Tectonic Stress Field in Central Europe

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Summary. — Scheidegger's statistical method for the tectonic inter-
pretation of earthquake fault plane solutions is applied to recently published
solutions of earthquakes which occurred in two areas of Central Europe.
The results of the calculations show that in Southwestern Germany, east of
the eastern border of the Rhine Trench, the tectonic stress state is a ten-
sional one, while in Belgium it seems to be compressional. The P and T
directions, however, are very similar in both regions.

Riassunto. — Il metodo statistico di Scheidegger per l'interpretazione
tettonica del meccanismo dei terremoti all'ipocentro (" earthquake fault
plane solutions ") è qui applicato a recenti indagini di sismi occorsi in due
differenti regioni dell'Europa centrale. I risultati dei calcoli mostrano che
nella Germania sud-occidentale, ad Est del bordo orientale della fossa rena-
na, lo stato tettonico predominante è a carattere tensionale, mentre in Belgio
sembra essere a carattere compressionale. Tuttavia le direzioni delle com-
pressioni e delle tensioni sono molto simili in ambedue le regioni considerate.

Introduction.

It is a well known fact that the crust of the Earth is subject to a
" tectonic " stress state which may vary in its character from region
to region. It remains one of the more important problems in geophy-
sics to ascertain the precise nature of this stress state inasmuch as it is
not easily possible to measure underground stresses by direct means.
Thus, most of our knowledge of tectonic stresses has come from indi-
rect evidence, such as analyses of surface fault patterns, etc.

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One of the most promising alleys for investigating the regional tectonic stresses is based on seismic evidence. A statistical analysis of fault plane solutions of earthquakes yields directly the direction of greatest compression (P-axis), the direction of least compression (T-axis) and the axis of relative motion (normal to the intermediate principal stress [B] axis) in any one area (see Scheidegger, [9]). This statistical treatment of earthquake fault plane solutions has already given information about the tectonic stress state in various areas of the world [Scheidegger ([9]), ([10]), ([11]), ([12]), ([13])]. Recently, new sets of fault plane solutions have been calculated. These news solutions available make now possible a detailed study of some region previously not very well known from the point of view of seismotectonics. In this instance, the present paper deals with two areas of central Europe north of the Alps, namely Southwestern Germany and Belgium.

As to Southwestern Germany, eleven earthquakes which have occurred in the Southern Black Forest, in the southwestern part of the Swabian Jura, and in the western part of the Molasse Basin have been studied. The region in question is roughly confined between 47°-49° N and 7°-10° E. The references in the literature have been given by Hordejuk ([8]), Hiller ([5]), ([6]), and Schneider, Schick and Berckhemer ([14]). The directions of the P, T, and B axes have been calculated for each one of these earthquakes. The fault plane solutions are listed in Table I in the standard form employed by Fara ([1]). The key to the literature references is as follows:

1: Hordejuk ([8]);

2,3: Hiller ([5]), ([6]);

4,5,6,7,8,9,10,11: Schneider, Schick and Berckhemer ([14]). For the first three earthquakes, planes I and II have also been calculated. In seven out of the eight earthquakes studied by Schneider, Schick and Berckhemer ([14]), the B axis has been assumed to be vertical, and accordingly, the P and T axes have been assumed to be horizontal, since the Authors give no information about the dip of the B axis, but only the projections of the two nodal lines on the surface of the Earth and the horizontal directions of the P and T axes. Sometimes the nodal lines are not perpendicular to each other; this can be explained by a slight tilt of the force system. Another case in which the nodal lines were not perpendicular has been studied by Caloi ([2]). This earthquake occurred on October 18, 1936, and its epicenter was located near the town of Belluno, in north-eastern Italy; its epicentral

