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Crustal vertical motion along a profile crossing the Rhine graben from the Vosges to the Black Forest Mountains: Results from absolute gravity, GPS and levelling observations

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Abstract

The Rhine plain is oriented north–south and limited by the Vosges Mountains (France) to the West and the Black Forest Mountains (Germany) to the East. The present-day tectonic evolution of this system is not well known and many questions are still pending: is the graben subsiding? Are the mountains uplifting? What is the relative behaviour of the three different geological components? In attempting to answer these questions, we compare for the first time in this region time series of absolute gravity (AG) measurements to the available GPS observations at three sites along a profile crossing the Rhine graben. Our reference station is the gravimetric observatory near Strasbourg (J9), located in the Rhine plain where AG measurements are performed regularly since 1997 and where superconducting gravimeter (SG) observations are available almost continuously for 17 years. The secondary sites are the Welschbruch station in the Vosges Mountains where six AG measurements have been conducted since 1997 and the Black Forest Observatory (BFO) where three AG measurements are available. GPS permanent receivers are collocated at the Strasbourg-J9 site since 1999, at the Welschbruch station since 2000, and at BFO since 2002. Levelling data are only available in the BFO region. We compare the long term content of two types of geodetic measurements with special emphasis on the trend despite the limited duration of our data sets. Assuming that the gravity changes are linear in time, we obtain $\dot{g} = 1.9 \pm 0.2\,\mu\text{Gal/yr}$ at Strasbourg-J9, $\dot{g} = -0.96 \pm 0.2\,\mu\text{Gal/yr}$ at Welschbruch site and $\dot{g} = 2.5 \pm 0.5\,\mu\text{Gal/yr}$ at BFO. The trends according to GPS observations are, respectively: -1.51 ± 0.07 and -0.74 ± 0.10 mm/yr at Strasbourg-J9 and Welschbruch site, respectively; there is no GPS result available at BFO. The AG results for BFO are very questionable, as well as the GPS observations at the Welschbruch station. Nonetheless, Strasbourg-J9 and Welschbruch AG measurements lead to subsidence and uplift, respectively, which are expected results in agreement with GPS at Strasbourg-J9.

Keywords: Absolute gravity; Gravity variations; Vertical displacement; GPS; Levelling; Rhine graben

1. Introduction and tectonic settings

The ultimate goal of this study is the determination of the absolute vertical displacement of the three components of the Rhine graben system (France and Germany) and their relative behaviour. The comparison of observations of (i)

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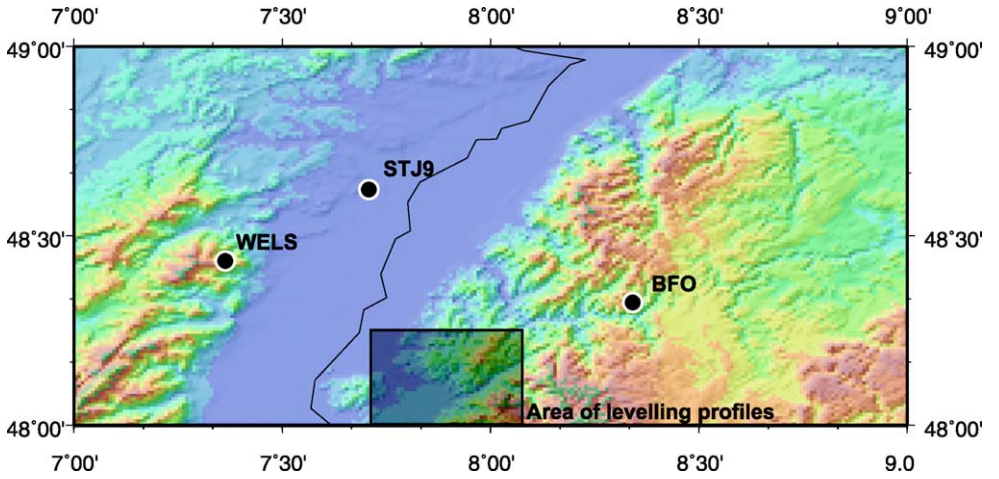

Fig. 1. The Rhine graben with the location of the three stations under study.

geometric data (GPS or levelling observations) and (ii) measurements of absolute gravity (AG) helps to separate the two effects, which may be involved: vertical displacement and mass variations. Different types of vertical movements have been analysed so far according to this methodology. Evidence has been given of post-glacial rebound (PGR) which is observed for many years, especially in the northern hemisphere: Canada (Lambert et al., 2001; Larson and van Dam, 2000), Greenland (Wahr et al., 2001), Spitzbergen (Sato et al., 2004), but also of rapid vertical displacement due to ice thawing (Larsen et al., 2004). Thanks to increasingly accurate and precise instruments, the survey of the vertical displacement of the crust in regions of low-level tectonic activity becomes possible. Low-level vertical displacements of lower amplitude have been monitored in Italy and Germany (Richter et al., 2004), Iran (Hinderer et al., 2003), and in the Ardennes (Camelbeeck et al., 2002; Francis et al., 2004a).

The main features of the so-called Rhine graben system (Fig. 1) are presented in Amalvict et al. (2004). They can be summarised as: (i) the graben itself with the Rhine river flowing from south to north (150 km long), (ii) the Vosges Mountains in France on the west side and (iii) the Black Forest in Germany on the east side. The total width of the graben is not more than 150 km.

The geodynamic context presents the Upper Rhine Graben as part of the complex Cenozoic rift system of Western and Central Europe that extends from the shores of the North Sea over a distance of some 1100 km into the western Mediterranean. It corresponds to a zone of elevated seismic activity and hazard, as evidenced by historical earthquakes, such as the 1356 event that destroyed the city of Basel located in the southern part of Rhine graben. The present-day tectonic evolution of this region is a challenging question on which authors do not agree. Is the graben subsiding and are the mountains uplifting? This question is still controversial and there are extremely few geodetic papers on the subject (Malzer and Schlemmer, 1975; Villemin et al., 1986).

Research institutes from France, Switzerland, Germany and Holland have agreed to initiate in January 1999 a 5-year joint multi-disciplinary research project that aims to provide a better understanding of the seismic hazard, neotectonics and evolution of the Upper Rhine Graben.

This project, called EUCOR-URGENT (Upper Rhine Graben evolution and tectonics), integrates all kinds of information provided by geological, magmatic, geophysical, geomorphologic, geodetic and seismological data. In particular, recent crustal movements, which are to a large extent unknown, will be tracked by geodetic and geomorphologic data.

A network of about 25 GPS stations has been installed recently in the Upper Rhine Graben in order to determine present-day displacement rates. In addition, it is also planned to determine any subsidence/uplift in this tectonically active region from repeated precision levelling (see, e.g. Lenôtre et al., 1999; Demoulin and Collignon, 2000 in another tectonic settings). This integrated GPS system is in operation and to our knowledge, no final conclusion could yet be inferred which is not surprising in view of the small observational period available and the small vertical rates which are expected. Nevertheless one can find interesting conclusions on the Freiburg region in Rózsa et al. (in press) (especially on vertical displacements).