COMMENT ON THE "ANALYSIS OF THE STATE OF STRESS DURING THE 1997 EARTHQUAKE SWARM IN WESTERN BOHEMIA" BY A. SLANCOVÁ AND J. HORÁLEK (Studia geoph. et geod. 44(2000), 272–291)

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I think that the paper by *Slancová and Horálek (2000)* (hereinafter referred to only as SH) is confusing for the reader in several aspects and presents several misleading conclusions. In this Comment, I shall attempt to point out some of the controversial results of the paper and offer, according to my opinion, their corrected version.

1. HOW ARE THE FAULT PLANES OF THE A AND B EVENTS ORIENTED?

Horálek et al. (2000) show that the earthquakes of the January 1997 earthquake swarm are grouped into several types according to their waveforms, but two of them are predominant. The events of these types were denoted as the A and B events. *Fischer and Horálek (2000)* located the swarm events and found that the foci of the A and B events form clusters with different geometries (see Fig. 1). *Horálek et al. (2000)* and *Dahm et al. (2000)* selected 70 well-recorded events and calculated their moment tensors by inverting the P- and S-wave amplitudes. They found that the A and B events also differ in their mechanisms: the A events are oblique normal, while the B events are oblique reverse. Obviously, we are faced with the question, which of the two nodal planes in the mechanisms is the fault plane. SH try to answer this question on the basis of stress analysis. They applied this rather unreliable method (see Sec. 2) ignoring another more natural approach: a comparison of the geometry of the foci clusters with the focal mechanisms (see *Lund and Slunga, 1999*). The latter approach is, in particular, very suitable for application to swarm earthquakes, because of the high number of foci located. I performed this comparison and the results are shown in Fig. 2. For both types of events, one of the nodal planes almost perfectly coincides with the fault plane calculated by *Fischer and Horálek (2000)* from the clustering of foci. It coincides even with the orientation of the faults obtained by simple visual interpolation of the foci clusters (see Figs 1 and 2). Therefore, Figure 2 indicates that the A and B events are related to two nearly perpendicular fault systems. The strikes of the fault planes for the A events lie in the interval (290°, 315°) and for the B events in the interval (20°, 60°). This result, however, contradicts one of the conclusions made by SH.

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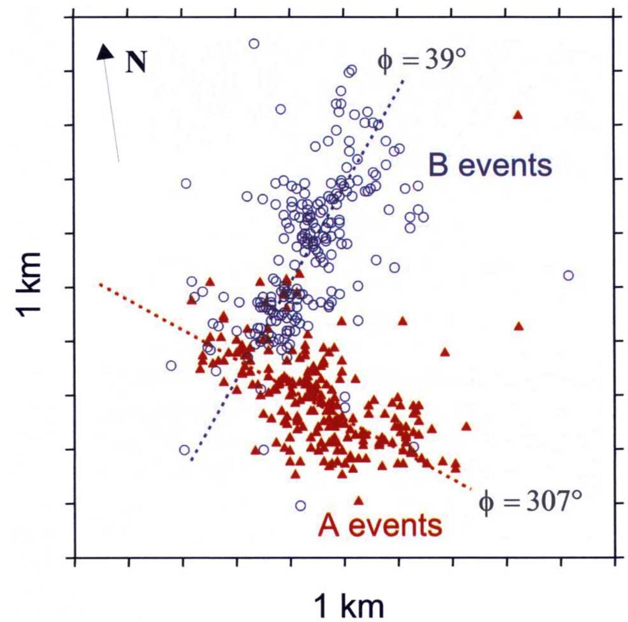

Fig. 1. The epicentres of the A (red triangles) and B (blue circles) events of the January 1997 earthquake swarm calculated by *Fischer and Horálek (2000)*. The dashed lines delineate the fault plane orientations estimated by visual interpolation of the foci clusters. Angle ϕ denotes the strike of the fault planes.

