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AMPLITUDE ATTENUATION AND INDUSTRIAL NOISE ORIGIN IN THE EASTERN ALPS

W. LENHARDT* and K. ARIC**

A seismic model of the crust is presented, based on data evaluated by the 'Alpine Explosion Seismology Group' (AESG). Information taken from the amplitudes are derived. It is shown that the amplitude decay in this region can be simulated by introducing a relatively low quality factor (Q) in the crust.

The resulting Q values appear to be relatively small since they include scattering effects. Based on two different seismic phases, direct P-wave and Moho reflections, a crustal model could be divided into an upper and a lower part. The upper crust showed relatively constant absorption with Q at 6 Hz is about 90. In the lower crust a slight trend could be observed, starting with Q=350 in the west and increasing to 550 in the east. Geothermal sources should be situated in the upper crust due to the lower Q at shotpoint F.

Industrial noise covered the range of signal frequencies. Most of the noise could be attributed to agricultural machines and appeared to be monochromatic.

Keywords: seismic modeling, crust, quality factor, absorption, noise

1. Introduction

In September 1975 seismic measurements were carried out in European cooperation on a long range profile (Alp 75) along the strike of the Alps between France and Hungary [AESG, Reporter: H. MILLER 1976]. *Fig. 1a* shows the refraction profiles 04 and 05 of ALP 75 with shotpoints D near Innsbruck, E near Judenburg and F in Hungary and also the main tectonic

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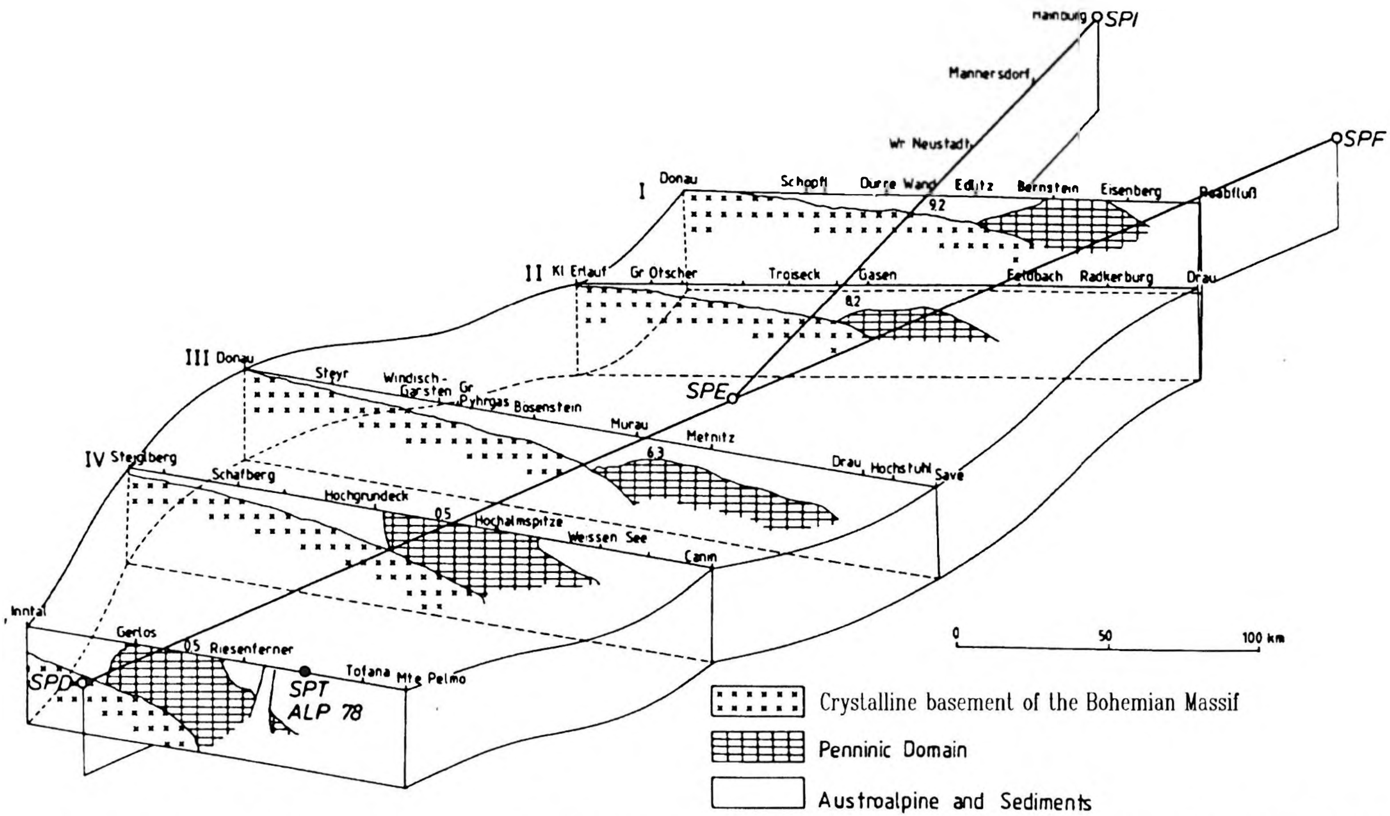

