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Application of ArcView GIS to geological mapping

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BRITISH GEOLOGICAL SURVEY

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Foreword

This report considers how GIS may be used in geological mapping to facilitate best practice, improve efficiency and accuracy and to address problems inherent in traditional processes and products. It is based on innovative use of ArcView GIS (Version 3.2) in revision of the geological map of the Isle of Man during the period 1999-2001.

The Isle of Man project was sponsored by TotalFinaElf Exploration UK PLC and their partners Enterprise Oil plc and Amerada Hess Limited and involved contributions from researchers in several UK universities and the Geological Survey of Ireland.

The report was compiled as part of the SIGMA (System for Integrated Geospatial Mapping) project, the aims of which are as follows:

1. To provide a structured best practice methodology for the complete survey process in BGS, including acquisition and management of existing data and knowledge, evaluation of existing geological models and prioritisation of new surveys, and the output of updated maps, databases and spatial geoscientific models
2. Development of an integrated GIS application for data assembly, capture, manipulation and management
3. To address all aspects of the implementation process, including development of equipment and software, re-engineering of management systems and work processes, and the enhancement of human resources.

Acknowledgements

The revision of the Isle of Man geological map and development of the GIS were sponsored by TotalFinaElf Exploration UK PLC and their partners Enterprise Oil plc and Amerada Hess Limited. The project was supported by the Isle of Man Government Department of Trade and Industry and Department of Local Government and the Environment (DOLGE), who made available digital mapping at 1:10,000 scale. Wardell Armstrong provided access to reports relating to mine entries on the island. D J Burnett and D G Quirk (Oxford Brookes University), R C Chiverrell and G S P Thomas (University of Liverpool), J H Morris (Geological Survey of Ireland), G M Power (Portsmouth University), D Roberts (University of Durham) and N H Woodcock (University of Cambridge) contributed to the scientific and technical work and provided unpublished data.

The Isle of Man project was managed by H Johnson who encouraged the application of GIS to revision of the geological map of the Isle of Man. The development of the mapping GIS concept was made possible by the expertise of M Harvey.

This report has been prepared for the SIGMA project and has been reviewed by A Howard.

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Summary

This report considers how modern geographical information systems (GIS) technology can be used to address the practicalities and failings of the 'traditional' geological mapping process. It is based on the development of an ArcView-based GIS which was used to revise the map of the Isle of Man.

With limited resources precluding extensive resurvey work, the commercially funded Isle of Man project used ArcView GIS (Version 3.2) to develop new solid and Quaternary map interpretations from the substantial amount of existing data with limited infill mapping. Existing data, ranging from 1890's primary survey mapping to recent research mapping, were compiled into the GIS as georeferenced raster images. An application was developed to allow rapid and accurate capture of point data (bedding, cleavage, structural, sedimentary and glacial lineations, sample details, mine entries etc) in vector format. New data acquired during field work were added to the GIS at the field base and the GIS was used to iteratively develop the solid geology map as line and polygon vector files. Quaternary map data were already partly available in ArcView format as a result of ongoing research at Liverpool University. These were supplemented by a limited amount of new mapping and by using primary survey linework where necessary (mainly upland areas). The final product was provided to the Drawing Office as a series of digital files, precluding redrafting at the publication scale.

The major advantage of the GIS approach was to make all of the information easily accessible, allowing it to be viewed, compared and used at any scale. The complete compilation of existing information facilitated planning and execution of focused field work. Point data were extracted accurately and rapidly into digital tables. The new map interpretation was iteratively developed within the GIS, prior to, during and after fieldwork, making full use of previous interpretations from a wide range of sources. Ultimately, the map, the underlying data and all of the contributing information existed in the GIS and could be accessed and utilised as necessary. For publication, the map was provided to the BGS Drawing Office as polygon, line and point data files, thereby considerably simplifying the drafting process.

The major disadvantage of the GIS approach as applied in the Isle of Man was the lack of formal field slips and clean copies. Maps at 25k scale were used to capture field locations for transfer to the GIS; observations were recorded on field note cards. Clean copies could be prepared from the GIS if necessary.

Practical experience gained during use of ArcView GIS for the revision of the Isle of Man map and applications written to facilitate data capture will be of use in further development and implementation of GIS systems for geological mapping. A number of recommendations are made for future application of GIS to mapping projects, including:

- A minimum requirement and procedures for the capture and archiving of information need to be established (i.e. is the digital record sufficient and/or are field slips and notes and clean copies necessary interim products)
- Common standards need to be defined and established for 'corporate datasets' (e.g. image databases of field slips & clean copies, structural databases), such that scanning and point data capture from existing materials need only ever be done once
- The point data entry application developed specifically for the Isle of Man project needs to be modified to reflect corporate standards and to make it more generally applicable.
- A number of additional mapping tools could be developed as applications to improve the functionality of the GIS software for geological mapping purposes.

