Doklady Earth Sciences, Vol. 387A, No. 9, 2002, pp. 1063–1066. Translated from Doklady Akademii Nauk, Vol. 387, No. 4, 2002, pp. 528–532.

GEOPHYSICS

Lithospheric Inhomogeneities and Strong Earthquake Sources in the Central Tien Shan Region

Yu. F. Kopnichev[1], G. Pavlis[2], and I. N. Sokolova[1]

Presented by Academician V.N. Strakhov May 22, 2002

Received June 4, 2002

Mapping of the shear wave attenuation field in the lithosphere of the Central Tien Shan region was carried out on the basis of deep-focus Hindu Kush earthquakes registered at more than 40 digital and analog stations. An intense attenuation stripe related to sources of two strongest earthquakes (M ≥ 7.0) in the Tien Shan region since the middle 1970s was distinguished in the western part of the area. It has been established that the structure of the lithospheric attenuation field substantially changed over 10–20 years. The data obtained can be attributed to an intense rearrangement of the fluid field in the Earth's crust and upper mantle, related among other things to the preparation of strong earthquakes.

Recent data on the important role of mantle fluids in the preparation of strong crustal earthquakes [1–3] indicate that characteristics of the attenuation field of short-period shear waves can be successfully used in the future for long-term and middle-term predictions. Only the electrical conductivity of rocks is comparable with the attenuation of *S* waves in terms of sensibility to the liquid phase [4]. The aim of the present work is to study spatiotemporal variations of the lithospheric attenuation field in the Central Tien Shan and compare them with the seismicity of the region the last 20–25 years.

The study region (39°–45° N and 73°–81° E) comprises a substantial part of the Central Tien Shan region along with the southern margin of the Kazakh Platform in the north and the northwestern margin of the Tarim massif in the south (Fig. 1).

We used the records of deep-focus Hindu Kush earthquakes obtained by 27 PASSCAL digital stations and 11 KNET digital stations of the Kirgiz telemetric network in 1997–2000, as well as in 4 analog stations (CKM-III) in 1976–1999. The analysis of Hindu Kush earthquake seismograms is convenient, since it allows us to obtain representative experimental material for a relatively short time period. In total, we processed about 500 earthquake records at the depth of 190–230 km and an epicentral distance (Δ) of 500–1100 km.

The frequency filtration of vertical components was carried out during the analysis of digital records. We used a filter similar to the corresponding FSSS filter with the following parameters: central frequency = 1.25 Hz, width = 2/3 octave at the level equal to 0.7 of the maximum [5]. Analog seismograms were preliminarily scanned with the assistance of a wide-frame scanner and digitized at the frequency of 40 Hz.

For analyzing the attenuation field characteristics, we used two parameters: logarithm of the ratio of maximum amplitudes in *S* and *P* waves (*S*/*P*), as well as logarithm of the ratio of maximum in the *S* wave to the coda level at $t = 400$ s, where t is counted from the lapse time (*S*/*c*400). Maximal amplitudes were measured during the 10-s interval from the arrival time for longitudinal waves and the ±10-s interval from the *S* wave arrival time on the travel-time curve for shear waves.

In the considered range of epicentral distances for hypocenters located at the depth of ~200 km, direct *P* and *S* waves fall onto the M boundary at sufficiently low angles and intersect the crust at $i_k \sim 46°–49°$. (For the simplest two-layer model of a medium with the *S* wave velocity in the crust and upper mantle equal to 3.5 and 4.6 km s^{-1} [6], respectively, the ray angle with the vertical is equal to $i_m \sim 71°–82°$.) Taking into account *S*/*P* values, which can substantially differ even for close stations, as well as earlier results of the attenuation field mapping for the northern Tien Shan region [7], one may assume that the *S*/*P* parameter mainly characterizes the attenuation of shear waves at the distance of 30–60 km southwest of the relevant stations in the Earth's crust (first of all, in its lower part at the depth of 30–55 km) and the uppermost mantle.