Fig. 1a. Profiles and shotpoints in the eastern parts of ALP 75, the upper crust with tectonic units [after Prey 1980, simplified]. The depth of the basement is given in km

1a. ábra. Szelvények és robbantási pontok az ALP 75 szelvény keleti részén, a felső kéreg tektonikai egységeivel [Prey 1980, egyszerűsítve]. Az aljzat mélysége km-ben van feltüntetve

Рис. 1a. Профили и точки взрыва на восточной части ALP 75 и тектонические единицы верхней коры [Prey 1980, с упрощением]. Глубинные отметки в км units. Some technical data of the ALP 75 shots used in this study are given in *Table I*.

Shot	Type	Elevation (m)	No. of charges	Total charge (TNT), (kg)
D1	Lake	2250	30	1500
D2	Lake	2250	50	2500
E1	Lake	2050	30	1500
E2	Lake	2050	50	2500
F1	Boreholes	200	15	1000
F2	Boreholes	200	32	2000
F3	Boreholes	200	60	4000

Table I. Description of shot points
I. táblázat. A robbantópontok leírása
Табл. I. Описание точек взрыва

Seismic energies were observed up to distances of 500 km with a MARS 66 recorder [BERCKHEMER 1970]. The equipment has a constant transfer function starting at 2 Hz. The seismic records were bandpass filtered from 2 to 30 Hz.

Intensive studies were carried out in seismic modelling based on traveltimes [MILLER et al. 1977, ARIC et al. 1979]. A seismic model for the East Alpine region published by ARIC [1981] was adapted and slightly improved near the shotpoints and at the Moho, to fit the observed amplitudes (*Figs.* 1a, *1b*). For this purpose a ray tracing program [ARIC et al. 1980] was improved in order to include the computation of theoretical amplitudes of first onsets and Moho reflections based on

$$A_{Theor.} = A_0 \cdot ke \cdot kz \cdot ks \cdot ka$$

where

A_0 amplitude at the shotpoint
ke geometrical spreading
kz reflection and transmission coefficient
ks effect of free surface
ka absorption

During the computation of theoretical amplitudes and the evaluation of the recordings, problems of seismic noise were encountered. Therefore, the second part of this paper deals with the identification and problems connected with the seismic noise [LENHARDT 1983]. Especially for the determination of the main signal frequency of the first onset, we found that noise spectra often covered the frequency range of the signal.

