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SKS Splitting observed at the Hungarian station PSZ - GEOFON Network

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***Abstract**: By using two different processing codes, a splitting analysis of SKS waves has been performed at the Hungarian Station PSZ – GEOFON Network. The obtained direction of the fastest splitted wave has the mean value of 141.2° ± 8.7° (95% confidence level) when the **ah_splitest2** code is used. The mean value of the delay time is 0.62 ± 0.12 seconds. By using a second code, the direction of the fastest splitted wave is 133.3° ± 8.6°. The corresponding mean value of the delay time is 0.73 ± 0.13 seconds. The results are discussed in relation to other stress indicators in the area and to the regional tectonic features.*

***Key words**: SKS Splitting, PSZ – GEOFON, Anisotropy, Stress*

INTRODUCTION

Splitting analysis of SKS (or SKKS) waves from large distant events (usually $\Delta \geq 87°$) is considered to be a valuable tool for investigating the anisotropy beneath the recording station. For the upper crust, the direction of polarization is usually associated to the average orientation of the cracks (e.g. Douma and Helbig, 1987). For the upper mantle, the coherent directions of the fast quasi-shear wave are assumed to be parallel to the direction of the fast crystallographic axis of the olivine (100). In both cases, information about the direction of the tectonic stress (orthogonal to the direction of the fast wave) is provided in the investigated area, mainly at the subcontinental mantle level. The delay time interval between the two splitted waves is correlated to the thickness and intrinsic anisotropy of the medium (e.g. Barruol and Mainprice, 1993). Mainly beginning with the paper of Vinnik *et al*. (1989), such investigations have been performed in various geographical areas (e.g. Wilegalla *et al*., 1999). Closed values of the anisotropy are usually obtained at stations placed at relatively confined distances, often similar to the results derived by various methods (e.g. Pn anisotropy or absolute plate motion vectors). In some cases, the SKS splitting analysis can be also satisfactory correlated to the break-outs stress values or to the local/regional tectonics inferred from earthquake fault plane solutions (e.g. Peacock *et al*., 1988, Crampin *et al*., 1990). In this paper, a splitting analysis is performed at the GEOFON PSZ station (47.919º N, 19.894º E), which is equipped with a BB STS-2 instrument.

DATA USED AND METHODOLOGY OF THE ANALYSIS

Recordings of 60 major earthquakes (IRIS magnitudes exceeding 6.0) in the time range 1995/01/01÷2001/01/24 have been web requested from the GEOFON Data Center (Archive and On Line Data Base), positive replays being obtained for 54 events. In each case, the wave forms have been carefully investigated and the arrival times for the most visible phases (P, Pdif, PKP, PP) have been checked with respect to the computed ones by using the IASP91 TTIM software (Buland and Chapman, 1983; Kennett and Engdahl, 1991). Routinely, the O-C values do not exceed 2-3 seconds. Only 32 events displaying clear SKS or SKKS arrivals have been selected (Fig. 1). However, the particle motion tool of **PITSA** (Scherbaum and Johnson, 1992) has been further used in each case in order to identify exactly the wave arrival. In an ideal case, the particle motion describes a complete ellipse for a full period of the SKS wave. Consequently, a time window equal to a quarter of the wave period should be theoretically sufficient to recover the splitting information carried out by the wave. By checking the quasi-monochromatic aspect of the wave and its quasi-elliptical polarization along the approximate source to receiver path, an optimum width of the time window has been selected (Fig. 2). These values are in the range 3.5÷28.5 s. Events displaying improperly polarized ellipses have been excluded. Finally, only the 24 events listed in Table 1 have been processed. The analyzed sequences are exceptionally clear ones. Consequently, in only a limited number of cases, a zero-phase

