7. Cleanup of Radioactive Floating Refuse at Vromos Bay

The Cold War legacies in the United States and countries of the former Soviet Union are daunting enough in the aggregate. However, even when looking at a single example site, the difficulties of clean up can be staggering. This chapter presents a case study of remediation of the contamination legacy in Bulgaria. Tailings from mine milling operations dumped a total of about 8,000,000 tons of refuse in Vromos Bay on the Black Sea. The heavy iron sulphides and oxides, copper, and uranium minerals remained deposited in the surf area, right on the beach, where they formed a field about 2,300 meters long, up to 150 meters wide, and 2.3 meters thick. In 1995, the Bourgas Copper Mines chose to apply for the PHARE-ECOLOGY Programme to sponsor the restoration project.

From 1954 to 1977, part of the refuse resulting from operations at the Rossen Flotation Mill in Bulgaria was discharged into the Black Sea, to the west of the village of Chernomorets, in Vromos Bay. Vromos Bay is a smaller bay located at the southern end of the Bay of Bourgas (Figure 7.1). To the east and west, Vromos Bay borders on two rocky capes: Atia and Akin (Figure 7.2). A long (2,500-m) and comparatively narrow beach covered with sand stretches between the two capes. The sand is naturally tiny and yellow; detritus prevails to the west.

After 1968, all mill refuse, a total of about 8,000,000 tons, was discharged there. As a result, the beach at Vromos Bay has been covered with flotation refuse between Cape Atia and Chernomorets (Tschernomorez in Figure 7.3), and the coast line has been extended some 150 m into the sea in the area of the discharge. Being a source product, the flotation tailings consist mainly of rock-forming minerals (feldspars, pyroxene, quartz, and chlorite) and gangue minerals (quartz, calcite, dolomite, anchorite, fluorite, and clays), as well as five to six ore minerals (pyrite, chalcopyrite, magnetite, haematite, molybdenite, chalcocite, etc.).

Certain radioactive materials have also been detected–uraninite, nasturane, and uranium resins. Both lighter rock-forming and gangue materials have been carried far

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into the sea, where they are building a thick layer of slime. The heavy iron sulphides and oxides, copper, and uranium minerals have been chiefly deposited in the surf area and right on the beach area, where they formed a field about 2,300 m long, up to 150 m wide, and 2.3 m thick. This field included about 10% of the total amount of flotation refuse, but with copper, iron, and uranium contents several times higher[1].

As a result of the combined influence of sea waves and other processes, the border between the beach and adjacent areas was encircled by a continuous bank of flotation refuse of height 2 to 3 m. In the central parts where the beach is over 150 m wide, these same processes led to the formation of single dunes up to 5 to 6 m in height.

This chapter presents a case study of how Vromos Bay was restored. It describes conditions before restoration, initial restoration attempts, a major restoration project, and its results.

7.1. Conditions Before Restoration

As early as the 1970s, research sought to determine the concentration of radioactive components on the beach and in bottom sediments of Vromos Bay. In 1970, Ouzounov[2] pointed out an increased value of the exposition power of concentrations in the "black" sand of the beach. The most detailed studies were carried out in 1976, 1978,

