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Article

The influence of stabilizers on the strength characteristics of soils in the Western Kazakhstan region

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Abstract. The paper presents the results of laboratory studies of soils in four regions of Western Kazakhstan: Atyrau, West Kazakhstan, Aktobe, and Mangystau regions. Laboratory tests determined their physical and mechanical properties, while IR Fourier spectroscopy was applied to analyze mineral composition. Modern stabilizing additives were introduced into the soils, and compressive strength was evaluated after 7 and 28 days. The results demonstrated a 1.5–2.5-fold increase in strength compared to untreated samples, with maximum values ranging from 4 to 6 MPa. The greatest effect was observed in sandy loams and carbonate-rich soils, confirming the high potential of stabilizers for enhancing road base performance in the region.

Keywords: road construction, soil stabilization, carbonate soils, IR Fourier spectroscopy, compressive strength.

1. Introduction

One of the pressing problems of road construction in the Western Kazakhstan region (WKR) is the low bearing capacity of local foundation soils. The climate of the region is characterized by sharp temperature fluctuations, dry summers, and cold winters, which, combined with the diversity of soil composition (sandy loam, clay loam) and their high sensitivity to moisture, lead to deformations and destruction of road surfaces [1].

The physical and mechanical properties of soils in road foundations depend primarily on their mineralogical composition, homogeneity, the presence of salts and organic residues, local climatic conditions, and hydrogeology, which have a significant impact on the stability of road infrastructure. Soil subsidence, its heaving, the presence of a soluble phase, filtration rate, and other characteristics of weak soils require study, taking into account the dynamic loads from large-capacity transport [2].

Being in a stressed state under the weight of the structure and its own weight, these soils, with an increase in humidity, provide additional subsidence deformation caused by a radical change in the soil structure [3]. In the current conditions, the development of moisture- and temperature-resistant road bases is one of the primary tasks [4].

In recent years, considerable attention has been paid to soil stabilization technologies as an effective method of improving the load-bearing capacity of problematic soils [5]. The use of mineral and chemical additives allows modifying soil structure, reducing water absorption, increasing strength and frost resistance, and thus extending the service life of road pavements. However, the effectiveness of such additives depends not only on their chemical composition, but also on the type of soil, climatic conditions, and methods of incorporation into the soil matrix [6].

Recent studies systematized various approaches to soil stabilization, showing that both mineral and polymer additives can significantly increase load-bearing capacity, but the degree of improvement strongly depends on soil type [7]. Some works demonstrated that biopolymers in combination with geosynthetics effectively increase cohesion and shear strength, although their efficiency decreases under higher cyclic stresses [8]. Other studies confirmed the potential of using local soils for road construction when treated with stabilizers, while highlighting the limitations imposed by salinity and mineralogical variability [9]. Investigations of geosynthetics proved their role in reducing subsidence and improving durability, but also revealed partial strength losses under long-term loading [10]. Overall, previous research emphasizes the need for approaches that directly relate mineralogical composition to mechanical performance after standard curing periods [11].

Therefore, the present study aims to conduct a comparative analysis of soils from four regions of Western Kazakhstan and to evaluate the effectiveness of modern stabilizers in relation to mineralogical composition determined by IR Fourier spectroscopy, with emphasis on compressive strength development and frost resistance.

2. Methods

The experimental study was aimed at determining the physical, mechanical, and structural properties of soils typical for WKR and evaluating the effectiveness of various stabilizing additives. The methodology included several stages of research.

First, the source materials were characterized in terms of granulometric composition, physical properties, and classification according to current national and interstate standards [12], [13], [14], [15]. The optimum moisture content and maximum density were established by standard laboratory procedures [16]. These characteristics provided the basis for selecting the preparation and compaction modes of the test specimens.

Next, the influence of inorganic binders on the properties of soils was assessed. For this purpose, mixtures of soils with Portland cement M400 and the following experimental stabilizers were prepared (Figure 1): 1) “EZCON” high concentration; 2) “EZCON” low concentration; 3) “ANT”; 4) “Gistrong pul”; 5) “Nova create”; 6) “Gistrong”. Laboratory cylindrical samples with a diameter and height of 71.4 mm were molded at the determined optimum moisture and maximum density (Figure 2). The samples were cured under humid conditions for 7 and 28 days.