It was shown in [8, 9] that the *S* coda of Hindu Kush earthquake records was mainly formed by shear waves reflected from numerous subhorizontal boundaries in the upper mantle. In this case, as time elapses, *S* waves on the coda intersect the lithosphere and asthenosphere at more and more acute angles. Hence, parameter

[1] *Schmidt Joint Institute of Physics of the Earth, Russian Academy of Sciences, Bol'shaya Gruzinskaya ul. 10, Moscow, 123810 Russia*
[2] *Indiana University, USA*

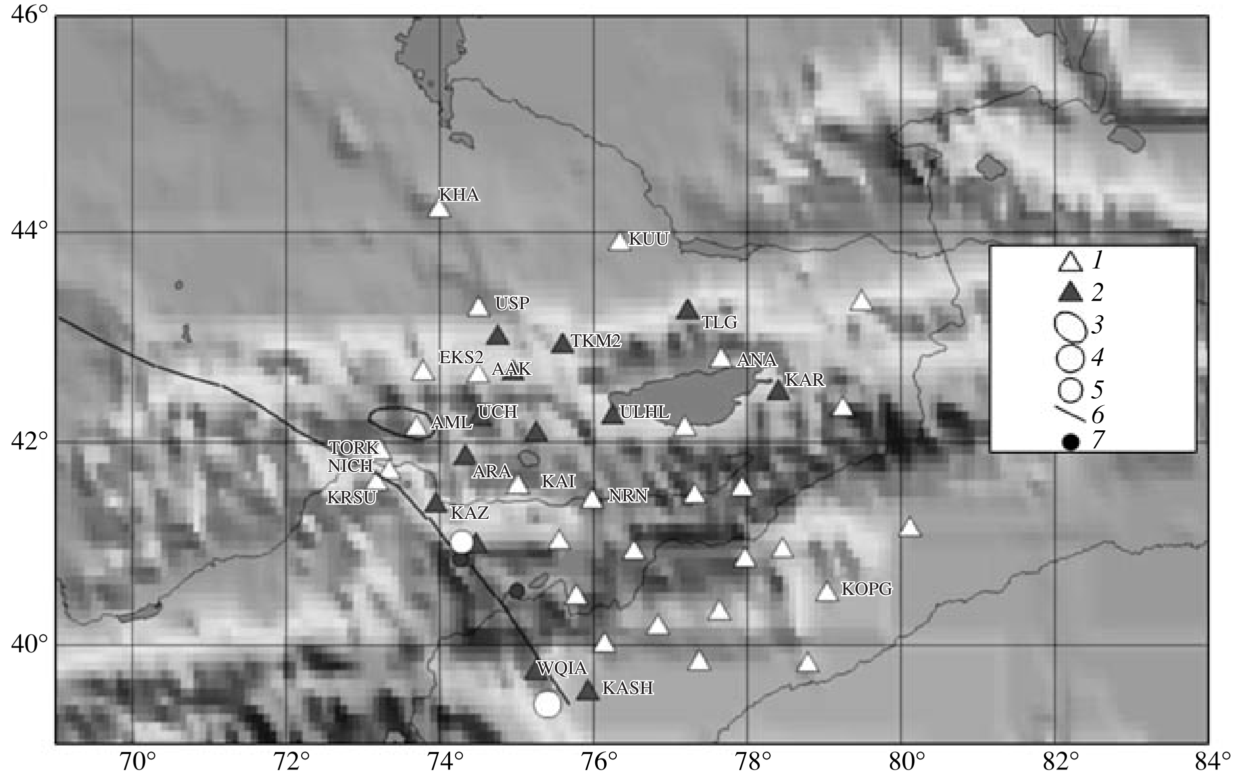

Fig. 1. Map of the study region. Triangles denote seismic stations. Parameter: *S/P* (*1*) weak attenuation, (*2*) strong attenuation; (*3*) source zone of the Suusamyr earthquake. Epicenters of large earthquakes in the strong attenuation stripe area: (*4*) $M = 7.0$, (*5*) $M = 6.0$; (*6*) Talas–Fergana Fault; (*7*) sources with anomalously high values of the helium isotope ratio.

S/*c*400 characterizes the correlation of *S* wave attenuation in the crust and upper mantle with distance from the station (reflected *S* waves appearing on the coda at $t \sim 400$ s intersect the M boundary at distances of ~10–15 km from the stations).

