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Local Sources of Polychlorinated Biphenyls (PCB) in Russian and Norwegian Settlements on Spitsbergen Island, Norway

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Samples of surface soil, flaking paint, concrete, transformer oils, and small capacitors were collected from the three largest coal-mining settlements on Spitsbergen—Barentsburg (Russian), Pyramiden (Russian), and Longyearbyen (Norwegian)—to study the role of potential local sources of polychlorinated biphenyls (PCB) in the arctic areas (78° N). Median concentrations of PCB_7 in soil from Barentsburg and Pyramiden were 0.268 and 0.172 mg/kg, respectively, with a maximum concentration of 28.7 mg/kg. High concentrations found in paint (3520 mg/kg) and small capacitors (114,000 mg/kg) indicated that these two are the main sources of local PCB contamination. Only traces of PCB were found in the Longyearbyen samples compared to the results from the other two settlements. Large amounts of building refuse, electrical waste, and scrap metals constitute major pollution sources in Barentsburg and Pyramiden. Weathering and general decay facilitate the mobilization of PCB from these sources to the local soil, which consequently is readily available for fluvial and eolian transport to the more vulnerable marine environment.

Levels of polychlorinated biphenyls (PCB) in various sample media in Arctic areas have thus far mostly been attributed to long-range transport, including atmospheric transport (LRAT), ocean currents, trans-polar ice movements, or migrating animals (Macdonald et al., 2000; Skotvold & Savinov, 2003; AMAP, 2004; Kallenborn et al., 2007; Carroll et al., 2008). LRAT is described as a temperature-driven air–surface exchange controlled by a global fractionation process (Wania & Mackay, 1995, 1996; Ockenden et al., 2003). Subsequent condensation and possible accumulation in Arctic areas is by far the most accepted explanation for the high levels of PCB found in samples of biota such as liver, blood, and brain of wildlife animals on Svalbard, including polar bears (Lie et al., 2003; Braathen et al., 2004; Dietz et al., 2004; Verreault et al., 2005; Ropstad et al, 2006; Sonne et al., 2007), seals (Wolkers et al., 2004), fish (Jorgensen et al., 2006), and birds (Henriksen et al., 1998; Krokje et al., 2006; Knudsen et al., 2007; Murvoll et al., 2007; Verreault et al., 2007). Hop et al. (2001) used macrobenthos near urban settlements in Svalbard to study the contribution of local input of PCB to the marine environments. Later studies of marine sediments indicated elevated concentrations of PCB outside Barentsburg and Pyramiden (Evenset et al., 2006). The PCB concentrations increased between 1997 and 2005, indicating an active source of contamination onshore.

PCB have been added to a wide range of applications, including hydraulic oils, electrical transformers and capacitors, double-glazed windows, masonry coatings, sealants, and paint (Sundahl et al., 1999; Poland et al., 2001; Andersson et al., 2004; Herrick et al., 2004; Shin & Kim, 2006). The addition of PCB to hydraulic oils as a flame-retardant agent was especially essential for the coal mining industry during the decades preceding the national PCB ban in the 1980s.

Some studies indicated that local sources may contribute to the PCB loadings within the Arctic. One such study was performed in Saglek Bay (Labrador) and showed that military sites were possible sources of PCB dispersion to the local marine environment (Kuzyk et al., 2005). However, the Arctic Monitoring and Assessment Programme (AMAP) states that more detailed studies of local sources of PCB contamination within the Arctic are needed. The impact of local and active sources of PCB within areas heavily affected by anthropogenic activity on the Norwegian mainland has recently been studied by Jartun et al. (2008) in the city of Bergen. The objective of our study was to provide an overview of possible local sources of PCB in Svalbard, and the significance of these sources to the local environment based on previous knowledge of PCB utilization in such a wide variety of applications. The study was initiated by the Governor of Svalbard, Norwegian Pollution Control Authority, and Geological Survey of Norway to cover the three largest coal-mining settlements on Spitsbergen Island.

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METHODS

Sampling

Svalbard is a Norwegian archipelago in the Arctic Ocean consisting of several islands situated from 74 to 81° N and 10 to 35° E. Three of the islands are inhabited, including Spitsbergen, where our study was carried out. In total, 133 samples of surface soil, paint, concrete, capacitors, and transformer oils were collected from Barentsburg, Pyramiden, and Longyearbyen, the three largest settlements on Svalbard. Surface soils (0–2 cm) were sampled into Rilsan bags using a small, paint-free spade. The sample locations were randomly selected, but the sample density was increased in areas of current or previous activities such as waste deposition or workshop. Samples of flaking paint were collected from random buildings using a filling knife. From some of the buildings, a drill core sample of the concrete was collected. Small capacitors and transformer oils were collected from random buildings in collaboration with the Russians and Norwegians living in Barentsburg and Longyearbyen, respectively. The Governor of Svalbard approved and supervised the sampling in the abandoned settlement of Pyramiden. All samples were sent to our collaborative lab Alcontrol AB for PCB determination.

