CAUSES OF INSTABILITY

Introduction

A1. Instability which may pose a threat to development and/or to public safety, and which therefore needs to be considered in land-use decisions, is caused both by natural processes and by human activities. The ground movements which result are variable in their extent and in their effects on the surface and subsequently on development. Some ground movements can be predicted very precisely in both space and time; the likelihood of other movements occurring may be predictable in space but not in time. There are, however, few situations where, given an adequate investigation and geotechnical assessment of a site, the magnitude of possible future ground movements cannot be predicted with reasonable accuracy, thus allowing the measures necessary to prevent such movements or to minimise their effects to be identified, designed and costed.

A2. The causes of instability may be placed in three broad categories:-

1. the effects of underground cavities;
2. unstable slopes; and
3. ground compression.

A3. Whatever the ultimate cause of instability, the triggering factor which initiates instability problems is very often human activity. Thus, the act of development in a green field site or the intensification of development in areas which are already developed may result in instability which may affect both that development and the land surrounding it.

1. Underground cavities

A4. Underground cavities may pose a hazard to many types of development in Britain. Problems associated with natural sinkholes in chalk, for example, affected the construction of several of the motorways radiating from London. The collapse of old limestone mine workings in the West Midlands has caused surface subsidence and some damage to houses, roads and industrial buildings. Subsidence effects due to coal mining are also well known.

(a) Natural cavities

A5. Underground cavities are created by a number of natural geological processes.The commonest, and those most likely to affect surface development, are created by groundwater dissolving the bedrock.

(i) Solution cavities

A6. All carbonate rocks (limestone, dolomite, chalk) are prone to dissolution by natural groundwaters, as are evaporite minerals such as gypsum and rock salt. Solution leads to the development of an often interconnecting network of caves, microcaves and enlarged fissures and the occurrence on the surface of closed depressions known as sinkholes or dolines (Fig A1). These depressions may arise:

- directly by dissolution of rock at the surface;
- by collapse of the roof rocks directly into caves;
- by collapse of the ground surface into secondary cavities in the cover material caused by washing out of that material into underlying solution cavities; these are one form of subsidence sinkholes;
- by gradual subsidence of the ground surface due to washing out of loose sandy cover material into underlying solution cavities; another form of subsidence sinkhole.

A7. Collapse sinkholes into caves are rare in Britain but secondary collapse through cover material presents a hazard in many localities. This form of subsidence sinkhole usually develops rapidly and there is often no prior surface indication of collapse; they are therefore largely unpredictable as to location and time. The other type of subsidence sinkholes develop more gradually and solution sinkholes very slowly indeed. They may thus present less of a hazard in terms of predictability but they do indicate the presence of subsurface cavities.

A8. All sinkholes may be infilled naturally or by man. Their location may thus be hidden and ground movement may be initiated naturally or due to human activities such as groundwater extraction or alteration of

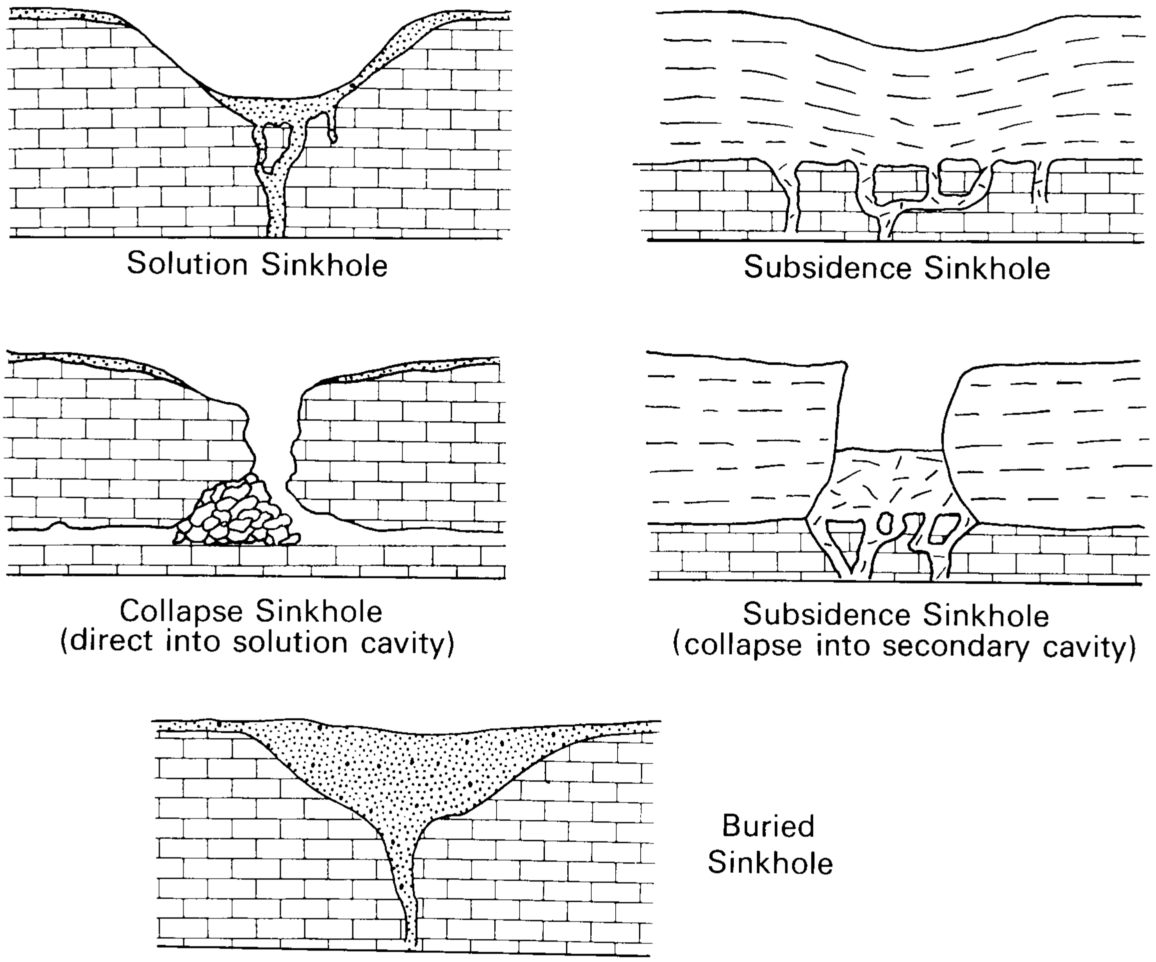

FIGURE A1 TYPES OF SINKHOLES

drainage. The presence of buried sinkholes may pose problems for excavation and for foundations. Unsuspected solution cavities themselves may cause particular problems to excavation by causing failure of rock faces or unpredictable scattering of rock debris during blasting.

A9. Rock salt is much more soluble than most other natural materials. Any salt within the zone of circulating groundwater is dissolved out and the overlying ground then subsides. The effects on the surface are to create circular depressions and, often, linear subsidence features where preferential flow paths are established within circulating ground waters. The subsidence so caused is usually gradual unless the flow of groundwater is increased by pumping operations.

