# Interpretation, description and representation of anthropogenic deposits.

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**Abstract.**

The term Anthropocene Epoch was introduced by Paul Crutzen in 2002. Whilst deposits of the Anthropocene might be deemed to include post-Holocene, naturally occurring sediments deposited in unique energy environments that are attributed to human impacts, another component of the Anthropocene Epoch, should this term be adopted, is that of anthropogenic deposits. These deposits occur between the ground surface and the point where the “real” geology begins. This zone has hitherto been largely ignored by geologists. It is generally categorised using broad classifications, such as made, worked, landscaped, or disturbed ground. The greatest resolution being applied in terms of its contaminating potential, yet it is this zone that is first encountered in the majority of developments. Anthropogenic deposits can be described materially, in a variety of ways including “grain composition” and “grain-size” characteristics with its mass characterised by varying degrees of heterogeneity (represented by grain size distribution) and structure. Buried infrastructure, or buried transport routes offer the potential to impose a mass structure on anthropogenic deposits, whereas waste might be characterised as heterogeneous and structureless. In this context understanding the palimpsest of earlier heritage and industrial development, including former transport routes and foundations, as well as earlier industrial and social archaeology becomes important in the characterisation of the anthropogenic deposits. This paper introduces a number of approaches to the description and classification of anthropogenic deposits and aims to demonstrate how integrated regional desk studies and the development of conceptual understanding,

hosted in the 3-D modelling environment, can facilitate greater understanding of what this volume really represents. Many of these aspects have been incorporated in a number of the British Geological Survey urban research projects (focused on London, Glasgow, Manchester, Warrington and Liverpool), aspects of which have been described here to exemplify this work. One of the key challenges of this research lies in the integration of the individual concepts in the context of an *urban earth observatory* to observe, monitor, model and apply anthropogenic processes and their impacts.

**Introduction.** In 2002, the Nobel Prize-winner Paul Crutzen introduced the term Anthropocene Epoch to reflect the human domination of once natural processes, including atmospheric chemistry. This has led to considerable discussion amongst geologists not least of all because of the connotation of the term Epoch. However, there is broad support for the adoption of this term as presented by members of the Stratigraphy Commission of the Geological Society of London in Zalasiewicz et al. (2008). The reason for incorporating the term into the Geological Time Scale is based on the recognition of the wide-ranging effects of anthropogenic influences on stratigraphically significant parameters such as: global atmospheric composition and temperature; cryosphere stability, and ocean chemistry, which are reflected in biodiversity and sedimentation trends. There are also more direct human impacts on the form and chemistry of Anthropocene stratigraphy, which takes the form of human sedimentation (archaeological and industrial waste and construction materials) and disturbance and redistribution of materials in the zone between the ground surface and the point where the "real" geology begins. This zone can be considered a shallow 'Zone of Human Interaction'. Until relatively recently it has been poorly characterised. Generally classified as made, worked, infilled, landscaped, or disturbed ground this zone is usually categorised in very broad terms, commonly with the greatest resolution being applied in terms of its contaminating potential, yet it is this zone that is first encountered in the majority of developments and it offers the potential for significant variation in material properties (grading and consistency). Over the last fifteen years the British Geological Survey (BGS) has increasingly focused attention on the description, classification and representation of made ground. This is particularly relevant in the context of 3-D modelling, which allows model specific attribution of the made ground and the volume representation provides further clues on the physical properties and understanding of the anthropogenic processes of this zone. Douglas and Lawson, (2001) highlight the geological and geomorphological significance of anthropogenic processes. They estimate that on a global scale, the deliberate removal, transport and deposition of material from mineral extraction is 57 000Mt (megatons)/yr compared to 22 000Mt/yr transported by rivers. The 3-D characterisation of the physical sedimentological and geomorphological impacts of anthropogenic processes provides a framework for monitoring and quantifying the magnitude of human impact on the landscape and its subsurface.

**Description of anthropogenic deposits.** The BGS favours a genetic approach to mapping and modelling artificial ground (McMillan and Powell, 1999, Table 1, Ford et al, 2006), which is described further below. Although McMillan and Powell (1999) make specific reference to the potential for describing fill, made ground and waste using published documentation: DoE (1993), European Waste Catalogue (1993; subsequently updated in January 2002) and DETR/EA (1998) they do not provide guidance on the description of made ground. These descriptions are primarily focused on knowledge of the composition of the waste (an equivalent of grain type), which is currently not captured in broader descriptions of anthropogenic deposits. A key factor in terms of the behaviour of artificial ground is an assessment of the organic component. The organic component may be both naturally occurring, e.g. river dredgings, or peat, or artificially introduced, e.g. placement of organic wastes. This is one of the aspects considered by BS EN ISO 14688-1 (2002, which replaces BS 5930, 1999) in its guidance on the description of anthropogenic deposits (Made Ground, distinguished between fill [controlled placement] and reconstituted ground [uncontrolled placement]). BS EN ISO 14688-1 (2002) recommends good descriptions of proportion, condition and type of the components in the made ground and that natural materials in the made ground should be described in the same level of detail as naturally occurring deposits. Whilst this does not currently directly inform BGS mapping, it is a standardised approach, which has a significant following and provides practitioners with a better understanding of the anticipated ground conditions.