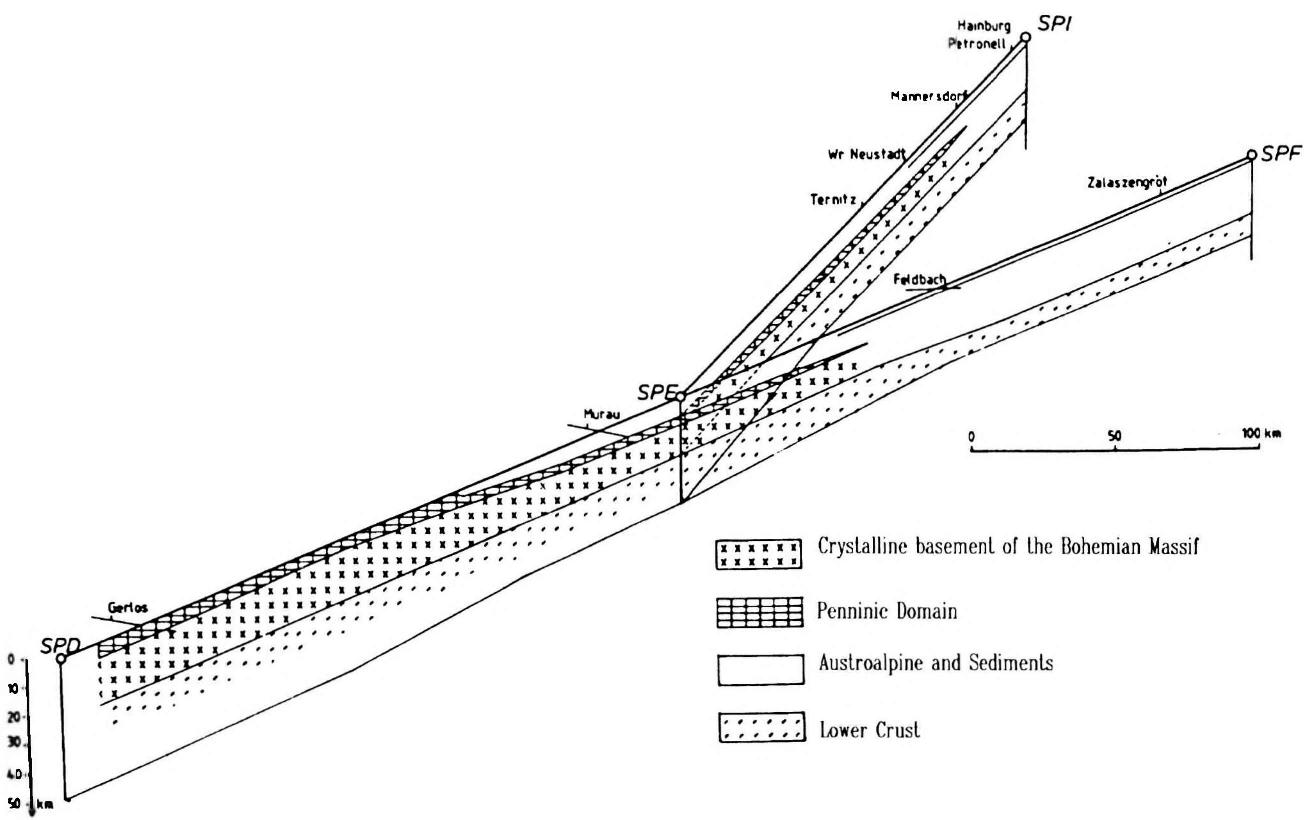

Fig. 1b. Crust in the Eastern Alps and its tectonic geological interpretation based on the available seismic data [ARIC 1981]

1b. ábra. A kéreg a Keleti-Alpok területén tektonikai-geológiai értelmezéssel, a rendelkezésre álló szeizmikus adatok alapján [ARIC 1981]

Рис. 1b. Земная кора на участке Восточных Альп по имеющимся сейсмическим данным и геолого-тектоническая интерпретация [ARIC 1981]

2. First estimation of quality factor in the crust based on an empirical law of amplitude decay

The evaluation of first onsets showed a remarkably constant decay of amplitudes. Therefore, a first estimation of the seismic quality factor *Q* [KNOPOFF 1964] based on a simplified crustal model (see *Figs. 2* and *3*) was carried out [LENHARDT 1983].

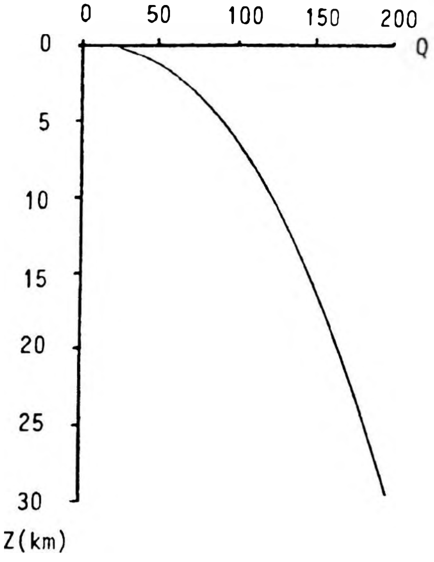

Fig. 2. First estimation of $Q=f(z)$ from an amplitude decay of $x^{-1.8}$ (km)

2. ábra. A $Q=f(z)$ első közelítése $x^{-1.8}$ (km) amplitúdócsökkenéssel

Рис. 2. Первое приближение функции $Q=f(z)$ при затухании амплитуд $x^{-1.8}$ (km)

