Doklady Earth Sciences, Vol. 379A, No. 6, 2001, pp. 724–728. Translated from Doklady Akademii Nauk, Vol. 379, No. 5, 2001, pp. 670–674.

Variations in the Structure of Transverse Wave Absorption Field in the Semipalatinsk Test Site Area

Yu. F. Kopnichev and I. N. Sokolova

Presented by Academician V. N. Strakhov September 4, 2000

Received September 16, 2000

This work shows for the first time that the Earth's crust and upper mantle (at depth of ~10–120 km) in the Balapan area of the Semipalatinsk nuclear test site (SNTS) are characterized by an extremely high absorption of transverse waves. The absorption of *S* waves in the crust sharply increased over 10 yr (1979–1989). The data obtained indicate that this effect is related to the rise of fluids from the upper mantle along large fracture zones produced by a prolonged and sufficiently intense impact of powerful explosions on the geological medium.

It has been established that a fairly large region in northeastern Kazakhstan, inclusing the SNTS area, was characterized by a very bright thermal anomaly in 1997–1999: the surface temperature here exceeded by more than 10°C the surrounding area temperature during winter periods [1]. In order to clarify the nature of this anomaly, we investigated spatiotemporal variations in the structure of the transverse wave absorption field in the test site area.

The overwhelming majority of underground nuclear explosions (UNE) in the SNTS area were performed at two sites, Degelen and Balapan [2]. Charges were placed in adits cut within a rock massif at Degelen and in boreholes below a thin layer of young sedimentary rocks at Balapan. It is essential that two large fractures (Kalba-Chingiz and Chinraus [3]), which reach, according to geophysical evidence, the Moho boundary, pass in the Balapan area (Fig. 1). Only small fractures are distinguished in the Degelen area [4].

We considered the records of calibrating chemical explosions, each having a power of 25 t, that were performed during 1997 and 1998 in the SNTS area. These records were obtained by the REFTEC digital stations mounted at epicentral distances up to 90 km away.

In addition, we processed UNE records obtained during 1964–1989 by the TLG station located in the northern Tien Shan region at distances of 730–770 km from the epicentral area. We analyzed the records obtained by the frequence-selective analog seismic station (FSSS [5]), which consists of a vertical channel with the central frequency of 1.25 Hz and the width equal to two-thirds of the octave at 0.7 of the maximum level.

We applied the method based on the analysis of characteristics of the short-period *S* coda. It has been previously established that in the region of Central Asia at frequencies of about 1 Hz, the coda of local earthquakes and quarry explosions is chiefly formed by transverse waves reflected from numerous subhorizontal boundaries in the Earth's crust and upper mantle [6, 7]. In this case, sites with relatively fast and slow attenuations of amplitudes in the coda are related to the penetration of *S* waves into the layers with strong and weak absorptions, respectively. Depths of these layers are determined under the assumption of the coda formation by singly reflected waves.

Using the records of calibrating explosions at the Balapan site for the FSSS channel with the central frequency of 1.25, the coda envelopes were constructed for different stations. It can be seen from Fig. 2 that the shape of envelopes noticeably varies even for stations that are separated by distances equal to only ~6 km (stations 4 and 6 in Fig. 1). The most characteristic feature of the envelopes is a very fast attenuation of amplitudes at $t = 10–60$ s on the records of stations located immediately before or behind the deep-seated fracture zones (stations 4, 6, and 8) as compared to other stations (the time t is counted from the beginning of radiation in the source). At first glance, the envelope for Station 9 is an exception; however, the fracture in the this area is distinguished insufficiently reliably. Within the 20–60 s interval, the effective quality Q_S determined from the formula $A(t) \sim \exp(-\pi t/Q_S T)/t$, where T is the period of oscillations [6], varies from 55 (Station 8) to 115 (Station 7).