Figure 1 – Preparation of soil-cement mixes

Figure 2 – Cylindrical samples from soil-cement mixes

The physical and mechanical tests of stabilized and non-stabilized samples included: determination of compressive strength under uniaxial loading according to [16] (Figure 3); evaluation of frost resistance by repeated freezing–thawing cycles at –18°C, followed by strength testing; assessment of water resistance through capillary and full water saturation tests. In addition, mineralogical studies were conducted to determine the composition of soils. Fourier-transform infrared spectroscopy was used to identify the main functional groups of minerals, while microscopic examination provided information on soil microstructure.

Figure 3 – Determination of the compressive strength of samples

The obtained results were processed statistically and compared with the requirements of the regulatory documentation [17]. The compliance of the tested compositions with these requirements was analyzed to evaluate the efficiency of the stabilizing additives.

3. Results and Discussion

Table 1 below shows the physical and mechanical properties of soils typical for the cities and regions of West Kazakhstan.

Table 1 – Physical and mechanical properties of soils

Region	Soil class	Liquid limit moisture, %	Rolling limit moisture, %	Plasticity index, %	Maximal density, g/cm^3	Optimum moisture, %
Atyrau city	Sandy loam	21.3	15.2	6.1	2.18	8.9
WKR	Sandy loam	20.6	14.85	5.75	2.25	9.09
Aktobe city	Loam	36.4	26.1	10.3	2.31	11.9
Mangystau region	Loam	32.8	18.2	14.6	2.34	11.8

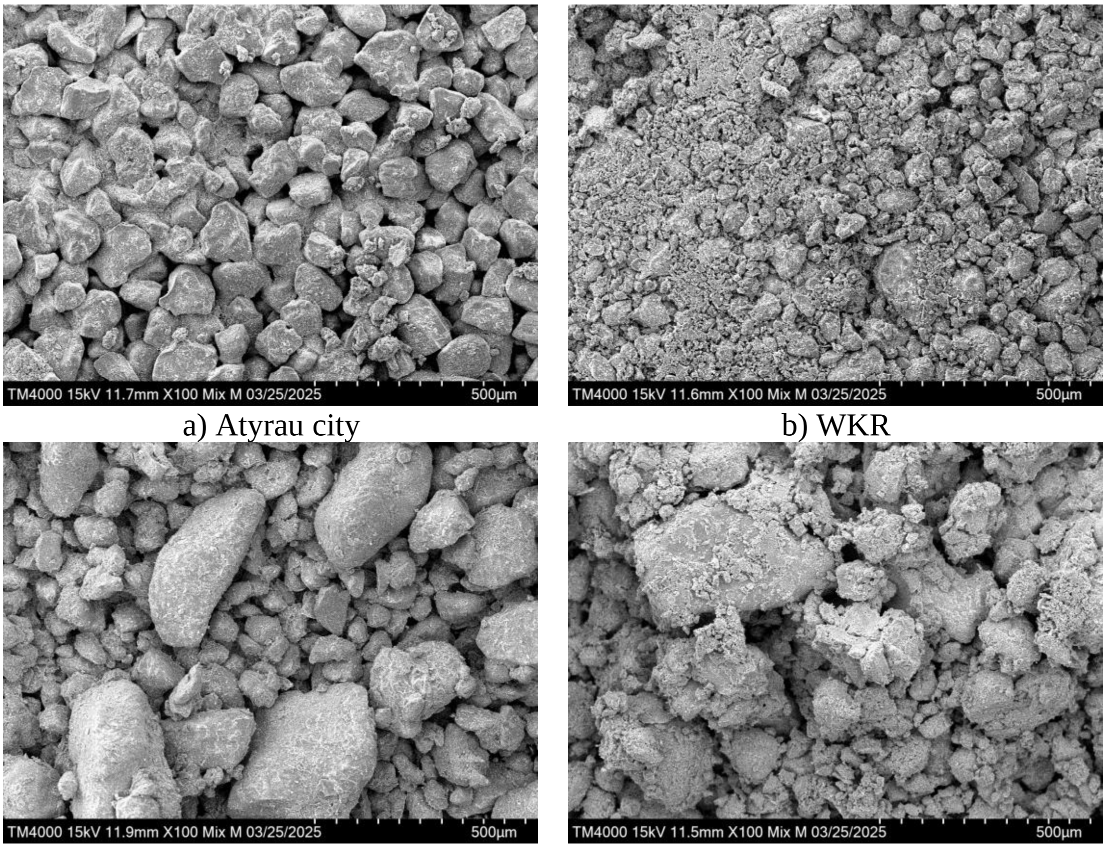
The table shows that sandy loams (Atyrau city and WKR) are characterized by relatively low plasticity (plasticity index of ≤ 6.1) and optimum moisture content of ≤ 9.1%, which makes them less sensitive to moisture saturation. At the same time, loams (Aktobe city and Mangystau region) have significantly higher liquid limit moisture values (up to 36.4%), plasticity index (from 10.3 to 14.6 %), and optimum moisture content (almost 12%). This indicates a greater variability of their structure with changes in humidity and the need for a more careful selection of stabilizers. The maximum density of loams is slightly higher (from 2.31 to 2.34 g/cm^3) compared to sandy loams (from 2.18 to 2.25 g/cm^3), which reflects their denser constitution.