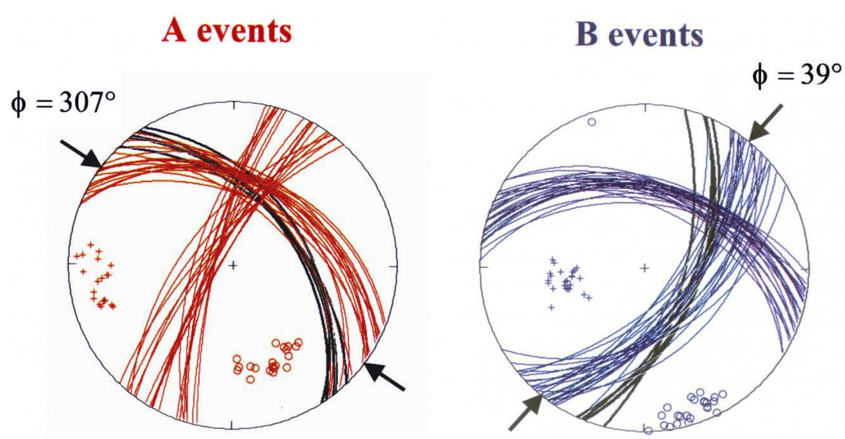

Fig. 2. Focal mechanisms of the A (red lines) and B (blue lines) events calculated by *Dahm et al. (2000)*. Black lines denote several alternative orientations of the fault plane calculated by *Fischer and Horálek (2000)* from foci clustering. Black arrows show the orientation of the fault planes determined by visual interpolation of foci clusters (see Fig. 1). Symbols 'o', and '+' denote the P- and T-axes, respectively.

2. HOW RELIABLE ARE THE FAULT PLANES PREDICTED FROM STRESS?

SH applied the *Gephart and Forsyth (1984)* method in determining the stress during the swarm. This method is very robust and produces reliable results providing that (1) the mechanisms are accurately determined, (2) we know which of the nodal planes is the fault plane, and (3) the dataset used consists of a variety of different mechanisms. If the fault plane orientation is not available, the algorithm can still produce some values of stress but with smaller resolution (*Michael, 1987*). The algorithm can also predict which of the two nodal planes is more likely to be the fault plane. However, these results can often be unstable, i.e. a small change of stress can result in selecting the incorrect nodal plane as the fault plane using the algorithm. Therefore, we should always be very careful in using this method for determining the orientation of the fault and, if possible, apply other methods. Of course, if we have independent information about the fault plane orientation, we should utilize it in the inversion, because it can significantly improve the reliability of the inverted stress tensor (*Lund and Slunga, 1999*).

From this point of view I think that the approach of SH is mistaken due to reverse logic. Instead of trying to determine the true fault orientation from the clustering of foci (see Fig. 1) and to take advantage of this information in obtaining the most reliable values of the stress tensor, they determine the fault orientations from unreliable values of stress. Obviously, if the inverted values of stress are incorrect, the fault orientations found will also be incorrect.

3. WHAT WAS THE STATE OF STRESS DURING THE SWARM?

SH present three possible alternatives for the stress in the region (A, B and C in their notation). They claim that the C alternative is the most probable because of its consistency with the European stress field. Nevertheless, the other two alternatives are also representative in some way and cannot be completely rejected, because "we do not have a comprehensive idea of the ratio of shear and normal stresses acting on fault planes" (SH). I cannot agree with SH and I think that the A and B alternatives of the stress (do not confuse with the A and B events) are simply false. They are very curious for several reasons. First, the σ_1- and σ_3-axes of these stresses are in directions quite different from the clusters of directions of the P- and T-axes for the individual mechanisms. Second, the directions of the σ_1- and σ_3-axes for the A and B stresses coincide with the intersection of all theoretically predicted fault planes (see SH, Fig. 3b, left-hand plots). It is well known, however, that the σ_1- or σ_3-axes located at a fault plane, or in its vicinity, produce no shear traction at the fault (see SH, Fig. 3b, right-hand plots). Hence it is very strange to propose a stress characterized by the σ_1- and σ_3-axes, which lie at the intersection of all predicted fault planes. In fact, this stress should be viewed as the less probable stress of the whole set of conceivable stresses. Third, I do not understand how SH obtained the A and B stresses predicting low values of misfit. I have tried to verify this also by using the *Gephart and Forsyth (1984)* method, but I obtained no low misfits for the A and B stresses (see Fig. 3). The only minimum of the misfit function is located in the area close to model C. The achieved average misfit of 8° seems to correspond reasonably to the estimated average error of the focal mechanisms. Therefore, I suspect that the A and B stresses are due to an error in the algorithm used, or due to the misapplication of this algorithm by SH. Note that Figure 3 demonstrates only the incorrectness of the minima in the misfit function for the A and B stresses found by SH. For reasons formulated in Sec. 2, I do not consider this stress to be very accurate. For a more accurate determination of the values of stress, see *Vavryčuk (2000)*.

