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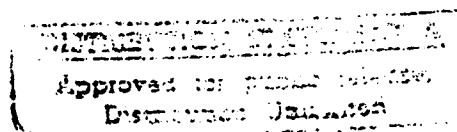
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Summary

This report was presented at the 14th annual PL/DARPA Seismic Research Symposium on September 16, 1992. In it, we describe a decoupling experiment undertaken by the former Soviet Union at Azghir, north of the Caspian Sea. The properties of the cavity are given, including a rough description of the geology (salt-dome overlain by 275 m of shale, sand, and anhydrite), the size and depth of the cavity (equivalent 38 m radius sphere, 987 m deep), velocities, densities, etc. These shots had larger yields than the Salmon - Sterling decoupling experiments undertaken by the U.S. in the mid-sixties. Like the U.S. experiment, this Soviet experiment did not achieve full decoupling. The energy decoupling factor (computed from statistical relationships between the yield and amplitude-distance curves rather than spectra) increased to a maximum of 30 as distance increase. Based on our observations and theoretical limits to decoupling, we conclude that a fully decoupled 1 kt explosion could be observed at a distance of 2,500 km.

Introduction

A physical model of decoupling was developed in the US in the fifties and submitted to experts meeting in Geneva (1958) as a possible method for evading detection of underground nuclear explosions. It was suggested that for a decoupled explosion in hard rock the seismic signal may be 100-200 times less than for a tamped explosion of the same yield. These models were presented in the papers of Bete, Latter, Martinelly, Teller (USA), and Gubkin (USSR). Theoretical predictions were tested in 1960 in two series of model experiments in salt (Cowboy, USA) and in limestone (Kirhgizia, USSR). Measurements in the near-field showed a seismic amplitude decrease of 20 or more times, which could be interpreted as partial decoupling. Full decoupling was not achieved in these experiments.

Nuclear decoupling was first tested in the US in 1966. The Sterling explosion (yield - 0.38 kt, cavity radius - 17 m) was fired in the cavity which had been created by the Salmon explosion (5.3 kt) and confirmed general theoretical predictions, but full decoupling was not achieved (D=70). The decoupling factor was observed to be dependent on frequency.

Cavity Properties from Explosion A-III

A Soviet decoupled explosion was fired on March 29, 1976 07:00:00 at a depth 987 m in borehole A-III. This explosion had a much larger yield and energy density than Sterling. The cavity had been created on December 22, 1971 by a tamped nuclear explosion in a salt

dome in Eastern Azghir. The cavity was almost spherical with a radius of 38 m. The results of the seismic observations of this decoupled explosion were published by Adushkin, et al. [1992]. Geological and technological conditions of this explosion are shown on Figure 1. This figure shows a geologic cross-section of the borehole and tables with physical and mechanical properties of the salt in the borehole and averaged over the Eastern Azghir region (density ρ, strength σ, and longitudinal velocity v_p). A comparison of the physical properties of Sterling and the Soviet decoupled explosion - reduced cavity radius and energy density (R - cavity radius in meters, E - energy of explosion in kt, V - volume of the cavity in m^3) is also shown.

The cavity measurements before the decoupled explosion were made using a Luch-2 laser rangemeter. The accuracy of measurements was 5-8%. Horizontal and vertical cavity radii were 38 and 33 m, respectively. There was no water in the cavity.

Local Seismic Observations of Coupled and Decoupled Explosions

A profile of 17 portable seismic stations was installed trending west from 1 to about 84 km and then south-west to a distance of 154 km from the explosion. The wavefield pattern for the decoupled explosion was the same as was observed during tamped explosions within the same salt dome. Observed periods of seismic waves from the decoupled explosion were 3-4 times less than for the cavity creating explosion. A comparison of amplitude attenuation curves of horizontal velocity in longitudinal waves shows that for the decoupled explosion, attenuation is more rapid due to high frequency enrichment of the signal (Figure 2).

Figures 3 and 4 show spectra of the longitudinal waves for both explosions (in Figure 3 the spectrum labeled 1 is the tamped explosion and the spectrum labeled 2 is the decoupled explosion; in Figure 4 solid lines refer to the tamped explosion and the dashed lines to the decoupled explosion). At close ranges, the spectra of the tamped explosion have a maximum at frequencies from 1.8 to 2.5 Hz which shifts to 1 Hz at a range of about 80 km. At 113 km the high-frequency subcritical Moho reflected wave (*PmP*) shifts the maximum to 1.5 Hz. The decoupled explosion spectra at distances less than 18 km are characterized by corner frequencies between 15 and 20 Hz. At ranges greater than 35 km, intense high frequency attenuation makes the spectra of the decoupled explosion similar to that of the tamped explosion: rapid roll-off at high frequencies and the maximum at 1.5 Hz.

