Patterns and rates of deposition, migration and retention of pollutants in man-made strata depend on the depositional history and physical and chemical characteristics of the constituent materials. A sound understanding of the spatial and chronological relationships of materials is required for effective evaluation of solid, liquid and gaseous geo-pollution and design and understanding and interpretation of investigations of potentially contaminated land. Description of materials and boundaries requires clear terminology. A proposed terminology has been developed based on experience from a variety of sites in Japan including the experimental infilling of an old quarry. The terminology is commended for further discussion.

Introduction

Geo-pollution is a term used in Japan for pollution that leads to contamination of land. This is defined as compound underground pollution consisting of “strata pollution”, soil pollution, “ground water pollution” and “ground air/gas pollution”. These types of underground pollution have complex interactions with each other (Nirei et al., 2010). Contaminants that give rise to geo-pollution may be solid (e.g. slag with toxic heavy metals, concrete containing contaminants, metallic products, shards, plastics, asphalt, lumber and paper (Nirei et al., 1994), liquid (e.g. engine oil, chlorinated solvents such as volatile organic compounds (VOCs), leakage from drainage and waste water tanks, and other waste liquids (Shibasaki et al., 1995), or gaseous (Sladen et al., 2001).

Patterns and rates of deposition, migration and retention of pollutants in man-made strata depend on the depositional history and physical and chemical characteristics of the constituent materials. Solid contaminants are contained in certain materials deposited from time to time at a site. But liquid and gaseous contaminants migrate through pathways such as pores in, and boundaries between, materials, until these reach places where further migration is inhibited, for instance by a fine grained layer with limited interconnected porosity. Therefore a sound understanding of the spatial (materials and discontinuities between these) and chronological relationships (depositional sequences) is required for effective evaluation and interpretation of geo-pollution and designing and undertaking investigations of potentially contaminated land. Discrimination of materials and boundaries in terms of time and properties requires a clear set of descriptive terms. This paper sets out a proposed terminology.

Investigation of potentially contaminated sites

Investigation of contaminated land to detect and evaluate the concentrations of types and levels of geo-pollution generally consists of:

a) drilling or trial pitting, often on a regularly spaced grid pattern, and evaluation of the extent of contamination on the basis of predictive models using probability or geostatistical methods (Ersoy et al, 2004; Öberg and Bergbäck, 2005; Petts et al. 1997; Ramsay et al. 1995); and

b) taking and analysing samples at prescribed depths (e.g. surface, 5 cm, 0.5 m, 1 m, 2 m, …10 m etc.) as in, for example, the Japanese Soil Contamination Countermeasure Law.

But these does not have reference to the source of pollution or unit boundaries that pollution may be retained within.

Initial surveys may, of course, be modified by varying the spacing in the drilling grid or depths of sampling when pollutants are detected. But techniques that are essentially mechanistic and independent of a considered framework of the actual distributions of materials and pollutants (i.e. essentially, “unit independent”) are commonly specified in regulations or guidance. These may not allow sufficient flexibility to take site-specific circumstances properly into account.

Therefore a mechanistic approach does not necessarily secure the information needed to determine geo-pollution mechanisms, sometimes fails to locate the pollution source, and can miss localised concentrations of pollutants because the grid or vertical sampling intervals are too widely spaced. Consequences may be the need for additional investigation during remediation with delays and increased costs and, in some cases, secondary pollution where, for instance, boring for sample extraction can cause further spreading of pollution.

An alternative approach is to take proper account of the sequence of deposition of materials as well as their physical characteristics. The full identification of units within man-made ground can establish how pollutants may have entered, passed through and accumulated within these deposits. In addition to helping to establish inter-relationships between the pollutants and materials, this helps in
defining sources and mechanisms of pollution and allows more effective design of site investigation and sampling. It helps to guide investigations towards the most likely areas that have been polluted, with potential savings in the time taken, costs and risks.

This “Geo-Stratigraphical Unit Investigation Method” (Nirei et al., 2008) involves inspection of the geo-stratigraphic unit, chronological unit and material unit where pollution originates. This approach investigates the physical properties of the pollutants as well as the relationship between chronological units and material units to determine the source and mechanism of pollution. The method requires close attention to unit boundaries as well as depositional structures within geo-stratigraphical units. It establishes interrelationships between pollutants and depositional units, and, ultimately, pollution sources and mechanisms. But a well defined terminology is required for this approach.

