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2.8 BGI on minerals sites

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Abstract

Former mineral extraction sites are a legacy of The UK's varied geology and industrial history. Together with current operations they offer significant opportunities for formal or informal provision of BGI. Many, such as for construction materials and major infrastructure developments are close to or within expanding urban areas. Mineral sites may naturally cluster and interconnect via former haul roads or mineral railways, providing the connectivity at a landscape scale which is critical to their functionality as BGI. Increasingly they are recognised as a unique opportunity to compensate for habitat loss and address biodiversity goals at landscape scale.

The process of creating BGI on former mineral sites is analogous to natural colonisation and succession and there are already well-establish protocols for direct restoration to woodland. The longevity of mineral extraction favours both natural regeneration and seclusion for species, but site conditions may be challenging for habitat creation and any mandated net gains in biodiversity. However, the economic value of minerals resource extraction provides possible funding and leverage through planning towards BGI creation. The key stages for BGI on mineral deposits are described, then case studies are suggested. Permanent woodland and increasing soil carbon stocks could both help to deliver Net Zero.

2.8.1 Introduction

The UK has numerous current and former mineral extraction sites, reflecting its wide-ranging geology and long history of resource exploitation and related industrialisation. These include quarries for limestone, ironstone, chalk or hard-rock aggregate, pits for clay, sand or gravel extraction, historic metal mines, industrial mineral pits or mines, opencast coal sites or deep coal mines and their associated spoil tips. As surface features these can range in scale from a single shaft or borrow pit (an area where material has been extracted for use at another location) to former open cast coal mines or quarries spanning several hundred hectares. Historic sites (pre 1948 in UK) or orphan sites (those without a current owner (UNEP, 2001)) may have been abandoned largely without decommissioning work. However, a key function of current mineral planning is to ensure that restoration occurs to allow for a suitable future use and so avoid sites becoming derelict or unuseable without further treatment following extraction of the mineral resource. This restoration has largely been for agriculture in the past, but modern planning processes can both facilitate the implementation of blue-green infrastructure (BGI) and require specific approaches to deliver the blue or green elements that are agreed.

The close association between population centres, industrialisation and resource extraction means that many former mineral extraction sites are close to or within expanding urban areas, offering potential opportunities for formal or informal provision of BGI. Due to the extractive nature of their origin, many are now represented by voids, or negative relief features (i.e. concave landforms, lowering of original ground levels), offering shelter for wildlife, natural water habitats, recreational or watersport facilities. Conversely, spoil heaps from underground workings for coal, ironstone or industrial minerals offer positive topographic features (i.e. convex landforms, raising of original ground levels) in the landscape. Some former mineral extraction sites provide an important scientific and/or educational resource in their own right, with notification as Sites of Special Scientific Interest or as Regionally Important Geological sites contributing to geodiversity as a related benefit.

A feature of many mineral sites is that they are spatially associated with others of the same type, due to the lateral extent of many geological resources. For example, sands and gravels may be extracted intensively in adjacent areas of a suitable river flood plain. Coal sites and former deep mines are concentrated in coalfields where the productive coal seams outcrop or subcrop beneath covering strata. When combined with former haul roads, mineral railways and wagonways, mineral sites may naturally cluster and interconnect, providing the potential for BGI connectivity at a landscape scale, which is critical to its functionality (Hysa, 2021). For former coal mines in particular, population distribution, industrial development and dereliction often closely follow the patterns of resource extraction, providing a target community for consultation as likely beneficiaries of prospective BGI projects and initiatives.

Historically, mineral workings were often used for uncontrolled waste disposal, without any capping, so often contain unknown fill and made ground (i.e. where the pre-existing land surface is raised by artificial deposits). Former mineral extraction voids were commonly used as modern engineered landfills. However, this reuse option has declined since the 1990s due to increasing levels of waste recycling and energy recovery, presenting an increasing opportunity for retrofitting BGI, including nature-based approaches (IUCN, 2016), or passive C capture and storage (Washbourne *et al.*, 2015).

Common issues for most sites are a lack of soil resources, due to removal, disturbance or contamination. Dereliction or abandonment may have allowed for uncontrolled waste disposal, fly-tipping or antisocial behaviour. Conversely, on sites which have been disused for long periods natural regeneration may have allowed colonisation by protected species (e.g. great crested newts) or extremophiles (i.e. an organism that is tolerant to environmental extremes and that has evolved to grow optimally under one or more of these extreme conditions). The presence of these may have, in turn, resulted in sites being designated for their nature conservation values, for example, as the priority habitat, Open Mosaic Habitats on Previously Developed Land (BRIG, 2011), Sites of Specific Scientific Interest (SSSIs), nature reserves, or other features requiring preservation and future incorporation, such as mining relicts representing historic monuments.

Box 1 Major challenges for establishing BGI on mineral sites (modified from Moffat, 2015).

- Lack of soil/soil-forming materials
- Engineered topography -overly steep (gullying) or shallow (water-logging)
- Poor soil quality – disturbance/compaction/poor structure or texture, low organic matter & nutrient content, extreme pH, geogenic contaminants
- Hydrology – lack of drainage, infiltration or storage capacity, leading to droughting or flooding
- Physical challenges – excessive exposure to wind, surface temperature variation, snow accumulation, surface water flows
- Ensuring safe public access – highwalls, settlement lagoons, deep water, unguarded drops, mine shafts
- Relicts of historic structures, historic monuments, industrial archaeological value or cultural significance, geological or botanical SSSI status

In contrast to many other target areas covered in this handbook, BGI on mineral sites in the UK is inherently achieved through retrofitting (i.e. following resource extraction), although this may increasingly be envisaged at the resource extraction planning stage. This means that the location is predetermined by that of the mineral resource, which in turn dictates the opportunities and issues for BGI through the nature of the resource and the requisite means of extraction. The range of scale, type, age and complex history of former mineral extraction sites means that there is no “one-size-fits-all” solution to their reuse for BGI. Indeed, mineral extraction typically creates a series of serious challenges for subsequent installation of BGI in terms of the requirements of the biological components that need to be installed (Box 1). However, using typology (i.e. a classification according to general types or characteristics), case studies and exemplars a generalised range of issues and steps can be identified. Common BGI types which may be included in former mineral workings include aquatic or wetland features for sediment stabilisation, SUDs and contaminant attenuation, recreation or conservation, public open space for recreation, cultural and aesthetic ecosystem services, nature conservation, biodiversity enhancement, forestry or amenity woodland, carbon capture and management supporting Net Zero goals.

2.8.2 Development of UK mineral workings, management and relevant planning policy.

Widespread mineral extraction has taken place in the UK since pre-Roman times, then increasing in scale and impact exponentially during the industrial revolution. Production of mineral ores peaked in the 18th and 19th centuries. In contrast, maximum coal production was in 1914, declining steadily through the 1940s and 50s, in spite of widespread mechanisation and much larger scale mine development, then falling more rapidly from the 1960s to the present day. The UK's last deep coal mine, Kellingley, closed in 2015, with a handful of opencast sites remaining after this, although there is an ongoing application to open a new deep mine in Cumbria. UK aggregates production rose steadily in the post-war period, tracking construction activity, to a peak in 1990, as did several industrial minerals, whereas extraction of brick clay and limestone or chalk for cement declined slowly from the 1970s (UK Minerals Forum, 2014). In 2019, onshore mineral extraction of 196.9 x 10^6 t was dominated by crushed rock (66 %) and other construction materials (28 %) (British Geological Survey, 2021b). The extent of mineral extraction in the UK can be gauged by the 3300+ entries for active, inactive and dormant mines/quarries currently held by the British Geological Survey's BritPits GIS database (British Geological Survey, 2020), with >230,000 records in the full database including historic sites and mineral occurrences. Meanwhile, the Coal Authority has over 170,000 mine entrances recorded in the National Coal Mining Database (Coal Authority, 2014). Abandoned former mine workings are a global issue, with the term orphan mine applied to abandoned sites where no known or living owner exists and responsibility defaults to the state (UNEP, 2001). Legacy mine land includes orphaned, abandoned and derelict land (Worrall *et al.*, 2009). Abandoned mine lands are often included with other "marginal" land types (Mellor *et al.*, 2021), such as brownfields.