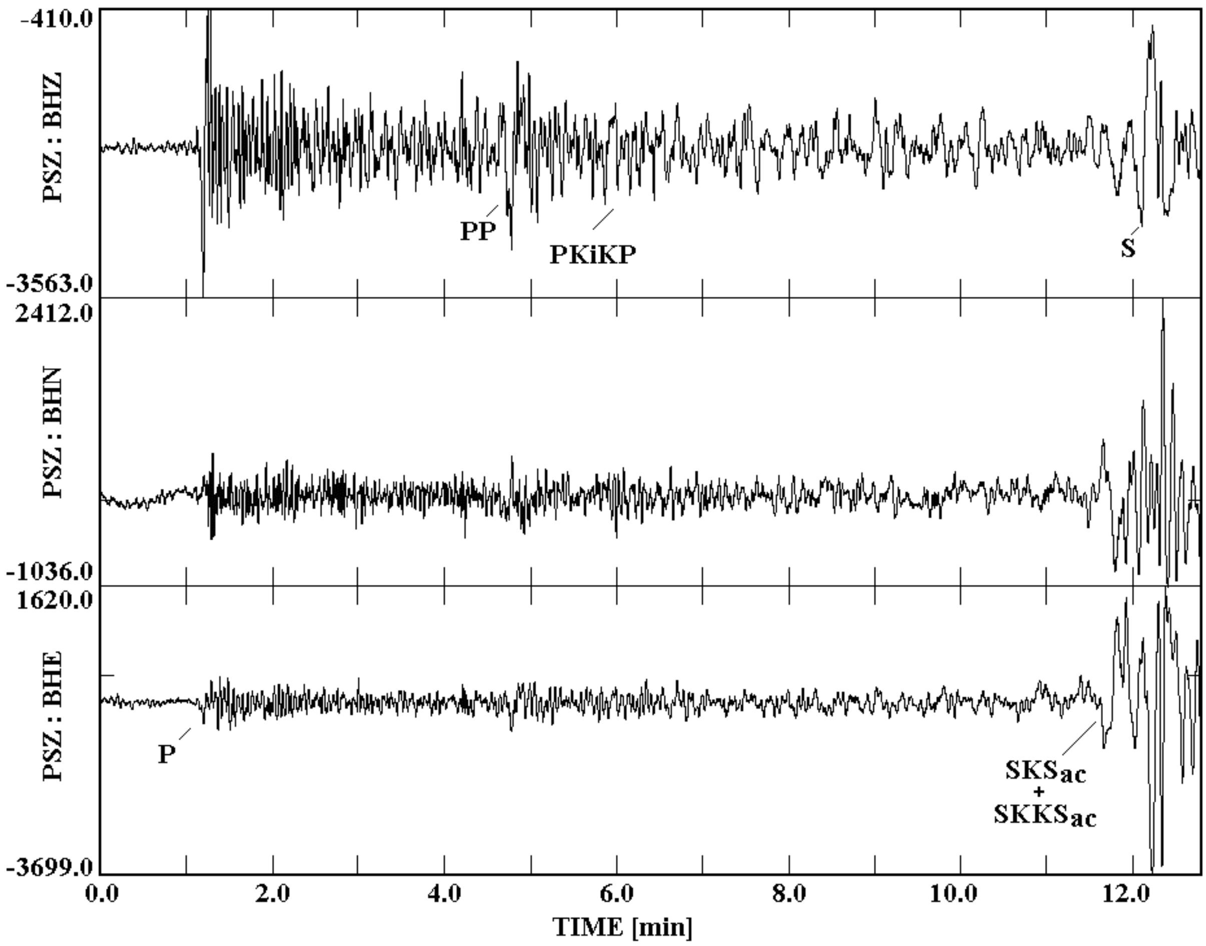

FIG. 1. PSZ record of 1999/07/11 event (see Table 1 for details). Most visible phases are indicated.