Chemical Analysis

The extraction of PCB followed the same procedure for all sample media, and started with 10 g of homogenized material. Acetone (20 ml), *n*-hexane (9 ml), and an inner standard (PCB-53, 100 µg/ml, 1 ml) were added followed by mixing and centrifugation. A solution of 15 ml phosphoric acid (0.1 *M*) and NaCl (0.2 *M*) was then added to the acetone/hexane phase. Two milliliters tetrabuthylammonium hydrogen sulfate (TBA), 2 ml propanol, and a spatula of sodium sulfite were added to 2 ml of the hexane phase in a new test tube, followed by heating to 50°C. Deionized water and subsequently concentrated sulfuric acid were added to clean the hexane phase before the extract were condensed to 1 ml at 40°C. The quantification of seven PCB congeners (PCB_7 IUPAC numbers 28, 52, 101, 118, 138, 153, 180) was carried out using a gas chromatograph with electron capture detection (GC-ECD). The method is based upon the Nordtest Technical Report No. 329 (Karstensen et al., 1997).

Quality Control

Certified reference materials (EC-2, sediment from National Water Research Institute, Canada) and analytical blanks were analyzed continuously in accordance to ISO/IEC 17025. Table 1 presents the results of the quality control comparing the measurements of PCB_7 in a reference material (EC-2) obtained from Alcontrol with the certified values from NWRI. The results are acceptable for all seven congeners.

TABLE 1
Results of Quality Control for PCB_7 (n = 6) in a Standard Reference Material Obtained at Alcontrol Compared to Certified Values from NWRI (EC-2)

Congener, IUPAC number	Alcontrol (mg/kg dw)	SD[a]	CV[b] (%)	Reference (mg/kg dw)	CV (%)
PCB 28	0.0210	0.0038	18.0	0.028	60
PCB 52	0.0366	0.0064	17.6	0.034	70
PCB 101	0.0571	0.0103	18.0	0.053	45
PCB 118	0.0272	0.0073	26.7	0.035	49
PCB 153	0.0764	0.0123	16.1	0.081	59
PCB 138	0.0888	0.0158	17.8	0.089	43
PCB 180	0.0494	0.0079	16.0	0.048	49

[a]SD, standard deviation.
[b]CV, coefficient of variation.

RESULTS

Analytical results of our study of local, active sources of PCB on Svalbard are summarized in Table 2. PCB were found in high concentrations in samples of surface soil, paint, concrete, and small capacitors. Low concentrations were detected in a limited number of samples of transformer oils and undefined plastic materials. The median values of PCB_7 found in surface soil within the two Russian settlements of Barentsburg and Pyramiden are 0.268 and 0.172 mg/kg, respectively, whereas the median value in Longyearbyen was below the detection limit of 0.004 mg/kg. Compared to a study of PCB in building materials and adjacent surface soil from Bergen, Norway (Andersson et al., 2004), the median soil concentrations of PCB_7 from the Russian settlements on Svalbard are considerably higher (0.268 and 0.172 compared to 0.15 mg/kg in Bergen). The concentrations of PCB_7 found in paint from buildings on Svalbard are also high, but at levels comparable with other studies from Norway (Andersson et al., 2004). Only traces of PCB were found in a limited number of samples of transformer oils and plastic materials, but the PCB concentrations found in small capacitors from the Russian settlements exceed 11%.

Geographical distributions of PCB_7 in surface soil and paint within the three settlements are shown in Figures 1 and 2, respectively. For surface soil, high concentrations are distributed evenly within the sampled area of Barentsburg (Figure 1A) and Pyramiden (Figure 1B), whereas the concentrations are consistently low in Longyearbyen (Figure 1C). The distribution pattern for paint is somewhat different, indicating that the surface coatings on buildings around the Heliport and in the southern part of Barentsburg are more contaminated with PCB than those in the central area around the main pier (Figure 2A). In Pyramiden and Longyearbyen there are a few selected buildings containing PCB (Figures 2, B and C, respectively), but the

TABLE 2
Analytical Results of PCB_7 (mg/kg) in Samples of Soil, Paint/Concrete, Oils, Plastic Materials, and Small Capacitors from Barentsburg, Pyramiden, and Longyearbyen

		n	Minimum	10%	25%	Median(50%)	Arithmetic mean	75%	90%	Maximum
Soil	Barentsburg	22	0.052	0.080	0.155	0.268	2.96	1.16	3.11	28.7
	Pyramiden	31	<0.004	0.025	0.042	0.172	1.14	1.04	2.68	13.9
	Longyearbyen	30	<0.004	<0.004	<0.004	<0.004	0.010	0.007	0.019	0.131
Paint	Barentsburg	16	<0.004	0.042	0.200	0.621	229	10.8	55.6	3520
	Pyramiden	10	<0.004	<0.004	0.005	0.018	130	0.625	134	1290
	Longyearbyen	9	<0.004	<0.004	0.005	0.064	0.124	0.121	0.251	0.695
Oils	—	5	<0.004	—	—	—	—	—	—	0.054
Plastics	—	2	<0.004	—	—	—	—	—	—	0.021
Capacitors	—	8	<0.3	—	—	—	—	—	—	114,000

Note. Results are shown for selected percentiles and the arithmetic mean.

number of samples here is too low to provide a significant inventory of PCB-containing paint in these two settlements.