A10. The locations of strata which are susceptible to dissolution is fairly well known. Fig A2 shows as an example the broad distribution of soluble carbonate rock outcrops in England and Wales. Other strata which may in part be susceptible to dissolution include the evaporite-bearing Triassic strata of such areas as the Vale of York and the Cheshire and Worcestershire salt basins. However, the distribution of cavities within the broad outlines of such strata or where such strata occur beneath a thin cover of other materials and the consequent risks to surface development and land use are not so readily defined.

(ii) Other natural underground cavities

A11. Buried cavities may be created on a small scale by a number of other geological processes. The most significant of these are probably tension gulls - fissures caused by tilting of strata along plateau edges. Such gulls are particularly large (up to a few metres across and several metres deep) and common along plateau and scarp edges in the Mesozoic limestones of Northamptonshire, the Cotswolds and North Yorkshire Moor and the Coal Measures sandstones of South Wales. Many tension gulls originated under glacial conditions and may now be infilled or bridged by soil or drift deposits. Any lateral movement down the valley side or mining subsidence may result in renewed opening of

FIGURE A2 DISTRIBUTION OF SOLUBLE CARBONATE ROCK OUTCROPS IN ENGLAND AND WALES

-tension gulls; such opening may be concealed beneath a soil/vegetation mat.

(b) Man-made cavities

A12. Britain has a long history of mining but reliable records are available only since the latter part of the nineteenth century. As a result, the first intimation of earlier mine workings may often be the occurrence of surface subsidence. Mining has taken place at some time in every county in England and Wales. Fig A3 is an illustration of the widespread geographical distribution of mining in England and Wales. It is by no means comprehensive and it is not intended to give accurate locations but simply to give a general picture of how extensive mining has been and a broad indication of the range of minerals that have been mined in different areas. Almost every mineral that has been extracted in Britain has been mined underground somewhere. The impacts of mining on surface stability depend to a large extent on the method of mining, which has varied with time and with the mineral extracted. (Fig A4)

(i) Outcrop mining and bell pits

A13. The earliest underground mining comprised shallow drift mines from the mineral outcrop. Later, shallow shafts were sunk through cover rocks to reach the seam. Around the central shaft the mineral was extracted until the roof showed signs of collapsing. Such bell pits were commonly used for the extraction of clays and ironstones as well as coal and for chalk and/or flint in south-east England (dene holes).

A14. Most bell pits are unrecorded but their presence may be indicated by the characteristic hummocky ground caused by collapses and spoil dumping. Bell pits often occur in large numbers, either clustered together or in linear belts. All are shallow, generally less than 12m, with diameters of the order of 8-20m at seam level. Whilst most bell pits have already collapsed causing very variable ground conditions, those still open may yet cause severe ground disturbance on collapse.

(ii) Room and pillar mining

A15. Subsequent to outcrop and bell pit mining, roadways or galleries were driven into the seam either from adits or from shafts. Excavations were made into the sides of such roadways and later passages were cut between parallel roadways. This room and pillar mining goes under a variety of names in different areas but essentially entailed pillars of intact mineral being left in place to support the roof of the workings.

A16. Early room and pillar workings had a somewhat haphazard distribution of pillars but later ones were developed on a more regular grid pattern. With some minerals, such as coal and ironstone, waste material was backstowed into the rooms rather than taken to the surface. Because a substantial proportion of the mineral was locked up in the pillars it was often removed or 'robbed' on retreat, often to the extent that the remaining pillars could no longer support the roof.

A17. Room and pillar mining for coal, ironstone and fireclay was almost universal in the coalfields. This technique was also used elsewhere for many other minerals eg limestone in the West Midlands, the Bath area and parts of Scotland, sand and sandstone in parts of Surrey and West Yorkshire, ironstone in Cleveland, Lincolnshire and Northamptonshire and chalk in south-east England. The method is still used for the mining of limestone, gypsum, salt and potash in Britain.

A18. Modern room and pillar mining is generally designed to minimise surface subsidence. The use of room and pillar mining is, however, largely limited to working depths not greater than 300m and to situations where adjacent strata have not been destabilised by previous mining. Older room and pillar mines were often not so designed and the likelihood of subsidence is greater, especially if pillars were robbed.

A19. The effects on the surface of collapse of older room and pillar workings depend on the depth and geometry of the workings and the strength and integrity of both the pillars and the surrounding and overlying strata.

A20. At shallow depths, the collapse of pillars may cause severe localised ground disturbance in the form of intense trough subsidence or total collapse of the surface into crown holes. At such depths, however, the load imposed by overlying strata may often be insufficient to cause pillar collapse unless the pillars were robbed or have deteriorated with time. Disturbance by human agencies, such as surface loadings and vibrations or changes in groundwater regime may, however, promote collapse.

A21. More commonly, falls of rock from the roof of rooms, galleries or roadways results in the formation of a chimney above the workings. Depending on the depth and the competence of overlying strata, this chimney may progress upwards to reach the surface as a crown hole. Crown holes are localised and unpredictable as there is seldom any prior surface indication of collapse which may take place very rapidly. They may occur many years after the mine has been abandoned. In disused mining areas the widespread cavities