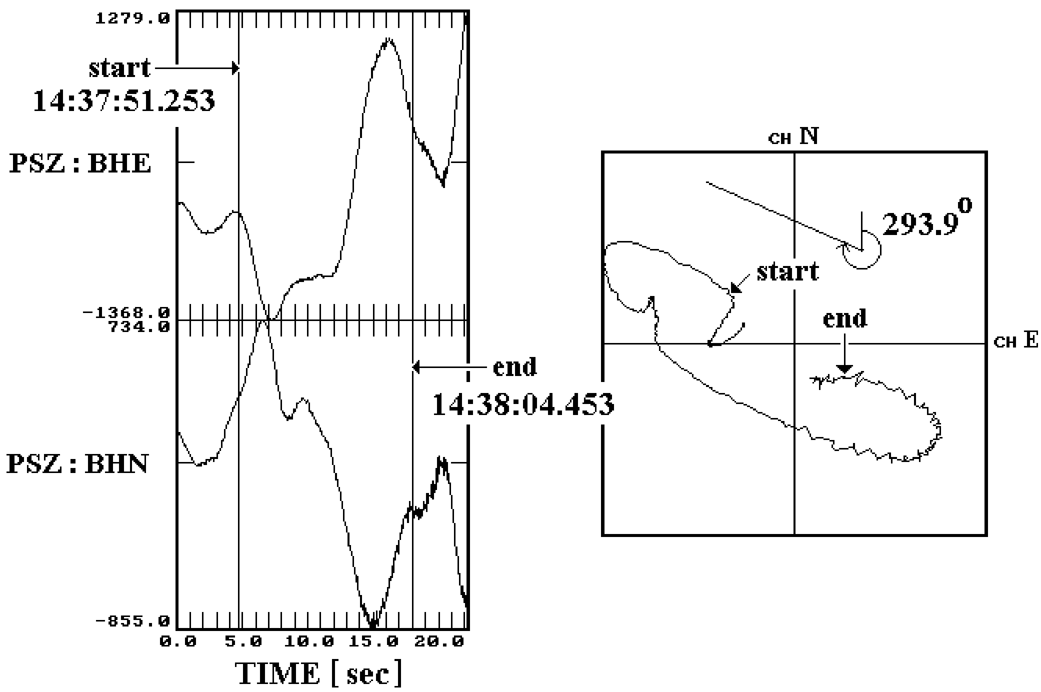

FIG. 2. Particle motion corresponding to the SKSac arrival from Fig.1. The beginning and the end of the processed time window are indicated. No filtering.

Table 1. Events parameters used in this study (source: IRIS catalogue). The fastest wave direction (D) and the time delay (dT) are also listed for each event. The first values are derived by using the **ah_splitest2** code, together with the corresponding errors. The second values have been obtained by using the code presented by Ivan (2000). The length of the processed window is indicated too in each case.

DATE	TIME	REGION wave	M	LAT	LON	H	Δ (°)	bAz (°)	D (°)	D_error (°)	DT s	dT_error s	window (s)
950306	184340.17	Celebes SKKSac	6.	2.686N	118.222E	16.7	93.6	82	129 137.8	21.29	0.33 0.62	0.09	3.6
951225	044323.16	Banda Sea SKKSac	6.2	6.9207S	129.2035E	133	108	80	169.7 143	53	0.17 0.68	0.15	5
961231	124140.93	Mexico SKSac	6.1	15.7779N	93.0423W	90	92.8	297	173.64 175.84	14.76	0.48 0.48	0.19	7.3
970111	202839.10	Mexico SKSac	7.1	18.27N	102.51W	45.8	96	306	171.2 137.64	6.57	0.23 0.71	0.07	22.65
970123	021533.10	Jujuy SKSac	6.4	22.03S	65.85W	285.3	103.4	252	127.84 143.79	24.44	0.57 0.76	0.5	4.2
980521	053425.50	Minahassa SKSac	6.2	0.207N	119.584E	33	96.3	83	122.83 158.87	13.72	0.43 1.11	0.21	6.15
980522	044850.44	Bolivia SKSac	6.5	17.731S	65.431W	24	100.	255	118.33 131.24	29.39	0.54 0.34	0.22	7.35
980902	083739.91	Mindanao SKKSac	6.7	5.41N	126.764E	50	97.1	74	118.99 148.85	12.46	0.46 1.19	0.19	12
990206	214759.47	Santa Cruz SKKSac	7.3	12.853S	166.697E	90.1	135.4	49	159.08 157.78	29.19	0.11 1.16	0.17	3.5
990331	055442.13	Panama SKSac	6.0	5.827N	82.616W	10	94	283	156.86 126.58	6.74	0.86 0.36	0.13	11.4
990403	061718.36	Peru SKSac	6.2	16.66S	72.662W	87.2	104	260	147.82 103.05	13.56	0.88 0.68	0.33	11.25
		SKSdf							131.45 87.68	25.65	0.65 0.78	0.2	16.55
990615	204205.93	Mexico SKSac	6.5	18.386N	97.436W	70	93	302	169.23 129.96	9.11	0.15 0.25	0.08	16.25
990618	105525.75	Mindanao SKSac	6.1	5.514N	126.639E	33	96.9	74	119.32 134	7.67	1.16 0.53	0.21	4.8
990711	141416.53	Honduras SKSac	6	15.782N	88.33W	10	90	294	167.37 140.27	5.23	0.76 0.51	0.1	13.2
990812	054459.59	Indonesia SKSac	6.0	1.716S	122.456	33	99.7	82	152.49 146.1	14.9	1.2 0.95	0.36	7.45
990814	001652.29	Sumatera SKSac	6.0	5.885S	104.711E	101.4	90.9	98	148.13 128.75	6.12	0.59 0.67	0.1	11.35
990820	100221.10	Costa Rica SKSac	6.1	9.044N	84.159W	20	92.5	286	152.52 120.7	7.4	0.97 0.33	0.22	21.55
990915	030124.32	Bolivia SKSac	6.1	20.934S	67.275W	218	103.5	254	128.07 116.14	12.19	0.91 0.79	0.17	7.9
991221	141457.61	Sunda SKSac	6.2	6.845S	105.555E	56	92.2	98	122.02 165.83	8.82	0.49 1.14	0.08	5
		SKKSac							115.07 160.39	10.63	0.5 1.42	0.11	5.65
000423	092723.32	Argentina SKSac	6.9	28.307S	62.99W	608.5	106.2	245	105 131.16	13.6	0.63 0.45	0.13	4.8
		SKKSac							126.09 85.84	12.9	0.46 0.43	0.12	5.7
000512	184323.8	Jujuy SKSac	7	22.988S	66.743W	244.1	104.7	252	105.84 113.97	14.65	0.81 0.85	0.31	24.75
000618	144413.31	S Indian SKSac	7.5	13.81S	97.41E	10	92	108	164.07 140.74	7.44	0.7 0.61	0.12	10.55
001108	065959.03	Panama SKSac	6.3	7.052N	77.885W	17	89.9	280	163.89 114.54	6.71	0.49 1.3	0.08	9.9
010113	173332.38	Salvador SKSac	6.4	13.049N	88.66W	60	92.3	292	147.02 119.96	41.28	1.15 0.54	2.06	28.5

