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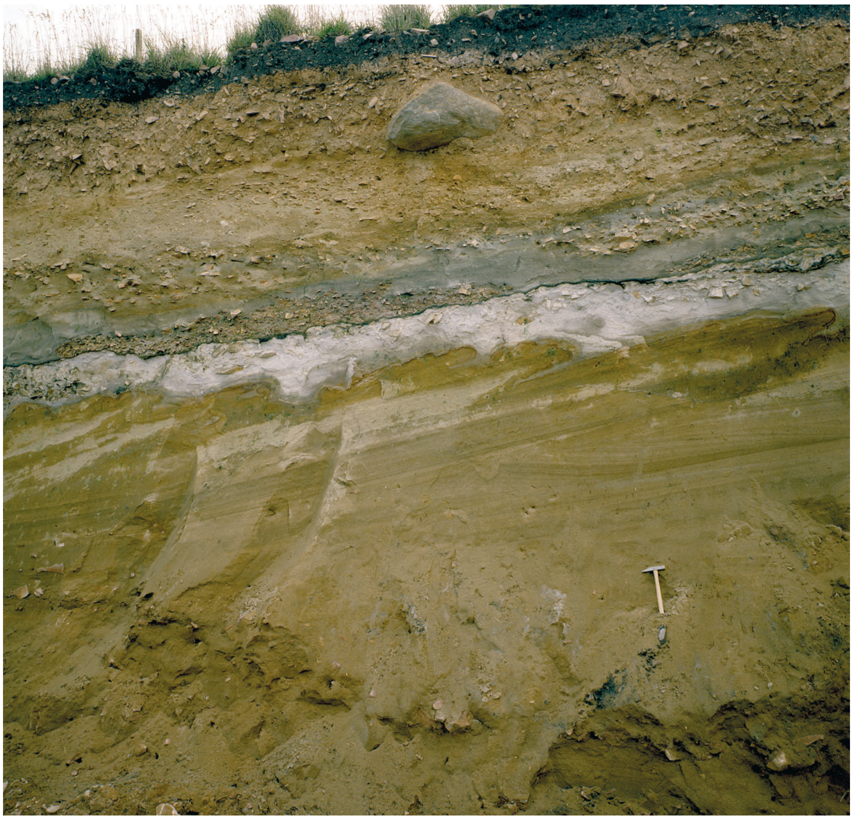
An overview of the lithostratigraphical framework for the Quaternary and Neogene deposits of Great Britain (onshore)

Geology, Geotechnics and Palaeontology, Development of Capability Programme

Research Report RR/04/04



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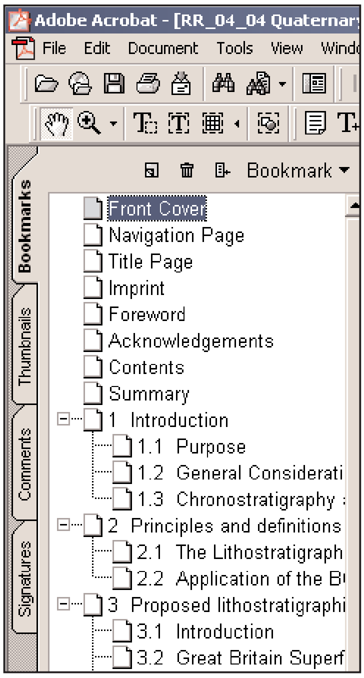

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BRITISH GEOLOGICAL SURVEY

RESEARCH REPORT RR/04/04

An overview of the lithostratigraphical framework for the Quaternary and Neogene deposits of Great Britain (onshore)

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Keywords

Quaternary, Neogene, lithostratigraphy, superficial deposits.

Front cover

Kirkhill Interglacial Site [NK 011 528], near Strichen, Aberdeenshire; showing interbedded tills, fossil soils (white horizon), sand and gravel and solifluction deposits of the Caledonia and Albion Glacigenic groups.

Bibliographical reference

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Foreword

This report results from a study by the British Geological Survey (BGS) to rationalise the Quaternary lithostratigraphy of Great Britain (England, Scotland and Wales). The report proposes a new lithostratigraphical framework which utilises the full hierarchy of the stratigraphical code, that is supergroup, group, subgroup and formation (together with smaller units) for the correlation of the onshore Quaternary and Neogene deposits of Great Britain. It presents an overview of the proposed framework. Formations (the principal mapping units) will be described in greater detail in the forthcoming full framework report (in preparation). The objective of both reports is to provide a regional lithostratigraphical scheme for Great Britain to aid future Quaternary mapping and correlation (onshore and offshore), and to propose a stratigraphical scheme capable of use in a wide variety of applications.

David A Falvey
Executive Director
British Geological Survey

Acknowledgements

This report is the result of much discussion and lively debate both within the BGS and with external researchers regarding the application of lithostratigraphical principles to Quaternary deposits. Following a workshop held at the British Geological Survey (BGS), Keyworth in February 1998, two framework committees (SFCs) were established by Dr Peter Allen (at that time, Assistant Director, BGS) to consider stratigraphy to the north and to the south of the main Late Devensian ice sheet limit. The SFCs were chaired by Dr Richard Hamblin (South) and Mr Andrew McMillan (North). Draft reports prepared by the committees aimed at a common goal of establishing a useable lithostratigraphy for Great Britain (onshore). The exercise also highlighted differences of approach to the application of lithostratigraphy to the Quaternary and differences across Great Britain in the nature of the deposits, and both depositional and post-depositional environments. Concurrently the Geological Society Special Report No. 23 entitled *A revised correlation of Quaternary deposits in the British Isles* was published in 1999. That report described over 1400 units at formation, member and bed level and considered the criteria for defining larger bodies of Quaternary deposits.

To inform the framework committees an Open Progress Meeting on Quaternary lithostratigraphy was held at BGS, Keyworth in February 2001. Subsequently, during the autumn of 2002, the original participants of the two committees were brought together under the BGS Superficial Deposits Advisory Group (SDAG) as a result of the recommendations of the Programme Development Group for Onshore Surveys (Walton and Lee, 2001). The SDAG, led by Andrew McMillan, was part of the BGS Geology, Geotechnics and Palaeontology Programme, under the direction of Dr J H Powell. The authors of the present overview report acknowledge the work of the SDAG members together with others in BGS who have offered constructive advice. The counsel of external contributors is also acknowledged especially that of Professor Jim Rose (Royal Holloway, University of London) who participated in SDAG committee meetings and Dr Phil Gibbard (University of Cambridge) who provided helpful advice following the 2001 Open Progress meeting.

In compiling this report, the authors readily acknowledge the assistance of several BGS colleagues. They thank members of the BGS Stratigraphy Committee for contructive comment, and J H Powell and S J Booth who reviewed an earlier draft. They also extend thanks to three external reviewers acting for the Geological Society Stratigraphy Commission, namely Dr P L Gibbard, Dr W Westerhoff and Prof D Q Bowen.

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This report presents an overview of the proposed BGS lithostratigraphical framework for the onshore Quaternary deposits of Great Britain (England, Scotland and Wales). The objective of the report is to provide a practical framework to aid future Quaternary correlation, mapping and research, and a stratigraphical scheme capable of use in a wide variety of applications. A full lithostratigraphical framework report describing the scheme in greater detail is in preparation (McMillan and Hamblin, in prep).

A framework that utilises the full hierarchy of the stratigraphical code (supergroup, group, subgroup, formation and smaller units) is proposed. Although the framework is built around the formation, the primary unit for mapping and correlation, it is recommended that some classes of lithogenetically-defined deposits are not accorded formational status. However, at group level the scheme embraces all Quaternary deposits, thus enabling a coded lithostratigraphical superscript to be applied to every Quaternary map symbol defined in the BGS specifications for the preparation of 1:10 000 scale geological maps (Ambrose, 2000). The map specifications are based upon the lithogenetic classification of Quaternary deposits, as outlined in BGS Rock Classification Scheme (RCS) for artificial and natural superficial deposits (McMillan and Powell, 1999). In parts of Great Britain lithostratigraphical mapping at formation level can only be regarded as a long-term objective. Products such as lithostratigraphical maps, cross-sections and three-dimensional models may therefore be regarded as an evolving layer in the geological model of Great Britain.

The unified lithostratigraphical framework for onshore Quaternary deposits is designed to be of use for regional mapping and correlation and may also be of relevance for regional hydrogeological and geotechnical applications. For example the lithostratigraphical classification can be used to enhance geological and hydrogeological domains maps and models depicting landform–sediment associations (McMillan et al., 2000).

The current report is based upon a review of published literature (including BGS geological maps and reports), and expert local knowledge. Extensive reference is made to the Geological Society of London Special Report No. 23–*A revised correlation of Quaternary deposits in the British Isles* (Bowen, 1999).

1 Introduction

1.1 PURPOSE

The purpose of this report is to set out a lithostratigraphical framework for onshore Quaternary deposits of Great Britain (England, Scotland and Wales). Some Neogene deposits are also considered with the framework. The framework has been constructed using established principles of stratigraphy that involve firstly, the description and interpretation (lithostratigraphy) of Quaternary units, correlation by all possible means and finally classification. There should be a clear distinction between factual description based upon observation and inference such as inferred correlation with chronostratigraphical scales defined by climatic fluctuation or with the oxygen isotope stratigraphical scale derived from ocean sediments.

The framework is based upon a review of the extensive British literature (including BGS geological maps) and the Geological Society of London Special Report No. 23–*A revised correlation of Quaternary deposits in the British Isles*, edited by Bowen (1999), a revision of Mitchell et al. (1973). As discussed below, for practical reasons emphasis is placed on the application of the full hierarchy of lithostratigraphical codes which may have application for regional mapping, classification and correlation.

The report demonstrates how the lithostratigraphical codes have been interpreted and applied to Quaternary deposits (Chapter 2) and presents an overview of the new lithostratigraphical framework and units at supergroup, group, subgroup and formation levels (Chapters 2 and 3, Tables 1–6). Groups and subgroups are wholly or partially defined by formations, which form the primary mapping unit, and by lithogenetic units. Inferred correlation with marine isotope stages is presented in Tables 1–6. Recommended nomenclature for Quaternary units is shown in Table 7.

The more detailed, lithostratigraphical framework report (McMillan and Hamblin, in prep), will describe formations and members region by region throughout Great Britain. In compiling both reports the authors resolved that, the lithostratigraphical framework should aim to:

- conform as far as possible with international stratigraphical principles for lithostratigraphical classification as provided by the International Union of Geosciences (IUGS) (Hedberg, 1976; Salvador, 1994). Regional application of these guides is offered by the North American Commission on Stratigraphical Nomenclature (NACSN, 1983) and the guidance of Whittaker et al. (1991) and Rawson, et al. (2002)
- serve as a basis for geological mapping and correlation
- assist the user (both the Quaternary specialist and non-specialist) of geological data including BGS maps memoirs and sheet explanations, and
- provide a basis ultimately for a Quaternary lithostratigraphical map of Great Britain and three-dimensional modelling.

1.2 GENERAL CONSIDERATIONS

As Powell (1998) has stated, 'In science and engineering, classification is essential if written and oral communications are to be precise and unambiguous.' For onshore Quaternary strata the application of a strict lithostratigraphical classification presents unique difficulties. A wide range of processes has operated during the Quaternary (the last 1.81 Ma, as internationally defined*; see also Lourens et al., 1996; Ehlers and Gibbard, 2003) (Table 1). Deposits are discontinuous, variable in thickness and commonly poorly exposed. The regional significance of unconformities and discontinuities seen in sections or boreholes may be poorly understood. The fragmentary nature of the record, the ill-defined field relationships and the poorly fossiliferous nature of many deposits, with little organic or other dateable material, make the construction of a lithostratigraphical framework a sizeable task.

Where lithostratigraphy has been applied to British Quaternary deposits it has usually been to define locally well-exposed sequences in natural sections, excavations and boreholes, where stratigraphical relationships can be observed. National or regional correlation may not be possible. This is reflected in the stratigraphical schemes published by Bowen (1999) in which formations may be restricted to districts where correlation is secure. Tentative correlation may then be made with differently named units of adjoining areas. Many of the lower level units, particularly at member and bed level, referred to in Bowen (1999) have been defined at one or more well-exposed sections or from boreholes. Such units, as Bowen (1999) confirms, 'are not amenable to systematic and widespread mapping away from their stratotypes'. Nevertheless these units are important for correlation and for inferences about climate and palaeoenvironment.

To address the need to regionally correlate larger bodies of Quaternary deposits, the BGS Superficial Deposits Advisory Group (a Stratigraphical Framework Committee) has been preparing a new lithostratigraphical framework for the onshore Quaternary deposits of Great Britain. The current overview report and a more detailed Quaternary lithostratigraphical framework report (McMillan and Hamblin, in prep.) take into account conclusions from two workshops on stratigraphical classification and nomenclature of British Quaternary deposits held at the BGS, Keyworth, Nottingham in February 1998 and February 2001. McMillan and Hamblin (2000) published initial ideas on the framework. An early version of the current framework was presented at the TNO International Workshop on Integrated Land-Sea Lithostratigraphic Correlation in Utrecht, The Netherlands (April 2003) (McMillan, 2005).

* The BGS Timescale currently adopts the internationally accepted 1.81 million years (Ma) (after Gradstein and Ogg, 1996). Many Quaternary scientists support the proposal to redefine the base of the Quaternary as the current GSSP of the Gelasian Stage at about 2.6 Ma (for discussion see Pillans, 2004; Gibbard et al., 2005). This age, which more accurately represents the onset of northern hemisphere glaciations, is coincident with the Gauss/Matuyama palaeomagnetic Epoch boundary and is correlated with the peak of Marine Isotope Stage 103.

Table 1 Summary of the Quaternary and late Neogene lithostratigraphical framework for Great Britain with relationship of groups to Quaternary stages and suggested correlation with marine isotope stages.

Notes. Climatostratigraphical stages for Great Britain and north-west Europe are based on inferences from biostratigraphical (pollen) and lithological evidence for 'temperate' and 'cold' events. Ages: bases of series and subseries are taken from the Phanerozoic time scale of Gradstein and Ogg (1996). The early/middle Pleistocene boundary is correlated with the Bruhnes — Matuyama magnetic reversal, correlated with Marine Isotope Stage 19. The base of the Pleistocene Series is defined at the base of the marine claystones conformably overlying the marker bed sapropel layer 'e' in the Vrica section, Calabria, Italy (Aguirre and Passini, 1985). Suggested correlation with marine isotope stages for Early to Middle Pleistocene is after Zagwijn (1992) and Funnell (1996), based on the stages of Shackleton et al. (1990).
Abbreviations: ka = 1000 calibrated radiocarbon years; Ma = 10^6 years; MIS = Marine Isotope Stage (inferred correlation).
The Crag Group is defined by marine formations.
The Dunwich Group is defined by fluvial formations within pre-Anglian palaeocatchments.
The Residual Deposits Group includes Clay-with-Flints.
The British Coastal Deposits Group is defined by coastal, estuarine and marine formations.
The Britannia Catchments Group is divided into subgroups defined by fluvial formations within major drainage systems (includes peat, head, cover sand, loess and mass movement deposits).
The Caledonia Glacigenic Group, lying mainly to the north of the Devensian limit, is divided into subgroups defined by till formations with associated glacigenic units. Some glaciofluvial units extend south of the Devensian limit.
The Albion Glacigenic Group, preserved mainly to the south of the Devensian limit, is divided into formations; to the north, the group is divided into subgroups defined by till formations with associated glacigenic units.

SERIES	SUBSERIES	**British Quaternary Stage (Onshore)** (Gordon and Sutherland, 1993; Mitchell et al., 1973; West, 1961, 1980; Zalasiewicz et al., 1991)		**NW European Quaternary Stage** (Gibbard et al., 1991; Funnell, 1996; Lister, 1998, 2000; Zagwijn, 1992)	**MIS**	SUPERGROUP	**GROUPS** Glacigenic deposits	**GROUPS** Non-glacigenic deposits		
HOLOCENE 11.5 ka					1–2	GREAT BRITAIN SUPERFICIAL DEPOSITS SUPERGROUP			BRITANNIA CATCHMENTS GROUP	BRITISH COASTAL DEPOSITS GROUP
PLEISTOCENE	LATE	DEVENSIAN	Loch Lomond Stadial (Younger Dryas)	WEICHSELIAN			CALEDONIA GLACIGENIC GROUP			
			Windermere Interstadial (Bølling/Allerød)							
			Dimlington Stadial		3					
					4					
					5a–5d					
	0.126 Ma	IPSWICHIAN		EEMIAN	5e					
	MIDDLE	'WOLSTONIAN'		SAALIAN	6–10		ALBION GLACIGENIC GROUP			
		HOXNIAN		HOLSTEINIAN	11					
		ANGLIAN		ELSTERIAN	12					
	0.78 Ma	CROMERIAN		CROMERIAN COMPLEX	13–21			RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAG GROUP
	EARLY	BEESTONIAN		BAVELIAN	22–64					
				MENAPIAN						
				WAALIAN						
				EBURONIAN						
	1.806 Ma	PASTONIAN		TIGLIAN C5–6						
PLIOCENE	GELASIAN	PRE-PASTONIAN		TIGLIAN C4c	65–95					
		BAVENTIAN								
		ANTIAN/ BRAMERTONIAN		TIGLIAN C1–4b						
		THURNIAN		TIGLIAN B						
		LUDHAMIAN		TIGLIAN A						
		PRE-LUDHAMIAN		PRAETIGLIAN	96–100					
	2.588 Ma			REUVERIAN C	103					

Table 2 Examples of formations of the Crag Group, Dunwich Group and Residual Deposits Group.

Lex Code = Codes from the BGS Lexicon of named rock units (where assigned). Emboldened codes denote that the unit has been formally defined in the Lexicon. MIS = Marine Isotope Stage (inferred correlation).

GROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
DUNWICH GROUP	Letchworth Gravels Formation	**LTH**	13–?	Defined by Smith and Rose (1997)	
	Cromer Forest-bed Formation	CRF	17–?	Freshwater members of the Cromer Forest-bed Formation of Lewis in Bowen (1999)	Lewis, p.15
	pedogenic units (Valley Farm Soil) above Kesgrave Formation and Bytham Formation			Lewis in Bowen (1999)	Lewis, p.22
	Bytham Formation	BYTH	13–?	Proposed formation. Members include: Timworth Gravel, Knettishall Gravel, Ingham Farm Gravel, Seven Hills Gravel, High Lodge Gravel, Lakenheath Gravel, Fodderstone Gravel and Shouldham Thorpe Gravel members. Bytham Sands and Gravels defined by Rose (1994) and Bateman and Rose (1994). Includes the Ingham Sand and Gravel (Clarke and Auton, 1982; Lewis, 1993; Lewis in Bowen, 1999). Also includes the Shouldham Formation of Lewis in Bowen (1999)	Lewis, p.19
	Kesgrave Formation	**KES**	? 61–13	Proposed formation. Includes Lower St Osyth, Wivenhoe, Ardleigh and Waldringfield members, of the Colchester Formation (Kesgrave Group) of Whiteman and Rose (1992)	Lewis, p.22 Allen, p.24 Gibbard, p.57
				Beaconsfield*, Satwell*, Westland Green*, Waterman's Lodge† and Stoke Row* members of the Sudbury Formation (Kesgrave Group) of Whiteman and Rose (1992)	Gibbard, p.47–49: (*Middle Thames Formation. †Northern Drift Formation)
		GCGR WLGR	Pre-12	Gerrards Cross Gravel Formation and Westmill Gravel Formation of Ellison et al. (2004). Members of Middle Thames Formation of Gibbard in Bowen, 1999)	Gibbard, p.47–49
CRAG GROUP	Stanmore Gravel Formation	STGR	? Pre-22	'High-level' gravels formerly referred to 'Pebble Gravel' (Gibbard in Bowen, 1999; Ellison et al., 2004)	Gibbard, p.48
	Wroxham Crag Formation	WRCG	? 17– ? 67	Established by Hamblin (2001), Rose et al. (2001) and Moorlock et al. (2002). The Sidestrand Member of the Norwich Crag Formation (Lewis in Bowen, 1999), and the marine Paston and Mundesley members of the Cromer Forest-bed Formation (Lewis in Bowen, 1999) are included.	Lewis, p.15
	Norwich Crag Formation	**NCG**	? 68– ? 81	Established by Funnell and West (1977). Four members (Mathers and Zalesiewicz, 1988; Lewis in Bowen, 1999); the Chillesford Clay, Chillesford Sand, College Farm Clay and Creeting Sand	Lewis, p.22
	Red Crag Formation	**RCG**	? 82–	Established by Funnell and West (1977). Zalasiewicz et al. (1988) defined two members in Suffolk: Sizewell and Thorpeness members. The Ludham Member of Norfolk (Lewis in Bowen, 1999) and the Netley Heath Member of the Blackwater–Lodden valleys (Gibbard in Bowen, 1999) also defined	Lewis, p.22 Gibbard, p.53
	Coralline Crag Formation	CCG		Defined by Balson et al. (1993) with three members: Aldeburgh, Sudbourne and Ramsholt members	
RESIDUAL DEPOSITS GROUP	Clay-with-Flints	CWF		Defined by Pepper (1973), Catt (1986) and Ellison et al. (2004).	
	Buchan Gravels Formation	**BUG**		Merritt et al. (2003)	

The BGS workshops addressed a number of questions fundamental to the establishment of a workable lithostratigraphical framework which takes as its premise its ability to be applied to geological mapping. Principal conclusions from the workshops and subsequent discussion included the following:

- The formation is the fundamental mapping unit (Hedberg, 1976; North American Commission on Stratigraphic Nomenclature — NACSN, 1983; Whittaker et al., 1991; Salvador, 1994; Bowen, 1999; Rawson et al., 2002).
- Members and beds may also be mappable units at appropriate scales.
- Grouping of formations is desirable, particularly to aid regional mapping (Salvador, 1994) and interpretation by non-geologists.
- Groups and subgroups may or may not be composed entirely of named formations (NACSN, 1983) but the establishment of groups without constituent formations should be avoided (Salvador, 1994).
- Lithogenetic descriptors for high-level units (super-groups, groups and subgroups) and for formations

Table 3 Examples of formations of the British Coastal Deposits Group.

Formations comprise mainly coastal and marine deposits. Locally interbedded fluvial and organic deposits may also be present.
LLS = Loch Lomond Stadial (Younger Dryas); WIS = Windermere Interstadial (Bølling/Allerød).
Lex Code = Codes from the BGS Lexicon of named rock units (where assigned). Emboldened codes denote that the unit has been formally defined in the Lexicon. MIS = Marine Isotope Stage (inferred correlation).

GROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
BRITISH COASTAL DEPOSITS GROUP	Beauly Silt Formation Moniack Peat Formation Foulis Silt Formation Lemlair Sand Formation Ardullie Silt Formation		1	Proposed formations — Beauly Firth, NE Scotland. Formerly members of the Cromarty and Clava formations (Sutherland in Bowen, 1999)	Sutherland, p.103–106
	Balmeanach Silt Formation Barnyards Silt Formation		1 (LLS)		
	Culbokie Silt Formation Kessock Bridge Silt Formation	 **KEBR**	1–2 (WIS)		
	Spynie Clay Formation St Fergus Silt Formation	**SPYCL** **SFSI**	2	NE Scotland formations (Merritt et al., 2003)	
	Ardyne Formation		1–2 (LLS-WIS)	Killelan, Toward, and Ardyne Point members defined as units by Peacock et al. (1978)	Sutherland, p.110
	Clydebank Clay Formation	 GOSA ERSK LUGH BCHN	1	Proposed formation with following members (after Browne and McMillan, 1989): Gourock Sand Member Erskine Clay Member Longhaugh Sand and Gravel Member Buchanan Clay Member	Sutherland, p.110
	Clyde Clay Formation	 INVN BOCH LIWD PAIS KARN BRON	1–2 (WIS-LLS)	Proposed formation with following members (after Browne and McMillan, 1989): Inverleven Gravel Member Balloch Clay Member Linwood Moss Clay Member (Linwood Borehole) Paisley Clay Member (Linwood Borehole) Killearn Sand and Gravel Member Bridgeton Sand Member	
	Grangemouth Formation		1	After Browne and Gregory (1984); Saltgreens, Skinflats and Grangemouth Docks members after Barras and Paul (1999)	Sutherland, p.113–114
	Claret Silt and Clay Formation			After Claret Formation of Barras and Paul (1999)	
	Letham Silt Formation		1–2 (WIS)	Units established by Browne et al. (1984), assigned as members of the Forth–Teith Formation by Sutherland in Bowen (1999) and now proposed as formations	
	Bothkennar Gravel Formation Abbotsgrange Silt Formation Kinneil Kerse Silt Formation Loanhead Clay Formation		2		
	Kingston Sand Formation Post-Carse Estuarine Formation Carse of Gowrie Clay Formation		1	Proposed formations. Units defined by Paterson et al. (1981) and Armstrong et al. (1985). Mainly assigned as members of the Forth–Teith Formation by Sutherland in Bowen (1999)	Sutherland, p.114
	Carey Sand and Silt Formation		1 (LLS to Holocene)		
	Culfargie Sand Formation Powgavie Clay Formation		1–2 (WIS)		
	Errol Clay Formation		2	Proposed formation. Errol Beds of Paterson et al. (1981), Errol Member of Tay Formation (Sutherland in Bowen, 1999) Correlated with St Abbs Formation (offshore) Stoker et al. (1985)	Sutherland, p.114; Holmes, p.130
	Girvan Formation		1	Established by Sutherland in Bowen (1999)	Sutherland, p.109
	Redkirk Formation		1	Established by Sutherland in Bowen (1999). Component units defined by Bishop and Coope (1977). Bigholm Burn Member now assigned to the Solway Esk Valley Formation	Sutherland, p.107
	Point of Ayre Formation	POA	1	Established by Thomas in Bowen (1999); revised by Chadwick et al. (2001)	Thomas, p.94

Table 3 *continued*

GROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
BRITISH COASTAL DEPOSITS GROUP (cont.)	Lytham Formation		1	After formation established by Thomas in Bowen (1999)	Thomas, p.95
	Drigg Point Sand Formation			Formation established by Merritt and Auton (2000)	
	Hall Carleton Formation		1–2 (WIS)	Nethertown Gravel, Rabbit Cat Silt, Netherholme Sand and Fern Bank Silt members established by Merritt and Auton (2000)	
	Glannoventia Formation	**GVA**	? 3	Formation established by Merritt and Auton (2000)	
	Grange Formation		1–2	Formations established by Thomas in Bowen (1999)	Thomas, p.95–96
	Seacombe Sand Formation		? 2		
	Shirdley Hill Sand Formation	**SSA**	1–? 2		
	Kenfig Formation		1	Defined by Bowen (1999)	Bowen, p.83
	Ynyslas Formation			Proposed formations in Wales. Stratotypes to be defined.	
	Wentloog Formation				
	Gower Formation		5e		
	Breydon Formation	BRYD	1	Formations defined by Arthurton et al. (1994) for NE Norfolk	
	North Denes Formation	NRD			
	Fenland Formation	FEND	1	Ventris (1985), McCabe in Bowen (1999), Lewis in Bowen (1999)	McCabe, p.14 Lewis, p.16
	Morston Formation		? 6	Formerly Morston Member of Hunstanton Formation (Lewis in Bowen, 1999)	Lewis, p.18
	Romney Marsh Formation		1	Formation established by Gibbard and Preece in Bowen (1999)	Gibbard and Preece, p.61
	West Sussex Coast Formation		2–13	Component units described by Hodgson (1964)	Gibbard and Preece, p.61–62
	Poole Harbour Formation		1	Proposed Formation. To include Poole Harbour Member (Gibbard and Preece in Bowen, 1999)	Gibbard and Preece, p.64
	Gwent Levels Formation Oldbury and Avonmouth Levels Formation		1	Proposed formations. Stratotypes to be defined.	
	Somerset Levels Formation		1	Defined by Campbell et al. in Bowen (1999)	Campbell et al., p.78
	Burtle and Kenn Gravel Formation		? 5b	Defined as Burtle Formation with several members by Campbell et al. in Bowen (1999)	Campbell et al., p.77–78

(if lithologically heterogeneous) could help to define the framework.

- Lithological/grainsize descriptors (e.g. sand, gravel) for formations and members are desirable where they clearly convey a dominant lithological/ grainsize component of the unit.
- Morphological descriptors (e.g. moraine, terrace) for members could be valuable for deposits of variable or poorly known lithology.
- It is not necessary or desirable to define all Quaternary units in a formal lithostratigraphy at formation level. In Britain and elsewhere, lithogenetic classification is a tried and tested practical mapping and descriptive tool, and will continue to be used as the primary method for describing Quaternary deposits. Lithogenetic units are locally mappable assemblages of rock strata, considered without regard to time (Schenck and Muller, 1941; Salvador, 1994). Some lithogenetic units are not readily amenable to lithostratigraphical classification at formation level because their stratigraphical relationships are poorly known (e.g. mass movement deposits).
- River terrace deposits should be considered as members of formations defined by a single catchment (i.e. major river and its tributaries).

Traditionally, and in common with many other geological surveys, the BGS has published maps and literature that employ a mixture of lithological, morphological and genetic terminology (Foster et al., 1999). The terminology has been developed by successive generations of survey geologists to map surface Quaternary deposits (usually within the top metre of the surface) and to log sections and boreholes. Observation and recording of lithology, structure and morphology of deposits has led to the interpretation of their origin. Mapping practice has led to the refinement of the familiar specification of mapping symbols which feature on BGS maps at all scales ranging from the primary mapping scales of 1:10 000 and 1:25 000 to the most commonly published 1:50 000 scale (Ambrose, 2000). The specification corresponds to the hierarchical *Rock Classification Scheme for Natural and Artificial Superficial Deposits* (McMillan and Powell, 1999). The BGS classification now forms the basis of, and the dictionary for, digital products such as the digitised and attributed 1:50 000 scale geological map coverage of Great Britain (DigMapGB-50) which requires the data to be structured for sensible retrieval of information (McMillan, 2002). Such objectives are common to many geological surveys and similar lithogenetic schemes have been established in many European countries (e.g. in France, Lebret et al., 1993).

In attempting to define a broad framework based upon international and national stratigraphical guidance (North American Commission on Stratigraphical Nomenclature, 1983; Whittaker et al., 1991; Salvador, 1994; Rawson et al, 2002; see also Chapter 2) the BGS Superficial Deposits Advisory Group identified a number of factors which, if not unique to British and continental north European Quaternary deposits, are unusual in other parts of the stratigraphical column.

- Onshore Quaternary deposits vary greatly in both lateral and vertical extent. Although sequences can attain thicknesses of 200 m or more, commonly component lithostratigraphical formations may be only a few metres thick.
- By their nature many Quaternary units (e.g. till sheets) are strictly allostratigraphical, i.e. defined and identified on the basis of bounding discontinuities. However allostratigraphy has not been popularly applied in Britain (Rawson et al., 2002).
- Many Quaternary lithostratigraphical units, being surficial deposits, will have no overlying strata (or bounding surface). However, the associated landform may show characteristic features that can aid the definition of a unit.
- The distribution of some mass movement and fluvial deposits can be related to the present day physiography but caution should be applied when assigning lithostratigraphical classification to units which are unrelated to modern catchments (see Section 1.2.2 below).
- The lithology of many Quaternary deposits is determined by the medium of transport, the medium of deposition and by provenance. Inferred genesis and provenance may aid lithostratigraphical classification of heterogeneous superficial deposits but always there should be a clear distinction made between inference and description. Provenance may not be directly related to the present-day surface distribution of bedrock (level of erosion).
- Weathering characteristics and soil development play an important role in Quaternary stratigraphy.
- Some Quaternary deposits may be the result of modern, active processes, e.g. storm beach which may be removed in a very short period of time.

Differentiation of Quaternary lithostratigraphical units by origin is to be avoided (Salvador, 1994) but it has long been recognised that such units can be classified in this way. For example, in establishing the Pleistocene stratigraphical framework of Illinois, Willman and Frye (1970) noted that their formations, defined by lithology, could also be differentiated by origin into five general types. They commented that 'Although these are genetic groupings, their different origins impart distinctive compositions, grain size and structure and the formations are differentiated on lithology and not on origin.' These authors did not define groups but noted that groupings could be made as the need arises.

This recognition of the link between origin and lithology has guided the development of the proposed framework for Great Britain. Thus whilst formations are defined on the basis of distinctive lithology, they may be grouped on both lithological criteria and principal sedimentary environment (e.g. glacial, fluvial, marine). For example, the newly proposed facies association scheme of the integrated land and sea stratigraphical model of the Netherlands and the Dutch sector of the North Sea (Laban et al., 2003) assigns formations to broad facies associations (glacigenic, marine and fluviatile). As Salvador (1994) notes, 'the degree of change in lithology required to justify the establishment of distinct formations (or other lithostratigraphic units) is not amenable to strict and uniform rules. It may vary with the complexity of the geology of a region and the detail needed to portray satisfactorily its rock framework and to work out its geologic history'. Pragmatic decisions require to be taken about the grouping of formations. For example interbedded marine and fluvial sediments of coastal embayments or fenland may appropriately be grouped together. Additionally, it is evident that the distribution of Quaternary formations can be linked not only to the processes by which they formed or were modified, but also to geographical setting (see Sections 1.2.1 and 1.2.2 below). This too has influenced the establishment of the proposed groups and subgroups (Figures 1–3, Table 1; see Chapters 2 and 3).

1.2.1 Glacigenic deposits

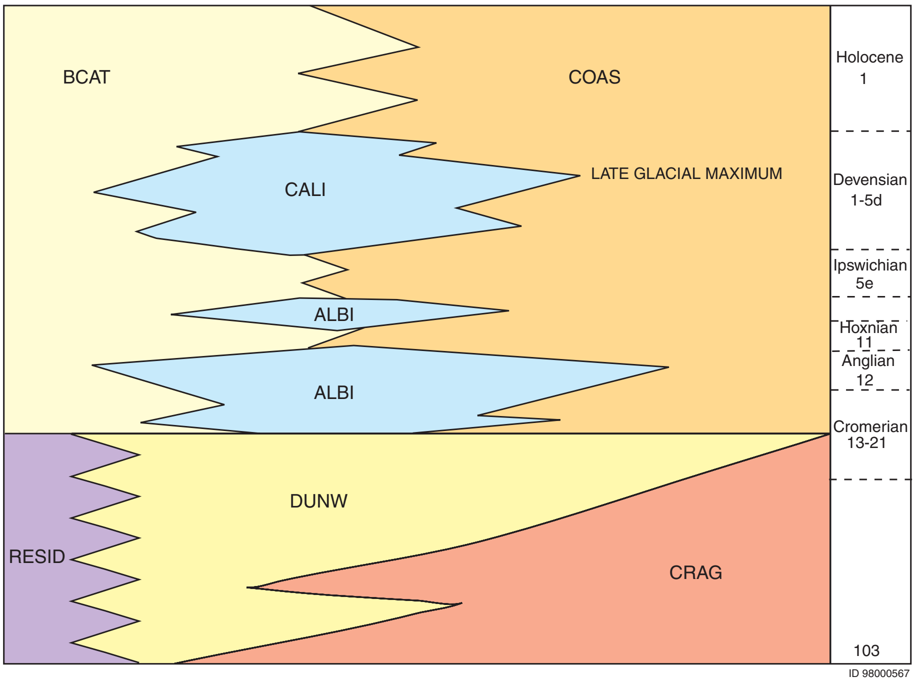
The extent and behaviour of ice sheets during the Quaternary directly influenced the distribution of a range of glacigenic deposits including diamictons and glaciofluvial deposits. Thus, in Britain the limits of the most extensive (Anglian) ice-sheet and the latest (Devensian) ice-sheet (Figure 2) play an important part in defining distribution. Early glacigenic deposits of the Anglian ice-sheet are present mainly to the south of the Devensian ice-sheet limit (Bowen, 1973; Bowen et al., 2002 and references therein) and north of a line approximately east–west from the River Thames to the Bristol Channel (Figure 2). Inferred Anglian deposits also occur, locally, farther north and may be present in the subsurface below deposits of the Devensian ice-sheet. Pre-Devensian deposits may exhibit complex weathering profiles (indicative of a range of climatic conditions) that may aid stratigraphical correlation. Devensian glacigenic deposits are present mainly to the north of the Devensian ice-sheet limit (Figure 2). Some Devensian glacigenic deposits (e.g. glaciofluvial terrace deposits) may extend south of the limit.

1.2.2 Fluvial deposits

A river catchment is a physiographic entity, not a lithostratigraphic division. It is the deposits of the catchment that determine what classification is valid. However, the linking of broad catchment geology to present-day drainage systems will have advantages for a wide range of environmental users. In Scotland, for example, the Scottish Environment Protection Agency has proposed the development of the first River Basin Management Plan with a supporting network of up to eight River Basin District catchment areas (SEPA, 2004). These areas will be defined by surface water catchments and it may prove valuable to establish a catchment lithostratigraphical framework, albeit

Figure 1 Relationship of the proposed lithostratigraphical groups.

