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# AIRBORNE GAMMA ANOMALIES IN THE ELBE VALLEY NEAR KÖNIGSTEIN, GERMANY — ORIGIN AND VARIATION WITH TIME

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**Abstract**

In 1982, an airborne gamma spectrometer survey was undertaken by SDAG WISMUT which was directed at the detection of further uranium mineralization in Saxony and Thuringia. Anomalies outlined along the Elbe river near the existing Königstein uranium mine were attributed to one or a combination of the following causes: radioactive residues from uranium processing facilities located upstream, temporary accumulation of Rn-decay products attached to dust particles in the atmosphere at the time of the survey, and radioactive waters emerging from uraniferous rocks along tectonic structures. In 1994, WISMUT GmbH re-evaluated the survey to determine the need for implementing cleanup measures. Subsequent to the verification of the original airborne data, ground surveys were undertaken that included gamma spectrometry, percussion probing and river sediment sampling. The new results did not confirm the magnitude of most of the 1982 airborne anomalies. The general decline of the radioactivity pointed out by the 1994 ground measurements is interpreted to be a result of the partial erosion and dilution of radionuclides in fluvial sediments as well as burial by additional river sediments since. Additional anomalous copper and zinc concentrations are attributed to sources other than mining. The ground follow-up delineated a new anomalous zone that is caused by radionuclides discharged with treated process and mine water. It is the only area, which may require further investigations and possible remedial action.

## 1. INTRODUCTION

In Saxony and Thuringia, exploration for uranium started under the supervision of the Soviet military in 1945 and was initially focused on the historic mining districts in Saxony. Successful exploration lead to production of uranium ore in 1946. In 1947, all mining activities in the Soviet occupation zone were transferred into Soviet ownership as part of the reparation payments after World War II. Uranium exploration and mining was carried by the company SAG Wismut until 1954. Then, the hitherto purely Soviet company was converted into the bi-national Soviet-German Aktiengesellschaft (SDAG) Wismut with the East German and the Soviet government holding 50% each. SDAG Wismut continued mining under a Soviet-German agreement renewed in 1962 and 1975. Production ceased by the end of 1990 as result of an agreement between Germany and the Soviet Union dated October 9, 1990. The produced uranium ore and the yellowcake were shipped to the Soviet Union for further processing.

By the end of 1990, Wismut had produced a total of 216 000 tonnes of uranium. Most of this production originated from the black schists-type ore in the Ronneburg district and the world largest uranium vein deposit Schlema-Alberoda in the Aue district. Minor contributions to the total production came from sediment-type ores of Permian and Cretaceous age at Culmitzsch, Gittersee and Königstein (Fig. 1). This puts Germany after USA. and Canada in third place with regard to total post-war world uranium production [1a, 1b].

In 1991, the Soviet-held shares were absorbed by the German government. At the end of 1991, Wismut-GmbH was created as a company wholly owned by the German government. The business objective of Wismut-GmbH is to close down all mining and to rehabilitate the uranium mining and milling facilities in Saxony and Thuringia, which had not been abandoned by 1962.

The rehabilitation of the areas affected by the mining activities encompasses a wide variety of measures including assessing the present site conditions and establishing the need for rehabilitation activities, cleaning up the underground workings, i.e. removal of hazardous and toxic materials and backfilling as required by the hydrological or geomechanical conditions, flooding of the mines and treatment of contaminated waters that discharge into surface waters, demolition of contaminated surface structures and disposal of contaminated materials, stabilization of tailings ponds including the removal of supernatant and pore water as well as the construction of covers, rehabilitation of waste rock piles entailing the contouring of slopes where required and installation of covers, environmental monitoring of radiological and chemical parameters in order to take corrective measures during the rehabilitation activities and to document the success of the restoration efforts.

In order to support the environmental assessment of the Königstein mine site, a portion of a regional airborne gamma spectrometer survey originally directed at the expansion of uranium ore reserves during the mining phase was re-evaluated.

The present account deals with the results of the original survey and its re-evaluation. It is based on the compilation of Wismut data and investigations undertaken by Geophysik GGD, Leipzig [2] commissioned by Wismut-GmbH in 1994. Similar investigations were carried out by the Bundesamt für Strahlenschutz [3] within a regional assessment program.

## 2. GEOGRAPHICAL AND GEOLOGICAL SETTING OF THE KÖNIGSTEIN AREA

The survey area is located near the Königstein mine where the Elbe river valley cuts into the "Elbsandsteingebirge" — plateau to a depth of approximately 150 m. The valley is 300 to 500 m wide. The river itself has a width of about 100 m. The river banks are used mostly as pastures. A number of towns and settlements are located on both sides of the river. A road and railway track pass along the river connecting Dresden in the west with Prague, the capital of the Czech Republic, in the southeast (Fig. 2).

The uranium ore at Königstein had been discovered in 1961 and exploited from 1966 to 1990. The orebody extends over an area of 10 km by 4 km. The underground mine covers an area of up to 5 km by 3 km. Average grades were in order of 0.08% U. A total of 19 500 tonnes of uranium was produced initially by conventional methods and from 1984 onward exclusively by underground leaching [4].

The structural geology of the Königstein area is characterized by the presence of the tectonically controlled northwest — southeast trending Elbe River Valley trough. Accordingly, the major structures trend northwesterly. A conjugate system of structures strikes in northeasterly direction. In addition, east-west as well as north-south trending joints have developed of which the "Nordstörung" is of major significance for the Königstein mine (Fig. 2).

The oldest rock units are Paleozoic granites and granodiorites. Within the Elbe trough, Upper Cretaceous sediments with a thickness of up to 800 meters overlie the partially eroded paleoweathered crystalline rocks (Fig. 3). The sedimentary sequence consists from bottom to top of a Cenomanian series of basal terrestrial sandstones passing into younger marine silt and mudstones, which in turn, are overlain by Turonian marlstone and sandstone. The series is discontinuously developed due to synsedimentary tectonic activity. It dips northeast at one to three degrees. The youngest rock units are Tertiary basalt dykes and sills cutting through the Cretaceous sedimentary sequence.

The Königstein deposit belongs to the peneconcordant, stacked [5] or "tabular/ peneconcordant sandstone" uranium deposit type [6]. Mineralization is present in two horizons of the terrestrial basal Cenomanian sediments and in one horizon of the transitional terrestrial/marine sediments. The principal ore mineral is pitchblende. The ore is spatially associated with clay stone and organic material and often paragenetically combined with iron sulfides. Elevated concentrations