Consequently, if we discard the false stress alternatives A and B, then also the fault planes predicted from the stress will be more similar to the results obtained from the foci clustering (see SH, Fig. 3b, left-hand lower plot).

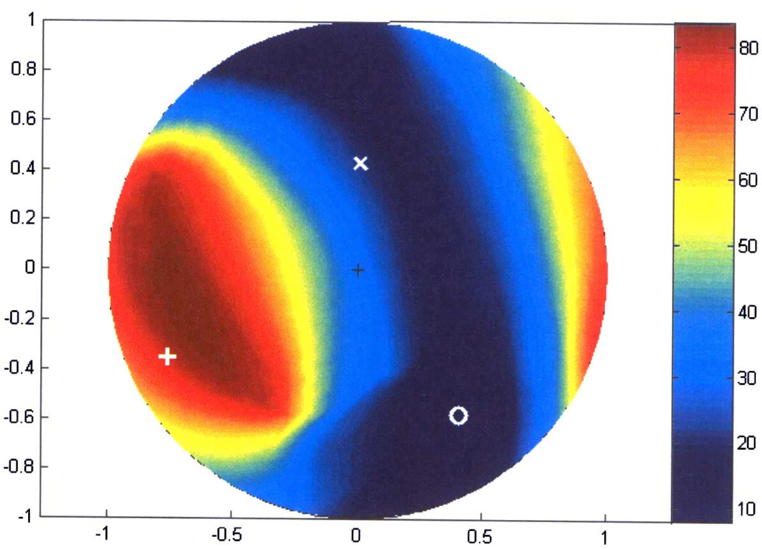

Fig. 3. Inversion for the stress tensor by the *Gephart and Forsyth (1984)* method. The misfit function (the average of the absolute values of the deviations between the slip and shear traction on the fault) for the σ_1 direction is displayed for the whole lower hemisphere. Symbols 'o', 'x' and '+' denote the optimum σ_1, σ_2 and σ_3 directions, respectively. No a priori information about orientations of fault planes has been used. The search was performed in a 5° grid of spherical angles φ and θ. The minimum misfit was 8°. The stress with the minimum misfit is defined by the following principal stress directions (plunge/azimuth): σ_1 = 30°/145°, σ_2 = 55°/1°, σ_3 = 17°/245°, and by R = 0.58.

4. DID THE STRESS CHANGE DURING THE SWARM?

SH speculate that stress model C could change into the A or B models during the swarm. They claim that "such variations of the stress magnitudes cannot be excluded, particularly in the middle phase of the swarm when the swarm activity culminated and its character dramatically changed." Unfortunately, SH bring no other quantitative evidence or indication to support their speculative conclusion. I cannot agree with their conclusion for the following reasons. Figure 2 shows the mechanisms of the A and B events. The A events in Fig. 2 cover the period from January 15, 1997 to January 19, 1997. The B events in Fig. 2 cover the period from January 16, 1997 to January 27, 1997. Hence the periods of occurrence of both types of events overlap. We can see that both families of mechanisms are very homogeneous, and their P- and T-axes are located in well-defined clusters. Neither were events with a different or anomalous positions of P- and T-axes detected, nor was a remarkable trend in the position of the P- and T-axes with time observed. But any significant change in stress (either in the orientation or in the relative size of the principal stresses) should generate the mentioned phenomena. Therefore, I conclude that the stress was consistent during the swarm and did not display any remarkable changes in time like those proposed by SH.

5. CONCLUSION

To summarize, SH applied a robust and complicated inversion method in calculating the stress field, in order to get more rigorous results than those obtained by other simpler methods. They present many pictures showing results for different confidence limits, for different datasets of mechanisms and also for datasets with differently fixed fault plane orientations. They even use a new statistical method for determining the true fault plane orientation from the retrieved stress. But they arrived, paradoxically, at results, which contradict even basic simple physical insight. It is surprising that the authors have ignored this fact.

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