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A Study of the Echzell/Wetterau Earthquake of November 4, 1975

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Abstract. The earthquake of November 4, 1975 at the Wetterau, South-West of the Vogelsberg volcano provides a first opportunity to infer the actual tectonic motion in that region. Beside the isoseismal map of the felt area with a rated maximum intensity of IV–V (MSK) a determination of the focal mechanism is presented.

The focal depth has been found to be 10–12 km by both instrumental and macroseismic determinations, providing an absorption coefficient $\alpha = 0.025$ in the latter case.

The source mechanism has been inferred from seismic observations and the fault pattern of the region. It represents a predominantly left lateral strike-slip faulting on a fault plane with the characteristics: strike N 18° W, dip 50° NE, slip vector 154°, dip 10°.

The relation of the Wetterau earthquake to the tectonics of te epicentral region implies that the NNW striking direction which is predominant at the Taunus mountains is to be found in the Wetterau through beneath the small "rheinisch", NNE-striking Horloff Graben at the southwestern Vogelsberg.

Key words: Faultplane solution – Seismotectonics upper rhine graben – Rhinish shield.

Introduction

The present seismic activity at the northern part of the Upper Rhine Graben is mainly confined to the graben proper. While seismicity is observed along the Middle Rhine Valley down to the Lower Rhine Graben, the so-called Hessian graben zone, north of Frankfurt is known to be seismically inactive (Ahorner 1975; Bonjer and Gelbke, 1976).

Data on historical earthquakes in the period between 1500–1960 (Sponheuer, 1962) indicate only one event of apparently low intensity near Giessen.

So the earthquake of November 4, 1975, 8^h30^m GMT, with its epicenter nearby Echzell in the Wetterau, therefore was the first known stronger event in that region and provides the opportunity to derive the present local tectonic movements. It has been felt over an area of about 4200 km^2. Furthermore this earthquake at the southern border of the Vogelsberg volcano has been recorded for the first time by a sufficient number of seismic stations to permit investigation of the focal mechanism of the event.

The epicentral zone is characterized by a structural pattern of two significant directions. There is strong evidence that the Upper Rhine Graben continues north of Frankfurt, represented by a system of NNE striking faults. On the other side NNW to NW striking faults will be observed in the inner, northern part of the Upper Rhine Graben and at the southern and eastern Taunus mountains (Anderle, 1974). This tectonic situation might be related to focal mechanism of the seismic event.

This paper is concerned with three topics of the Echzell/Wetterau earthquake. First the macroseismic information is compiled in a intensity map of the felt area. Furthermore the source mechanism is examined and the fault plane will be determined by means of the shape of the isoseismals. Finally the relationship of the tectonic structure of the epicentral region with the focal mechanism is discussed. The macroseismic and the microseismic observations appear to be in good agreement with the current structural concept of the epicentral region.

Macroseismic Observations

The Echzell/Wetterau earthquake of 4 November 1975 was felt over an area which is confined by the Taunus mountains in the west and the Spessart in the east. The felt area extended from Marburg in the north to beyond the Main river in the south. In order to determine the intensities in the epicentral region about 250 original reports have been examined and rated after MSK-intensities (Sponheuer, 1965). The results are shown in Figure 1.

The maximum intensity of IV–V has been assigned to the localities of Inheiden, Wölfersheim, Echzell, Effolderbach and Ortenburg. The assignment is based on the reports that most of the people have felt the earthquake within houses. Sleeping people woke up, houses vibrated. From Inheiden a broken window glass was reported. Nearly all observers in this region remarked on a rolling sound of the earthquake. Thus the maximum intensity can be restricted to an area of about 200 km^2. The intensity IV zone is well established. The location of the outer isoseismal II is less certain in the western and north-eastern parts as indicated by dashed lines. Especially in the north-western Vogelsberg all reports were negative. Thus from the extension of the intensity II zone, the maximum felt area can be derived to be about 4200 km^2.
All isoseismals indicate the trend of a N–S to NW–SE striking elongation. According to the inner isoseismals, IV and IV–V, a SSE strike with an average azimuth of 165° has been inferred. This feature will give the most consistent relationship to the strike of the probable fault plane. However the higher intensity isoseismals will certainly be influenced to a certain extent by the sediments of the Wetterau trough.