Given the longevity and extent of UK mineral extraction, it is perhaps surprising that until 1981 there were no formal requirements for restoration of former mineral workings. However, various sector specific acts existed prior to this date, with more limited powers. The Mineral Workings Act (1951) provided financial assistance, through the Ironstone Restoration Fund, for the restoration of derelict open-cast ironstone sites to agriculture, primarily by government departments and on sites where this land use had not been profitable at the time (Bradshaw and Chadwick, 1980). Similarly, the Mines and Quarries Act 1954 and Mine and Quarries (Tips) Act 1969 set out requirements for the safety of waste tips including fencing and stability respectively but not for the restoration of mineral extraction sites or their wastes. The difficulties restoring wastes from coal, metal or china clay extraction to viable agricultural uses meant that many sites remained abandoned, culminating in an estimated 21,800 ha of derelict land in England associated with mining activities in 1974 (Wickens *et al.*, 1995). The Control of Pollution Act 1974 required a systematic approach to the disposal of household, industrial and commercial waste but did not apply to wastes from mines or quarries.

The Town and Country Planning (Minerals) Act 1981 introduced a formal requirement for reclamation for all current sites with planning permission dating back to 1948. This included a restoration strategy, encompassing all stages of reclamation: soil stripping and storage, restoration (e.g. regrading, placement of soils, topsoil or soil-forming materials) and after care. The after-care period, typically five years post-restoration, included drainage, cultivation, planting, fertiliser additions and ongoing maintenance (DoE Welsh Office, 1989). The three specified after uses were: agriculture, forestry and amenity, although others, including landfill waste disposal and development, were possible via a separate planning consent. The subsequent Derelict Land Act 1982 included

Derelict Land Grants which provided between 50% and 100% of the costs of restoration of abandoned sites by local authorities and other organisations. Between 1974 and 1993 this had led to restoration of 31% of derelict land from mineral extraction in England (Wickens *et al.*, 1995) and similar action on 61% of sites in Wales (Perry and Handley, 2000). The evolution of minerals planning guidance on the reclamation of mineral workings first added nature conservation as part of the increasingly broad range of amenity end uses, including open grassland, country parks, informal recreational areas, conservation of landscape, natural features and wildlife, basic preparations for more formal sports facilities, amenity woodland, and water areas (Department for Communities and Local Government, 1996). However, most restoration in the post-war period (with figures given for example for 1982-94 in England and Wales) favoured agricultural end uses (58%) over amenity (26%) or forestry (5%) (Perry and Handley, 2000). Generic nature conservation featured as a small component of the amenity end uses. Meanwhile the potential biodiversity value of UK mineral sites was increasingly recognized (Davies, 2006). In 2006 it was estimated that efforts aimed at only 412 of a total of 1,300 mineral sites in England, those lying within 1 km of nine priority habitat types, would be able to deliver the existing UK Biodiversity Action Plan habitat creation targets for 7 of the 10 priority habitats. With over 64,000 ha then under planning permission for active mineral working, concerted action at landscape scale could address the fragmentation of existing habitats and future challenges such as climate change. More recent guidance (Department for Levelling Up, Housing and Communities and Ministry of Housing Communities & Local Government, 2014) now specifically includes the creation of new habitats and biodiversity as a separate form of after use, alongside the requirements for mineral planning authorities to safeguard resources while considering the sustainability, economic and environmental impacts of extraction (Ministry of Housing Communities & Local Government, 2021; Scottish Government, 2021; Welsh Government, 2021). In England plans for a Nature Recovery Network have recently been confirmed (*Environment Act 2021*, 2021; DEFRA, 2021).

In parallel to planning policies, the environmental regulation of mines, quarries and other mineral extraction industries now follows that of other industrial wastes management following introduction of the Mining Waste Directive (EC 2006). It applies only to wastes generated at a prospecting, extraction or treatment site operational after 2008, excluding imported or exported materials for landfilling or reuse. Article 10 required the placing of extractive waste back into the excavation void, where stable and pollution of soil and water can be avoided, with appropriate monitoring thereafter. However, the definition of mining waste facility excludes the backfilling of the extraction void for the purposes of rehabilitation and construction from the scope of the Directive. Thus unsaleable excavated materials are not considered as “waste” due to their future use for reclamation purposes and are not subject to Landfill Tax. The Directive also required the regulator to prepare and maintain by 2012 a publicly available list of closed mining waste facilities (including those that have been abandoned) which were causing serious pollution or had the potential (in the medium or short term) to be a serious threat to human health or the environment (DEFRA, 2010). Prior to 1999 permitting water from an abandoned mine to enter controlled waters was excluded from being an offence under the Water Resources Act 1991 in England and Wales, or Control of Pollution Act 1974 in Scotland (Johnston *et al.*, 2008).

In conclusion, due to the longevity of many mineral extraction activities, historical precedents and evolving legislation, a variety of site conditions and restoration standards may be encountered on parts of mineral sites, many of which were operational until very recently. However, the scale and distribution of UK mineral workings is increasingly recognised as a uniquely important opportunity to compensate for habitat loss for other reasons and so to address biodiversity goals at landscape scale.

2.8.3 Typology of UK mineral sites (Table 2.8.1)

2.8.3.1 Coal

The UK's coal and associated iron ore deposits kick-started the Industrial Revolution, powered the British Empire's manufacturing and transport sectors, and coal was still responsible for three-quarters of electricity production as late as 1994 (British Geological Survey, 2010). This has fallen dramatically in recent years but coal remains an important feedstock for many industrial processes in the UK (British Geological Survey, 2021a). The economic and social importance of "King Coal" has shaped the demography and settlement pattern of several UK regions, including large areas of NE England, South Wales, Northern England and the Midlands (Table 2.8.1). This spatial association of coal mining and population is illustrated by the Coal Authority's estimation that one quarter of UK residential properties lie above coalfields. Although this is intended to illustrate the future potential of geothermal energy services from disused mineworks it might equally well apply to the distribution and potential ecosystem service delivery of mining sites above ground. Although the majority of colliery spoil heaps and pitheads have already been restored to some degree, the geotechnical challenges of ground stability, subsidence, settlement, combustibility and ground gases often make hard redevelopment challenging, while the shale-dominant materials, compaction, acidity, contamination, waterlogging/droughty and heavy, low fertility soils make for low grade agricultural use or forestry at best. Thus much previous restoration of former coal extraction sites has favoured amenity uses (29%), such as golf courses, country parks or community forests (Sinnett, 2019). Pre-planned, progressive restoration has allowed better restoration of open cast sites to agriculture (51%) and forestry (8%) often to original quality and addressing legacy impacts such as contamination, dereliction, coal residues and mining hazards. As early restoration was of poorer quality, has since degraded or lacked considerations of visual impact and relationship to the local landscape character, significant future opportunities exist for creating semi-natural habitat lost by development. This can include reworking and regrading of previously-restored older tips where coal contents may be >25%. Collieries were spaced at intervals linked by railways, while coal sites may be phased or extended, using haul roads or conveyors to railheads. Hence connectivity may be good and total area significant, with good access to local communities nearby.