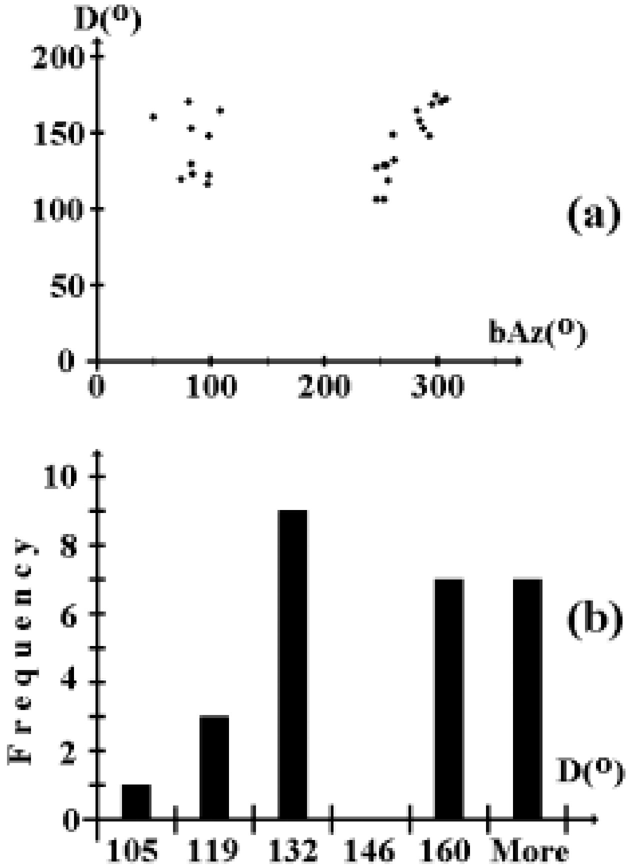

FIG. 3. The directions D of the fastest waves versus back azimuth bAz (a) and the corresponding histogram (b).