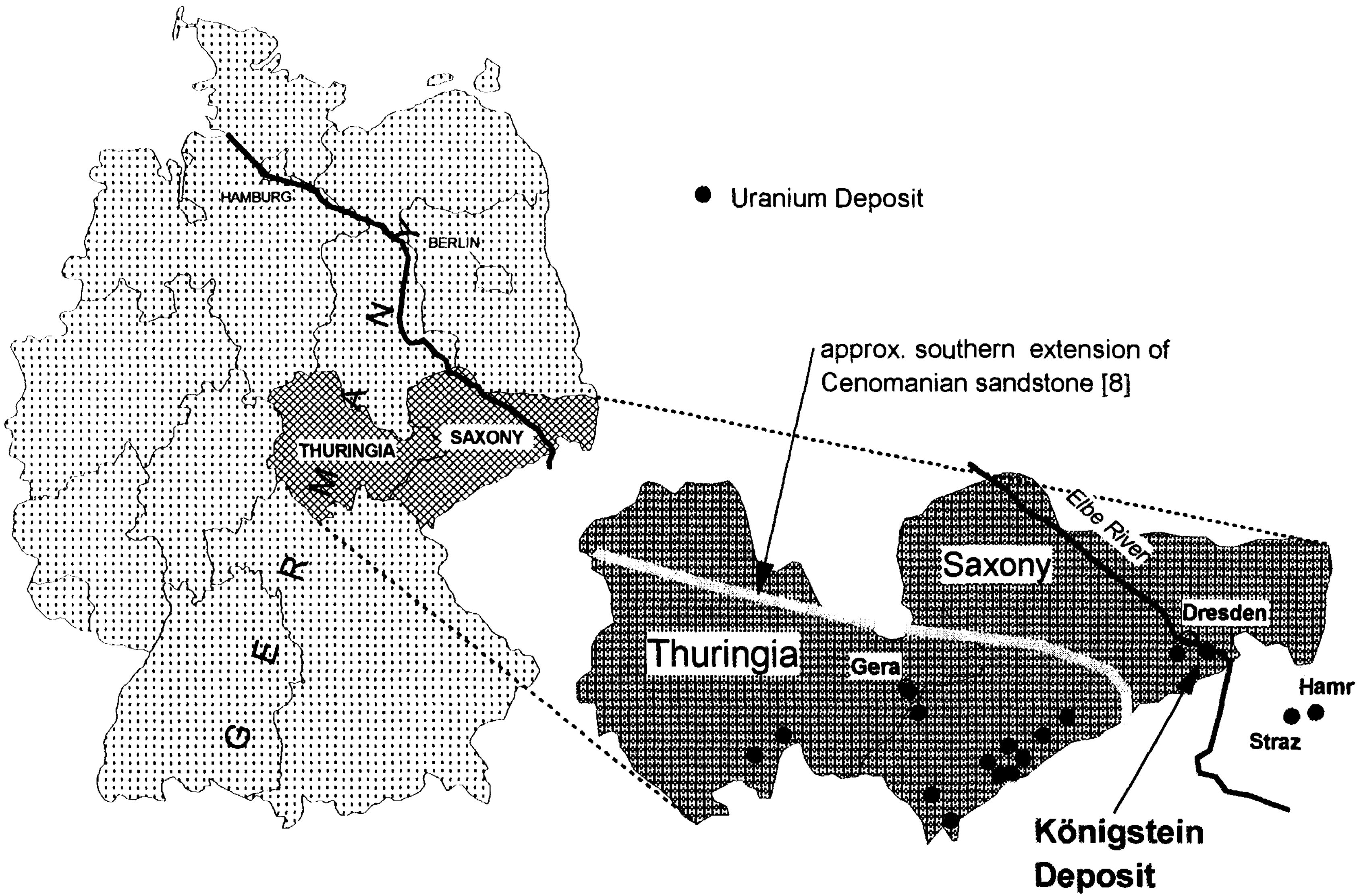


*Fig. 1. Uranium deposits in Thuringia and Saxony.*

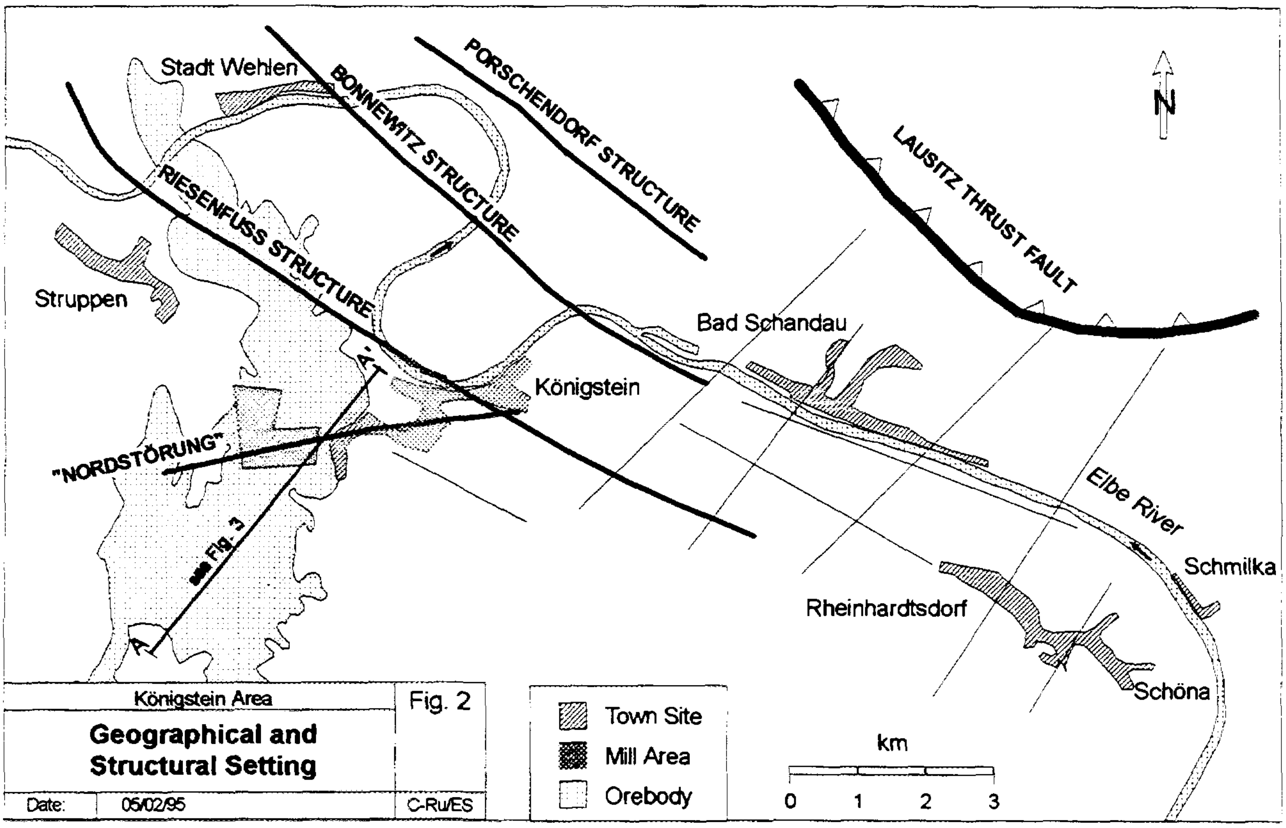


*Fig. 2. Geographical and structural setting.*

of lead and zinc are commonly associated with the ore. Fractures filled with pitchblende are also present. In that case, the ore is associated with sulfides, hematite and barite [2]. The structural and stratigraphic setting is similar to that of the North Bohemian ore bodies of Hamr-Strá in the Czech Republic [7].