2.8.3.2 Construction aggregates

Aggregates, including sand and gravel for concrete, roadstone, rail ballast and constructional fill, are the largest tonnage materials used by the construction sector, accounting for the bulk of UK mineral extraction (68% in 2017) (British Geological Survey, 2019). They are also the most widespread, with c.1400 active quarries in 2021, with crushed rock slightly exceeding sand and gravel sites. Although secondary by-products and recycled aggregates are now widely used (30% in 2017) and exempt from the Aggregates Levy (£2/tonne in 2021), the inherent downcycling means that higher specification uses still require primary aggregates. As a result exploitation is likely to continue in the UK, with overall demand linked to infrastructure and housing development. Aggregates are the lowest value materials transported by road, rail or sea, so transport is a high proportion of cost, requiring sustainable production to be close to the market. This is typically the peri-urban areas of major conurbations, possibly including green-belts, as they can provide strong BGI opportunities during restoration. The exception is high-quality aggregates for rail ballast or road wearing courses, which are naturally scarce in SE England where demand is highest. Hard-rock resources are naturally situated in areas of higher relief and potential landscape interest, while areas of Carboniferous limestone commonly overlap with landscape, amenity and ecological designations (see cement components), providing tensions for exploitation but opportunities thereafter. Thus future opportunities for BGI creation from aggregate extraction are widespread and significant, either through retrofitting or as the original aim of restoration.

All types of aggregate extraction involve removal of a bulk resource so the opportunities relate to the void space created, whether water-filled, or providing a sheltered, semi-enclosed space. Extraction, crushing, grading/washing and stockpiling areas are commonly arranged at sequential levels to use gravity to assist movement where possible to reduce energy use. Since aggregate extraction is a temporary use of land, albeit sometimes a protracted one, beneficial use after effective restoration can provide enhanced opportunities for habitats, biodiversity and geodiversity. This longevity of use, coupled with restricted access, may also lead to benefits during use, such as bird nesting sites on rock or sand faces, rock platforms, silt or water for colonising plants. As a result, many SSSIs and some Special Protection Areas and Special Areas of Conservation have been provided by quarrying, due to the range of habitats and ecological niches provided, corresponding to those lost or threatened by development elsewhere.

The type of aggregate resource largely dictates physiography, location, soil availability and conditions: sand and gravel wet pits can be allowed to flood to become artificial lakes or wetlands for amenity (e.g. watersports) or conservation, except near to airports, while dry pits can be recolonised to heathland or restored to agricultural use, amenity or forestry. The common lack of overburden or soil-forming material in both hard-rock and limestone quarries can make progressive restoration difficult, other than on quarry floors. Blasting and regrading may be required to address stability issues of working faces. Examples of direct amenity uses include hiking, cycling, horse riding, rock climbing (Baczyńska *et al.*, 2018), shooting ranges or motorsports. Wet quarries may flood providing water bodies for specialist amenity (e.g. diving, sailing, water-skiing), if accessible, or nature conservation. Education opportunities may be provided by the artificial rock exposures, alongside geological SSSIs, Regionally Important Geological Sites (RIGS) or other geodiversity benefits. The combination of hard or compacted surfaces with little soil and droughty conditions make dry quarries particularly challenging, with either low (hard-rock, sand and gravel) or high (limestone, dolomite) pH, and low nutrients. Natural recolonization may have occurred at older limestone quarries, with the conditions providing important habitats for rare or protected plant species such as gentians or orchids, or other wildlife refuges, although if unassisted this may take up to 50 years (Sinnett, 2019). On areas of best and most versatile (BMV) agricultural land, careful restoration after temporary sand and gravel working can provide equivalent or even improved land quality (Bransden, 1991).

2.8.3.3 Metal mines

The historic legacy of C19th non-ferrous metal mining and lack of restoration policy (see above) is a widespread distribution of relatively small disturbed and potentially contaminated sites across significant areas of Cornwall and Devon, the Mendips, North and Central Wales, Shropshire, the Northern and Southern Pennine Orefields, the Lake District and Southern Scotland. As is the case with aggregates, former metal mining areas are focussed in older, harder rocks in upland areas so often overlap with areas designated for their landscape or ecological importance. Processing and mining often used water power so these sites commonly have significant impacts on river catchment quality (Johnston *et al.*, 2008). Relatively few sites persisted into the C20th and all have now closed, other than three new gold mines or likely prospects (Cavanacaw and Curraghinault near Omagh in N Ireland and Cononish in the S Scottish Highlands) with one intermitantly operational open pit tin-tungsten mine now looking to reopen (Hemerdon, near Plymouth), and by-products from industrial minerals processing (Derbyshire) (British Geological Survey, 2015). However, exploration for base metals, gold and other metals continues in the UK, at greenfield and former mining sites (e.g. for lithium at the flooded South Crofty tin copper mine). Furthermore, the possibility of future exploitation of other supply-constrained “critical” or “e-tech” elements (e.g. Li, Co, Te, Se, Nd, In, Ga, heavy rare-earth elements) required for the green energy economy, cannot be ruled out. Metal mine sites are both technically challenging and costly to remediate to pre-mining condition, potentially favouring alternative uses involving BGI. Natural regeneration over extended timescales has, however, led to many historic mine sites now possessing significant biodiversity or botanical interest e.g. bats in underground workings, newts and toads in washing pools, metal tolerant higher plant species, mosses or liverworts (bryophytes) and lichens (Sinnett, 2019). Abandoned mine buildings and landscape features may also be of archaeological, cultural or geological significance (e.g. the Cornwall and West Mining Landscape UNESCO World heritage site (UNESCO, 2006), The North Pennines UNESCO Geopark (Global Geoparks Network, 2004). Opportunities for creating landscape-scale BGI from the existing networks of abandoned sites must be balanced against the challenges of the potential costs of maintaining historic structures, health and safety issues of mine-workings, potential human health and environmental risks of acidified or contaminated minewaters and soils (in common with some brownfield sites, see chapter 2.7).

2.8.3.4 Cement components

Cement kilns must be located where suitable limestone reserves are available, while utilising more widely available clay or mudstone. Due to the scale of capital investment in cement plants they require significant (>25 year) reserves of feedstock at high throughputs (up to 2.5 $Mt.a^{-1}$) with the bulk of the UK's c 10 $Mt.a^{-1}$ consumption still produced from about a dozen UK plants. The original wet process used the softer, waterlogged lower horizons of the Chalk in the Thames and Medway Basins. Technological improvements in grinding then allowed "dry" processing of the magnesium-poor Carboniferous or Jurassic limestone and a lower overall energy use. Over 25% of the Carboniferous Limestone resources lies within a National Park with a similar proportion of both the Chalk and Jurassic Limestone within Areas of Outstanding Natural Beauty (AONBs) or National Scenic Areas in Scotland (British Geological Survey, 2014). This illustrates the potential tension between conservation interests and the domestic supply of a critical component of concrete and mortar, both widely used in all construction sectors. Concerns over the significant greenhouse gas emissions from cement manufacture have prompted energy use reductions from efficiency gains, substitution of renewable or waste fuels, or partial substitution of Portland cement clinker with pulverised fuel ash (PFA), ground granulated blast-furnace slag or other natural pozzolanic (supplementary cementitious) materials in modern UK cement blends, potentially extending the life of current facilities.

As cement works are situated near limestone quarries to reduce transport and also require clay/mudstone extraction, the challenges and opportunities for restoration and BGI are similar to limestone quarries and brick clay pits respectively.

2.8.3.5 Brickclay workings

Various locally available brick clays and mudstones were once widely worked across the UK but declined due to replacement of common brick in internal walls (British Geological Survey, 2007). Current specifications and colour variants may require blending with transported clays, leading to isolated pits, especially in favoured lithologies, e.g. Etruria Clay.

Due to the impermeable nature of the lithologies, former brick, mudstone or fireclay pits may be used for engineered landfills, or to provide landfill capping materials. The challenges of acidity or sulphate contamination, waterlogging/droughty and heavy, low fertility soils are shared with coal sites, making for non-agricultural use or community woodland at best.

