert scarp is most likely due to the scattered nature of the data points (generally 300-400 m apart) on which its location is based. We showed above that variations in the elevation of the gravel base within the same tectonic block may approach the total fault offset. The same was noted by Beerten et al. (1999) for a resistivity profile in the Maas river.

The other investigated sites are located in the SE corner of the study area, directly E of the centre of the village of Rotem (Fig. 2). Site Rotem-1 is located in the Holocene alluvial plain of the Maas river, site Rotem-2 is located 350 m westward, in ambiguous terrain (outside the alluvial plain according to Paulissen, 1973, within Holocene alluvium according to Beerten et al., 1999). Both sites show a clear morphologic scarp more or less coinciding with the new position of the Bichterweert scarp proposed by Beerten et al. (1999), and in the case of Rotem-1, with the surface projection of a major fault identified by Dusar et al. (2001) on a recent seismic reflection profile. At both sites, 2-D resistivity profiles show abrupt displacements of gravel base and top at the foot of those scarps: at least 7-8 m for the gravel base, and 1-1.5 m for the top (Fig. 4a). Interestingly, the resistivity picture is different in both cases. At Rotem-1, the gravels are characterised by intermediate resistivities (300-500 Ω.m) in both the footwall and hanging wall; the IP section shows no obvious anomaly, only elevated values associated with the gravel body. At Rotem-2, the fault again corresponds to a hydrological barrier, separating wet gravel with intermediate resistivity (400-600 Ω.m) in the hanging wall from dry, high-resistivity (800-1200 Ω.m) gravel in the footwall (Fig. 4a); on the IP section, the position of the fault is marked by a prominent subvertical anomaly (Fig. 4b).

Geo-radar and hand borings carried out at Rotem-2 confirmed that the gravel top is displaced ± 1 m at the same location as the resistivity and IP anomalies, i.e. at the foot of a gentle scarp with comparable topographic offset (Fig. 4c). The situation is not so clear at Rotem-1, where the high clay content of superficial layers strongly limited the penetration depth of the geo-radar. The data seem to indicate, however, that the fault at this site does not coincide with the position of the morphologic scarp, but probably about 10 m downslope of it. The scarp is also unusually steep compared to the one at Rotem-2, which leads us to suggest that it may not be a fault scarp, but rather a fluvial scarp that was created by backwards erosion of an original fault scarp. This is also supported by a map of Paulissen (1973), which shows an abandoned meander parallel to the supposed fault trace.

The elevation of the gravel top in the footwall is at 31 m at Rotem-1, and at 34 m at Rotem-2, indicating that at the latter site, the gravel is still part of the Maasmechelen terrace, and thus not Holocene in age. However, the low resistivities (150-200 Ω.m) of the overlying sediments indicate the presence of a rather loamy cover, which has been confirmed by hand borings. These loams may represent an outlier of the Holocene Leut alluvium, which may be affected by the fault as well, as suggested by topography and boreholes. This possible intra-Holocene faulting will be the subject of more thorough future investigation (trenching).

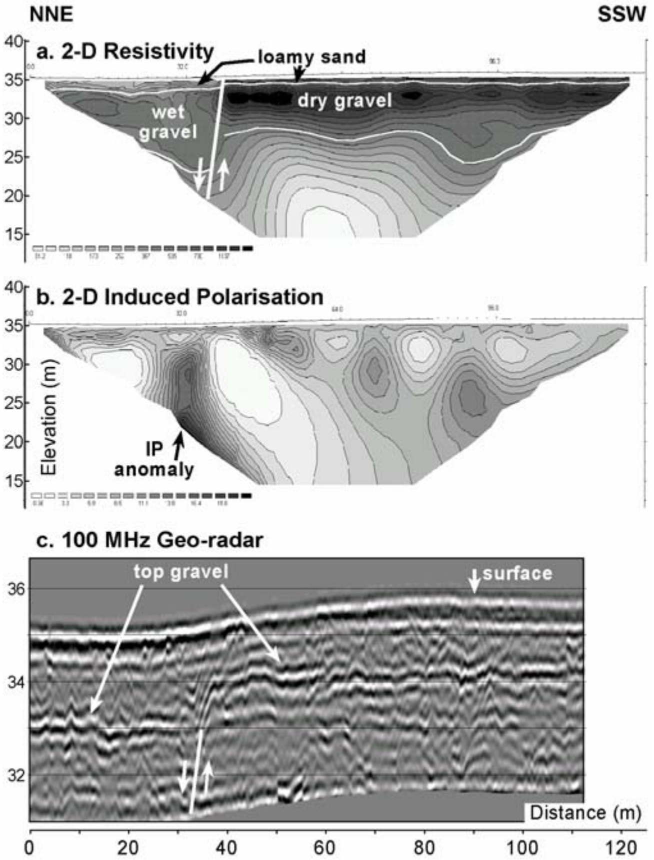

Fig. 4. 2-D resistivity, 2-D induced polarisation and 100 MHz geo-radar profiles at site Rotem-2.

So far we have only studied the area NW and SE of Rotem. The region in between is more urbanised, and includes only a few sites where investigation is possible. Our observations indicate that the faults identified NW and SE of Rotem do not line up (Fig. 2). It is not clear if these faults are actually connected, if they represent two different faults, or if they define an en échelon arrangement of segments of the same fault, separated by a (right) step-over. The latter case would indicate a significant right-lateral slip component. We did observe a suspect scarp, however, at site Rotem-3 (Fig. 2), which might define a relay between both fault segments. The nature of this scarp will be investigated in the near future.

Conclusions

We have shown that a targeted multidisciplinary approach, combining geomorphologic analysis, 2-D electric resistivity and IP imaging, radar and hand borings is most appropriate for locating and identifying "slow" active faults such as the Neeroeteren fault in the Belgian Maas valley, and thus a prerequisite for paleoseismologic investigation. Particularly electric tomography proved to be an invaluable tool to map abrupt displacements of the base and top of the buried Maas gravel terraces. Moreover, this method revealed that the fault defines a major hydrological barrier at some sites, and where this is the case, it is also associated with a distinct IP anomaly. Mapping of the fault is not yet finished, but it is clear already that it shows significant departures from the earlier mapped Bichterweert scarp. In contrast to the Bree fault scarp further north, the fault running through the Maas valley has very limited surface expression, except for the clear fault scarp just E of the centre of Rotem. In the NW of the study area, the fault seems to have no morphologic expression at all, but we suspect that it was erased by human landscape modification. Previous investigators concluded that the faults in the Belgian Maas valley did not experience any post-Upper Pleniglacial (Paulissen et al., 1985) or post-Weichselian (Beerten et al., 1999) activity. For the first time, however, we show evidence from several sites that the top of the Weichselian Maasmechelen terrace in the Maas valley is displaced ± 1 m by a fault. At Rotem-2, overlying loamy sands of possible Holocene age may be affected by the fault as well, and within the alluvial plain, fault activity may have determined the position of some abandoned channels. We hope to resolve whether the fault has been active during the Holocene by excavation of a trench at this site later this year.

Acknowledgements

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