**Table 1: BGS Classification of fill, made ground and waste (McMillan and Powell, 1999).**

| Category | Definition |
|---|---|
| Made ground | Areas where the ground is known to have been deposited by man on former, natural ground surface: road, rail, reservoir and screening embankments, flood defences; spoil (waste) heaps; coastal reclamation fill; offshore dumping grounds; constructional areas (land raise). |
| Worked ground | Areas where the ground is known to have been cut away (excavated) by man: quarries, pits, rail and road cuttings, cut away landscaping, dredged channels. |
| Infilled ground (formerly termed “Worked Ground and Made Ground”) | Areas where the ground has been cut away (excavated) and then had artificial ground (fill) deposited: partly or wholly back-filled workings such as pits, quarries, opencast sites; landfill sites (except sites where material is dumped or spread over the natural ground surface; see land raise). |
| Landscaped ground | Areas where the original surface has been extensively remodelled, but where it is impractical or impossible to separately delineate areas of worked (excavated) ground and made ground. |
| Disturbed ground | Areas of surface and near-surface mineral workings where ill-defined excavations, areas of man-induced subsidence caused by the workings and spoil are complexly associated with each other, for example collapsed bell pits and shallow mine workings. |

Although implicit in BS EN ISO 14688-1 (2002) discrimination between fill and reconstituted ground neither this approach, nor the genetic approach specifically considers the “structure” of the anthropogenic deposits, which can be important in the interpretation of fluid pathways, albeit that this may be captured where made ground is subdivided. 3-D modelling provides one tool to characterise the distribution and geometric structure of artificial deposits and excavations.

**Classification of anthropogenic deposits.** The BGS genetic hierarchy for artificial (made ground) was outlined by McMillan and Powell (1999). It comprises the major categories mapped by BGS: worked ground, made ground, infilled ground, landscaped ground and disturbed ground (Table 1). These categories lend themselves to further subdivision and an enhanced classification of artificial ground was proposed by Ford et al. (2006), which provides two further levels of resolution and provides further genetic detail, as in the example of made ground (Table 2). This level of interpretation, which may also draw upon information from the National Land Use Database land classification scheme (ODPM, 2006), provides the practitioner with useful, but implicit information with respect to the level of engineering associated with the made ground. This can be important in the context of proposed redevelopment, especially when modelling potential flow paths in the context of groundwater recharge, or contaminant migration.

Other types of classification may be required for specific applications, e.g. zoning of contaminated ground for scheduling remediation; generating hydrogeological domains for modelling aquifer recharge to assist decision making for groundwater management and aquifer vulnerability (Ball et al., 2004; Lelliot et al., 2006) and scheduling earth movements for engineering purposes.

**Table 2: Example of the enhanced classification of artificial ground proposed by Ford et al. (2006).**

| Class | Type | Unit |
|---|---|---|
| MGR<br>Made Ground<br>(Undivided) | MBU<br>Engineered embankment<br>(Undivided) | MBRO<br>Road embankment |
| | | MBRA<br>Rail embankment |
| | | MBFL<br>Flood defence embankment |
| | | MBRV<br>Reservoir embankment |
| | | MBSR<br>Screening embankment |
| | | MBSE<br>Sewer outfall or raised pipe embankment |
| | | MBDA<br>Dam or barrage |
| | | WMCY<br>Opencast (colliery) |
| | | Etc. |

**Modelling of anthropogenic deposits in the context of the BGS Urban projects.** The specific classifications of anthropogenic deposits required for applied research can be readily hosted by 3-D modelling, because it is underpinned by a borehole framework that can be coded according to the required output, providing the material description supplied in the borehole logs is sufficiently detailed. Accordingly, research in urban areas within BGS, has focused on 3-D geological modelling and development of approaches to the classification of anthropogenic deposits, as exemplified in the descriptions of the UK Lower Mersey (Liverpool, Warrington and Manchester) and Thames Gateway models.