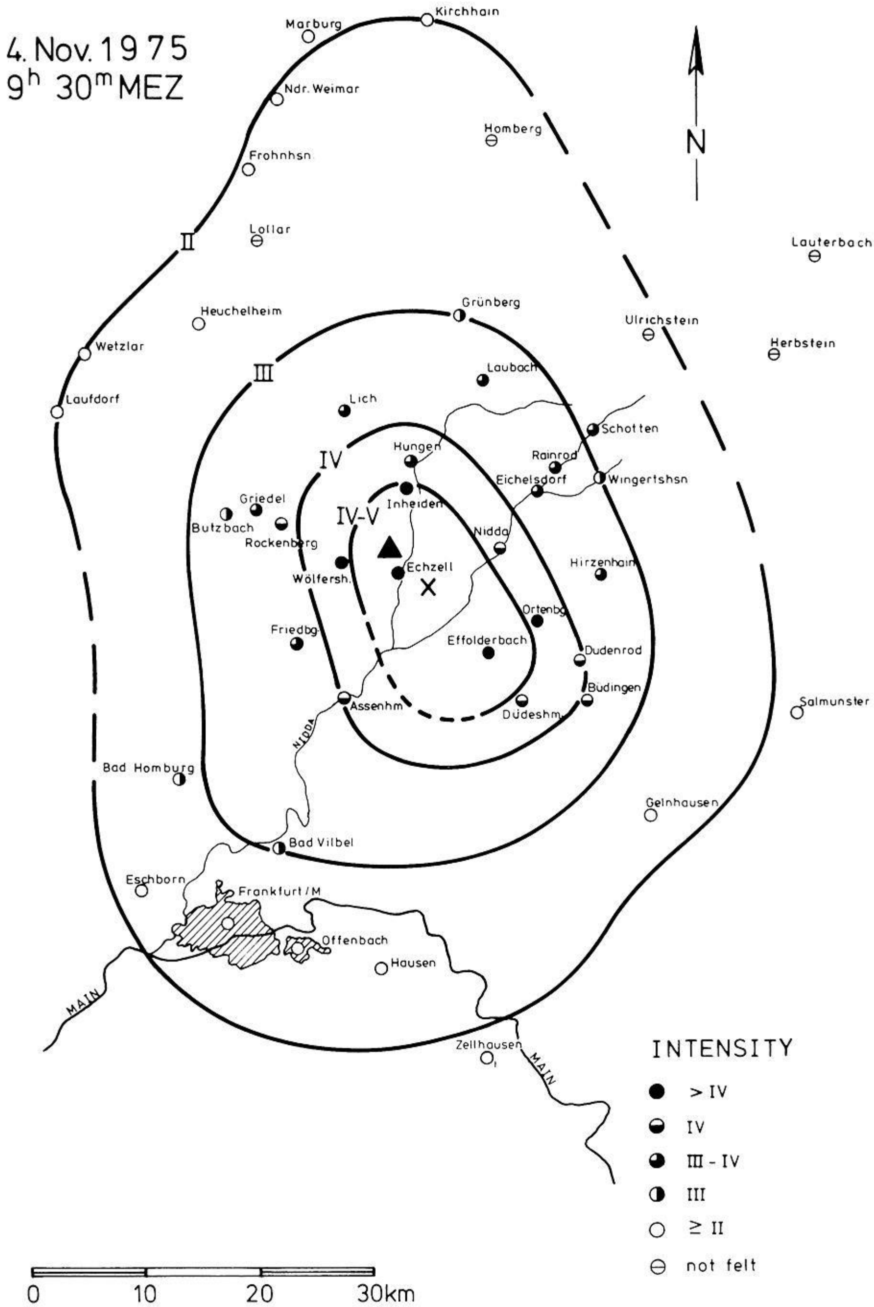

Fig. 1. Isoseismal map of the epicentral region of the Echzell/Wetterau earthquake. Intensities (MSK) are inferred from the reported observations (Sponheur, 1965). (▲) calculated epicenter, (×) macroseismic epicenter