On the congener level, the PCB_7 profiles in soil samples from Barentsburg and Pyramiden exhibited a mid-chlorinated pattern mainly consisting of penta- and hexa-CB. The same pattern is observed in the paint samples from these two locations. In Longyearbyen, the observed congener profiles in samples with detectable levels of PCB indicated a highly chlorinated pattern, represented by high relative concentrations of hexa- and hepta-CB. Small capacitors with high concentrations of PCB_7 exhibited a different congener composition, only represented by less chlorinated homologues such as PCB 28.

DISCUSSION

The environmental effects of persistent organic pollutants (POP) in the Arctic are serious. High concentrations of PCB, among other compounds, were detected in a wide range of animals and the concentrations increased in a process of biomagnification through the trophic levels (AMAP, 2004). The search for significant sources of PCB within the Arctic environment has mostly focused on long-range atmospheric transport (Macdonald et al., 2000; Kallenborn et al., 2007) or specific local sources such as a military site (Kuzyk et al., 2005). Long-range transport is one of the screening criteria under the POP protocol and the Stockholm Convention, whereas the role of local sources may have been underestimated in many of the discussions concerning the levels of pollutants in Arctic areas. As for PCB, this group of compounds has been added to an abundance of applications globally, and our study clearly shows that products containing high concentrations of PCB have been used to a large extent on Svalbard, which consequently affected, and is continuing to affect, the local environment in terms of elevated concentrations in surface soils susceptible to erosion.

PCB concentrations in soils from areas heavily affected by anthropogenic activities are probably higher than in more pristine areas of Spitsbergen Island. Breedveld (2000) performed a survey of background levels of contaminants in Longyearbyen, demonstrating low concentrations of PCB_7 in surface soil (range: 0.0001–0.0009 mg/kg). The three largest settlements on the island constitute only a minor part of the whole Svalbard area. However, the concentrations of PCB that were discovered in surface soil and applications in these areas are a source of concern because of the potential of dispersion to larger areas. Surface soil collected in this study is available for erosion by creeks, rivers, rainfall, and snowmelt, facilitating a particle-bound transport to the marine environment. During early snowmelt, runoff may occur outside regular river channels. Scarce vegetation and permafrost may in turn reduce infiltration to the ground, consequently making previously unavailable surface materials exposed to erosion (Bogen & Bønsnes, 2003). The river system outside Pyramiden flushed through the abandoned settlement in 2006, transporting some of the surface materials directly to the sea. The dispersion of pollutants from the settlements facilitated by fluvial transport may be an environmental challenge for years to come. Dispersion mechanisms through eolian transport of sand and dust on dry, windy summer days may also originate from the settlements.

A large amount of waste such as building materials, electrical installations, barrels, and scrap metal is located in open terrain in and around the settlements of Barentsburg and Pyramiden. Weathering and decay are starting to mobilize the PCB added to, e.g., paint and capacitors, first contaminating the adjacent soil and sediments, and subsequently the marine environment. The typical small capacitor is a silver-colored cylinder (approximately 6 $cm^2 \times 10$ cm), and each may contain as much as 50–60 g PCB. Hundreds of these were lying around as waste close to the shore in Pyramiden. Small capacitors, manufactured before 1980, are most likely to contain PCB and are now prohibited in Norway, including the Norwegian settlements on Svalbard, as of January 1, 2008