2.8.3.6 Borrow pits, spoil tips, habitat translocation & peatland restoration

Borrow pits, where material is extracted for use at another location, provide a cost and transport-efficient solution to balance the material management plan requirements for major infrastructure projects (e.g. High Speed 2) (HS2, 2017b). Road traffic impacts can be minimised by using temporary haul roads and back-loads. Thus in some locations suitable aggregate requirements may be met internally from excavated material within the development, without affecting aggregate supplies from local quarries, while minimising landfilling of unsuitable material and loss of landfill capacity. Typically, sands and gravels or cohesive clays are extracted and replaced with less suitable silty or soft clay materials in the borrow pit areas, so net impacts on hydrogeology and flooding must be considered. However, planned separate stripping and storage of topsoils and subsoils allows for restoration to near original conditions, possibly to equivalent or improved agricultural land capacity, including compensating for anticipated climate change effects. Restoration of hedgerows and field trees, pasture and water bodies to their previous or equivalent condition can be sought, including incorporating physical linkages, so as to maintain connectivity between these features where that previously existed, in order to preserve existing BGI. This can also provide further opportunities to improve biodiversity, such as by adding native species or reprofiling water bodies to favour protected species. This can support development projects in achieving targets of no net biodiversity loss or biodiversity net gain.

As some habitats, such as ancient woodland, cannot be recreated translocation may be an option (Buckley *et al.*, 2017). If loss is unavoidable, such as for HS2 (HS2 2017a), these must be offset by bespoke compensation measures instead, while still reported as a negative impact on irreplaceable habitat (Ministry of Housing Communities & Local Government, 2021).

Development on upland peatlands, such as in onshore wind farm construction, provides a special case of borrow pit restorations due to their fragility, carbon-storage and biodiversity value. For example, Scotland's peatlands store an estimated 3 billlion tonnes of carbon (Aitkenhead *et al.*, 2021). Declining use for horticulture or fuel and the implications of degredation for greenhouse gas emissions accounting now strongly favours reuse of the extracted material for peatland habitat restoration. Challenges include storage and maintaining the peatland ecosystem services after replacement, especially for carbon sequestration, coupled with habitat, water quality or storage, while avoiding geotechnical issues such as peat slides (EnviroCentre, 2011). Opportunities for BGI creation may come from using peat to dam drainage channels in degraded or previously drained peatland, or novel applications, such as wetland creation in construction borrow pits, or spreading over agricultural soils in heathland creation. For peatland ecosystems the challenge is to maintain water saturated, low nutrient and pH soil conditions unfavourable for higher plant and tree growth. Paludiculture, or the rewetting and productive use of peatlands, is now emerging as a potential future emission reduction measure (Ziegler *et al.*, 2021).

Table 2.8.2. Key ecosystem and energy service provision of UK mineral extraction sites in use and as restored for BGI.

2.8.4 How to create BGI on former mineral sites

The creation of BGI on former mineral sites is often analogous to the processes of natural colonisation and succession to woodland. The generalised protocols established for brownfield regeneration directly to woodland (Atkinson and Doick, 2014) might equally be applied to the creation of other green and open space or the particular instance of mineral site restoration to BGI[1]. The authors argue that the key to successful delivery is adequate planning and assembling a suitable project team. For woodland project sites or programmes of multiple sites they identify six key stages, which for mineral sites might include the following:

- Site selection (feasibility analysis, funding, partnership)
- Project initiation (proposal, site investigation, surveys)
- Design draft (design, consultations, permits, design refinement & consultation iterations)
- Master planning (specification of works, tenders & contracts, baseline monitoring)
- Site delivery (hard (engineering) and soft (planting) works, management plan)
- Site establishment (site handover, monitoring evaluation & maintenance)

These are accompanied by six ongoing core tasks: Administration, project management, health & safety, communications & engagement, sustainability analysis, monitoring and evaluation. They identify 10 technical disciplines and the same number of competences which may be required, in addition to a dedicated project manager. Other standard approaches to project planning could also be adapted to BGI development, such as PRINCE2, Six Sigma or the relevant aspects of the RIBA Plan of Work template (Royal Institute of British Architects, 2020).

2.8.4.1 Objective setting & stakeholder consultation framework

Before any consideration of technical challenges and approach, the first practical steps in restoring any former mineral site to BGI are likely to involve identifying relevant stakeholders and establishing a framework for their engagement and consultation, even before setting the high-level objectives for

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[1] In the UK definition brownfield land is that which was previously developed for non-agricultural purposes, so brownfield could be historic, unrestored mineral sites. However, the presumption of restoration for suitable use in modern mineral planning should mean these sites do not become future brownfields.

the scheme. These might include the site's land owner, the site operator where this is different, the mineral planning authority, local planning authority and contaminated land officer, the relevant environmental and other regulatory bodies (e.g. Environment Agency, Scottish Environmental Protection Agency, Natural Resources Wales, NatureScot, Natural England), relevant non-governmental organizations (NGOs, e.g. RSPB, the local wildlife trust), local residents and potential users of the scheme. Stakeholder engagement is now a consideration for corporate social responsibility and achieving a triple bottom-line balancing social, environmental and economic cost benefits, so mineral extraction companies are likely to have engaged with stakeholders during the planning and operational phase of the active site prior to commencing restoration. Community engagement is one of seven core considerations of the ISO26000 voluntary corporate social responsibility standard (BSI, 2020b). The underlying principle is that the stakeholders engaged have a genuine opportunity to influence the decision making process, especially about actions that could affect their lives or environment. Local communities may have different priorities for restoration, be it for amenity use, habitat creation, or preserving mining heritage (Sinnett and Sardo, 2020) and sufficient time and resources should be allocated to ensure these different perspectives can be considered.

2.8.4.2 Desk study

In common with any other brownfield development, a timely desk-based study before site investigation can save time and money by focusing resources towards key targets and salient information gaps. For example, historic map sets can quickly indicate the development of a site through time, working phases, areas of made ground, waste deposits or settling ponds, any earlier restoration stages, and so the likely context of and ambition for these. Commercially available desk study information packages will cross-check environmental information, such as statutory or other designations on site or in the hinterland, waste and licencing history. It is usual to start to formulate a Conceptual Site Model at the desk study and site reconnaissance stage which can then be used to guide future physical investigation (BSI, 2017, 2020a).

2.8.4.3 Site Investigation

Compared to that of a hard development, the emphasis of site investigation will tend towards identifying the extent and characteristics of soil-forming materials (i.e. for sub-soils and topsoils), rather than the geotechnical properties of soils and rocks for engineering purposes. For a soil resource survey, surface soil sampling, hand auger or hand-dug soil pitting may be suitable, accompanied by trial pits or window sampling, rather than cable percussive or rotary drilling. The exception to this will be for determination of groundwater levels and flow direction, requiring the installation of three or more standpipes or piezometers, which together with permeability or infiltration tests, topographic and surface hydrological surveys will be necessary when water features are planned.

A soil resource survey should consider soil-forming materials, which could be blended or amended with suitable and locally available waste materials (Bending *et al.*, 1999). Soil sampling should be directed towards the determination of both contaminant and nutrient status, in addition to more general physical-chemical measurements and particle size analysis for soil textural classification (ADHB, 2021).

- Organic matter is a key determinant and indicator of soil quality and contaminant bioavailability. Previously it was common to determine this directly in soils but the Walkley-Black procedure used hazardous chromic acid, so is generally replaced by elemental analysis of Total Organic Carbon and then calculation of organic matter by multiplying by a factor for the other contained elements. Loss on ignition can be used as an approximation but may be affected by incomplete combustion of some organic carbon, release of water from clays and the decomposition of some carbonate minerals.

- Many commercial laboratories offer suitable “waste-to-land” and “contaminated land” testing suites designed to determine the nutrient and contamination status of soils and potential additions, with suitable accreditation (Environment Agency, 2021; UKAS, 2021). These can be used to determine the nutrient requirements and contaminant loadings, depending on the intended planting type, so as to inform waste benefit statements for application of unrecovered waste materials through Environmental Permits (England and Wales) or Exemptions from Waste Management Licencing (Scotland). Both total nutrient concentrations and water-leachable or plant available concentrations of the major elements nitrogen, phosphorus and potassium may be required.