Empirically we can approximate the observed amplitude decay by

$$A(x) = A_0 \, x^{-1.8}$$

which should also agree with the theoretical formula including both geometrical spreading and absorption given by

$$A(x) = \frac{A_0 \, e^{-\alpha(x)\, s(x)}}{s(x)}$$

x	surface distance from shotpoint (km)
$\alpha(x)$	depth-dependent absorption coefficient
$s(x)$	length of ray path (km)

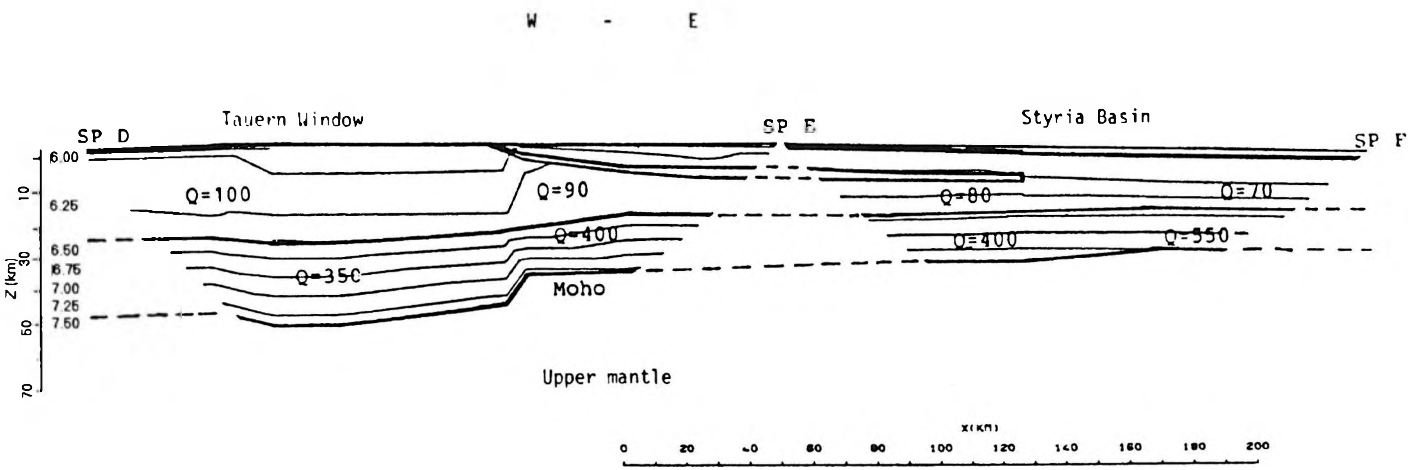

Fig. 3. Model of the crust between shotpoint *D* (Tyrol) and shotpoint *F* (Hungary) derived from traveltimes. The *Q* values computed from *P*-wave amplitudes refer to a frequency of 6 Hz. Accuracy of *Q* is 20 % (see also Figs. 1a, 1b)

3. ábra. A menetidő adatokból levezetett kéregmodell *D* (Tirol) és *F* (Magyarország) robbantópontok között. A *P*-hullám amplitúdókból számított *Q* értékek 6 Hz-re vonatkoznak. *Q* pontossága 20 % (lásd még 1a, 1b ábrákat)

Рис. 3. Модель коры, полученная по данным времени хода между точки взрыва *D* (Тирол) и *F* (Венгрия). Значения *Q*, расчитанные по амплитудам волн *P*, относятся к частоте 6 гц. Точность параметра 20 проц (см. также рис. 1a. и 1b.)

α is related to Q by

$$Q = \frac{2\pi}{1 - e^{-2\alpha\lambda}}$$

with λ wavelength. In a lateral homogenous medium with constant gradient, the maximum depth of ray penetration is tied to the surface distance of emergence by

$$z(x) = \left(\frac{x^2}{4} + \frac{v_0^2}{b^2}\right)^{\frac{1}{2}} - \frac{v_0}{b}$$

$z(x)$ maximum depth (km)
v_0 P-wave velocity at surface (km/s)
b gradient of the v_0

hence $\alpha(x)$ as a function of depth can be described by the observation distance $\alpha(x) \approx \alpha(z)$. To find a variation of the absorption coefficient with depth or distance, we can solve the problem iteratively by incrementing the observation distance x (equivalent to the depth of penetration of the seismic ray) taking into account the absorption which was computed from the layers above.

