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Neotectonics of The Netherlands: a review

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Abstract

Earthquakes and vertical land movements inferred from geodetic levelling results demonstrate that the Netherlands is situated on a tectonically active part of the Earth's surface. Tectonic subsidence analyses of the sedimentary records in the basins and the history of tectonic uplift inferred from Meuse river terraces show that the current tectonic activity is part of a deformation phase which began in the late Early Miocene, which we take as the start of the neotectonic period. The neotectonic faulting mode is normal-slip. This is in accordance with the present-day orientation of the maximum horizontal stress, and the vertical orientation of the maximum stress. However, the neotectonic fault zones are reactivated Variscan or older wrench faults. These faults have been reactivated repeatedly during the Mesozoic and Cenozoic in normal and wrenching modes, and therefore represent fundamental crustal weakness zones. As a result, the surficial neotectonic fault pattern resembles the inherited wrenching fault pattern, although the faulting mode is normal-slip. This is illustrated for the area where normal faults have displaced the Meuse fluvial terrace system in the southeastern part of the Netherlands.

The neotectonic vertical motions in and around the Roer Valley Rift System have affected the courses of the Rhine and Meuse rivers from Pliocene times until the present. In addition, a fluvial terrace staircase developed along the Meuse river in response to the uplift of the Ardennes-Rhenish Massif and its foreland, for example near Maastricht. Furthermore, small fault scarps are present along segments of the bounding fault zones of the Roer Valley Graben: the Peel Boundary Fault Zone and the Feldbiss Fault Zone. In other parts of the Netherlands the neotectonic vertical motions have no direct expression in the morphology. Examples of possible indirect control on the morphology in these areas occur in glacial landscapes, the Zuiderzee Basin and the coastal zone.

1. Introduction

Tectonically, the Netherlands is situated between the Mesozoic rift systems of the southeastern North Sea Basin and the Cenozoic Lower Rhine Graben (Figs. 1 and 2; Illies, 1977; Ziegler, 1992). The present-day tectonic activity of the Dutch subsurface is evidenced by earthquakes (Fig. 3; Van Eck and Davenport, 1994) and the results from geodetic levelling (Groenewoud et al., 1991; Kooi et al., 1998). Lineament analyses on satellite images and digital elevation models suggest that faults have been active during the recent past (Sesören, 1976; Van den Berg, 1996; Houtgast and Van Balen, 2000; Michon and Van Balen, 2005). In addition, tectonic subsidence analyses (Zijerveld et al., 1992; Geluk et al., 1994; Houtgast and Van Balen, 2000; Van Balen et al., 2000a), paleogeographic reconstructions and gradient analysis of the Rhine and Meuse delta (Stouthamer and Berendsen, 2000; Cohen et al., 2002), and geomorphological analyses (Vandenberghe, 1990; Van den Berg, 1996; Houtgast et al., 2002; Michon and Van Balen, 2005) show that the recent activity is part of a tectonic deformation phase which has been going on during the Neogene. The deformation of the subsurface is characterized by NE–SW extension, as a result of the approximate NW–SE orientation of the compressive maximum horizontal stress in the area (Fig. 4; Müller et al., 1992; Dirkzwager et al., 2000). The compressive

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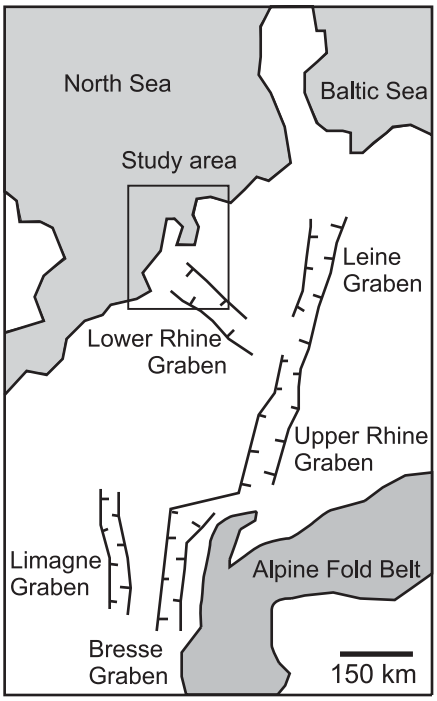

Fig. 1. Outline of the Cenozoic western European rift system (after Ziegler, 1992). The box indicates the study area.