It has been shown previously [8] that the coda usually attenuates more weakly than in seismoactive regions in the weakly seismic regions of Central Asia, to which the SNTS territory also belongs. Figure 3 illustrates for comparison the data scatter range for

*Schmidt Joint Institute of Physics of the Earth (OIFZ), Russian Academy of Sciences,
Bol'shaya Gruzinskaya ul. 10, Moscow, 123810 Russia*

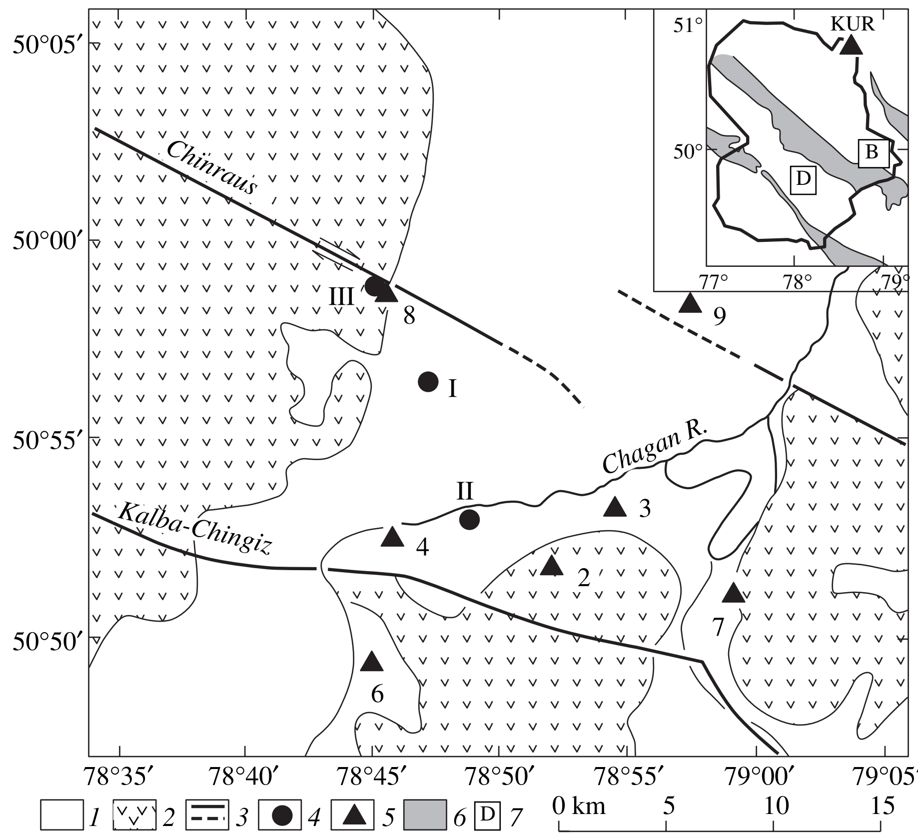

Fig. 1. Map of the Balapan site (modified after [3]). (*1*) Cenozoic sedimentary rocks; (*2*) Paleozoic and Mesozoic sedimentary and volcanogenic rocks; (*3*) fracture zones; (*4*) explosion epicenters: (I) August 3, 1997, (II) August 31, 1997, (III) September 17, 1998; (*5*) seismic stations. The inset shows SNTS boundaries, anticlinoriums (*6*), and Degelen and Balapan sites (*7*).

envelopes of the coda of local earthquakes and quarry explosions that are constructed using the records of 24 digital stations in the Tien Shan region restricted by the coordinates 39°–44° N and 73°–80° E. It is known that a considerable part of this region is characterized by substantially reduced average velocities of *P* waves in the lower crust and upper mantle compared to the Kazakh Shield region, in the northeastern part of which the SNTS is located [9]. Nevertheless, it can be seen that when the envelopes at $t = 60$ s are superposed in the interval from 10 to 60 s, corresponding to the range of depths ~20–120 km, all envelopes for the Tien Shan region attenuate considerably slower than those for Station 6 in the Balapan site area.