In the Thames Gateway, an area where groundwater is a particularly valued potable resource (80% of the total public water supply in southeast England is derived from groundwater (Lloyd et al., 1998), recharge considerations were prioritised. The approach that was adopted built on the domain approach to recharge, whereby superficial deposits are grouped according to their sequences of hydraulic properties in terms of aquifer recharge or vulnerability (Lelliot, et al., 2006). Although much of the urban environment is covered by hard surfacing (protecting aquifers from potential contaminant migration, whilst minimising recharge over significant areas of the urban/ peri-urban environment), in areas of soft landscaping it was possible to classify the anthropogenic deposits in terms of their potential permeability with a view to integrating the anthropogenic deposits with the hydrogeological domains. The variable quality of the logging of the boreholes used in the development of the Thames Gateway model was such that only a relatively simple classification, based on grading as a proxy for hydraulic conductivity, could be applied.

In the Manchester, Warrington and Liverpool models emphasis has been placed on the use of historical data to inform 3-D modelling. In particular, mapping and borehole information has been supplemented with the interpretation of information obtained from the comparison of historic Ordnance Survey maps and the implication for the nature of the made ground, e.g. voids identified on historic maps that are not evident in subsequent maps suggest the occurrence of infilled ground. By applying these techniques it has been possible to capture the courses of transport routes, including the Manchester Ship Canal, and its relationship to the infilled former course of the River Irwell, prior to the construction of the canal. This 3-D approach offers benefits in predicting zones of potential gains, or losses of water to and from the canal (Lelliott et al., 2006) and former courses of stretches of the River Mersey (Figures 1 and 2). This offers the potential for understanding preferential flow paths, which is comparable at different scales with the influence of buried valleys (a domain identified in the hydrogeological domains of a Doncaster to Retford study, Price et al., 2008), or the trenches associated with buried services (considered in the Knowsley Industrial Park Study, Liverpool (Price et al., 2008).

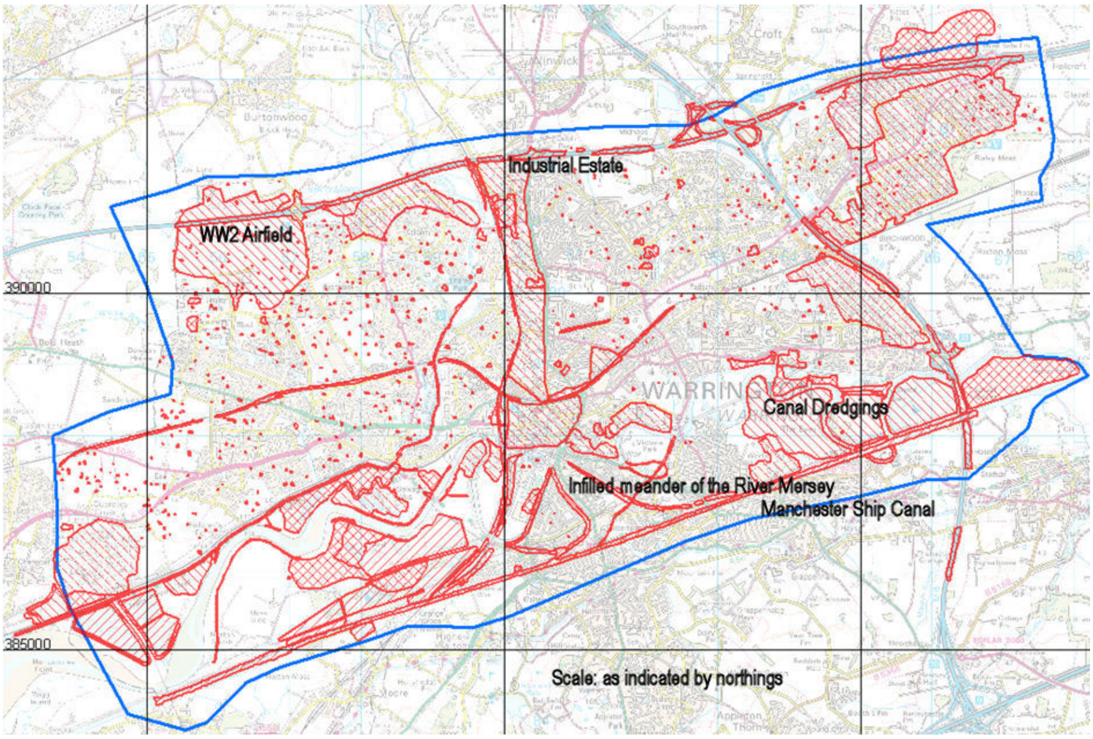


**Figure 1: Anthropogenic deposits in Warrington, including an infilled former meander in the River Mersey, Warrington (OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010).**