Therefore

$$\alpha_i = \frac{-\ln\left((s_i + 2\sum_{j=1}^{i-1} s_j) / (x_i^{-1.8} \prod_{j=1}^{i-1} e^{-2\alpha_j s_j})\right)}{s_i}$$

x_i surface distance (km)
s_i ray path length in layer i (km)
s_j ray path length in layer j (km)
α_j absorption coefficient of layer j

The factor 2 in the summation of the ray paths in the recently computed layers refers to the down and upgoing ray. By introducing the simple model for the crust with velocity of

$$v = v_1 + k \cdot z\,; \quad v_1 = 6.00\ \text{km/s}\,; \quad k = 0.04\ 1/\text{s}$$

z depth (km)
v average P-wave velocity (km/s) from z (km)

and the initial condition where the first layer has a constant absorption and velocity, we find the depth dependence of Q. Figure 2 shows the resulting discrete function $Q=f(z)$ using the dominant frequency of 6 Hz.

In the upper part of the model we get Q values less than 150. Since the lower crust should show much higher values (Fig. 3), a ray tracing program was adapted to enable Q to be computed from a crustal model derived from traveltimes observed in the East Alpine region. By using both of the first onsets (refracted P-waves) and reflections from the Moho, it was possible to divide the crust into an upper and a lower layer with constant Q. As a result of three shotpoints at large distances from each other (distance about 220 km) a slight lateral change in Q becomes apparent (Fig. 3).

It can be stated that the upper crust has an almost constant Q of about 90. ARIC et al. [1980] introduced a low-velocity layer in the upper crust near to shotpoint E to explain reflection onsets. This thin zone at a depth between 8 and 12 km was interpreted by ARIC [1981] as the 'Schieferhülle' of the Austroalpine unit (PREY [1980], see Figs. 1a and 1b). This layer is also supported by theoretical amplitudes which show their maximum in the observed range between 60 and 90 km.

The absorption in the lower crust seems to be very much less, hence the Q-factor is higher. We find Q values of 350 in the western part which increase to 550 in the east shotpoint F. This result contradicts the usual concept of low Q — high geothermal gradient. Therefore the source of heat in Hungary has to be expected in the upper crust [ARIC et al. 1987].

Knowledge of the origin of seismic noise is interesting from several aspects. First of all the design of a seismic array strongly depends on the background seismicity. Further, if recorded data are disturbed by unwanted stationary time series, the design of filters can be optimized by applying a noise analysis. Practically all unwanted signals and time series are usually understood as noise. Now we can differentiate between sources of natural origin and those that are man-made. Whereas emitted time series of natural sources are extremely broadbanded due to different mechanisms like tides, wind and natural background seismicity, man-made noise in the near field due to industry mainly lies between 2 and 50 Hz. Especially in this frequency range we have to expect signals on the seismic long range profiles.

The evaluation of industrial noise is determined and limited by amplification. Recordings in the near field (10 km) could not be used since the signal to noise ratio was too high and a filter to remove the noise became ineffective. Due to the amplification which is chosen for a good evaluation of the first onset, the noise is simply covered by white noise from digitizing.

As a lower level of industrial noise an empirical amplitude of 10^{-4} cm/s was chosen.

3. Evaluation and identification of seismic noise

As mentioned above only a frequency range from 2 to 30 Hz can be interpreted. Time intervals of 256 samples equivalent to 2.56 seconds were analysed by FFT [COOLEY and TUKEY 1965] of each vertical component. Since the amplitude decay approximately follows an exponential law we have a short explanation on the distribution of noise amplitudes for the profiles (*Fig. 4*).