Figure 5 shows the relationship between distance and the ratio of maximum amplitudes of displacement and velocity of these two explosions. These ratios increase with distance due to attenuation of high frequencies. Similar ratios of spectral amplitudes were obtained.

$2 \div 154$ км

17

глины, пески

210
275

гипс, ангидрит

соль

Физ-мех свойства соли

	S г/см³	$бсж$ кг/см²	V_p км/сек
A-III	2,17	170	3,81
Средн	2,20	270	4,25

1000 м — 38м

Физические условия опыта

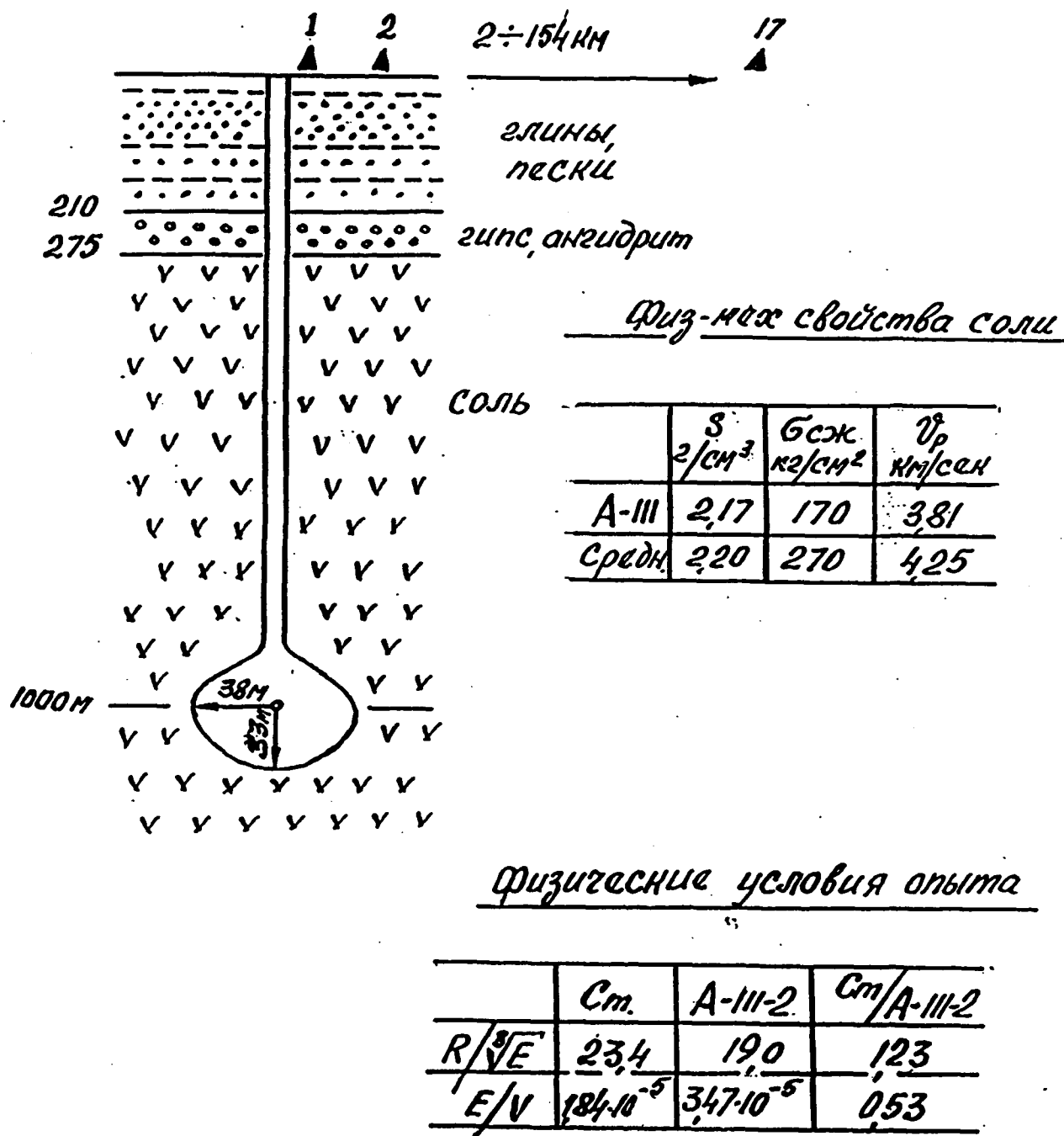|	Ст.	A-III-2	Ст/A-III-2
$R/\sqrt[3]{E}$	23,4	19,0	1,23
E/V	$184 \cdot 10^{-5}$	$347 \cdot 10^{-5}$	0,53

