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JOINT RUSSIAN–AMERICAN HYDROGEOLOGICAL–GEOCHEMICAL STUDIES ON THE KARACHAI–MISHELYAK SYSTEM, SOUTH URALS, RUSSIA

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ABSTRACT

In September 1994, a Russian–American team conducted hydrogeological, geochemical, geophysical, and radiometric measurements in the territory of the Mayak Production Association, Russia. The primary purpose of these operations was to examine the frontal area of a radioelement- and nitrate-laden groundwater plume moving from the disposal site, Lake Karachai, toward the Mishelyak River. Activities encompassed (1) isolation of hydrologic intervals in two wells and production of water from these intervals, to compare isolated versus open-well sampling methods and to determine hydraulic transmissivities of the aquifer(s); (2) surface and soil-water sampling, accompanying radiometric measurements and subsequent chemical analyses; and (3) electrical resistivity profiling in areas of expected contrasting resistivity.

Preliminary results indicate that; (1) ^{60}Co, ^{137}Cs, and ^{90}Sr are present in small concentrations (~0.1 percent of permissible levels) in water of the Mishelyak River; (2) analyses of water samples collected by a downhole sampler and of water produced from packed-off intervals agree within limits of laboratory accuracy, attesting to the efficacy of the sampling methods presently used by the Russian workers; (3) considerable differences in contaminant concentrations exist between nearby wells, supporting the concept that the plume from Lake Karachai toward the Mishelyak River is controlled by steeply dipping fractures and shear zones; and (4) strong contrasts occur between the electrical resistivities of soil and bedrock.

Further collaborative work is strongly recommended, and should include more detailed isolation of intervals in wells by multi-packer installations, to better determine the geochemical and hydrological characteristics of the Karachai–Mishelyak system; deployment of a broader soil-water and soil sampling array; a more detailed examination of the distribution and concentration of radionuclides by high-resolution

field gamma spectrometry; and a detailing of the area's electrical resistivity setting, using a mobile electromagnetic measurement system.

Key words: *fractured rock, radiometrics, hydrogeology, electrical geophysics*

INTRODUCTION

This paper presents initial results of collaborative Russian–American hydrogeological, geophysical, and radiometric operations, conducted in September 1994 in the territory of the Mayak Production Association, Russia, 13 km southeast of Chelyabinsk-65 in the vicinity of the Mishelyak River (Fig. 1). The work described here presents an integrated approach to characterize the distribution of contaminants in surface waters, soils, and ground water, associated with liquid radioactive waste disposal in a fractured-rock environment.

Historically, nitrate-rich radioactive waste fluids from the Chelyabinsk-65 facility were discharged directly into the Techa River from 1949 until 1951, resulting in serious contamination of the river valley. Direct discharge into the Techa River ceased in 1951, followed that year by the construction of large impoundment reservoirs on the river, and the use of the Karachai marsh for disposal. Fluids from Chelyabinsk-65 facilities then continued to be deposited in what became Lake Karachai. In the early 1990s disposal into Lake Karachai ceased. Presently, remaining fluids are percolating through lake bottom sediments, and the lake is being filled with rock and concrete.

The primary purpose of the work reported here was to apply different methods than those previously used, to examine the frontal area of a plume of ground water moving southward from Lake Karachai toward the Mishelyak River (Fig. 1). Field activities in September 1994 principally encompassed: (1) surface and soil water sampling, accompanying radiometric measurements and subsequent chemical analyses;

(2) isolation of specific hydrologic intervals in two wells and production of water from these intervals to compare isolated and open-well sampling methods and to determine hydraulic transmissivities of the intervals; and (3) surface electrical resistivity profiling in areas of expected contrasting resistivities. Survey lines and wells are shown in Fig. 2; instrumentation, methodologies and results of initial measurements are described below.

HYDROGEOLOGICAL SETTING

The Karachai-Mishelyak area is underlain by bedrock of andesitic to basaltic porphyrite and volcaniclastics of Silurian-Devonian age which have been metamorphosed to the greenschist facies (Solodov and others, 1994; Velichkin and others, 1994). Observation of cores, walls of cuts and quarry faces indicates that the rock is ubiquitously fractured, with steeply-dipping joint sets intersected by low-angle to sub-horizontal sets. The steep joints are spaced as closely as a decimeter, while the sub-horizontal joints are generally spaced a few decimeters to a meter apart. In the oxidized zone, fracture surfaces are coated with manganese-oxide and iron-oxide minerals; all fractures generally contain quartz, calcite, and chlorite; epidote occurs in older fault zones. The thickness of the weathered zone ranges from nearly zero to several tens of meters and varies markedly over short horizontal distances (<100 m). Where thickness is adequate, an upper intensively weathered zone supports abundant vegetation and a lower, less weathered zone retains fractures.

The distribution of nitrate-ion concentrations in the groundwater, observed in monitoring wells in 1990, in the Lake Karachai-Mishelyak River system is shown in Fig. 3. The number of wells arrayed between the Techa River reservoirs and the Mishelyak is also shown; most wells have been monitored for nitrate and radioelement concentrations since the middle 1960s. Solodov and others (1994) point out that ground water between Lake Karachai and the Mishelyak River is oxidizing (Eh +400

MeV) and slightly acidic (pH 6.45). The 1990 configuration of the nitrate plume in longitudinal section is shown in Fig. 4 and illustrates the presence of this dense (specific gravity >1) water in a position beneath the Mishelyak River.

Wells which penetrated the weathered rock-to-bedrock interface indicate the position of a bedrock "high" north of Lake Karachai (Fig. 4) that appears to direct most of the contaminated water southward toward the Mishelyak. The southeastward bend of the plume near the river is most likely due to the influence of the southeastward-striking Mishelyakski Fault in that area. Therefore it is probable that, where the base of the weathered zone intersects through-going shear zones, the thickness of the weathered zone is effectively increased and the ground water flow path is deepened, creating linear weathered hydraulically conductive zones. These are the main paths for ground water moving from Lake Karachai toward the Mishelyak river (Solodov and others, 1994; Velichkin and others, 1994).

RADIOMETRIC MEASUREMENTS

Radiometric measurements and surface water sampling were conducted concurrently in traverses on the left and right banks of the Mishelyak River. Detailed descriptions of radiometric equipment, methods, and results are given by Drozhko and others (1995). The Russian team used Geiger-Mueller (GM) survey meters, and the U.S. team used a pressurized argon gas ionization chamber and a portable gamma-ray spectrometer. The ion chamber was calibrated with standard radium sources, with a small correction for differences in response to cosmic and typical natural gamma fields. The gamma spectrometer employed a 5×5 cm NaI(Tl) scintillation detector–phototube assembly coupled to a 256-channel pulse-height analyzer.

Results of reconnaissance traverse measurements performed away from the river banks by both Russian and American equipment agreed within 10 percent. As a basis for comparison, NaI(Tl) spectra at a location ~14 km north of the study area yielded a gamma exposure rate of ~8uRh^{-1}, considered to be representative of the exposure rate from cosmic-ray and terrestrial gamma emitters at this location. In contrast, exposure rates measured on the reconnaissance traverses averaged approximately three times higher. Examination of the NaI(Tl) spectra from the field indicated that ^{137}Cs is the most significant contributor to the excess external exposure, while the natural radionuclide ^{40}K was present in all field gamma spectra. Calculation of the areal activity of ^{137}Cs was based in part on previous soil-depth profiles in the Urals region showing exponential decreases of ^{137}Cs with depth (Aarkog and others, 1992; Karavaeva and others, 1994). In the reconnaissance traverse area, ^{137}Cs concentrations ranged from 100 to 162 kBq m^{-2}, within the range of concentrations (37–185 kBqm^{-2}) for this general area reported previously by Aarkog and others (1993).

Gamma spectra by the portable spectrometer, along with total gamma exposure rates by the Russian GM counters, were also measured at locations on the banks of surface water bodies (Fig. 2; Table 1). Activities at these sites included: (1) measuring the gamma background of the river bank at the ground surface and at 1m elevation with the GM counters; (2) measuring gamma spectra of the water by direct immersion of the NaI detector; and (3) gamma spectrometry of the bank with the detector 1m above the surface. Gamma background measurements on the surface and at 1 m were repeated at least 3 times at each site; they are summarized in Table 1. The averages of surface measurements by the Russian and American scintillation detectors were essentially identical (19.6 uR h^{-1}). At 1 m elevation the average of the Russian measurements was 21.1 uRh^{-1}. These measurements reflect the presence of ^{137}Cs. Due to its sensitivity to the cosmic-ray component of the gamma background, the exposure rates measured by the pressurized ion chamber were about 10 percent higher. Field gamma spectra taken on the river bank at two locations also contained the 1173 keV peak of the anthropogenic radionuclide ^{60}Co, as did spectra taken with the detector in the water at locations 1, 2, and 7 (Fig. 2). Overall, field radiometric measurements show good agreement between Russian and American equipment and methodologies. They also show that gamma radioactivity on the traverses and at the Mishelyak water sampling sites poses no danger to people who work there.