- For contaminated sites, such as former metal mines, contaminant levels should be compared to suitable screening values for human health risk assessment for an appropriate future land use scenario, such as the Suitable For Use Levels (S4ULs) for Public Open Space (Park) (Nathanail *et al.*, 2015). Certain phytotoxic elements such as copper, nickel or zinc may still limit plant growth at levels well below those of concern for human health risk assessment, especially at low pH. Trigger levels for the onset of phytotoxic effects on plants of boron, copper, nickel or zinc were originally given in ICRCL59/83 but this widely-used document was withdrawn by DEFRA in 2002 for human health assessment risk assessment purposes and these values have not been replaced. Recent soil screening values (SSVs) have been produced on behalf of the collective UK regulators to take account of new European Chemicals Agency data on soil ecotoxicology (Martin *et al.*, 2020). These are intended to screen out low risk activities from spreading waste materials to agricultural land, so would be unduly conservative for other restoration land uses and also lack values for As, Hg or Pb, which are key elements for various mineral deposit wastes, including coal, limestone, iron and non-ferrous metals.

- In addition, soil analyses may be compared to the two respective British Standards for subsoil (BSI, 2013) and topsoil (BSI, 2015) as guidance, including variants for low fertility, acidic or calcareous soils. However, it should be stressed that these are designed for natural and manufactured soils that are moved or traded for creating soil profiles, rather than those remaining *in situ*, which may possess a much wider range of natural compositions and should still remain suitable for use in restoration projects.

- Depending on the site condition, ecological surveys may be required, particularly if protected species, priority habitats or significant natural revegetation has occurred. Multi-disciplinary teams may require an ecologist, archaeologist, soil scientist, agronomist, landscape architect, forester or arboriculturist, depending on the site.

2.8.4.4 Design approach

The fundamental approach of land restoration is to apply ecological principles derived from natural ecosystems to develop soils and vegetation on anthropogenically disturbed substrates (Moffat, 2015). This approach has been the subject of extensive research since the 1970s (Bradshaw and Chadwick, 1980), with various guidance documents developed specifically for mineral sites (DoE, 1996b, 1996a) or specifically for metal mining sites (DoE Minerals Division, 1994). The generic challenges for different types of mineral deposit have been described above (2.8.2). Thereafter, the technical challenges are likely to be highly site-specific. However, in general, working in sympathy with site conditions is likely to produce better results. Soil availability and fertility are likely to be common limiting factors on former mineral extraction sites, so in practical terms this could mean selecting plants suitable for the soil or soil-forming material conditions on site, rather than for purely aesthetic or ecological reasons. Where new mineral extraction seeks to conserve soil resources on site, reference should be made to the best practice for soil handling and storage in the Code of Practice for the Sustainable Use of Soil on Construction Sites (DEFRA, 2009). Phased restoration can be planned to reduce soil storage times and its degradation.

Any existing water bodies are likely to require reprofiling to provide more gently sloping gradients and shallower areas than their original purpose might allow. For the intended creation of blue infrastructure after mineral extraction, an analogy can be drawn to the Working with Nature idea (PIANC, 2018) whereby win-win opportunities are identified at the planning stage rather than assessing and mitigating the likely environmental impact of a marine navigation intervention.

A similar approach is Nature-Based Solutions, which are defined as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2016). These are increasingly seen as a solution to balancing societal development goals with ecosystem resilience and service provision in response to global challenges and climate change. Given that in many areas mineral extraction sites are located in relatively close proximity there are opportunities for BGI to be provided at the landscape scale; reconnecting fragmented habitats and increasing ecological resilience. The design approach should therefore consider the landscape context and maximise connectivity between mineral extraction sites and other habitats.

2.8.4.5 Planning & approvals

The majority of BGI restoration projects will be deemed as an "engineering operation" by virtue of their earth-moving requirements and scale, so will require planning permission from the local planning authority as a "development". Possible exceptions to this might include the use of various organic wastes for agricultural improvement (e.g. waste-water treatment biosolids, non-product composts, paper de-inking sludges, composted organic fractions of municipal solid waste (Nason *et al.*, 2007; SNIFFER, 2010)) which would require environmental permits or waste exemptions (see 2.8.4.3 Site Investigation), although evidence that planning is not required may still be a condition here. Cascading of bioresources is a fundamental principle of the Circular Economy (Ellen MacArthur Foundation, 2019) but requires adherence to the relevant protocols and standards to adequate reduce environmental and health risks (Longhurst *et al.*, 2019). The deposit of any waste materials to greater height or area on land, even where they already exist, will also constitute a material change of use and so require planning approval. Work to extend or create a pool will require planning permission, together with the necessary permits and consultation and with the relevant water environment regulator (i.e. SEPA, Environment Agency, Natural Resources Wales). A general principle is that an early pre-application discussion with the planning authority and regulator is highly recommended as a way to scope out possible requirements and issues with the outline design. Site design is typically an iterative process but after formal planning approval flexibility is more limited and becomes a matter of how best to do it, not what is best to do.

2.8.4.6 Implementation

Although implementation methods will largely depend on the scheme, a common feature is likely to be the use of soil as a plant growing medium which requires particular methods to be adopted to avoid further compaction by machinery or to mitigate this widespread challenge in restoration sites. Introduced or transported soils should be loose tipped near to the working area and spread by a 360º excavator also working from the unamended area. Existing areas of compacted soils can be de-compacted *in situ* using the system of complete cultivation in which a 360º excavator systematically double digs trenches across an area with the excavated soil loose tipped from the bucket. Amendments can be incorporated at the same time and extensive practical guidance is available on this and other best practice (Bending *et al.*, 1999; Welsh Assembly Government, 2004; Forest Research, 2015). Loose tipping is now preferred to replacing soil with an earthscraper, or to ripping with tines and bull dozer, as it minimises soil compaction and the consequent impacts on soil structure, root penetration, infiltration and erosion.

2.8.4.7 Aftercare & maintenance

Good design, technical implementation and appropriate naturalistic planting schemes should minimise future maintenance requirements for BGI. However, establishment will be a long-term, dynamic process, likely taking several decades for tree species. The cost of maintaining widespread greenspace has been raised as a societal challenge, largely as many sites will be in public ownership (Moffat, 2015). Some capacity for future management must be included in the financial planning arrangements as revenue budgets, in addition to the availability of the capital budget which initially led to creation of the scheme, especially where this is grant funded or by application to a specific regeneration initiative. In this respect the previous commercial operation and mineral planning process give former mineral extraction sites an advantage over orphan mine or derelict brownfield sites, although the lack of revenue from other end uses has previously favoured agricultural restoration (Davies, 2006).

2.8.5 Case studies (see Figure 2.8.1)

In view of the wide range of mineral extraction sites, their varied history, landscape context and intended afteruse for BGI, a series of case studies have been identified as inspirational examples. In each case the site location details are followed by a summary of the resource extraction, current use for BGI, the landscape context, connectivity and contribution to BGI infrastructure. A photograph of each is included in Figure 2.8.1. The site owners and operators are thanked for their help providing background information and the attributed photographs.

Little Orme Quarry, Penrhyn Bay, Conwy (former limestone quarry) SH 818 825
A 19th to early C20th limestone quarry used for steel, chemicals and cement it became a 2nd World War artillery training camp (*Historypoints.org*, 2020). It is currently an area of Public Open Space, crossed by the North Wales Coastal Path and providing access to Angel Bay for watching seabirds, grey seals and their pubs and occasionally dolphins. It connects with adjacent areas of limestone pavement and lowland calcareous grassland with SSSI and SAC designations on Little Orme and the Rhiwledyn Nature Reserve, managed by the North Wales Wildlife Trust.