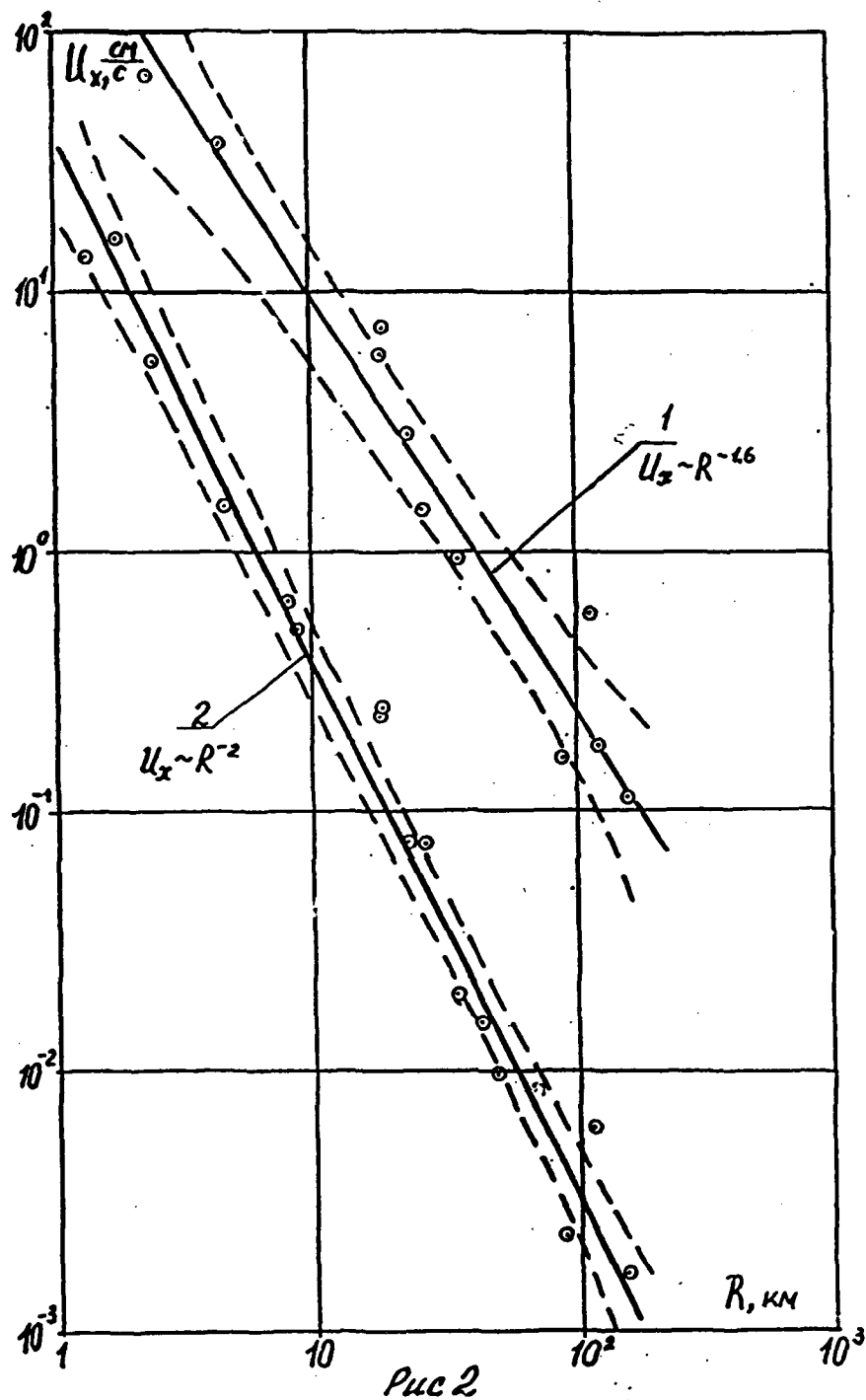Figure 1:   Cross-section and physical properties of borehole A-III.

