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Present-day intraplate stress field in the Varican Front and Rhenish Massif: Influence of rifting and reactivation of pre-existing structures

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ABSTRACT

The Present-day intraplate stress field in the Variscan Front and the Rhenish Massif of Belgium and adjacent regions is re-examined on the basis of a new stress inversion of published earthquake focal mechanisms. The influence of the Lower Rhine Graben on the intraplate compressional stress field is clearly expressed by a change in tectonic regime to semi-radial extension, without rotation of the stress axes. This points to a "passive" influence of local lithospheric sources on the regional stress field generated by plate boundary forces. Reactivation of pre-existing structures in the present-day stress field is relevant to seismic risk assessment in Belgium and adjacent regions.

KEYWORDS

Lower Rhine Graben, neotectonics, reactivation, Rhenish Massif, rifting, stress field

Introduction

The European stress map is based on a regional compilation of 1500 present-day stress indicators by Müller *et al.* (1992), as part of the ILP World Stress Map Project (Zoback, 1992). The direction of maximum horizontal principal stress (S_{Hmax}) and the stress trajectories are interpreted by Müller *et al.* (1992) and Grünthal & Stromeyer (1992), assuming a statistical parallelism between the orientation of the principal axes $\sigma 1$, $\sigma 2$, $\sigma 3$ of the stress ellipsoid and the geometrical strain axes associated with focal mechanisms. They did not perform formal stress inversion on the data, to compute the three principal axes and the shape of the stress ellipsoid (reduced stress tensor).

To obtain more detailed information on the stress field, it is necessary first to determine subregions of homogeneous stress field (and tectonic structure), and then to invert the focal mechanisms of these subregions, using standard procedures. Delouis *et al.* (1993) compiled 14 focal mechanisms for the Rhenish Massif and the Lower Rhine Graben together, and obtained an extensional strike-slip stress tensor with a N105°E S_{Hmax} direction. Camelbeeck (1993) computed additional focal mechanisms for this region and subdivided it into five subregions, each with 3 to 9 focal mechanisms.

Here, the definition of subregions for stress tensor calculation is re-examined on the basis of both geological and stress field homogeneity, and keeping enough data per subregion (minimum 6) to reasonably constrain the tensor inversion. The focal mechanisms of the 25 aftershocks of the Roermond 1992 earthquake, determined by Camelbeeck (1993), were added to the Lower Rhine Graben subregion, with an appropriate weighting. Additional data from the eastern Rhenish Massif are also used to have a better spatial coverage.

Geodynamic context

The major seismo-active zones of Belgium are to the North-Variscan Front in West Belgium (Hainaut) and in East Belgium (Liège-Gulpen), the Lower Rhine Graben, the Brabant Massif and the western part of the Rhenish Massif (Stavelot-Venn Massif). The present-day active faults mostly reactivate pre-existing structures of Variscan and post-Variscan origin: the Ardenne Allochthon with NW-trending subvertical tear faults, strike-slip faults in the Variscan Front, and the normal faults of the Roer Graben in the Lower Rhine Embayment.

The "Nord-Artois" shear zone controlled the development of the Mons basin in the Late Cretaceous-Paleocene (Vandycke *et al.*, 1991). This zone seems now to extend eastwards, as far as in the Liège basin (Delvaux, 1997). It is composed of discontinuous segments of dextral strike-slip faults. The Lower Rhine Graben developed by pure normal faulting since the Pliocene, in general parallelism with the regional S_{Hmax} direction.

The interpretation of the European Stress Map (Müller *et al.*, 1992; Grünthal & Stromeyer, 1992) shows that the general stress field in western Europe is of transpressional type, with a NW-SE S_{Hmax} direction, and is uniform at the plate-scale. The stress orientation is only affected locally by the Alps, and not by the Rhine Graben. Simple finite element modelling of the European intraplate stress field indicate that the NW-SE S_{Hmax} orientation in western Europe can be explained only by plate-boundary forces: ridge push forces generated by the Mid-Atlantic spreading ridge to the Northwest, and the Alpine continental collision to the south.

Table 1: Present-day reduced stress tensors from focal mechanisms

Area	coordinates (latitude/longitude)		n	nt	s1	s2	s3	R	a	Q
Hainaut	50°10'-50°30'N	3°40'-4°40'E	8	9	17/335	09/068	70/183	0.10	11.9	B
Liège-Gulpen	50°30'-50°55'N	5°20'-6°00'E	7	7	02/095	78/356	12/185	0.47	5.1	B
Stavelot-Venn	50°10'-50°25'N	5°50'-6°10'E	7	7	15/304	70/083	13/210	0.46	1.21	B
Lower Rhine Graben	50°45'-51°15'N	5°40'-6°20'E	23	29	78/074	09/302	08/210	0.33	14.6	A
E-Rhenish Massif	50°15'-51°00'N	7°45'-10°0'E	4	6	60/133	27/283	13/020	0.99	2.9	C

n - fault data used in inversion; nt - data measured; $\sigma1$, $\sigma2$ and $\sigma3$ - plunge and azimuth of principal stress axes; R - stress ratio $(\sigma2-\sigma3)/(\sigma1-\sigma3)$; *a* - mean slip deviation (°); Q - quality ranking (A: very good, B: good, C: medium, D: poor).