SURFACE WATER

Surface water sampling was conducted at locations 1 through 7 (Fig. 2) where there was good access to the Mishelyak River. At each site, along with the aforementioned radiometric measurements, water samples were collected, with 10 liters for Russian analyses and 2 liters for future American analyses. In-situ gamma-spectral measurements of the Mishelyak River showed the presence of ^{60}Co in the water, especially at locations 1, 2, and 7. All gamma spectra on the bank indicated the presence of ^{137}Cs.

Concentrations of principal contaminants: nitrate ion, cobalt-60, strontium-90, and tritium were determined by the ONIS and Central Laboratories at Chelyabinsk 65. Determination of nitrate ion concentration was by the colormetric method, whereby the intensity of coloring was compared with that of a standard; accuracy is +/–7%. Volume activity of ^{60}Co was measured by a scintillation gamma spectrometer, consisting of a 4096-channel analyzer and a 15 cm × 15 cm NaI(Tl) detector containing a 200 cm^3 well. Concentrations were determined by comparison with a ^{60}Co standard. Quality control was maintained by counting selected samples with a high-resolution germanium detector system. The sensitivity for a 1 h counting is ~0.5 Bq per sample. Tritium volume radioactivity was determined by beta- counting of a ZnS liquid scintillator "cocktail" containing 40 ml of scintillator and 5 ml of water sample. Sensitivity for tritium is ~40 Bq/l. ^{90}Sr was determined from the beta activity of ^{90}Y, extracted from acidified samples.

Laboratory analyses of ^{60}Co, ^{3}H, ^{90}Sr and NO_3-ion concentrations in surface water are listed in Table 1. Appreciable concentrations of tritium occur at all 7 locations. ^{60}Co exists at 6 of the 7 sites, with the highest value at location 2, confirming the field measurements. ^{90}Sr occurs in relatively low abundances (the highest being 2.48 Bq/l) at all seven locations, suggesting its introduction to the water from river-bank sediments and vegetation. Earlier reports by the Russian Environmental Laboratory state that the concentrations of ^{60}Co and ^{137}Cs do not exceed 1.5 Bq/l, a level ~0.1 percent of the presently permissible concentrations for radiation safety in Russia, and that the ^{90}Sr concentrations are ~10 percent of permissible levels. Additional sampling is recommended down-stream from site 7 to determine if river bottom sediments and aquatic vegetation may be helping to remove ^{60}Co from the river water.

SOIL WATER SAMPLING

To provide data continuity between surface and ground water samples, two sets of samplers were installed to collect soil water from the vadose zone near wells 173 and 176 (Fig. 2). The permanent water table is expected to be 1 to 1.5 m deep at these locations. A sampler set had two samplers, at different depths, emplaced in hand-dug holes which were then backfilled. Each sampler consisted of a PVC tube 75 cm long, with a capillary-porous tip at the bottom end and suction/pressurization and sampling tubes at the other end. A hand vacuum pump provided suction for water collection. At well 176, one sampler was installed with its porous tip 1m below ground level and one at a depth of 50 cm. Because bedrock was very close to the surface near well 173, installation depths there were 75 and 50 cm.

Samples of the order of 10 to 30 ml were successfully collected from the 1 m-deep sampler at well 176 after one day, from the 50 cm-deep sampler after three days, and from the samplers at well 173 beginning after five days. The samples were combined to obtain sufficient volumes for laboratory analyses. No appreciable concentrations of radionuclides were found near well 173. Moisture from the 1m-deep sampler near well 176 contained ^{106}Ru, ^{137}Cs and ^{60}Co, possibly due to introduction from splashing of pumped water during well purging operations.

Future sampling should incorporate nests of samplers emplaced to provide vadose-zone soil-water samples at 10 cm intervals from depths of 20 cm to 1 to 2 m. Chemical analyses of soil samples taken from each of the 10 cm intervals could then be compared with soil-water chemistries to reveal the partitioning of contaminants between the solid and fluid phases.

GROUND WATER SAMPLING

Ground water samples were obtained from wells 173 and 176 , initially by a downhole fluid sampler and later by pumping from packed-off intervals. Procedures and preliminary results are described below, a diagram of the wells is shown in Fig. 5.

To prepare the wells for the September 1994 samplings, the wells were washed with clean (neutral) water in July, 1994. They were then allowed to stabilize for 60 days to recover their natural hydrochemical balance. A downhole resistivity survey was conducted in relatively undisturbed conditions before starting the sampling sequence; to some extent the zones selected for sampling were based on this survey. The first sampling of 80 L was then done with a plunger-type sampler developed by P.S.A. Hydrospetzgeologia. Then, the resistivity survey was repeated, followed by extraction of 330 L of water using a downhole pump to stimulate the flow of water into the well. This production was accompanied by a third resistivity survey. A second set of samples was then collected with the plunger sampler. Results of surveys before and after the first sampling indicated no substantial change in the resistivity pattern. However, after pumping the 330 L, the third resistivity survey showed a decrease of specific resistance from 13 to 8 0hm.m in the interval 20–50 m because of the production of more mineralized water from below, e.g., from the 55–70 m interval.

Following open-hole sampling, a two-packer system was deployed in the wells, permitting isolation and subsequent sampling and pressure measurements, first of five intervals in well 176 and then of three intervals in well 173 (Fig. 5). The assembly consisted of two packers, each 1 m in length, inflated by compressed air. Choosing the specific intervals was aided by examination of detailed borehole-wall photographs, examples of which are shown in Fig. 6. Successful isolation was achieved in all intervals, as demonstrated by the lack of response of pressure transducers located above and below the packed-off interval, compared to the response of a transducer within the interval, as water was produced from the interval by an electrically-driven downhole pump. The pump was limited in depth of operation to <100 m. Pressures were regulated and recorded by a computer- controlled data acquisition system. Water samples were collected during production and were analyzed on site by the "express method," whereby the nitrate-ion concentrations of successive samples taken at 10 minute intervals, measured by specific-ion electrode, reach a "plateau" indicating the presence of true formation water. Then the 10 liter (Russian) and 1 liter (U.S.) samples for laboratory analyses were collected.

HYDRAULIC TRANSMISSIVITIES

The purpose of transmissivity tests was two-fold. First, the vertical distribution of hydraulic transmissivity was measured to determine the vertical stratification of the hydrological system and to obtain the range in transmissivity. Secondly, the test served to work out the logistics of carrying out joint Russian-American hydraulic testing, including problems related to adapting the instruments and cables from both teams to ensure their compatibility to each other, and to compare the new results with those of previous Russian field measurements.

Three pressure transducers accompanied the two-packer systems in Wells 173 and 176, one in the packed-off interval and one above and below the packers, respectively. The top and bottom pressure transducers monitor any responses as the packer interval is pumped, thus giving a measure of the effectiveness of the packers. As the packer interval was pumped at a constant flow rate (Q L/min), the pressure drop (Δh) was measured in meters of water head. If the pressure transducers above or below the two-packer system recorded little or no response, the packers had negligible leakage and the data were analyzed to obtain the hydraulic transmissivity (T = kH) of the interval, where k is the hydraulic conductivity and H is the effective aquifer thickness.

Figure 7 shows an example of such a measurement for Well 176 and test zone 4, from 44 to 55 m depth (Fig. 5). Three curves are shown in Fig. 7. The middle one is the pressure in the packed interval, which was initially at about 54 m of water head and dropped in response to pumping between 1000 to 2000 seconds (labelled Test 4). The pumping was stopped and then resumed with Q = 55 L/min from about 2700 seconds until 4100 seconds (labelled Test 4A). The lower curve in Fig. 7 shows the pressure in the well above the packer system, while the top curve gives the pressure just below the packers. For Test 4, the top curve shows a response to pumping in the packed interval, indicating poor packer seal, whereas no response was noted for Test 4A. Thus, data from Test 4 were discarded and only those from Test 4A were used in the analysis (even in Test 4A, a small response was observed above the packers, which however was deemed not significant).

The analysis proceeds as follows. The change in pressure head Δh due to flow Q is given by,

$$\Delta h = \frac{Q}{4\pi\ T}\left(-\gamma - \ln\frac{r_w{}^2 S}{4Tt} + ...\right)$$

where the bracket gives an expansion of the exponential integral or the so-called Well Function. Now let us assume that Well 176 and Well 173 are at a distance r_L from a constant pressure boundary, which may be a fault or a nearby fracture. By the image method, Δh is then given by,

$$\Delta h = \frac{Q}{4\pi\ T}\left[\left(-\gamma - \ln\frac{r_w{}^2 S}{4Tt} + ...\right) - \left(-\gamma - \ln\frac{2r_L{}^2 S}{4Tt} + ...\right)\right]$$

so that,

$$\Delta h = \frac{Q}{4\pi\ T}\ \ln\frac{(2r_L)^2}{r_w^2}$$

$$T = \frac{Q}{2\pi\ \Delta h}\ \ln\frac{2r_L}{r_w}$$

All the tests were made in the upper parts of Well 176 and Well 173, where r_w (well diameter) is 0.112 m (Fig. 5). The value of r_L is not known, though the result for T is not very sensitive to this value because of its logarithm dependence. Thus, for example, if r_L is changed from 100 to 200 m, the results for T are changed by ln2/ln (200/0.112); i.e., by only about 10%. For a study of relative transmissivity variation along the well, the value of r_L is constant for all well intervals. Then, we need only to study variations of Q/Δh, which is proportional to T.