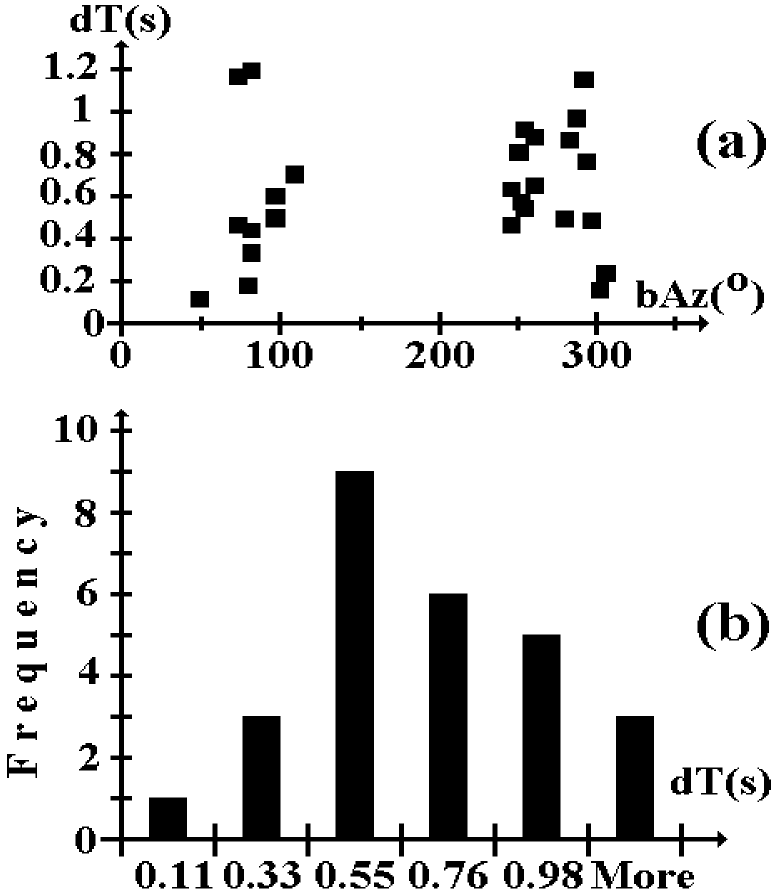

FIG. 4. The time delay dT versus back azimuth bAz (a) and the corresponding histogram (b).