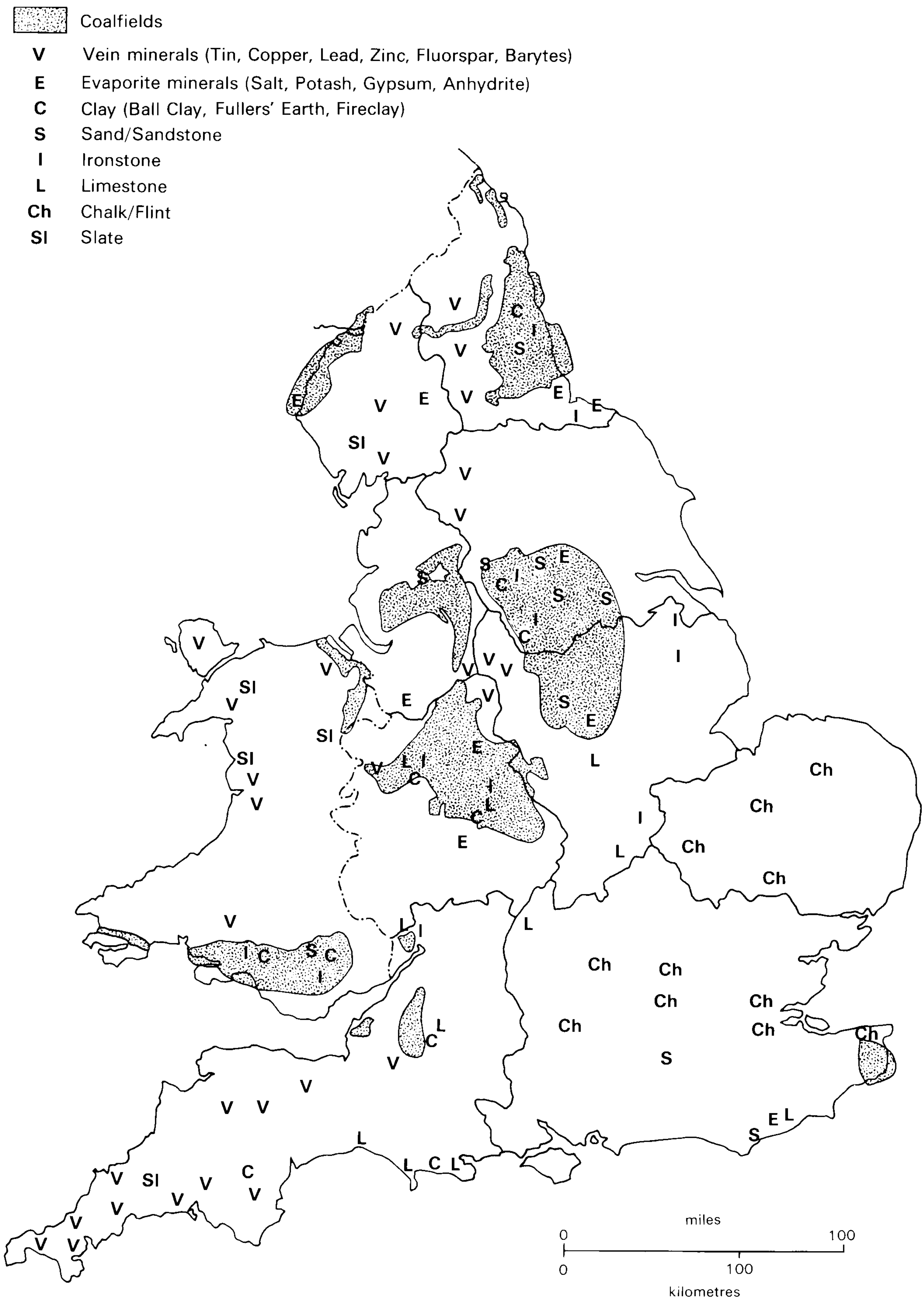

FIGURE A3 ILLUSTRATIVE DISTRIBUTION OF MINING IN ENGLAND AND WALES

(see paragraph A12)

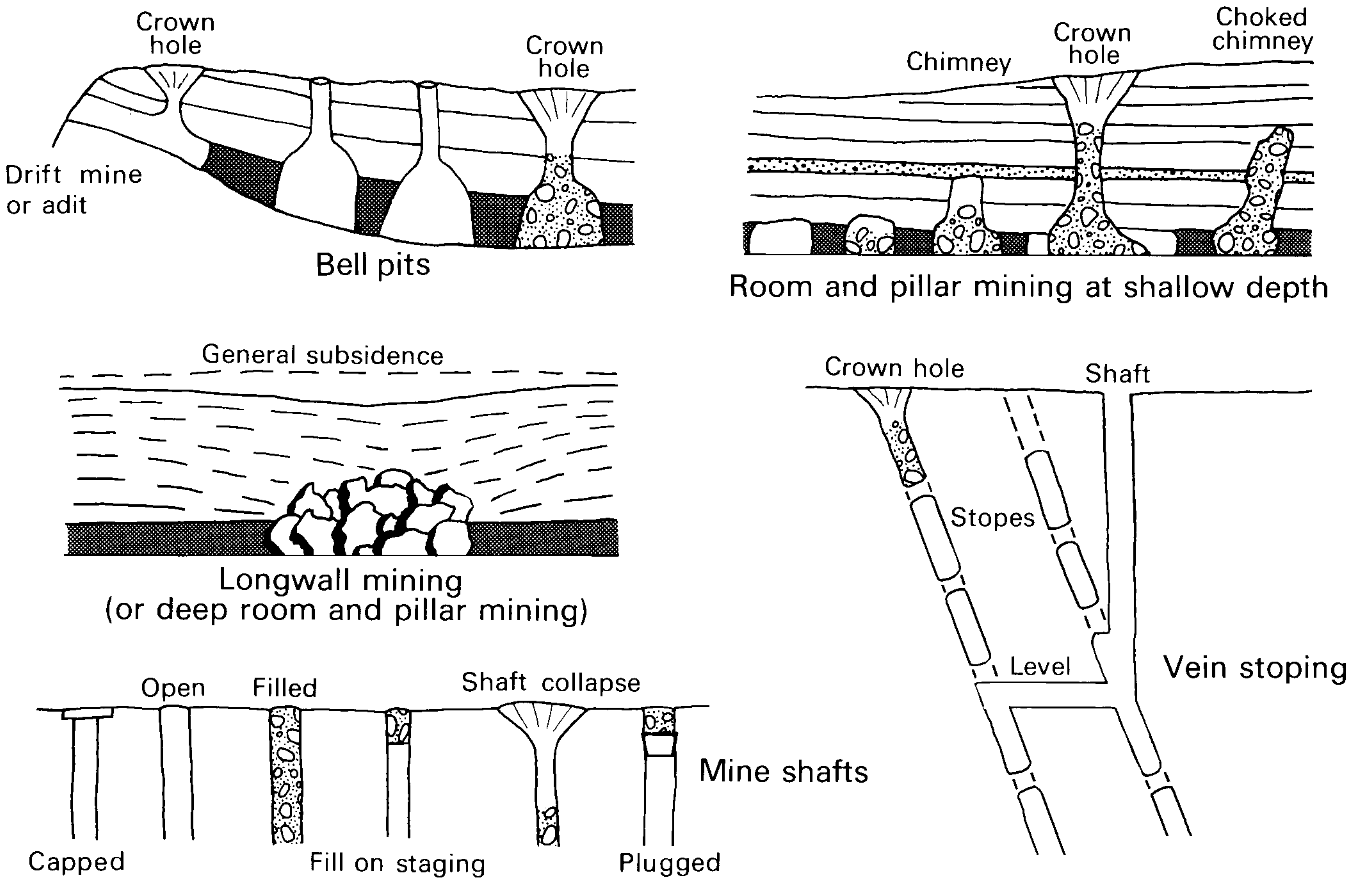

FIGURE A4 DIAGRAMMATIC REPRESENTATION OF MINING METHODS AND EFFECTS ON SURFACE

which may remain in shallow workings are generally not detectable even from a close inspection of the ground surface and the absence of any defects or damage at the surface is no indication that future damage will not occur.

A22. The depth from which a chimney will progress to the surface to become a crown hole varies with the geometry of the workings and the nature and condition of overlying strata. A depth of ten times the height of the workings is commonly quoted as the maximum thickness of strata through which failure can be transmitted to produce a crown hole. Whilst this may be a reasonable estimate relating to many types of mineral and mining method, there will be exceptions and the circumstances obtaining in any particular situation need to be considered.

A23. At greater depths, chimneys will choke themselves before they reach the surface due to the bulking of the fallen debris which takes up more space than the intact strata. Because at greater depth, the weight of the overlying strata is much greater, the crushing of pillars or the punching of pillars into soft underlying strata are common modes of failure.