## 3. AIRBORNE GAMMA SPECTROMETER SURVEY (1982)

The helicopter-borne survey had been flown during the time period from September 16 to 19, 1982 after calibration over test pads with known eU concentrations. The flight lines were oriented in north-south direction at a spacing of approximately 250 m. The flight altitude was 100 m (Fig. 4).

The results showed that most anomalies are located in the Elbe valley (Fig. 5). They form part of a broad anomalous zone straddling the Elbe river and side valleys. The geographic situation, which is characterized by the pronounced relief, gave rise to the assumption that atmospheric conditions were causing at times higher radioactivity in the deep valley. It was speculated that the anomalies had been partially the result either of a wash-out of radon decay products, particularly $^{214}Bi$, or of decay product particles adhering to suspended water droplets shortly before the survey had been flown.

The strongest anomaly was detected in some distance from the Elbe river valley. This anomaly is in the order of 10 times background (10 × BG) and is located over the mill facilities at Königstein including a portion of the cable conveyor that transported ore to a railway terminal. The airborne data indicated otherwise eU-anomalies in the order of 2 × BG mostly confined to the Elbe river valley. Some anomalies could be allocated to certain geographic features. For instance, the anomaly located close to the center of Bad Schandau is caused by the pavement at the market square.

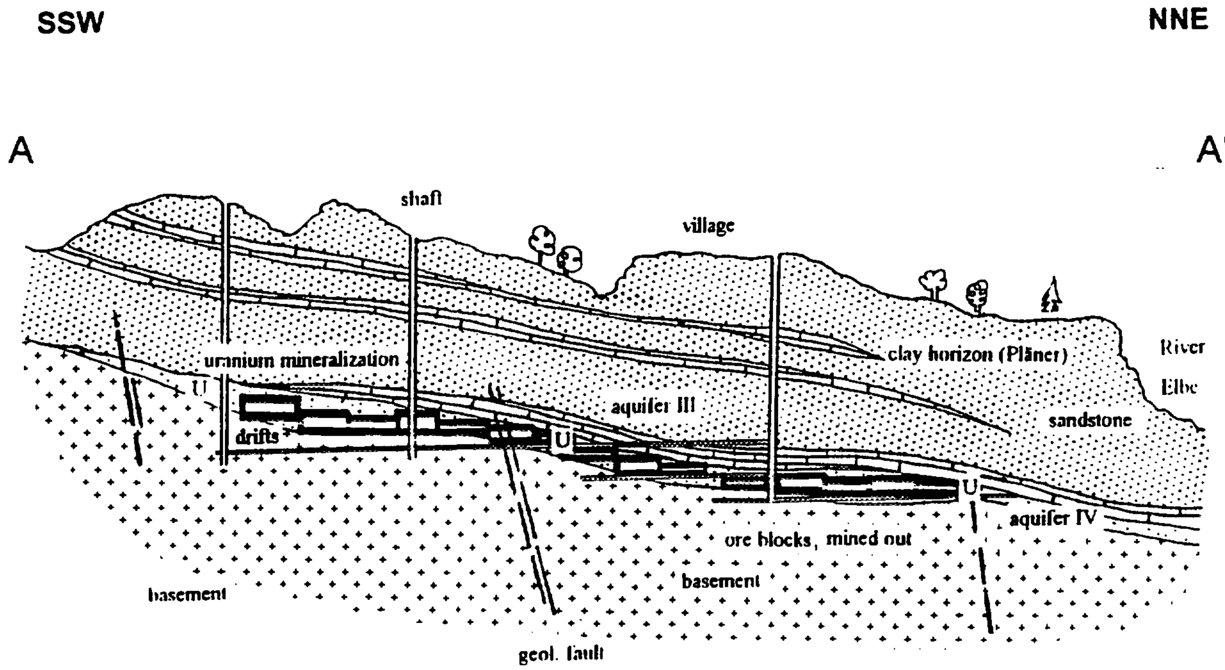


*Fig. 3. Schematic cross section of the Königstein Mine.*

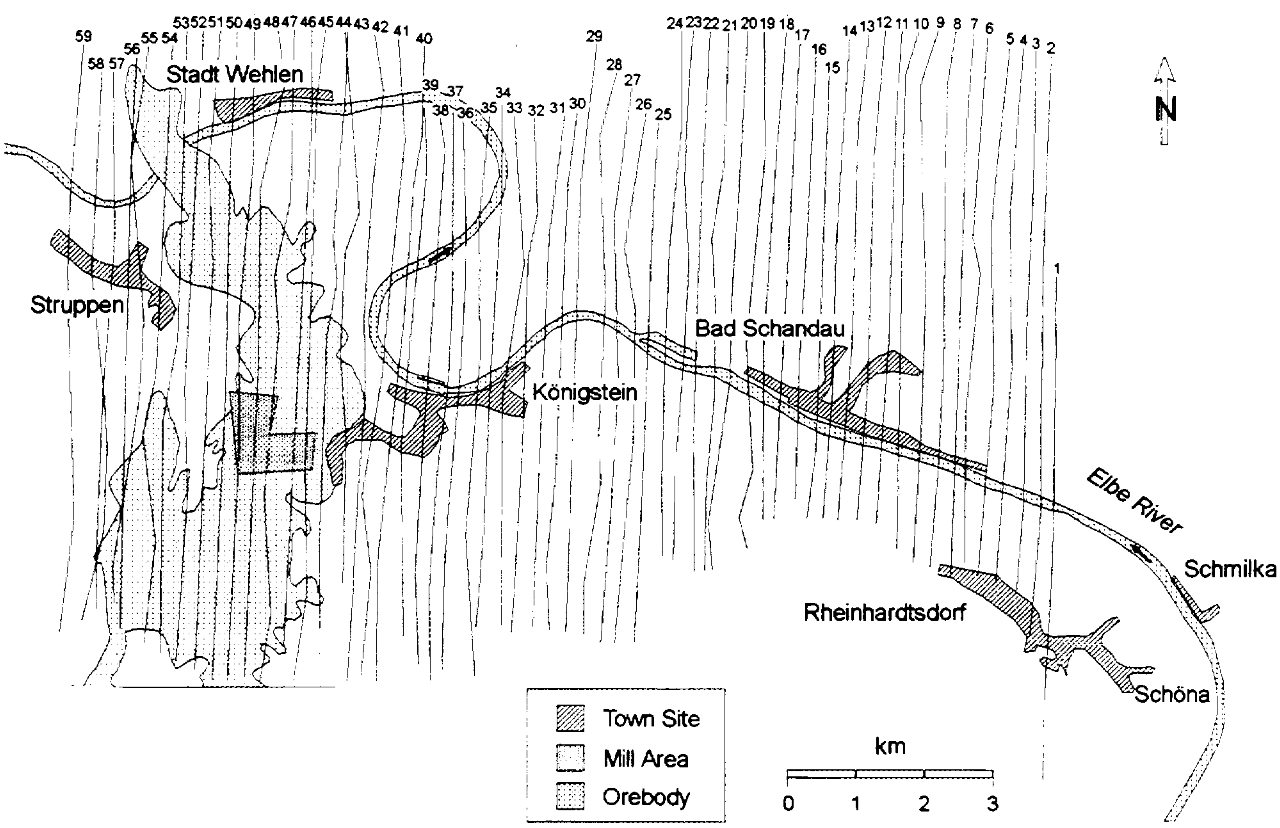


*Fig. 4. Survey area - flight lines.*

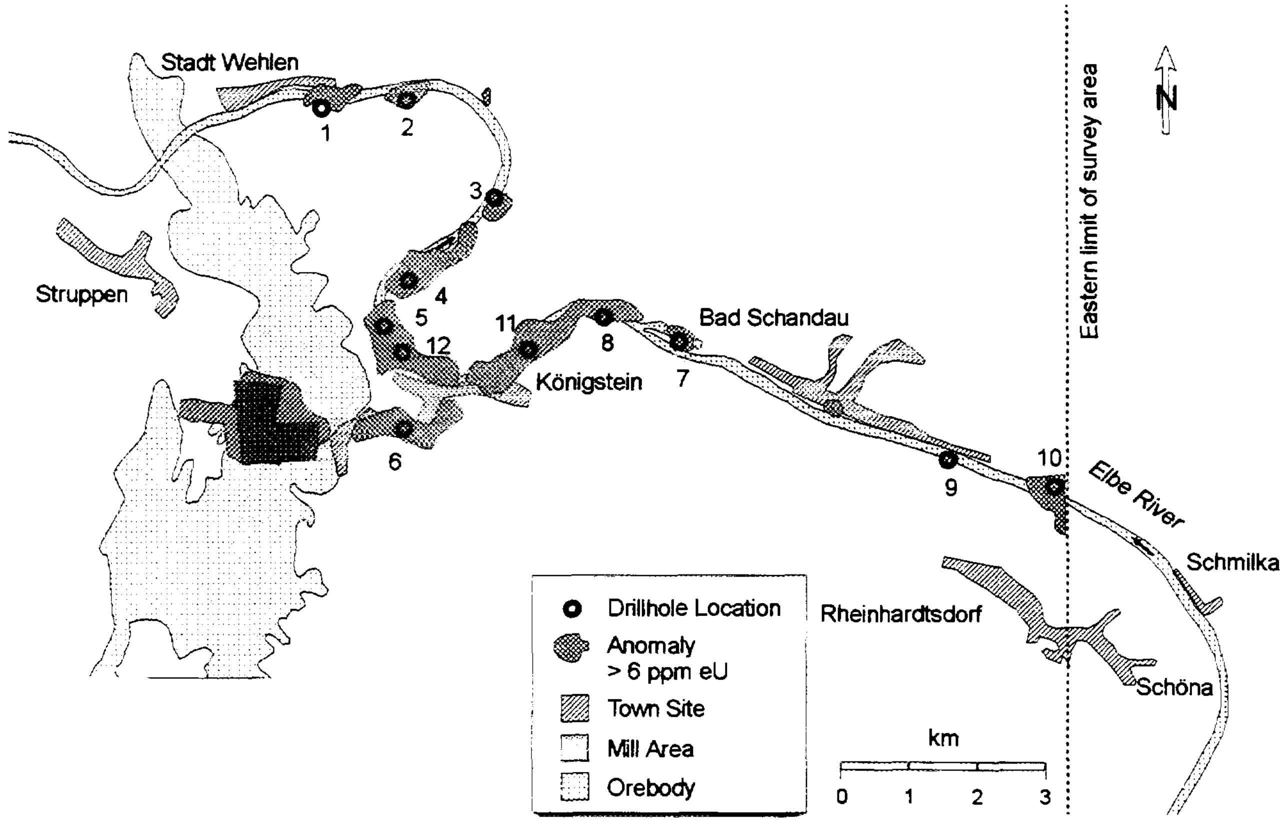


*Fig. 5. Major airborne anomalies.*

Here, slag from the smelters that processed uraniferous copper ore from the Mansfeld area in Saxony-Anhalt was used as construction material. The anomaly over the protruding table mountain of Lilienstein is most likely caused by reduced flying altitude (mass effect). Similarly, the valley geometry may have contributed to a mass effect resulting in the broad anomaly along the river. Then, atmospheric processes need not be invoked for its explanation.

The better defined anomalies along the river were attributed to contamination from ore processing facilities. Upstream from the Königstein mine, contamination of the fluvial sediments could have been related to the uranium ore processing facilities at Hamr-Strá in the former Czech-Slovak Federal Republic. These facilities are located within the catchment area of the Elbe river. Ore processing residues may have been released some time before the survey had been flown.

Alternatively, anomalies were thought to be caused by radioactive waters and their precipitates emerging from mineralized rock along tectonic structures. A definite relationship between airborne anomalies and tectonic structures could, however, not be established.