The scatter of data within the 100–300 s interval for the envelopes brought in coincidence at $t = 100$ s is shown in the same figure (the data of 19 digital stations located in the same region were used). In this case, the coda in the Tien Shan region usually attenuates more strongly than in the KUR station area, located 90 km north of the calibrating explosion epicenters (Fig. 1). In the 100–300 s interval, corresponding to the depths of ~230–700 km, the Q_S value for the KUR station is equal to 2800.

Using the records of the nearest stations at the Balapan site ($\Delta < 7$ km), the envelopes of the *S* coda were constructed for the FSSS channel with a central frequency of 5 Hz for short times ($t = 5$–10 s). It turned out that within this interval corresponding to the upper section of the crust (depth ~10–20 km), the effective quality is very low ($Q_S \sim 50$). This is much less than, for instance, in the Garm region of Tadzhikistan [6], which is characterized by a fairly high level of seismicity.

Thus, the *S* wave absorption field in the Balapan site area was characterized during 1997 – 1998 by a very strong absorption in the crust and upper mantle and by a sufficiently weak absorption in the lower part of the upper mantle.

In order to study temporal variations of the absorption field structure in the SNTS area, we analyzed about 250 UNE records obtained by the TLG station. We considered the ratio of maximum amplitudes in *Lg* and *Pg* waves on the FSSS channel with a central frequency of 1.25 Hz ($\log(A_{Lg}/A_{Pg})$), which is designated as *Lg*/*Pg* for brevity. These waves propagate within the Earth's crust, and the ratio of their amplitudes serves as a measure of the absorption of transverse waves along the entire track from the source to the station.

It follows from Fig. 4 that the dispersion of data on this parameter is usually larger for the Balapan site than for the Degelen site. This is connected to the fact that

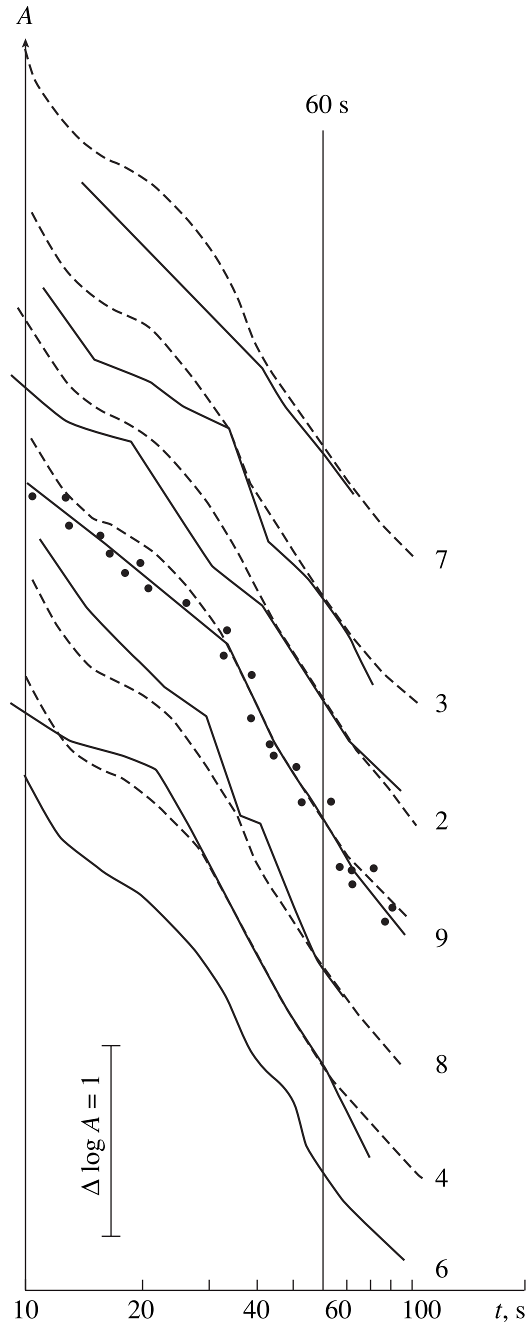

Fig. 2. Coda envelopes of explosion records for different stations at the Balapan site. The numbers of stations corresponding to Fig. 1 are indicated. Dashed lines designate the coda envelope for Station 6. The data scatter for the records of three explosions is shown for Station 9.