A24. Pillar failures at such depths generally do not give rise to crown holes but to a more extensive and more gradual general subsidence of the surface. The amount of subsidence depends on the depth, width and thickness of mineral extracted, on the ratio of extracted void to pillars and on the area over which underground pillar failures occur.

A25. In relatively weak materials such as coal and ironstone, pillar failures at depth will largely have occurred within a few years after abandonment or the void will have been infilled by floor lift or roof collapse. Pillars in stronger materials, such as limestone and some sandstones, may retain their integrity for many years and the mining voids may remain open. However, natural deterioration may lead to pillar failures many years after abandonment. For example, pillars at a depth of 150m in part of the Cow Pasture limestone mine in Wednesbury collapsed, causing subsidence and damage to property on the surface in 1978, almost 100 years after abandonment of the mine.

(iii) Longwall mining

A26. For coal mining in particular, longwall working has now replaced the partial extraction methods in which a significant proportion of the mineral was left behind as support pillars. This method maximises the amount of mineral extracted and it is almost universal practice in the British coal industry. It was also used in some nineteenth century ironstone and coal workings.

A27. Faces 100-300m long are worked by either advance or retreat longwall mining methods. In advance longwall mining, service roadways move forward with the working face whereas in retreat mining the service roadways are formed prior to the commencement of longwall extraction. As the seam is worked the overlying strata are allowed to collapse into the worked area behind the face. Longwall mining inevitably produces almost instantaneous general subsidence of the land surface. The amount of subsidence depends on the depth, thickness and width of the seam being worked and on the nature and condition of overlying strata.

A28. General subsidence due to longwall mining (or to deep room and pillar mining) extends beyond the plan areas of the worked seam. It results in lateral compression of the ground in the centre of the subsidence and extension in the outer area. As a face is worked beneath an area, it may suffer successive waves of tension and compression. The opening up of pre-existing fractures within the area of extension may create underground voids which have important implications for foundation design. Zones of extension and compression may also have significant effects on groundwater flow and on gas migration.

A29. General subsidence due to longwall mining is reasonably predictable in extent and magnitude (it is less so for deep room and pillar mining), though there may be abnormal and less predictable subsidence effects due to near-surface geological conditions or the effects of geological faults or previous multi-seam working. The precise effects on buildings and structures may not be so readily predictable. The areas of maximum tension and compression within a subsidence zone can cause the most damage to buildings and structures but careful subsidence prediction and proper mine planning can limit these effects.

(iv) Vein stoping

A30. Metalliferous ores such as haematite iron, copper, tin, lead and zinc and associated minerals such as barytes and fluorspar commonly occur in steeply dipping veins or lodes. These are worked by driving levels along the veins then cutting away (stoping) between the levels. The resulting void is then a steeply dipping cavity, often of the same dimensions as the original vein, which may extend to great depth with little or no support of the overhanging wall.

A31. Metalliferous ores also occur as pipes (ancient solution cavities of an irregular nature within the host rock and less predictable than veins) and flats (where extensive mineralisation has taken place sandwiched between two barren horizons). These may have been worked by stoping, block caving or room and pillar mining and may give rise to large caverns after the mineral has been extracted. Veins pipes and flats can often be interconnected and frequently occur in metalliferous orefields associated with limestone areas.

A32. Old metalliferous mines are distributed over large parts of western and northern Britain. Examples include tin and copper mines in Devon and Cornwall, lead (and subsequently fluorspar and barytes) mines in the Pennines, Shropshire and Wales, haematite iron mines in Cumbria and South Wales. The slate mines of North Wales and the Lake District are worked by similar methods , ie in steeply dipping chambers following areas of suitable characteristics for working.

A33. As most of the metalliferous mines followed steeply dipping narrow veins, often in competent rock and often at great depth, subsidence may not be a geographically widespread problem. Where the stoping was at shallow depth, however, void migration may progress to the surface as crown holes and can be a serious risk where veins reach the surface in mining areas. In particular, where veins have been worked from the surface and may be linked to underground workings, problems can arise from inadequate backfilling.

(v) Solution mining

A34. Readily soluble evaporite minerals such as salt and potash may be extracted by conventional mining techniques or by solution mining. The salt industry in Cheshire, and elsewhere was initially developed by pumping brine from natural underground brine streams. Pumping increases the flow of groundwater, and thus increases solution and subsidence; this practice has now virtually ceased.

A35. Around the turn of the century, old rock salt mines which had been excavated below the levels of circulating groundwater were allowed to fill with water; this caused pillar solution and collapse. The pumping of brine from the old mines allowed further inflow of fresh water, caused renewed solution and led to major subsidences in the Northwich area. This practice had ceased by about 1930 and the cavities remaining are now brine filled and thought to be relatively stable, unless circulation of groundwater is restarted.

A36. Modern mining of salt, apart from one room and pillar mine and one natural brine pumping operation, is by controlled solution. Boreholes are drilled to the salt horizon, water is injected to dissolve the salt and the resulting brine is pumped out. The cavities created are controlled in size and shape. On completion they are filled with saturated brine and they are believed to be stable with no threat of surface subsidence.

(vi) Mine entries

A37. Entry to mine workings is normally gained by means of vertical shafts or horizontal or inclined tunnels called adits. Other openings such as fan drifts and wheel pits are often associated with mine shafts. Such openings may or may not have been filled, wholly or partially, or otherwise sealed to prevent entry when the mine was abandoned. Under the Mines and Quarries Act 1954, there is a requirement that mine entries should be adequately protected on abandonment to prevent accidental ingress. Many earlier mine entries remain open, however, and may pose a threat to human safety.

A38. Like many of the old workings, many mine entries are unrecorded. Even when shaft records exist the location is often imprecise and the shaft may be hidden and difficult to locate.

A39. Collapse of shaft linings or of shaft walls, particularly in superficial deposits and collapse of shaft fillings, particularly if partial filling was founded on wooden staging part way down the shaft, pose an obvious threat to life and safety and to any buildings or structures in the vicinity. In unconsolidated superficial deposits, a funnel-shaped crater may form which is considerably more extensive than the area of the original shaft. Research has shown eg in South Wales and Shropshire, that many of the most severe subsidences have occurred in the vicinity of shafts or adits. Emissions of methane and other noxious gases from shafts may also pose a threat to public safety.

(vii)Other man-made cavities

A40. Various forms of cavities are associated with civil engineering works. Tunnels driven for roads, railways, canals, sewerage, water etc are usually well recorded. Older tunnels may not, however, be adequately documented and problems may arise through broken ground above tunnels or deterioration of the tunnel lining or of such features as access or ventilation shafts. Similar problems may arise due to unrecorded cellars and foundations in older urban areas now subject to redevelopment. Wells sunk for water (or brine) extraction pose similar problems to mine shafts. Many of these are unrecorded and they may be inadequately protected.

A41. An increasing interest is being shown by industry in positive uses of underground space. For example, cavities created by controlled brine pumping operations have subsequently been used for the storage of such materials as ethylene or for the disposal of waste from the chemical industry which uses the salt. In the Holderness area, solution mining techniques have been used to create cavities at great depth specifically for storage of natural gas. Existing mined space, natural cavities and purpose-built cavities may all be modified or designed for long-term stability to enable such positive uses to take place.