Ground follow-up investigations were undertaken on several anomalies as part of the WISMUT site assessment in 1991-1992. The ground measurements yielded puzzling results since the airborne anomalies could not be reproduced. It was speculated that the radioactive material in the alluvial beach sediments had been either diluted, covered by younger non-radioactive river sediments or altogether eroded. In order to explain the disappearance of the anomalies, an investigation on all anomalies delineated by the 1982 survey was initiated in 1994.

## 4. FOLLOW-UP WORK IN 1994

On the basis of a regional background of 4 to 5 ppm eU, a total of 12 anomalous areas exceeding two times background were identified for ground follow-up. In these areas, gamma spectrometric measurements were centered on the airborne anomalies. A hand-held Scintrex GAD-6 with a 20 cubic inch sodium iodide crystal was used. Data from four channels (potassium %, eU ppm, eTh ppm and total count - 0.8 to 2.77 MeV) were recorded on a grid with 50 m spaced stations. Atmospheric background was established daily by taking three control readings (integrating over 1000 seconds) in the middle of the Elbe river.

The ground data confirmed the lack of correlation between airborne anomalies and follow-up measurements as already indicated by the initial radiometric test survey undertaken by WISMUT in 1991/92. Exceptions were the market place of Bad Schandau and the area of the Königstein mine that both could be clearly confirmed by the ground follow-up measurements.

As the airborne survey had been successful in detecting obvious anomalies like the mine site and the market square of Bad Schandau, it remained unclear why the other anomalies did not have a ground spectrometer expression.

In order to identify the source of the airborne gamma anomalies, soil samples were collected from 11 locations centered on the original anomalies and one anomalous location identified by the recent ground spectrometric survey. Percussion probing was employed to recover sub-surface material from a depth of between 10 cm and 1.7 m (39 samples). In addition, 11 surface and river sediment samples were taken from near-shore zones, ox-bow lakes and river harbors using a rubber dinghy. All 50 samples were analyzed for radionuclides, lead, zinc, copper, nickel, arsenic and aluminum. The radionuclide analyses included $^{40}K$ (4 Bq/kg - detection limit), $^{226}Ra$ (1 Bq/kg), $^{228}Ra$ (3 Bq/kg), $^{210}Pb$ (8 Bq/kg), $^{238}U$ (8 Bq/kg), $^{228}Th$ (1 Bq/kg) and $^{137}Cs$ (1 Bq/kg). These were determined by spectrometry of gamma radiation emitting nuclides or their long-lived daughter products. For instance, uranium concentrations were determined by the activity of $^{234}Th$ (half-life of 24.1 days) which produces values comparable to chemical assays.