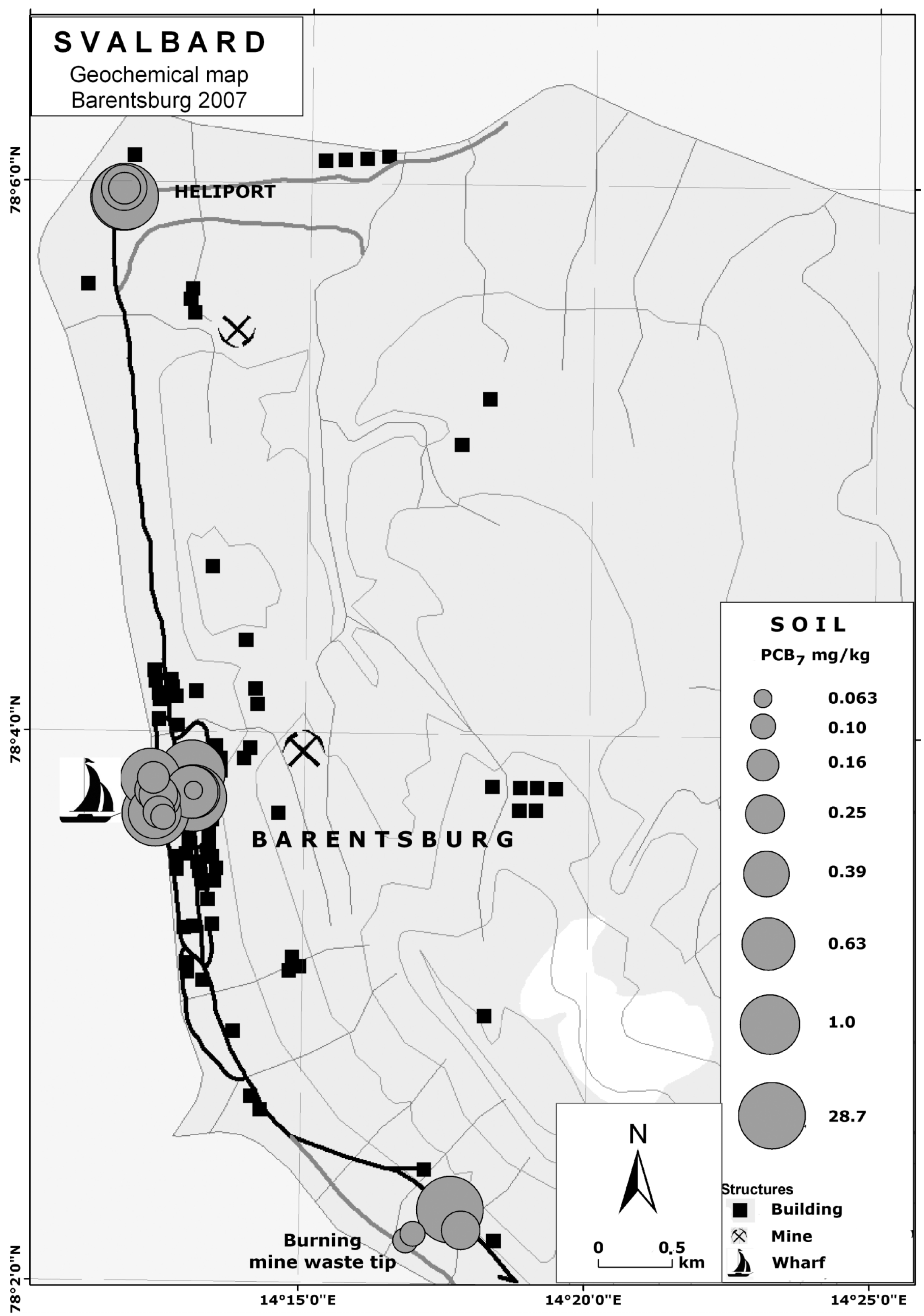

FIG. 1. (A) Geographical distribution showing the concentrations of PCB_7 (mg/kg) in samples of surface soil collected from Barentsburg (n = 22). (B) Geographical distribution showing the concentrations of PCB_7 (mg/kg) in samples of surface soil collected from Pyramiden (n = 31). (C) Geographical distribution showing the concentrations of PCB_7 (mg/kg) in samples of surface soil collected from Longyearbyen (n = 30).