the *Lg*/*Pg* values for explosions performed near fracture zones (at distances of no more than 2–3 km from fracture axes), are substantially (on the average, by 0.3–0.4 log. u.) lower than for the rest of events at the Balapan site (Fig. 4). It is important to emphasize that a gradual diminishing of the *Lg*/*Pg* values is observed for Balapan beginning in 1980. On the average, they decreased during 1988 and 1989 by 0.4–0.5 log. u.

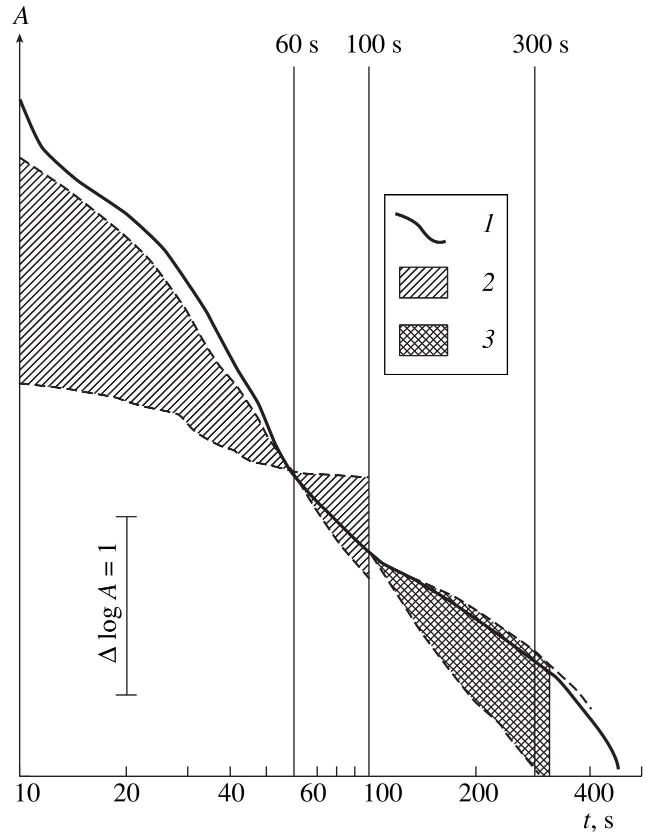

Fig. 3. Comparison of the coda envelopes for the Balapan site (*1*) and for the Tien Shan region. Curve (*1*) is plotted using the records from the stations 6 ($t < 100$ s) and KUR ($t > 60$ s); (*2*) data scatter for the records of local earthquakes and quarry explosions obtained from 24 stations with the superposition of envelopes at $t = 60$ s; (*3*) the same for the records from 19 stations with the superposition of envelopes at $t = 100$ s.

Note that this inference is in qualitative agreement with the results obtained by Ringdal *et al.* [3], who considered the m_b–m_{Lg} parameter for explosions at the Balapan site (the magnitude for *Lg* waves determined for the NORSAR group was used). We averaged over the years the initial data presented in the mentioned work. It turned out that the average m_b–m_{Lg} value for these explosions in 1989 is substantially (by 0.15–0.20 log. u.) higher than in the 1970 s.

A large quantity of data were processed for explosions at the Degelen site. It can be seen from Fig. 4 that the average *Lg/Pg* values for these events are everywhere larger than for Balapan, and they even tend to increase from the beginning of the 1970s. At the end of the 1980s, the difference between the average values of this parameter for the two sites attained 0.6 log. u.