Figure 7.1 Location of Vromos Bay

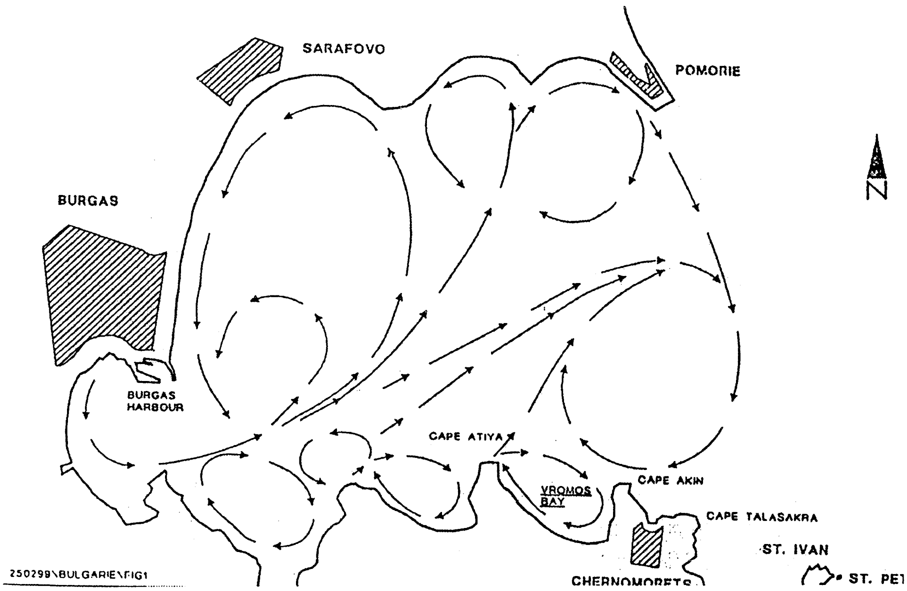

Figure 7.2 Bay of Bourgas and sea currents

1983, and 1991. In the 1976 studies, some quite high values of P_x–up to 940 μR/h–were detected[3]. It was then that a larger area was measured for the first time, and "hot spots" were detected where the radium-226 concentration was as high as 41,400 Bq/kg[4].

7.1.1. Beach Area

The results from three studies carried out by Bourgas Copper Mines Co. pointed out that a unique technogenic placer deposit had been formed in the west and central part of the beach. This deposit has the component distribution and typical oblique structures of sedimentation characteristic of coastal sea placers, as determined by the combined gravity and separating effect of the sea in the surf zone and the accumulative processes in the confluence point. The black colour of that beach was not natural, but resulted mainly from the magnetite and haematite brought by the tailings (see Figure 7.1) as well as the rock-forming materials.

The copper contents were within the range of 0.06% to 2.20%, the iron content was within 8.4% to 49.2%, and concentrations of radionuclides were present. Results from the radioactivity measured as of September 15, 1993, are given in Table 7.1. The same table also shows the natural radioactivity of some adjacent beaches for the sake of comparison.