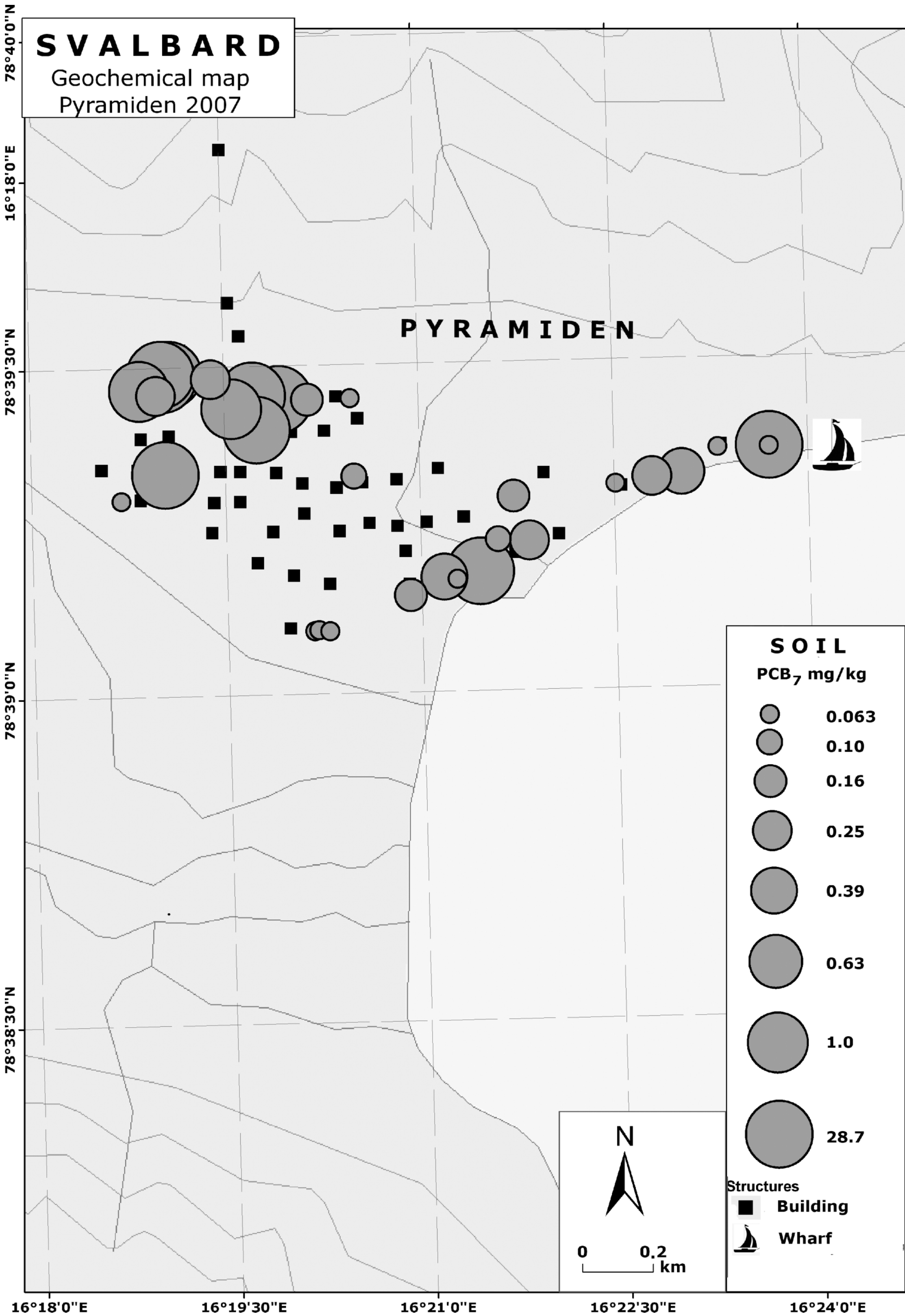

FIG. 1. (*Continued*).

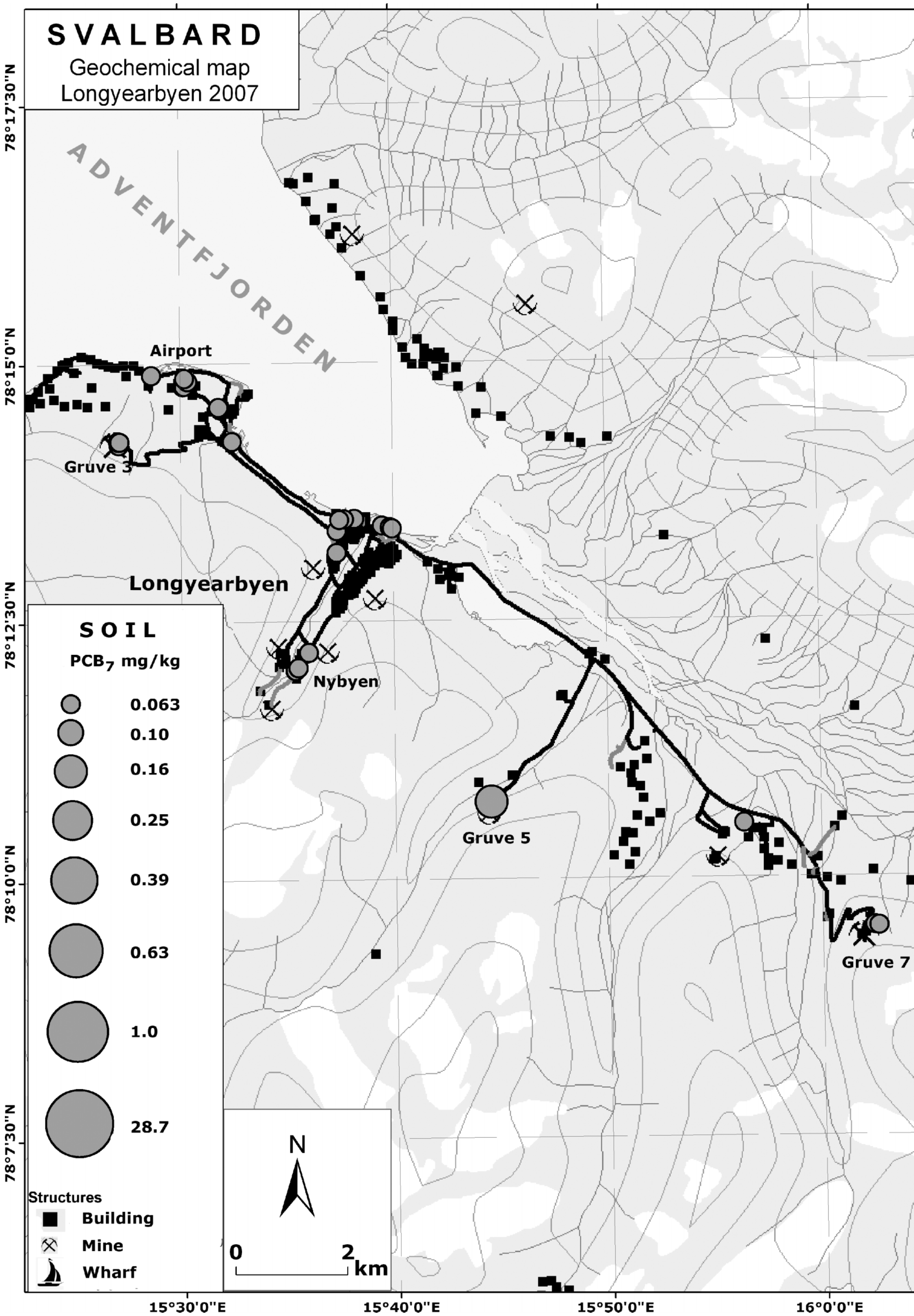

FIG. 1. (*Continued*)