The GIS approach developed during the Isle of Man project offers a clear way forward for geological mapping in the 21st century. It provides a convenient and flexible means for project and data management and it facilitates iterative interpretation and digital map drafting throughout the map making process. All of the information used in the development of a map, and interim and alternative interpretations, can be captured digitally and are readily available in support of published products. The system also provides the potential to capture for the first time meaningful information relating to accuracy and uncertainty.

1 Introduction

In late 1999, BGS was invited to tender for a series of geological products to be commissioned by Elf Exploration plc on behalf of the Isle of Man government. This included a geological map to replace the extant version produced in the 1970's as a 1:50k reconstitution of the original one-inch primary survey map (Geological Survey 1898, Lamplugh 1903). The work was timely because of the publication of the results of an academic study (Woodcock *et al*. 1999a) which had provided new insight into the stratigraphy of the Lower Palaeozoic rocks that make up much of the island.

A GIS was originally excluded from the contract specification for the Isle of Man map, but became an appropriate tool for several reasons:

- ?? The Isle of Man Government (Department of Local Government and the Environment, DOLGE) has for some years been developing an ArcView based approach to cartography and was able to provide detailed digital topographical information.
- ?? Collaborators at Oxford Brookes University were understood to be in the process of developing some form of GIS for the solid geology (although this subsequently proved not to be the case).
- ?? Collaborators at Liverpool University had been using ArcView for mapping the Quaternary deposits in the north of the island.
- ?? A GIS was seen as a convenient means of capturing linework and point information from contributory data sources at a range of scales, including primary survey six-inch field slips and clean copies, the published 1:50,000 scale map, data from contributors' clean copies at 1:25,000 scale and published diagrams.

The revision of the geological map of the Isle of Man and initiation of the mapping GIS is described below, following brief consideration of the practicalities and problems of geological mapping. The report concludes by considering development of the mapping GIS and the potential for enhancing the geological mapping process. Details of the application created for the capture of point data are given in Appendix 1 and metadata for the raster images and vector components of the Isle of Man GIS (Barnes 2001) are given in appendices 2 and 3 respectively.

2 Geological mapping

A geological map is a 'view' through a three-dimensional model of the stratigraphy and structure of an area, typically as intersected by the topographical or rockhead surface. The model is an interpretation, based on varying amounts of information and influenced by the experience and expertise of the interpreter(s). Input data range from 'hard' (repeatable observations from surface mapping and subsurface information (e.g. boreholes and mine plans)) to 'soft' (interpretations of information such as non-diagnostic fossil collections, aerial photography, satellite imagery and potential field data) and may be weighted and combined in various ways. The amount and quality of the input data and the nature and complexity of the geology determine the level of interpretation necessary to construct a model. The interpretation process depends to an extent on the expertise and experience of the interpreter, who may also bring to bear an element of prejudice. Ultimately, a range of uncertainty is inherent in any model but is rarely documented.

2.1 THE MAPPING PROCESS

The 'traditional' mapping process has changed little in over one hundred years. Existing information is collected and some detailed information (e.g. from boreholes and mine plans) may be extracted. The results of field survey or resurvey work, including an interpretation of the geology, are also recorded on paper maps and in note books. Information subsequently acquired from laboratory studies of sample materials may significantly influence the final map interpretation which is prepared as 'clean copies' prior to redrafting at the publication scale.

This mapping process can be drawn out and difficult to manage. Compilation of existing information may be selective and inaccurate, especially when source material is at different scales. Iteration of interpretations on paper is limited, partly because they are laborious and time consuming to prepare. Interim interpretations and other working materials are rarely preserved. The rationale behind an interpretation may be obscure and not fully documented, such that it is unrepeatable to anyone other than the original author(s). Some information relating to quality and uncertainty may be apparent from the nature and density of the information recorded on field maps and clean copies, but is rarely explicitly provided. Updating or revision of a map requires the process to be repeated from the start.

2.1.1 Collation of information

Modern geological mapping is rarely carried out in areas where there has been no previous work. Consequently the results or products of previous work can be a major source of information to a 'new' survey. The usefulness of existing work depends on how the information is presented: a large-scale record of point observations supporting linework (e.g. a well-compiled traditional field slip) is of considerable value as it contributes both an interpretation and the underlying information; a small-scale map or diagram may be of relatively little use as it offers only an unsubstantiated interpretation.