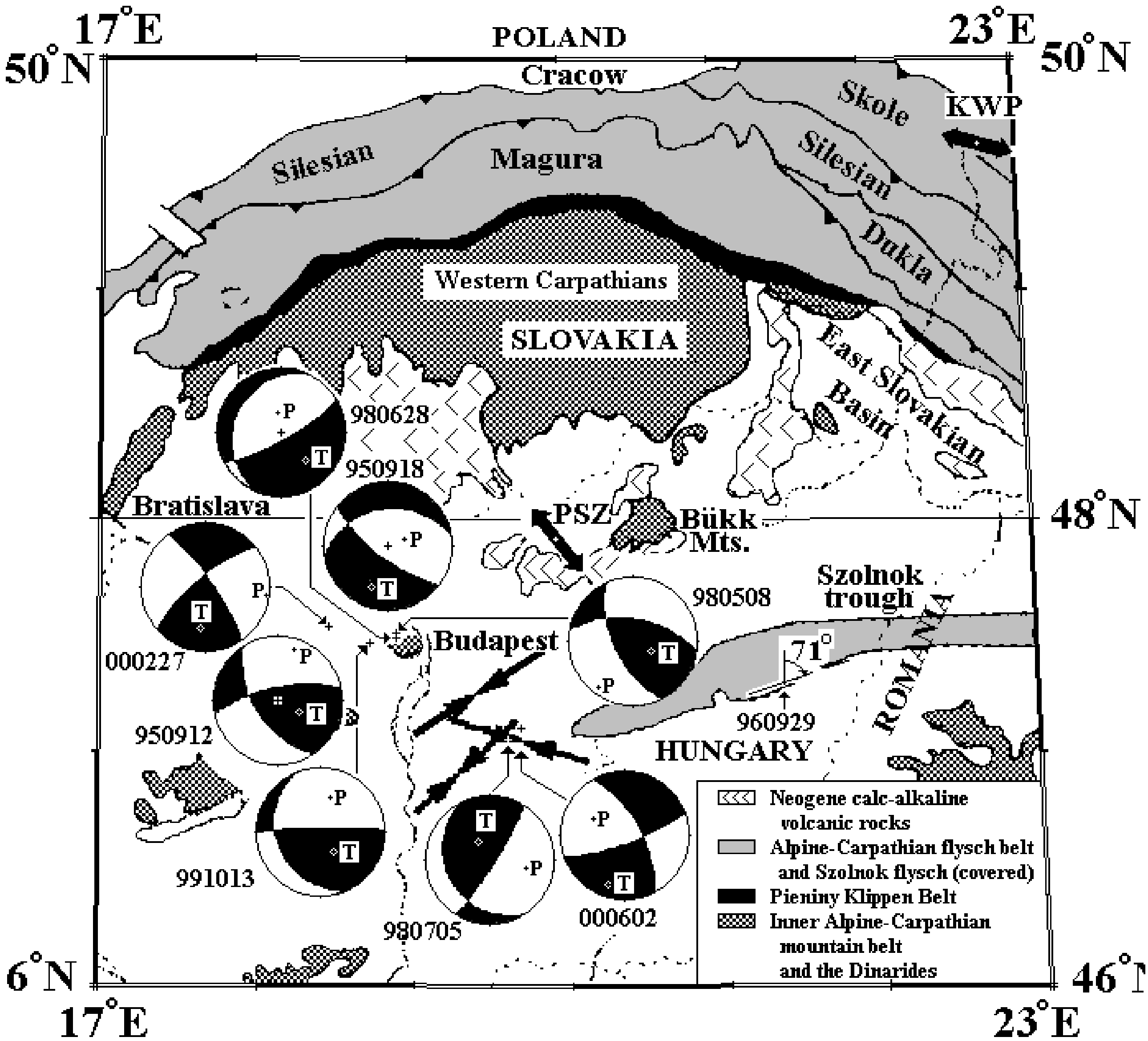

FIG. 5. Geologic map of the Pannonian area (modified after Csontos and Nagymarosy, 1998). Fault plane solutions are presented for the main events in the area of the PSZ stations. Thick arrows show several breakouts stress orientation.

Butterworth band-pass filter (0.0333÷0.333 Hz at 3 sections) has been used. The corresponding SEED window strings have been saved into ASCII format and converted into the AH format by using the ASC2AH code. The splitting analysis has been performed by using the ah_splitest2 code (Levin *et al.*, 1999). By minimizing a LSQ norm, a robust treatment of the noise has been performed. The output of the code is represented by the most probable values of the direction of the fast splitted wave and by the time delay, together with the corresponding 1-σ errors. Signal to noise ratio values for both channels and a cross-correlation coefficient are provided too. They allow one to estimate the quality of the derived values. The results are presented in Figs. 3 and 4. The obtained direction of the SKS (21 values) or SKKS (6 values) fastest splitted wave has the mean value of 141.2° ± 8.7° (95% confidence level) and a standard deviation of 21.9°. The mean value of the delay time is 0.62 ± 0.12 seconds (95% confidence level), with a standard deviation of 0.3 seconds. Exactly the same data strings have been processed by using a code described by Ivan (2000). The direction of the fastest splitted wave has the mean value of 133.3° ± 8.6° (95% confidence level) and a standard deviation of 21.7°. The mean value of the delay time is 0.73 ± 0.13 seconds (95% confidence level), with a standard deviation of 0.32 seconds.

RESULTS AND CONCLUSIONS

The values obtained in this study are similar to the directions of the fastest splitted wave and to the delay times reported in the area. They are 99.3° ± 4.3° and

0.82 ± 0.38 seconds at KWP (49.631º N, 22.708º E) and 104.9° ± 2.3° and 0.75 ± 0.16 seconds at KSP (50.843º N, 16.293º E), on the outer border of the Carpathian Arc (Wiejacz, 2000). In the KWP area, the observed polarization of the Pn waves is around 127º (Smith et Ekström, 1999). Makeyeva et al. (1990) reported a fast direction of 100º and a time delay of 1.1 seconds at KHC (49.131º N, 13.578º E), where a direction of 137º is also available for the absolute plate motion vector (Minster and Jordan, 1978). At a local scale, a stress orientation at an azimuth of 51.2° ± 8.7° is well correlated to some fault plane solutions derived in the area and to some sparse observations of the breakouts orientation (Fig.5) (Tóth et al, 2001). The spatial location of the aftershock sequences associated to the main events from 1996/09/29-30 (ML=2.1÷3.1) and 1999/10/13 (ML=0.5÷1.8) seems also to support that assumption. Also, it is very closed to the local trend of the Mid-Hungarian line, having an azimuth of approximately 48° (Csontos and Nagymarosy, 1998).

The estimated value of the delay time seems to exceed the eventual contribution of the crust, having an upper limit of 0.1 s per 10 km of crustal rocks (Barruol and Mainprice, 1993; Barruol and Kern, 1996). Consequently, it is a result of both crustal and upper mantle anisotropy beneath PSZ station.

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