Key: ALBI Albion Glacigenic Group; BCAT Britannia Catchments Group; CALI Caledonia Glacigenic Group; CRAG Crag Group; DUNW Dunwich Group; COAS British Coastal Deposits Group; RESID Residual Deposits Group. Numbers refer to Marine Isotope Stages.



informal (e.g. using a subgroup nomenclature, see Sections 2.1.4 and 3.2.5.1), to aid the characterisation of catchment deposits. Similarly, in other parts of Great Britain, catchment subgroups could provide the lithostratigraphical framework for the 126 Environment Agency Catchment Abstraction Management areas (see www.environment-agency.gov.uk).

Allowing for glacio-isostatic and relative sea level changes, in practice, within each river system, late Devensian to Holocene river terrace and alluvial deposits lying to the north of the Devensian ice-sheet limit (Figure 3), can be related to that system. At, and to the south of, this ice-sheet limit, the distribution, elevation and correlation of river terrace deposits is more complicated. River terrace deposits, such as those of the River Thames and its precursors, extend back to pre-Anglian time and have been subject to variations in base level over time (reflecting relative sea level and isostatic changes). Early rivers changed course during and between glaciations and deposits of palaeovalleys are common. Therefore lithostratigraphical correlation between formations of different river catchments, both modern and ancient, needs to be applied with caution. The application of lithostratigraphical classification to river terrace deposits is discussed further in Chapters 2 and 3.

1.3 CHRONOSTRATIGRAPHY AND OXYGEN ISOTOPE STRATIGRAPHY

Chronostratigraphy is the element of stratigraphy that deals with the time relations and ages of rock bodies (Salvador, 1994). The purpose of chronostratigraphical classification is to organise systematically the rocks into named units (systems, series and stages) that correspond to intervals of geological time (geochronological units including periods, epochs and ages). Some methods for dating and determining the time sequence of Quaternary deposits are described in Appendix 1. The Quaternary is the latest system of the Cenozoic Era and embraces two series, the Pleistocene and the Holocene — the last 11.5 ka (calendar years) (Gradstein and Ogg, 1996) (Table 1).

The concept of time plays little part in establishing or identifying lithostratigraphical units and their boundaries. Lithological character is generally influenced more strongly by the conditions of formation than by the time of origin. Thus caution should be applied when linking ages to lithostratigraphical boundaries. However, for many deposits where no correlatable stratigraphical relationships are evident, dating techniques (e.g. ^{14}C or terrestrial cosmogenic nuclide dating — Appendix 1) may provide ages allowing the deposits to be placed within the framework.

The British Quaternary has traditionally been divided into climatostratigraphical temperate ‘interglacial’ and longer cold ‘glacial’ stages inferred primarily from the vegetational pollen record (Mitchell et al. 1973; Rose, 1989; Gordon and Sutherland, 1993). However the vegetational response during temperate stages was influenced by variation in altitude and latititude and the pollen biozone boundaries are diachronous.

Although there is continuing debate about the application of a climate-driven chronostratigraphy and nomenclature (for discussion see Rose, 1989; Mitchell et al., 1973; Bowen, 1999) reference is made in this report to the British onshore climatostratigraphical stages. These are broadly correlated with the proposed higher status lithostratigraphical units (e.g. groups) (Table 1). Variation in depositional environment resulting in changes in gross lithological characteristics and lithofacies may be effected by climate change. With the exception of the ‘Wolstonian’, the British stages are defined from type sections in East Anglia (Mitchell et al., 1973) (Table 1). It should be noted that there is, as yet, no formal proposal to replace the stage term ‘Wolstonian’ (Mitchell et al., 1973; Gibbard and Turner, 1988; Rose, 1988; Bowen, 1999), although the proposed framework adopts the lithostratigraphical Wolston Glacigenic Formation which may correlate with the Lowestoft Formation of East Anglia (Anglian/Elsterian) (see Sumbler, p. 37 in Bowen, 1999).

With the exception of some long sequences known from Lake Baikal, Columbia, Greece and Italy, the Quaternary onshore record is incomplete. Thus, in addition to correlation with the British and north-west European stages,

Figure 2 Distribution of glacigenic groups and subgroups and marine deposits of the Crag Group (approximate courses of the pre-Anglian river systems also shown).
Note that the geographical boundaries are approximate and are based on mapping formations of till. They will be refined as knowledge of the distribution of defining formations is improved.

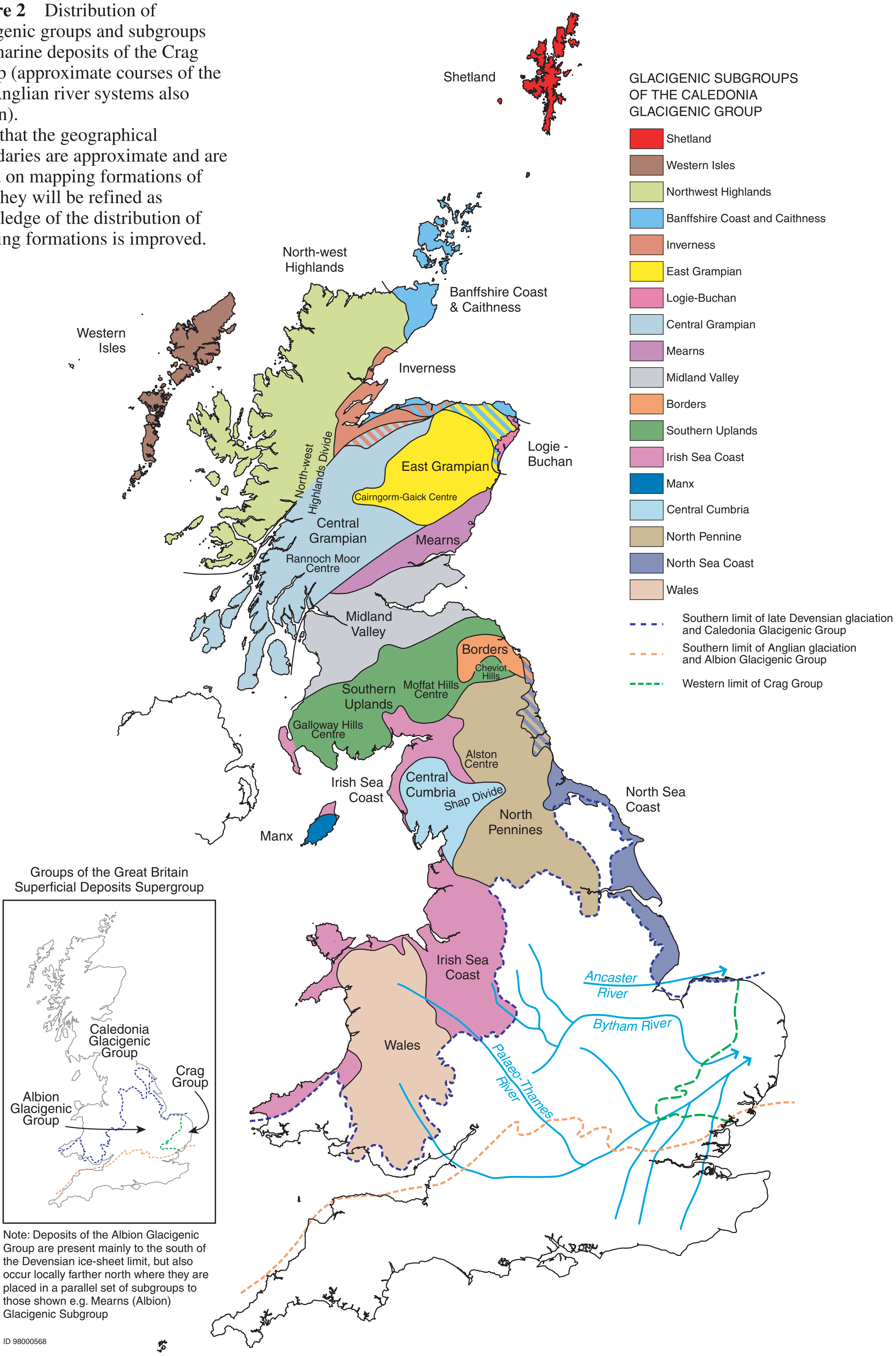
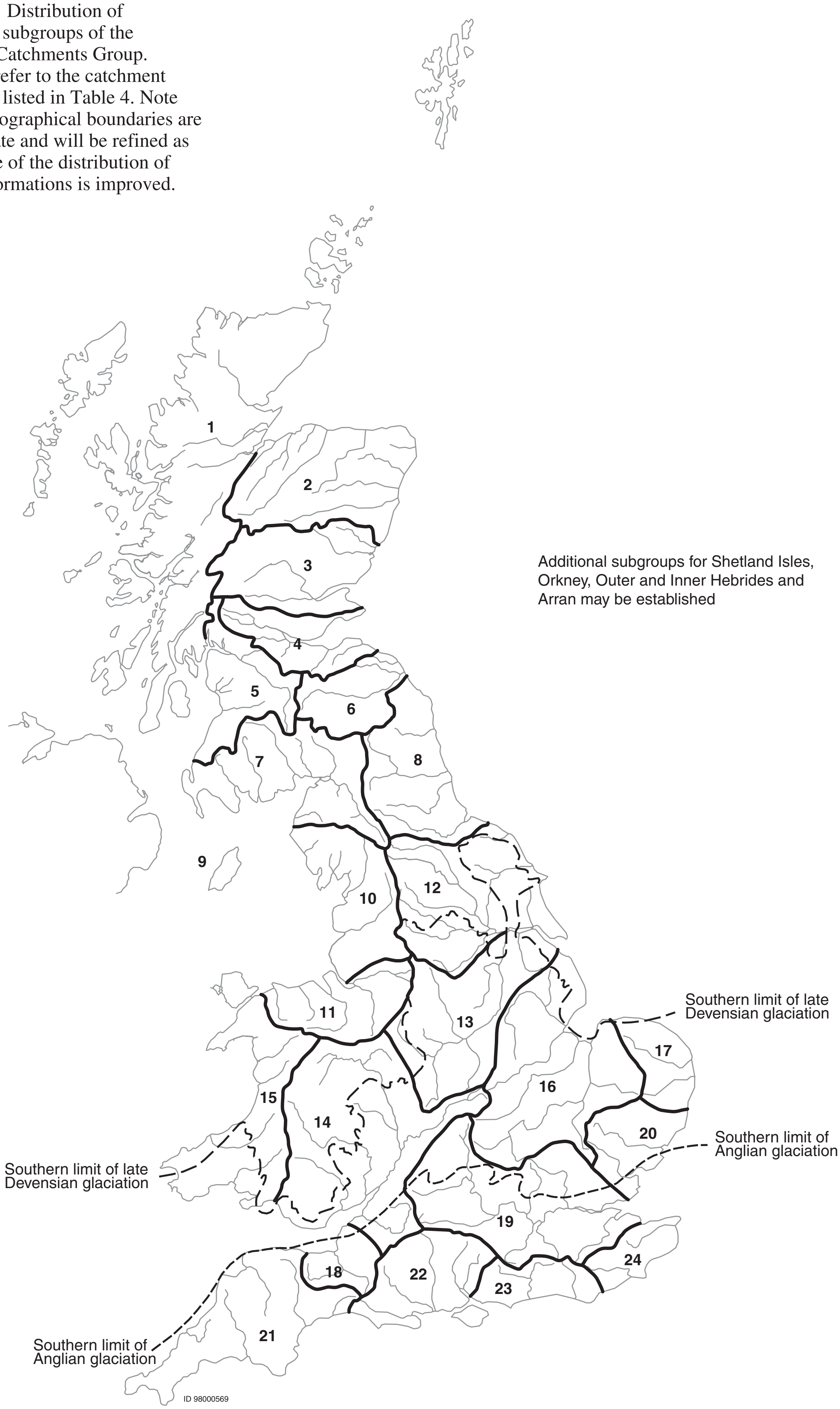


Figure 3 Distribution of catchment subgroups of the Britannia Catchments Group. Numbers refer to the catchment subgroups listed in Table 4. Note that the geographical boundaries are approximate and will be refined as knowledge of the distribution of defining formations is improved.



inferred land–sea correlations are also *tentatively* proposed using the marine oxygen isotope stratigraphic scale derived from ocean sediments (Gordon and Sutherland, 1993; Bowen, 1999). The oxygen isotope stratigraphical framework (strictly not a chronostratigraphical scale) was developed from the analysis of calcareous microfossils preserved in deep ocean floor marine sediments. In this report reference is made to the marine isotope stages from the record of cores V28–238 and Ocean Deep Drilling Project 667 (Shackleton and Opdyke, 1973; Shackleton et al., 1990; Bowen, 1999) (Table 1).

Marine isotope stages ($\delta^{18}O$ stages which are designated in a numerical scheme) provide a universal means of subdividing the Quaternary (Emiliani, 1954; Shackleton and Opdyke, 1973). The changing microfaunal assemblages preserve a record of fluctuating oceanic water temperature and the relative proportions of the two common isotopes of oxygen contained in the skeletons provide an indirect record of global ice volume and global sea level (Imbrie et al., 1984; Mix et al., 1995; Clark and Mix, 2002). During glacial periods water is lost from the oceans to form ice sheets and the oceans become relatively enriched in water containing the heavy isotope of oxygen (^{18}O). The changing ^{18}O content of ocean water can be used as an index of ice sheet growth and decay although it should be noted that a number of variables (e.g. fluctuating ocean bottom temperatures during the Pleistocene, local hydrological effects) mean that the index cannot be directly related to ice volume as once thought by Shackleton and Opdyke (1973).

The correlation of $\delta^{18}O$ stages to informal climatic events (e.g. interglacials) should be undertaken with caution if used in isolation. The numerical scheme provides inexact 'high' and 'low' ice volume reference points. The duration of an interglacial, as defined by evidence from onshore Quaternary sequences, may be subject to continued revision. However, evenly numbered $\delta^{18}O$ stages generally refer to cold 'events' and odd numbers to warm 'events' within each global glacial — interglacial cycle. Some $\delta^{18}O$ stages are subdivided: for example, Stage 5 is subdivided into 5a–5e (or 5.1 to 5.5, see Imbrie et al., 1984). Of these subdivisions 5a, 5c and 5e represent low ice volume events and may be equated with interstadials and interglacials. Stage 5e is generally accepted to represent a full interglacial and the equivalent of the Ipswichian (Eemian) climatostratigraphical stage and Stage 11 to the Hoxnian (Holsteinian) (Table 1).

Table 4 Subgroups and examples of formations of the Britannia Catchments Group (see also Figure 3).

The catchment subgroups are defined principally by formations of fluvial deposits. The Britannia Catchments Group also embraces lithogenetic units including mass movement deposits (e.g. head, talus), organic deposits (e.g. peat), mountain regolith and cover sand. Where appropriate some of these units have been raised to formation status: examples are denoted thus *.

Lex Code = Codes from the BGS Lexicon of named rock units (where assigned). Emboldened codes denote that the unit has been formally defined in the Lexicon. MIS = Marine Isotope Stage (inferred correlation).

GROUP	SUBGROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
BRITANNIA CATCHMENTS GROUP	1. Northern Highlands and Argyll Catchments Subgroup	Longman Gravel Formation	**LNGR**	1 (LLS)	After Fletcher et al. (1996).	
		Strath Ullie Formation Halladale River Formation		1	Proposed formations. Stratotypes to be defined.	
		Argyll Formation		1	Lacustrine, fluvial and organic members of the Argyle Formation of Sutherland in Bowen (1999)	Sutherland, p.111
	2. Grampian Catchments Subgroup	Strath Spey Formation		1	Proposed formation. Stratotypes to be defined.	
	3. Tay Catchments Subgroup	Strathtay Formation South Esk Formation Strathearn Formation		1	Proposed formations. Stratotypes to be defined.	
	4. Forth Catchments Subgroup	Lothian Tyne Valley Formation Carron Valley Formation Almond Valley Formation Forth Valley Formation		1	Proposed formations. Stratotypes to be defined.	
	5. Clyde Catchments Subgroup	Clyde Valley Formation		1	Proposed formation will include fluvial members (after Browne and McMillan, 1989) of the Clyde Valley Formation of Sutherland in Bowen (1999) including: Law Sand and Gravel Member (Law Borehole) Lochwinnoch Clay Member (Lochwinnoch Borehole)	Sutherland, p.110
		Strathendrick Formation		1	Proposed formation will include fluvial members of the Clyde Valley Formation of Sutherland in Bowen (1999). Includes Endrick Sand Member (Mains of Kilmaronock Borehole) (Browne and McMillan, 1989)	Sutherland, p.111–112
		Strathkelvin Formation	KELV	1	Stratotype to be defined.	
		Leven Valley Formation Ayr Valley Formation Irvine Valley Formation		1	Proposed formations. Stratotypes to be defined.	
		Kilmaronock Silt Formation	KILK	1	Lacustrine unit defined by Browne and McMillan, (1989) (Mains of Kilmaronock Borehole)	Sutherland, p.111
		Clippens Peat Formation*	CLPT	1	Defined from Linwood Borehole (Browne and McMillan, 1989)	Sutherland, p.111–112
	6. Tweed Catchments Subgroup	Tweed Valley Formation		1	Proposed formation. Stratotypes to be defined.	
	7. Solway Catchments Subgroup	Cree Valley Formation Fleet Valley Formation Kirkcudbright Dee Valley Formation Nithsdale Formation Annandale Formation		1	Proposed formations. Stratotypes to be defined.	
		Solway Esk Valley Formation	**SESKV**	1	Proposed formation will include Bigholm Burn Member (Bowen, 1999)	Sutherland, p.107
		Eden Valley Formation Wampool Valley Formation Waver Valley Formation Ellen Valley Formation Solway Derwent Valley Formation		1	Proposed formations. Stratotypes to be defined.	