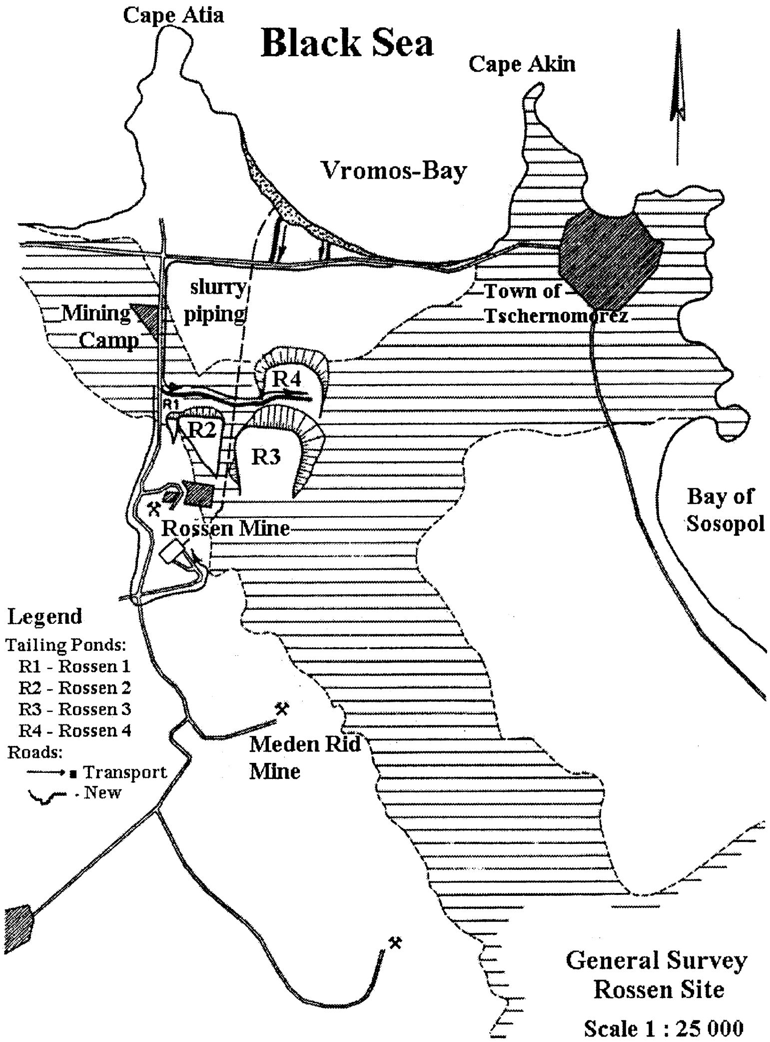

Figure 7.3 Plan of the Rossen Mine and Vromos Bay

TABLE 7.1 Radioactivity measured in September 1993 near Vromos Bay

Location	Power of Exposition, μR/h	Specific Activity, Bq/kg		
		Uranium-235	**Radium-226**	**Thorium-232**
Vromos Bay				
1. Exurb I	50	950 + 12%	600 + 20%	30 + 10%
2. Exurb II	110	1800 + 15%	3700 + 20%	30 + 18%
3. Central part	100	5000 + 7%	4900 + 12%	40 + 17%
4. Central part (soil)	35	300 + 25%	200 + 30%	45 + 7%
5. Poplar forest	80	2900 + 10%	2800 + 15%	30 + 19%
Adjacent Beaches				
6. Bourgas	6-7	< MDA *	25 + 5%	20 + 10%
7. Village of Chernomorets	15	< MDA	18 + 10%	20 + 10%
8. Gradina campground	7-8	< MDA	12 + 10%	10 + 10%
9. Sozopol	10-12	< MDA	20 + 5%	15 + 10%

* MDA=Minimal Detectable Activity

7.1.2. Bay Bottom

Of the 8,000,000 tons of tailings thrown into Vromos Bay, about 1,000,000 tons have been re-deposited on the beach area, and over 900,000 tons have been dredged and used in the fundamental construction of the Port of Bourgas-West. The remaining 6,000,000 tons cover the greater part of the bay bottom with a layer over 1 m thick. The tailings have been separated by the bottom stream and waves according to the size and density of the primary material (Table 7.2). Table 7.3 shows the number of samples taken in the respective year, and the range of radium-226 contents.

TABLE 7.2 Screen analysis of tailings in Vromos Bay

Particle Size, mm	Percent
>0.4	1.4
<0.4 > 0.3	3.1
<0.3 > 0.25	6.9
<0.25 > 0.12	10.1
<0.12 > 0.08	12.3
<0.08	61.3
Other	4.9

TABLE 7.3 Range of radium-226 in samples in Vromos Bay, 1978, 1983, and 1991

Year	No. of Samples	Specific Activity of Radium-226 (Bq/kg)
1978	7	10- 640
1983	37	54-1380
1991	78	10-1150

7.1.3. Requirements for Radiation Protection

Bulgarian main rules for radiation protection (the Committee for Peaceful Use of Nuclear Power, 1992) defined the basic levels of radiation and their control (Table 7.4). Regulation No.7, 1986, the Environmental Ministry, provides instructions and rules to define the allowed pollution of flowing surface water for radium-226 as 150 mBq/L. Pursuant to Regulation No.7, the Committee for Peaceful Use of Nuclear Power/07.01.1992, the residue characterised by a value of over 1 mSv/h of the equivalent dose of gamma radiation at a 0.1-m distance from the surface shall be deemed hard radioactive residue.

TABLE 7.4. Regulations for radiation exposure

Groups	Definition	Basic Limits for Effective External Radiation for 1 year
A	People working temporarily of permanently with sources of ionising radiation; people exposed to such radiation by profession; people involved in extreme lifesaving activities.	50 mSv
B	People or groups of population including both sexes above 18 years of age.	5 mSv
C	The population of the country as a whole.	1 mSv

7.2. Initial Restoration, 1991-1994

Initial restoration efforts sought to clean the beach area and find a way to utilise the useful components of deposit. The Bourgas Copper Mine developed an effective technology for this purpose. They started by studying the mineral and material composition of the tailings. According to their studies, the copper in the tailings is mainly represented by chalcopyrite. Chalcocite and bornite are detected much more rarely. The highest copper contents can be found in classes of +0.08, +0.12, and +0.16 mm. Most of copper minerals are covered with a thin film of copper oxides. The iron is found as magnetite and haematite, mostly in the classes below 0.16 mm. Most radioactive minerals are distributed in the non-magnetic fraction (the classes below 0.16 mm).

The technology developed based on these findings was put in place in early 1991. Tailings are collected and carried to the Rossen Flotation Mills for additional grinding to remove the oxide film from the mineral surface. Tailings are then subject to magnetic separation and flotation in accordance with the operative technological scheme. The result is a copper concentrate with copper contents of 13% to 15% and gold contents of 4 to 5 g/ton, as well as an iron concentrate with 55% iron contents.

