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Are red wood ants (*Formica rufa*-group) tectonic indicators? A statistical approach

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ABSTRACT

Recent research in seismically active areas indicated that the spatial distributions of geochemical soil gas anomalies and nests of red wood ants (RWA; *Formica rufa*-group) are strongly correlated. Here we applied a modified Hough Transform (mHT) and an Iterative Mode Detection (IMD) to RWA nest positions, which we mapped in two Southwest German study areas (Black Forest and Bodanrück), to test for statistical significance of correlation with tectonic features. RWA densities in the seismically active study areas reaching up to 1600 nests/100 ha are about 100× higher than overall values for Northern and Southern Germany. Since the shape of edges of the study area was found to strongly influence the selection of distribution patterns, all subsequent analyses were carried out for circular study areas. Results of the mHT applied on the RWA nests in both study areas clearly showed several modes which correspond to preferred directions. Centres of the modes further processed by IMD transferred into a GIS as RWA prototype lines showed very dominant directions of RWA nest distributions in right lateral strike-slip mode in WNW-ESE resp. NW-SE direction but also in extension direction caused by the recent main stress field in NW-SE resp. NNW-SSE direction. It could thus be clearly shown that the large scale spatial distribution of RWA nests directly reflects significant components of the present day stress field and its accompanying conjugated shear systems: Linear alignments of RWA nests indicate the course of active degassing faults zones and nest clusters indicate area-wide geochemical anomalies respectively crosscut zones of different fault systems. Furthermore, directions of re-activated shear systems, e.g. from Eocene-Oligocene but also from Late Jurassic that had been modified by overprinting due to changes of the main stress field could be identified. Therefore, RWA prototype lines complement and clarify the shear sense and the tectonic regime identified in previous tectonic studies. The high degree of statistical significance of these results will also allow a rating with former contrasting interpretations as to the drivers of RWA distributions.

1. Introduction

Early in the last century, myrmecologists assumed that the spatial distribution of red wood ants (RWA; *Formica rufa*-group) nests depends on geological structures (Gösswald, 1939; Eichhorn, 1962; Rammoser, 1961). Wellenstein (1929) found that RWA nests are not located at preferential locations within a forest stand. Alignments of RWA nests in the nature reserve Rudolfshagen (West of Kassel, northern Hesse, Germany), without any preferential direction, were described by Sauer (1983). Recent research in seismically active areas in the Quaternary West Eifel Volcanic Field (northern Rhineland-Palatinate, Germany) demonstrated a strong correlation between the spatial distributions of geochemical soil gas anomalies, e.g. elevated concentrations of Helium, Radon and RWA nests. The directions of linear alignments of soil gas anomalies and of RWA nests tended to be similar, indicating the course of active degassing faults zones, while geochemical anomalies within nest clusters could be interpreted as being due to crosscut zones of fault systems (Berberich, 2010; Berberich and Schreiber, 2013; Berberich

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et al., 2014a,b). In contrast, no RWA nest were found in seismically inactive areas without any soil gas anomalies (Berberich et al., unpublished results).

For tectonic studies of rock deformation and resulting fault structures as a response to stress, such an approach is paramount since it complements information traditionally gained by different methods, e.g. in situ geophysical investigations, fault plane analyses of earthquakes, or lineament analyses (Hinzen, 2003; Schwarz, 2012; Franzke et al., 2003). However, the degree of statistical significance of such relations still needs to be established to allow a comparison and rating with former contrasting interpretations as to the drivers of RWA distributions.

Therefore in our present statistical investigation we addressed two main questions:

- Does RWA nest distribution follow a pattern or is it random?
- Are similarities between identified patterns and underlying tectonic structures statistically significant?

We applied geostatistical techniques (modified Hough Transform (mHT) and an Iterative Mode Detection (IMD)) to a well-based dataset of approximately 10,000 RWA nests in correlation with known tectonic structures and further features, such as dike rocks and mineral veins, to test and statistically validate our hypothesis and thus establish new fundamentals with regard to tectonic pattern analysis.

2. Materials and methods

2.1. Location, tectonic settings

The Freiburg–Bonndorf–Bodensee Fault Zone (FBBFZ), a prominent large-scale tectonic structure in Southwest of Germany, is part of the European Cenozoic Rift System (ECRIS; Fig. 1a) and tectonically active since late Mesozoic-Cenozoic period (Müller et al., 2002; Marchant et al., 2005). The FBBFZ trending in WNW-ESE/NW-SE direction encompasses large faults and lineaments with a maximum length of 200 km and identified as well as inferred Permo-Carboniferous trough structures aligned in E-W direction which comprise blind, hidden boundary faults. At both ends of the FBBFZ the two Late Neogene volcanic fields Kaiserstuhl and Hegau are situated (Müller et al., 2002; Burkhard and Grünthal, 2009). Our two study areas within the FBBFZ are located near Freiburg in the Black Forest (BF; Schluchsee/Titisee; 170 km^2) and on the peninsula Bodanrück (BR; Lake Constance; 115 km^2). Both were affected by complex tectonic processes since the Paleozoic which are still persisting during the Cenozoic (Schreiner, 1992; Franzke et al., 2003; Véron, 2005).