The results of the analysis are presented in Table 2. The transmissivity ranges from 0.2 to 22 m^2/day. This is to be compared with the transmissivity values over the total depth of wells in the Lake Karachai area given by Drozhko and others (1996) (i.e., T = 3–220 m^2/d). Along the wells the values of the different intervals are about 15–22 m^2/d, except between 24 and 45 m depth where the transmissivity is one or two orders of magnitude smaller. This indicates a layer of low permeability, an aquitard, at this level, which was not apparent in earlier hydraulic tests.

The vertical transmissivity variation for Well 176 is plotted in Fig. 8 against the gamma and caliper logs from Solodov and others (1994). This figure shows that the low-permeability layer at 24–45 m depth corresponds to low gamma log values and a relatively smooth part of the caliper log. In contrast, the intervals of higher transmissivity show higher gamma log values and larger fluctuations in the caliper log.

From the limited measurements made, no significant differences in hydraulic properties between Wells 176 and 173 are noticeable (see Table 2).

The low transmissivity zone at 24–34 m in Well 176 is matched at a similar depth in Well 173, while the transmissivities of the zones deeper than 40 m in both wells are an order magnitude greater. It is also interesting to note that even though the transmissive zones are at similar depths in the two wells, suggesting the possibility of horizontal conductive zones between them, concentrations of NO_3, ^3H and ^{60}Co are two orders of magnitude greater in Well 176 than in Well 173 (Table 3). This implies that steeply-dipping fracture zones, rather than low-angle zones, are more likely the conduits for fluids percolating from Lake Karachai in the vicinity of the Mishelyak River, and that these structures control the eastern border of the plume between Wells 176 and 173.

Future activities should include the deployment of multi-packer assemblies to depths much greater than 100 m, isolating several intervals concurrently. These, and the existing single-packer assembly could be used to examine the response of intervals in nearby wells to production of an interval in another well, providing a broader picture of the hydrological continuity within and between zones.

GROUND WATER CONSTITUENTS

The results of NO_3-ion and radioelement concentrations in Wells 173 and 176 are listed in Table 3 (methods of analysis were described earlier). The highest concentrations are from the sample taken at 63 m depth, though NO_3 and tritium are also relatively high in samples from 162 and 189 m. It is interesting to note that the relatively high concentrations of ^{60}Co in the 63 m sample occur in a zone of high gamma radioactivity measured in Well 176 (Solodov and others, 1994). Changes in the nitrate ion concentration are consistent when results for samples taken by different methods are compared. For each interval in Well 176, there is an increase in nitrate ion concentration for samples taken using the plunger sampler after pumping water from the well, and a relative decrease in nitrate in samples collected from the isolated intervals. This may be due to the introduction of nitrate from interval 5 into the higher intervals by movement of water along the outside of the casing. The concentrations in the packed-off interval samples compare well with the concentrations in plunger samples obtained under "natural" conditions, i.e., before pumping, attesting to the efficacy of the ground water sampling methods presently used by the Russian team. The largest difference between interval and plunger samples is in interval 5, the main zone of incoming contaminated water. There the packers span a 20 m depth interval, while the plunger sampler was placed at one position near the center of the interval.

A good match in the pattern of increasing concentrations with depth in Well 176 and nearby Well 8/69 is shown in Fig. 9. Well 8/69 is closer to the axis of the contaminant plume than Well 176; therefore it has higher concentrations. However, the similar depth distributions of concentrations in both wells suggests that they intersect the same transmissive zone below 50 m depth.

Table 4 compares concentrations and volume activities of contaminants in well and Mishelyak River surface waters. Average NO_3 ion concentrations of surface water are about 1/1000 of those of Well 176 water and 1/10 those of Well 173 water. Average ^3H volume activities of surface water are slightly less than those of Well 176 water, while average ^{90}Sr in surface water slightly exceeds that in Well 176 water. Average ^{60}Co volume activities of Well 176 water are ~200 times those of surface water, and average ^{60}Co activities of Well 173 and surface water are roughly equal. These results demonstrate the preponderance of contaminants in water of Well 176, in contrast to nearby Well 173 and to Mishelyak river water, and indicate that Well 176 is definitely within the plume of contaminants moving from Lake Karachai toward the

Mishelyak River. The presence of statistically-significant concentrations of ^{60}Co in the surface water suggests that some contribution from the ground water plume is reaching the surface water. The near parity of ^{90}Sr in surface water, compared to Well 176 can be attributed in part to the introduction of this isotope to the water from river bank sediments (suggested also by the presence of low concentrations of ^{137}Cs in surface water and its abundance on the river bank).

GEOPHYSICAL SURVEYS

Surface geophysical methods may help to determine the location of contaminated ground water at less cost, but with lower resolution than by drilling and sampling wells. In this respect, an electrical resistivity and induced polarization (IP) survey was conducted; the locations of the survey lines are shown in Fig. 2. A dipole-dipole resistivity array was deployed because it permitted both vertical sounding and lateral profiling. Lightweight equipment brought from the U.S. included a stable-oscillator based phase-measuring IP set, a low-power current-controlled transmitter, and a set of non-polarizing measuring electrodes. A dipole spacing of 20 m provided good resolution between depths of 5 and 40m. Traverses encompassed ~1.8 line km; including profiles through Wells 173 and 176, a parallel profile south of the Mishelyak River and its marsh, and two profiles roughly orthogonal to these: one to the north and one south of the Mishelyak (Fig. 2). A more detailed description of the procedures and resistivity profile diagrams are given by Frangos and Ter-Saakian (1995).

An example of a resistivity profile is shown in Fig. 10. The profile is oriented S 37° E and passes through the location of Well 176 (Fig. 2). It indicates the presence of an electrically conductive sequence of soil and weathered rock overlying a resistive bedrock basement, which appears closer to the surface to the southeast in the direction of Well 173. Estimates of the overburden thickness from the resistivity surveys range from zero in the area of well 173 to over 10 m near the northwest end of the westernmost line. The more conductive bedrock near Well 176 than to Well 173 may be due to the effect of contaminated water in bedrock fractures near Well 176, in contrast to “cleaner” water in bedrock in the well 173 area.

Induced polarization properties vary strongly along the observed lines. The highest apparent IP effects occur south of the Mishelyak River and the lowest are to the east, near Well 173. IP effects also show a contrast between the Well 176 and 173 areas, like in the electrical resistivity survey, which may also be attributed to the contaminated water.

It is suggested that electromagnetic methods, which permit rapid determination of resistivity, be used in future work. The equipment for those methods is quite mobile, and has the advantage that it can be deployed on frozen surfaces, which would allow a comprehensive survey of the Mishelyak marshes during winter months. At this juncture the resistivity profiles suggest the presence of contaminated water in bedrock and provide a baseline against which future changes due the further influx of conductive fluids may be compared.

CONCLUSIONS

The initial work described here demonstrates how integrated radiometric, hydrological, geochemical and geophysical activities were used to characterize the presence of contaminants in the surface water, soil- and ground-water of the frontal area of a long-term plume moving from a disposal site into and through fractured bedrock. More detailed investigations are required for complete characterization, which can then lead to determination of remedial methodologies appropriate to this, and perhaps other fractured-rock sites.

Though this is a report of initial measurements, there are some important preliminary results:

1) ^{60}Co, ^{90}Sr and ^{137}Cs are present in small concentrations (~0.1 % of permissible levels) in water of the Mishelyak River; ^{3}H is present in appreciable abundance in both river and ground water. The source of the activation product ^{60}Co, in contrast to ^{90}Sr and ^{137}Cs which are global fallout radionuclides, is liquid effluent from Lake Karachai; it occurs in the ground water and at 6 of the 7 surface water sampling sites.

2) Analyses of ground water samples collected by a downhole sampler and of water produced from packed-off intervals agree within limits of laboratory accuracy, attesting to the efficacy of the sampling methods presently used by the Russian workers. These two methods of sampling produced essentially identical results.

3) The plume of contaminants from Lake Karachai has undoubtedly reached Well 176, as evidenced by the well's relatively high concentrations of nitrate, ^{60}Co and ^{3}H. Concentrations about two orders of magnitude lower indicate that little water from Lake Karachai has reached the well 173 area. Though there are similarities in hydraulic transmissivities in the two wells, the strong contrast in their fluid chemistries suggests that high-angle fractures and/or shear zones are the principal conductors of fluids from Lake Karachai toward the Mishelyak River and that these structures control the present eastern border of the plume between Wells 173 and 176.