The spectral analysis with the IR-Fourier spectrometer used to conduct a comprehensive assessment of the structural features of the soils revealed the presence of the main functional groups of minerals present in the samples under study. The results of the spectral analysis of the soils are presented in Table 2.

Table 2 – Mineral composition of soils in the studied areas

Region	Main minerals, %							
	O	Na	Mg	Al	Si	K	Ca	Fe
Atyrau city	48.06	0.73	1.77	4.67	34.33	1.23	4.25	4.95
WKR	44.89	1.32	8.22	26.61	26.61	2.96	10.74	5.26
Aktobe city	46.64	0.93	1.76	11.40	27.62	2.63	3.78	5.22
Mangystau region	39.64	0.67	1.93	7.74	16.74	1.68	26.19	4.82

The mineral composition of soils varies significantly across regions. In the Atyrau region, silica (Si ~34%) and oxygen (~48%) predominate, which corresponds to light sandy loams with a high quartz content. WKO soils are distinguished by an increased content of aluminum (Al ~27%) and calcium (Ca ~10.7%), which indicates admixtures of clay minerals and carbonates. Aktobe loams contain more aluminum and iron oxides (Fe ~5.2%), which determines their high plasticity. The most specific are Mangystau soils, where a significant calcium content is observed (Ca ~26%), indicating the presence of carbonate compounds that reduce plasticity and increase soil rigidity. These features are clearly visible in the microstructural images shown in Figure 4.



a) Atyrau city b) WKR

c) Aktobe city d) Mangystau region

Figure 4 – Microstructure of soils under a microscope

Sand and gravel mixtures were used as inert components, providing the structure and required density of the soil base. Their use contributed to the improvement of the distribution of the modifying additive in the mixture and the stabilization of the structure of the studied samples. Both traditional and innovative additives were used to stabilize the soils: Portland cement grade M400, as well as experimental stabilizers. Individual and combined compositions were studied to increase strength, reduce water absorption, and enhance frost resistance. The results of the test for compressive strength (CS, MPa) and frost resistance (RF, cycles) of the samples are shown in Table 3.

Table 3 – Compressive strength and frost resistance of soils with various stabilizing additives

No.	Additive	Atyrau city				WKR				Aktobe city				Mangystau region			
		CS, MPa			FR, cycles				FR, cycles				FR, cycles				FR, cycles
		7 days	28 days	Grade		7 days	28 days	Grade		7 days	28 days	Grade		7 days	28 days	Grade	
-	No additive	1.1	2.2	M20	F15	1.1	2.3	M20	F15	1.1	2.7	M20	F15	1.1	2.4	M20	F15
1	"EZCON" high concentration	1.4	3.6	M20	F15	2.2	4.7	M40	F25	1.6	3.7	M20	F25	1.8	4.2	M40	F25
2	"EZCON" low concentration	1.7	3.6	M20	F15	1.9	3.3	M20	F15	1.3	3.3	M20	F15	1.9	3.3	M20	F15
3	**"ANT"**	1.7	3.7	M20	F15	1.4	4.3	M40	F25	1.9	3.5	M20	F15	1.4	3.0	M20	F15
4	**"**Gistrong pul**"**	1.3	3.0	M20	F15	2.5	6.0	M60	F50	2.0	3.8	M20	F15	1.8	4.2	M40	F25
5	"Nova create"	1.9	4.7	M40	F25	1.8	4.3	M40	F25	1.3	2.7	M20	F15	1.9	3.8	M20	F15
6	"Gistrong"	1.9	4.1	M40	F25	1.4	3.6	M20	F15	1.5	3.1	M20	F15	2.1	4.1	M40	F25

The results of compressive strength obtained at 7 days are presented in Figure 5, while the strength values at 28 days are shown in Figure 6.