Table I – FAULT PLANE SOLUTIONS OF EARTHQUAKES IN SOUTHERN GERMANY

Date	Epicenter	P	T	B	Plane I	Plane II	No.
16.11.11	48.3N 009.1E 00	N75W38	S60E51	N21E07	N68W84	N63E 10 *D 1 1	1
08.02.33	48.8N 008.2E 00	N25W00	N65E00	N00E90	S70E90	N20E 90 S	2
27.06.35	48.1N 009.4E 00	S05E00	N85E00	N00E90	N50W90	N61E 90 S 0 1	3
02.05.43	48.3N 009.0E 00	N40W00	N46E00	N00E90			4
28.03.60	48.3N 009.0E 00	N43W00	N43E00	N00E90			5
19.04.61	48.1N 009.0E 00	N28W00	N63E00	N00E90			6
28.04.61	47.7N 007.9E 00	N38W00	N51E00	N00E90			7
27.03.65	48.1N 009.5E 00	N02W00	N88E00	N00E90			8
30.03.65	48.1N 009.5E 00	N03W00	N87E00	N00E90			9
25.05.65	48.1N 009.5E 00	N01W00	N89E00	N00E90			10
19.09.65	47.9N 008.2E 00	S23W10	N23E80	S67E00			11

coordinates are approximately 46° N and 12° E. It is interesting to note that the horizontal projections of the P and T axes are N 29° W and N 61° E respectively, i.e. very similar to those of southwestern Germany and Belgium. In earthquake (11) the B axis is horizontal, and the dips of the P and T axes have been calculated on the basis of a method proposed by Hiller ([7]).
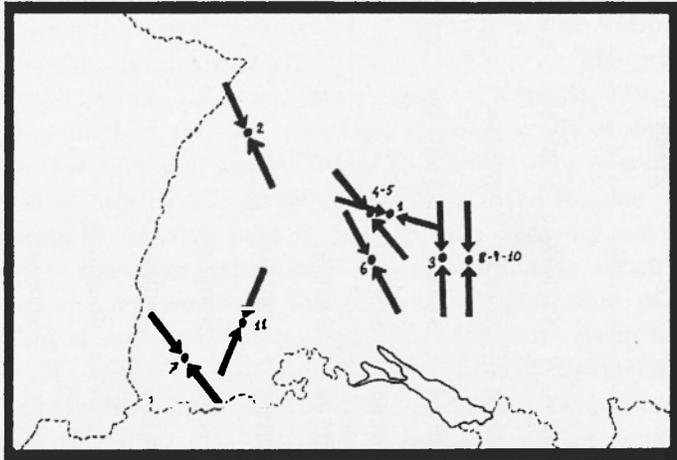

Fig. 1 – P-directions for earthquakes in Southwestern Germany.

Fig. 1 shows the P directions for each of these earthquakes which have occurred in Southwestern Germany.

The second region considered is Belgium. The area under consideration is roughly confined between 50°-52° N and 4°-6° E. The data have been calculated from information given in papers by Ahorner and Van Gils ([1]), and Van Gils ([15]). Three earthquakes have been taken into account, but, since in the earthquake of December 15, 1965, the foreshock and the main shock showed a completely reversed ground motion direction, four cases are listed in Table II. The key to literature references is:

12: Ahorner & Van Gils ([1]);

13,14,15: Van Gils ([15]).

Cases listed as (13) and (14) refer respectively to the foreshock and to the main shock of the above mentioned earthquake of December 15, 1965. For earthquake (12), planes I and II have also been calculated. The B axis has been assumed to be vertical in (13), (14),

Table 11 – FAULT PLANE SOLUTIONS OF EARTHQUAKES IN BELGIUM.

Date	Epicenter	P	T	B	Plane I	Plane I	No.
25.06.60	51.2N 005.7E 00 4.2	N00E00	N90E32	N90W58	N90E 77	N00E 00 *	12
15.12.65	50.2N 004.0E 00 4.4	N57W00	N33E00	N00E90			13
15.12.65	50.2N 004.0E 00 4.4	N33E00	N57W00	N00E90			14
21.12.65	50.4N 005.3E 00 4.4	N66W00	N24E00	N00E90			15

(15). Since these solutions are based upon recordings from Belgian stations only, they have no exaggerate claim of accuracy.

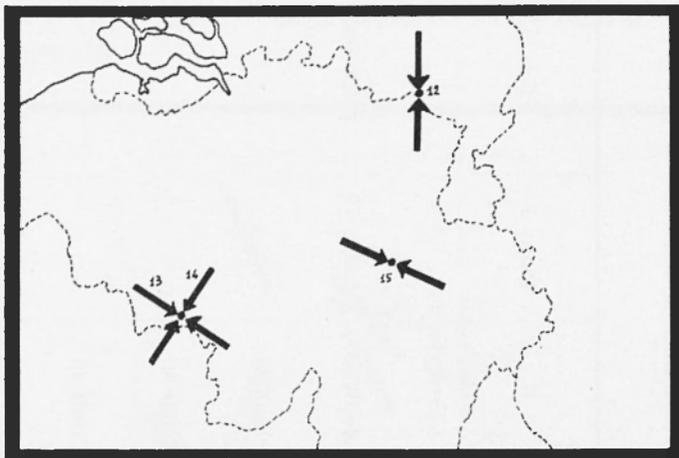Fig. 2 shows the P directions for each case.