Figure 2: Amplitude-distance curves for coupled (upper) and decoupled (lower) explosions.
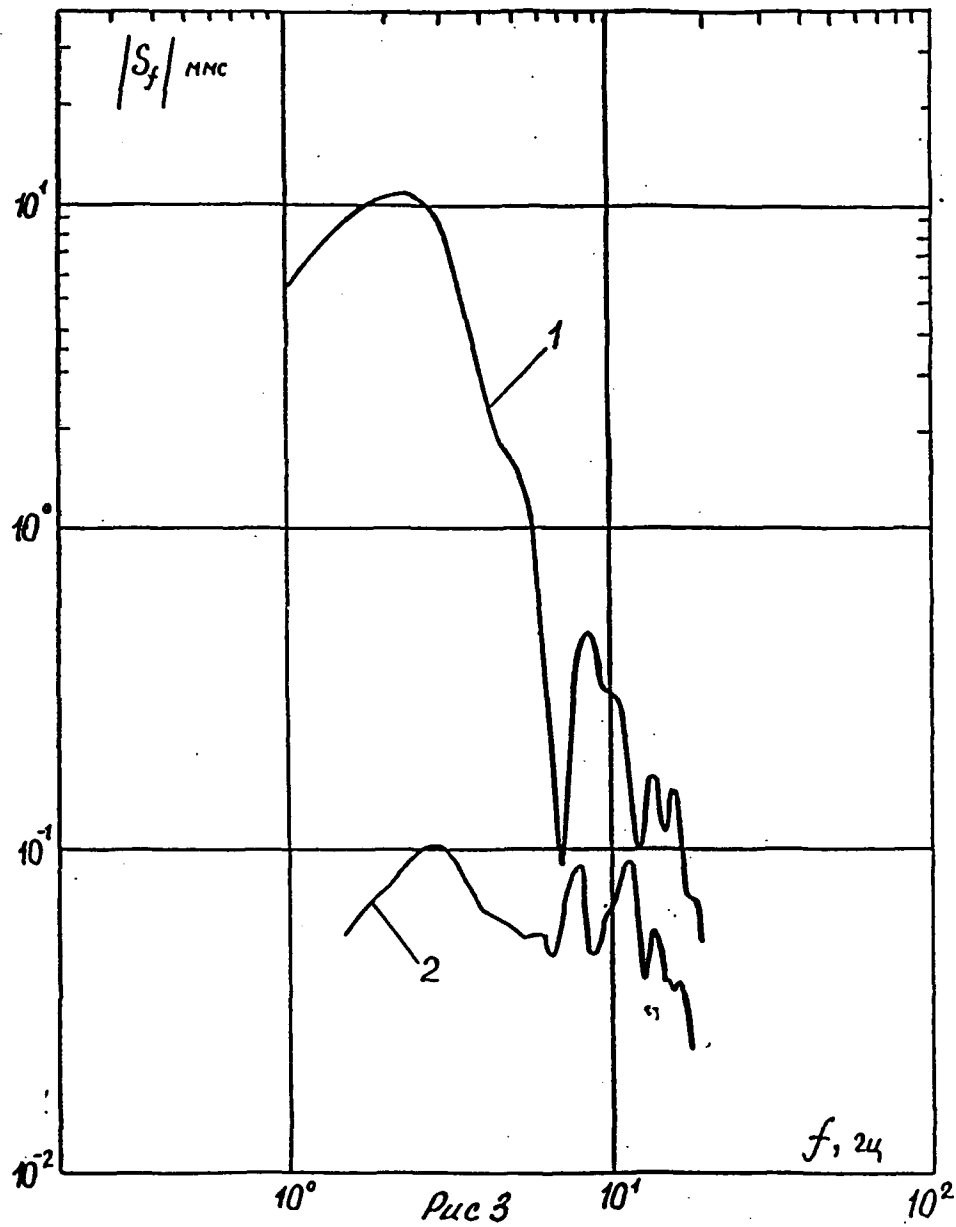
Figure 3:   Spectra of coupled (1) and decoupled (2) explosions at a distance of 2.3 km.
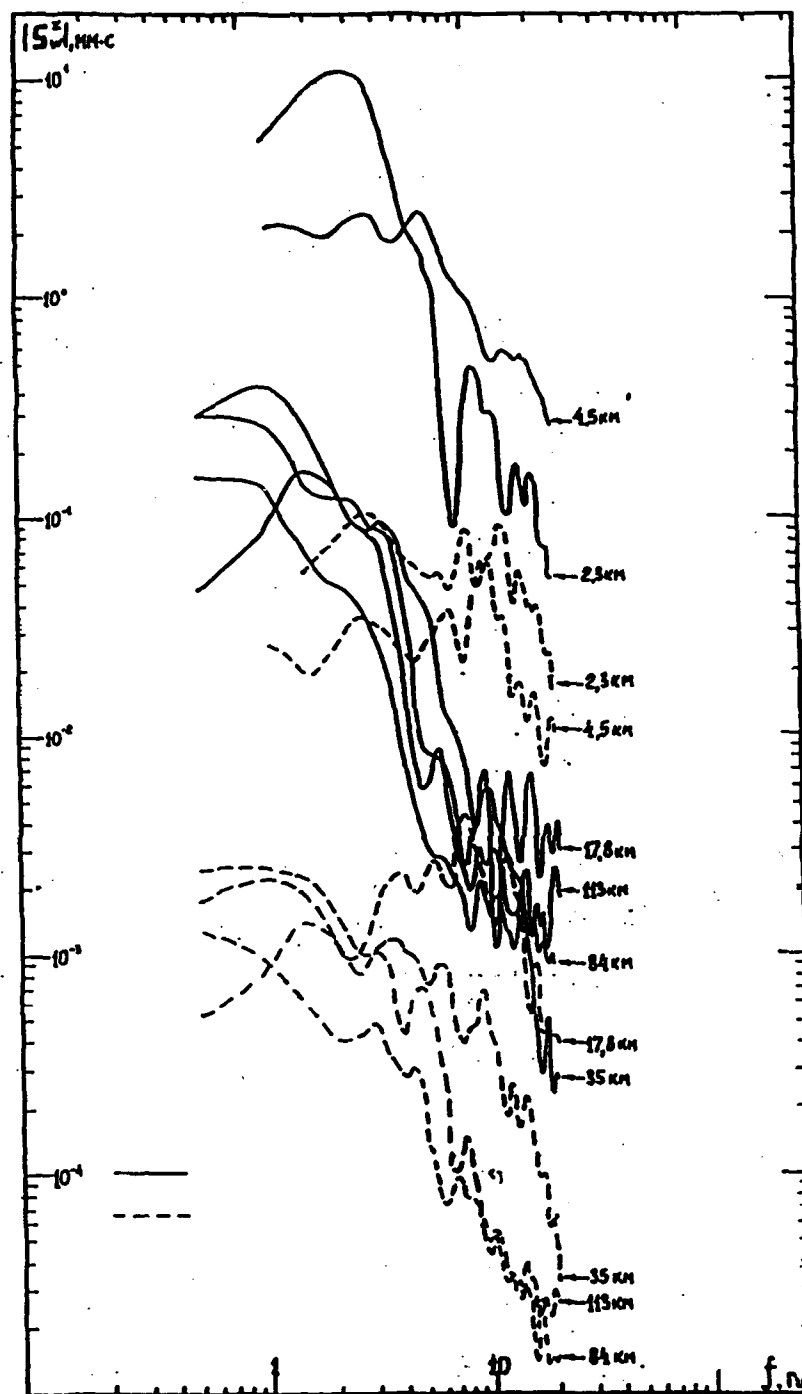