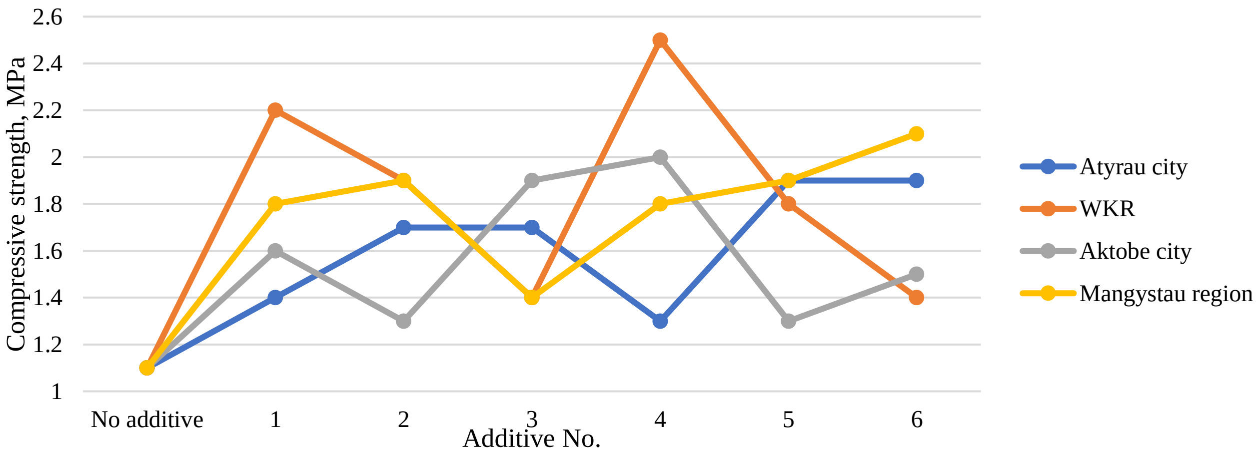


Figure 5 – Compressive strength of samples after 7 days of curing

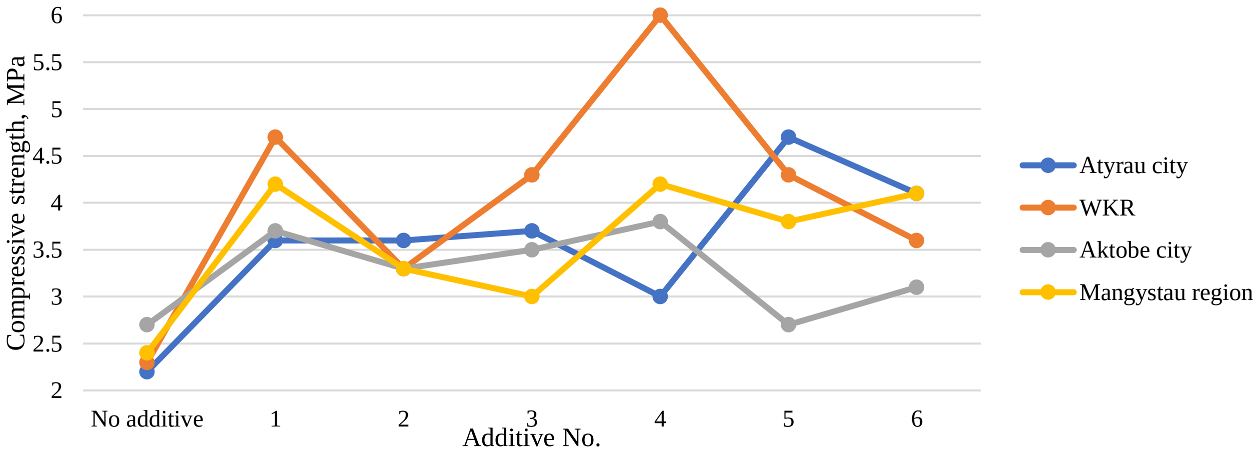


Figure 6 – Compressive strength of samples after 28 days of curing

Without additives, the strength of all soils did not exceed 2.7 MPa on the 28th day, which corresponds to a low strength grade (M20). The use of additives significantly increased the indicators. Thus, additive No. 4 in WKR turned out to be the most effective (up to 6.0 MPa, M60), indicating high compatibility with the aluminosilicate components of this soil. In the Atyrau city, additives No. 5 and 6 showed the best results (4.1-4.7 MPa, M40), which is almost twice as high as in the control. For the Aktobe city loams, the increase was less significant – a maximum of 3.8 MPa (additive No. 4), which is due to their high plasticity. The most stable results are observed in Mangystau soils: strength of 4.1-4.2 MPa (M40) with additives No. 4 and 6, which is explained by their carbonate nature. Thus, the effectiveness of stabilizers depends on the mineral composition of the soil: in carbonate and sandy loam soils, a higher increase in strength is achieved than in clay loams.

These tendencies are consistent with the results of previous studies conducted by foreign researchers. In particular, it has been shown that cement–slag systems demonstrate the highest efficiency in soils with a significant proportion of aluminosilicates [3], which corresponds to the findings obtained for WKR soils in this study. [5] noted that additives based on industrial by-products contribute to improving the durability of sandy loams, which is confirmed by the results for the Atyrau city soils. For carbonate soils, such as those in the Mangystau region, earlier research highlighted the higher effectiveness of stabilizers due to their reduced plasticity [9], which also agrees with the current results. At the same time, the relatively weak effect of additives on the Aktobe city loams is consistent with conclusions from previous studies emphasizing the strong dependence of clayey soils on mineral composition and fines content [2]. Overall, the comparative analysis confirms that soil mineralogy is the key factor determining the compatibility and efficiency of stabilizers.

4. Conclusions

The study examined the physical, mechanical, and mineral characteristics of soils in various regions of Western Kazakhstan, as well as the effectiveness of modern stabilizing additives.