The soil samples collected from the upper zone (0.1 to 0.3 m) and the river sediment samples display equivalent uranium concentrations in the range of 27 Bq/kg (2.2 ppm) to 260 Bq/kg (21 ppm). The highest concentrations are located close to the discharge point of the "Elbe-Leitung" in agreement with the ground spectrometer anomaly discovered by the latest survey (Fig. 6). Similarly, the $^{226}Ra$ activity concentrations in sub-surface soil range from 58 Bq/kg to 230 Bq/kg. The highest value of 1800 Bq/kg is also related to the discharge point of the "Elbe-Leitung"(Fig. 7). Since the accumulation of radionuclides near the discharge point of the "Elbe-Leitung" must have occurred mostly after the survey was flown (1982), the values from this location are not considered in the following attempt to correlate the soil anomalies with the airborne anomalies.

The concentrations of up to 9.6 ppm eU encountered in the 0.1 to 0.3 m layer in the centers of the airborne anomalies indicate that radionuclides are still present. Hence, a complete erosion of the radioactive material has not occurred but the material is rather shielded by soil of background radioactivity. This soil was deposited most likely from flood waters of the Elbe river.

In order to test whether the eU concentration in the 0.1–0.3 m layer would produce an airborne anomaly if it was at the surface, the respective eU concentrations were calculated taking into account any disequilibrium. Fig. 8 shows that the adjusted eU concentrations in the 0.1–0.3 m depth zone match the airborne data fairly well. It shows also that the majority of the samples produces a lower eU concentration than was measured 12 years before. This points to a partial removal of the radioactive particles since then.

The activity concentrations of the radionuclides show that in addition to erosional and sedimentary processes uranium was mobilized chemically. The profile of activity concentrations shows