Figure 4: Spectra for coupled (solid) and decoupled (dashed) explosions at several distances.
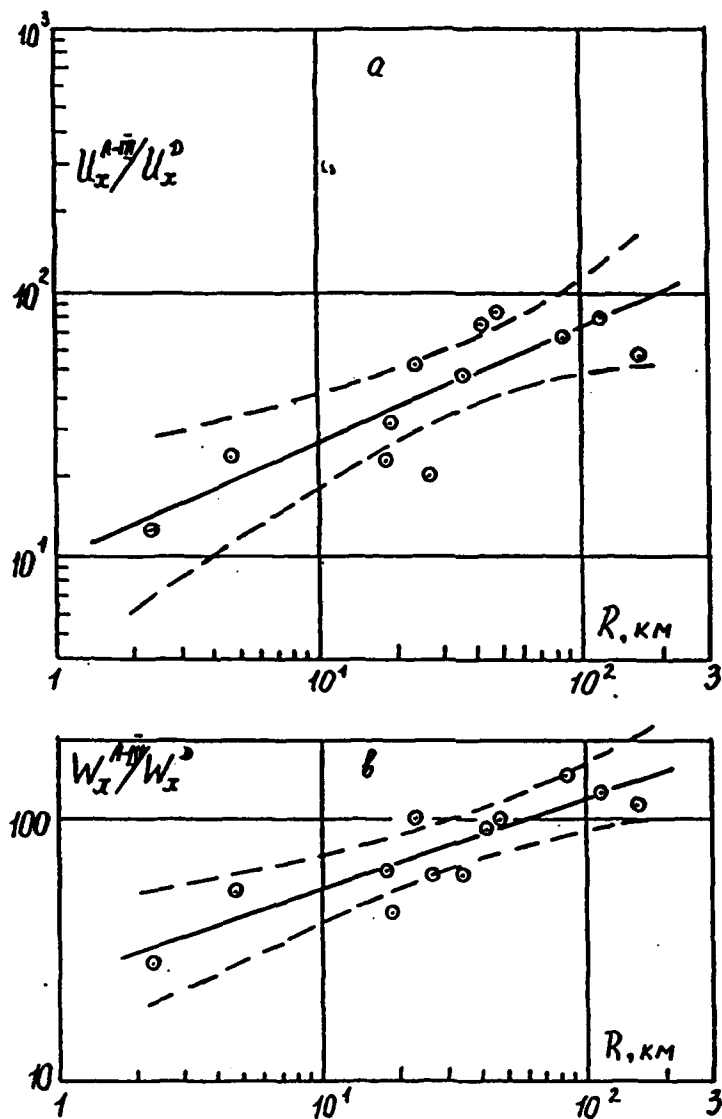
Figure 5: Maximum amplitude ratios of coupled and decoupled explosions in velocity (upper) and displacement (lower).