Diaspora Gardens, Heartlands, Redruth, Cornwall (former metal mine) SW 668 412
Part of the former South Crofty metal mine site has been used to create the Diaspora Gardens, a name reflecting the global influence of Cornish mining technology through C19th emigration. Planting of the previously contaminated site reflects these destinations, forming an area of public open space, part of the Heartlands redevelopment, celebrating Cornish heritage and Culture (*Heartlands*, 2021) with the Robinson’s Shaft and Cornish engine house at its centre.

Crawick Multiverse, Sanquar, Dumfries & Galloway (former opencast coal site) NS 776 112
This derelict site has been restored by the private landowner creating landforms and artwork inspired by cosmology. Designed by landscape artist Charles Jencks in 2005 work began in 2012 utilising topographic features of the abandoned workings and materials won from the site, such as sandstone boulders. Opened in 2015, the 22 ha visitor attraction includes walking trails, engineered landforms, woodlands, water features and art installations (*Crawick Multiverse*, 2021).

Herrington Country Park, Sunderland (former colliery & opencast site) NZ 340 535
Situated at the foot of Penshaw Monument, opencast mining of the former Herrington New Pit colliery, 11Mt spoil tip and adjacent fields from 1996 allowed restoration to public open space and country park in 2000. The landscaping from extraction of 1Mt coal largely paid for the project, regrading the pit heap, created three hills, lakes, reedbeds and a restored stream, together with an amphitheatre, events field and public art celebrating the 211 years of mining heritage and reconnecting communities in the neighbouring former pit villages on the city outskirts. Since opening it has hosted major music and sports events, becoming a popular regional visitor attraction and wildlife corridor, connected with the Great North Forest trail and won a Green Flag Award (*Green Flag Award*, 2021).

A14 Cambridge to Huntington improvement scheme, Cambridgeshire (borrow pits) TL 192 712
Road construction in this topographically flat area meant that requirements could not be met by balancing cut and fill within the materials management plan, leaving an additional c 5 x 10^6 m^3 to be met from six dedicated borrow pits. As part of the Development Consent Order, Highways England (now National Highways) committed to restoring these to a standard comparable to that expected for a commercial minerals site, including ensuring that a 10-year aftercare maintenance regime was followed. The borrow pits are being restored to a mixture of farmland, woodland, grassland, wetland and open water as part of the overall A14 landscape scheme which covers 204 ha and included flood mitigation, landscaping of connecting roadside verges and 24 wildlife crossing tunnels. Using Natural England's Biodiversity Metric 2.0 the Integrated Delivery Team predicted a scheme-wide net increase in biodiversity units of 11.5% (National Highways, 2021) and the habitat creation in the borrow pits made an important contribution to this.

Crown Farm Quarry, Cheshire (active sand quarry, including area in restoration phase) SJ 572 703
Tarmac's 65 ha glacial sand quarry has been worked for sand for concrete, mortar and asphalt since 1989. Planning permission included restoration to a variety of habitats. In 2019 the transfer to Cheshire Wildlife Trust began with the creation of a 17 ha nature reserve. Habitats include wetland, young woodland and grassland which support a wide range of mammals, birds, amphibians, reptiles and invertebrates.

College Lake, Tring, Buckinghamshire (former chalk pit) SP 935 141
This 65 ha flagship reserve transformed and managed by Berks, Bucks and Oxon Wildlife Trust is a geological SSSI and accessible wetland birdwatching site, combining habitats for breeding waders with chalk grassland, cornfield flowers, rare butterfly species, small mammals and birds of prey. It includes a two mile circular wildlife walk and connects with the Grand Union Canal and towpath via the Tring Reservoirs wild walk and is 1 mile from the Ridgeway National Trail. It includes an eco-centre opened in 2010 overlooking the lake which offers information and educational facilities, including displays of Cretaceous fossils found during the chalk extraction.

Walltown Country Park, Northumberland (former dimension stone & aggregate quarry) NY 669 659
This was formerly the largest "whinstone" quarry on Hadrian's Wall, originally worked by hand for kerbstones and setts, then road chippings. It exploited the hard dolerite of the Whin Sill, whose outcrop forms the prominent topographic feature utilised in the Roman defences, now a UNESCO World Heritage Site. After closure in 1976 it was partly filled and planted with trees and plants. It now provides visitor facilities, a park, lake and access to scenic sections of Hadrian's Wall and its long distance path. It lies within Northumberland National Park and the International Dark Sky Park. In 2011 the Peace Labyrinth was planted using over 1000 willow trees of 20 different varieties and of different colours, forming a seven-path Cretan labyrinth (*Northumberland National Park*, 2021).

Dorney Lake, Windsor (extraction of sand and gravel) SU 930 780
Dorney Lake (www.dorneylake.co.uk) is wholly owned by Eton College, with whole community access through the Dorney Lake Trust. Set in 160 ha of parkland, the Lake is a 2,200-metre rowing course of international standard. It hosted the 2012 Olympic and Paralympic Games rowing and flat-water canoeing regattas, and continues to be used for national and international competitions. Construction of the Lake involved extraction of 4.5 million tonnes of sand and gravel, 1.97 million tonnes of topsoil and subsoil and 585,000 tonnes of basal clay.

2.8.6 Future Opportunities or challenges for establishing BGI on former mineral sites

2.8.6.1 Biodiversity net gain

Restoring sites after mineral extraction provides an opportunity to increase the biodiversity of the site and reconnect fragmentated habitats, for example, through Nature Recovery Networks. The concentration of mineral extraction in some landscapes, especially in areas of intensive agriculture, means they can make an important contribution to nature recovery targets. The requirement for biodiversity net gain to be achieved through new development, including mineral extraction, has attracted significant attention in the sector. This requires an increase in biodiversity, recently set at 10% (*Environment Act 2021*, 2021), to be achieved through development in England based on calculations using DEFRA's Biodiversity Metric (Natural England, 2021). This metric uses the baseline and proposed importance, condition and significance of a habitat along with the difficulty of new habitat creation and time to estimate a net change in biodiversity. Concerns have been raised that the assumed times for creation of new habitats are longer and the level of difficulty for creation greater than those experienced in the sector, which is accustomed to engineering habitats, and that this creates an incentive for less difficult habitats, and therefore less biodiverse options, to be prioritised (Humphries, 2021). The operation of the mineral extraction means that the time between the habitat being lost and created is likely to be significant. However, many sites used for mineral extraction would be classified as low or moderate value and the existing practices of phased restoration and establishment of diverse high value habitats is likely to achieve a 10% biodiversity net gain within the site. Sites judged to have high biodiversity value pre-extraction are likely to be more challenging to deliver 10% net gain, without also providing new or enhanced habitats offsite, and those with very high value could be disincentivised unless there is an overriding economic need for the mineral (Humphries, 2021). In addition, the metric rewards enhancement pre-development which may provide opportunities during phased operations where areas planned for later phases of extraction can be improved pre-extraction.

2.8.6.2 Carbon Net zero

The UK's ambitious net zero targets (Department for Business Energy & Industrial Strategy, 2021) may provide fresh impetus for consideration of the carbon-storage potential of former mineral sites and the methods used in their restoration. Land is both a source and sink of greenhouse gases, therefore the way in which it is used and managed will be fundamental for the achievement of net zero targets (CCC, 2020; IPCC, 2020). Nature-based solutions (NBS) can address societal problems in ways that benefit both people and nature, combining climate-change adaptation with other ecosystem services and biodiversity benefits (Stafford *et al.*, 2021). The role of NBS, such as woodland creation and peatland restoration, are much discussed in policy (e.g. Scottish Government, 2020), for meeting net zero goals. Although NBS offer a range of benefits have they should be seen as complementary to other climate and conservation actions, not as a replacement for them, and the local conditions and community context must be carefully considered (Stafford *et al.*, 2021). For example, recently concluded field experiments have shown that planting two native tree species (*Betula pubescens* and *Pinus sylvestris*) on peaty soils did not lead to an increase in net ecosystem carbon stock (i.e. when soil organic carbon is accounted for) at 12 or 39 years after planting (Friggens *et al.*, 2020). Accordingly woodland planting for climate change objectives may need to be diverted away from organo-mineral soils towards lower risk mineral soils (RSPB, 2021), and indeed this is the direction of travel for forestry policy (e.g. (Scottish Forestry, 2020; 2021). However this raises obvious challenges and trade-offs given the finite nature of land as a resource, notably as better quality mineral soils are preferred for agricultural uses (RSPB, 2021). Therefore, disused mineral sites as examples of "non-agricultural lands" (Mellor *et al.*, 2021) may again provide an important opportunity for planting of woodland to help meet climate change objectives whilst also providing various co-benefits (e.g. amenity, landscape, biodiversity, remediation).