Table 1. Intensities and their relation to spatial parameters

Intensity (MSK)	Mean isoseismal radii (km)	Isoseismal area (km^2)
IV–V	8.3	216
IV	13.0	531
III	22.3	1562
II	36.4	4160

The macroseismic center of the earthquake differs from the instrumentally determined one by about 5 km, taken along a NW–SE striking line. An attempt has been made to find the hypocentral depth of the seismic event by means of macroseismic intensity data. According to Sponheuer (1960) the attenuation of the observed intensities is to be represented as a function of the mean isoseismal radii. The best fit of this function to calculated curves allows the determination of the 'macroseismic' hypocentral depth for an assumed absorption coefficient. The required data of the Echzell/Wetterau event are listed in Table 1. Here the mean radii have been derived from the equal area circles of the isoseismals shown in Figure 1.

Providing an epicentral intensity $I_0 = \text{IV–V}$ (MSK), the best fit of the data suggest a focal depth of h = 12 km for an absorption coefficient $\alpha = 0.025$.

The coincidence of the 'macroseismic' depth with that instrumentally determined is not necessarily significant, as for an assumed epicentral intensity $I_0 = V$ (MSK) a focal depth of about 9 km, $\alpha = 0.025$ will result from the discussed procedure.

According to Karnik (1969) a macroseismic magnitude can be calculated from the empirical expression:

$$M_m = 0.5\, I_0 + \log h_0 + 0.35$$

where the depth is taken in kilometer. Therefore the intensity $I_0 = \text{IV–V}$ and the hypocentral depth $h_0 = 12$ km yield a macroseismic magnitude $M_m = 3.7$.

This value is very similar to the local magnitude based on recorded ground motions.

Focal Mechanism

The records of 26 Middle European seismic stations have been examined in order to study the focal mechanism of the Echzell earthquake. The *P*-wave arrival times are listed in Table 2. The calculated focal data are based on the assumption of an average crustal velocity depth function which is in reasonable agreement with the travel time date. The calculations have been carried out by use of the computer program HYPO 71 (Lee and Lahr, 1971) which has been modified by K.-P. Bonjer and C. Gelbke of the Geophysical Institute Karlsruhe. The used procedure basically minimises the residuals of the observed and calculated travel times.

Table 2. Microseismic data

Station	Epicentral Distance (km)	Azimuth (deg.)	Arrival time Pn	Pg
TNS	36.7	236		08:30:19.85
TRO	89.7	183	08:30:28.05	
HEI	113.0	185	08:30:32.60	
KLT	133.9	205	08:30:34.30	
BNS	134.8	297	08:30:34.40	08:30:35.20
GTT	147.8	31	08:30:35.60	
BUG	161.5	315	08:30:39.80	
STU	183.8	173	08:30:41.20	08:30:43.80
GRF	186.1	115	08:30:41.50	
CLZ	190.9	33	08:30:40.20	
MOX	196.4	82	08:30:42.40	08:30:44.20
BUH	198.6	194	08:30:43.0	
WLF	212.0	247	08:30:43.95	
SCH	234.6	190	08:30:47.50	
WLS	248.0	206	08:30:48.0	08:30:54.30
CDF	250.5	208	08:30:48.20	
FEL	288.8	193	08:30:53.35	
BUB	296.7	184	08:30:54.80	
CLL	307.3	71	08:30:55.40	
HBG	313.1	192	08:30:55.90	
BAF	317.6	206	08:30:57.0	
WET	321.0	116	08:30:58.90	
BSF	324.4	208	08:30:57.80	
HAU	324.6	215	08:30:57.60	
ZUL	327.7	186	08:30:58.40	
LOR	508.4	227	08:31:19.50	

Finally the resulting hypocentral parameters of the Echzell/Wetterau earthquake of the 4 November 1975 are:

Ho(GMT) = 8:30:13.37
Latitude = 50° 24.63′ N
Longitude = 8° 52.41′ E
Depth h = 11.4 km
Magnitude M_1 = 3.6

The epicenter is thus located between Echzell and Berstadt. The most significant tectonic feature in this area is the small NNE-striking Horloff Graben.