They vary from 100 at frequencies of 1-3 Hz to 10 at frequencies greater than 4 Hz.

To evaluate the decoupling factor, η, by using displacement and velocity records (η_w and η_u, respectively) the effective yield, q_{eff}, of the decoupled explosion at all recording distances was calculated. The effective yield is equal to the yield of the tamped explosion that would generate seismic waves with the observed amplitude. These calculations were made on the basis of statistical relationships obtained for tamped explosions at the same salt dome in the 1-100 kt range. As range increases up to 70 km, the effective yield decreases. At 70 km the effective yield reaches a constant value of 0.25 kt.

The variation of the energy decoupling factor $\eta = q_{tamped}/q_{eff}$ with range is shown in Figure 6. It is clear that the decoupling factor is near 30 which is consistent with an effective yield $q_{eff} = 0.27$ kt and has the same value for velocity and displacement measurements.

Teleseismic Observations of the Decoupled Explosion

Teleseismic observations were made using a network of seismic stations with standard seismic equipment for that time (seventies). SKM type seismometers had limited dynamic range (photo paper recordings) and low amplification (~50,000) at 0.7-1.2 Hz. Data from Soviet stations in the distance range from 785 to 4,300 km are presented in Table 1. Below the table are locations from the ISC Bulletin for which 8 seismic stations in Romania, Sweden, Finland, Norway were used. It is worth noting that the location error is approximately 350 km and that this event was identified as earthquake. The Sterling explosion was not recorded beyond 240 km.

Figure 7 shows the vertical component seismogram from a SVKM seismometer with 6 times exaggeration. At all stations, the records are characterized by high frequency signals on top of low frequency seismic noise.

