Microstructural observations

Thin sections of soil were prepared from the undisturbed samples after soil water and immiscible hydrocarbon contaminants had been removed and replaced by acetone. They were then impregnated with a polyester resin containing a fluorescent dye (Uvitex PB, Ciba-Geigy). The methodology for soil-water removal, sample impregnation, and thin-section preparation is widely documented, having been described by Fitzpatrick (1984).

The use of thin sections facilitates the description of the arrangement of soil particles and pores, and provides information on the particular features and how they are associated with properties such as hydraulic conductivity. Morphology of the thin sections was described according to a glossary of micromorphology terminology (Fitzpatrick, 1984; Howes and White, 1991). Soil fabric descriptions were made from vertically oriented thin sections at 12 x magnification. This magnification showed the gross morphology that characterises the structure of the soil fabric.

Optical and scanning electron microscope (SEM) micrographs from undisturbed soil samples taken from the contaminated summer and winter spill sites and the selected control site (assumed to have been uncontaminated) are illustrated in micrographs Plate 1 to 23. They show various morphologies with differences in soil aggregation and porosity. There are two major factors important for the microstructure. Soils in the active layer are exposed to bi-directional freezing and thawing annually, and thus have been frozen and thawed many times. Secondly, immiscible contaminants of different concentrations have a significant impact on pore water chemistry and dielectric constants which also modify the microstructure.

Distinct gross morphologies characteristic of contaminated soils, are seen in all the samples *including those sampled from the selected control site.* It is consequently not possible to make direct comparisons of uncontaminated and contaminated materials but only to point out these characteristics as we recognise them from other studies (White and Williams, 1999). The optical thin sections prepared from contaminated and control sites for soil horizons O1 (Plates 1 to 3), A1 (Plates 7 to 9) and C1 (Plates 13 to 15) in the active layer show evidence of soil aggregation. The aggregates are the dark, apparently dense zones, best seen in Pls.19 and 20. All three soil horizons examined in the 'summer-', 'winter-' and control-sample pits show structures at the interparticle and interaggregate level, associated with the presence of immiscible hydrocarbon compounds. Total petroleum hydrocarbon (TPH) determinations (Table 1) confirmed the presence of hydrocarbons in all three horizons for the three sample locations. TPH concentrations decreased as a function of increasing depth in the three profiles.

In the O1 horizon the morphology is characterised by moderately decomposed organic particles with inclusions of sphagnum moss fragmics. Organic fragments tend to be clustered together, the aggregation being due to immiscible hydrocarbon compounds. Undecomposed peat which makes up the O1 horizon has become clogged by hydrocarbons (black film surrounding organics, Plates 1 to 3). SEM micrographs (Plates 4 to 6) reveal additional information on how the peat fibres have been affected by hydrocarbons. Peat which has a high absorption capacity associated with its high surface areas absorbs the hydrocarbons along its outer surfaces; its internal cellular structure, however, remains intact. Immiscible compounds present in the film water at the surface of particles and unfrozen soil water are responsible for lowering the dielectric constant of the soil water. This results in a tendency for the clay and silt size particles to move closer together and to form aggregates (see especially Plates 19 to 23).

In the A1 horizon (Plates 7-12) the morphology is characterised by dense soil fabric consisting of silt and clay size mineral material, with fine organic material distributed throughout (which is evidence of faunal activity). Dark patches are the discrete structural units (aggregates) in which contaminants have accumulated.

In the C1 horizon the morphology is characterised by planar pores in a fine granular matrix which is often aggregated, forming mullgranoidic fabric components. Optical microscope observations (Pls. 13, 14) show planar pores (White and Williams 1999). Pl. 13 shows clearly a zone of compaction along the upper boundary of a planar pore. Hydrocarbon contaminants, which appear black, have accumulated there.

In the A1 and C1 horizons, the clay and silt size minerals show the "signature" aggregate structures which identify contaminated soil at the microscopic scale. They appear to confirm that cation exchange sites present on the surface and along the edges of the clay size minerals have become occupied by immiscible hydrocarbon compounds present in the soil water. However, close packing of the particles within the aggregates also results from the effective stresses that develop in the silt because of cryogenic processes, along with the reduction of surface area and thickness of the adsorbed water layers of the clay-size minerals and organic particles by the contaminant. The formation