4) The presence of contaminated water near Well 176 is suggested by the electrical resistivity and induced polarization data.

Further collaborative work is strongly recommended, and should include: (1) more detailed isolation of intervals in wells by multi-packer installations, and well-to-well testing to better determine the geochemical and hydrological characteristics of the Karachai - Mishelyak system; (2) deployment of a broader and more vertically detailed soil-water and soil sampling array; (3) a very careful examination of the distribution and concentration of radionuclides by high-resolution field gamma spectrometry; and (4) a detailing of the area's electrical resistivity setting, using a mobile electromagnetic measurement system.

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CAPTIONS

Table 1. Concentrations of tritium, cobalt-60, and nitrate ion at surface water sampling sites.

Table 2. Hydraulic transmissivities of packed-off intervals in Wells 173 and 176.

Table 3. Concentrations at different stages of sampling at Wells 173 and 176.

Table 4. Comparison of concentrations of surface and ground waters.

Table 1. Surface water concentrations and shoreline measurements.

	Constituents				Gamma Radioactivity	
Sample Point	Tritium (Bq/l)	Cobalt-60 (Bq/l)	Strontium-90 (Bq/l)	Nitrate ion (mg/l)	1m above surface (uR/h)	On soil surface (uR/h)
1	132	0.9	1.18	<0.45	—	17
2	198	1.3	1.37	<0.45	14*	21*
3	264	0.4	1.26	2.8	20	13
4	198	0.42	1.30	<0.45	28	29
5	264	0.89	2.48	<0.45	25	20
6	176	<0.4	1.37	8.8	13	13
7	176	0.75	1.41	3.1	17	14

*Over water surface.

Table 2. Results of Packer Flow tests.

Well	Test zone	Depth of test interval (m)	Q (L/min)	Δh (m)	Q/Δh (m^2/d)
176	1	18–28	30	2	15.0
	2	25–35	24	Bad seal	
	2A	24–34	24	23.5	1.0
	3	35–45	3.6	21.5	0.2
	4	44.5–54.5	12	Bad seal	
	4A	45–55	55	2.5	22.0
	5	55–75	40	2	20.0
173	1	3–13	2.2	Transducer failed	
	2	29–39	14.4	13.5	1.1
	3	42–52	36	2.8	12.9

cf. Drozhko and others (1995): T = 3–220 m^2/d in wells in Karachai area.

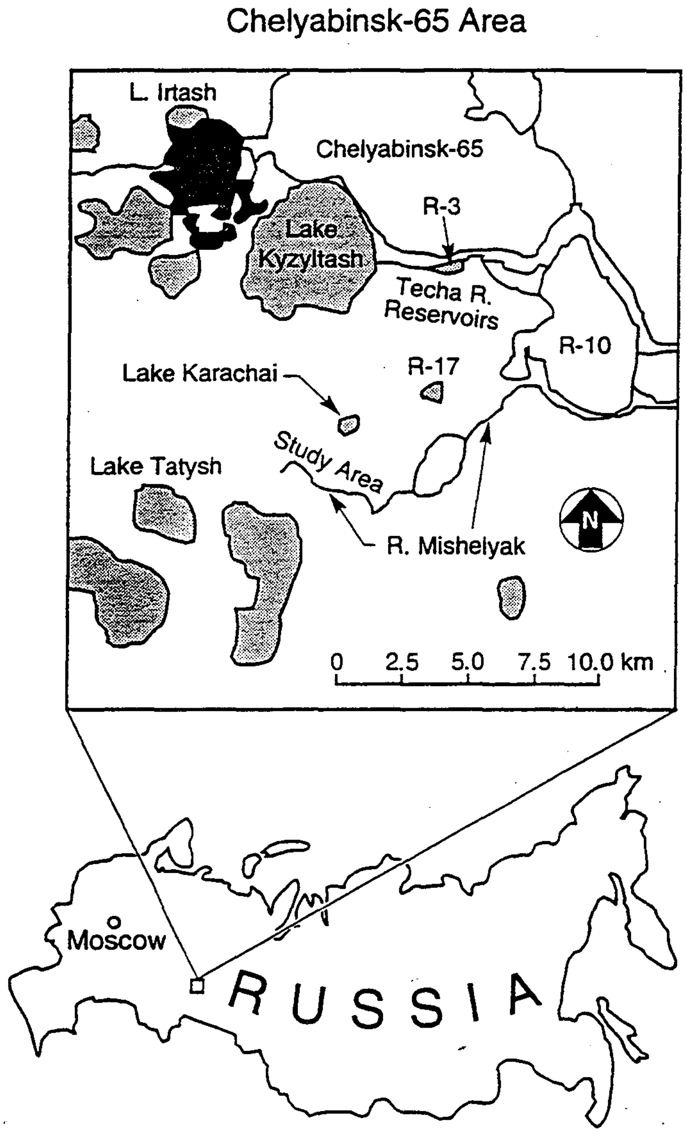
Table 3. Wells 173 and 176 concentrations at different stages of sampling.

Well No.	Interval No.	Nitrate-ion concentration (g/l)			Tritium concentration (Bq/l)		
	(sampler depth (m))	Before pumping	After pumping	Packer sample	Before pumping	After pumping	Packer sample
176	1 (24)	1.1/1.0	1.6/1.69	1.09	286	527	286
	2 (31)	0.9	1.8	0.9	286	616	264
	3 (40)	1.03	2.04	0.94	330	748	330
	4 (50)	1.3	1.4	1.15	396	573	264
	5 (63)	2.5/3.0	4.6	3.17	814	1474	1320
	6 (137)	1.4	1.6	—	426	616	—
	7 (162)	2.4	—	—	638	—	—
	8 (198)	2	—	—	748	—	—
173	1 (8)	0.021	—	0.021	<70	—	<70
	2 (31)	0.022	—	0.015	<70	—	<70
	3 (43)	0.019	—	0.016	<70	—	<70

Well No.	Interval No.	Cobalt-60 Concentration (Bq/l)			Strontium-90 Concentration (Bq/l)		
	(sampler depth (m))	Before pumping	After pumping	Packer sample	Before pumping	After pumping	Packer sample
176	1 (24)	114	204	96	0.63	2.41	1.0/1.26
	2 (31)	116	242	86	0.96	3.15	0.85
	3 (40)	121	277	104	1.01	2.85	1.15
	4 (50)	158	196	121	1.44	2.59	1.33
	5 (63)	318	564	557	3.03	8.88	5.18
	6 (137)	109	124	—	0.7	1.7	—
	7 (162)	133	—	—	—	—	—
	8 (198)	167	—	—	—	—	—
173	1 (8)	0.54	—	0.9	—	—	—
	2 (31)	0.6	—	0.72	—	—	—
	3 (43)	0.6	—	0.74	—	—	—

Table 4. Summary of concentrations, surface and well water.

	Nitrate ion (mg/l)	Tritium (Bq/l)	Cobalt-60 (Bq/l)	Strontium-90 (Bq/l)
Well 173	21	<70	0.6	n.d.
Well 176	1600	495	155	1.11
Mishelyak River	2.3 (s.d. 3.1)	201 (s.d. 48)	0.7 (s.d. 0.4)	1.48 (s.d. 0.45)
Surf. Water / Well 176 water	1.4×10^{-3}	4.5×10^{-1}	4.5×10^{-3}	1.4



XBD 9510-05004.ILR

Figure 1. Location map, Chelyabinsk 65 area.