The maximum amplitudes of longitudinal waves are observed at periods less than 0.4 s and have values of approximately 20 nm. At periods of 0.6-0.8 s the maximum amplitudes decrease to 5-8 nm. Longitudinal waves periods for the decoupled explosion in the distance range from 1,000 to 4,300 km are 1.5 - 2 times less than that of the tamped explosion A-III, and slightly less than periods for a tamped explosion with 1 kt yield in the same salt dome. The average value of magnitude, m_b, for the decoupled explosion over four stations was estimated as 4.35. q_{eff}, estimated from the relationship $log(q) = 1.30\, m_b - 5.88$ and accounting for a factor of 1.55 at low yields, is $q_{eff} < 0.4$ kt. Better results were obtained using an amplitude method which is based on experimental relationships between the amplitude of the signal and yield: $w \sim q^{0.8}$, $u \sim q^{0.75}$ (where w is displacement, and u is
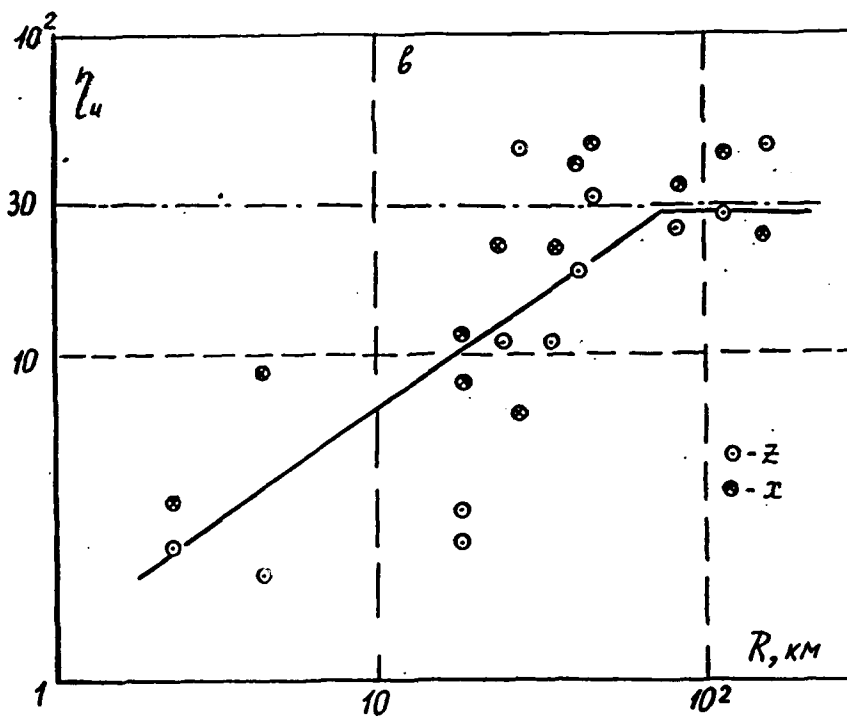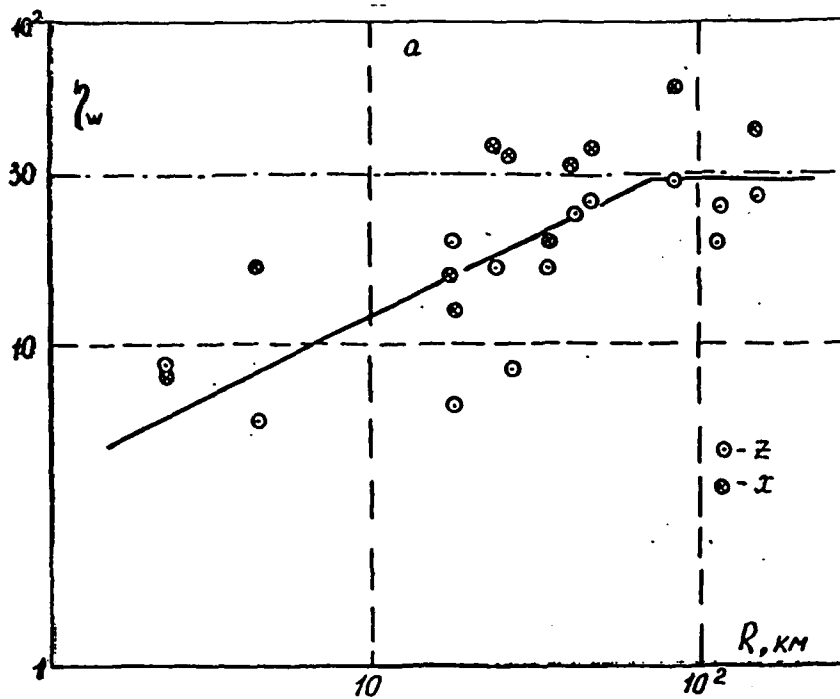
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ure 6: Energy decoupling factor as a function of distance for displacement (upper) and velocity (lower).
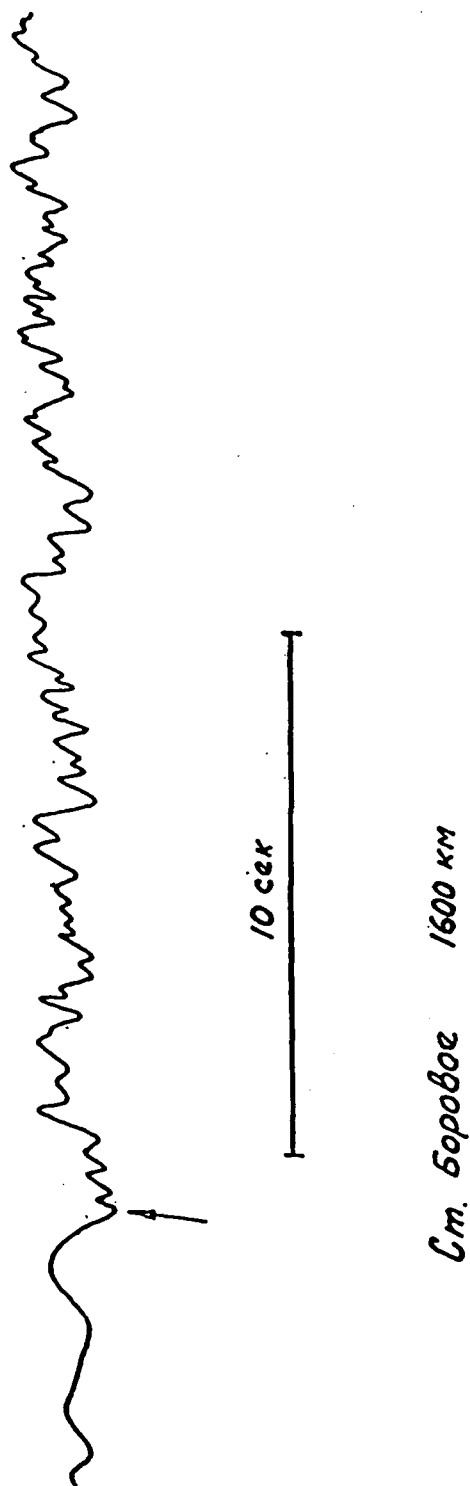
Ст. боровое   1600 км