Proposed terminology for man made strata

A stratum is a natural accumulation of particles such as gravel, sand, silt or clay. The hierarchial terminology for describing natural strata is well established through international agreement as the fundamental basis for describing, interpreting and evaluating geological phenomena. The hierarchy includes groups, formations, members and beds, with some beds consisting of individual laminae. The system is defined in terms of differences in composition and chronology of strata. Some units may be isochronous while others are, to a greater or lesser degree, diachronous including various associations of materials that are referred to as facies (Salvador, 1994). But no stabilised, and internationally agreed, terminology has been developed, as yet, for anthropogenic deposits.

Man-made strata are often regarded as too randomly deposited and inter-mixed to be classified into a hierarchy. But that is not always so. These deposits are often formed of a material deposited in one or more stages or a group of materials deposited in several stages. Materials and stages can sometimes be identified through historical records but can also be identified during site investigations. It is important to use terms for each stage in a proposed hierarchy that do not duplicate terms used for natural strata. Therefore, the following terminology is tentatively proposed (Table 1):

a) chronological or chrono-layer – materials laid down in a single action of deposition by one or more people at a specific time; and
b) material layer – consisting of a particular material laid down in one or more depositional events.

c) a “bundle” consisting of a number of adjacent, but not all of, an association of chronological layers; and
d) an “association” consisting of the whole assemblage of units within the body of man made strata present at the site.

The use of these terms is shown diagrammatically in Figure 1.

Figure 1 Diagram illustrating the relationship between chrono- and material layers in a man-made deposit. In this example, concrete or slag grains containing Cr6+ are confined to A3 of the materials layer (chrono-layer 3) rather than throughout chrono-layer 3 or through all deposits of material A. Knowledge of this could limit the need for site investigations and remedial action.

Examples leading to the basis for the terminology

The site of a factory built on reclaimed land bordering Tokyo Bay was investigated to establish the distribution of dense non-

Table 1. Proposed classification of man-made strata in terms of chronological and material layers

| Association | Bundle | Layer |
|-------------|--------|-------|
|             | 3      |       |
|             | 2      |       |
|             | 1      |       |

For example, a continuous borehole core showing the distribution of DNAPLs, such as perchloroethylene (PCE) and trichloroethylene (TCE), in reclaimed land bordering Tokyo Bay. The Jinji Unconformity is the term used in Japan for the boundary between man made and natural deposits.
aqueous phase liquids (DNAPLs), notably solvents such as perchloroethylene (PCE) and trichloroethylene (TCE), and the occurrence of solid wax associated with VOCs. A continuous core was retrieved (Figure 2). This established that DNAPLs accumulated above a fine grained layer within the association of man-made deposits and that the concentrations of PCE and TCE varied with depth depending on the big grain of the solid wax (Figure 3).

Examination of rural paddy fields in a lowland area near Tokyo established that slag and concrete grains with high Cr\textsuperscript{6+} concentrations had been carried into the area from a chromium metal refinery (Figure 4a). These were distributed through a number of adjacent chronological layers (bundles).

An old quarry at Rokkoh Upland, Itako, is an important experimental site for the study of the spatial and chronological relationships between materials during various phases of controlled tipping (Figure 4b) thus a number of adjacent chronological layers (bundles) could be observed directly in relation to the nature of the material layers (Figure 4c).

More generally, the distribution of solid pollutants within a single chronological layer in an old infilled quarry is shown diagrammatically in Figure 5. Figures 6 and 7 demonstrate how migrating liquid contaminants may accumulate at the base of a material layer, because of contrasting porosity, cross-cutting the depositional chrono-layers.

A clear understanding of such relationships can significantly aid site investigation and evaluation and the design and implementation of timely and cost-effective remedial work.

**Conclusions**

Careful definition and description of sequences of deposition of man made strata through the “Geo-Stratigraphical Unit Investigation
Method” helps to establish boundaries between units that are crucial to the investigation of the dispersal and accumulation of geo-pollutants and provides a foundation for improved planning of strategies for investigation and remediation. But this requires a sound terminology for chronological and materials layers at these sites. The proposed terminology is commended for wider discussion.

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