Based on the calculated radiation angles together with the observed polarities two alternative fault plane solutions A and B can be constructed, Figure 2. The data are represented by an stereographic projection on the lower focal hemisphere. P represents the axis of maximum compression and T that of least compression or tension while B indicates the intermediate stress component.

Both solutions clearly determine a strike-slip solution with left-lateral motion on the nodal planes striking towards the NNW. While solution A indicates

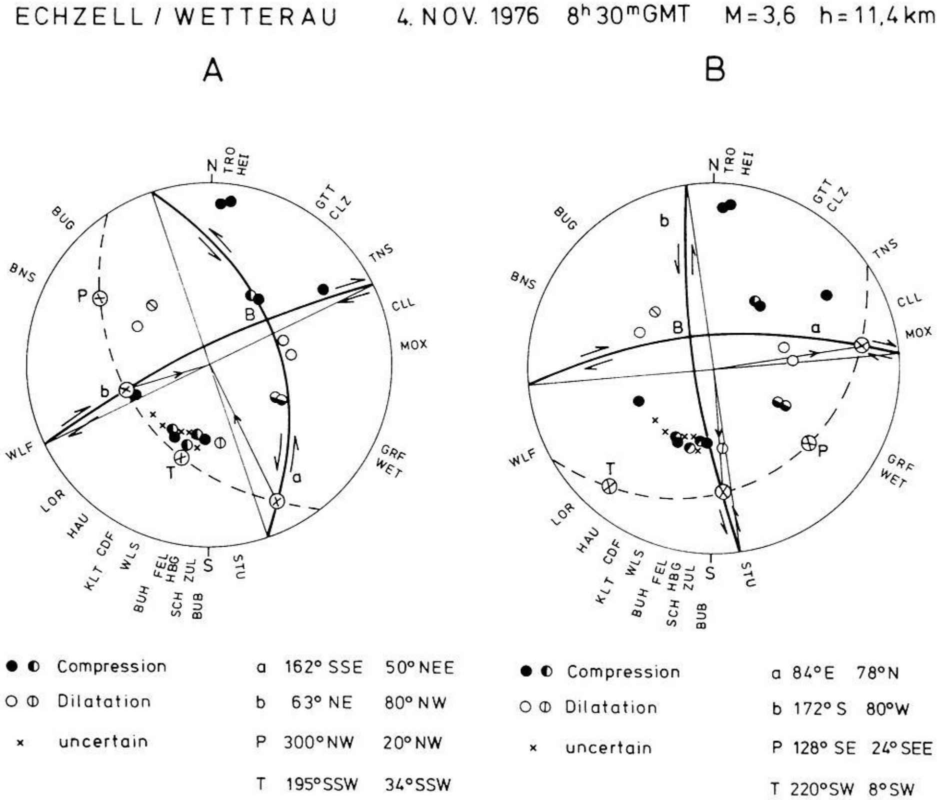

Fig. 2. Fault plane solutions of the Echzell/Wetterau earthquake. Alternative mehanisms A and B are based on the same compilation of data. Symbols indicate the quality of the data (●, ○ good. ◐ ⦶ less good). Our favorite choice is solution A: for explanation see text

an additional reverse component of motion, solution B shows a normal component beside the dominant strike slip.