Historical sources provide data and interpretation in varying measure and in various forms (e.g. borehole records, reports, diagrams, maps). Diagrams and maps (including mine plans) come in a range of scales and with varying amounts of topographical information and may or may not be accurate at a given threshold. Topographical maps, aerial photographs, satellite images and processed geophysical data may all provide relevant information above a scale cut-off, and any or all of these may be used as base maps for new survey work.

Often the only common ground between different or disparate pieces of information is the geographical context. Previously, items at different scales were reconciled by enlargement to the working scale of the study (e.g. by eye, plan variograph, photography or photocopier) and pertinent detailed information transferred to some form of working map, often a 'field' map or mining slip. The accuracy of the working compilation obviously depended on the accuracy of the original materials and on the enlargement and data transfer process. The completeness of the compilation depended on the density and clarity of the source information and the diligence and remit of the individual transferring the information.

Once historical information has been compiled and combined with new information to derive a new interpretation, much of the original information may subsequently be lost. Some underlying data (e.g. in relation to samples, biostratigraphy, geochemistry, structural geology etc) may have been tabulated but may be difficult to use out of context, even if they are available.

2.2 ACCURACY AND UNCERTAINTY

There is a temptation to believe that a geological map is correct, particularly amongst the user community faced with a professionally published product. Unfortunately at some level it is certainly not. There are two types of potential error:

- the simplest is 'accuracy' – does a feature represented by a symbol or line (e.g. a geological boundary or a shaft) actually occur where it is shown to occur?
- at a more fundamental level there is 'uncertainty' – does an interpreted feature (e.g. a fault) actually exist?

Measures of accuracy and uncertainty are difficult because they vary in space and are not straight forward to portray. Both depend to some extent upon the amount of information available and the complexity of the geology. A gently dipping sequence with no drift cover might easily be interpreted and mapped from features and natural exposure. In this case a geological map would have considerable certainty and accuracy, particularly if supported by data from hundreds of boreholes (e.g. an opencast coal prospect). A similar sequence in a fold and thrust belt buried beneath a variable thickness of drift may be difficult to interpret with any certainty and may not be mappable with any accuracy, even with hundreds of boreholes.

One relatively simple means of qualifying the potential accuracy and uncertainty in an interpretation is to make available all of the information (preserving the distinction between data and interpretation) upon which it has been based. A user interested in a particular location or feature may then be able to explore to what extent the interpretation is substantiated by data and may even be able to gain an impression of the quality of the underlying data itself.

2.3 DIGITAL SYSTEMS

With the rapid development of accessible digital technology over the last two decades a range of digital approaches have been tried in different situations relating to geosciences. A full review of these activities is outwith the scope of this report, but a few comments are apposite.

Early attempts revolved around digital data storage, ranging from simple spreadsheets to large relational databases. Whilst effective for certain data types (e.g. boreholes, structural observations), mapping use required codification of all observable attributes (e.g. Geological Survey of Canada, Brodaric, 1997). However, very careful design is needed to avoid systems that are inflexible and difficult to use.

BGS has made substantial progress in the development of databases and in recent years a considerable amount of development has gone into the GIS-based network Geoscience Data Index (GDI) in order to provide a range of index level information and basic mapping functionality. A recently completed user requirement for digital capture of geological data in the field (Farrant et al., 2001) is being used as the basis for field trials of digital data capture systems (e.g. Golledge, 2001).

Most attempts to apply digital technology to geological mapping endeavour to replicate the traditional mapping process using digital tools, but fail to address its weaknesses. Modern digital technology allows the entire process to be reviewed and a more effective solution designed to suit survey and user requirements in the 21st century.

3 Revision of the geological map of the Isle of Man

Funding from TotalFinaElf Exploration UK PLC to prepare a revised 1:50,000 scale map of the solid and Quaternary geology of the Isle of Man was timely in the light of recent work on the Lower Palaeozoic rocks and ongoing work on the Quaternary deposits. However, the budget was limited and the map revision had to be based on a compilation of BGS primary survey data and data from published and other sources as outlined below.

3.1 EVOLUTION OF THE GEOLOGICAL MAP OF THE ISLE OF MAN

3.1.1 Historical mapping

The primary survey of the Isle of Man was carried out by G S Lamplugh based on fieldwork on the island from 1892 to 1997. His six inch field slips provide a very detailed record of his observations of the solid and drift geology and information extracted from old mining records. This information is summarised and the linework developed on six-inch clean copies prepared during or immediately after completion of the field survey. The one-inch map was published in two forms, with and without Quaternary (drift) deposits, in 1898 (Geological Survey, 1898). A very detailed account of the geology was provided in a memoir published in 1903 (Lamplugh, 1903). A colour printed solid and drift version of the map, for the first time including cross-sections, was published in 1912. This map was recompiled at 1:50,000 scale without significant change and published in 1975 by the Institute of Geological Sciences.