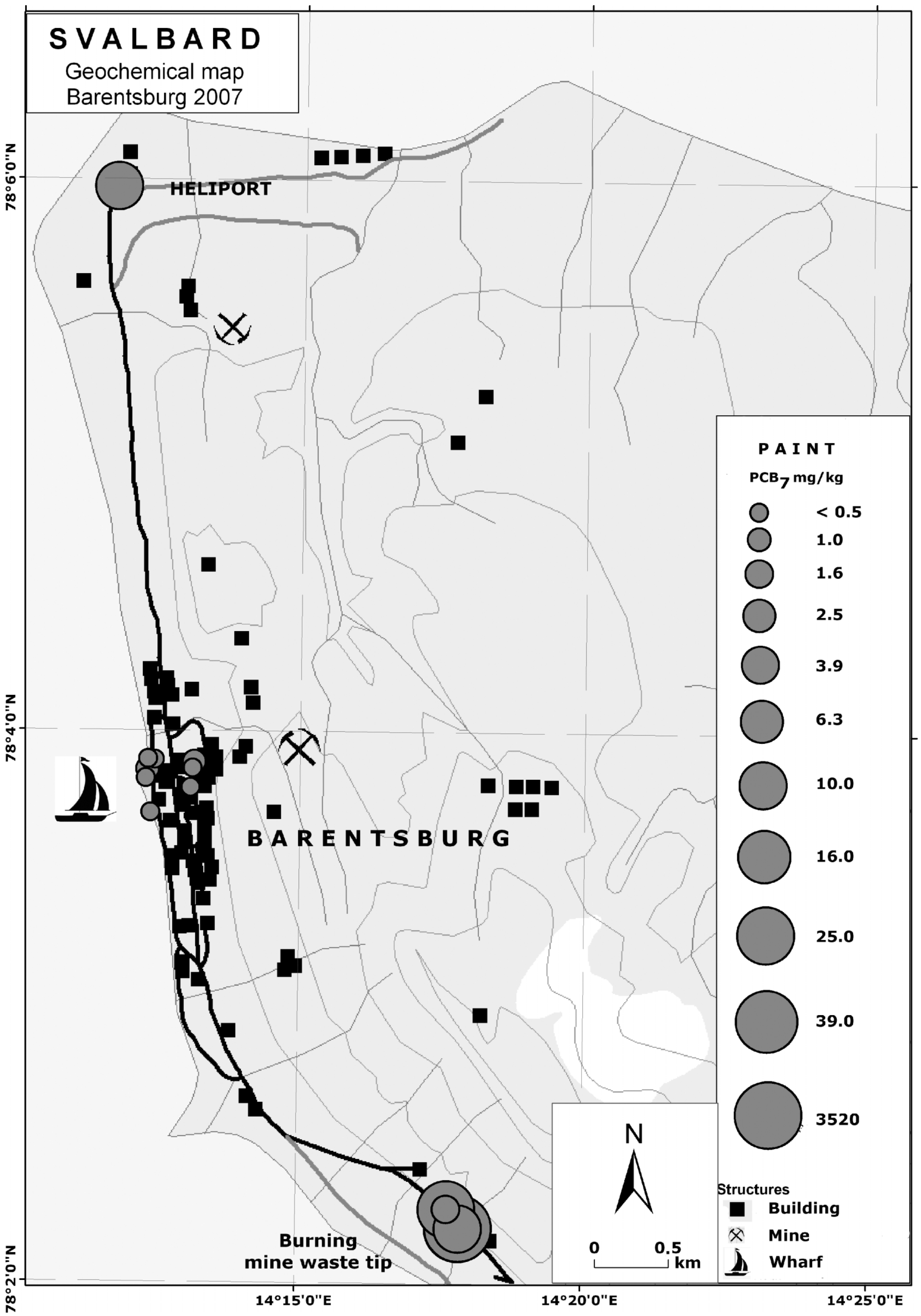

FIG. 2. (A) Geographical distribution showing the concentrations of PCB_7 (mg/kg) in samples of paint collected from Barentsburg (*n* = 16). (B) Geographical distribution showing the concentrations of PCB_7 (mg/kg) in samples of paint collected from Pyramiden (*n* = 10). (C) Geographical distribution showing the concentrations of PCB_7 (mg/kg) in samples of paint collected from Longyearbyen (*n* = 9).