The solution presented in Figure 2A differs from the one in Figure 2B in that the dilatational first motion at the station Stuttgart has been related to the south-western quadrant rather than the south-eastern quadrant. As the seismograms of the station Stuttgart showed only small dilatation, A will represent the most consistent solution. Although the case B might be a possible choice, it will be unlikely on account of the examined set of data. Beside the better consistence of polarity date solution A will even provide a more convincing explanation of tectonical features which will be discussed later. Hence, the expected motion is either related to the NNW–SSE striking nodal plane (a) dipping 50° NEE, which is a left lateral strike slip, with the slip vector: 154° azimuth, 10° dip or to the NE–SW striking plane (b) dipping 80° NW with right lateral strike slip, with the slip vector: 252° azimuth, 40° dip. According to the indicated *P* and *T* axis there is a component of reverse vertical displacement in addition to the dominant horizontal slip.

The southern border fault of the Taunus mountains is assumed to be a series of SW striking step faults (Anderle, 1974). Along the south-western continuation of this fault system Ahorner and Schneider (1974), Ahorner and Murawski (1975) found normal faulting focal mechanism at the southern Hunsrück mountains. Some evidence has been found indicating a continuation of this SW–NE striking structure into the southern Wetterau (Prüfert, 1975). However, the zone in question is located about 30–60 km south of the discussed epicenter. On the other hand, we have inferred a dominant strike slip motion in contrast to the dip slip along the step fault system. So the SW–NE striking nodal plaine (b) is not likely to be the fault plane of our solution.

Considering the prevalence of the NNW striking elongation of the high intensity isoseismals, it can be concluded that a close correlation between the orientation of the isoseismals and the NNW strike of the fault plane (a) exists. Thus the fault plane (a) of the mechanism A appears to be of major tectonic significance.

Based on the Magnitude M_1 of the examined earthquake, the seismic focal dislocation is found to be about 2 cm for an extension of the fault plane of about 1.2 km, from the relations given by Schick (1970). These numbers are of course rather rough estimates. As the determined strike of the fault plane is strongly related to a major regional fault system the tectonic implications of the event will be discussed in more detail.

Tectonic Implications

Small grabenlike structures as the Horloff Graben and the Nidda Graben reflect the NNE-strike of the Upper Rhine Graben in the Wetterau trough, Figure 3. These structures are regarded to be an extension of the Upper Rhine Graben north of the Main river although a continuous central graben does not exist. Schenk (1974) has shown by means of statistical analysis of the strike of magnetic anomalies, that the 'rheinisch', NNE striking direction is even evident beneath the Vogelsberg volcano. While the rhinisch direction is retained at the Wetterau and further north, NNE striking structures are nowhere found to extend to the Taunus mountains, as emphasized by Anderle (1974).

On the contrary, however, at the northern end of the Upper Rhine Graben a pronounced NNW to NW structural trend is superimposed on the rhinish direction. So a fault pattern at the inner graben, which extends from Darmstadt into the Idstein Depression in the Taunus mountains exhibits a turn from the NNE graben trend to the predominant NNW–NW striking structures of the Taunus. These structural features appear to be closely related to the subsidence of the graben fill, as the synclinal axis of the Quaternary and Tertiary sediments coincide with the above mentioned structural trend (Doebel, 1967; Bartz, 1974; Doebel and Olbrecht, 1974).
There is some evidence that these phenomena follow the trend of crust-mantle boundary elevation (Giese and Stein, 1971) and thus probably reflect an uplift of the crust.

The idea that the overall turn is controlled by deep reaching causes is supported by the great number of basaltic dikes of mainly Eocene age in the