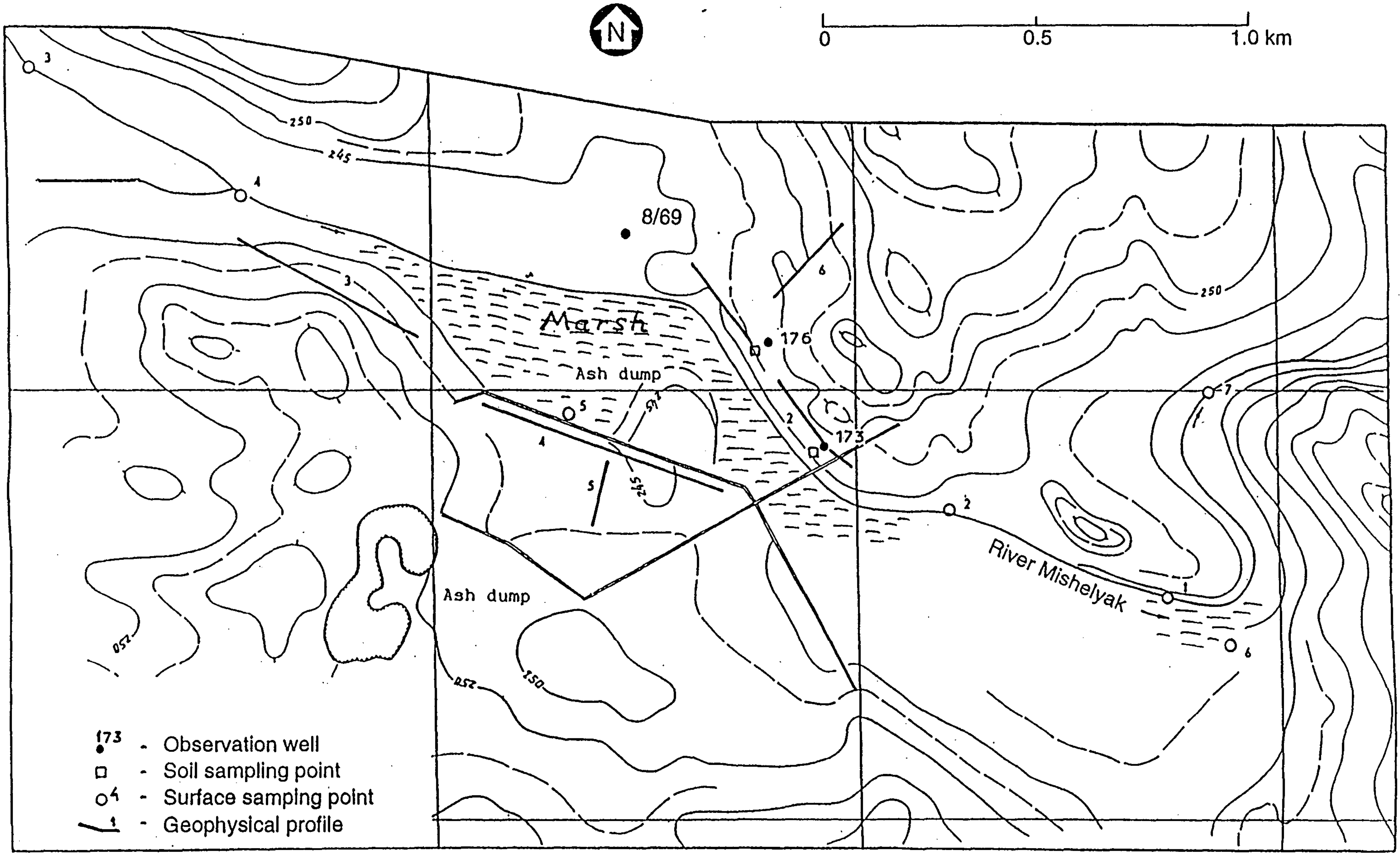
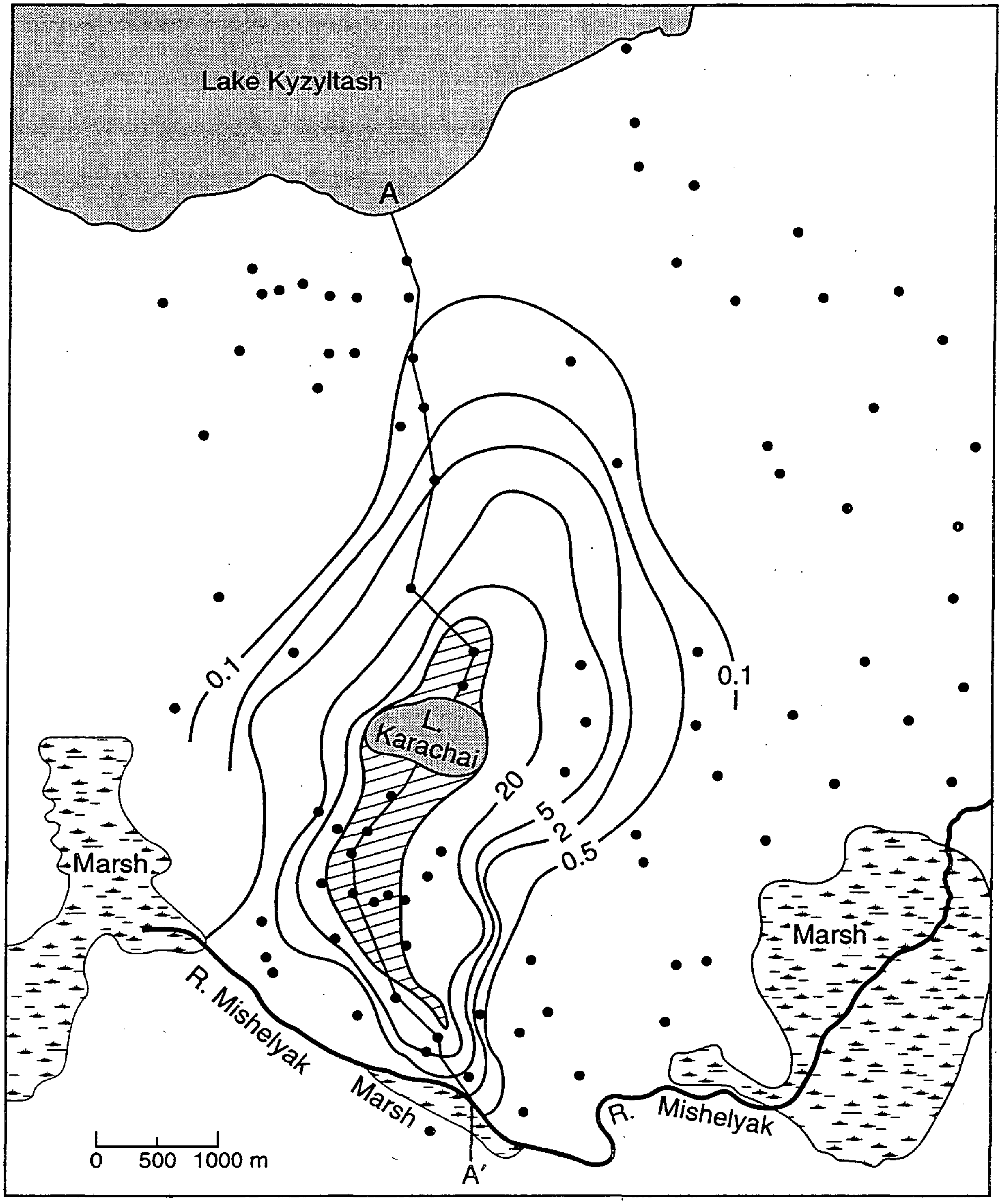
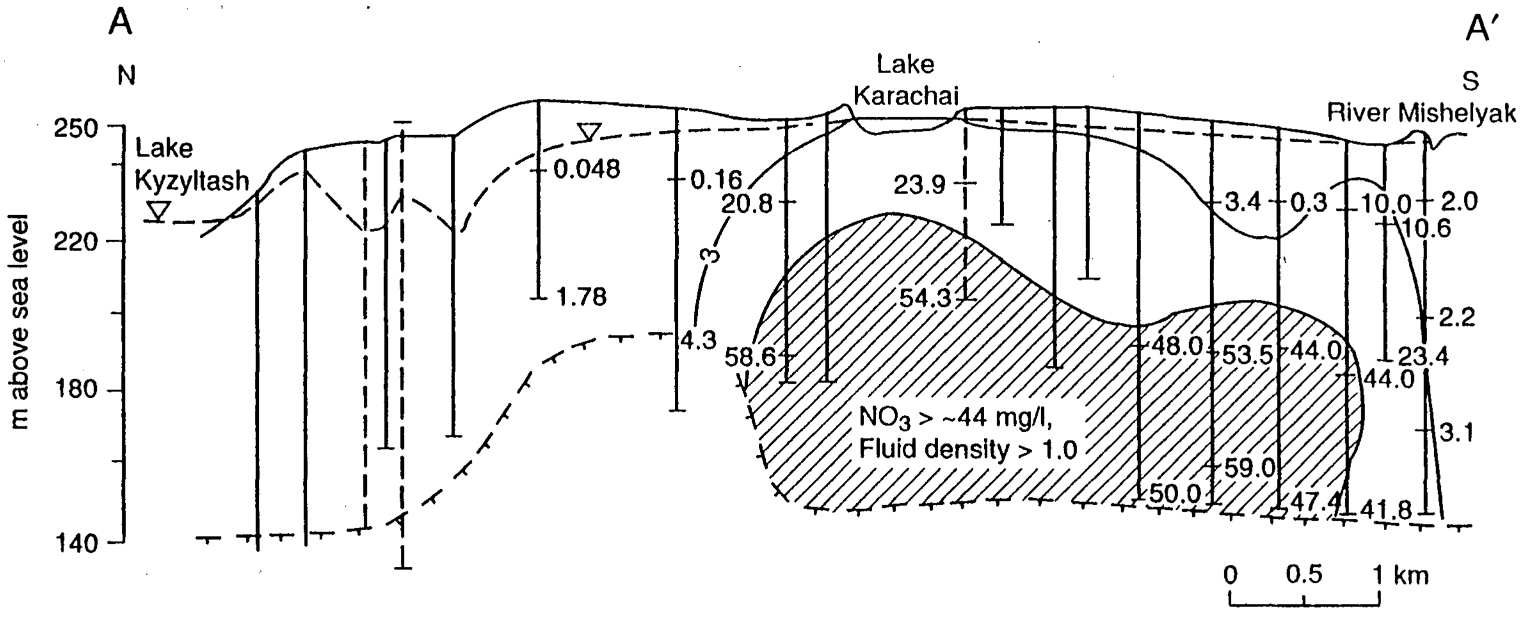


Figure 2. More detailed map of Lake Karachai - Mishelyak River field activities area. Dashed areas indicate marshes; elevations in meters above sea level.



