Detailed paleoseismic investigation of the Rurrand Fault in Hambach trench, Germany

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ABSTRACT

In a first paleoseismological experience in the German part of the Lower Rhine Graben (LRG) area, a trench was excavated across the Rurrand Fault near Hambach. A complex fault zone was exposed consisting of several SW-dipping normal fault strands characterized by different histories of activity. More than 7 m of fault displacement was observed, most of it contemporaneous with, or younger than a stratified loam unit of undetermined age. A number of observations indicates that coseismic slip is the dominant mode of fault movement, whereas no evidence for growth faulting has been found. This finding challenges earlier hypotheses that LRG block movements evidenced by repeated geodetic leveling are the result of continuous fault creep. Determination of the minimum age of latest fault activity is not possible, as the plough zone truncates most faults and thus their possibly associated event horizons. Modern aseismic fault slip, induced by extensive pumping of aquifers for mining purposes, seems to be expressed in the trench as diffuse bundles of anastomosing cracks rather than singular, razor-sharp fault planes.

KEYWORDS

Coseismic slip, fault creep, induced fault slip, paleoearthquake, Lower Rhine Graben.

Introduction

In the summer of 1999 a paleoseismological investigation was carried out for the first time in the German part of the Lower Rhine Graben area, within the framework of the EC project "PALEOSIS". Following geomorphological and geophysical reconnaissance surveys (Lehmann et al., this volume), a trench was excavated across the Rurrand Fault near the village of Hambach. The geological setting and general stratigraphy of the trench are described by Lehmann et al. (this volume). A complex fault zone, consisting of several fault strands dipping ± 70° SW, was exposed about halfway on the slope of the overall escarpment. We mapped the main fault zone on 1:20 scale, and analyzed it for evidence of paleoearthquakes.

Observations

The stratigraphic log of the main fault zone on the NW wall of Hambach trench is shown in Fig. 1. At least five individual fault strands (labeled F1, F2, F3, F4 and FZ5) have been identified, and indications were found of a possible sixth fault F6. With the exception of F1 (located a few m NE of Fig. 1) all faults displace a 2-m-thick, iron-stained, coarse gravel unit (hereafter referred to as "main gravel unit"), as well as an overlying stratified sandy loam unit. The main fault corresponds to FZ5, displacing the main gravel unit by at least 5 m; the position of FZ5 also aligns with a striking SW-dipping resistivity contrast on an electrical tomography profile carried out before excavation (Lehmann et al., this volume). The total vertical displacement along these faults since deposition of the main gravel unit amounts to at least 700 cm (F1: 0 cm; F2: 65 cm; F3: 30 cm; F4: 105 cm; FZ5: > 500 cm; F6: ?). Geometrical and stratigraphical relationships indicate that the faulting history was quite complex, with different fault strands active at different times. For instance, F1 was only active before deposition of the main gravel unit; F2 was active before deposition of the main gravel unit, inactive during deposition of the main gravel unit and overlying stratified sandy loam deposits, and active again afterwards; F3 was inactive before deposition of the main gravel unit, may have shown minor activity during deposition of the main gravel unit, and experienced its main displacement after deposition of the stratified sandy loam; finally, all displacement visible along F4 was produced after deposition of at least the lower part of the stratified loam. The faulting history deduced for each individual fault branch is summarized in Fig. 2.