The amplitudes of the seismic waves which were caused by the charges fired by ALP 75, were comperable if they were weighted by $x^{1.8}$ (km). Yet Fig. 4 shows a signal to noise ratio exceeding 1.0 in about 100 km which calls for effective filtering in the far field for that charge and geometry of blasting. At distances up to 100 km first onsets and noise amplitudes can have similar amplitudes (Fig. 4). It should be mentioned that any kind of distributed shots (borehole, lake) produced similar signals and the frequency range always overlapped with that of the noise. A variation of signal

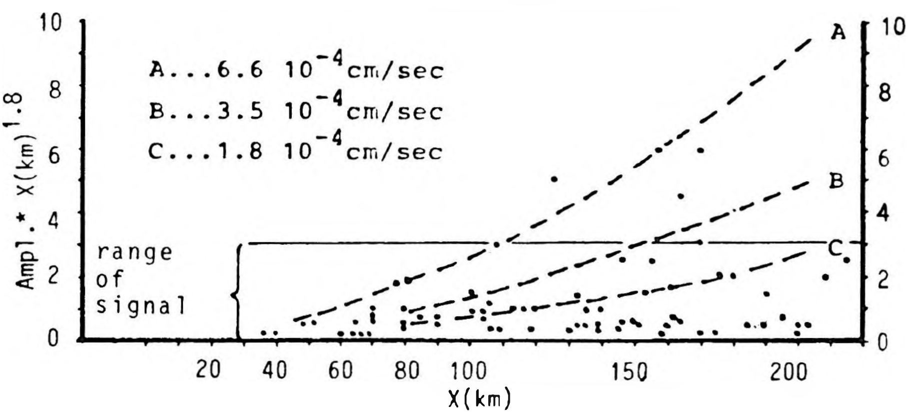

Fig. 4. Noise amplitudes on both profiles and their increase due to distance weighting to ensure that the amplitude of the first onset is constant. The dots are the observed noise amplitudes along the profiles. The signal has a reference amplitude from 0.1 to 3. Minimum noise amplitude belongs to $1 \cdot 10^{-4}$ cm/s

4. ábra. Zaj-amplitúdók a szelvényeken és növekedésük az első beérkezések konstans amplitúdóját biztosítva a távolság szerinti súlyozásnak megfelelően. A pontok az észlelt zaj-amplitúdókat jelölik. A jel referencia amplitúdószintje 0,1-3. A minimális zaj-amplitúdó $1 \cdot 10^{-4}$ cm/s-nak felel meg

Рис.4. Амплитуда шумов по профилю и ее увеличение согласно взвешиванию по расстоянию при сохранении постоянства амплитуды первых поступлений. Точками обозначены наблюденные амплитуды шума. Уровень амплитуды опорного сигнала 0.1-3. Минимальная амплитуда шума соответствует $1 \cdot 10^{-4}$ см/сек form by shot geometry and charge on a long-range profile seems to be impossible due to the absorption of seismic waves in the earth.

Noise interpretation can be carried out only at distances greater than 10 km from the shotpoint. At smaller distances the amplification of the equipment was usually very low in order to read the amplitudes. Similarly MEISSNER and STEGENA [1977] (pp. 51-53) observed that a noise level of 10^{-4} cm/s limits the radius (10 km) of seismic observations around each station.

Especially next to the Tauern window (Fig. 3), in absence of any industry, only 16 2/3 Hz were observed but not completely explained. The Austrian Railway usually uses this frequency otherwise it should not influence stations at a distance of more than 10 km (*Fig. 5*). One feature which appeared very soon was the strong amplification of low frequency noise (2-5 Hz) in sedimentary basins as described STEIN et al. [1967] and PLESINGER and WIELAND [1974], in the same range of amplification of factor 10. Extremely high absorption in sediments is the reason for the loss of the higher parts of the frequency spectrum and the low frequency parts of the seismic signature are enhanced due to resonance.

Low frequencies (4-6 Hz) are also produced by industrial organizations equipped with machines such as saw-mills (Fig. 5) which are very frequent in the Alpine region. Other industries (coal mining, steel) cover a frequency range from 2-6 Hz that is precisely the expected spectra from blasts in the far field. Since the frequency content of the *P*-wavelet lies between 5 and 6 Hz for *P*-waves at distances from 30 to 200 km, monochromatic noise emitted by industry could be eliminated by using filters.