Table 4 *continued*

GROUP	SUBGROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
BRITANNIA CATCHMENTS GROUP *(continued)*	8. Northumbria Catchments Subgroup	Coquet Valley Formation Tyne Valley Formation Wear Valley Formation Tees Valley Formation Esk Valley Formation Teeside Formation		1	Proposed formations. Stratotypes to be defined.	
	9. Isle of Man Catchments Subgroup	Sulby Glen Formation	SUGL	1	Formations established by Thomas in Bowen (1999) and revised by Chadwick et al. (2001)	Thomas, p.94
		Curragh Formation* Ballaugh Formation* Glen Balleira Formation*	CAGH BALGH GLNBA	1		
	10. Cumbria-Lancashire Catchments Subgroup	Ehen Alluvial Formation		1	Formation established by Merritt and Auton (2000)	
		Esk Alluvial Formation		1	Proposed formation. Stratotypes to be defined.	
		Lune Valley Formation Ribble Valley Formation		1	Formations are proposed for fluvial deposits of the Swettenham Formation and Lytham formations of Thomas in Bowen (1999)	Thomas, p.95
		Blelham Peat Formation*		1	Blelham Formation of Thomas in Bowen (1999) and adopted by Merritt and Auton (2000)	Thomas, p.96
	11. Cheshire–North Wales Catchments Subgroup	Mersey Valley Formation		1	Formation is proposed for fluvial deposits of the Swettenham Formation and Lytham formations of Thomas in Bowen (1999)	Thomas, p.95
		Weaver Valley Formation Dee Valley Formation Conway Valley Formation Clwyd Valley Formation		1	Proposed formations	
	12. Yorkshire Catchments Subgroup	Swale Valley Formation Ure Valley Formation Nidd Valley Formation Aire Valley Formation Hull Valley Formation Humber Formation Yorkshire Ouse Valley Formation Derwent Valley Formation Wharfe Valley Formation		1	Proposed formations. Stratotypes to be defined.	
		Ringingslow Formation*		1	Thomas in Bowen (1999)	Thomas, p.97–98
		Sutton Blown Sand Formation	SUTN	1		
		Breighton Cover Sand Formation*	BREI	2	Proposed formation	
	13. Trent Catchments Subgroup	Trent Valley Formation		1–8	Members after Brandon in Bowen (1999)	Brandon, p.41
		Proto-Trent Valley Formation			Members after Brandon in Bowen (1999)	Brandon, p.42
		Devon Valley Formation			Members after Brandon and Sumbler in Bowen (1999)	Brandon and Sumbler, p.42
		Bain Valley Formation			Members after Brandon and Sumbler in Bowen (1999)	Brandon and Sumbler, p.14–15
		Trent Derwent Valley Formation			Members after Derwent Valley Formation of Brandon in Bowen (1999)	Brandon, p.39
		Soar Valley Formation			Members after Maddy in Bowen (1999)	Maddy, p.39
	14. Severn and Avon	Severn Valley Formation	SEVN	1–11	Members after Maddy and Sumbler in Bowen (1999)	Maddy and Sumbler, p.34–36
		Avon Valley Formation	AVON		Members after Maddy in Bowen (1999)	Maddy, p.37–38
		Bristol Avon Valley Formation			Members defined within the Avon Valley Formation of Maddy, Keen and Sumbler in Bowen (1999)	Maddy, Keen and Sumbler, p.37–38

Table 4 *continued*

GROUP	SUBGROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
BRITANNIA CATCHMENTS GROUP *(continued)*	14. *continued*	Teme Palaeovalley Formation		2–?11	Proposed formation with Little Hereford, Bank Farm and Shakenhurst members. See also fluvial Bodenham Member of Herefordshire Formation, Bullingham Member of Wye Valley formation and Marden Member of Lugg Valley Formation (Brandon in Bowen, 1999)	Brandon, p.29–31
		Chelford Sands Formation*		3–6	Congleton Sand of Evans et al. (1968); described by Worsley (1991)	Worsley, p.34
	15. West Wales Catchments Subgroup	Dovey Formation Afon Formation Teifi Valley Formation Tywy Valley Formation Neath Valley Formation Tregaron Formation Ystog Formation		1	Possible formations for consideration (Tywi after Bowen, 1999, but restricted to deposits of the Tywi valley). Tregaron and Ystog formations after Bowen (1999)	Bowen, p.79–90 (Wales)
	16. Ouse–Nene Catchments Subgroup	Nar Valley Formation	NARC	1–?9	Marham, Pentney, Wormegay and Nar members after Ventris (1985) and Lewis in Bowen (1999)	Lewis, p.18
		Lark Valley Formation		1–?	Lackford, Cavenham, Kentford, Fornham, Eriswell and Sicklesmore members after Lewis in Bowen (1999)	Lewis, p.21
		Cam Valley Formation		1–?	Barnwell Station, Sidgwick Avenue, Barnwell Abbey, Barrington Village, Histon Road, Huntingdon Road, Little Wilbraham, Bordeaux Pit and North Hall members after Lewis in Bowen (1999)	Lewis, p.21–22
		Nene Valley Formation		1–?		
		Ouse Valley Formation				
		Slea Valley Formation				
		Welland Valley Formation				
		Witham Valley Formation				
	17. Yare Catchments Subgroup	Waveney Valley Formation		1–11	Terrace deposits described by Moorlock et al. (2000a). Shotford, Wortwell and Broome members after Lewis in Bowen (1999). Hoxne Formation (Wymer in Bowen, 1999) assigned member status	Wymer, p.24, Lewis, p.25
		Yare Valley Formation	YV		Defined by Moorlock et al. (2000a)	
	18. Somerset Catchments Subgroup	Parrett Formation			Defined with several members by Campbell et al. in Bowen (1999)	Campbell et al., p.78
	19. Thames Catchments Subgroup	Thames Valley Formation	TV	1–12	Proposed formation. River terrace deposit members and ‘brickearth’ (loessic) deposits after Ellison et al. (2004) (members of the Maidenhead and Lower Thames formations of Gibbard, in Bowen, 1999)	Gibbard, p.49–51
		Kennet Valley Formation		1–8	Members after Kennett (sic) Valley Formation (Collins in Bowen, 1999)	Collins, p.51–52
		Blackwater–Lodden Valley Formation	BL2 to BL4	1–8	Possible members after Blackwater–Lodden Valley Formation (Gibbard in Bowen, 1999)	Gibbard, p.53
		Colne Valley Formation	CVD		Possible members after Colne Formation (Gibbard in Bowen, 1999)	Gibbard, p.53
		Mole-Wey Valley Formation	MO1 to MO2	1–9	Possible members after Mole-Wey Formation (Gibbard in Bowen, 1999)	Gibbard, p.54
		Wandle Valley Formation		1–8	Possible members after Wandle Formation (Gibbard in Bowen, 1999)	Gibbard, p54
		Lea Valley Formation		1–11	Possible members after Lea Formation (Gibbard in Bowen, 1999)	Gibbard, p.54–56

Table 4 *continued*

GROUP	SUBGROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
BRITANNIA CATCHMENTS GROUP *(continued)*		Darent-Cray Valley Formation		1–11	Possible members after Darent Formation (Gibbard in Bowen, 1999)	Gibbard, p.56
		Medway Valley Formation	ME1 to ME4	1–9	Possible members after Medway Valley Formation (Bridgland in Bowen, 1999)	Bridgland, p.56–57
	20. Suffolk Catchments Subgroup	Currently lithogenetic units				
	21. Cornubian Catchments Subgroup	Currently lithogenetic units				
	22. Solent Catchments Subgroup	Meon Formation		1–pre 13	Proposed formation. Seven aggradations above alluvium	
		Hamble Formation			Proposed formation. Three aggradations above alluvium	
		Itchen Formation			Proposed formation. Up to seven aggradations above alluvium	
		Test Formation			Proposed formation. Up to eleven aggradations above alluvium	
		Hampshire Avon Formation			Proposed formation. Up to eleven aggradations above alluvium. Includes the Ringwood Formation (formerly 'Older River Gravel Formation') and some members of the New Forest Formation of Gibbard and Preece in Bowen (1999)	Gibbard and Preece, p.63
		Dorset Stour Formation			Defined by Allen and Gibbard (1994). See Sway Member of New Forest Formation of Gibbard and Preece in Bowen (1999)	Gibbard and Preece, p.63
		Frome–Piddle Formation			Defined by Allen and Gibbard (1994). Members described by Gibbard and Preece in Bowen (1999)	Gibbard and Preece, p.64
	23. Sussex Catchments Subgroup	Cuckmere Formation		1	Proposed formation. Two aggradations above alluvium. Cuckmere Member of the Sussex Valleys Formation of Gibbard and Preece in Bowen (1999)	Gibbard and Preece, p.62
		Sussex Ouse Formation			Proposed formation. Four aggradations above alluvium. Lower Ouse Member of the Sussex Valleys Formation of Gibbard and Preece in Bowen (1999)	
		Arun Formation	AR1 to AR7		Proposed formation. Seven aggradations above alluvium. Arun Member of the Sussex Valleys Formations of Gibbard and Preece in Bowen (1999)	
		Adur Formation	AD1 to AD3		Proposed formation. Three aggradations above alluvium	
		Sussex Rother Formation	RS1 to RS5		Proposed formation. Five aggradations above alluvium	
	24. South Kent Catchments Subgroup	Kentish Rother Formation		1	Proposed formation. Stratotypes to be defined.	
		Pegwell Formation		2–3	Formation established by Gibbard and Preece in Bowen (1999)	Gibbard and Preece, p.61
		Kent Ouse Formation	OK and OK1 to OK2		Terrace deposits	
		Kentish Stour Formation		3–10	Possible members after Gibbard and Preece in Bowen (1999)	Gibbard and Preece, p.59

Table 5a Examples of formations of the Albion Glacigenic Group south of the Devensian ice-sheet limit.

Lex Code = Codes from the BGS Lexicon of named rock units (where assigned). Emboldened codes denote that the unit has been formally defined in the Lexicon. MIS = Marine Isotope Stage (inferred correlation).

GROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
	Briton's Lane Formation	BRLA	?6	Lee et al. (2004)	
	Oakwood Formation			Worsley in Bowen (1999)	Worsley, p.32–34
	Ridgacre Formation			Maddy in Bowen (1999)	Maddy, p.34–36
	Trysull Silt Formation		9	Member of Seisdon Formation	Worsley, p.32
	Sheringham Cliffs Formation	SMCL	?10	Lee et al. (2004)	
ALBION GLACIGENIC GROUP (Beyond the main Devensian ice-sheet limit)	Wolston Formation	WOLS	10–12	Sumbler in Bowen (1999) includes the following members:	Sumbler, p.37
		ODT	10	Oadby Till Member	
		MTON	12	Moreton Member	
		THT	12	Thrussington Till Member	
	Nurseries Formation		12	Horton (1974)	Maddy, p.34–36
	Lowestoft Formation	LOFT	12	Modified from Lewis in Bowen (1999)	Lewis, p.19–20
	Happisburgh Formation	HPTI	?16	Member of North Sea Drift Formation after Lunkka (1994) (Lewis in Bowen, 1999) and Lee et al. (2004).	Lewis, p.15–16

Table 5b Examples of formations and subgroups of the Albion Glacigenic Group north of the Devensian ice-sheet limit.

Lex Code = Codes from the BGS Lexicon of named rock units (where assigned). Emboldened codes denote that the unit has been formally defined in the Lexicon. MIS = Marine Isotope Stage (inferred correlation).

GROUP	SUBGROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
ALBION GLACIGENIC GROUP	Shetland (Albion) Glacigenic Subgroup	South Wick Till Formation		?12	Described by Mykura and Phemister (1976) and Hall et al. (1993a, b); member of the Shetland Formation (Sutherland in Bowen, 1999)	Sutherland p.106–107
	Western Isles (Albion) Glacigenic Subgroup	No formations currently identified				
	Banffshire Coast and Caithness (Albion) Glacigenic Subgroup	Camp Fauld Till Formation Red Burn Till Formation		?6	Merritt et al. (2003); Red Burn Member of Teindland Formation (Sutherland in Bowen, 1999)	Sutherland p.102
	East Grampian (Albion) Glacigenic Subgroup	Rottenhill Till Formation Bellscamphie Till Formation Birnie Gravel Formation	 **BLTI** **BEGR**	?6	Auton et al. (2000) and Merritt et al. (2003); Rottenhill Till Member of Kirkhill Formation (Sutherland in Bowen, 1999); see also Bellscamphie Formation (Sutherland in Bowen, 1999)	Sutherland p.100–102
		Pitscow Sand and Gravel Formation Leys (Denend) Gravel Formation Leys Till Formation	 LEY	8	Merritt et al. (2003); member of Kirkhill Formation (Sutherland in Bowen, 1999)	Sutherland, p.99
	Mearns (Albion) Glacigenic Subgroup	No formations currently identified				
	Logie-Buchan (Albion) Glacigenic Subgroup	Benholm Clay Formation	**BECL**	6	Auton et al. (2000); Merritt et al. (2003), Johnshaven	
	Central Grampian (Albion) Glacigenic Subgroup	Boyne Craig Till Formation	BCTI	?6	Merritt et al. (2003), Keith	
		Tangy Glen Till Formation		?8	Member of Cleongart Formation (Sutherland in Bowen, 1999)	Sutherland p.110
	Inverness (Albion) Glacigenic Subgroup	Dalcharn Palaeosol Formation	**DNPS**	5e	After Fletcher et al. (1996); Rehiran and Drummournie members of Sutherland (in Bowen, 1999)	Sutherland p.103
		Craig an Daimh Gravel Formation	**CDGR**	6	Member of Dalcharn Formation (Sutherland in Bowen, 1999)	Sutherland p.103
		Drummore Gravel Formation Cassie Till Formation	DRGR **CASS**		Members of the Clava Formation of Sutherland (in Bowen, 1999)	Sutherland p.103
		Suidheig Till Formation	**SUTI**		Member of Allt Odhar Formation (Sutherland in Bowen, 1999)	Sutherland p.105
	Northwest Highlands (Albion) Glacigenic Subgroup	No formations currently identified				
	North Sea Coast (Albion) Glacigenic Subgroup	Warren House Till Formation		?6	Thomas in Bowen (1999)	Thomas, p.98
		Easington Formation	EASN	(7 or 9)	Thomas in Bowen (1999)	Thomas, p.98
	Midland Valley (Albion) Glacigenic Subgroup	No formations currently identified				
	Southern Uplands (Albion) Glacigenic Subgroup	No formations currently identified				
	Borders (Albion) Glacigenic Subgroup	No formations currently identified				
	Irish Sea Coast (Albion) Glacigenic Subgroup	Drigg Till Formation	DGTI	6	Glacigenic formation in West Cumbria established by Merritt and Auton (2000); Akhurst et al. (1997)	
		Kiondroughad Formation			Formations revised by Chadwick et al. (2001). Ayre Lighthouse Formation formerly the Isle of Man Formation of Thomas in Bowen (1999)	Thomas, p.91–94
		Ayre Formation		9–12		
		Ayre Lighthouse Formation				
		Seisdon Glacigenic Formation	SEIS	10 or 12	Worsley in Bowen (1999)	Worsley, p.32
	Central Cumbria (Albion) Glacigenic Subgroup	Thornsgill Till Formation		pre-5e	After Thomas in Bowen (1999)	Thomas, p.95
	Manx (Albion) Glacigenic Subgroup	No formations currently identified				
	North Pennine (Albion) Glacigenic Subgroup	Harrogate Formation Cattal Formation		?6	Proposed formations	
	Wales (Albion) Glacigenic Subgroup	No formations currently identified				

Table 6 Examples of subgroups and formations of the Caledonia Glacigenic Group mainly north of the Devensian ice sheet limit.

Lex Code = Codes from the BGS Lexicon of named rock units (where assigned). Emboldened codes denote that the unit has been formally defined in the Lexicon. MIS = Marine Isotope Stage (inferred correlation).

GROUP	SUBGROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
CALDEONIA GLACIGENIC GROUP	Shetland Glacigenic Subgroup	Burrier Wick Till Formation Sandness Till Formation		?2–4	Described by Mykura and Phemister (1976) and by Hall (1993a, b); members of the Shetland Formation (Sutherland in Bowen, 1999)	Sutherland, p.107
	Western Isles Glacigenic Subgroup	Port Beag Till Formation		2–4	Described by von Weymarn and Edwards (1973); member of the Lewis Formation (Sutherland in Bowen, 1999)	Sutherland, p.106
	Banffshire Coast and Caithness Glacigenic Subgroup	Alturlie Gravel Formation* Ardersier Silts Formation* Reisgill Burn Till Formation† Essie Till Formation Kirk Burn Silt Formation§ Blackhills Sand and Gravel Formation§ Whitehills Glacigenic Formation§	**ALGR** **ARDS** **REDR** **KBSI** **BLSG** **WHGL**	2	Formations of Auton (2003), Fletcher et al. (1996), Merritt et al. (2003) * Moray Firth † Caithness and Sutherland § Keith and Banffshire	
		Clava Shelly Formation*	**CLSH**	3	Merritt (1992) * Moray Firth	Sutherland, p.103
	East Grampian Glacigenic Subgroup	Lochton Sand and Gravel Formation Glen Dye Silts Formation Banchory Till Formation Crovie Till Formation Byth Till Formation	**LOSG** **GDSI** **BATI** **CRTI**	2	Formations of Merritt et al. (2003)	Sutherland, p.101
	Mearns Glacigenic Subgroup	Drumlithie Sand and Gravel Formation• Ury Silts Formation• Mill of Forest Till Formation•	**DSG** **USI** **MFT**	2	Formations of Merritt et al. (2003); members of the Mill of Forest Formation (Sutherland in Bowen, 1999) • Aberdeen–Stonehaven	Sutherland, p.114
	Logie-Buchan Glacigenic Subgroup	Ugie Clay Formation Kippet Hills Sand and Gravel Formation Hatton Till Formation	**UGCL** **KHG** **HATT**	2	Formations of Merritt et al. (2003); members of the Bellscamphie Formation (Sutherland in Bowen, 1999)	Sutherland, p.102
	Central Grampian Glacigenic Subgroup	Ardverikie Till Formation Ceardaich Sand and Gravel Formation Linn of Pattack Silt Formation Pattack Till Formation	**ARDT** **CEAR** **LPSI** **PATT**	2	Formations of Merritt (1999)	
	Inverness Glacigenic Subgroup	Finglack Till Formation* Kincurdy Silts Formation	**FINT** **KSI**	2	Merritt et al. (1995) and Fletcher et al. (1996); Finglack member of Clava Formation (Sutherland in Bowen, 1999) * Moray Firth	Sutherland, p.103
		Red Craig Gravels Formation	**RCGR**	4	Fletcher et al. (1996) Cromarty Firth	Sutherland, p.103
		Allt Gravel Formation		5a–d	Member of Allt Odhar Formation (Sutherland in Bowen, 1999)	Sutherland, p.105
	Northwest Highlands Glacigenic Subgroup	Reay Burn Till Formation† Loch Lurgain Till§	**REBU**	2	† Caithness and Sutherland (Auton, 2003); § Inchnadampth (Bradwell, 2003)	
		Dunbeath Till Formation†	**DUTI**	4	† Caithness and Sutherland (Auton, 2003)	
	Midland Valley Glacigenic Subgroup	Drumbeg Sand and Gravel Formation	DRBG	1 (LLS)	Formations of Browne and McMillan (1989) (members of Clyde Valley Formation of Sutherland in Bowen, 1999)	Sutherland, p.111
		Gartocharn Till Formation	GATI			
		Broomhouse Sand and Gravel Formation	BHSE	2	Formation (after Browne and McMillan (1989) (member of Clyde Valley Formation of Sutherland in Bowen, 1999) including:	Sutherland, p.109
			RSSA		Ross Sand Member	
			BILL		Bellshill Clay Member	
		Wilderness Till Formation	WITI		Formation (after Browne and McMillan (1989) (member of Clyde Valley Formation of Sutherland in Bowen, 1999) including:	