New interpretations of the stratigraphy and structure of the Lower Palaeozoic rocks that make up much of the Isle of Man were developed in research studies in the 1950's by Gillott (1954, 1956) and Simpson (1961, 1963). However, following the recognition of the occurrence of microfossils (Downie and Ford, 1966), the first widespread biostratigraphical data derived by Molyneux (1979) showed that these interpretations were incorrect in detail. A more broadly based research study in the mid-1990's re-examined much of the coastal exposure of the Lower Palaeozoic rocks (including the Peel Sandstone Group) and produced a new insight into their geology (Woodcock et al., 1999). This included the first recognition of rocks of Silurian age but left a number of uncertainties concerning the stratigraphical relationships within the bulk of the exposed sequence belonging to the Ordovician Manx Group. A parallel PhD study by Burnett (1999) provided additional information inland and led to an alternative version of the stratigraphy of the Manx Group (Quirk and Burnett, 1999).

Carboniferous strata resting unconformably on the Lower Palaeozoic rocks in the south of the Isle of Man were left undivided by Lamplugh (1898) with the exception of the 'Basement sandstone and conglomerate'. These strata were remapped in a PhD study by Dickson (1967), whose detailed stratigraphy was later published by Dickson et al. (1987). Carboniferous rocks and, in the vicinity of Point of Ayre, Permo-Triassic rocks, are also known from sparse boreholes (e.g. Dawkins 1984, Gregory 1920) to be preserved beneath the thick cover of Quaternary deposits in the north of the Isle of Man. A relatively simple outcrop pattern was interpreted in this area by Lamplugh (1898) on the basis of the borehole information. An alternative interpretation of the subcrop, adopted on the geological map of the Irish Sea (IGS, 1982), is used on the revised 1:50,000 geological map.

Lamplugh's traditional representation of the Quaternary deposits of the Isle of Man has been progressively revised over the last 35 years by a group based at Liverpool University (e.g. Thomas, 1976; 1977; 1985; 1999; Dackombe and Thomas 1985; 1989; Thomas et al., 1985; Chiverrell et al., 2001). A relatively complex stratigraphy of glaciogenic deposits is now recognised in the lowland areas of the island, reflecting the glacial history of the Irish Sea area

(Thomas, 1999). Although early work was based mainly on cross-sections provided by the coastal exposures, detailed mapping of the main areas of lowland Quaternary deposits has been carried out in recent years, the data having been compiled in ArcView format by R C Chiverrell.

3.1.2 New mapping

The project to revise the geological map of the Isle of Man relied heavily on pre-existing data. However, limited new work was possible in collaboration with individuals involved in recent work on the island, many of whom also provided unpublished data. This was focussed on solving outstanding problems as follows:

?? Collection, preparation and analysis of 130 samples for micropalaeontological study in order to provide a basis for re-interpretation of the stratigraphy and structure of the Lower Palaeozoic rocks. Detailed results were reported by Molyneux (2001).

?? Field survey to investigate uncertainties in the geological interpretations of the Lower Palaeozoic rocks published in Woodcock et al. (1999) and to extend the coastal mapping inland based on Lamplugh's original observations.

?? Field verification of details and stratigraphical interpretation of the Carboniferous sequence cropping out in the south of the Isle of Man published by Dickson et al. (1987) in the context of ongoing work in NW England.

?? Field survey to complete Quaternary mapping of the northern part of the Isle of Man.

The results of these studies are described by Barnes et al., Jones and Riley and Chiverrell et al. in Chadwick et al. (2001).

3.2 APPLICATION OF GIS

From an early stage in the Isle of Man project, data compilation was carried out using ArcView 3.2. Extant information in map format was captured as georeferenced raster images and these were used as the basis for the development of the map and supporting information as vector files.

3.2.1 Raster images

Using traditional methods, a compilation of data from extant sources perceived as 'relevant' might be made graphically on a field or mining slip. Often, disparate data are only brought together at the 'clean copy' stage. The Isle of Man GIS project set out to compile available map information unselectively as raster images as follows (Figure1 and Appendix 2):

?? Lamplugh's six-inch scale field slips.

?? Lamplugh's six-inch scale clean copies.

?? Previous published 1:50,000 scale geological map.