The decrease in the *Lg/Pg* values for the Balapan site indicates that the integral absorption of *S* waves in the Earth's crust along the track towards the TLG station substantially increased during the 1979–1989 period. At the same time, a virtual stability of this

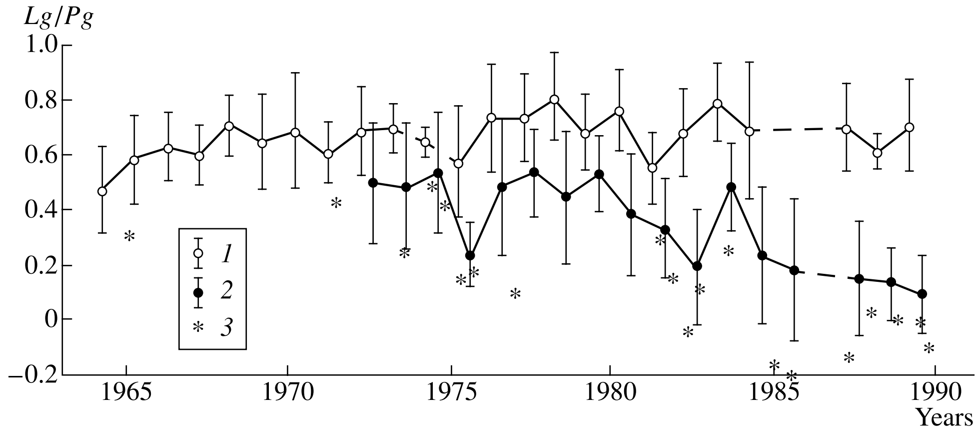

Fig. 4. Variations of the *Lg/Pg* parameter based on the records of underground nuclear explosions (carried out at the SNTS) obtained at the TLG station. (*1, 2*) average values and standard deviations for the Degelen (*1*) and Balapan (*2*) sites; (*3*) data for separate explosions with epicenters near fracture zones at the Balapan site.

parameter for explosions at Degelen, in view of the fact that the wave tracks to the TLG station for the two sites are quite close (their azimuths differ no more than by 5°), indicates that the largest changes in the absorption field structure from the end of the 1970s to the end of the 1980s occurred in the Earth's crust directly in the Balapan area.

In our opinion, the only possible explanation for the detected effects is associated with the rise of fluids from the upper mantle. It has been shown previously that the active migration of fluids across the Trans-Ili fracture zone was observed in the northern Tien Shan region after relatively weak chemical explosions (several kilotons in power) [10]. Further more, this could be expected for the SNTS region, where about 350 UNE explosions were performed for 30 years, and the power of many of these explosions exceeded 100 kt [2, 3].

It is characteristic that the rise of fluids was most dramatic in the Balapan area, where two large fractures penetrate the upper mantle. As it is known, the deep-seated fracture zones containing a noticeable fraction of fluids are dissipative structures (according to Prigozhin [11]), which have a high sensitivity to external influences [12]. Under the action of seismic oscillations during powerful explosions, fissures and pores of different scales open, which facilitates the rise of mantle fluids along fracture zones. The obtained data on the absorption field structure indicate that the migration of fluids can occur from depths exceeding 200 km.

At the same time, the absence of large fractures in the Degelen area makes fluid replenishment from the upper mantle impossible. It is believed that explosions in the study area during the 1960s are responsible for the exhaustion of fluids in the lower section of the crust. Consequently, the *Lg/Pg* parameter for events at this site even slightly increased during the 1970s and 1980s. Judging by the absorption field structure, the channels of fluid migration were retained in the Balapan region for 10 years after the termination of nuclear tests. This is in compliance with the available data on the rise of mantle fluids in source zones of strong earthquakes of the Tien Shan region at least for several decades after events with $M > 6.5$ [13].