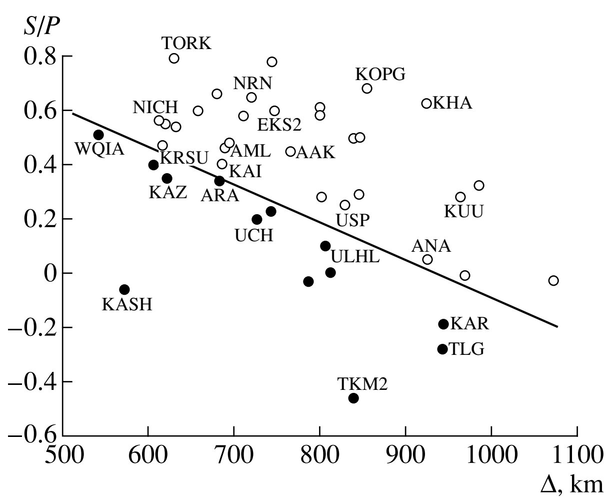

Fig. 2. Dependence of parameter *S*/*P* on epicenter distance. Black and white circles denote strong and weak attenuation, respectively (Fig.1). The straight line shows a conditional boundary separating the regions of *S*/*P* values corresponding to strong and weak attenuation.

Figure 2 shows the relationship between average *S*/*P* values and average epicentral distance for the studied stations. It can be seen that parameter *S*/*P* for similar Δ values can change by more than one order of magnitude (KOPG and TKM2 stations). Confidence interval for the average *S*/*P* value at the level of 0.9 varies for different stations between 0.10 and 0.30.

The attenuation is generally weak for the Tarim massif margin, (except for the westernmost stations WQIA and KASH (Figs. 1, 2)). This statement is also valid for the following stations located at the northern margins of large depressions where following direct *P* and *S* waves intersect the lower crust: USP (Chu Depression), ANA (Issyk-Kul Depression), and KAI and NRN (Naryn Depression). Sufficiently high *S*/*P* values were obtained for stations KHA and KUU (southern margin of the Kazakh Platform), which is consistent with elevated velocities of *P* and *S* waves here relative to the Tien Shan region [6].

It follows from Fig. 1 that comparatively high *S*/*P* values are observed in the majority of the study region. Against this background, one can see a strong attenuation stripe extending from KASH to TKM2 (minimum corrected for Δ *S*/*P* values correspond to these stations). In the southern part, this stripe extends along the Talas–Fergana Fault, which separates the western and central Tien Shan regions, and in the KAZ station area turns to the north-northeast. A comparatively strong attenuation is recorded in the Zaili Fault (station TLG) area and the southern margin of the Issyk-Kul Depression (stations ULHL and KAR).

It should be noted that the sources of the two strongest earthquakes in the Tien Shan region during the last 25 years, namely, the Kashgar earthquake of August 23, 1985, ($M = 7.0$) and the Suusamyr earthquake of August 19, 1992, ($M = 7.3$), were confined to boundaries of the above-mentioned attenuation stripe. This stripe also provoked the earthquake of January 9, 1997, ($M = 6.0$) in a region where, according to instrumental and historical data, no events with $M > 5.0$ had been known before.

Figure 3 shows common envelopes of the *S* coda for several stations installed in and nearby the source zone of the Suusamyr earthquake. The envelopes were constructed beginning from the maximum in the *S* wave. At $t < 400$ s, the envelopes substantially differ in shape and reveal abrupt bends related to the increase and decrease of slope. As the numerical simulation indicated [10], these bends resulted from the existence of zones characterized by a strong contrast of attenuation in the Earth's crust and upper mantle (in the given case, near the recording stations).

The envelopes were plotted for two stations over different time intervals. It can be seen that the coda decay rate in 1992 was higher (relative to 1980) at station TORK located at a distance of ~20 km from the source zone of the Suusamyr earthquake. At the same time, it substantially decreased in 1991–1992 (relative to 1976–1977) at station KRSU located approximately 35 km southward (farther from the source zone).

Figure 4 demonstrates the dependence of the average value of parameter *S*/*c*400 on distance. It should be noted that the dispersion of this parameter at the studied stations is substantially (approximately two times) lower than that for parameter *S*/*P*. Relatively low *S*/*c*400 values are observed for the majority of stations. At the same time, very high values of this parameter correspond to stations located in the source zone of the Suusamyr earthquake (AML) and in its vicinity (TORK and NICH). The envelopes are also relatively steep at stations located up to 60–70 km away from the source zone (KRSU, UCH, EKS2, and AAK).