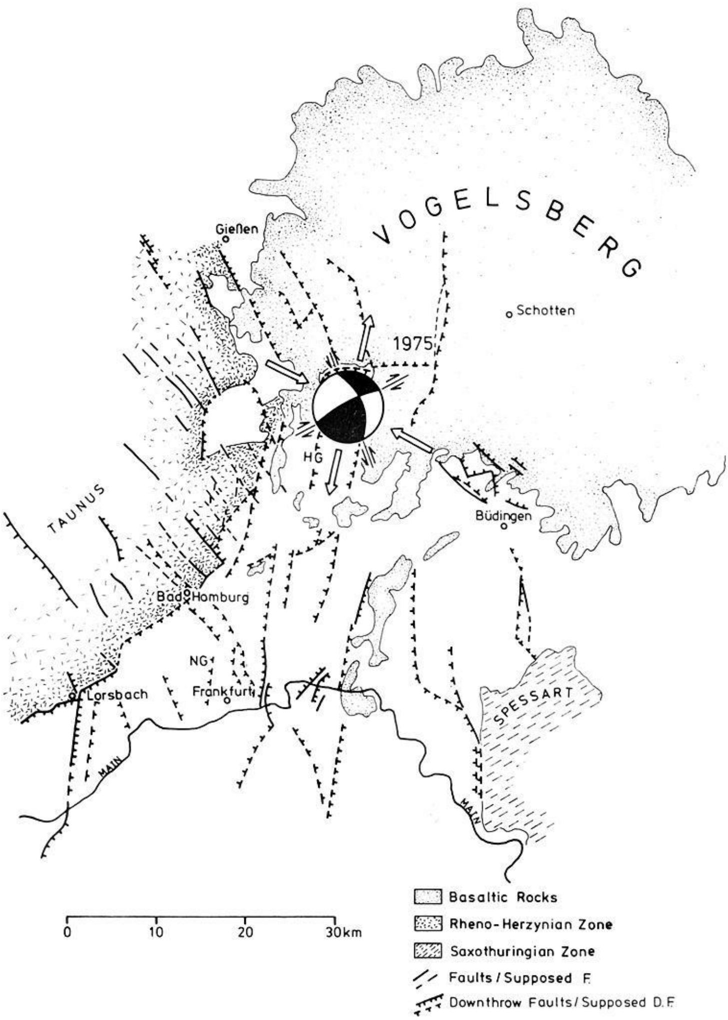

Fig. 3. Tectonic structure of te epicentral region after Anderle (1974). Fault plane solution A, 1975, this study. H.G.-Horloff Graben, N.G.-Nidda Graben

vicinity of the Upper Rhine Graben and the Taunus mountains (Horn et al. 1972; Lippolt et al. 1974; Anderle 1974).

Finally the observed spacial distribution of earthquake hypocenters of the Rhine rift region additionally reflect the discussed structural trend (Bonjer and Gelbke, 1976).

Focusing upon the epicentral region in question, the boundary between the eastern Taunus mountains and the Wetterau through indicate NNW striking block faulting, while south of the Vogelsberg NNE striking faults are predominant as pointed out.

From our determination of a NNW–SSE striking fault plane beneath the NNE striking Horloff Graben it can be concluded that the structural NNW striking trend of the eastern Taunus mountains extends into the Wetterau trough at the derived hypocentral depth of about 10–12 km, Figure 3. This appears to be of major tectonic significance indicating deep causes of the rotation of the NNE- to the NNW direction.

Both the strike and the position of the inferred fault plane of the Wetterau earthquake imply that the orientation of the plane might be affected by vertical crustal movements. This is supported by the number of focal mechanisms at the flanks of the Upper Rhine Graben and at the Rhinish Massif. They are predominantly of the strike-slip type while the corresponding fault planes are strongly grouped along the common line of evident crustal uplift (Ahorner, 1975; Bonjer, 1977). Thus the examined earthquake fits in the general seismotectonic pattern of the Rhine rift region although it is located at a somewhat isolated position with respect to the well-known active seismic regions. The observed stress field inferred from both fault plane solutions as well as in situ measurements is generally assumed to be related to the Alps. We think that the position of the hypocenters and their probable fault planes give some evidence that the influence of the Alps is superimposed on the tectonics of the crustal uplift of the region. This idea is supported by numerical investigations on the crustal uplift of the Rhine rift region (Neugebauer and Braner, 1977).

We can conclude from this study that in the Wetterau trough the tectonic motions take place seismically to some extent, with displacements of some centimeters or so. This does, however, not exclude nonseismic movements along the existing faults. In view of the lack of a pronounced seismicity in the Wetterau region, one might suggest that most of tectonic displacements are likely to occur aseismically there.

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