After the penetration of juvenile fluids into the upper crust, they diffuse along the network of fractures encompassing vast territories. The temperature of near-surface groundwater increases as a result of mixing with the fluids. This process is responsible for the appearance of a thermal anomaly on a sufficiently large area, exceeding the test site territory by many times [1].

In order to study changes in the fine structure of the absorption field in the test area, it is necessary to analyze the records of local events during different time periods. In addition, for verifying the conclusions regarding the rise of fluids from the upper mantle, it would be reasonable to investigate the isotope helium ratios that serve as an independent indicator of the depths at which geodynamic processes take place [14].

ACKNOWLEDGMENTS

We are grateful to N.N. Belyashova, V.-E. Kim, and S.W. Roecker for placing at our disposal the numerical records of calibrating explosions in the SNTS area and local earthquakes in the Tien Shan region.

REFERENCES

1. Sultangazin, U.M., Zakarin, E.A., Spivak, L.F., *et al.*, *C. R. Acad. Sci. Ser. Method. Instrum.,* 1998, vol. 328, pp. 135–140.
2. Andryushin, I.A., Bogdan, V.V., Vashchinkin, S.A., *et al.*, *Ispytaniya yadernogo oruzhiya i yadernye vzryvy v mirnykh tselyakh SSSR, 1949–1990* (Nuclear Weapon Testings and Nuclear Explosions for Peaceful Purposes in the Soviet Union, 1949–1990), Sarov, 1996.
3. Ringdal, F., Marshall, P., and Alewine, R., *Geophys. J. Int.*, 1992, vol. 109, pp. 65–77.

4. Peive, A.V. and Mossakovskii, A.A., *Ob"yasnitel'naya zapiska k tektonicheskoi karte Kazakhstana* (Explanatory Note to the Tectonic Map of Kazakhstan), Moscow: Nauka, 1982.
5. Zapol'skii, K.K., in *Eksperimental'naya seismologiya* (Experimental Seismology), Moscow: Nauka, 1971, pp. 20–36.
6. Kopnichev, Yu.F., *Korotkoperiodnye seismicheskie volnovye polya* (Short-Period Seismic Wave Fields), Moscow: Nauka, 1985.
7. Aptikaeva, O.I. and Kopnichev, Yu.F., *J. Earthquake Predict. Res.*, 1993, vol. 2, no. 4, pp. 497–514.
8. Kopnichev, Yu.F., in *Seismicheskie volnovye polya* (Seismic Wave Fields), Moscow: Nauka, 1992, pp. 104–115.
9. Roecker, S.W., Sabitova, T.M., Vinnik, L.P., *et al.*, *J. Geophys. Res., B9*, 1993, vol. 98, pp. 15 779–15 795.
10. Kopnichev, Yu.F., *Dokl. Akad. Nauk*, 1998, vol. 363, no. 6, pp. 819–822.
11. Nicolis, G. and Prigogine, I., *Self-Organization in Non-Equilibrium Systems*, New York: Wiley–Interscience, 1977. Translated under the title *Samoorganizatsiya v neravnovesnykh sistemakh. Ot dissipativnykh struktur k uporyadochennosti cherez fluktuatsii*, Moscow: Mir, 1979.
12. Rodkin, M.V., *Rol' glubinnogo flyuidnogo rezhima v geodinamike i seismotektonike* (Role of Abyssal Fluid Regime in Geodynamics and Seismotectonics), Moscow, 1993.
13. Kopnichev, Yu.F., Sokolova, I.N., and Shepelev, O.M., *Dokl. Akad. Nauk*, 2000, vol. 374, no. 1, pp. 99–102.
14. Polyak, B.G., *Teplomassopotok iz mantii v glavnykh strukturakh zemnoi kory* (Heat and Mass Flow from Mantle in Major Structures of the Earth's Crust), Moscow: Nauka, 1988.