1. Analysis of the physical and mechanical properties showed that sandy loams (Atyrau and West Kazakhstan regions) have relatively low plasticity and lower optimum moisture content, which makes them less sensitive to changes in the moisture regime. At the same time, loams (Aktobe and Mangystau regions) are characterized by increased plasticity and higher optimum moisture content, which requires the use of additional stabilization measures.

2. The mineral composition of the studied soils demonstrated significant differences: silica predominates in sandy loams, while WKO soils have a high content of aluminum and calcium, Aktobe soils have iron oxides, and Mangystau soils have a significant proportion of carbonates. These features determine the different reactions of soils to the use of modifying additives.

3. Compressive strength tests showed that without additives, soils in all regions have low values (up to 2.7 MPa, M20). The use of stabilizers made it possible to increase strength by 1.5–2.5 times. Additive No. 4 turned out to be the most effective in the West Kazakhstan region (6.0 MPa, M60), while additives No. 5 and 6 (up to 4.7 MPa, M40) turned out to be the most effective in the Atyrau and Mangystau regions. The increase was the smallest for Aktobe loams, which is due to their high plasticity and structural heterogeneity.

4. The comparative analysis demonstrated that the efficiency of stabilization depends primarily on soil mineralogy. Sandy loams and carbonate soils are most responsive to combined additives, showing a significant increase in strength and frost resistance. Loams with high plasticity require the development of specialized stabilizer compositions, potentially with a higher proportion of binding phases and improved dispersion technologies.

Thus, the findings highlight soil mineralogy as the determining factor for selecting stabilizers and predicting their performance. The differentiated approach to the choice of additives, depending on the mineralogical composition of soils, should become the basis for the design of durable and climate-resistant road foundations in Western Kazakhstan.

References

[1] R. Lukpanov, S. Yenkebaev, Z. Zhantlessova, D. Dyussembinov, A. Altynbekova, and R. Rakhimov, "Assessment of the bearing capacity of variable profile piles in soil using static load model tests on a testing apparatus," *Eastern-European Journal of Enterprise Technologies*, vol. 2, no. 1 (128), pp. 6–13, Apr. 2024, doi: 10.15587/1729-4061.2024.301421.