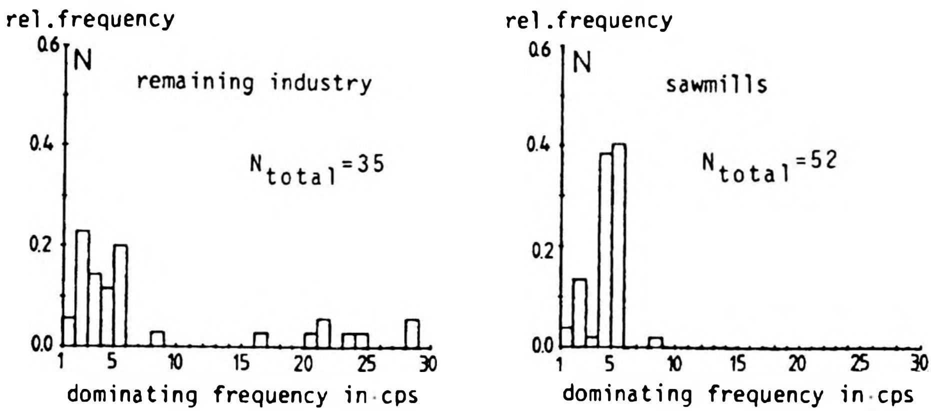

Fig. 5. Dominating frequencies of noise and their corresponding sources
5. ábra. Domináns zaj-frekvenciák és a hozzájuk tartozó források
Рис.5. Доминирующие частоты шума и отвечающие им источники

Acknowledgement

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AMPLITÚDÓCSILLAPODÁS ÉS IPARI ZAJOK EREDETE A KELETI-ALPOKBAN

W. LENHARDT és K. ARIC

Az "Alpine Explosion Seismology Group" (AESG) által kiértékelt adatokon alapuló szeizmikus kéregmodell kerül bemutatásra. Levezetik az amplitúdókból nyerhető információkat és megmutatják, hogy az amplitúdócsökkenés ezen a területen a kéregre vonatkozó, viszonylag kicsi Q faktor bevezetésével szimulálható.

Az eredményként kapott Q értékek alacsonynak bizonyultak mivel tartalmazzák a szóródási hatásokat. Két különböző szeizmikus fázisnak megfelelően—direkt P-hullám és Moho-reflexiók—a kéregmodell egy felső és egy alsó részre osztható. A felső kéreg viszonylag állandó abszzorpciót mutatott Q=90 értékkel 6 Hz-nél. Az alsó kéregben egy enyhe emelkedő tendencia figyelhető meg Q=350-től Q=550-re, nyugatról kelet felé haladva. Az F robbantópontnál jelentkező alacsonyabb Q-nak megfelelően geotermikus forrás valószínű a felső kéregben.

Az ipari zajok lefedték a jelfrekvenciák tartományát. A zajok legnagyobb része monokromatikusnak bizonyult és mezőgazdasági berendezéseknek tulajdonítható.

ПРИЧИНА ЗАТУХАНИЯ АМПЛИТУД И ПРОМЫШЛЕННЫХ ШУМОВ В ВОСТОЧНЫХ АЛЬПАХ

В. ЛЕНХАРДТ, К. АРИК

Показывается сейсмическая модель земной коры, основанная на интерпретации данных, выполненной (AESG). Приводятся данные, получаемые по амплитудам, и показывается, что затухание амплитуд на участке хорошо симулируется введением фактора Q относительно небольшой величины, и отнесенной к коре.

Полученные в результате величины Q оказались низкими в связи с влиянием дисперсии. Модель коры, составленная по двум разным волнам (прямая P волна и отражения от поверхности Мохо), разделяется на верхнюю и нижнюю часть. Верхняя кора характеризуется постоянством абсорбции при Q=90 на 6 гц. В нижней коре отмечается тенденция слабого повышения значения Q с запада Q=350 на восток Q=550. Согласно низким значениям Q у точки взрыва F в верхней коре предпологается наличие геотермического источника.

Диапазон частот сигналов перекрыт шумом промышленного происхождения. Основная часть шумов оказалась монохроматичной, и, по-видимому,связана с работой сельскохозяйственной техники.

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INVITATION

The Association of Hungarian Geophysicists decided at its annual meeting to establish the "Foundation for Hungarian Geophysicists" and elected its first Advisory Board for 3 years. The foundation has been started with a moderate initial capital of 300 000 HUF, which has by now increased to more than 3 million and it is open for everybody.

The aim of the foundation is to help Hungarian geophysicists. There are two main target groups whose application for grants will be accepted with preference: young geophysicists needing assistance (travels, participation at conferences, publications,post-graduate education etc.) at the beginning of their professional life as well as retired and unemployed colleagues whose economic and social position became especially unfavourable.

The nine members of the Advisory Board invite everybody to join this foundation; donations should be communicated with the Board. Organisations and persons donating sums exceeding the initial capital will have the opportunity to delegate representatives into the Board. Detailed information is available at the following address:

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