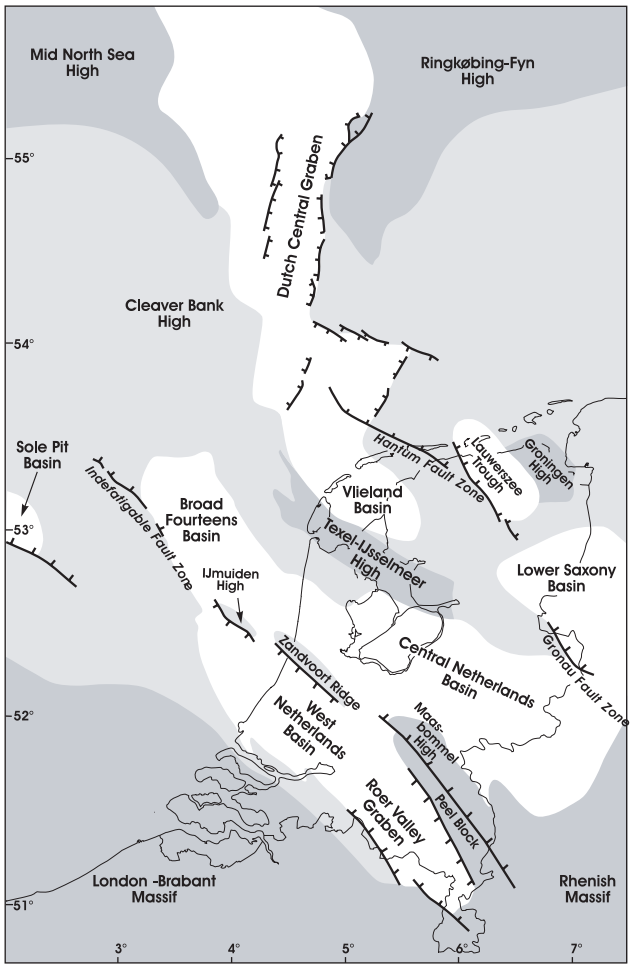

Fig. 2. Structural outline of the Netherlands (after Van Adrichem Boogaert and Kouwe, 1993–1997). White colour represents basins, shades represent structural highs.

intraplate stress also provides a flexural contribution to the Pliocene and Quaternary subsidence, which can explain the acceleration of subsidence which takes place during this period in the North Sea Basin (Kooi et al., 1989; Van Balen et al., 1998).

In addition to the neotectonic fault movements, the continuous rise of salt diapirs since the Mesozoic may potentially affect the geomorphology in the northern and eastern Netherlands, like it has done in the adjoining German area (Sirocko et al., 2002). A possible example is the island Rottumeroog (Fig. 5), situated above a salt diapir which has been rising during the Neogene (RGD, 1995). It is, however, unknown whether this diapir is still rising at present, and thus affects the location of the island. Another example is the Schoonlo diapir situated in the north-eastern Netherlands. A cross-section through this diapir shows that the thickness of Quaternary deposits above the diapir is about half the regional thickness (De Gans, 2000), suggesting a control on the Quaternary sedimentation by diapiric ascent. In addition, the Schoonlo diapir is approximately situated at the center of a radial drainage system, suggesting sub-recent halokinetic uplift of the surface (De Gans, 1981). Because of a lack of detailed studies on near-surface halokinetic movements, and because halokinetics is not part of neotectonics, the Quaternary halokinetic movements are not discussed in this paper.

Below, we first define the neotectonic period for the Netherlands, and discuss the neotectonic structural framework. Next, the results of an analysis of the neotectonic vertical motions of the tectonically most active part of the subsurface, the Roer Valley Rift System, are presented. Subsequently, we discuss the impact of these motions on the behaviour of the Rhine and Meuse rivers during the Pleistocene and Holocene. In the final section, we discuss the possible impact of neotectonic vertical motions on the geomorphology and on the present-day sedimentation and erosion patterns.

2. Definition of the neotectonic period for the Netherlands

The term ‘neotectonics’ refers to the processes and effects of recent regional tectonic activity and is usually applied to Late Cenozoic events. The definition excludes tectonic processes like halokinetics. Becker (1993) gives a historical overview of the use of the term. Originally, the term was based on age only, which gave rise to confusion because such a definition is not based on tectonic structures. Becker (1993) proposed that the start of the neotectonic period should be based on the