XBD 9603-01047.ILR

Figure 3. Areal distribution of nitrate in groundwater between Lake Karachai and the Mishelyak River, as of 1990. Small dots are well locations. Nitrate concentrations in g/liter.



XBD 9511-05288.ILR

Figure 4. Longitudinal section A-A′ (Fig. 3) of the nitrate distribution, as of 1990. Upper dashed line is the water table, lower dashed line is the bedrock-weathered rock interface. Nitrate concentrations in g/liter.

Well Profiles

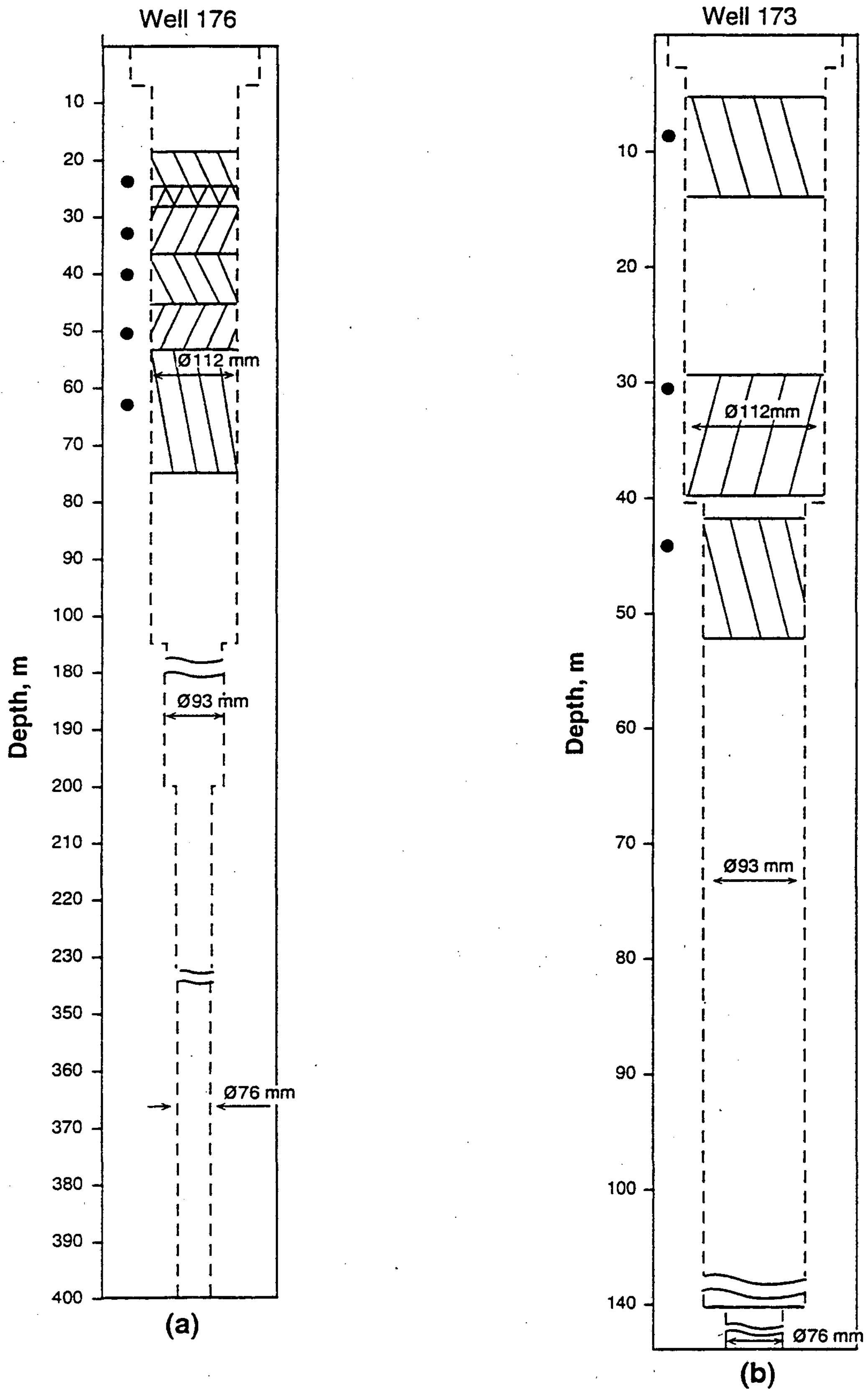


Figure 5. Diagrams of Wells 176 and 173. Striped zones indicate packed-off intervals. Heavy dots indicate corresponding fluid sampler positions.

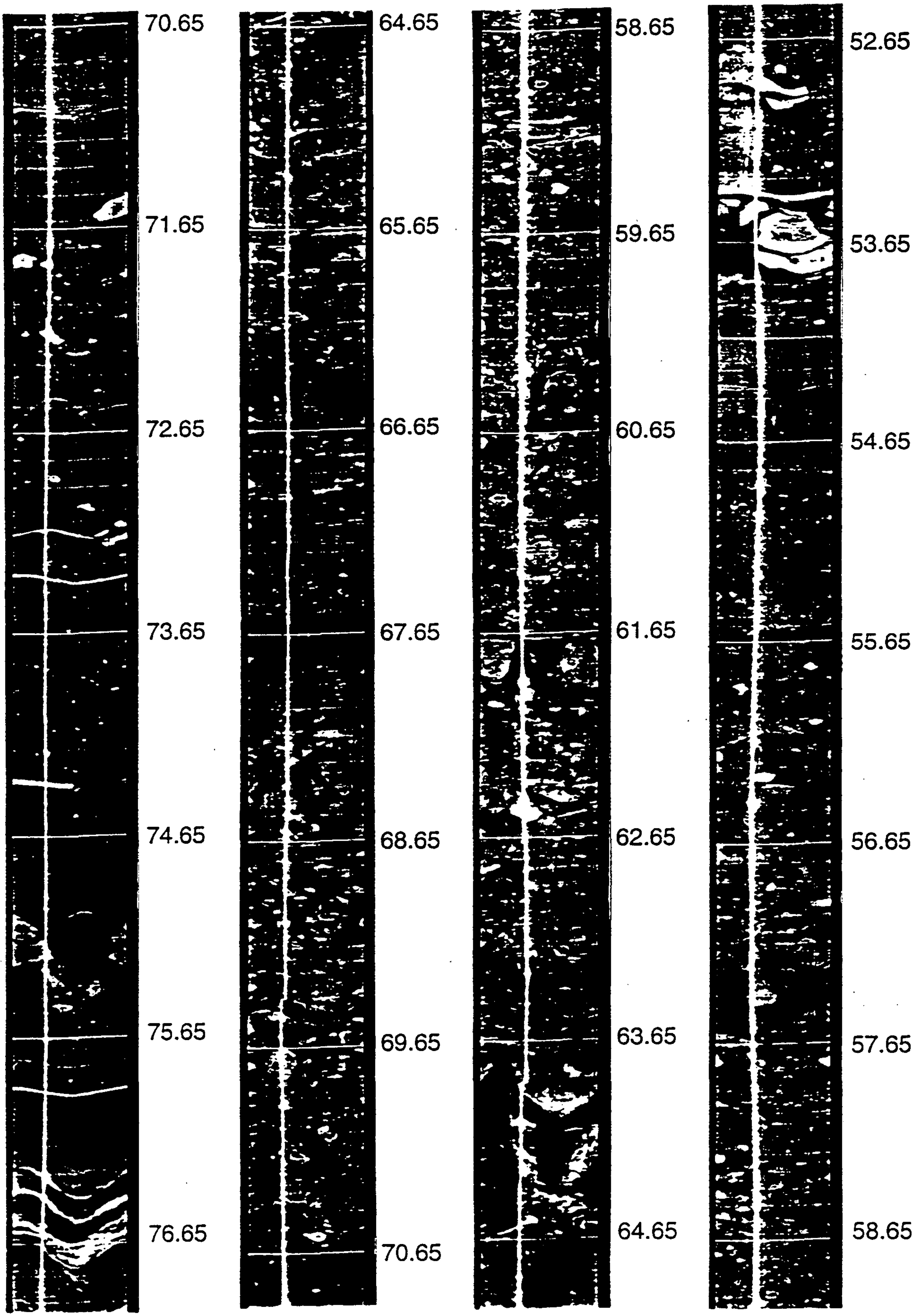


Figure 6. Well 176, example of an unfolded wellbore telephotograph. The light vertical line indicates true north; steeply dipping fractures have a sinusoidal pattern. (Numbers indicate depths in meters.)