Table 6 *continued*

GROUP	SUBGROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
CALDEONIA GLACIGENIC GROUP *(continued)*			CADR		Cadder Sand Member	
			BRLL		Broomhill Clay Member	
		Baillieston Till Formation	BNTI	Pre-2	Formation (after Browne and McMillan (1989) (member of Clyde Valley Formation of Sutherland in Bowen, 1999)	
	Southern Uplands Glacigenic Subgroup	Langholm Till Formation	LHTI	2	Proposed formations for Dumfries and Galloway (McMillan et al., in prep.)	
		Kirkbean Sand and Gravel Formation	KN			
		Dalswinton Moraine Formation	DSMO			
		Mouldy Hills Gravel Formation	MOHI			
	Borders Glacigenic Subgroup	Greenlaw Gravel Formation Kale Water Till Formation		2	Proposed formations	
	North Sea Coast Glacigenic Subgroup	Holderness Formation	HOLD	2	Described by Catt and Penny (1966); includes Sewerby and Skipsea and other members, and Dimlington Bed (McCabe and Bowen in Bowen, 1999)	McCabe and Bowen, p.13
	Irish Sea Coast Glacigenic Subgroup	Gretna Till Formation	GRET	2	Proposed formations for Dumfries and Galloway (McMillan et al., in prep.)	
		Kilblane Sand and Gravel Formation	KBSG			
		Cullivait Silt Formation	CUS			
		Kerr Moraine Formation	KEMO			
		Plumpe Sand and Gravel Formation	PLSG			
		Baronwood Sand and Gravel Formation		2	Proposed glacigenic formations in North Cumbria.	
		Greystoke Till Formation				
		Great Easby Clay Formation				
		Gillcambon Till Formation				
		Gosforth Glacigenic Formation		2	Glacigenic formations in West Cumbria established by Merritt and Auton (2000)	
		Aikbank Farm Glacigenic Formation	**AIK**			
		Seascale Glacigenic Formation		2 early		
		Carleton Silt Formation	CNSI	?4		
		Jurby Formation	JURBY	2	Isle of Man glacigenic formations. Thomas in Bowen (1999) and Chadwick et al. (2001)	Thomas, p.94
		Orrisdale Formation	ORRIS			
		Shellag Formation	SHLAG			
		Morecambe Bay Formation Kirkham Formation		2	Glacigenic formation in Lancashire correlated with the Stockport Glacigenic Formation (Thomas in Bowen, 1999)	Thomas, p.95–96
		Lleyn Till Formation		2	Proposed till formation (NW Wales). Other till and glaciofluvial formations to be considered (e.g. members of St Asaph Formation of Bowen, 1999 after McKenny-Hughes, 1887)	Bowen, p.84 and 89
		Stockport Glacigenic Formation		2	Defined by Worsley (1991). Maddy in Bowen (1999)	Maddy, p.34
		Four Ashes Sand and Gravel Formation	FASG	3–5e		

Table 6 *continued*

GROUP	SUBGROUP	Examples of defining formations	Lex code	MIS	Status of units (stratotypes indicated where known)	Reference in Bowen, 1999
CALDEONIA GLACIGENIC GROUP *(continued)*	Central Cumbria Glacigenic Subgroup	Wolf Crags Formation		1	Thomas in Bowen (1999)	Thomas, p.96
		Windermere Formation		1–2		
		Blengdale Glacigenic Formation	**BLGL**	2–?4	Glacigenic formation in West Cumbria established by Merritt and Auton (2000)	
		Threlkeld Till Formation		2	Member of Thomas in Bowen (1999)	Thomas, p.96
	Manx Glacigenic Subgroup	Snaefell Formation	SNAEF	2	Isle of Man paraglacial formation. Thomas in Bowen (1999) and Chadwick et al. (2001)	Thomas, p.94
	North Pennine Glacigenic Subgroup	Pocklington Gravel Formation	POCKG	2	Proposed formations. Pickering and Hemingbrough formations of Thomas in Bowen (1999)	Thomas, p.97
		Alne Glaciolacustrine Formation	ALNE			
		Elvington Glaciolacustrine Formation	ELV			
		Hemingbrough Glacio-lacustrine Formation	HEM			
		Littlethorpe Glaciolacustrine Formation				
		Pickering Glaciolacustrine Formation				
		Vale of York Till Formation	VYORK			
		Bickerton Moraines Formation	BICKM			
		Poppleton Glaciofluvial Formation	POPP			
	Wales Glacigenic Subgroup	Eyri Till Formation Berwyn Till Formation Plynlimon Till Formation Brecknockshire Formation		2	Proposed formations (cf. glacigenic Eyri Formation, Meirion and Becknockshire formations of Bowen, 1999)	Bowen, p.79–90
		Teifi Formation			Proposed glaciolacustrine formation	
		Shrewsbury Formation			Defined by Worsley (1991). Maddy in Bowen (1999)	Maddy, p.34

2 Principles and definitions

2.1 THE LITHOSTRATIGRAPHICAL CODE AND ITS APPLICATION TO THE QUATERNARY DEPOSITS OF GREAT BRITAIN

Salvador (1994), amplified by Rawson et al. (2002 and references therein) sets out the internationally accepted hierarchy of lithostratigraphical units. The unit terms (Sections 2.1.2–2.1.7) are described in order of rank.

2.1.1 Naming of lithostratigraphical units

It is recommended that each lithostratigraphical unit should be formed from the name of an appropriate geographical feature combined with the appropriate unit term (e.g. group, formation). To aid the user of the proposed lithostratigraphical framework for Quaternary deposits, especially the non-geologist, it is recommended that both a geographical and a lithological term are included within the unit name (e.g. Bridgeton Sand Formation), although this practice is discouraged by Salvador (1994). The use of the same geographical term for units of different status (e.g. formation and member) is not recommended except where historical precedent may be an over-riding consideration. Recommended descriptor terms for formations, members and beds are given in Tables 7a–c.

2.1.1.1 Naming of groups and subgroups

One of the distinguishing characteristics of many Quaternary deposits is the rapidity of vertical and lateral changes in lithofacies. Diversity of lithology may constitute a form of unity for bodies of sediment with similar gross depositional characteristics. To highlight this diversity, at the level of group and subgroup (see below), the proposed Quaternary Lithostratigraphical Framework utilises a genetic epithet (e.g. glacigenic, catchments), albeit recognising that genesis is inferred. Whilst this practice is not recommended by Salvador (1994), the proposed nomenclature serves to highlight that the strata are heterolithic superficial deposits that may be readily distinguished from bedrock lithostratigraphical units.

2.1.1.2 Naming of formations and members

For formations it is recommended that lithological descriptors are defined by the dominant grain-size (e.g. sand, gravel, silt, clay) or grain-size range (e.g. sand and gravel) or lithology (e.g. peat). Morphological descriptors (e.g moraine) have been rarely used but are useful for lithologically heterogeneous deposits. If a landform is considered to be an important attribute, a link may be made between the deposit and the associated landform by referring to the lithogenetic classification and mapping schemes (Chapter 3).

Although genetic epithets for formations should be avoided (Salvador, 1994) the use of the descriptor 'till' is recommended as a useful practical term for the main till sheets containing lenses of stratified deposits (e.g. Gretna Till Formation). We prefer this term to the less familiar 'diamicton' unless genesis is unclear or controversial (note that not all diamictons are tills). Other lithogenetic terms that have been used previously for formations (e.g. glacigenic, glaciolacustrine, glacial lake, glaciofluvial) are useful where the units are particularly lithologically heterogeneous.

For deposits of fluvial origin it is recommended that formations be named after the principal river valleys (Table 7b). A single formation is normally considered sufficient to define the fluvial deposits (floodplain alluvium and terrace deposits which are defined as members) of a river and its tributaries (e.g. Clyde Valley Formation) or a palaeovalley (e.g. Proto-Trent Formation). For major drainage basins (e.g. those of the Thames, Trent and the Severn) separate formations, defined by terrace deposit members with broadly unified lithostratigraphical characteristics, may be established for both the principal river (e.g. Thames) and major tributary valleys (e.g. Kennet). The formation may also include, at member or bed level, interbeds such as peat. For fluvial deposits at member level terms may include 'alluvium' or 'fan' of a named river valley formation. Where correlation is possible between terrace deposits of both a tributary and the principal river these members may be accorded the same name. River terrace deposit members may be geographically named or numbered sequentially with reference to the river valley formation name. For terrace surfaces identified by numbers, the first river terrace (Terrace No. 1) is the lowest and youngest.

2.1.2 Supergroup

2.1.2.1 Definition

A supergroup may be used for several associated groups or for associated formations and groups with significant lithological properties in common (Salvador, 1994).

2.1.2.2 Application

For Quaternary and upper Neogene deposits a single supergroup is proposed for the onshore natural superficial deposits of Great Britain. This supergroup distinguishes superficial deposits from bedrock.

2.1.3 Group

2.1.3.1 Definition

A group is the formal lithostratigraphical unit next in rank above a formation and is commonly applied to a sequence of contiguous formations with significant diagnostic lithological characteristics (Salvador, 1994).

2.1.3.2 Application

As indicated above, it is proposed to establish groups of Quaternary formations that reflect the diverse lithologies associated with the principal modes of inferred origin (i.e. marine, fluvial, glacial and residual). When assessed within the Quaternary chronstratigraphical framework the defining formations may be classified in seven major groups (Table 1, Figure 1, Chapter 3).

Table 7a Recommended nomenclature for the Crag Group, the Dunwich Group and the Residual Deposits Group.

GROUP	FORMATION	MEMBER	BED	Lithology	Lithogenetic units after McMillan and Powell (1999) and Ambrose (2000)
	Examples	Examples	Examples		
DUNWICH GROUP	Cromer Forest-bed Formation	Bacton Member etc.		Clay, sand	Organic/fluvial/lacustrine deposits
	Not defined				Pedographic units (soil)
	Letchworth Gravel Formation			Gravel, sand, soil	Fluvial deposits
	Bytham Formation	Timworth Gravel Member High Lodge Gravel Member etc.			
	Kesgrave Formation	Waldringfield Sand and Gravel Member etc.			
CRAG GROUP	Wroxham Crag Formation			Gravel, sand, clay	Marine and coastal zone deposits
	Norwich Crag Formation	Chillesford Clay Member Creeting Sand Member etc.			
	Red Crag Formation	Ludham Member etc.			
	Coralline Crag Formation	Aldeburgh Member etc.			
RESIDUAL DEPOSITS GROUP	Clay-with-Flints			Clay, sand, gravel	Residual deposits

2.1.4 Subgroup

2.1.4.1 Definition

Salvador (1994) notes that, exceptionally a group may be divided into subgroups. Rawson et al. (2002) acknowledge that the term subgroup is not in the formal hierarchy but has been usefully employed for subdividing certain groups.

2.1.4.2 Application

For Quaternary deposits, subgroups are introduced which are defined on lithological characteristics and geographical extent of component formations (Chapter 3).

Across Great Britain a series of catchment subgroups are proposed for formations, defined by river terrace deposit members, and associated lithogenetic units within physiographic regions (Figure 2). The boundaries of these regions broadly coincide with major modern 'catchment' boundaries but the subgroups may include both Holocene and pre-Holocene deposits (see section 3.2.5.1). Additional catchment subgroups may be established for the major Scottish islands (Figure 2).

Lying mainly to the north of the Devensian ice sheet limit (Figure 2) a series of glacigenic subgroups are proposed for formations and lithogenetic units of similar lithology and provenance (see section 3.2.7.1).

2.1.5 Formation

2.1.5.1 Definition

The formation is the primary formal unit of lithostratigraphical classification used to map, describe, and interpret the geology of a region (Salvador, 1994). Rawson et al. (2002) state that it is generally defined as the smallest mappable unit and has lithological characteristics that distinguish it from adjacent formations. However 'mappability' is a loose criterion, for it depends on the scale of mapping. In Britain, formations should be mappable and readily represented on a 1:50 000 scale map: individual members may be mappable at this scale, but are not necessarily so. In three-dimensional models, scale variations will allow both members and beds to be shown as mappable units.

A formation is defined by a type section or by type area. Where possible, top and base should be defined but it is recognised that the nature of these boundaries and the bounding deposits may vary laterally. Many Quaternary lithostratigraphical units will have no upper boundary defined by an overlying unit because the upper geological surface is the present day aggradation or erosion surface. Although Salvador (1994) indicates that formations need not be aggregated into groups, it is recommended that for Quaternary deposits there is merit in such an approach to aid broad correlation and regional mapping.

2.1.5.2 Application to glacigenic deposits

Formational status may be assigned for any regionally significant mappable unit. The decision to define a unit as a formation commonly rests with the surveyor or researcher and, as has been demonstrated by Lowe and Walker (1997, fig. 6.2) for glacigenic deposits this can result in a range of opinions as to the most useful subdivision of units. Ideally, the key tests include demonstrating type section(s) where top and base of the unit can be observed (but see above, Section 2.1.5.1), noting the nature of those boundaries and the lithological and physical characteristics of both the unit and bounding units, and tracing lateral continuity, accepting that lateral and vertical lithological variation is likely.

In assessing the definition of formations established in Bowen (1999) it is observed that some include all the superficial deposits of a geographical area (e.g Clyde Valley Formation of Sutherland in Bowen, 1999). Whilst such units are broadly mappable, a more systematic approach has been adopted in the proposed framework in which significant mappable units are established as formations.

Table 7b Recommended nomenclature for units of the Britannia Catchments Group and the British Coastal Deposits Group.

GROUP		FORMATION Examples	MEMBER Examples	BED	Lithology	Lithogenetic subdivision	Lithogenetic units after McMillan and Powell (1999) and Ambrose (2000)
BRITANNIA CATCHMENTS GROUP	Subgroups (informal)	Thames Valley Formation Trent Valley Formation Strathendrick Formation	Alluvium of the River Thames etc.	Beds may be established for locally significant units of sand, gravel, silt, clay	Sand, gravel, silt, clay	Alluvium	Fluvial deposits
			Alluvial fan		Sand, gravel	Alluvial fan deposits	
			Named or numbered and referred to named river: Boyn Hill Gravel Member Holme Pierrepont Sand and Gravel Member Beeston Sand and Gravel Member etc.		Sand, gravel, silt, clay	River terrace deposits	
			Dartford Silt Member		Silt	Fluvio-aeolian deposits, loess	
		Breighton Cover Sand Formation	-		Sand	Cover sand	Aeolian deposits
		Kilmaronock Silt Formation	-		Gravel, sand, silt, clay, peat		Lacustrine deposits
		Clippens Peat Formation etc.	-		Peat, shell marl, diatomite		Organic deposits
		Not assigned formational status	-		Soil, palaeosol		Soil
					Bone bed		Bone beds etc.
					Tufa, bog iron		Chemical deposits
					Gravel, sand, silt, clay		Mass movement deposits (landslip, head, talus)
BRITISH COASTAL DEPOSITS GROUP		Drigg Point Sand Formation			Sand	Blown sand (dune)	Aeolian deposits
		North Denes Formation Breydon Formation etc.			Gravel, sand, silt, clay	Shoreface and beach, tidal river deposits	Marine and coastal zone deposits
		Clyde Clay Formation Errol Clay Formation etc.			Sand, gravel, silt, clay	Raised beach and marine deposits	Marine and coastal zone deposits and interglacial marine deposits

Most lithostratigraphic units should have a geographical prefix. Additonal descriptors are defined by major lithological component or combination (e.g. sand and gravel), or by morphology if lithology variable.

In practice, regionally significant glacigenic units such as till sheets or glaciofluvial sheet deposits may be distinguished as formations. Discontinuous interbedded units may be best assigned member or bed status.

2.1.5.3 Application to Fluvial deposits

A single formation is normally considered sufficient to define the fluvial deposits (including the alluvium and terrace deposits) of a major river and its tributaries (as for the Severn and Avon valleys, Maddy in Bowen, 1999) (Table 7b).

It is recommended that river terrace deposits and alluvium should be assigned as members of a river valley formation (Table 7b). A member may extend from one formation to another (Salvador, 1994) (e.g. correlated terrace deposits of the Thames valley and its tributaries, Gibbard in Bowen, 1999). The formation may also contain beds of non-glacial fluvial deposits such as organic (peat), and lacustrine deposits.

Terrace deposits and alluvium of a present-day river system can be regarded respectively as the abandoned and modern parts of the present fluvial system (Figures 4, 5). These deposits can be mapped as members of a river valley formation within a catchments subgroup.

River terrace sequences fall into three categories:

- terraces representing discrete aggradational events (e.g. Severn)
- terraces representing multiple incisions of a single (syn- to post-glacial) aggradational event
- a combination of the above (e.g. Teifi)

On BGS maps currently no distinction is drawn between discrete aggradational terrace-forming events (Figures 4a, 5a), and the multiple terrace staircases formed by incision and erosion with little or no deposition on the terrace flat. Modern mapping practice would allow truly erosional landforms to be distinguished by formlines only (Figures 4b, 5b).

However, in practice it is implicit in the way that river terraces have been portrayed on BGS maps that the whole

Table 7c Recommended nomenclature for glacigenic units of the Albion Glacigenic Group and the Caledonia Glacigenic Group.