Let us note that the very high level of *S* wave with respect to the coda and the impulsive character of this group at station AML is related to a weak attenuation in the lower crust located in the south rather than the effect of focusing, since our data show that direct *P* and *S* waves recorded by this station have very high frequency spectra relative to the neighboring stations. At the same time, very high values of *S*/*c*400 for stations AML and TORK point to a sharp increase of attenuation in the lower crust and upper mantle as the Suusamyr earthquake source is approached. This effect can be explained by the existence of a subvertical, strong attenuation zone penetrating from the lower crust into the upper mantle. Similar features of the fine structure of

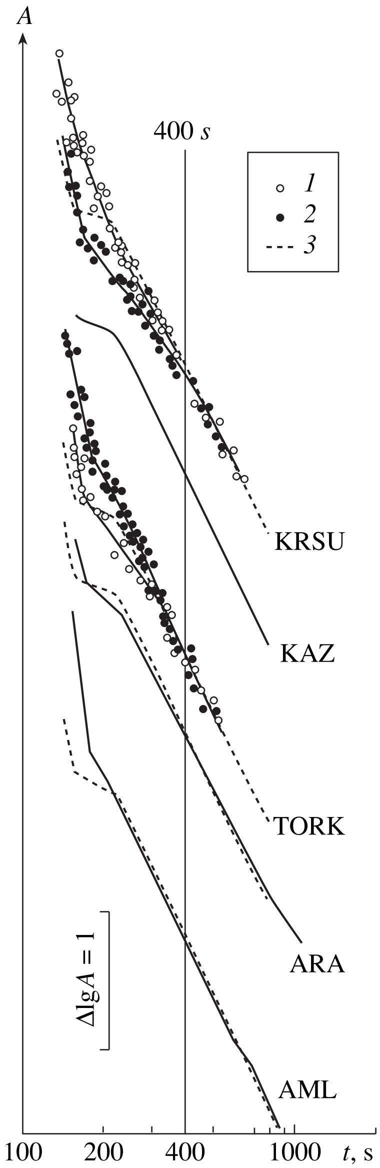

Fig. 3. Common envelopes of the *S* coda for stations located in the source zone of the Suusamyr earthquake and its vicinity. (*1*) Records of stations KRSU and TORK in 1976–1977 and 1980, respectively; (*2*) the same in 1991–1992; (*3*) envelope for station KAZ.

lithosphere were previously detected in source zones of other strong earthquakes in the Tien Shan region [2, 3].

A detailed mapping of the attenuation field in this region was carried out in [11] on the basis of numerous local earthquakes recorded by a remote highly sensitive station. Judging from these data, the strong attenuation stripe identified by the authors of this work between the KASH and TKM2 stations was absent during the 1970s. In addition, Figure 3 suggests that the structure of the attenuation field at KRSU and TORK underwent a sharp change by 1992.

The comparatively fast change of the *S* wave attenuation field can be related only to a rearrangement of

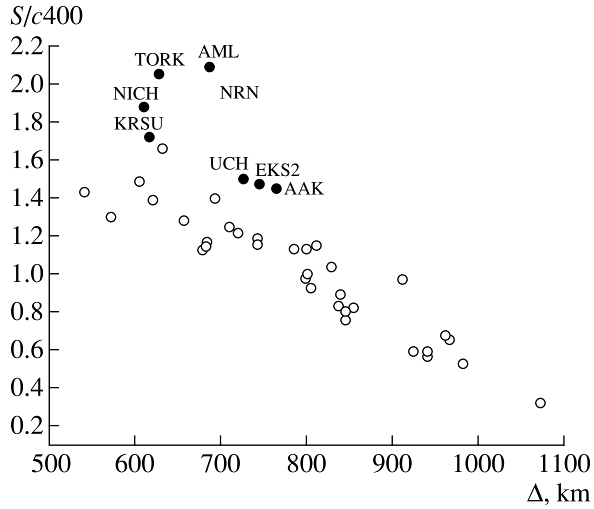

Fig. 4. Dependence of parameter *S*/*c*400 on the epicenter distance. Black circles denote the stations located within the source zone of the Suusamyr earthquake and its vicinity.

the fluid field in the Earth's crust and upper mantle. Judging from our previous data [1, 11, 12] and MTS data [4], fluid-filled interconnected channels, which intersect various tectonic structures existing in the lower crust of the Tien Shan region. At the same time, the fluids can rise along the roots of large fault zones from the upper mantle into the crust [2, 3, 13]. It should be noted that very high (submantle) ratios of helium isotopes were recorded at the end of the 1980s in groundwater within the strong attenuation stripe (Fig.1). Previously, such ratios were never encountered beyond the areas of modern volcanism [14].