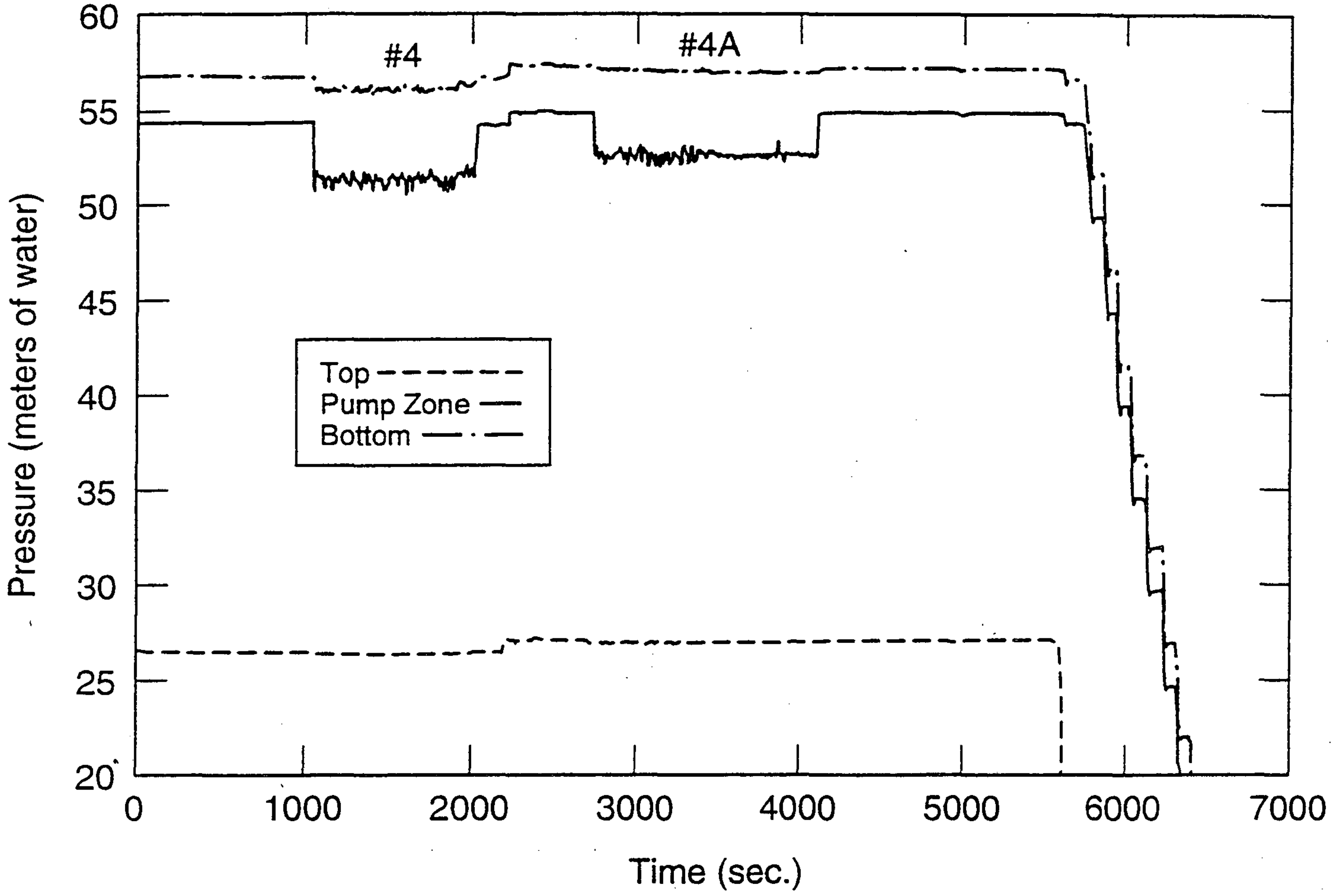


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Figure 7. Well 176, test zone 4. Pressure record during pumping tests 4 and 4A.

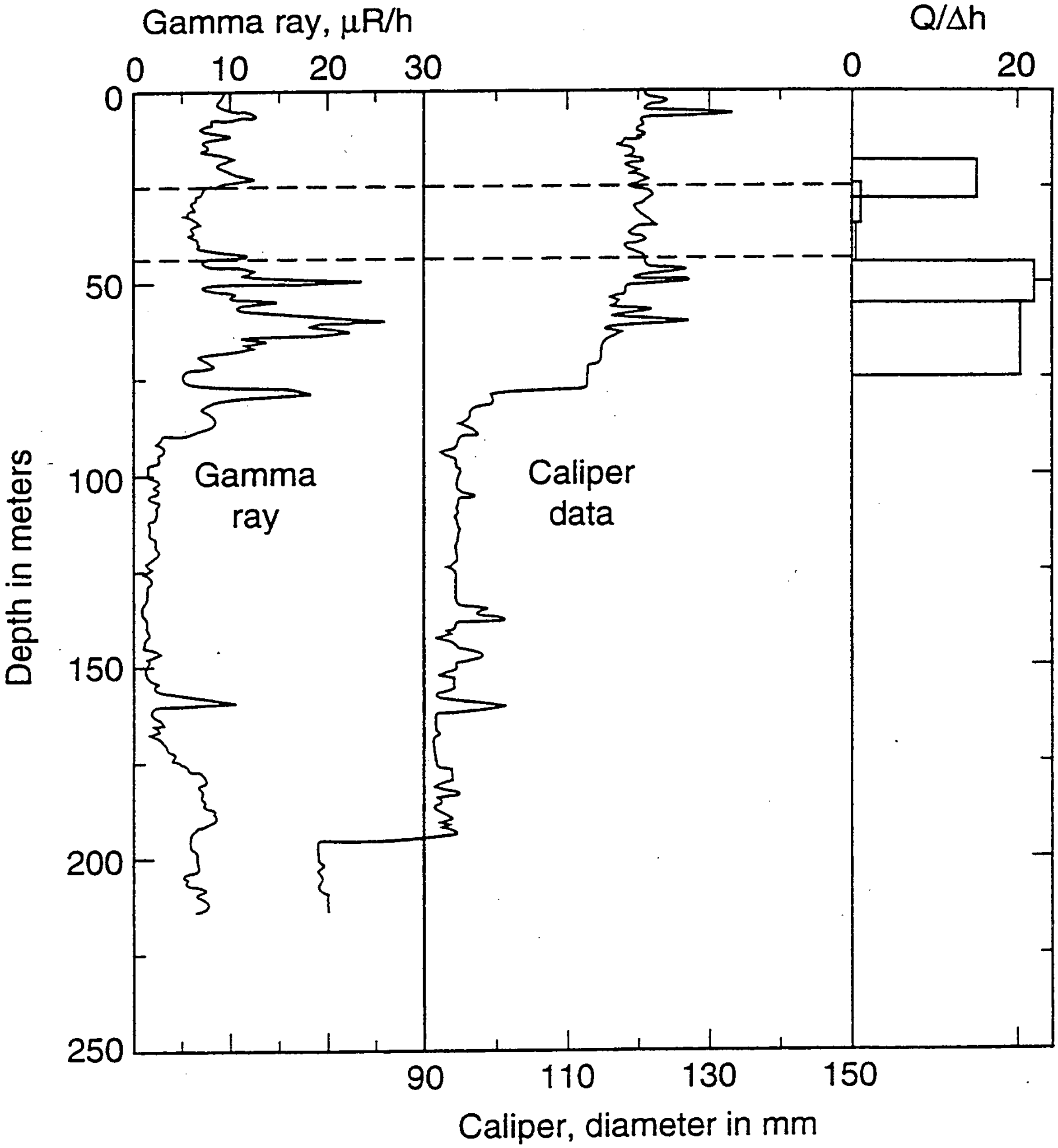

Figure 8. Well 176. Gamma and caliper logs from Solodov and others (1994), and hydraulic transmissivity data from the September 1994 tests.