GROUP	SUBGROUP	FORMATION	MEMBER	BED	Lithology	Lithogenetic	Lithogenetic unit
	Examples	Examples	Examples			subdivision	
ALBION GLACIGENIC GROUP and CALEDONIA GLACIGENIC GROUP	East Grampian Glacigenic Subgroup Irish Sea Coast Glenigenic Subgroup etc.	Lowestoft Formation	Haddiscoe Sand and Gravel Pleasure Gardens Till Member Lowestoft Till Member etc.		Diamicton, sand, gravel, silt, clay	Glacigenic (undivided)	Glacial/ glacigenic deposits
		Wilderness Till Formation	Cadder Sand and Gravel Member Roslin Till Member etc.	Beds assigned to locally significant	Diamicton, sand, gravel, silt, clay	Till (significant mappable till sheets with sand, gravel, silt, clay lenses)	
		Mouldy Hills Gravel Formation etc.			Diamicton, sand, gravel, boulder, silt clay	Glacial (Morainic) Deposits	
		Broomhouse Sand and Gravel Formation etc.	Ross Sand Member Bellshill Clay Member		Sand, gravel, clay, silt	Glaciofluvial sheet and ice contact deposits (terraces, eskers and kames) and glaciolacustrine deposits	
		Carleton Silt Formation etc.					

Each lithostratigraphic unit should have a geographical prefix. Additional descriptors are defined by major lithological component or combination (e.g. sand and gravel), or by morphology if lithology variable. Genetic qualifiers are to be used only where it is inappropriate to use lithological descriptors. Thin lenses or organic deposits and soils interbedded with till may be included in glacigenic groups.

terrace (riser and flat) has been considered as one deposit (otherwise there would have been a need to show the incised as well as the newly deposited material).

In a number of major river systems (e.g. Conwy, Wnion) both types of terrace may occur in intimate association. The following sections illustrate how the deposits underlying such terraces may be defined as lithostratigraphical units.

Erosional terraces

Erosional terraces consist of a series of incisions related to falling base level that may, for example, occur in valley fills of glaciofluvial sand and gravel (Figure 4b). Despite being subject to the same external base level fluctuation, no two rivers can be regarded as having a comparable history of incision, as this depends on factors such as their history, depositional milieu, longitudinal profile, discharge, river capture etc. Their catchments should therefore be considered as a single depositional system for the purposes of classification. The sequence thus consists of a single depositional unit to which formational status may be assigned, and within which are a series of erosional surfaces.

Aggradational terraces

These terraces represent several widely recognisable, lithologically distinctive and chronostratigraphically dateable periods of aggradation, separated by major episodes of downcutting. They are a series of discrete events in the evolution of a river and the deposits should form members of a river valley formation. Examples of aggradational terraces include those of the major river systems of South Wales (Usk) and the Welsh borders (Severn, Wye).

Combined terraces

Any stratigraphical scheme adopted needs to be able to recognise that erosional and aggradational terraces do not occur in isolation within a river valley, and must be able to discriminate between them. Even continuous flights of terraces have been shown to represent both erosional and aggradational events in some of the larger rivers of Wales (e.g Afon Teifi; Rheidol). To distinguish these events it is necessary to recognise, for example, that a single named aggradational terrace member may lie stratigraphically above or below erosional terraces cut into a separate formation (Figures 4b, 5b).

This scenario is potentially further complicated by the glacially overdeepened valleys of some Welsh rivers (e.g. Usk, Wnion, Towy), which has resulted in a long profile of discrete depositional basins separated by rock barriers through which the river has incised a gorge. In these river systems, the terraces may reflect local base levels as controlled by the rock barrier. Thus, the number of terraces from one basin to the next may not be consistent, although they may occur within the same depositional unit. This would be further emphasised should a single, correlatable aggradation terrace be present. When correlated between basins, this aggradation terrace may be the second terrace in one basin, and the third in the adjacent downstream basin (Figure 5b). In such a scenario, the numbering reflects the hierarchy within each basin, not the river as a whole.

Thus, by obeying the stratigraphical principles described above it is possible to produce a robust and useful classification of such a fluviatile depositional complex. It is likely that in any such scheme there will be a need to adopt an undifferentiated category for river terrace deposits.

It is recommended that:

- Members should only be named and defined if a river terrace deposit can be formally described.

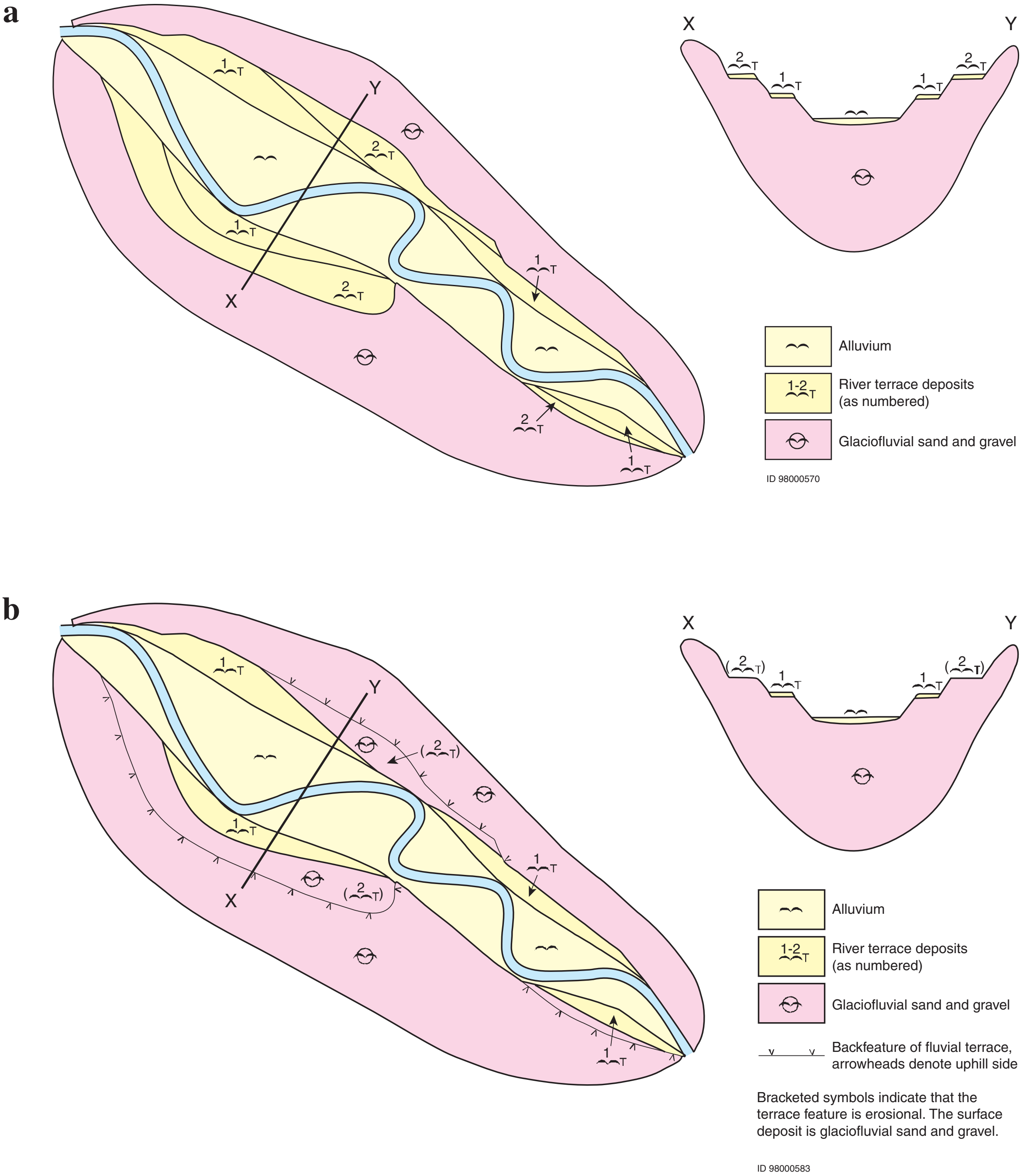


Figure 4 Interpretation of mapped river terraces: I.
a A sketch map and accompanying cross-section showing the floodplain alluvium and two stacked aggradational river terraces within a valley infilled with glaciofluvial sand and gravel.
b A sketch map and accompanying cross-section showing the floodplain alluvium and both aggradational and erosional terraces. In this case, the glaciofluvial deposits underlying Terrace 2 would form part of a glacigenic subgroup (e.g. Wales Glacigenic Subgroup), whereas the alluvium and the deposits of Terrace 1 are members of a river valley formation. Note that truly erosional terraces are quite rare and are not flat. There is nearly always some reworking and deposition.

- Erosional terraces cut into a single deposit (a separate formation) may be depicted on maps with formlines.
- Deposits of aggradational terraces related to the present river valley should be accorded member status of a river valley formation.

Palaeovalley terrace and 'buried channel' deposits

Terrace deposits of early fluvial systems and 'buried channel' deposits may be unrelated to the present-day physiography. Such deposits cannot necessarily be correlated with older terrace deposits of present-day valleys. In the West Midlands, the middle Devensian terrace deposits of the proto-Teme river and its tributaries (Cross and Hodgson, 1975) (Figure 6) formed during the period when the proto-Teme drainage system flowed southwards and westwards into the precursor of the River Lugg. Thus, the terraces were deposited in response to a markedly different fluvial system that bears little relation

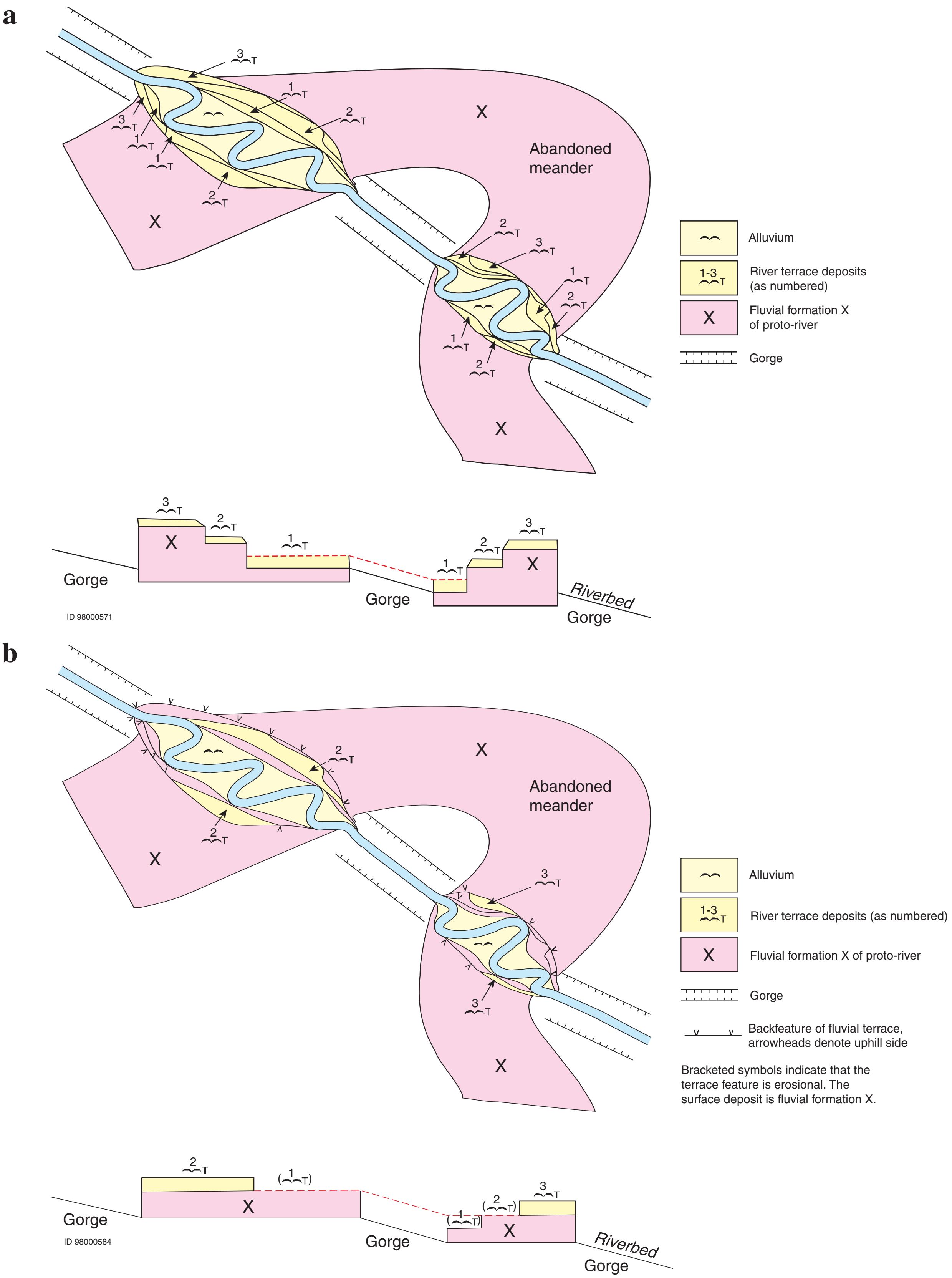
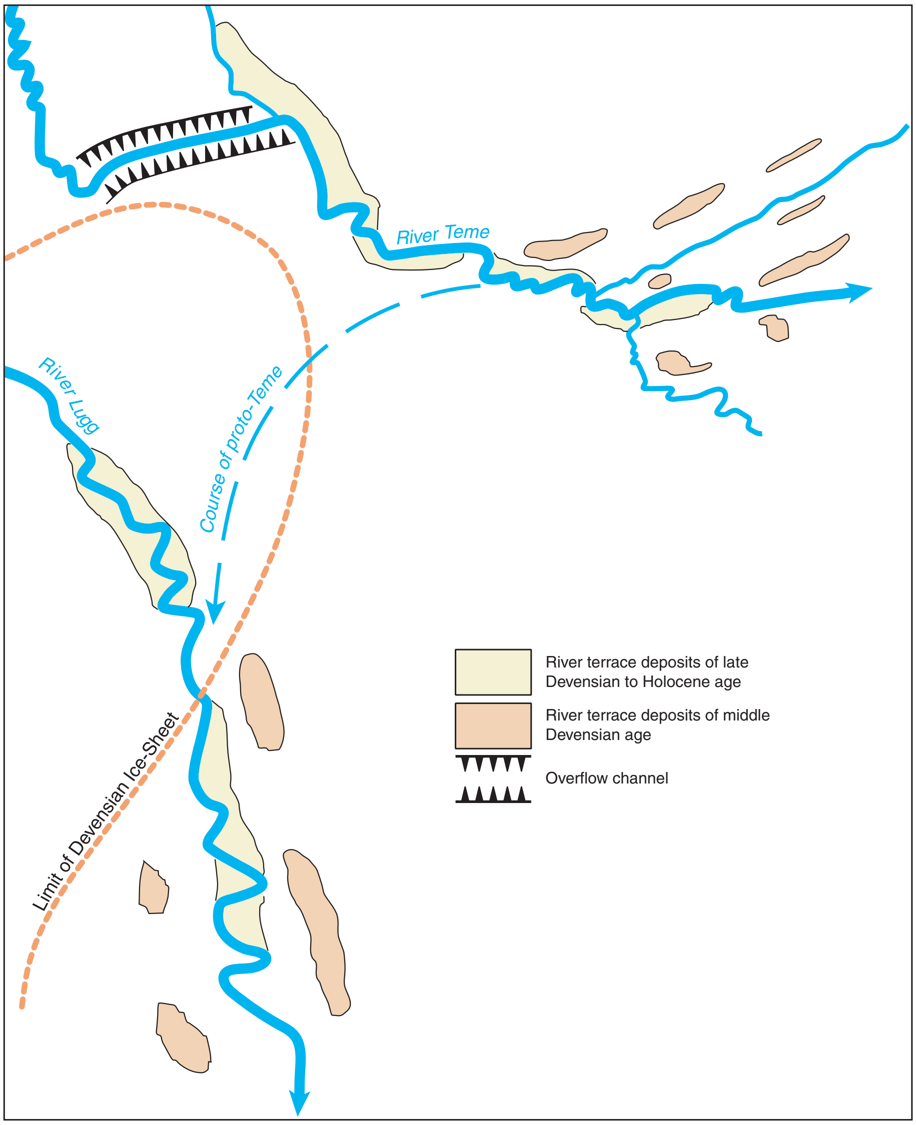


Figure 5 Interpretation of mapped river terraces: II.
a A sketch map and accompanying downstream profile showing the floodplain alluvium and three stacked aggradational river terraces within the valley of the Afon Teifi. The river has cut into deposits of a pre-existing formation (labelled X) related to the course of a proto- Afon Teifi.
b A sketch map and accompanying downstream profile showing the floodplain alluvium and both aggradational and erosional terraces within the valley of the Afon Teifi. In this case, the terraces may reflect local base levels as controlled by the rock barrier. When correlated between basins, aggradational Terrace 2 in one basin may be correlated with aggradational Terrace 3 in the adjacent downstream basin. Thus, the numbering reflects the hierarchy within each basin, not the river as a whole.

Figure 6 Sketch map of the distribution of terrace deposits of the proto-River Teme. Deposits of presumed middle Devensian age underlie high elevation terraces. These deposits are unrelated to the terrace deposits of the modern Rivers Teme and Lugg and are therefore assigned to a separate formation (Teme Palaeovalley Formation, see Table 4).



to the present-day Teme catchment in which they lie. It is possible that their correlatives are represented by the 'older river terraces' that lay beyond the limit of Devensian ice in the catchments of the rivers Lugg and Wye (Brandon, 1989). The terrace deposits of middle Devensian age cannot be considered as members of a present-day 'river valley formation' and it is recommended that they, and similar deposits, be designated as separate formations within the Britannia Catchments Group.

2.1.5.4 Application to other superficial deposits

Extensive lacustrine deposits, peat and mass movement deposits (e.g. head) may be accorded formation status or merely remain as lithogenetic units within a catchments subgroup or group, if related to more than one subgroup (see Section 3.2.5). Similarly, coastal and marine deposits with lateral continuity and lithological may be raised to formational status within a group.

2.1.6 Member

2.1.6.1 Definition

A member is the formal lithostratigraphical unit next in rank below a formation and is always part of a formation (Salvador, 1994). Formations need not be divided either wholly or partially into members. A member may extend from one formation to another (Salvador, 1994).

2.1.6.2 Application

Lithologically distinctive units interbedded within more regionally significant glacigenic formations may be separated as members (cf. Lowe and Walker, 1997). For fluvial deposits, see discussion under section 2.1.5. For members, grain-size descriptors (e.g. sand, gravel, silt) or lithological descriptors (e.g. peat) may be used. For pedostratigraphic units the terms 'soil' or 'palaeosol' are recommended.

2.1.7 Bed

A bed is the smallest formal unit in the hierarchy of sedimentary lithostratigraphical units (Salvador, 1994). Bed names are commonly applied to distinctive units that may be thin and laterally inextensive. Some beds may be fossiliferous or yield dateable material (e.g. a soil, peat or bone bed). Bed status tends to be assigned for units with some palaeogeographical, geochronological or specific lithological significance.