?? Published maps of the outcrop of Carboniferous rocks in the south of the Isle of Man from Dickson et al. (1987) (reproduced with the permission of the Yorkshire Geological Society)

?? 'Clean copies' at 1:25,000 scale by R P Barnes, J Morris and N H Woodcock of unpublished data acquired during the study of the Lower Palaeozoic rocks in the mid-1990's.

?? Topographical map at 1:25,000 scale supplied by DOLGE and used as the base map for field work.

?? Satellite image.

Additional information developed within the project was incorporated as it became available, including:

?? Maps of the outcrop geology and subsurface structure in the Irish Sea around the Isle of Man, derived in parallel with the 1:50,000 map revision project (Chadwick et al., 2001).

?? Processed images of airborne magnetic data and interpretations thereof (provided by G S Kimbell)

The resolution of scanning of the raster images is a crucial issue; too large and the files can be cumbersome and slow to use, too small and the detail required cannot be read. It is appropriate to scan small-scale materials (e.g. diagrams) at low resolution; the pixelated appearance when they are viewed at too large a scale reinforces the impression of a generalised product. Some trial and error may be necessary for detailed, large-scale materials such as field slips. It may be appropriate for corporate materials such as this to be scanned and georeferenced to pre-defined standards to facilitate the development of a corporate image database.

Scanning and georeferencing of the source documents represents a major input of staff time at the outset of the project. However, much more time would be required over the length of a project using more traditional methodologies in order to locate and capture available information as comprehensively. Completing the process ‘up front’ proved to have many advantages, including:

?? Clear cataloguing of all available information

?? Immediate access and the use of any document at any scale

?? Avoidance of duplication of effort in locating and extracting information

?? Comprehensive and accurate data capture

?? Establishment of databases which can be developed during new work

?? Accurate planning of new work

?? Validation of new interpretations

Ultimately, this process also provides a complete digital record of the data used in a project in support of the final digital and published map products and rendering it immediately available for any subsequent work. In some cases (e.g. mine entries discussed above) underlying documents are essential to provide supporting or more detailed information.

In other project situations, a greater range of ‘base map’ materials may be used, including aerial photographs and satellite images. A major advantage in having all of these available digitally is that information interpreted from or recorded on one can be easily transferred to the GIS where it can be compared with and joined to information from other sources.

3.2.2 Vector data

Initially the acquisition of vector was restricted to point data for which an application was developed by Mary Harvey (Appendix 1). Ultimately, however, most aspects of the development of the new geological map were carried out in ArcView. Details of the vector data (shape) files developed in the Isle of Man project are provided in Appendix 3.

3.2.2.1 POINT DATA

The Isle of Man mapping GIS was designed from the outset to capture geographically attributed point data digitally from raster images of the source documents. Data acquired in the field were added each evening, compiling comprehensive databases of the following point data:

?? Planar structural data (bedding, cleavage etc)

?? Linear data - including structural data and glacial striae and roche moutonnée orientations.

?? Dykes/minor intrusions

?? Mine entries

?? Wells and springs

?? Rock samples

The application written for point data capture by Mary Harvey is fully documented in Appendix 1. In summary, it provides a series of data entry forms activated initially by choosing a data type and defining a location in the active view. Rapid and accurate data entry is facilitated as far as practical by list boxes, most of which are project-specific. The underlying database for structural data was modified from that developed in discussion of a BGS structural database (Holmes et al., 2000). Data management facilities include snapping entries to a previously defined point (e.g. for multiple data from a single exposure) and promotion of data, for example to create a subset for presentation on a final map product.

Using the data presentation and selection facilities of ArcView, it is possible to display the point data in many ways, including orientated and labelled symbols. Data subsets are easily selected from their attributes or within a geographical area of any shape and can be output for presentation in other forms, for example to generate stereograms of structural data.

On completion of the map, shape files of selected point data for each map symbol type were prepared and provided to the BGS Drawing Office for translation to Microstation.

3.2.2.2 LINE/POLYGON MAPPING

Line/polygon mapping were not envisaged at the outset of the Isle of Man ArcView project development and early compilations of the solid geological map were made on paper at 1:25,000 scale. During the fieldwork, however, it became evident that with the availability of previous mapping as raster images, linework could be iteratively developed more effectively in ArcView. A draft was therefore captured as two ArcView shape files (polygons and faults) and all subsequent development was carried out by editing these within ArcView. On completion, the shape files were transferred to the BGS Drawing Office for translation to Microstation.