Figure 7:   Seismogram of the decoupled explosion as recorded at Borovoye.

velocity) for tamped explosions in hard rocks recorded at teleseismic distances. The following values of effective yields were obtained:

q_{eff} = 0.25 kt ± 0.04 kt (for displacement),

q_{eff} = 0.32 kt ± 0.075 kt (for velocity).

Table 1: Soviet Stations Recording Decoupled Explosion

Station	Distance (km)	Amplitude (nm)	Period (seconds)	m_b
Kirovobad	785	8	0.7	
Sta. No. 1	1065	20	0.4	
Sverdlovsk	1230	23	0.4	
Borovoye	1590	6	0.7	
Hagfors	2220	18	0.4	4.4
Garm	2205	5	0.8	
Talgar	2280	7	0.8	3.99
El'tsovka	2690	5	0.8	4.75
Bodaibo	4310	8.5	0.6	4.25

ISC Origin information (Vol 13, no. 3)
Origin Time: 07:00:29 ± 4.3 s
49.6 ± 0.25° N, 45.0 ± 0.56° E (350 km northwest of the true location)
Depth: 0.33 km
n = 8; σ = 1.52; range of distances for stations was 13.48° - 22.21°
Station data: MLR 13.48°
                 KIF, SOD 17.31° - 20.09°
                 UPP, UME, HFS, KIR 18.70° - 22.01°
                 NA0 22.31°

Conclusions

The experimental observations of the decoupled nuclear explosion on March 29, 1976 fired in an air-filled quasi-spherical cavity in the Eastern Azghir salt dome make it possible to draw the following conclusions:

a) Theoretical values of full decoupling were not achieved by the Azghir experiment.

b) Observations at local distances show the enrichment of seismic waves by high frequency energy and decrease of the decoupling factor with frequency, consistent with the Sterling experiment.

c) Seismic waves from the Azghir decoupled nuclear explosion were recorded at distances up to 4,300 km. The equipment used to record this explosion did not allow optimization of low-amplitude high-frequency seismic signals. Estimates made in the paper by Adushkin *et al.* [1991] show that it is possible to detect a fully decoupled 1 kt explosion at frequencies of 3-5 Hz at distances of 1000-1500 km. Using higher frequencies (up to 10-15 Hz) where the seismic efficiency of a nuclear explosion in a cavity is higher, it is possible to extend the detection range of a 1 kt decoupled explosion to 2,500 km.

d) Estimates of the decoupling factor using local and teleseismic data are consistent and are near 30.

Acknowledgments

References

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