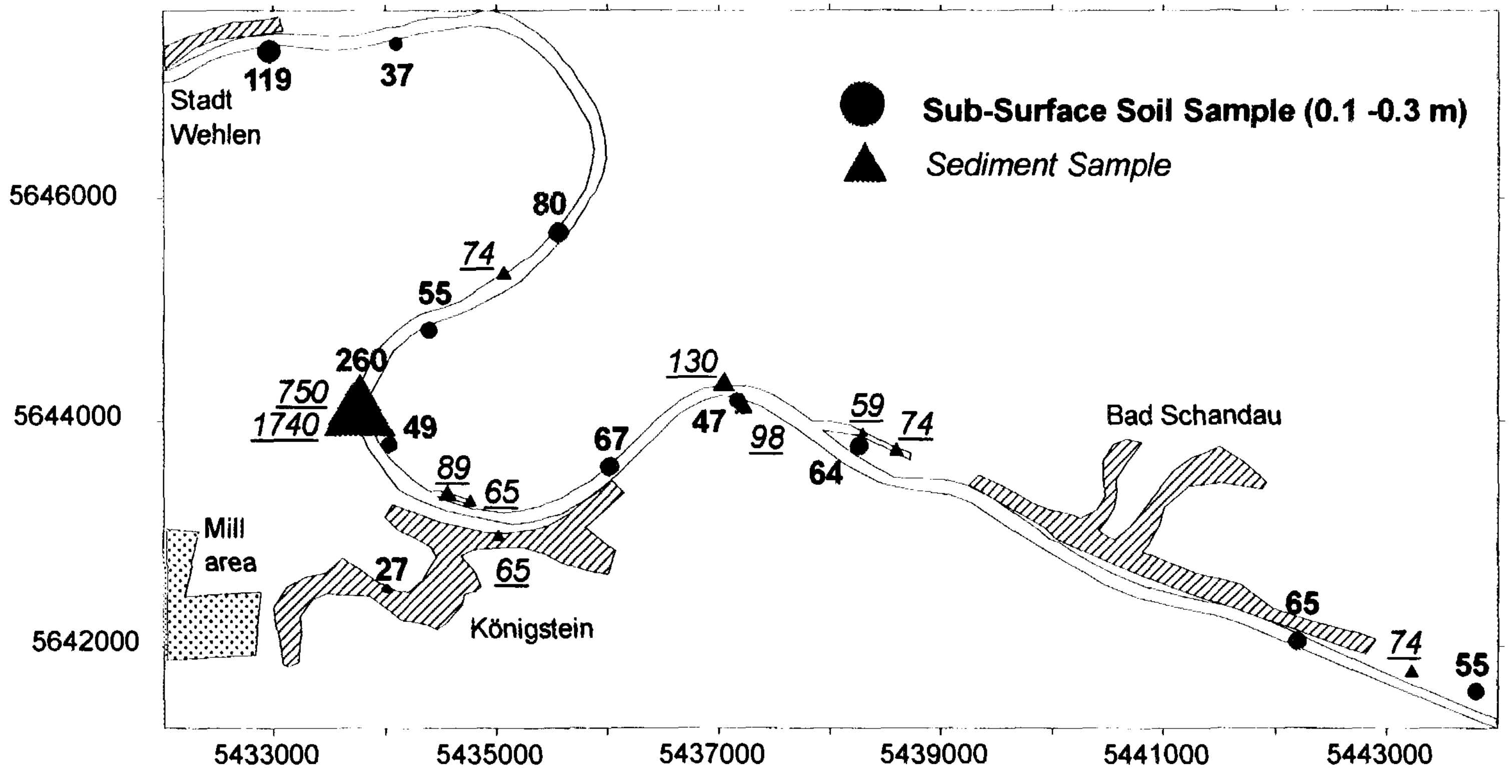


*Fig. 6. Uranium in soil and sediment samples (Bq/kg).*

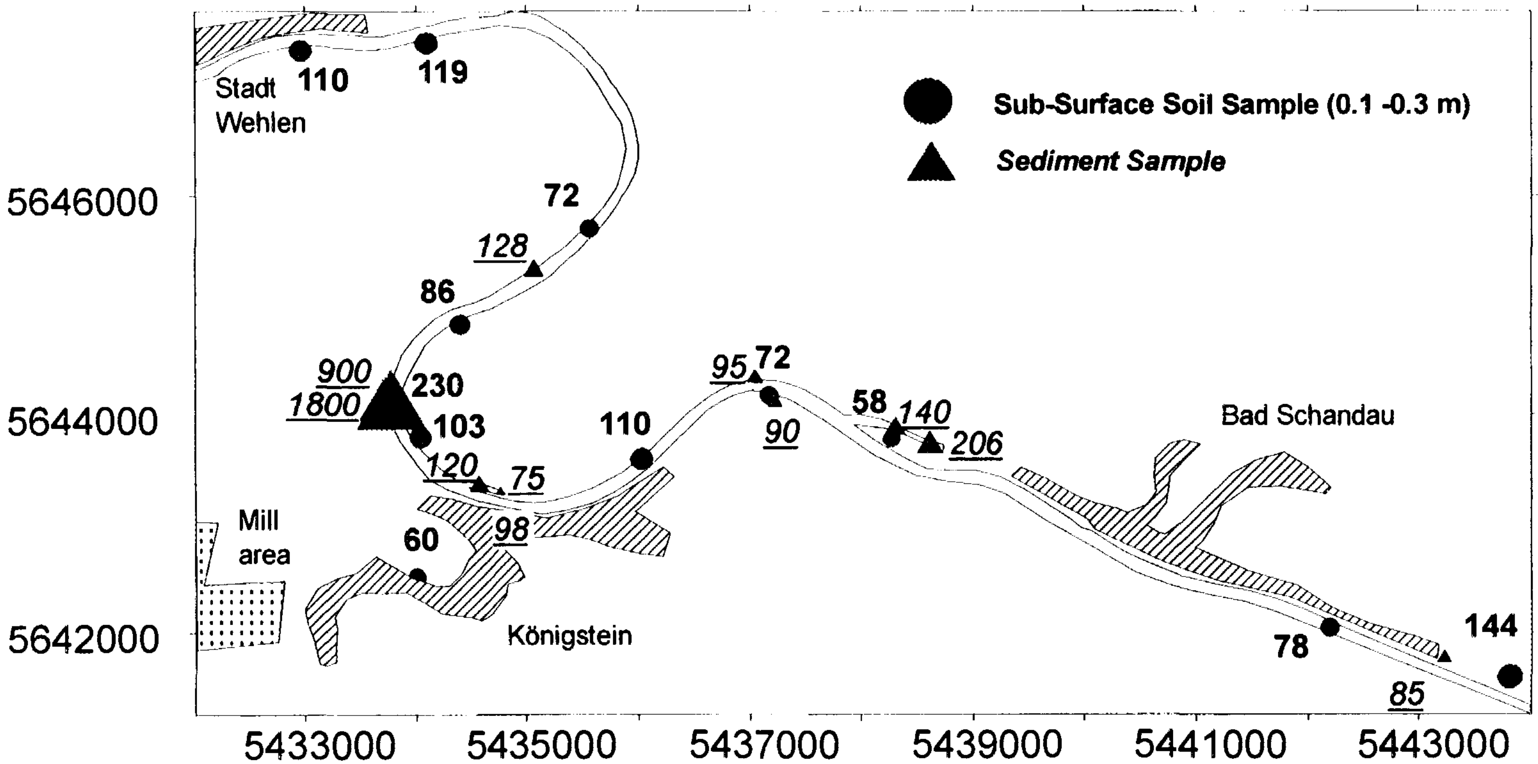


*Fig. 7. Radium in soil and sediment samples (Bq/kg).*

that radium is relatively enriched near the surface and uranium at depth (Fig. 9). This points to a mobilization of uranium from the oxidizing near surface zone to a more reducing environment at greater depth by percolating rain or meltwater. It is therefore unlikely that radium was mobilized upward.

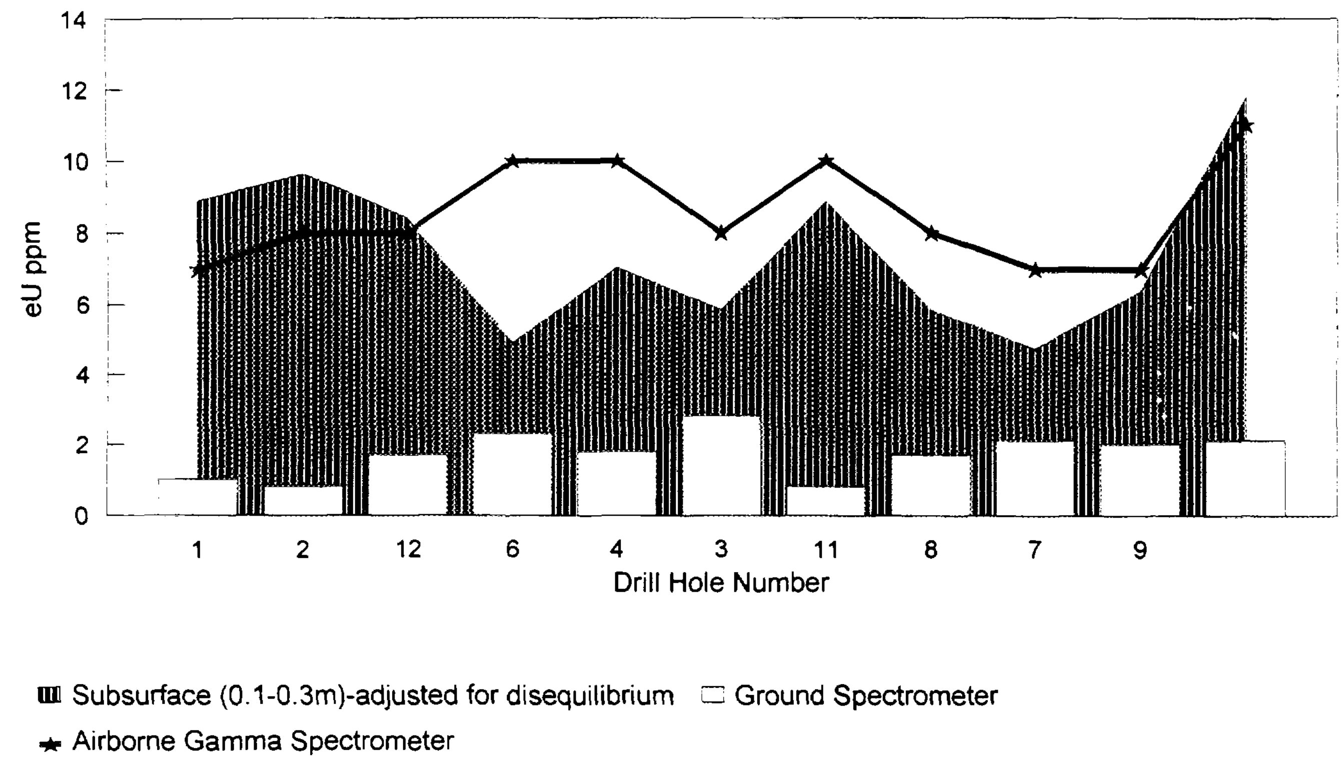


*Fig. 8. Comparison of airborne spectrometer with ground spectrometer and soil measurements.*

The overall near-equilibrium state of the radionuclides (Fig. 10) in combination with the systematic change of disequilibrium with depth suggests that the radioactive material represents natural mineralization introduced into the river sediments by mine water rather than by uranium-depleted tailings. Accordingly, the widely varying U/Ra ratios along the Elbe river (Fig. 11) suggest that a fractionation of the radionuclides occurred locally subject to the respective chemical conditions.

The concentrations of both radionuclides and base metals decrease toward depth. The ratios of the concentration at the upper level (0.1 to 0.3 m) and at greater depth (1.0 to 1.2 m) range from 1.5 for uranium to 9.5 for Zn (Table I). This could be explained by either increasing load with time or segregation of finer mineralized particles from coarser unmineralized sand grains during the deposition process. The second explanation is supported by the presence of silty material in the upper portion of the soil profiles versus predominant sandy material at depth.

While the maximum concentrations of uranium, radium and arsenic are present in the soil at shallow depth, nickel, lead, zinc and copper attain even higher concentrations in surface sediment samples, particularly in harbor sediments (Fig. 12). The increased concentration of nickel, lead, zinc and copper, which is not accompanied by corresponding radionuclide activities points to another source of contamination than mining residues. It is assumed that the use of the Elbe river as shipping route contributes significantly to the base metal pollution.