These flotation tailings (about 75% of the treated quantity) contain nearly all the radioactive minerals. They are stored in the Rossen-3 tailings dump (noted as R3 on Figure 7.3).

7.3. PHARE Project, 1995

Despite the technology developed to prevent additional contamination of the beach and bottom sediments, the areas still required restoration from the original deposits. In 1995, the Bourgas Copper Mines chose to apply for the PHARE-ECOLOGY Programme to sponsor the restoration project. This project involved purposeful research work to define the degree of pollution of both beach and sea bottom as well as the way of removing the radioactive flotation tailings.

7.3.1. Gathering Information

To prepare for the project, all information on the quantity of the ore treated in the Rossen Flotation Mill between 1954 and 1977, the time when flotation tailings were thrown in the sea, was collected and used. The quantity of flotation tailings was determined from the quantity of ore treated. All information related to the study of the beach area and bay (made in 1979, 1982, 1991, and 1993) as well as the partial study of sea sediments in the bay (made in 1978, 1983, and 1991) were collected and analysed.

7.3.2. Sampling

Additional information was gathered by sampling the beach and bay areas.

Beach Area

The beach area was sampled by profiles located a distance of 125 m apart; two points were sampled for each profile. The gamma radiation background was measured at these points, and a sample quantity of about 2 kg was taken for analysis. That sampling network proved optimal based on the wind and surf effect of many years on the beach area and the information collected from previous studies. (The 1993 study used profiles 50 m apart with three points on each profile.) The network was defined by using the rarefaction method and the information from the 1993 study. This network is denser than the one in the bay because the surf area has a more dynamic sedimentation environment (the formation of oblique structures), and the quantities subject to treatment and direct disposal required a more precise determination.

Bay Bottom

The bay bottom was sampled using a 250-m by 250-m network . A scuba diver took the samples, which weighed about 2 kg, from the upper 15 to 20 cm of the sediment. These samples are characteristic of the whole sediment thickness at the particular point based on a number of constants influencing the process of sedimentation. These constants include composition of flowing tailings, fixed place of flow, and typical and continuous streams in the bay. These factors resulted in the formation in the central part of the bay of an elliptical geological body, whose long axis coincides with the direction of the tailings flow (Figure 7.4, the information refers to radium-226 contents in bottom sediments and comes from a research carried out in 1995).

The sampling network was selected following an analysis of the information resulting from the above research and considering the slower sedimentation at depths over 10 m[5].

The water layer was also sampled by a 500-m by 500-m network. The sample volume was about 3 litres, and samples were analysed for radium-226.

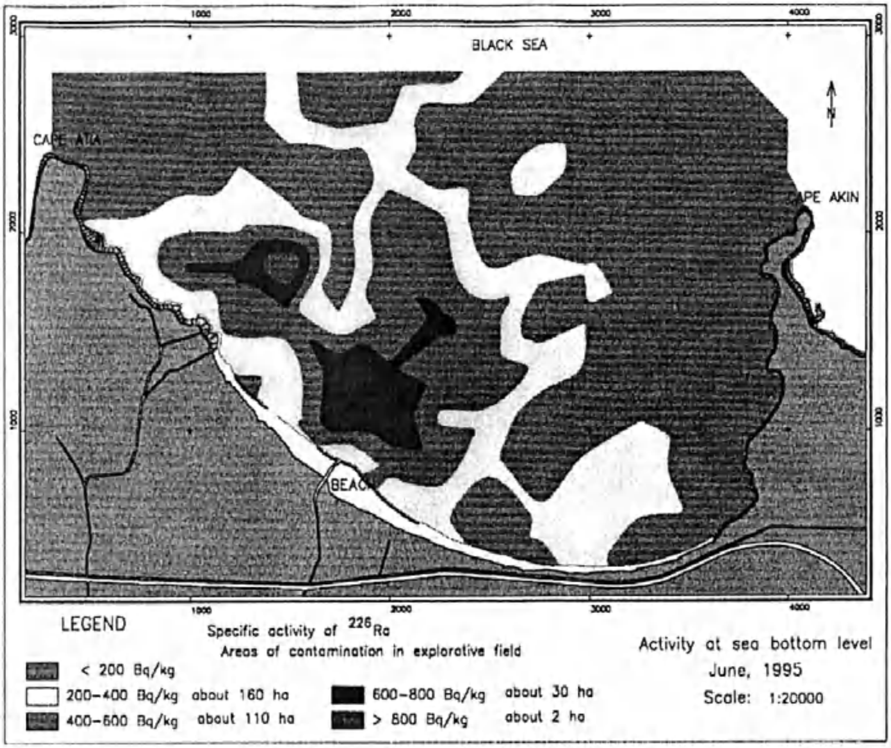

Figure 7.4 Activity at sea bottom level in Vromos Bay, June 1995

The motor boat used by the scuba divers was fixed to a particular point from the shore by an EOT-2000 light-distance-meter geodetic apparatus (made in Germany).