The Quaternary mapping for the lowland areas of the Isle of Man was derived from new work carried out in ArcView by the University of Liverpool. The upland drift was to have been taken from the original DigMap linework capture from the previously published 1:50,000 scale map of the Isle of Man. However, comparison of the latter with Lamplugh's field slips/clean copies showed that it was very inaccurate in detail, presumably because the original transfer of linework from six-inch to one-inch scale had been carried out by eye. It was therefore necessary to recapture the upland drift linework from the raster images of Lamplugh's clean copies. This task was completed in Microstation by the BGS Drawing Office and joined with the lowland linework derived from the Liverpool shape files.

3.2.3 Transfer of digital data to the BGS Drawing Office

Digital development of a map by the geologist carries many advantages but also a number of potential pitfalls when it comes to transferring the data to the Drawing Office for preparation of a final map product, including:

?? Poor quality linework

?? Non matching polygons

?? Stacked structural symbols

?? Small features which need exaggeration for presentation

In theory the digital preparation of a map at source obviates the need for recapture on submission to the Drawing Office, removing the need for several iterations of linework to accurately recreate the geologist's draft. However, this requires that the drafting work within the GIS has been done to an appropriate standard. Polygon boundaries and/or faults drawn crudely or with too few nodes may require substantial editing before being acceptable. Non matching polygons are a particular problem because the narrow gaps or overlaps form separate unattributed polygons on translation to Microstation and are laborious to remove.

The point data capture method developed for the Isle of Man allows several data elements to be snapped to the same location (for example if bedding, cleavage and other structures have been recorded at one exposure). The application also allows the point data to be filtered to derive a data-set appropriate for a derivative map (e.g. at a smaller scale than the survey). However, if two or more data elements are retained at one location these will require to be spread out for final presentation on paper. Ultimately, the positioning of all symbol and text elements of the geological map needs to be checked and perhaps modified in the context of the final map base.

Small line and polygon elements captured at a large scale may need exaggeration if they are to be clearly visible when presented at a smaller scale. Dykes are a typical example of this problem. The Isle of Man GIS allows capture of dykes as lines from the large scale base map (six-inch field slip). For presentation at 1:50,000 scale they need to be translated to two parallel lines bounding an attributed polygon and in many cases the length extended. Microstation can replace a single line with two lines and a polygon automatically, but exaggeration of the length must be done on a dyke by dyke basis and can be laborious.

4 Development of the (digital) mapping process

As discussed above, geological mapping is a complex process involving integration of existing information, some of which may be inaccurate and/or conflicting, and capture of new information in order to develop a three-dimensional interpretation of the geology of an area. This interpretation is represented on a map and in the form of cross-sections.

In recent years, resource limitations preclude extensive resurvey and the development of interpretations and supporting documents over a period of years. Mapping projects are increasingly forced to make full use of existing information and from these to design and execute focused and efficient field survey to complete a product to specification within a short timescale. Issues such as the assessment and portrayal of accuracy and uncertainty have yet to be properly addressed but will become important, further reducing the effective resources. Systems to reduce the cost of capturing and managing such data are therefore urgently needed.

Similar constraints are already apparent in recent BGS commissioned mapping projects carried out overseas, which require rapid turn around with a high level of underlying information within severely limited budgets. This is difficult to achieve using traditional mapping processes.

4.1 A PLACE FOR GIS TECHNOLOGY

Digital mapping technology may be adopted simply because it offers gains in efficiency and accuracy over traditional techniques. Can it also address some of the basic deficiencies in the traditional process or at least not make them worse?

In terms of data collation, the application of GIS technology in the Isle of Man project as described below showed that it has a number of major advantages:

?? All data which can be located in a geographical frame of reference can be captured and preserved within the same system (having first gained appropriate permission to capture published materials)

?? Capture in the GIS can be rapid and very efficient, reducing or removing any need to selectively capture a subset of the information perceived as ‘relevant’ at a given point in the process

?? The GIS provides an easy means of combining and viewing information whatever the original scale

?? Point data can be captured and databased rapidly and accurately

?? Lines and polygons can be iteratively interpreted, attributed and viewed in the context of all source information.

?? The assembled information is preserved for future work

Used carefully, the GIS can also address questions of accuracy and uncertainty:

?? All of the source information is preserved and can be viewed in the context of an interpretation, allowing at least a qualitative measure of accuracy and uncertainty

?? With care, the interpretation process and the origin and/or derivation of individual features can be documented and preserved

Other advantages include:

?? The developing GIS provides a tool for effective project management

?? Compilation of the map in the GIS removes the need for multiple drafting of paper map products; clean copies can be output as required.

?? Digital map components can be transferred directly to the Drawing Office for map publication, removing the need for redrafting.