2.2 APPLICATION OF THE BGS ROCK CLASSIFICATION SCHEME

2.2.1 Lithogenetic unit

Lithogenetic units are locally mappable assemblages of rock strata, considered without regard to time (Schenck and Muller, 1941; Salvador, 1994). A lithogenetic unit, mappable or otherwise, is defined by its lithology, morphology and inferred mode of origin (genesis). For Great Britain, the BGS classifies lithogenetic units according to the BGS Rock Classification Scheme (RCS) for artificial and natural superficial deposits (McMillan and Powell, 1999). The RCS forms the standard for mapping, section and borehole logging and for digital dictionaries and maps (McMillan, 2002). The BGS mapping classification of superficial deposits offers a tried and tested method of assigning various attributes to deposits. These include the lithology, morphology, genesis, lithostratigraphy and age of deposit. Tables 7a–c show recommended criteria for assigning lithostratigraphical status to deposits of the principal lithogenetic units of Great Britain. It is recognised that types of slope (mass movement) deposits (Dines et al., 1940) have been inconsistently mapped and are lithologically poorly known. Unless such deposits can be correlated it is recommended that initially they be assigned only a lithogenetic classification and informally related to a catchments subgroup or group.

At group and subgroup level the lithostratigraphical framework embraces *all* lithogenetically-defined units, thus enabling a coded lithostratigraphical superscript to be applied to every Quaternary map symbol defined in the BGS specifications for the preparation of 1:10 000 scale geological maps (Ambrose, 2000). The framework also offers a unique designation for use in digital databases and for digital map production where a strict hierarchy of units is necessary.

3 Proposed lithostratigraphical framework

3.1 INTRODUCTION

The objective of this report is to establish a practical lithostratigraphical framework for Quaternary deposits. To achieve this the framework utilises the full hierarchy of lithostratigraphical codes (supergroup, group, subgroup, formation, member, bed). It is concluded that not all Quaternary deposits (e.g. mass movement deposits) are capable of being satisfactorily assigned formational status and for these deposits the lithogenetic or morphogenetic classification (McMillan and Powell, 1999) is recommended. However, as noted above (section 2.2.1) all lithogenetic units may be assigned to a group.

McMillan and Hamblin (2000) published initial ideas on an outline of the proposed framework, placing deposits within a series of lithogenetically and provenance-defined groups. Further discussion has led to the new framework that is proposed in this report and in McMillan (2005). The framework distinguishes seven broad categories at group level (Tables 1, 2–6):

- Crag Group (marine deposits, Late Pliocene to Early Pleistocene)
- Dunwich Group (mainly fluvial deposits, pre-Anglian)
- Residual Deposits Group (including the Clay-with-Flints)
- British Coastal Deposits Group (coastal and marine deposits, Anglian to Holocene)
- Britannia Catchments Group (fluvial, organic and mass movement deposits, Anglian to Holocene)
- Albion Glacigenic Group (glacigenic deposits, pre-Devensian)
- Caledonia Glacigenic Group (glacigenic deposits, Devensian)

One supergroup for natural superficial deposits is established. It is recognised that in some regions where formations have not been defined, some groups may currently consist solely of lithogenetic units. Although Salvador (1994) and Rawson et al. (2002) state that a formation may stand separately or form part of a group, the proposed framework recommends that all Quaternary formations should be referred to a lithostratigraphical unit of higher status.

Examples of component formations and their position within the proposed framework, are presented in Tables 2–6. The units have been defined in a range of scientific publications (including published BGS maps and memoirs and Bowen, 1999) or are newly proposed. The list is not exhaustive. Further details will be published in the forthcoming Quaternary lithostratigraphical framework report (McMillan and Hamblin, in prep).

3.2 GREAT BRITAIN SUPERFICIAL DEPOSITS SUPERGROUP

The Great Britain Superfical Deposits Supergroup is established for all Holocene, Pleistocene and late Pliocene natural superficial deposits in onshore Great Britain.

3.2.1 Crag Group

The Crag Group (Tables 1, 2) is established for mainly marine deposits which formed in pre-Anglian time during the late Pliocene to early Pleistocene. The group straddles the current internationally defined age for base for the Quaternary (1.806 Ma, Gradstein and Ogg, 1996).

These deposits lie mainly to the south of the Devensian ice sheet limit (Figure 2) and their distribution is unrelated to the present-day physiography. The term 'Crag' originates from the early descriptions in the 18th and 19th centuries with formations being established in the 20th century (for a review of the literature see Reid, 1890; Funnell and West, 1977; Arthurton et al., 1994 and Moorlock et al., 2000). The group is defined with reference to stratotypes in Suffolk of the four principal constituent formations (Table 2), namely the Coralline Crag Formation (Balson et al., 1993), the Red Crag Formation (term first used by Funnell and West, 1977; with members defined from the Aldeburgh–Sizewell transect borehole, Suffolk, by Zalasiewicz et al., 1988), a redefined Norwich Crag Formation (Chillesford Church Pit, Suffolk, Funnell and West, 1977; Mathers and Zalasiewicz, 1988) and a newly proposed Wroxham Crag Formation (Hamblin, 2001; Rose et al., 2001; Moorlock et al., 2002; to include the marine members of the Cromer Forest Bed series of Funnell and West, 1977). Hamblin et al. (1997) have correlated the onshore deposits of the Red Crag Formation with the Westkapelle Ground Formation of the Southern North Sea which contains pollen spectra of Thurnian type (Cameron et al., 1992). Onshore deposits of the redefined Norwich Crag Formation (Antian/Bramertonian to Baventian age) are correlated with the Smith's Knoll Formation (Hamblin et al., 1997). Marine strata that succeed the Baventian regression form the newly proposed Wroxham Crag Formation (Hamblin, 2001; Rose et al., 2001), the oldest part of which (including the Sidestrand Member, formerly of the Norwich Crag Formation) may correlate with the Winterton Shoal Formation offshore (Hamblin et al., 1997).

Other onshore deposits of Neogene age including the St Erth Beds of Cornwall (Edmonds et al., 1975) may be considered within the framework in due course.

3.2.2 Dunwich Group

A new palaeocatchment Dunwich Group (Tables 1, 2) is established for mainly fluvial sands and gravels of rivers which formed in pre-Anglian (MIS12) time and were over-ridden by ice of the Anglian glaciation (Figure 2). These deposits lie to the south of the Devensian ice sheet limit and their distribution is unrelated to the present day catchment physiography. The group is defined with reference to stratotypes of five principal constituent formations described in Bowen (1999), namely the Nettlebed Formation (Rose et al., 2001), the Kesgrave Formation and associated pedogenic units of Suffolk (Hey, 1965; Rose and Allen, 1977; Kesgrave Group of Whiteman and Rose, 1992; Moorlock et al., 2000a), the Bytham Formation (to include the Ingham and Shouldham formations of Lewis, 1993), the Letchworth Gravel

Formation of Hertfordshire (Smith and Rose, 1997) and part of the Cromer Forest-bed Formation of Funnell and West (1977), redefined to include only the non-marine members exposed on the north coast of Norfolk.

3.2.3 Residual Deposits Group

The Residual Deposits Group (Tables 1, 2) is established for residual deposits that have undergone modification over lengthy periods during the Neogene and Quaternary. Included within this group are the Clay-with-Flints, a remanié deposit or alterite formed by weathering and solifluction of the original Palaeogene cover and early Quaternary deposits and dissolution of the underlying Chalk of southern Britain (Pepper, 1973; Catt, 1986; Ellison et al., 2004). Clay-with-Flints may be compared with *les biefs à silex* of the Paris Basin (Quesnel, 2003). These deposits may have resulted primarily from pedogenesis and clay illuviation during interglacials and cryoturbation under periglacial conditions.

The deeply weathered Buchan Gravels Formation of north-east Scotland is also assigned to the Residual Deposits Group. These flint and quartzite remnant gravels have undergone prolonged weathering during the Palaeogene and Neogene (Merritt et al., 2003).

3.2.4 British Coastal Deposits Group

The British Coastal Deposits Group (Tables 1, 3) includes all post-Cromerian non-glacigenic gravels, sands and silts of estuarine, marine and beach origin (including beach dune deposits). Thin, interbedded fluvial sediments may also be included within dominantly marine and estuarine sequences. These defining formations form coastal complexes, and also occur as raised marine and beach units, particularly in northern Britain. Examples of component formations are shown in Table 3. The group is defined with reference to established stratotypes of constituent formations including the St Fergus Silt Formation and Spynie Clay Formation of north-east Scotland (Merritt et al., 2003), the Clyde Clay Formation and Clydebank Clay Formation of west central Scotland (modified from Browne and McMillan, 1989) (Figure 9) and the Errol Clay Formation (after Paterson et al., 1981). In southern Britain, established formations with constituent members include the Fenland Formation (Ventris, 1985), the Breydon and North Denes formations (Figure 7) (Arthurton et al., 1994), the Romney Marsh Formation (Gibbard and Preece, p. 61 in Bowen, 1999) and the West Sussex Coast Formation (Gibbard and Preece, pp. 61–62 in Bowen, 1999).

3.2.5 Britannia Catchments Group

The Britannia Catchments Group (Tables 1, 4; Figure 3) includes all post-Cromerian deposits of a non-glacigenic and non-marine origin. They comprise predominantly gravels, sands and silts of fluvial, lacustrine and aeolian (cover sands and loess) origin. Organic (peat) and mass movement (head) deposits are also included within the group. The term 'Britannia' was referred to by Pliny as an alternative name for 'Albion', i.e. Scotland, England, Wales. The earliest, possibly pre-Anglian, terrace deposits of the southern England catchments are also currently included in the group. The group and constituent subgroups (see below) are defined with reference to stratotypes of several principal river valley formations described in Bowen (1999), most notably in southern Britain by the Thames Valley Formation (modified after three formations defined by Gibbard, pp. 45–58 in Bowen, 1999), the Trent Valley Formation (Brandon, p. 41 in Bowen, 1999) and the Severn Valley Formation (Sumbler and Maddy, pp. 34–36 in Bowen, 1999); and in northern Britain to proposed river valley formations including the Clyde Valley Formation (Figure 9) (modified from Sutherland, pp. 109–110 in Bowen, 1999, with members originally defined as formations by Browne and McMillan, 1989).

Separate formations may be set up within the Britannia Catchments Group for non-fluvial deposits (e.g. lacustrine deposits, blanket peat) that do not form part of a river valley formation and may extend across catchment boundaries.

3.2.5.1 Catchment subgroups

Fluvial formations are defined within either the Dunwich Group or catchments subgroups of the Britannia Catchments Group. Catchments subgroups have been identified geographically and are generally related either to present-day river systems draining to a major estuary (e.g. Forth Catchments Subgroup, Severn and Avon Catchments Subgroup) or to a broad physiographic region drained by several rivers (e.g. Cumbria–Lancashire Catchments Subgroup, Sussex Catchments Subgroup).

In total, 24 subgroups of the Britannia Catchments Group are currently proposed (Figure 3; Table 4). Of these units, eleven lie fully to the north of the Devensian ice sheet limit. These deposits comprise formations and lithogenetic units of generally Late Devensian to Holocene age. Six subgroups straddle the Devensian limit, three straddle the Anglian ice sheet limit and four lie to the south of it. In the proximity of, and to the south of the Devensian ice sheet limit, the catchments subgroups comprise formations and lithogenetic units that mainly range from Anglian to Holocene age. It is proposed that each catchments subgroup will contain river valley formations (see Section 2.1.5.3), named after the principal rivers or river valleys within the subgroup area.

3.2.6 Albion Glacigenic Group

The Albion Glacigenic Group comprises all formations and lithogenetic units of pre-Ipswichian age (Tables 1,5a–b; Figures 1, 2, 8, 10, 11). The term glacigenic is taken to

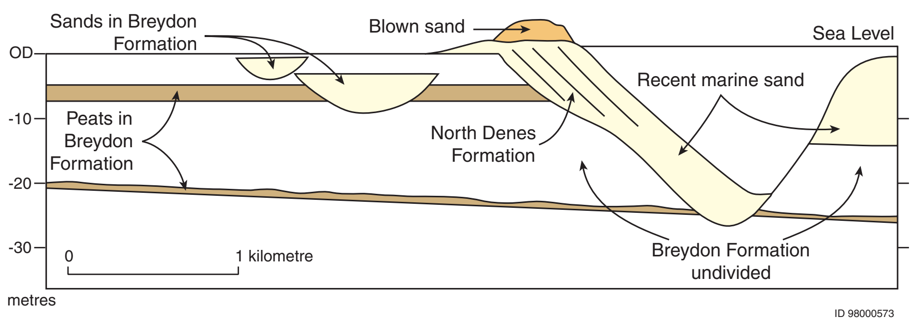


Figure 7 The British Coastal Deposits Group: relationships of formations and lithogenetic units in the Great Yarmouth district.

include deposits of glacial, glaciofluvial, glaciolacustrine and proximal glaciomarine origin together with associated interbedded, discontinuous periglacial, organic and paraglacial units. The name Albion is derived from the Old English (via Latin) from the Celtic name for Great Britain. The group comprises mainly, *but not exclusively*, the glacigenic deposits between the Anglian and Devensian ice sheet limits of southern Britain (Figure 2). Deposits of this group are also present both at the surface and as concealed sequences, locally, in Britain within the main Devensian ice sheet limit (see Section 3.2.7.1). In southern Britain, the surface, having been subjected to denudation and weathering over varying lengths of time and under a range of extreme climatic regimes, exhibits a generally subdued morphology. The group may be considered the equivalent of the 'Older Drift' of previous classifications (Wright, 1937). The group is defined with reference to stratotypes of several defining formations. These include the Happisburgh and Lowestoft formations of East Anglia (Table 5a, Figure 8) (after Lewis, pp. 11, 15–16 in Bowen, 1999) and, in the English Midlands, the Wolston (after Sumbler, p. 37 in Bowen, 1999), Nurseries (after Maddy, p. 34 in Bowen, 1999), Oakwood (after Worsley, pp. 32–34 in Bowen, 1999) and Ridgacre (after Maddy and Sumbler, p. 34 in Bowen, 1999) formations.

3.2.7 Caledonia Glacigenic Group

The Caledonia Glacigenic Group comprises all formations and lithogenetic units of Devensian glacigenic deposits (Tables 1, 6; Figures 1, 2, 9–11). The name is derived from the Latin for the Highlands of Scotland where the principal British ice sheets originated. The group comprises the glacigenic deposits of Scotland, most of Wales, northern England and parts of the English Midlands. Component formations are mainly distributed across land lying within the main Devensian ice sheet limit (Figure 2). Some deposits assigned to the group (e.g. glaciofluvial gravels) may extend beyond the limit. Being the products of the latest glaciations, the deposits commonly have distinct morphological expression and this morphology is commonly an important part of the definition of component formations and their subdivisions. In terms of age, distribution and morphology, the group comprises deposits of the 'Newer Drift' of earlier workers.

The group and constituent subgroups (see below) are defined with reference to stratotypes of regionally significant till formations and associated formations of glaciofluvial, glaciolacustrine and glaciomarine origin. Defining formations are described from Lincolnshire and from the Cheshire and the Severn Valley in the English Midlands. In Lincolnshire, the Holderness Formation (North Sea Coast Glacigenic Subgroup) is a succession of diamicton, gravel, sand, silt and clay with three till members, the Bridlington Till (Basement Till of Catt and Penny, 1966; Catt, 1991), Skipsea Till and the Withernsea Till members, all interpreted to be of Devensian age (McCabe and Bowen, p. 13 in Bowen, 1999; Bowen et al., 2002). In Norfolk, two members are recognised, the Holkham Till and the Ringstead Sand and Gravel members (after Lewis, pp. 18–19 in Bowen, 1999). In the English Midlands, the Four Ashes Formation (partly Ipswichian and partly Early to Middle Devensian; correlated with Marine Isotope Stages stages 5d–3) is overlain by Stockport Glacigenic Formation (Irish Sea Coast Glacigenic Subgroup) (Worsley, 1991). Examples of defining formations in northern Britain are shown in Table 6. Figure 9 shows the relationships of defining formations of the Midland Valley Glacigenic Subgroup. Regionally significant till formations include the Baillieston Till (pre- Late Devensian) and the Wilderness Till (Dimlington Stadial, Late Devensian) (Rose et al., 1988; Browne and McMillan, 1989). In north-east Scotland, Merritt et al. (2003) have defined the Whitehills Glacigenic Formation (here assigned to Banffshire Coast and Caithness Glacigenic Subgroup), the Banchory Till

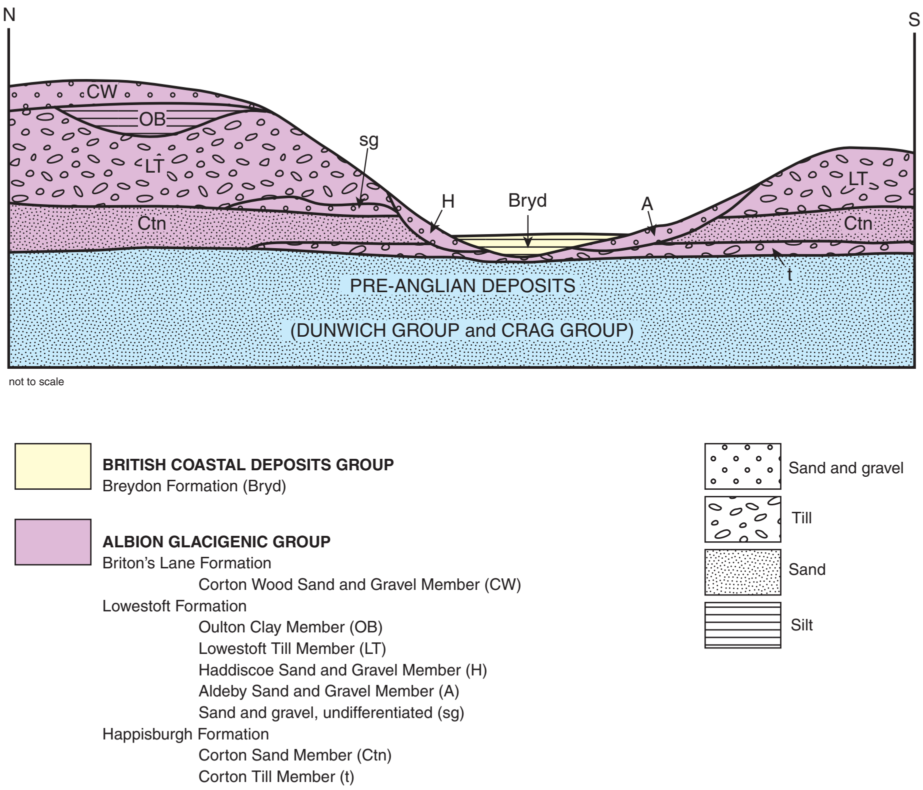


Figure 8 Schematic cross-section of formations of the Albion Glacigenic Group, Lowestoft district of East Anglia.