Adjacent Bays

The bays adjacent to Vromos–at Atia, the village of Chernomorets, the Chernomorets camping site, and the Gradina camping site–were sampled by single profiles. A sample was taken from the beach area and from sampling points at a distance of 250 m in the bottom sediments of the respective bays.

7.3.3. Independent Assessment of Project Plans

The project for the Vromos Bay cleanup was reviewed by URANERZBERGBAU, a German consulting company. The company consultants revised the project and researched alternatives. Variants considered included

- Pebbling the beach
- Sucking bottom radioactive deposits out of the Vromos Bay and disposing of them far out to sea
- Disposing the flotation tailings into the Rossen Flotation Mill
- Disposing the flotation tailings into the liquidated mine galleries of adjacent mines in the Rossen mine field.

To assess the variants, consultants developed a qualification system. According to their analysis, the most appropriate variant is the disposal in the mine galleries. Unfortunately, the galleries do not have the capacity required. Because of this, disposal of the tailings in the Rossen Flotation Mill was chosen as the optimal and environmentally friendly alternative.

7.3.4. Removal and Disposal of Tailings from the Beach

Cleanup of the Vromos Bay beach area started as early as September 1997 in compliance with the techniques in the project plans. The radioactive flotation tailings were collected by bulldozers, loaded onto dump trucks by front loaders and excavators (Figure 7.5), and then disposed either to the R-4 tailing dump or the Rossen Flotation Mill (see Figure 7.3). To speed the process, sand was excavated at three or four points simultaneously. This arrangement required 30 to 40 dump trucks of 14- to 16-ton capacity to be simultaneously operating.

The beach area was cleaned mainly in winter and spring, when storms frequent the bay. Thus, black sand from the beach area had to be extracted three times following each new release of new quantities by the sea. Before each new cleanup, the area was sampled. Samples were analysed in the laboratory of the Regional Inspection of Environment and Water, Bourgas. The beach was cleaned to the base layer of hard grey-black clays. Visual inspection show that, following each cleanup, the sands newly released by the sea are of a lighter and lighter colour and smaller radionuclide concentration (detected by the gamma spectrometric analyses of intermediate samples).

To dispose of the tailings, a tailing dump was built on a site owned by the Bourgas Copper Mines. The dump was built in agreement with the Bourgas Regional Inspection of Environment and Water, and was approved by the Ministry of Environment and Water. The soil layer and weathering material were removed in advance and disposed of separately. The south and west part of the tailing dump was walled by soil material. The wall has the following dimensions:

- Base, 8 m wide
- Crown, 4 m wide
- Height, 6 m.

Figure 7.5 Cleaning of the beach at Vromos Bay, 1998

The wall was shaped at two levels at a slope angle of 1:1. It was compacted by a road roller during construction.

7.3.5. Treating Residue in the Rossen Flotation Plant

A part of the tailings was treated in the Rossen Flotation Plant. The quantity was considerably smaller than the one originally suggested because of low prices at the London Metal Exchange. The quantities were characterised by copper content over 0.38%. After being transported to the plant reception bunkers about 7 km away from the beach, tailings were treated by grinding, flotation, and magnetic separation. The total output of both copper and iron concentrate was about 10% to 12%. The remaining quantity (88% to 90%), containing most of the radioactive minerals, was disposed of in the operating Rossen-3 tailing pond (noted as R3 on Figure 7.3).

7.3.6. Monitoring

In compliance with project plans, areas were sampled after cleanup in the same volume and within the same network as the original sampling in 1995. Areas were sampled in July and August 1998 (Table 7.5).