?? The interpretation can be examined in detail and easily updated in the light of new information

4.1.1 Development of the Isle of Man prototype

The Isle of Man GIS was based on standard ArcView Version 3.2. Early work was carried out with raster images of published topographical maps as base maps but progress was facilitated with 10k digital mapping provided by DOLGE. Otherwise, the only bespoke component was the application (Appendix 1) which facilitated the rapid capture of various types of point data and enabled databases to be populated to a high standard from the outset. This application needs further development to comply with corporate database standards and make it more generally applicable. Ultimately, however, a GIS mapping system can provide a range of tools that assist interpretation and mapping, for example:

?? Database formats and menu-based data entry for line and polygon data elements

?? Links with specialist data (e.g. potential field, stream sediment geochemistry)

?? Rockhead mapping

?? Extrapolation/interpolation and mapping of planar surfaces

?? Structural data selection and stereographic projection and analysis

?? Drafting and balancing of cross-sections

?? Thickness calculation and construction of generalised vertical sections.

?? Proforma side margin construction

Research and development are also necessary to allow accuracy and uncertainty parameterisation of all data elements and to include appropriate entry fields in data input applications.

4.1.2 Limitations to the mapping GIS concept

The Isle of Man GIS was used throughout the project for data collation, interpretation and iterative map drafting. During field work it was employed at the field base to capture point information, develop the interpretation and to plan field work in the context of the available information. It was not used for the capture of data in the field which was carried out in a traditional way using field note cards and field maps, an important distinction when considering the system in the context of ongoing field data capture trials. However, the system essentially achieved the objectives of digital field data capture without some of the disadvantages including reliance on GPS location, the tendency to only acquire point data and 'archivability' of the information acquired.

Total reliance on GPS locations without confirmation on a topographical base is unwise. Traditional mapping on some form of topographical base requires that point locations are plotted with reference to the landforms/cultural features mapped, facilitating some internal checking. In some circumstances (e.g. open terrain with few landmarks) accurate determination of location can be difficult and supporting GPS information is invaluable. However, practical experience of GPS in the field suggests that locations are not always accurate and errors are possible. In some circumstances where adequate satellite coverage cannot be achieved (e.g. deep valleys, cliff sections, heavily wooded terrain) some alternative to GPS is essential.

Digital field data capture is well-suited to point data capture but less amenable to line and polygon mapping and is likely to lead to a tendency to only acquire point data and leave map interpretation and development until return to the office. This is rarely good practice. Lines should be interpreted and mapped on an appropriate base in the field where their definition is influenced by a range of factors, some of which may be subtle. The Isle of Man style GIS encourages mapping; linework acquired in the field would be transferred to the GIS at the field base where it could be compared and modified as necessary in the context of all of the available information. Any conflicts or problems can be identified immediately and checked on the ground.

Archivability of information is an important consideration in the design of any mapping system. Over the last century, field maps have proved to be a successful means of recording and archiving information. One of the single most important data-sources used in revision of the Isle of Man map was Lamplugh' 1890's field maps on which his observations and interpretations are preserved in meticulous detail. Whilst digital data capture at source can lead to many efficiencies, there is the potential for loss of information subsequent to completion of the survey. Databases derived from digital capture should provide comprehensive information such that they can be easily incorporated into corporate databases and the information retained. Methodologies for interpretation and line/polygon mapping must preserve supporting information.

4.1.3 A conceptual GIS mapping project

An Isle of Man style GIS would be of major benefit to the planning and execution of geological mapping in a project situation in which a number of individuals are working closely together from a single field station and using a range of base and contributory materials. A conceptual example would be an overseas project in which, at any one time, several geologists are working within a very limited timescale to complete mapping and sampling work over a wide area. Topographical maps at a range of scales, aerial photographs and paper copies of satellite images may all be available as possible mapping base materials and used in the field depending on quality, the nature of the geology and individual preference. Previous mapping may also be available at a range of scale and accuracy. All locations are measured by GPS, in theory to a greater accuracy than is possible through plotting onto the base materials and therefore relied on without detailed cross-referencing. In such a situation, a number of problems have been experienced when working with predominantly paper-based media:

- Mapping carried out by individuals working in different areas is not compiled until return to the office, when it is found that there are major inconsistencies in interpretation or even areas totally uninvestigated
- Previous work is largely ignored because it cannot be easily related to the base materials
- Significant location errors result in difficulties compiling the final data; including a lack of correspondence between point locations (including samples) and polygons mapped on the aerial photograph or satellite bases
- On return to the UK, mapping staff with limited project time are easily distracted by other more pressing tasks; map compilation takes far longer than is necessary and is consequently very inefficient.