A42. Many underground cavities of both natural and man-made origin have been developed as show caves/mines or as part of museum complexes. Such cavities may also be of historical/archaeological interest or of value for nature conservation, particularly as bat roosts or as Sites of Special Scientific Interest. They also serve for adventurous recreation ie caving.

2. Unstable slopes

A43. Both natural and man-made slopes may be subject to instability due to landsliding or soil creep. Landslides are mass movements of soil and/or rock under the influence of gravity. The movement may be slow or it may be very rapid; it may be continuous or subject to intermittent surges. The scale of the movement also varies, from a few tonnes of material affecting a few square metres to many millions of tonnes affecting several hectares.

A44. Landslides have been classified in a number of ways by different authorities. Fig A5 shows diagrammatically the classification adopted for the national landslides review. It is essentially based on the type of movement, ie the mode of failure, involving a consideration of the initial rupture surface, the dominant form of displacement and the subsequent behaviour after movement has commenced and the material is deformed or runs out from its place of origin. The dominant forms of displacement are:-

- falls - abrupt movement of material detached from a steep slope or cliff with most of the motion taking place through the air as free fall, rolling or bouncing; initial detachment may be by sliding, free drop or toppling;

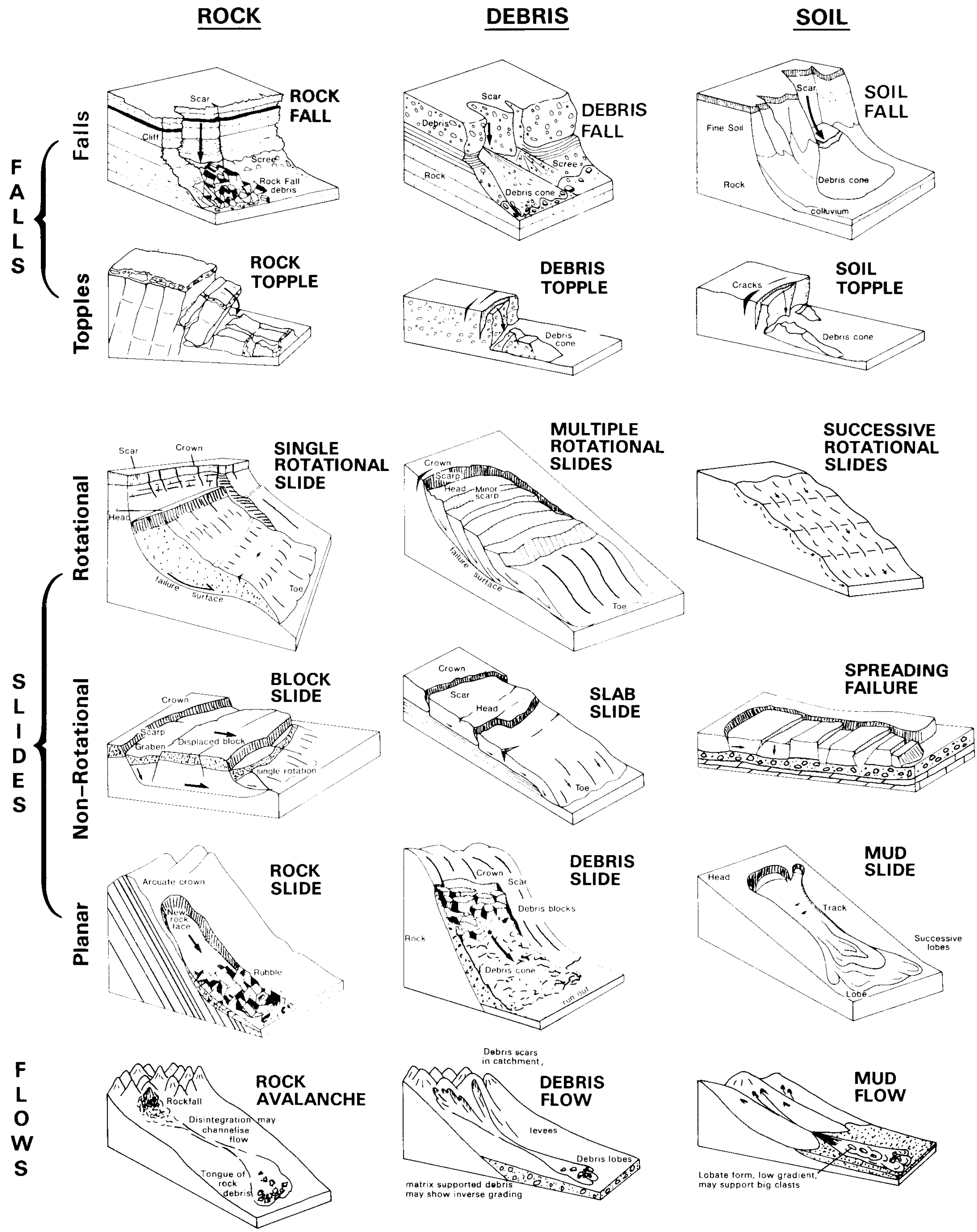

FIGURE A5 CLASSIFICATION OF LANDSLIDES

(After Geomorphological Services Ltd, Review of research into landsliding in Great Britain)

Falls – Mass detached from steep slope/cliff along surface with little or no shear displacement, descends mostly through air by free fall, bouncing, rolling or sliding; Topples – forward rotation about a pivot point; Rotational slides – sliding movement on one or more circular or near circular failure surfaces, may be rock, debris or soil; Non-Rotational slides – sliding out or down slope on more or less planar surface and little rotary motion; Spreading failure – may be in rock, debris or mixed deposits. Planar slides – translational planar movement on steep bedded slope; Flows – rapid mass movement with high proportion of water or air, advances by flowing involving uneven displacement of components.

- slides - material moves by sliding movement along a recognisable shear surface (or surfaces) which may be circular or near-circular (rotational slides) or essentially planar (translational slides);

- flows - rapid mass movements with a high proportion of water or air which advance over the land surface as a viscous fluid with movements between grains predominating over shear surface movements.

In practice, landslides may contain combinations of these various types of movements and there are other types of movement such as gravity creep, valley bulging, cambering and gravitational spreading which cannot readily be allocated to these categories.

A45. The importance of ground material in the classification of landslides is recognised by the further subdivision based on:-

- rock - ie bedrock;

- debris - coarse engineering soils (sandsize or greater and/or an admixture of gravel or even boulders);

- soil - fine engineering soils (silt, clay, organic material).

As with all classification systems, the boundaries between groups are artificial and one form often merges into another.