[2] A. Musbah, M. Mohammed, and A. Alfghia, "The Effect of Mineral Composition and Quantity of Fines on the Atterberg Limits and Compaction Characteristics of Soils," *Open Journal of Civil Engineering*, vol. 14, no. 02, pp. 258–276, 2024, doi: 10.4236/ojce.2024.142014.

[3] L. Liu, A. Zhou, Y. Deng, Y. Cui, Z. Yu, and C. Yu, "Strength performance of cement/slag-based stabilized soft clays," *Constr Build Mater*, vol. 211, pp. 909–918, Jun. 2019, doi: 10.1016/j.conbuildmat.2019.03.256.

[4] A. Zhussupbekov, A. K. Zhankina, A. S. Tulebekova, A. Yessentayev, and I. Zhumadilov, "Features of the bearing capacity estimation of the collapsing soil bases," *International Journal of GEOMATE*, vol. 22, no. 92, Apr. 2022, doi: 10.21660/2022.92.1656.

[5] B. Shinde, A. Sangale, M. Pranita, J. Sanagle, and C. Roham, "Utilization of waste materials for soil stabilization: A comprehensive review," *Progress in Engineering Science*, vol. 1, no. 2–3, p. 100009, Oct. 2024, doi: 10.1016/j.pes.2024.100009.

[6] R. Lukpanov, D. Dyussembinov, S. Yenkebaev, D. Tsygulyov, and M. Karacasu, "Complex additive for improving the strength properties of heavy concrete based on industrial waste," *Technobius*, vol. 4, no. 4, p. 0067, Oct. 2024, doi: 10.54355/tbus/4.4.2024.0067.

[7] M. Y. Yerzatova, K. K. Mukhambetkaliev, A. Jumabayev, and A. Tlegenov, "Enhancing the Load-Bearing Capacity and Stability of Weak Soils: An Evaluation of Soil Improvement Techniques," 2025, pp. 1–8. doi: 10.1007/978-3-031-82938-3_1.

[8] A. Tulebekova, Z. Kusbergenova, B. Dosmukhambetova, T. Abilmazhenov, and I. Zhumadilov, "Study of the impact of biopolymer and geosynthetics reinforcement on soil strengthening," *EUREKA: Physics and Engineering*, no. 6, pp. 70–80, Nov. 2024, doi: 10.21303/2461-4262.2024.003472.

[9] A. Kayumov, B. Salimova, R. Khakimova, and A. Kayumov, "Strengthening the roadbed of highways using soil stabilizers," *E3S Web of Conferences*, vol. 264, p. 02012, Jun. 2021, doi: 10.1051/e3sconf/202126402012.

[10] S. Zh. Jumadilova, V. A. Khomyakov, A. K. Kenebayeva, and Zh. N. Moldamuratov, "The use of geosynthetic materials to increase the bearing capacity of soil cushions," *Nanotechnologies in Construction A Scientific Internet-Journal*, vol. 16, no. 4, pp. 342–354, Aug. 2024, doi: 10.15828/2075-8545-2024-16-4-342-354.

[11] A. Tulebekova, A. Zhankina, R. S. Imambayeva, B. Makhiyev, A. Khapin, and D. Anop, "A practical solution for improving soil bases in problematic engineering conditions," *International Journal of GEOMATE*, vol. 25, no. 108, Aug. 2023, doi: 10.21660/2023.108.3849.

[12] *ST RK 973-2015 Stone materials and soils treated with inorganic binders for road and airfield construction. Specifications*. Astana, Kazakhstan, 2015.

[13] *ST RK 1273-2004 Soils, methods for laboratory determination of grain (granulometric) composition*. Astana, Kazakhstan, 2004.

[14] *GOST 25100-2011 Soils. Classification*. Moscow, Russia, 2011.

[15] *ST RK 1217-2003 Sand for construction works. Test methods*. Astana, Kazakhstan, 2003.

[16] *ST RK 1290-2004 Soils. Methods of laboratory determination of physical characteristics*. Astana, Kazakhstan, 2004.

[17] *ST RK 1218-2003 Materials and products of organic binders for road and airfield construction. Test methods*. Astana, Kazakhstan, 2003.

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