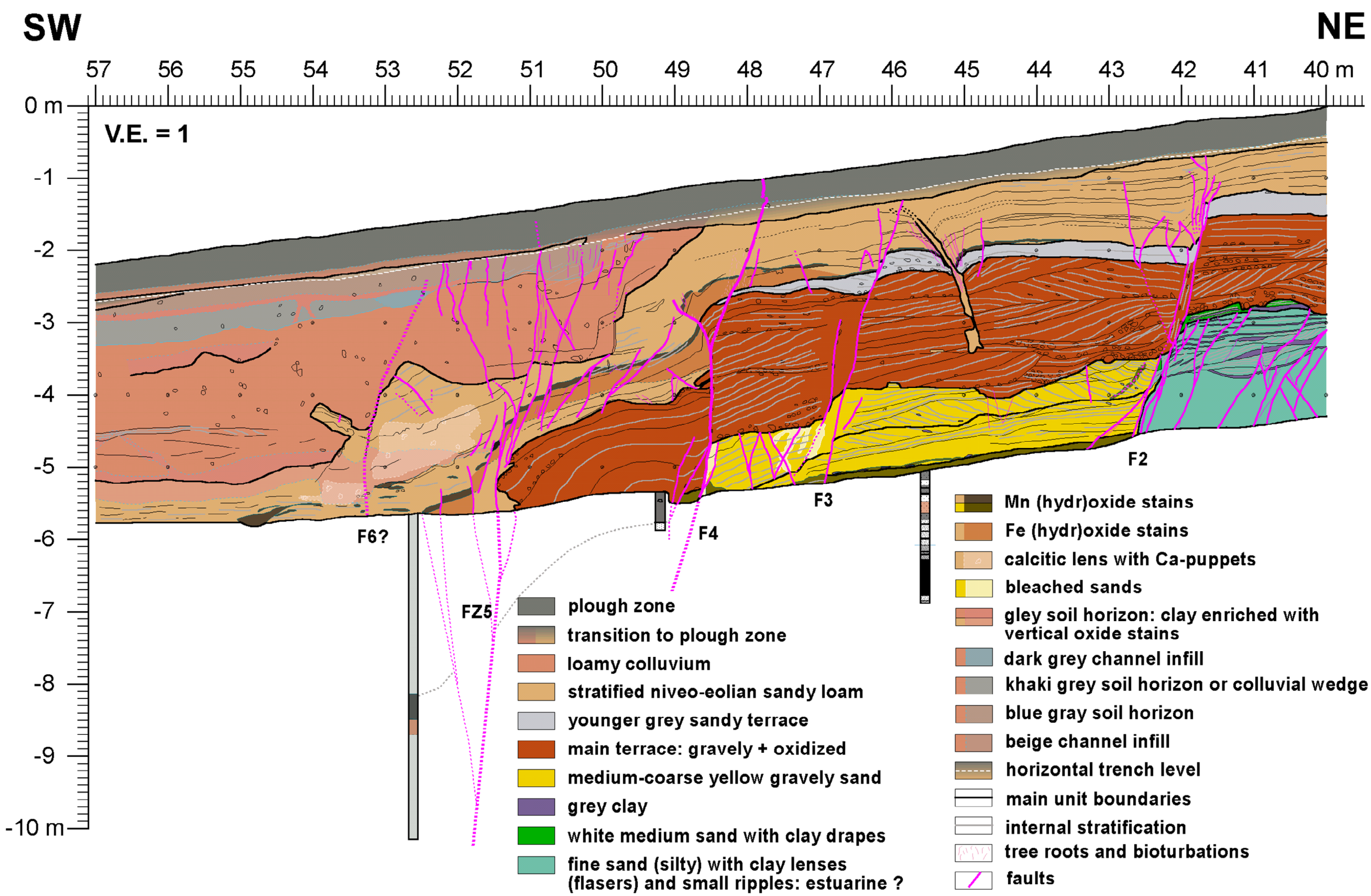

Figure 1 – Stratigraphic and structural log of the main fault zone on the NW wall in Hambach trench.

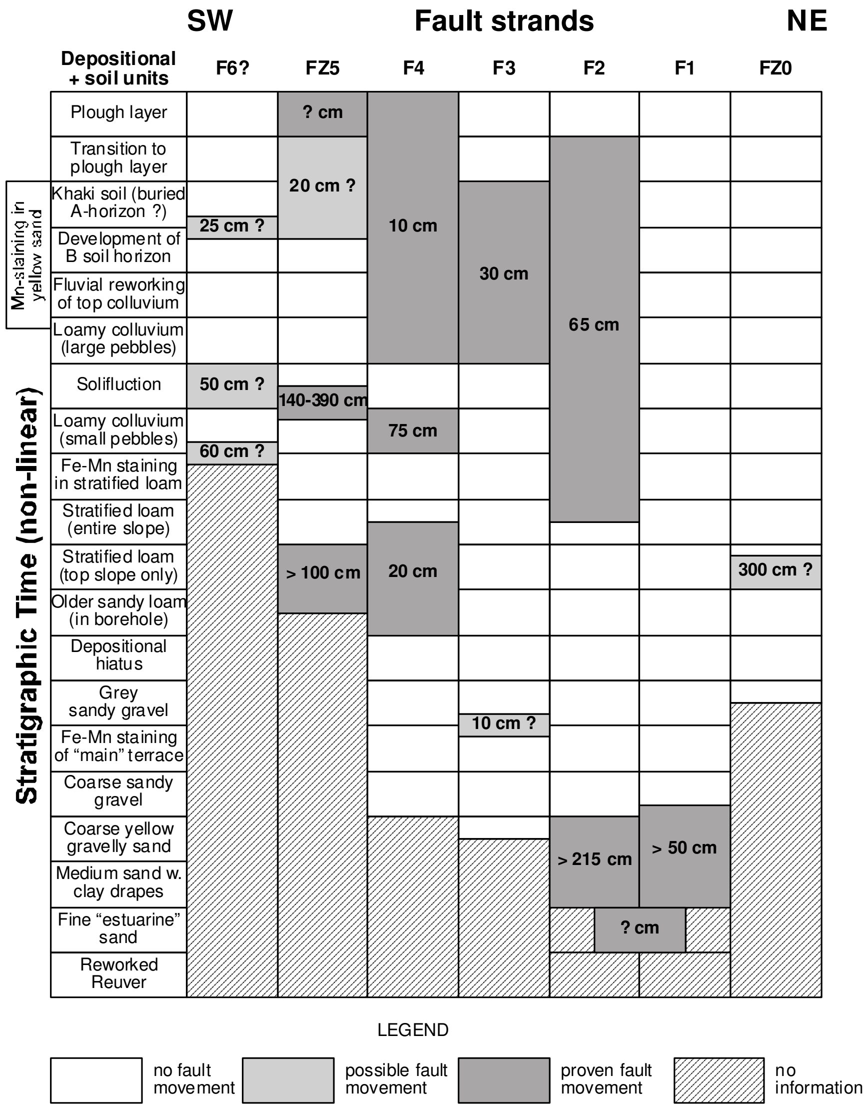

Figure 2 – History of activity of individual strands of the Rurrand Fault identified in Hambach trench.