A46. Landslide movement may be initiated by natural processes or by human activities. Table A1 illustrates some of the processes affecting hillslopes which may increase the likelihood of movement. Slopes will only move if the forces contributing to movement (eg gravity, water pressure, etc) exceed those resisting movement (eg strength of material, frictional resistance, etc). Movement can be initiated by changes in any of these factors individually or in combination. For example, undercutting of slopes by coastal or river erosion or by excavation removes support from the foot of the slope and thus reduces the resistance to movement. Loading of the top of slopes by natural deposition, tipping or by construction of buildings increases the weight (load) of the top of the slope, thus contributing to movement. Increases in water content due to heavy rainfall or alteration of drainage may increase water pressures and thus decreases the resistance to ground movement.

A47. Many landslides in Britain originated when climatic conditions were very different. For example, downslope slumping of saturated material over the frozen subsoil under periglacial conditions has mantled many slopes with fossil solifluction sheets or lobes (head), often with internal shear surfaces on which movement took place.

Table A1 Processes involved in landsliding

PROCESS	CHANGE TO HILLSLOPE
Weathering - physical, chemical, biological	Changes size, strength and chemistry of slope materials; weakens internal discontinuities eg opening up joints, forming internal layers and basal surface on which material may move; development of thick soil layer that could move.
Erosion - by rivers, sea, ice or man	Changes geometry, height and angle of slope; removes basal support and by unloading may cause expansion, swelling, fissuring, softening.
Undermining - leaching of cements, underground mining	Changes strength, water concentration and water pressure; removes physical support, causing ground subsidence; may weaken internal discontinuities.
Deposition - by rivers, ice, mass movement or man	Loading of slope changes weight, water content and water pressure.
Shocks and vibrations, seismic activity	Vertical and horizontal stresses within slope; change strength by disturbing intergranular bonds and cements; change water table and water pressure.
Water regime change - rainfall, flooding, drainage alteration	Increase water content of slope and change weight and water pressure.
Vegetation removal	Loss of root strength; less water extracted from slope by plants; more water arrives on slope because of reduced interception.

Whilst the evidence of earlier movements can often still be seen, some of them have no obvious surface expression. Under present conditions such slopes may be stable if undisturbed but the effect of human activities in developing and using the land will sometimes be sufficient to reactivate movement.

A48. Whilst present-day natural processes can cause or contribute to landsliding, it is fairly clear that, at the present time, the main cause of landslide movement, both in terms of first-time movements and reactivation of ancient landslides, is human activity.

A49. The distribution and significance of landslides is affected by a number of factors, including bedrock and drift geology, relief, climate, geomorphological processes and human activities. Whilst we do not know the distribution of all landslides, the national landslides review has enabled analysis of data relating to landslides recorded in the published literature. Fig A6 shows one interpretation of that data in terms of the number of landslides recorded per 100 km^2 of outcrop of individual stratigraphical units. It is useful in that it highlights some, though by no means all, of the strata which may be susceptible to landsliding. However, it must be regarded as indicative only and almost certainly represents a bias in the data rather than a true picture of landslide distribution. Coastal landslides, for example, are under-represented, particularly in areas of clay cliffs such as Holderness, Norfolk and north Kent. Many areas have a low density of landslides because there is no information in the literature rather than there being few landslides; given appropriate topographical and other conditions, landslides may be present or be caused in many areas where the apparent density is low. Similarly, individual areas of landsliding which have been intensively studied may bias the data in areas of the same strata in which there are actually few landslides and thus increase the apparent density.

3. Ground compression

A50. Ground conditions in Britain are very variable. Natural materials affected by development activities range from very soft and very weak sediments to very hard, very strong rocks. In addition, human activities, particularly quarrying and tipping may introduce major variations in local conditions.

A51. Ground compression occurs when all ground materials are loaded or drained but in certain situations the ground deformation may be sudden or of such magnitude as to cause or to be considered examples of instability. Some natural materials (eg peat, soft silts and clays) and landfills and quarry backfill may compress significantly under load or when drained and full consolidation may take many years. The variable nature of such materials and of the bedrock surface on which they occur often leads to particular problems of differential settlement, particularly over the edge of backfilled excavations or across geological fault lines.

A52. Whilst ground compression and differential settlements have to be taken into account in any proposed development, they are not in themselves aspects of unstable ground. However, broken ground (resulting from subsidence or underground fires), unconsolidated materials filling sink holes and other surface depressions, very soft silts and clays and loose sands and loose fill (eg in landfills, backfilled quarries and opencast mines) may settle suddenly or to an increased extent as a result of development or of activities outside the development. A rising groundwater table or increased water infiltration may cause collapse settlement of loose fills. Dewatering may cause increased settlement of a large area.

A53. Compression of ground materials at greater depth also occurs and may lead to ground subsidence. The extraction of water, oil or gas has caused particular problems in some countries overseas and in the North Sea.

A54. Ground compression is thus a physical constraint on development which may lead to instability. Similar constraints may arise from other properties of ground materials apart from compressibility. Whilst not strictly unstable land, such constraints may result in damage and development needs to take them into account.

- Some uncompacted sands can cause serious damage by flowing under load or when drained rather than simply being compressed (running sands).

- Some clay minerals swell when wet and shrink when dry. Change in the natural water content of such material due to exceptional weather (as in 1976) or to human activities (tree planting/removal, leaking services) may lead to settlement or ground heave and thus damage buildings.

- Pyrite and some other minerals increase in volume on oxidation or other chemical change and this can cause heave in some Coal Measures shales and Jurassic mudstones.

- Biodegradable landfill materials decay with time and development on or near such land could be adversely affected by leachate and/or landfill gas, which may