XBD 9508-03984.ILR

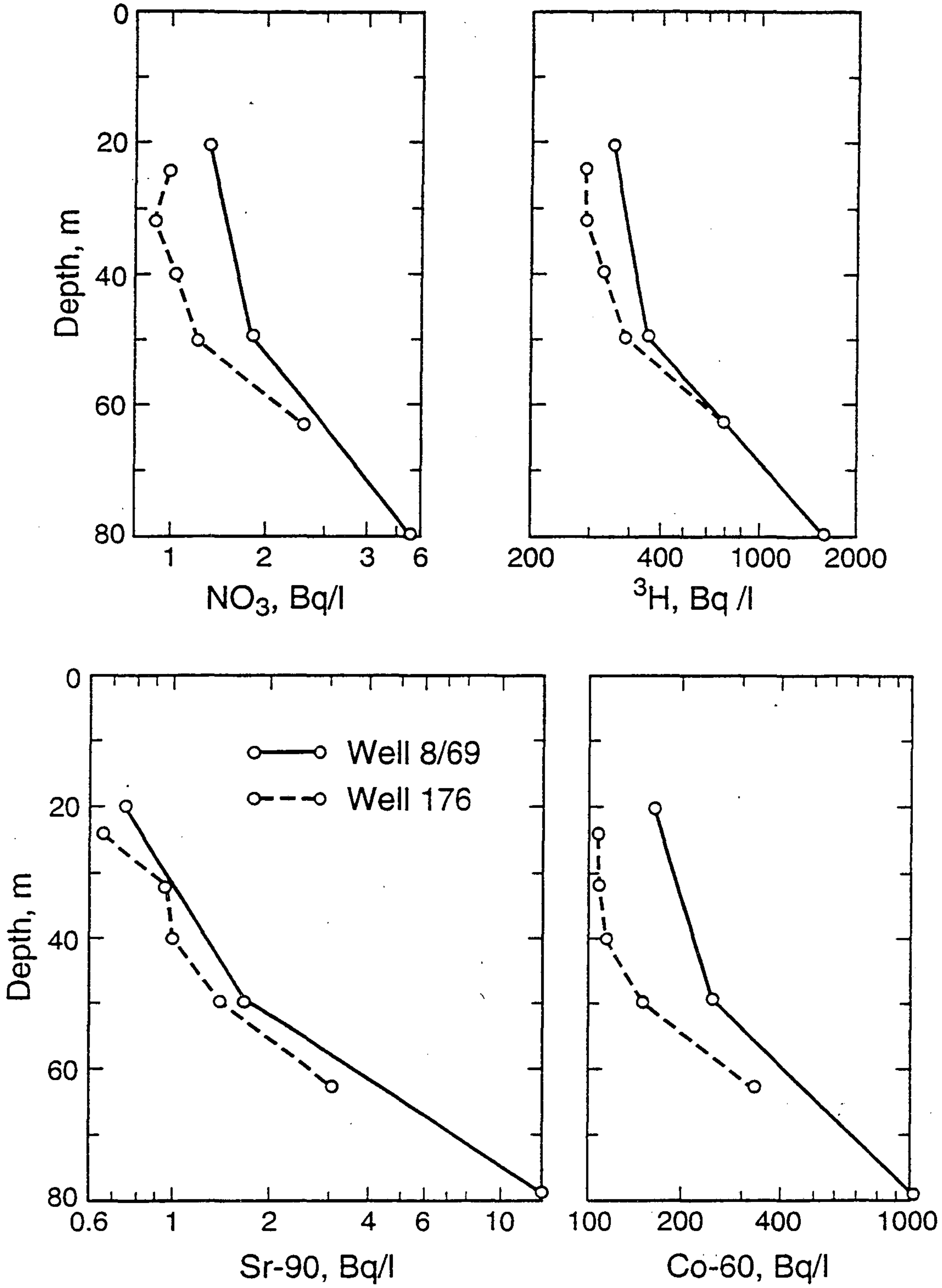

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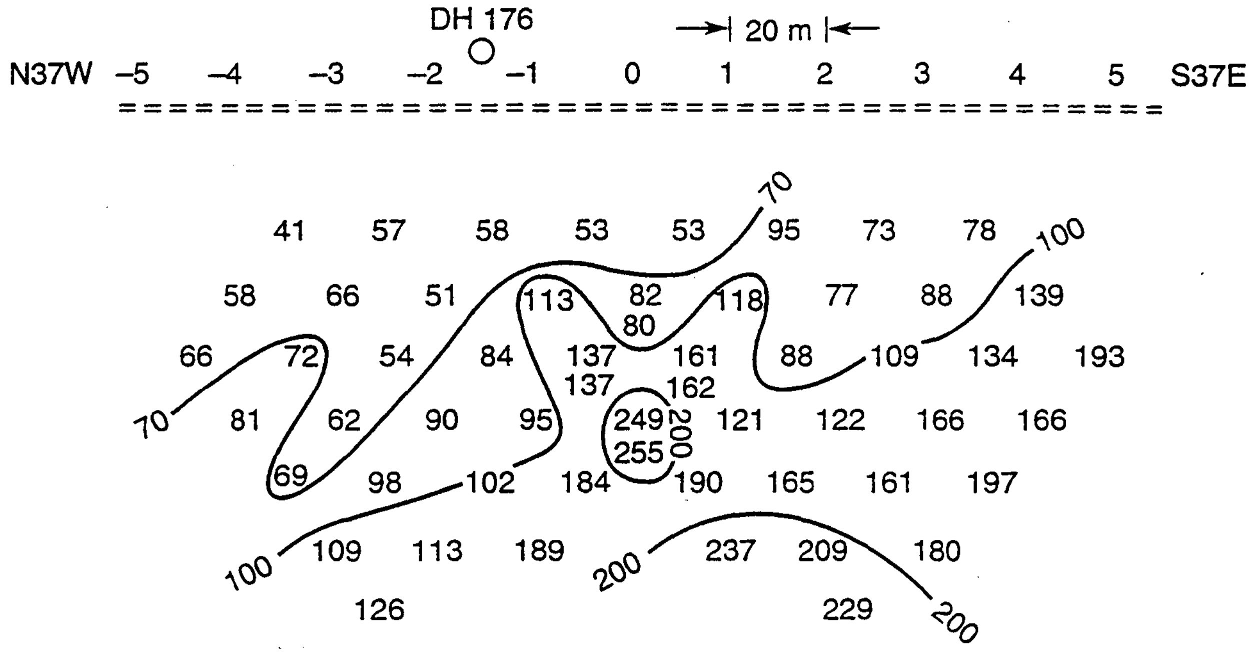
Figure 9. Depth distribution of NO_3 and radioelements by plunger sampler in Well 176 and nearby Well 8/69.

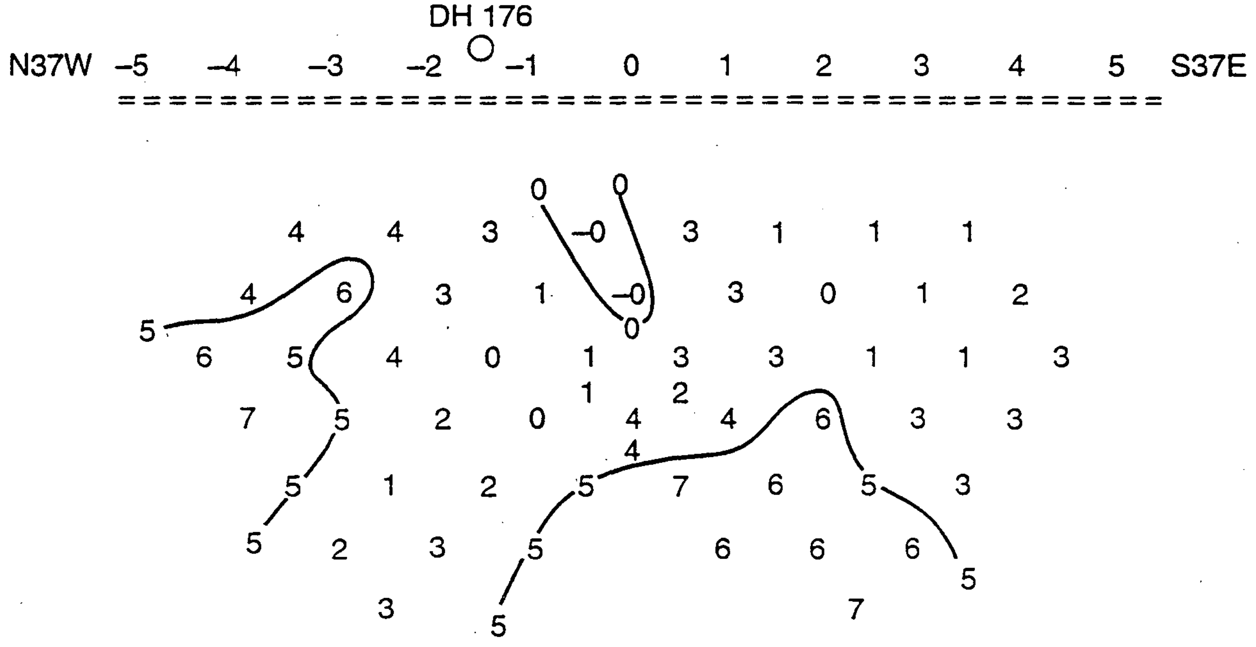
Dipole-Dipole Resistivity

Line 7 Mayak Area, Russia

Apparent resistivity, ohm–m



Apparent phase, mRads



a = 20 meters freq = 1 Hz

Figure 10. Electrical resistivity and induced polarization profiles through the Well 176 site. Electrode spacing is 20 m; vertical and horizontal scales are equal.