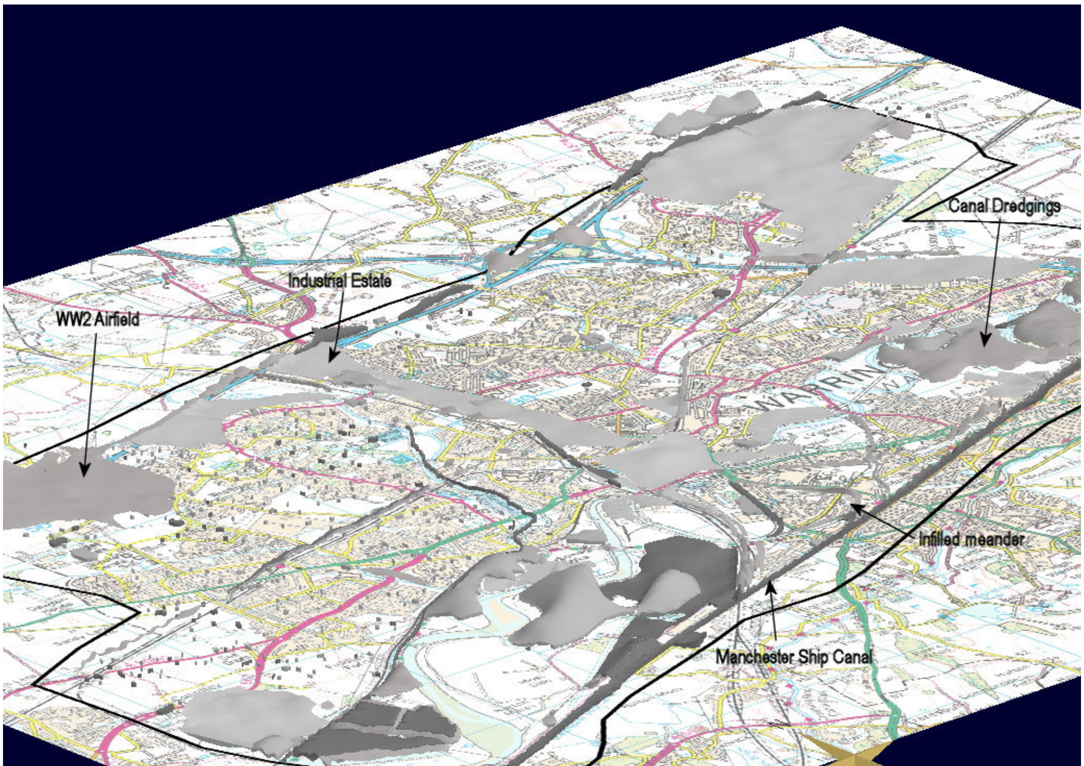


**Figure 2: Warrington; 3-D Model of the Anthropogenic deposits. (Scale as indicated by the 1 km grid on the base map) [OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010].**

**Discussion and conclusions.** The development of 3-D models of anthropogenic deposits is ongoing at the BGS. It is clear that there are numerous potential applications at a range of scales. 3-D modelling offers the potential for more detailed interpretation, e.g. in informing urban hydrology and zoning contaminated land for remediation, or in terms of historical and archaeological landscape change (de Beer et al, 2010). For example, focusing on the industrial history of Warrington it has been possible to commence an interpretation of the potential distribution of contaminants based on the: types of industry; the evolution of industry, e.g. small to large-scale engineering; age of the industry; responding growth of the town (e.g., Boscow, 2006), and regulation of industry. Informed by industrial archaeology there is the opportunity to consider associated foundation designs, which contribute to an interpretation of the potential depth, nature and form (engineering properties and contaminant distribution) of the associated anthropogenic deposits. Thus 3-D modelling offers the potential to build a number of classifications according to age, engineering properties, potential contaminants, or potential flow paths.

One of the key advantages of 3-D modelling of anthropogenic deposits is the introduction of the structural component that is associated with the provision of the detail and volumetric constraints derived from a number of sources, including the overlaying of historic maps. This is potentially valuable in terms of segregating materials requiring remediation and interpreting potential flow paths for hydrogeological and engineering applications.

The flexibility offered by 3-D modelling at a variety of scales increases the potential array of engineering applications, for example it is possible to model earthworks movements at the scale of the installation of a range of infrastructures from the scale of new transport routes to that of urban drainage schemes, as exemplified in the area of Knowsley Industrial Park study (Price et al 2008).

Descriptions of anthropogenic deposits underpin the 3-D modelling and ultimately the resolution of the models reflects the quality of the logging. Adherence with BS EN ISO 14688-1 (2002) could bring huge benefits to the development of 3-D modelling.

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