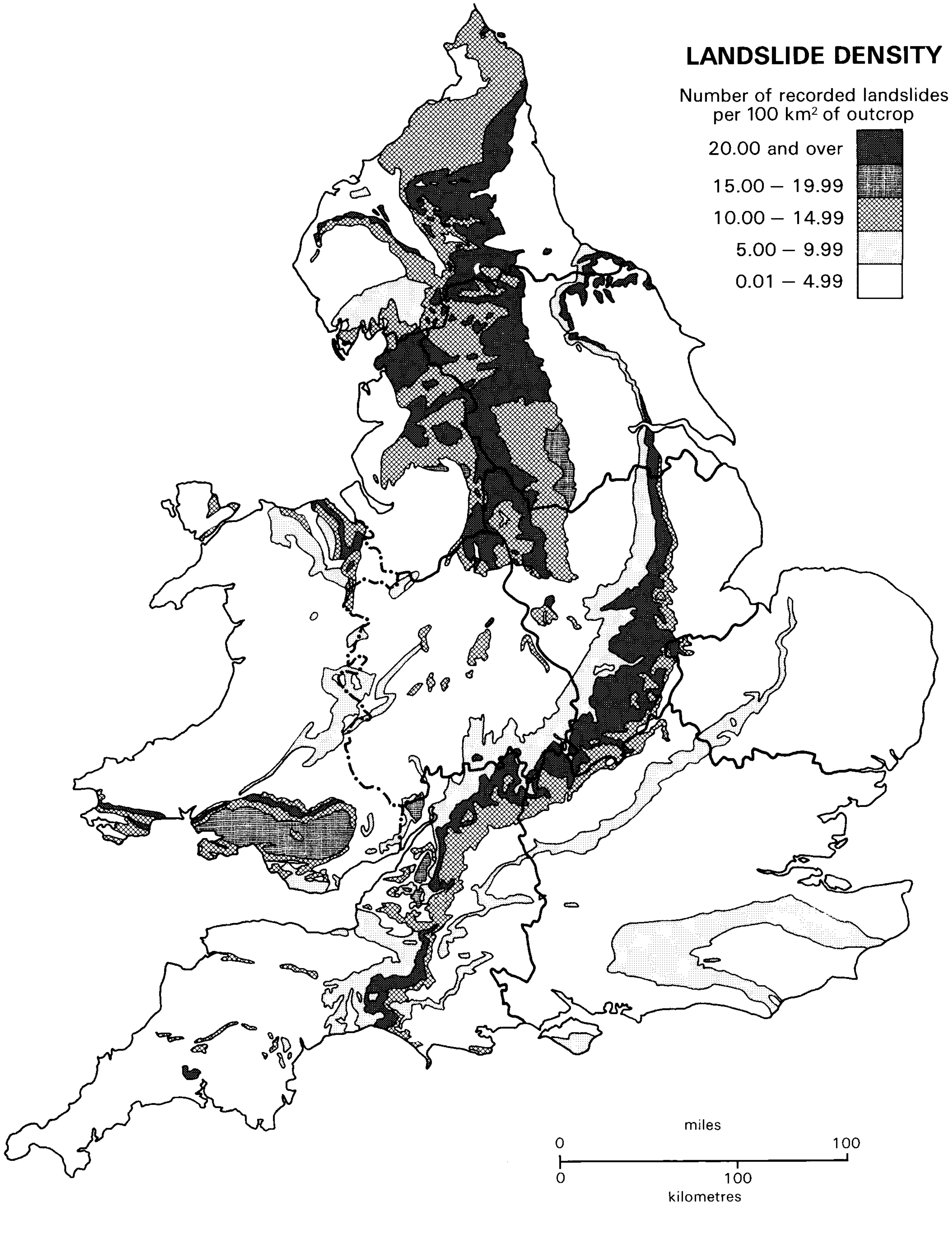

FIGURE A6 DISTRIBUTION OF STRATA WHICH HAVE A HIGH DENSITY OF RECORDED LAND SLIDES

(After Geomorphological Services Ltd. 1987. Review of research on landsliding in Great Britain.)

(see paragraph A49)

move some distance from the landfill site.

A55. Rising groundwater has been identified as a significant factor in causing instability due to ground compression. It may also adversely affect other ground characteristics and may put development, particularly tunnels and deep basements at risk of flooding. The groundwater table may rise for a number of reasons. Perhaps the commonest is reduced extraction of groundwater in older urban areas, where a long history of extraction may have considerably depressed the water table from its natural rest level. In some areas this reduction is such that with natural recharge the water table is rising at a rate of over 1m per year. Other activities which may cause groundwater level to rise include impoundment of water behind a dam, construction of a deep basement or underground barrier for pollution control, blockage of underground drainage channels (including unintentional drainage through old mine workings) or cessation of mine or quarry pumping on abandonment of operations.

A56. Knowledge on the distribution of this wide range of ground characteristics which constrain development, at least to some extent, and which may lead to instability is extremely patchy. Some characteristics, eg the distribution of swelling/shrinkable clays in the south east of England, are readily inferred from knowledge of the geology and are fairly well known. Others, such as old landfills or backfilled quarries, are much more site specific and may not be so well known.

SOURCES OF INFORMATION

1. Sources of information

B1. There are many sources of information on ground instability, its causes, effects, investigation and treatment.

B2. An obvious first source is the geological map and the British Geological Survey. The usefulness of this source has been extended by the various applied geological mapping projects carried out for the Department of the Environment by BGS and others. These have generally resulted in the establishment of databases of relevant information which may be held by the local authority in whose area work was carried out or by the National Geoscience Data Bank at the British Geological Survey, Keyworth.

B3. Coal mine abandonment plans are held at the Mining Records Offices of British Coal on behalf of the Health and Safety Executive. Abandonment plans for mines other than coal are held at the Health and Safety Executive Mines Inspectorate HQ at Bootle, except for plans of mines in Cornwall, which are held at the Cornwall County Council record office on behalf of the Health and Safety Executive. The Mineral Valuers Offices hold many records relating to mining and minerals of all types which have been collected since the formation of the Valuation Office in 1910. These are continually updated as further information becomes available. Additionally, Mineral Valuers collate and record mining subsidence incidents and analyse them. The Mineral Valuers provide advice on subsidence and the risk of damage in relation to all minerals on request to local planning authorities and other public bodies; however, they are not authorised to provide advice to private developers or their advisers.

B4. Local authority records, both technical and archival, are themselves an important source of information and will often contain records of previous events due to instability, of ground conditions and of mining.

B5. The Department of the Environment has recently completed a review of landsliding in Great Britain to determine the distribution of landslides, to review the causes and mechanisms of landsliding, to review and assess the methods of investigation, hazard assessment and remedial measures which are available and to examine the legislative and administrative provisions relating to the investigation and treatment of landslides. As a result of this review, distribution maps of landslides recorded in the published literature have been produced for all counties in England and Wales and for Scotland. A computerised data-base service has been established and is being operated by Geomorphological Services Ltd on behalf of the Department for a trial period.

B6. Reviews of the best methods of recording data about old mine entries and mine workings and of methods of treatment of mine entries appropriate to particular circumstances have recently been completed. It is likely that further specific guidance will result from these reviews.

B7. The Department has also completed a review of technical, operational, administrative and legal aspects of the stability and hydrogeology of deep mineral excavations. A comprehensive technical review has been published, together with a handbook which includes guidelines on the investigation, assessment and inspection of excavated quarry slopes. A similar handbook on quarry tips and backfill is also being produced.

B8. Further reviews of mining subsidence, natural underground cavities and of foundation conditions in Great Britain have just commenced or are about to start. These may also result in more specific guidance.

B9. Techniques for the assessment of stability problems for planning purposes have been or are being developed in the Mining Subsidence South Wales Desk Study, the Assessment of Landslip potential, South Wales and the Assessment of Landslip Potential, Isle of Wight Undercliff, Ventnor. These studies have aimed to develop techniques which are more generally applicable and could be taken on board elsewhere by local authorities and others where necessary.

B10. Other studies and guidance of value include publications by the Department of Transport, the British Standards Institution, the Construction Industry Research and Information Association, Building Research Establishment Digests and NCB (now BCC) Handbooks. Listed below are some examples of these and other relevant publications.

2. Some examples of useful publications on land stability

This list is not intended to be comprehensive but merely to give a general indication of the range of publications available which may be consulted to assist in the assessment of

stability problems and for advice on how such problems might be overcome.

DEPARTMENT OF THE ENVIRONMENT, 1988. *Review of the Geological and Minerals Planning Research Programme 1987* London, Department of the Environment - Annex I contains a catalogue of projects completed, in progress and in preparation as at December 1987.