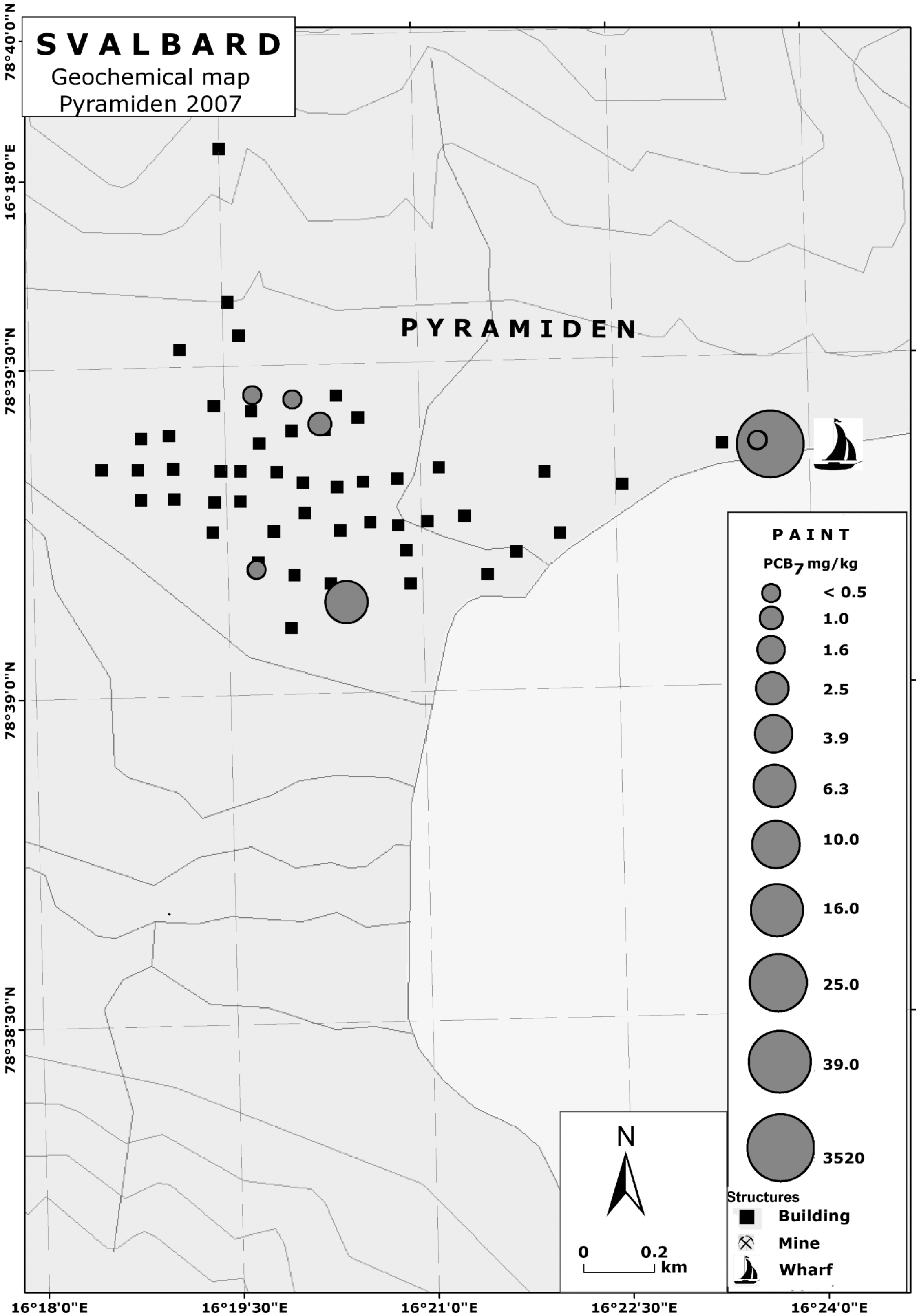

FIG. 2. (*Continued*)