Artificial soils produced by blending composted food wastes with dolerite and basalt quarry fines have been shown to store atmospheric carbon as inorganic carbonate minerals at rates of 4.8t C ha^{-1}, to depths of 0.3 m, raising the possibility that waste materials on site could be repurposed specifically for carbon capture at former mineral workings (Manning *et al.*, 2013). Soils in former mineral sites are also characteristically low in organic matter, which could be increased for more temporary storage, especially where permanent grassland or woodland are established. The “4 per mille initiative” launched at COP21 in Paris was based on the observation that the amount of C released annually as CO_2 emissions from fossil fuels is only 0.4% of the total organic C stored in soils globally to 2 m. This illustrates the potential of increasing soil carbon to manage CO_2 emissions, but this has been shown to be difficult in practice, at scale, in organic-rich or cultivated fertile agricultural lands. Again, former mineral sites restored for non-agricultural end-uses have significant potential: Brownfield restoration using green waste compost has been shown to raise the long-term soil carbon, with approximate half the amount added remaining after a decade (Lord and Sakrabani, 2019). Finally, if woodland is also established it will increase soil organic matter and accumulate and store atmospheric C in timber at around 4 t ha^{-1} yr^{-1} for a lowland oak, then reach a long term equilibrium after 80-100 years, of 170-220 t C ha^{-1} in the case of Sitka spruce (Broadmeadow and Matthews, 2003). Thus mineral site restoration could be a niche opportunity to manage C in soils and biomass as a future contribution towards net zero.

Of key relevance here is the likely growth in demand for voluntary carbon offsets, as a growing number of corporates make net zero, carbon neutral or even carbon negative pledges (McNeil *et al.*, 2016; Donofrio *et al.*, 2020; Turner *et al.*, 2021)). Thus there may also be scope for the owners / managers of disused mineral sites to sell carbon from BGI initiatives in voluntary carbon markets, providing a potentially significant alternative revenue source.

Box 2. Aspects of former mineral sites favourable to BGI development

- Scale, frequency & widespread distribution in UK, especially near industrial regions
- Clustering or contiguity with other mineral sites favouring habitat and BGI connectivity
- Proximity to post-industrial communities, especially for older sites or coal-related minerals
- Longevity of mineral extraction, favouring natural regeneration or seclusion for species
- Economic value of resource extraction, providing funding and leverage through planning for setting restoration goals
- Potential to develop permanent woodland and increase inorganic and organic soil carbon stocks.

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Table 2.8.1. Typology, characteristics and challenges for BGI establishment of UK mineral extraction and excavation sites.

Major category	Sub-category	Regionally important areas (or location examples)	Comments (working pattern, features)	Scale	Voids	Water	Soil
Coal	Underground (deep) mine	Fife, Lothian, Ayrshire, Lanarkshire, Northumberland-Durham, W Cumbria, Lancs., N Wales, York-Notts-Derby, N & S Staffs., Midlands, S Wales, Kent, Somerset	Coalfields underlie c. ¼ of UK residential properties. Comprises pit head industrial area and nearby dry/wet spoil/washery tip(s), often later reworked	Workings up to 1200 m below ground (normal limit), surface spoil increased from post-war mechanisation, tips may exceed 100 ha and 50 m high	Mineshafts on cleared pit head capped, typically with access for dewatering, minewater monitoring or mine gas ventilation. Subsidence in working area commonly away from pithead area, common above older shallow workings	Active or drying out slurry lagoons, pumped minewaters or emergent minewater seeps or flooded adits after closure & groundwater rebound	Very limited, due to prevalence of mine spoil and washery coal wastes, unless modern greenfield site. Shaley material, heavy textures, combustible, steep gradients, gulleying and instability issues, low pH, nutrient deficient and no soil organic matter, high salinity, sulphates, PTEs. Natural colonisation limited unless high pH
	Surface (opencast) mine	As above, specifically older "exposed" coalfield deep mining locations	Large-scale surface mining started in WWII. Often accompanied reclamation & landscaping of "brownfield" former deep mine sites or shallow workings but now "greenfield" sites dominate. Co-products: fireclays, refractories, brick clays, sandstone, sand & gravels. Phased working with looping back layout to replace spoil from first cut into final void	Few ha to several km^2, typically 100m but up to 200 m deep	Unlikely, unless by design, due to overburden:coal (replaced:extracted) ratio of < 20:1 and bulking factor and face-to-void working method	Likely in hollows by design or differential settlement. Run-off settlement ponds. Natural watercourses commonly diverted during operation or restoration	Natural soils stripped during greenfield site preparation for screening, soil-forming materials won from geological sequence during operation. May be limited if includes brownfield restoration Stoney, sandy to heavy clays, waterlogging/droughting, low major nutrients and organic matter unless amended with recovered wastes (e.g. biosolids, composted MSW, paper sludge, digestates etc)
Construction aggregates	Sand & gravel pits	Thames, Trent & Severn river valleys, glacio-fluvial deposits in	Laterally extensive spreads 1-10 m thick in valleys of large river systems, or more irregular glaciofluvial lens up to 30 m thick. 20% of sand &	Typically multiple adjacent workings, collectively	Can be shallow after restoration (2:1 overburden ratio, 1 m extraction), with agricultural	Often near to water table level so refill rapidly after abandonment.	Stripped soils and alluvium or associated glacial deposits, dewatered silts from washing. Droughty, stony, low pH, N & P

		all UK except S and SW England	gravel reserves in green belts of major conurbations. Clay/silt < 25%	several km^2, although sequential working and progressive restoration. Smaller or short-lived in high demand areas	improvement on reinstatement	13 km bird strike safeguarding zones around airports	deficient. High quality agricultural land (wet pits) or designated heathland (dry pits)
	Sand & gravel quarries	Cretaceous (e.g. Weald), Permian (e.g. Notts, Durham) & Devonian (e.g. Scotland, SW) sandstone areas	Excavated or crushed sandstone or conglomeratic formations	Highly variable (0.01-1 Mt/a, typically 0.1-0.3 Mt/a)	Typical	Free draining rocks allow flooding or natural drainage	Stripped soils and overburden/interburden, dewatered silts from screening, washing or crushing, associated mudrocks. Droughty, stony, low pH, N & P deficient
	Limestone quarries, including dolomite & chalk pits	Carboniferous limestone (Peak District, Mendips, S Wales), Permian (Durham), Jurassic (Cotswolds), Kent, Sussex, SE England	Often exploit natural escarpments or hillsides. 50% of Carb Lst outcrop in AONB/NP/SSSI/SAC/SPA	Highly variable	Typical, often tabular, steep-sided excavations, often with benches or artificial cliffs	Fractured rocks allow flooding or natural drainage	Characteristically thin soils and little overburden. Often contain waste crushed rock or boulders. Droughty, stony, high pH, N & P deficient, K deficient on chalk, Mg toxicity on dolomite
	Hard rock quarries	East Midlands, Scotland & SW England, granites, meta-sandstones	Rounded, tabular or elongate, as determined by form of igneous or metamorphic rock (overburden 0-30 m). Often in scenic landscape areas due to nature of rocks (e.g. Lakes, Snowdonia, Scotland)	Determined by geological extent and proximity to SE England market. Larger, longer-lived than sand & gravel due to scale of investment, 0.1-5Mt/a	Generally steep-sided excavations, with benches or high walls	Often partially flooded or with sump	Usually have very limited soils or overburden. Often contain waste crushed rock fines or oversize boulders. Droughty, stony, low pH, N & P deficient. Low value clay-rich “scalpings” and <63 μm “fines” from screening and or washing
Dimension stone		Portland, Penrith, Bath, Doncaster	Exploit specific rock layer(s), extending underground.	Relatively small compared to other types	Often partially backfilled with unwanted rock	Possibly flooded or with sump	Often contain waste rock or boulders