Coseismic or aseismic fault slip?

Ambiguities in the interpretation of the trench record are introduced by the recognition of only a limited set of the classic paleoseismic criteria (liquefaction features seem to be completely lacking for instance) and by the fact that most fault planes (F2, F3 and F4) are truncated by the plough layer, preventing the identification of an event horizon. It is thus not possible to confirm the coseismic nature of each individual displacement. Nevertheless, a number of observations do favor coseismic slip: [1] the faulting history was highly episodic, as indicated above; [2] there is no indication of growth faulting: thin sand and gravel horizons within the stratified loam show identical amounts of displacement as top and base of the underlying main gravel unit (e.g. fault F2); [3] several older synthetic and antithetic small-scale faults are truncated by the same stratigraphic horizon (the base of the main gravel unit), providing evidence for an event horizon in the earliest part of the trench record; [4] the position of a thick colluvial unit of structureless gravelly loam seems to be determined by the position of the main fault zone, suggesting that it may be interpreted as a colluvial wedge, resulting from fault scarp degradation (probably even in two phases); [5] and finally, from the position of the main fault FZ5, and the geometry of fault planes F4 and F3, a consistent sequence of faulting events can be derived: upslope of FZ5, which exhibits the largest displacements and is also associated with warping of the main gravel unit, solifluction of the stratified sandy loam deposits is indicated by overturning of the fault plane F4 and of a feature interpreted as an ice wedge (45-46 m in Fig. 1). This points to a single surface faulting event modifying the slope morphology. The main activity of F4 necessarily predates this event, whereas F3 is unaffected by solifluction, and thus probably slipped at a later time.

In the vicinity of the trench site several open-cast browncoal mines are situated, which are up to 300 m deep, and require pumping of groundwater and aquifers over a large area. As a result of this, the Quaternary faults in the area have been reactivated and are experiencing slow, continuous movements of up to 1 cm/yr. during the last 30 to 40 years. Exactly how these fault creep movements are spatially distributed is not made known publicly, unfortunately. The question is raised therefore, how this modern, induced fault creep is reflected in the trench record. Thanks to an extended period of non-cultivation of the site, it was possible to identify several open cracks in the plough layer and at the very surface. One of these cracks could be traced laterally for a few meters, and connects with a 10-cm reactivation of fault F4 on the trench wall. The other cracks appear in the colluvial unit below the plough layer as a diffuse pattern of anastomosing fissures, both in the horizontal and in the vertical plane, and are distributed over a 4-5 m wide zone. Some are seen to connect with singular fault planes in the underlying stratified loam, showing displacements of a few cm of the base of the colluvium. We interpret these cracks as the expression of modern, induced fault creep.

There is little or no description in literature of the expression of continuous aseismic fault slip in unconsolidated surface deposits, particularly for normal faults, but the above observations seem to indicate that upward propagation of a fault plane by creep into unfaulted strata occurs in an anastomosing pattern of cracks (maybe resulting from different creep events) rather than as a singular, knife-sharp fault plane. Particularly at the contact between cohesive loam and underlying coarse gravel, where the shear zone is necessarily broader, a more complex pattern of faults and cracks would be expected. Thus, if the expression of man-induced fault creep can be taken as a modern analog of long-term aseismic fault slip, the aspect of the observed fault planes suggests, in addition to the arguments cited earlier, that Late Pleistocene fault slip along the Rurrand Fault was probably mostly coseismic in nature.

Previous research (e.g. Ahorner, 1968, 1996) had suggested the Quaternary faults of the Lower Rhine Graben area, including the Rurrand Fault, to slip mostly by aseismic fault creep. This assumption was mainly based on the observation of ongoing uplift and subsidence on either side of these faults. Repeated geodetic leveling in the period before extensive mining indeed reveal deformation rates in the order of 1 mm/yr., much faster than the long-term geological average. However, these measurements suffer from a low spatial and temporal resolution (data points are several hundreds of meters apart), and therefore do not allow to distinguish between displacement along the actual fault plane (fault creep) and deformation distributed over a broader zone (strain accumulation in the fault zone). Both alternatives have radically different implications for present-day seismic hazard. In the absence of creepmeter records along faults not affected by present-day mining activities, we feel that, similar to the situation along the Feldbiss Fault Zone in Belgium (Camelbeeck & Meghraoui, 1996, 1998), there are at present more arguments in favor of coseismic slip of the Rurrand Fault than there are for aseismic slip. Dating results are expected to help constrain the history of faulting, and faulting characteristics (slip rate, recurrence interval, slip per event, elapsed time since last event) of interest for seismic hazard analysis.

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