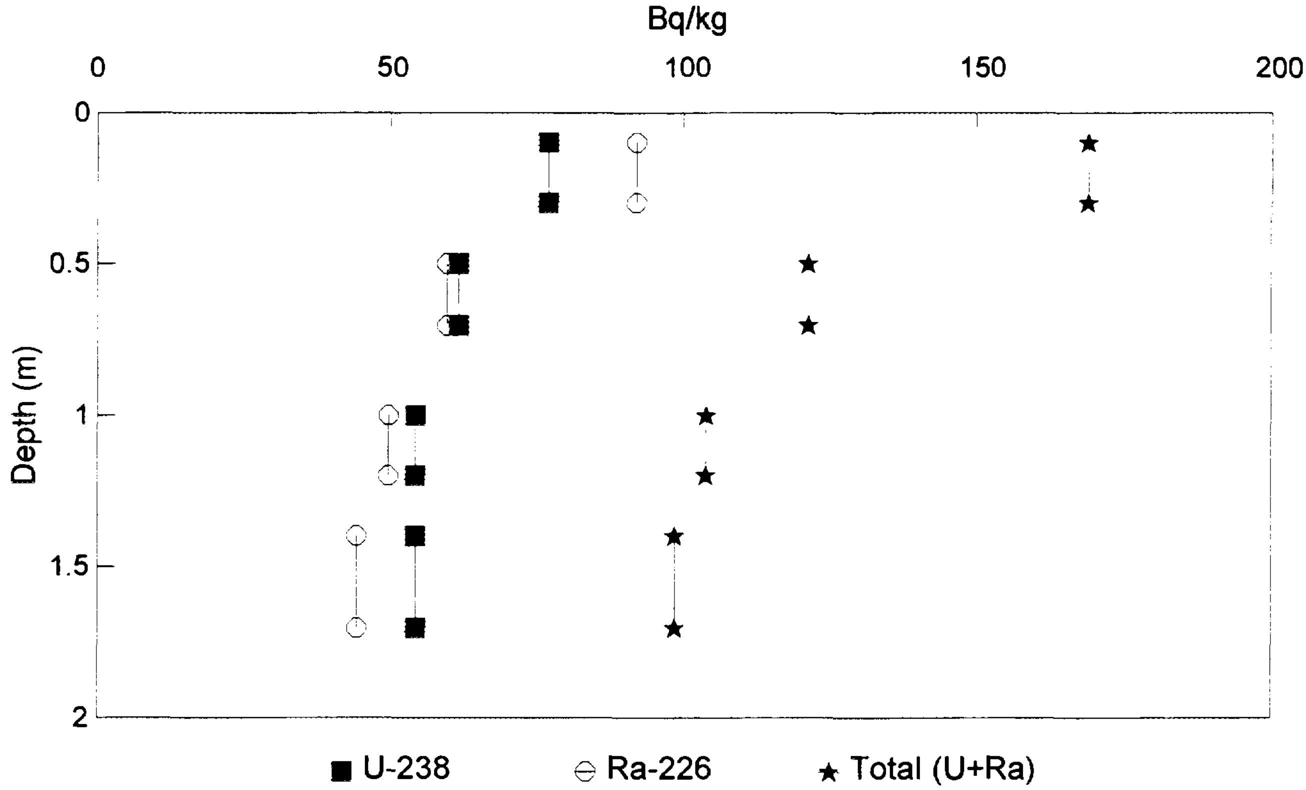


*Fig. 9. Average activity versus depth.*

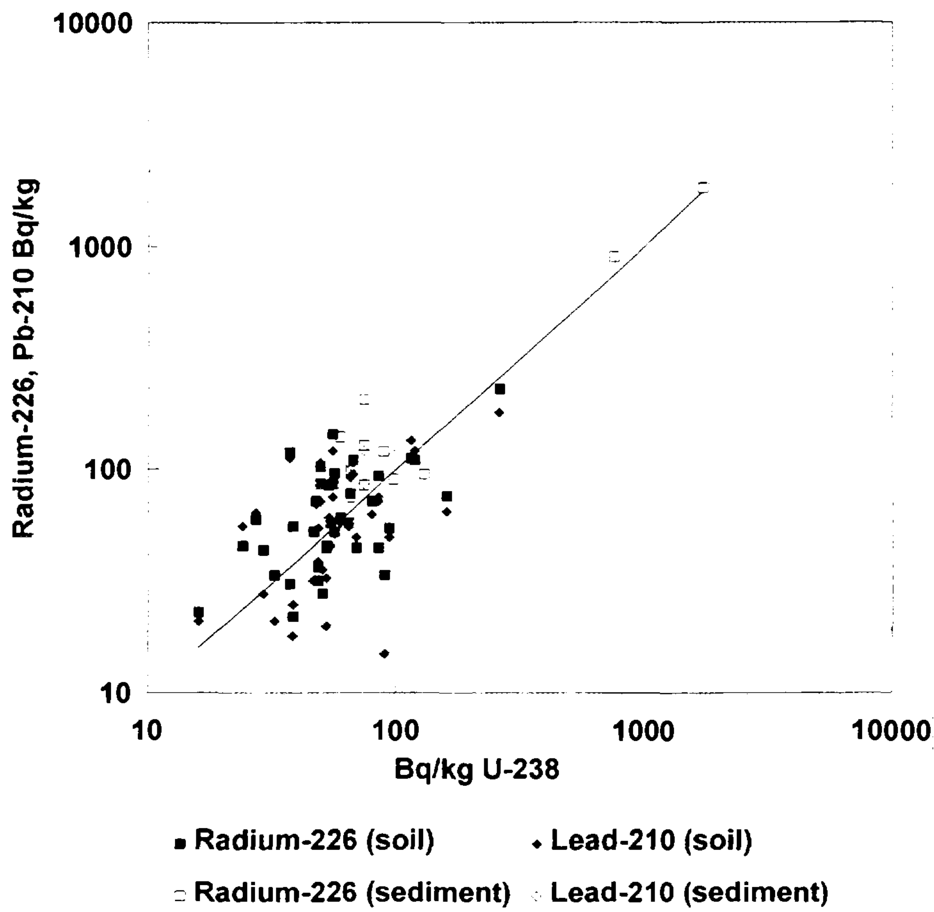


*Fig. 10. Ra-226 and Pb-210 versus U-238.*

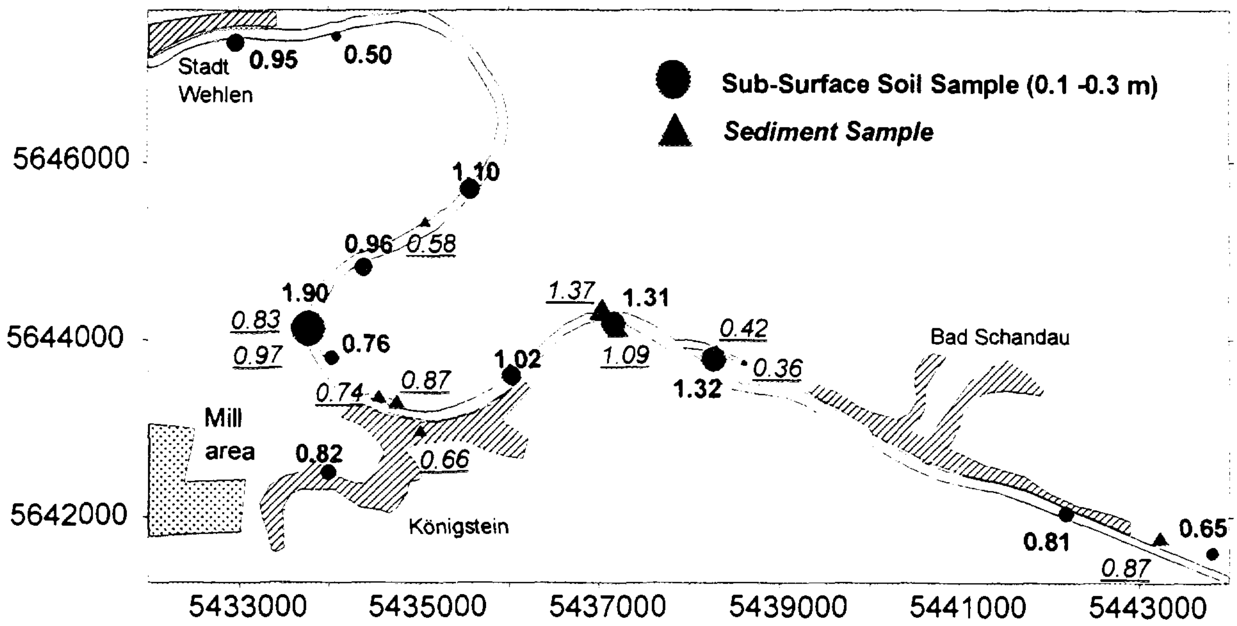


*Fig. 11. U-238/Ra-226 ratios in soil (0.1-0.3 m) and sediment samples.*

TABLE I. DISTRIBUTION OF ACTIVITIES/CONCENTRATIONS IN SUB-SURFACE SAMPLES

| | PARAMETER | | | | | | |
|---|---|---|---|---|---|---|---|
| | $^{238}U$ | $^{226}Ra$ | A | Ni | Pb | Cu | Zn |
| | Bq/kg | Bq/kg | ppm | ppm | ppm | ppm | ppm |
| minimum at 0.1–0.3 m depth | 27 | 58 | 12 | 31 | 57 | 28 | 97 |
| maximum at 0.1–0.3 m depth | 260 | 230 | 54 | 63 | 148 | 119 | 696 |
| average at 0.1–0.3 m depth | 77 | 103.5 | 31 | 44 | 96 | 75 | 411 |
| minimum at 1.0–1.2 m depth | 24 | 31 | 8 | 5 | 14 | 3 | 10 |
| maximum at 1.0–1.2 m depth | 160 | 85 | 17 | 27 | 57 | 29 | 150 |
| average at 1.0–1.2 m depth | 54 | 50 | 12 | 18 | 30 | 16 | 66 |
| average of concentration ratios avg(conc.@0.1–0.3m/conc.@1.0–1.2m) | 1.5 | 2.1 | 2.5 | 3.1 | 3.7 | 6.0 | 9.5 |
| harbor sediment maximum | 130 | 206 | 75 | 134 | 216 | 244 | 1347 |

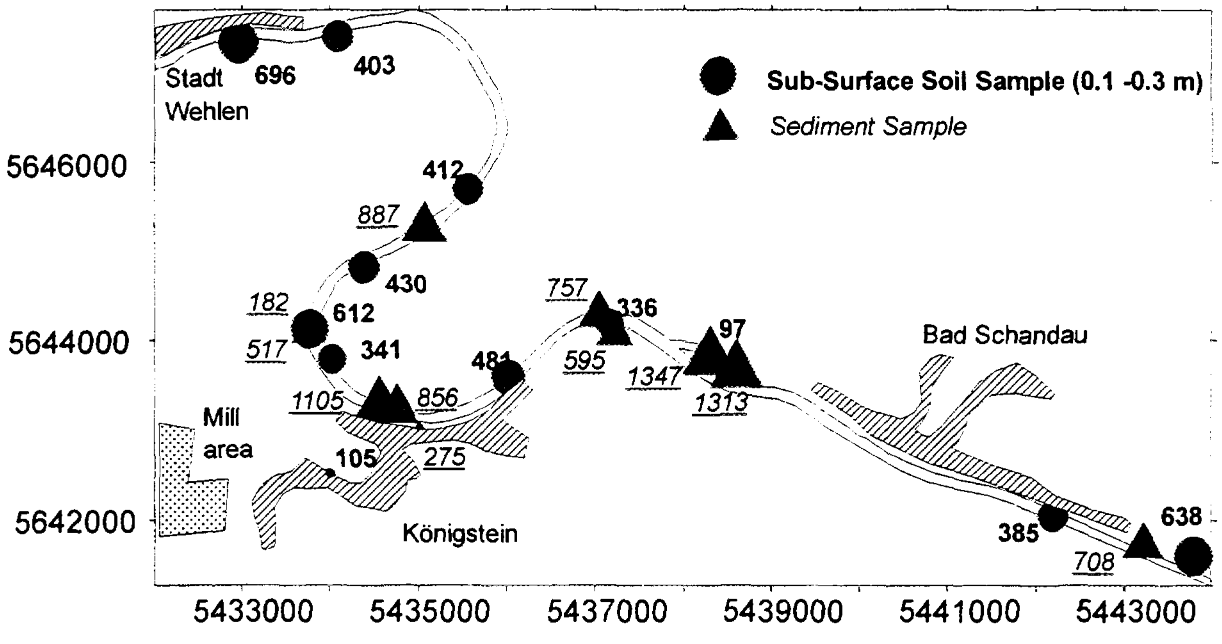


*Fig. 12. Zinc in soil (0.1-0.3 m) and sediment samples (ppm).*

## 5. CONCLUSION

Historical exploration data represent a source of valuable information for the environmental assessment of sites near former uranium mine and mill facilities. The value of airborne spectrometric data in connection with mine and mill remediation is, thereby, mainly in outlining large areas with potentially contaminated sites. The characterization and definition of such sites requires detailed ground investigation. Although the anomalies detected by the airborne survey in the Königstein area did not delineate locations requiring remediation, the data resulting from ground follow-up investigations provided an explanation for the change of radionuclide concentrations in river bank soils. In particular, the following results were obtained:

- flooding events resulted in dispersion, dilution and burial of radionuclides,
- as far as anomalies upstream of the Königstein mine are concerned, a source in the Czech republic must be considered, and
- the ground follow-up delineated a new anomalous zone that is caused by radionuclides discharged with treated process and mine water. It is the only area, which may require further investigations and possible remedial action.

In addition, the follow-up data show that the radionuclide source causing the airborne radiometric anomalies was related to mine water discharge rather than the release of residue from uranium ore processing, after deposition, uranium has been chemically mobilized, and additional base metal contamination is possibly related to the use of the Elbe river as shipping route.


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