Inversion of earthquake focal mechanisms

The focal mechanisms used are mostly those reported in Camelbeeck (1993). The same subregion definition was used for the Variscan Front, East Belgium (Hainaut) and the western Rhenish Massif (Stavelot-Venn). For the Liège region, the 3 focal mechanisms from Liège, 2 from Gulpen (The Netherlands) and 2 from the adjacent eastern Brabant Massif were grouped together. For the Lower Rhine Graben, the aftershocks of the Roermond 1992 earthquake were added to the 8 major well constrained mechanisms of the Roer Graben. The six focal mechanisms from Eastern Rhenish Massif are from the compilation of Delouis *et al.* (1993).

The present-day stress field was inverted from earthquake focal mechanisms according to standard procedures (Angelier, 1994), using the TENSOR program (Delvaux, 1993).

Influence of rifting on regional stress field

The results of the new stress inversion (Table 1) show a regional evolution of the S_{Hmax} orientation: N155°E in West Belgium (Hainaut), N123°E in the western Rhenish Massif and Lower Rhine Graben, and N103°E in the eastern Rhenish Massif. Compared to this general trend, the Liège region has an anomalous N095°E S_{Hmax}. The tectonic regime is transpressional in the Hainaut region, pure strike-slip in both the Liège-Gulpen region and the Stavelot-Venn Massif, pure-radial extensional in the Roer Graben, and transtensional in the eastern Rhenish Massif.

The influence of the Rhine Graben on the intraplate stress field is marked by an important modification of the intraplate tectonic regime, but without clear reorientation of the horizontal stress axes. The Liège region has a markedly different S_{Hmax} orientation, maybe due to the complex tectonic structure of this area. The general S_{Hmax} trend corresponds to the well-known pattern of stress field in western Europe (Müller *et al.*, 1992). The intraplate stress field is transpressional west of the Lower Rhine Graben, and transtensional east of it. The semi-radial extensional stress field of the Lower Rhine Graben suggests that the effects of the intraplate NW-SE compression is no longer dominant in the rift system. This is typical for rifts driven by a 'passive' rifting mechanism, in which extensional buoyancy forces are locally generated in the weakened lithosphere by gravitational instabilities related to lithospheric thinning and mantle uplift (Ziegler, 1996). A similar interpretation was given for explaining the stress field in the Baikal Rift System, also developing in compressional intraplate context, in parallelism with the S_{Hmax} direction (Petit *et al.*, 1996; Delvaux *et al.*, in press).

Reactivation of pre-existing structures

The characteristics of the present-day stress field has important consequences on the possible reactivation of pre-existing faults and their type of movement. This in turn is relevant to the seismic risk of the area. The likelihood that a pre-existing fault can be reactivated depends for a part on the orientation of the fault plane itself relative to the local stress tensor, but also from the friction, strain rate, stress magnitude, etc.. Knowing the regional stress tensor, it is possible to determine the faults which are potentially reactivated, and to predict their type of movement.

In the Lower Rhine Graben, faults dipping 50 to 70° and slightly oblique to the general trend of the graben are preferably reactivated by normal dip-slip movement (as for the Roermond 1992 earthquake - Camelbeeck & van Eck, 1994). In the Stavelot-Venn Massif, the Variscan thrust faults are less likely reactivated than the NNW-trending subvertical tear faults (sinistral strike-slip reactivation). In the Liège area, the post-Variscan (Late Cretaceous-Paleocene ?) NE-trending dextral strike-slip faults are likely to be reactivated is a same way as when they were initiated, while the shallow dipping Variscan thrusts are unlikely to be reactivated. This is indirectly shown by Camelbeeck (1993), from the distribution of the 1965-1984 earthquake epicenters in a subvertical zone, aligned along the major dextral fault system of the Liège basin, and from the strike-slip character of the focal mechanisms. A simple explanation for this reactivation is that the present-day stress tensor in the Liège subregion has a great similarity with the paleostress tensors obtained in the Engis and Flône quarries in the Meuse valley west of Liège (Delvaux, 1997).