GEOMORPHOLOGICAL SERVICES LTD 1986-87 Review of research into landsliding in Great Britain. Rpts to Dept Environ. Open-file reports.

Series A Regional review of landsliding Vol 1 South East England and East Anglia Vol II South West England Vol III The Midlands Vol IV Wales Vol V Northern England Vol VI Scotland

Series B Causes and mechanisms of landsliding Vol I International review Vol II Britain

Series C (by RENDEL PALMER AND TRITTON) Landslide investigation techniques and remedial measures - Research and Practice 2 Vols

Series D Landslides and policy Vol I Landslide hazard assessment Vol II Landslide risk in Britain Vol III Legislative and administrative provisions. Practice in England and Wales and a review of overseas practice.

Series E National summary and recommendations

FREEMAN FOX LTD 1988 *Methods of compilation storage and retrieval of data on disused mine openings and workings* Lond. HMSO

FREEMAN FOX LTD 1988 *Treatment of disused mine openings* Lond. HMSO

OVE ARUP AND PARTNERS 1976 *Reclamation of derelict land: procedures for locating abandoned mineshafts*, Lond. Dept Environ.

OVE ARUP AND PARTNERS 1983 *Limestone mines in the West Midlands: the legacy of mines long abandoned* Lond. Dept Environ, 24pp

DEPARTMENT OF THE ENVIRONMENT 1983 *Policy considerations arising from the study of limestone workings in the West Midlands* - Report by the Steering Group for the Black Country Limestone Study. Birmingham, Dept Environ, 28pp

GEOFFREY WALTON PRACTICE 1988 Handbook on the hydrogeology and stability of excavated slopes in quarries. Rpt to Dept Environ, Lond, HMSO

GEOFFREY WALTON PRACTICE 1988 Technical review of the stability and hydrogeology of mineral workings. Rpt to Dept Environ, London, HMSO

GEOFFREY WALTON PRACTICE 1986 Review of current geotechnical practice in British quarries and related interests and requirements of mineral planning authorities and other statutory bodies. Rpt to Dept Environ, Feb 1986

GEOFFREY WALTON PRACTICE 1986 Review of existing relevant controls and legal powers affecting the stability and hydrogeology of mineral workings Rpt to Dept Environ. July 1986

GEOFFREY WALTON PRACTICE 1986 Report on a hydrogeological and geotechnical study at a limestone quarry Rpt to Dept Environ, July 1986

GEOFFREY WALTON PRACTICE 1986 Final report on the stability and hydrogeology of mineral workings. Rpt to Dept Environ. July 1986

OVE ARUP AND PARTNERS 1985 Mining subsidence South Wales desk Study Report. Rpt to Dept Environ, Welsh Office, 5 vols Open-file report

SIR WILLIAM HALCROW AND PARTNERS 1986 Assessment of landslip potential: South Wales. Rpt to Dept Environ, Welsh Office, 3 vols. Open-file report

SIR WILLIAM HALCROW AND PARTNERS 1988 Rhondda landslip potential assessment; Planning guidelines. Rpt to Dept Environ, Welsh Office. Open-file report

BRITISH STANDARDS INSTITUTION 1981 Code of practice for site investigations: BS 5930. Lond, BSI

BRITISH STANDARDS INSTITUTION 1986 Code of practice for foundations CP 8004

BRITISH STANDARDS INSTITUTION 1975 Methods of test for soils for civil engineering purposes, BS 1377

BRITISH STANDARDS INSTITUTION 1988 Code of practice for the identification of potentially contaminated land and its investigation DD175. Lond. BSI

BRITISH STANDARDS INSTITUTION 198 Code of practice for earth retaining structures. BS 8002. Lond. BSI

BRITISH STANDARDS INSTITUTION 1981 Code of practice for earchworks. BS 6031. Lond. BSI

BRITISH STANDARDS INSTITUTION 1980 Code of practice for trees in relation to construction. BS 5837. Lond. BSI

BRITISH STANDARDS INSTITUTION 1988 Report on strengthened/reinforced soils and other fills. PD 6517. Lond. BSI

DEPARTMENT OF TRANSPORT 1982 *Design of highway structures in areas of mining subsidence*, BD 10/82

DEPARTMENT OF TRANSPORT 1987 *Ground investigation procedures* HA 34/87

NATIONAL COAL BOARD 1975 *Subsidence engineers' handbook*, Lond, NCB, 111pp

NCB MINING DEPARTMENT 1982 *The treatment of disused mineshafts and adits*, Lond, NCB 88pp

WELTMAN, A J *and* J M HEAD 1983 *Site investigation manual*, PSA Civ Engng Tech Guide No 35, CIRIA Spec Publicn 25, Lond.

HEALY, P R *and* J M HEAD 1984 *Construction over abandoned mine workings*, PSA Civ Engng Tech Guide No 34, Spec Publicn No 32, CIRIA, Lond

UFF, J F *and* C R I CLAYTON 1986 *Recommendations for the procurement of ground investigation*, CIRIA Spec Publicn 45, Lond.

SIMPSON, B and others 1989 *The engineering implications of rising groundwater levels in the deep aquifer beneath London*, CIRIA Spec Publicn No 69, Lond, CIRIA.

DUMBLETON, M J 1973 Available information for route planning and site investigation - Report on a TRRL Symposium *TRRL Lab Rpt* **LR 591**

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DUMBLETON, M J *and* G WEST 1976 Preliminary sources of information for site investigations in Britain *TRRL Lab Rpt* LR 430

DUMBLETON, M J 1983 Air photographs for investigating natural changes, past use and present condition of engineering sites. *TRRL Lab Rpt* LR 1085

O'REILLY, M P *and* B M NEW 1982 Settlements above tunnels in the United Kingdom - their magnitude and prediction *Proc Tunnelling '82* Lond, Instn Mining Metall, 173-81

BRITISH GEOTECHNICAL SOCIETY 1988 The geotechnical directory of the United Kingdom, 1987-88. Lond. Instn Civil Engrs.

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FORDE, M C 1988 Mine workings 88. Proc. Int. Cont. on Construction in areas of abandoned mineworkings. Edinb., Engineering Technics Press

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WALTHAM, A C 1989. *Ground Subsidence*, London, Blackie and Son Ltd

WHITTAKER, B N *and* D J REDDISH 1989 *Subsidence-Occurrence, prediction and control* Amsterdam, Elsevier, 528 pp

PARSONS, A W *and* J PERRY 1985 Slope stability problems in ageing highway earthworks *Proc Failures in Earthworks*, Lond, Instn Civ Engrs, 53-68

ROYAL INSTITUTION OF CHARTERED SURVEYORS 1978 *The problem of disused mineshafts*, Lond, RICS Minerals Div

NATIONAL HOUSE BUILDING COUNCIL 1988 *Registered house-builder's foundations manual. Preventing foundation failures in new dwellings*. Lond, NHBC, 47pp

NATIONAL HOUSE BUILDING COUNCIL 1986 Building near trees. *NHBC Practice Note 3 (1985)*, 22pp

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