The Black Forest study area with its Late Variscan basement is part of the WNW-ESE trending large-scale Badenweiler-Lenzkirch Zone (Sawatzki and Hann, 2003). The overall structural pattern of the Black Forest Massif and its surroundings is characterised by large ductile Lower Carboniferous shear zones (in NE-SW to E-W directions) and fractures (re-)activated in the Mesozoic-Cenozoic period. During the Neogene the direction of maximum tectonic stress changed from NE-SW to NW-SE/NNW-SSE (140–150°; Fig. 1b), resulting in right lateral strike slip along N-S/NNE-SSE trending faults (early Miocene), and in left lateral strike-slip along faults with directions between NNW/SSE and NNE/SSW (since late Miocene). Re-activations mainly occur in strike slip and oblique normal mode in dominant NW-SE and NNE-SSW directions (Franzke et al., 2003; Burkhard and Grünthal, 2009). In addition, NW-SE, E-W to WNW-ESE and also dominant N-S trending directions are developed (Sawatzki and Hann, 2003). Since the Late Oligocene, large-scale doming and erosion took place, resulting in a dissection of the crystalline base in Horst–Graben structures and the reactivation of old Paleozoic structures (Müller et al., 2002; Nagra, 2005). The present rates of the domal uplift, caused by Miocene transpression (Rotstein and Schaming, 2011), range between 0.2 and 0.6 mm a^{-1} (Schweizer, 1992; Franzke et al., 2003; Werner and Franzke, 2001; Burkhard and Grünthal, 2009; Schlatter, 2013). The eastern margin of the Upper Rhine Graben (URG), an approximately 5 km wide echelon rim, encloses normal to oblique faults with fracture-sealing mineral veins (Cretaceous to late

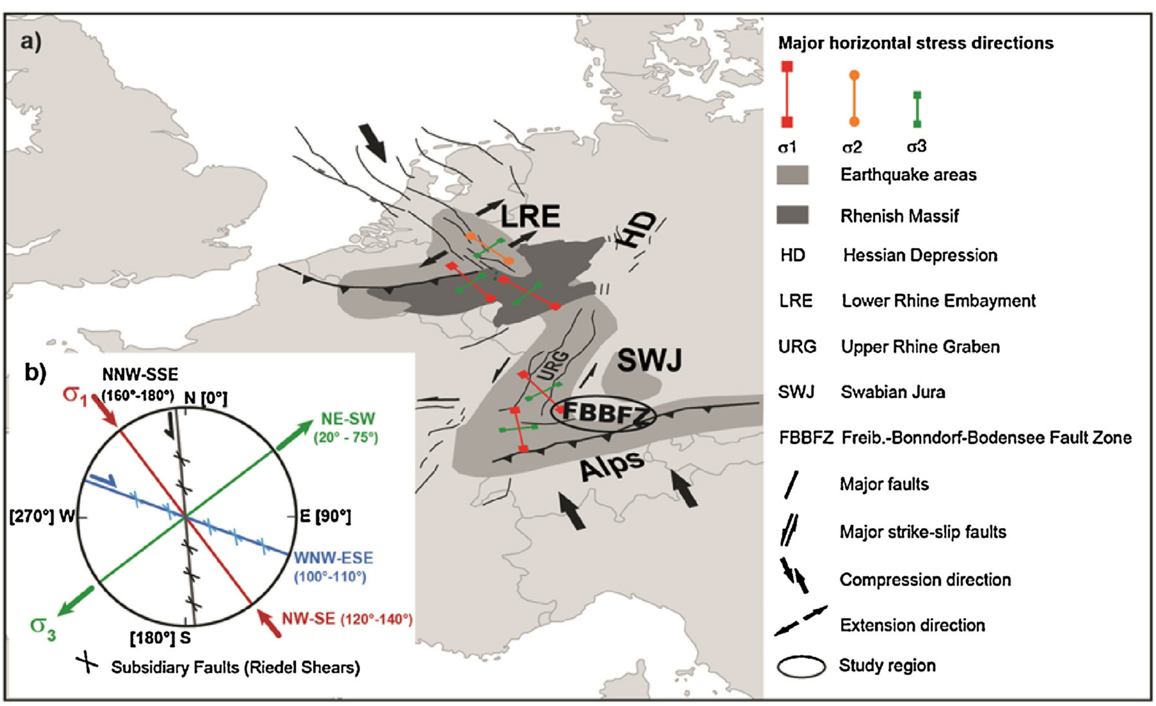

Fig. 1. Main tectonic features of the northern part of the European Cenozoic Rift System in Germany (a) with its simplified tectonic standard model (b) displaying the recent stress field (σ_1), its extension (rifting; σ_3) direction, conjugated shear systems and subsidiary fault systems (Riedel shears) (modified after Berberich, 2010; Hinzen, 2003). (For interpretation of reference to color in this figure legend, the reader is referred to the web version of this article.)