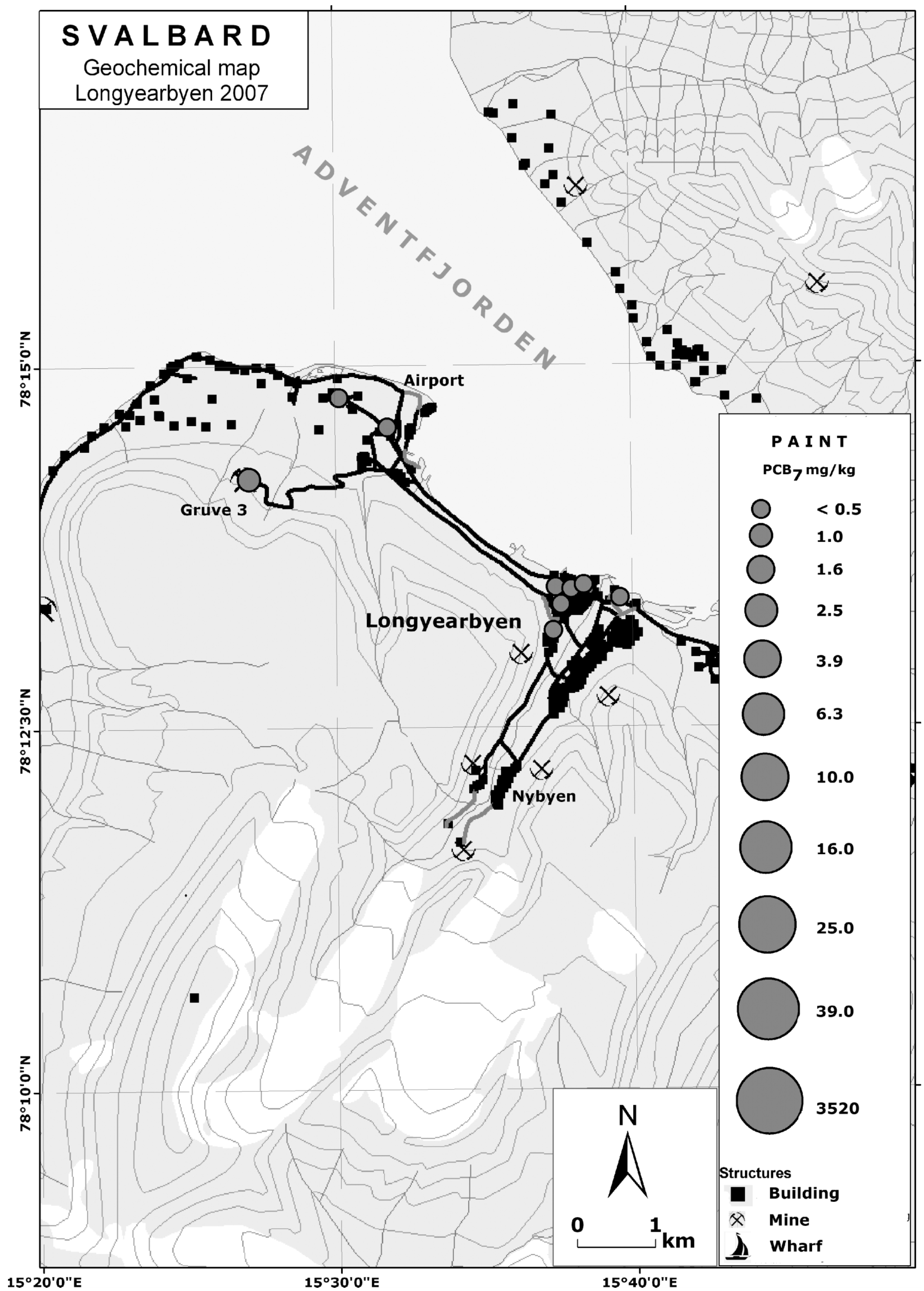

FIG. 2. (*Continued*)

(Norwegian Legislation, 2004). No such regulation has been effectuated in the Russian settlements yet. Flaking paint collected from random buildings may in addition be an important source of PCB because of the availability for further transport to the environment. Some indication of the active source in each area may be shown by comparing the congener profiles with standard technical mixtures of PCB manufactured by, e.g., Aroclor or Clophen (Schultz et al., 1989; Konieczny & Mouland, 1997). Some caution needs to be made when comparing the PCB_7 profiles because the degree of degradation of individual congeners remains unknown in this study. However, data indicate that the main soil profile in samples of soil from Barentsburg and Pyramiden derives from a mid-chlorinated technical mixture, such as the Russian Sovol, whereas the main congener profile in samples of soil from Longyearbyen originates from a technical mixture with a higher chlorination degree such as Aroclor 1260 or Clophen A60.

Whether or not the PCB found in surface soil and decaying products within these settlements are available for uptake by local or migrating animals such as seagulls will be an important scope of further studies. Stow et al. (2005) showed that local sources of PCB within the Canadian Arctic may exert an influence on the environment at least up to 10 km away from specific source areas. Given that PCB are semivolatile compounds, it would also be interesting to study the soil–air flux from the heavily contaminated areas of Barentsburg and Pyramiden. The local contamination of PCB in these areas is high, and the distance to the vulnerable arctic environment and food chains short. Some studies showed that PCB may form de novo in thermal processes (Schoonenboom et al., 1995; Ishikawa et al., 2007). The coal power station in Longyearbyen and in Barentsburg, and also other combustion facilities should be subject to a thorough study of possible PCB emissions. The establishment of a ratio of long-range PCB contribution versus local sources has not been the scope of our work thus far, but a more detailed estimation on the relative contribution of PCB contamination from local, contemporary sources compared to LRAT will be performed when additional data from Spitsbergen are available, probably within 2008. Based on current data, the amount of PCB in surface soils from Barentsburg alone may be as much as 2000 kg throughout this settlement alone (see Figure 1A). The scenarios of local contribution versus LRAT are likely to occur simultaneously. However, if the levels of PCB in various sample media on Svalbard are to decrease, it is important to start with the highly contaminated waste lying in open terrain throughout the areas affected by anthropogenic activity.

CONCLUSIONS

Local contamination sources for PCB in the Russian and Norwegian coal-mining settlements on Spitsbergen Island have been detected. Surface soils within the Russian settlements are highly contaminated with PCB. Samples of PCB-containing exterior building paints were found in all the settlements. In the Russian settlements PCB were also detected in concrete/plaster and small capacitors. Immediate abatement of the contamination risk is needed.

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