Formation (here assigned to the East Grampian Glacigenic Subgroup) and the Hatton Till Formation (here assigned to the Logie-Buchan Glacigenic Subgroup). The distribution and general relationships of these to other component formations are shown in Figures 10 and 11.

3.2.7.1 Glacigenic Subgroups

The term subgroup is here used to distinguish formations of glacigenic origin with similar lithological characteristics and common geographical distribution.

In Scotland, northern England and Wales, north of the Devensian limit, the lithology, and inferred provenance, of glacigenic deposits, is strongly influenced by the build-up and decay of regionally distinct ice sheets (e.g. central Grampians — Rannoch Moor) or ice domes (e.g. central Cumbria — Lake District) (Figure 2). In these areas it is possible and potentially useful to demonstrate lithological similarities of Quaternary sediments of varying age. It is proposed to divide the Caledonia Glacigenic Group into a series of subgroups that are defined primarily on the basis of mappable formations of till (see above for examples of the defining formations). The till formations are related, geographically to the principal areas of ice accumulation and dispersal that determine their gross lithological characteristics and provenance (e.g. Central Cumbria Glacigenic Subgroup, Irish Sea Coast Glacigenic Subgroup, Table 6) (Figure 2). Each subgroup will embrace associated formations of glaciofluvial, glaciolacustrine and glaciomarine deposits. All deposits will be placed in the Caledonia Glacigenic Group unless they are known to be older (e.g. as has been demonstrated in north-east Scotland, Auton et al., 2000; Merritt et al., 2003; figs 10–11). To maintain a strict hierarchy, within the main Devensian ice sheet limit known pre-Devensian units will be assigned to a set of glacigenic subgroups that mirror those of the Caledonia Glacigenic Group and will be identified by the

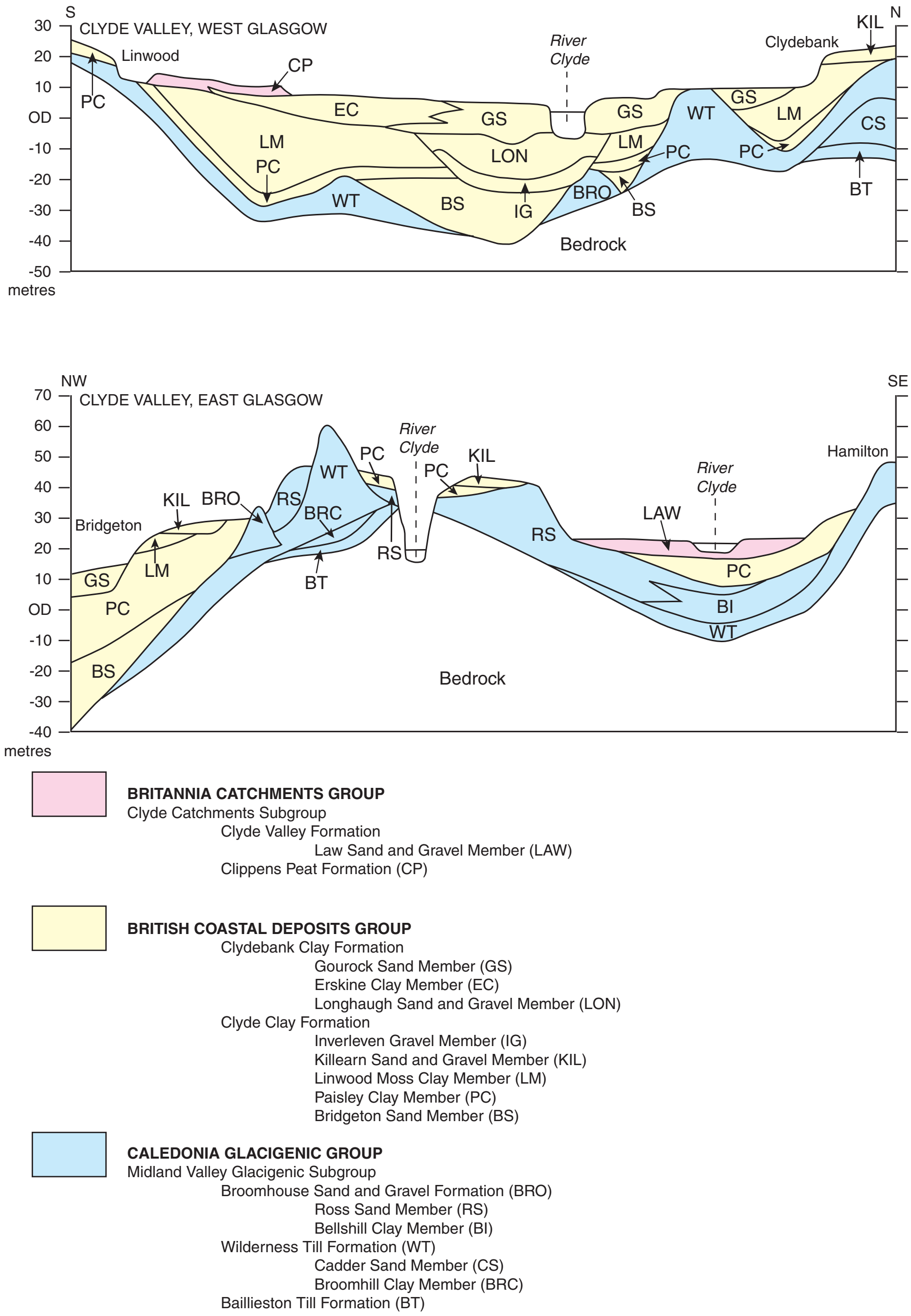
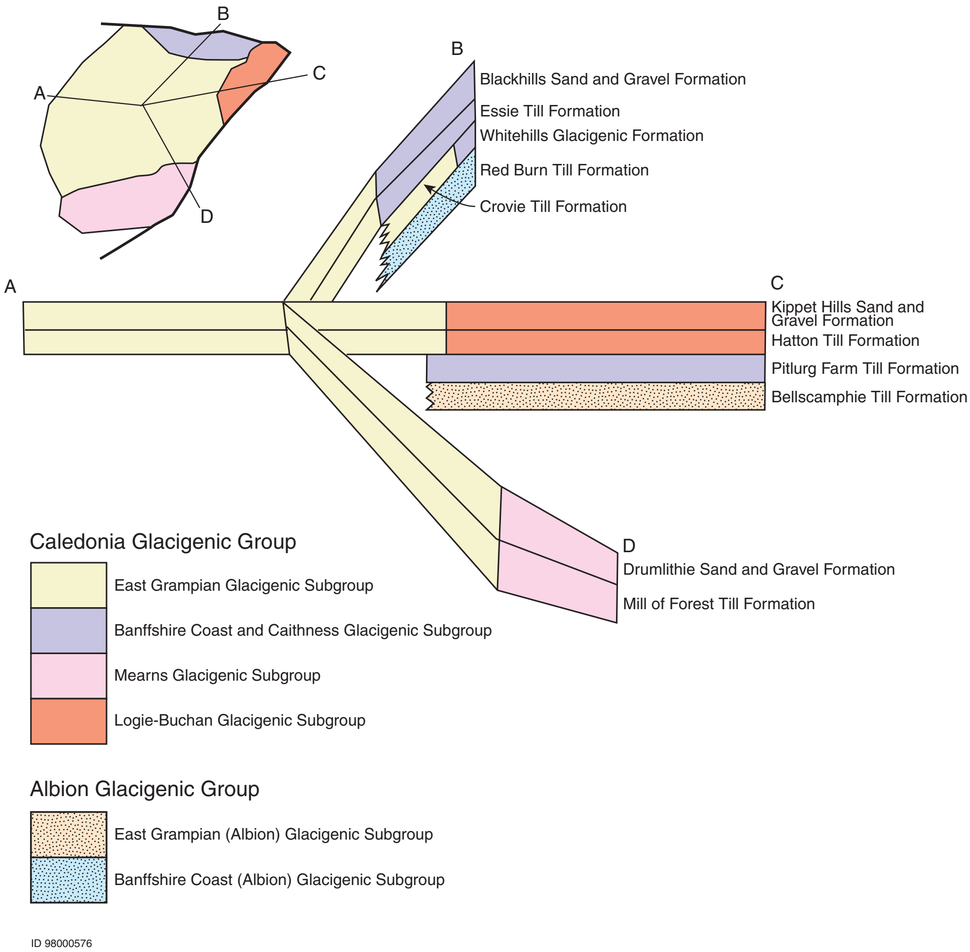


Figure 9 Schematic cross-sections across the Clyde Valley, west-central Scotland showing the stratigraphical relationships between formations and members and the assignment of groups and subgroups.

Figure 10 Model showing examples of the relationships of formations, subgroups and groups of the Great Britain Superficial Deposits Supergroup in north-east Scotland.



addition of the word 'Albion', e.g. Irish Sea Coast (Albion) Glacigenic Subgroup. Examples of component formations of these older subgroups are shown in Table 5b. It is not presently intended to propose subgroups of the Albion Glacigenic Group south of the Devensian ice sheet limit because the origin and lithological variation is less clear. However, lithological and palynomorph analysis of middle Pleistocene tills in East Anglia, reported by Lee et al. (2002, 2004), may offer the potential to extend the subgroup concept into this area.

As indicated above, glacigenic subgroups will be defined on the basis of lithological characteristics and properties common to two or more glacigenic formations. Subgroups will assume parental status for formations in areas where they are adopted. There are examples where it is possible to demonstrate interdigitation of formations belonging to different subgroups which are the product of different ice streams during several glaciations (e.g. in north-east Scotland, Figures 10–11, Auton et al., 2000; Merritt et al., 2003). The complexity of glacigenic sequences may depend on preservation potential associated with the location of a site with respect to the ice-dispersal centre (Figure 12) (for discussion see Andrews, 1979; Lowe and Walker, 1997). The thickest and most complex sequences may be preserved at sites that were glaciated for the shortest time.

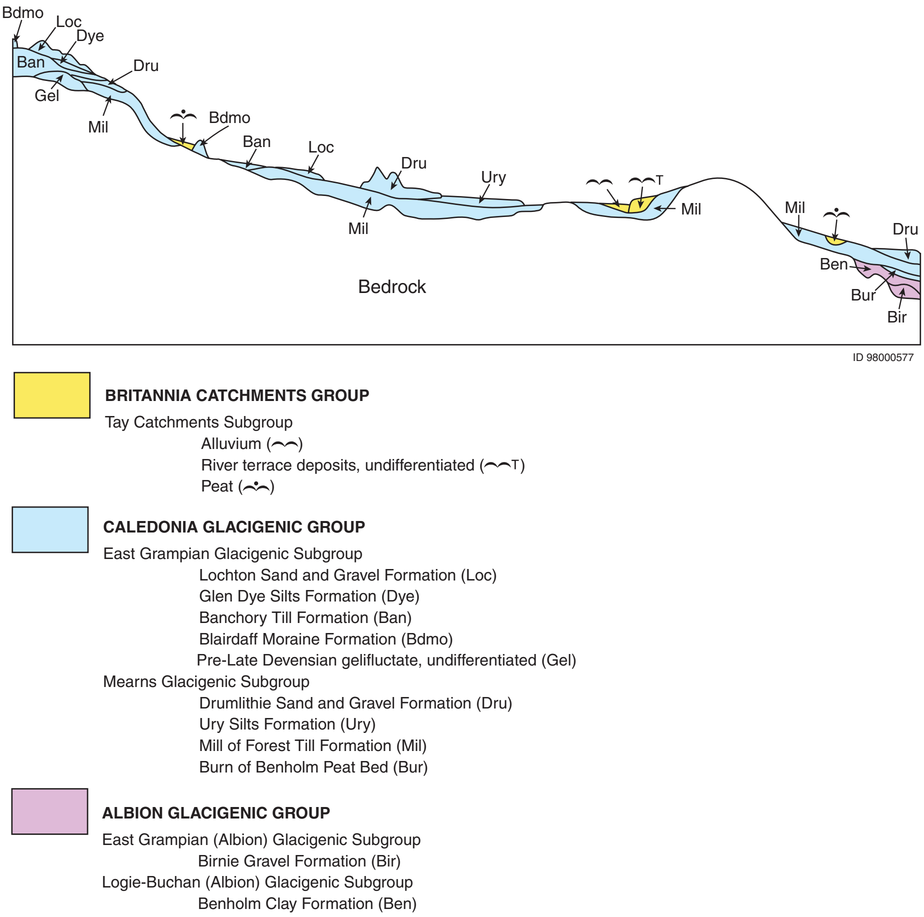


Figure 11 Schematic cross-section across the Highland Boundary and Strathmore, north-east Scotland, showing the stratigraphical relationships between formations and informal lithogenic units and the assignment of groups and subgroups.

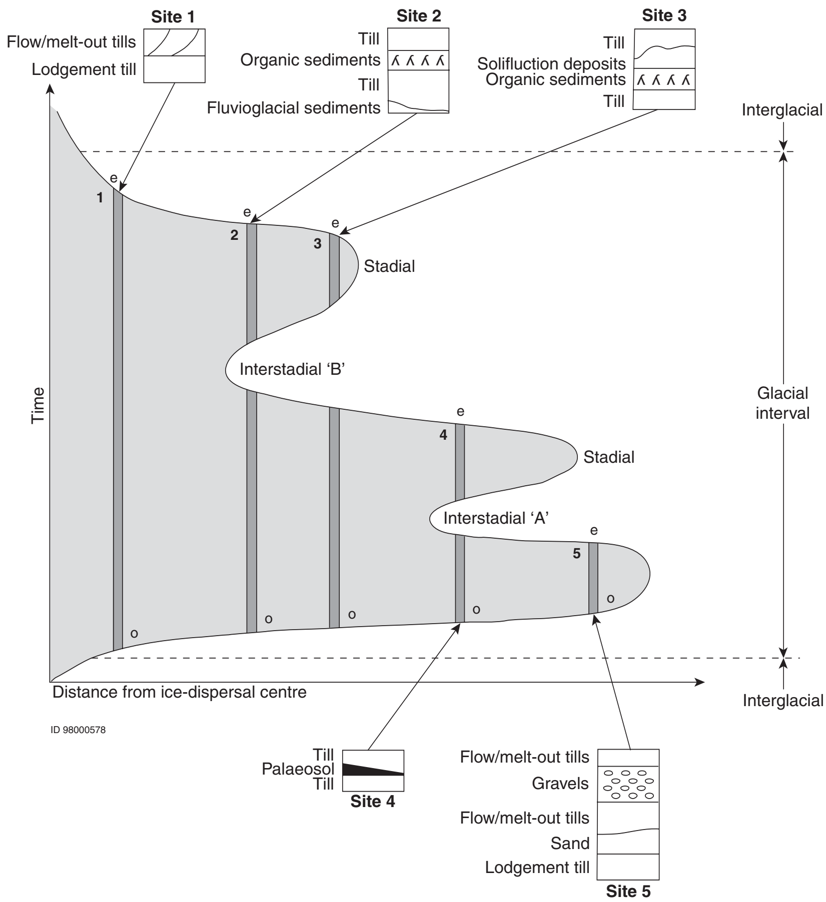


Figure 12 Preservation potential and complexity of glacigenic sequences associated with a glaciation (after Andrews, 1979; Lowe and Walker, 1997). Diagram shows the onset (o) and end (e) of glaciation at sites (1 to 5) at increasing distance from the ice dispersal centre. Possible glacigenic sequences and relative sediment thicknesses at each site are also indicated. The thickest and most complex sequence is likely to be preserved at Site 5, which was glaciated for the shortest time. Deposits preserved closest to the ice dispersal centre (Site 1) may be younger than those farthest away (Site 5).

Appendix 1 Geochronology

Geochronology is the science of dating and determining the time sequence of events (Salvador, 1994). In recent years a wide range of geochronological techniques have been applied to British Quaternary deposits. These have shown additional events not deduced from the pollen biozone record. For brief descriptions of these methods reference should be made to Foster et al. (1999) and the forthcoming BGS Quaternary Methodologies and Training Report. Methods include:

- Radiocarbon dating. This is the principal method for determining the age of organic materials from the present to about 60 000 years ago. Dates quoted in the style '12.5 ka BP' are calibrated radiocarbon years before present. A non-linear relationship exists between conventional radiocarbon years before present (taken as 1950) and Calendar (sidereal) years (Stuiver and Reimer, 1993).
- Amino acid dating which involves the analysis of proteins locked-up in the marine and non-marine bivalves and gastropods and tests of foraminiferids (Wehmiller and Miller, 2000). Several time-dependent chemical reactions occur upon death that provide a means of relative dating. Of these, racemisation is the most useful, involving the transformation of L-isomers of individual amino acids into D-isomers. A relative timescale may be constructed using the ratios of D-alloisoleucine to L-isoleucene (Bowen, 1999, 2001).
- Thermoluminescence (TL) and optically stimulated luminescence (OSL) dating techniques are based on the principle that naturally occurring minerals such as quartz and feldspar can act as dose meters, recording the amount of nuclear radiation to which they have been exposed (Miller, 1990). Although not referred to further in this report, the methods offer potential for dating loess and wind blown sand. They have proved less reliable for glaciofluvial and glaciolacustrine deposits.
- Uranium series $^{234}U/^{230}Th$ disequilibrium techniques on speleothems and wood, are applicable up to 400 ka.
- Electron spin resonance (ESR) dating can be carried out on fossil tooth enamel, applicable up to 600 ka.
- Terrestrial Cosmogenic Nuclide Dating (TCN) techniques are also used for Quaternary sediments. The technique is applied in two types of study, the first and simplest is exposure age determination, and the second is landscape evolution. TCN dating seeks to determine precisely (to the precision of $e \times 10^{-14}$ or better) the number of atoms of a series of rare isotopes occurring in rocks at the Earth's surface. These isotopes are produced when cosmic rays collide with atoms in certain minerals, particularly quartz, olivine and pyroxene. The mechanisms of production are complex, and it is important to note that these rare isotopes are also produced in the atmosphere, and may act as contaminants of samples.
- Lichenometry which uses growth rates of lichens determined by their presence on surfaces of known age. Size measurements of other lichens may then be used to provide dates for their substrates. Applicable to the last few hundred years.

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Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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