TABLE 7.5 Sampling conducted near Vromos Bay, 1998

Type of Activity	Dimension	Quantity
1. Beach area sampling	No	65
2. Beach area radiometric sampling	No	65
3. Beach area drilling	1 m	33
4. Taking samples from drill holes	No	66
5. Taking samples from bottom sediments	No	158
6. Taking water samples from bottom layer	No	37
7. Referring samples to a geodetic basis	No	251
8. Analysis of radionuclides	No	289

Samples from bottom sediments, the beach area, drill holes, and water taken from the bottom layer were analysed for uranium-238, radium-226, thorium-232, and potassium-40. Samples were analysed using an ORTEC low-background gamma-spectrometric apparatus in the laboratory of the Bourgas Regional Inspection of Environment and Water, and the Dosimetric and Radiation Protection Laboratory at the Physical Department of the Sofia University "St Kliment Ohridski."

7.4. Project Results

Restoration activities resulted in noted improvement to both the beach and bottom sediments.

7.4.1. Beach Area

As a result of the removal of some 800,000 tons of flotation tailings, the beach area of the bay was considerably influenced:

- The width of the beach area was reduced in the various profiles from 60 to150 m to 20 to 50 m, which has brought it near its original condition (Figure 7.6.)
- The thickness of the flotation tailings on the beach, which ranged from 2 to 6 m, was reduced to about 0.30 m, as detected by the drill holes (Figure 7.6). A number of places, particularly in the east part of the bay, were totally cleaned of their flotation tailings.
- Radionuclide concentration in the beach sand decreased considerably since 1979, mostly because of the excavation of flotation residue but partly because of its spreading over a larger surface (Table 7.6)
- Sand colour was essentially changed: from dark grey and black before restoration, to light grey and yellow after restoration (Figures 7.7 and 7.8).

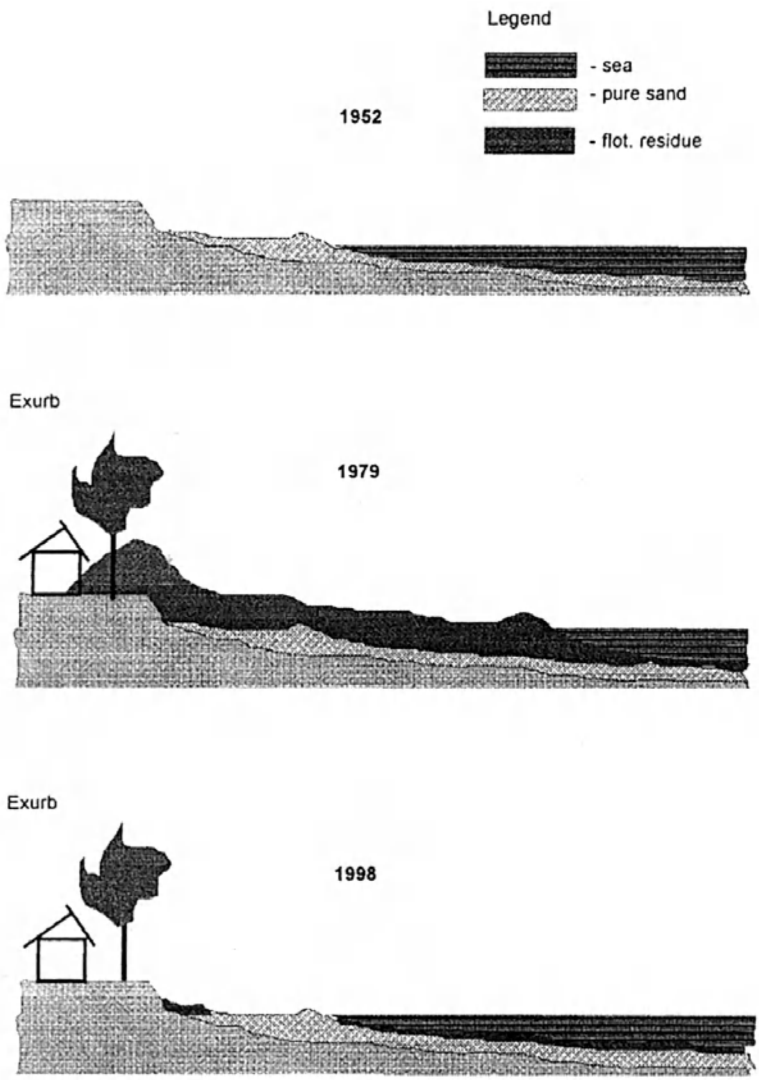

Figure 7.6 Profile No. 4, typical section of Vromos beach

TABLE 7.6 Changes in radionuclide concentrations over time at Vromos Bay

Year	No. of Samples	Exposition Power, μR/h		Specific Activity, Bq/kg	
		Min	Max	Min	Max
1979	15	25	940	74	41400
1993	28	35	110	200	3 700
1995	44	17	56	100	609
1998	44	15	32	83	400