The sharp change of the attenuation field at stations KRSU and TORK over 12–15 years points to a migration of fluids toward the Suusamyr earthquake source prior to this event. In addition, the attenuation anomaly in the AML station area indicates that the channels along which fluids ascended from the upper mantle were preserved here even within 7–8 years after the Suusamyr earthquake. This statement is consistent with data on the rise of mantle fluids in source zones of strong earthquakes over several decades after these events [3].

Sources of the two strongest earthquakes in the Tien Shan region during the last 25 years were confined to the high-attenuation stripe. Hence, the next strong earthquake could also take place in the area of this anomaly. Data of the Institute of Seismology, National Academy of Sciences, Kazakhstan suggest that a fairly vast area of seismic quietness can be distinguished south of station TKM2. Since 1996, earthquakes with source depths of ~20 km have been recorded here (it is known that increase in the share of relatively deep-focus events serves as an important prognostic indicator [2, 15]).

ACKNOWLEDGMENTS

We are grateful to R.T. Beisenbaev for placing at our disposal analog records from station KUU.

REFERENCES

1. Kopnichev, Yu.F., *Dokl. Akad. Nauk*, 1997, vol. 356, no. 4, pp. 528–532.
2. Kopnichev, Yu.F. and Mikhailova, N.N., *Dokl. Akad. Nauk*, 2000, vol. 373, no. 1, pp. 93–97.
3. Kopnichev, Yu.F., Sokolova, I.N., and Shepelev, O.M., *Dokl. Akad. Nauk*, 2000, vol. 374, no. 1, pp. 99–102.
4. Berdichevskii, M.N., Borisova, V.P., Golubtsova, N.S., *et al.*, *Fiz. Zemli*, 1996, no. 4, pp. 99–107.
5. Zapol'skii, K.K., *Eksperimental'naya seismologiya* (Experimental Seismology), Moscow: Nauka, 1971, pp. 20–36.
6. Roecker, S., Sabitova, T.M., Vinnik, L.P., *et al.*, *J. Geophys. Res.,* 1993, vol. 98, no. 9, pp. 15 779–15 795.
7. Kopnichev, Yu.F., *Dokl. Akad. Nauk*, 2000, vol. 375, no. 1, pp. 93–97.
8. Kaazik, P.B., Kopnichev, Yu.F., Nersesov, I.L., and Rakhmatullin, M.Kh., *Fiz. Zemli*, 1990, no. 4, pp. 38–49.
9. Kaazik, P.B., Kopnichev, Yu.F., and Rakhmatullin, M.Kh., *Seismicheskie volnovye polya* (Seismic Wave Fields), Moscow: Nauka, 1992, pp. 16–26.
10. Kaazik, P.B. and Kopnichev, Yu.F., *Vulkanol. Seismol.*, 1986, no. 5, pp. 64–74.
11. Kopnichev, Yu.F. and Nurmagambetov, A.N., *Fiz. Zemli*, 1987, no. 10, pp. 11–25.
12. Kvetinskii, S.I., Kopnichev, Yu.F., Mikhailova, N.N., *et al.*, *Dokl. Akad. Nauk*, 1993, vol. 329, no. 1, pp. 25–28.
13. Kopnichev, Yu.F. and Sokolova, I.N., *Fiz. Zemli,* 2001, no. 11, pp. 73–86.
14. Polyak, B.G., Kamenskii, I.L., Sultankhodzhaev, A.A., *et al.*, *Dokl. Akad. Nauk SSSR*, 1990, vol. 312, no. 3, pp. 721–725.
15. Nersesov, I.L., Ponomarev, V.S., and Teitel'baum, Yu.M., *Dokl. Akad. Nauk SSSR*, 1979, vol. 247, no. 5, pp. 1100–1102.