Fig. 2 – P-directions for Belgian earthquakes.

TREATMENT OF DATA.

The fault plane solutions listed in Tables 1 and 2 have been treated by a statistical method developed by Scheidegger (⁹); the best fitting P, T, and B-normal axes have been calculated by an eigenvalue technique with the help of the University of Illinois IBM 7094-1401 Computer System. The B-normal axis has the sense of direction of motion; if it is more or less in the same direction of the best P axis, the tectonic area is a compressional one, in the other case, we are dealing with a tensional tectonic region.

Table III – RESULTS OF CALCULATIONS.

Area	No. of Quakes	Best P	Best T	Motion axis
Southwestern Germany	11	N19W 01	N70E 04	S60W 01
Belgium	4	N33W 00	N51E 10	N00E 00

The results of the statistical calcultations are shown in Table III. The mean stress systems in Southerwestern Germany and Belgium are plotted in Fig. 3.
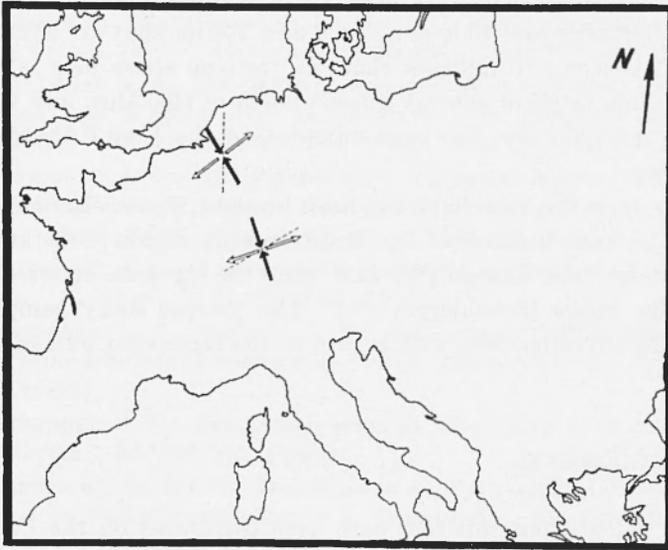

Fig. 3 – Mean stress systems in Southwestern Germany and Belgium (solid arrow: *P*-axis; blank arrow: *T* axis; dotted line: motion direction).

Results.

We shall consider separately the two geographical areas under consideration. In Southwestern Germany, all earthquakes under consideration have occurred in the region immediately east of the eastern border of the Rhine Trench, namely in intensely faulted areas (as the Southern Black Forest, and the western part of the Swabian Jura near the Hohenzollern Trench). Individual fault plane solutions show that both strike-slip and dip-slip motions are present in this zone [Schneider, Schick and Berckhemer ([14])]. The result of the statistical calculations points out that the stress system is a tensional one (the motion axis nearly coincides with the best fitting *T* axis). This is not unexpected in a border zone of a trench, and therefore this result is consistent with what one may reasonably infer from purely geological considerations.

As regards the Belgian region, it is to be again pointed out that the fault plane solutions are based on data from few seismic stations,

and, moreover, that the number of earthquakes is very small. Anyway, the result indicates that the area is one of compressional tectonic stress (the motion axis is closer to the P axis than to the T axis).

An interesting feature is observed in the fact that in both, Southwestern Germany and Belgium, the P and T directions are almost identical. This seems to indicate that the tectonic stress field is more or less the same in all of central Europe north of the Alps, and that it is only the intensity (i.e. the predominance) of the P or T direction that is different.

Very recently, new light has been brought, from seismic evidence, into the tectonic features of the Mediterranean region [Constantinescu, Ruprechtova, and Enescu (³)], and into the present stress state of the Alpine range [Scheidegger (¹³)]. The present study complements these other investigations with regard to the remaining part of Europe.

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