7.4.2. Bottom Sediments

The results from the research work carried out to determine the bay bottom lithodynamics show that, 20 years after the discharge of flotation residue ceased, the newly formed lithobodies are still slowly moving. This dynamic is a result of three main factors, the first and most significant being the removal of flotation residue from the beach. The other two factors involve bottom streams and waves. At the time of sampling, two areas of increased radioactivity of over 200 Bq/kg were located on the sea bottom. One of them was located against the discharge zone, with a centre of about 600 m away from the shore (Figure 7.9). Two comparatively smaller areas were detected within it, characterised by a radium-266 concentration of over 600 Bq/kg. Bottom

Figure 7.7 Beach at Vromos Bay, a view from the east (August 1998)

Figure 7.8 Beach at Vromos Bay, central part (August 1998)

sediments here comprised compact black clay materials, formed during the sedimentation of the pellet fraction of the flotation residue. The sand component, which had moved to that point during the discharge, was pushed back to the shore. The second area was located at about 1,500 m farther into the bay, at a depth of over 15 m below the surface. Sediments in that area comprised black slimes in a semi-liquid state. The area distribution and activity as determined in three successive studies are shown in Table 7.7.

Analyses also showed that the size of high concentration areas in bottom sediments is continually decreasing. The absolute value of specific activity is also decreasing.

7.5. References

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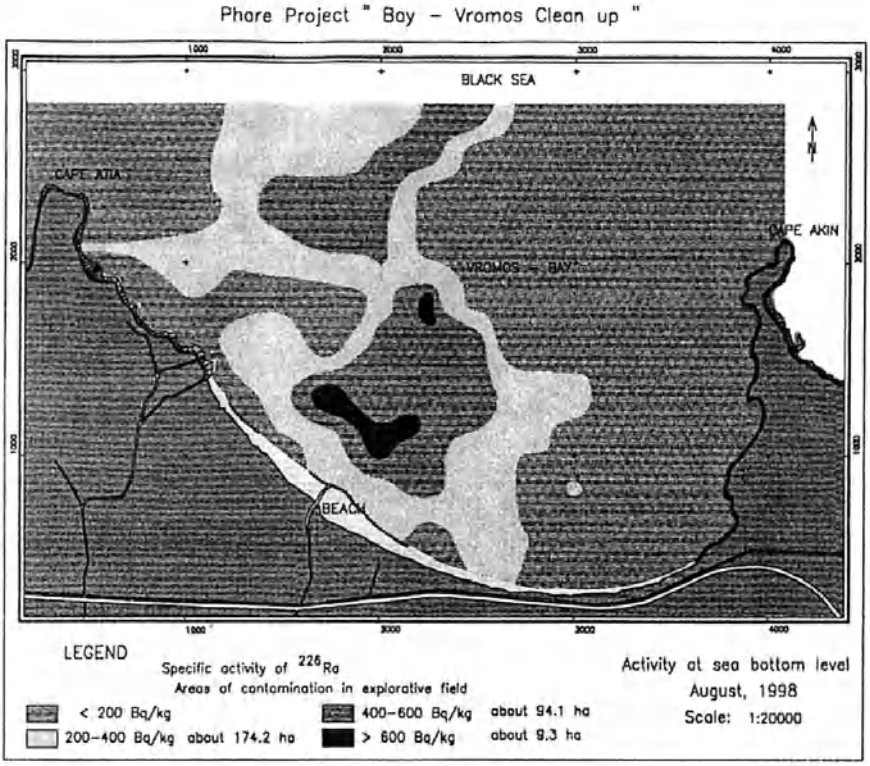

Figure 7.9 Activity at sea bottom level in Vromos Bay, August 1998

TABLE 7.7 Distribution of bottom sediments in Vromos Bay by area and activity

Specific Activity of Radium-226, Bq/kg	**Area, m^2**		
	1991	**1995**	**1998**
200-400	1,400,000	1,600,000	1,742,000
400-600	1,050,000	1,100,000	941,000
600-800	470,000	300,000	93,000
800-1000	60,000	20,000	–
> 1000	25,000	–	–

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