			Commonly a by-product or co-product of aggregates.				
Slate	Slate quarries & mines	N Wales, Lakes, SW England, W coast of Scotland	Quarried into underground caverns following slate horizon	Locally extensive in belts	Rarely backfilled but nearby waste heaps as most extracted material rejected	Often partially flooded as impermeable	Minimal other than slate wastes, fines from secondary aggregate crushing
Cement works	N/a	e.g. Dunbar (Scotland), Tunstead (Derbyshire), Ketton (Rutland)	Require significant limestone resource (Carboniferous or Jurassic- dry process) or chalk (original wet process) and local source of clay	Large scale & long-term operations due to highly capital intensive plant	Typical	Especially in clay pits	Stripped soils and overburden for progressive restoration, especially where limestone beds are thinner (e.g. Dunbar)
Brick clay pits	N/a	Widespread, mainly in England, in Coal Measures, the Potteries, Mercia Mudstone, Oxford Clay (previously) and Weald	Formerly adjacent to brickworks but now increasingly separate for blending to match tighter brick specifications. Used for structural clay products and engineering purposes	Large scale, low value bulk material. Now much smaller quantities than other aggregates (e.g. 3% in 2005)	Typical, although often used for landfills	Typical, due to impermeability	Heavy soils from weathered clay or mudstone, possibly organic- or sulphate-rich
Industrial minerals	High purity limestone	Derbyshire	As for limestone workings for cement or aggregate	As for limestone	As for limestone	As for limestone	As for limestone
	Potash, gypsum	Boulby & N Yorks, Eden Valley	Both worked underground as modern mines with limited surface expression	N/a	N/a	N/a	N/a
	Fluorspar & barytes	Derbyshire & N Pennines	As for metal mines, often reworking spoil	As for metal mines	As for metal mines	As for metal mines	As for metal mines
	Kaolin	St Austell, Bovey Tracey	Hydraulic mining	World-class deposits in SW England	Extensive excavations due to coalescing, deeper modern workings	Often flooded if not used for wastes or slurry	Minimal, other than waste granite, mica, quartz sands stockpiles. Natural revegetation to heathland takes 100 years. Used in Eden Project to make soils
Metal mines	Vein deposits	Sn-Cu-W-As (Cornwall & Devon), Pb-Zn-Ag (Derbyshire, N Pennines, Mid Wales), Au (Mid Wales, Tyndrum, N Ireland)	Historic steeply inclined, sheets and irregular bodies, accessed by horizontal adits, then vertical shafts. Modern spiral declines, adits or pits	Widespread, historically significant, small-scale, multiple workings in prospective areas. Rare	Minor opencast or narrow surface workings to limited depth, often by releasing surface water flows. Underground voids & entrances. Ground stability issues	Commonly impounded for power, ore processing and settlement ponds. Minewater issues typical,	Typically unvegetated due to lack of soil or contamination. Natural revegetation of mine spoil, or granular processed tailings may result in calaminarian grasslands or SSSI status, metallophytes & bryophytes. Possible

				modern examples		often acidified & contaminating	archaeological significance & soil contamination risk
	Sedimentary (& sediment-hosted) deposits	Corby, Scunthorpe, Cleveland ironstones, (W Cumbria & S Wales hematite deposits), coalfields	Recent strip-mining in E England with progressive restoration using overburden. Elsewhere mostly late C19th when UK dominated world production	Locally extensive in orefields	Extensive opencast or underground voids	Yes, where opencut (possibly industrial contamination). Fe-rich visually polluting minewaters	May have anomalously high geogenic As, Mn, Cr etc
Borrow pits & spoil mounds	N/a	Major infrastructure projects (e.g. HS2)	Coupled temporary (multi-year?) extraction/replacement of suitable/unsuitable materials during major infrastructure construction (e.g. HS2)	Depends on project scale (e.g. 8.34 Mt from 154 ha for HS2 phase 2a)	Possibly, if overall net materials deficit or designed as balancing ponds for storm water or flood risk requirements	Possibly, if aggregate washing settlement ponds or designed as balancing ponds or SUDs	Greenfield site allows separate stripping & storage of topsoil & subsoil for replacement and restoration to previous use/function, including improved long-term agricultural land capacity under climate change
Peat	N/a	Development on peatlands or fens (e.g. onshore windfarms, roads etc)	No longer extracted for use but commonly removed, stored and used for restoration to avoid loss or landfilling	Depends on project scale, peat depth and adjusted layout	May be used to restore associated borrow pits	Possible if used to restore degraded peatlands by damming or constructed wetlands	Separate stripping of living upper acrotelm allows replacement as viable peatlands to maintain carbon storage if waterlogged, low nutrient & pH conditions

Table 2.8.2. Key ecosystem and energy service provision of UK mineral extraction sites in use and as restored for BGI.

Key: * = negative impacts ● = delivered via restoration or disuse ☐ = also delivered while operational		Provisioning (including energy services)				Regulating				Cultural				Supporting (including biodiversity)			
		Food	Fresh water	Wood & fibre	Fuel & heat	Climate	Flood	Disease	Clean water	Aesthetic	Spiritual	Educational	Recreational	Nutrient cycling	Soil formation	Primary production	Biodiversity
Coal	Underground (deep) mine		*	●	☐	*	☐	*	*	●	☐	●	●	*●	*●	*	
	Surface mine (opencast)	●	●	●	●	*	☐		●	●		☐	●	●	●	●	●
Construction aggregates	Sand & gravel pits		*		●		☐		*●	●		●	●				☐
	Sand & gravel quarries		*				●		*●	●		●	☐				☐
	Limestone dolomite & chalk		*		●		●		●	●		●	●	☐	☐	☐	☐
	Hard rock quarries		*		●		●		●	●		●	●				☐
Dimension stone										●		●	●		*	*	●
Slate	Quarries & mines						●			☐	☐	☐	☐		*	*	☐
Cement works	N/a						●						●				☐
Brick works	N/a			●	●		●			●		●	●				●
Industrial minerals	High purity limestone												●				☐
	Potash, Gypsum		*						*					☐		☐	
	Fluorspar & barytes		*						*			●	●				●
	Kaolin		*							●		●	●			●	●
Metal mines	Vein deposits	*	*						*			●	●	*	*	*	☐
	Sedimentary (-hosted)	*	*						*			●	●			*	●
Borrow pits, spoil							●		●								●
Peat			*			*●								●	●	●	●

Figure 2.8.1. Case study photos.

(1) Little Orme Quarry, Penrhyn Bay, Conwy

Photo: R Lord

(2) Diaspora Gardens, Redruth, Cornwall

Photo: D Sinnett

(3) Crawick Multiverse, Sanquar

Photo: R Lord

(4) Herrington Country Park, Sunderland

Photo: H Lord

(5) A14 borrow pit(s)

Photo: National Highways

(6) Crown Farm Quarry

Photo: Luke Gorman

(7) College Lake

Photo: BBOWT

(8) Walltown Country Park

Photo: R Lord

(9) Dorney Lake

Photo: Eton College Dorney Lake