In the Hainaut subregion, the low-angle Variscan thrusts have a high probability of reactivation as the thrust faults, the normal faults bordering the Mons Basin have a medium probability of reactivation, but in a reverse to strike-slip sense depending on the fault trend. An hypothetical E-W-trending subvertical fault zone, representing the "Nord-Artois" shear zone is unlikely to be reactivated.

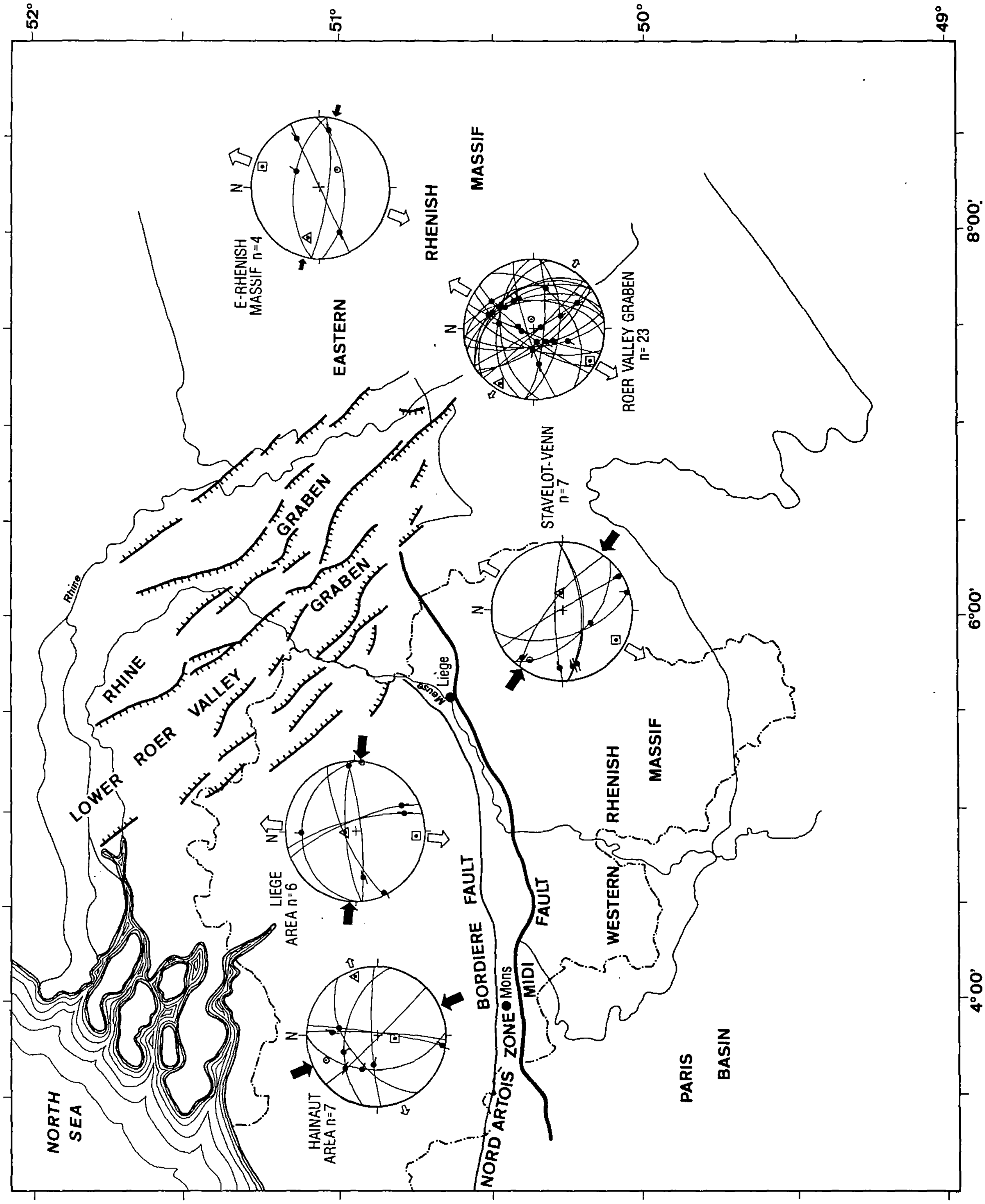

Fig. 1. Structural map of Belgium and adjacent regions, with major post-Variscan structures and regional present-day stress tensors from focal mechanisms. Lower-hemisphere Schmidt projection.

Another region of potential neotectonic activity is the Famenne shear zone in the Ardenne Allochthon, evidenced, by Delvaux de Fenffe (1990). This a diffuse zone of dextral strike-slip movements, trending E-W between Beauraing and Rochefort, also formed during a transpressional tectonic regime with WNW S_{Hmax} (Delvaux, 1997).

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