In such a situation, effective use of a mapping GIS would allow a map to be compiled within the time-frame of the mapping, fully validated against underlying information sources and underpinned by accurate point data-sets, as follows:

Prior to the start of field work:

- The GIS would be set up with raster images of all base map materials, satellite imagery, potential field data and existing mapping.

?? Databases would be set up and populated with existing information

?? A compilation of existing mapping would be made in the GIS, facilitating planning.

In the field:

?? The compilation map would be revised and/or developed or a new map prepared using the results of the daily mapping work within a day or two of acquisition.

?? Point locations and data would be transferred to the GIS daily and validated against topography and polygon mapping, allowing any problems to be detected and rectified immediately.

?? The full range of the raster images of base materials and existing maps would be used to extrapolate new mapping and interpretations and plan further field work as necessary

In theory, this could be achieved by geological mapping staff with appropriate GIS expertise, although the digital map may need further work on return to the office. However, a team of several geologists could be more effective if supported by a cartographically trained GIS operator working at the field base. This should result in the map being drafted as completely and accurately as possible in the field.

On return to the office it may be necessary to modify the map and databases in response to the results of laboratory work (biostratigraphy, petrography, geochemistry, dating etc). Ultimately, however, the map could be compiled in the GIS to a sufficiently high standard to require relatively little work by the Drawing Office prior to final production and publication. The final product would automatically be supported by complete and accurate databases of all field data (samples, structural data, photographs etc) and laboratory data.

5 Conclusion and Recommendations

The project to revise the geological map of the Isle of Man demonstrated that mapping can be carried out effectively, and within strict cost and timescale limitations, by uncomplicated use of existing GIS technology.

Many conclusions can be drawn from the experience gained in the application of GIS to the development and production of a new geological map of the Isle of Man. Key aspects are as follows:

?? The traditional geological mapping process needs to be fundamentally reviewed in the light of modern technology and likely requirements for greater information relating to accuracy and uncertainty

?? The Isle of Man experience demonstrates that GIS is a powerful tool which, with limited programming of specific applications, can provide a simple and effective system for geological mapping

?? GIS mapping allows effective project and data management and completion of a high quality product with limited resources and in a very short timescale compared with traditional methods

?? Application of GIS from the outset yields many benefits including comprehensive and accurate databases of the underlying point data and digital records of all of the contributing information, forming a complete digital archive available in support of published products

For BGS use, the GIS mapping system needs to be developed to a minimum level of functionality and tested in various settings. Procedures for the capture and archiving of information need to be established (i.e. is the digital record sufficient and/or are field slips and notes and clean copies necessary interim products). Common standards need to be defined and established for 'corporate datasets' (e.g. image databases of field slips & clean copies, structural databases). The point data entry application developed specifically for the Isle of Man project needs to be modified to reflect corporate standards and to make it more generally applicable. A number of additional mapping tools of general applicability could be developed as suggested above.

The GIS mapping system could be developed as a stand-alone, marketable product that would be of particular interest to newly established geological surveys in developing countries. The cost of commercial ArcView software licences may be prohibitive. However, a joint development venture with ESRI to produce a targeted version of ArcView which could be marketed more cheaply than the standard, full blown product may be a practical solution.

References

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.

Barnes, R P, 2001. Metadata for the ArcView GIS associated with the revised (2001) geological map of the Isle of Man. *British Geological Survey Research Report*, CR/01/242.

Bluck, B J, Halliday, A N, Aftalion, M, and MacIntyre, R M. 1980. Age and origin of Ballantrae ophiolite and its significance to the Caledonian orogeny and Ordovician time scale. *Geology*, Vol. 8, 492-495.

British Geological Survey. 1994. East Irish Sea (Special Sheet Edition). 1:250000. (Edinburgh, Scotland: British Geological Survey.)

British Geological Survey. 1996. Tectonic map of Britain, Ireland and adjacent areas 1:1500 000. (Keyworth, Nottingham: British Geological Survey.)

British Geological Survey. 2001. Isle of Man Solid and Drift Geology. 1:50 000. Sheets 36, 45, 46, 56 and 57. (Keyworth, Nottingham: British Geological Survey)

Brodaric, B. 1997. Field Data Cature and Manipulation using GSC Fieldlog v3.0. *U.S. Geological Survey Open-File Report*, No. 97-269, Available from http://pubs.usgs.gov/openfile/of97-269/brodaric/html.

Burnett, D J. 1999. The stratigraphy, geochemistry and provenance of the Lower Paeozoic Manx Group. Unpublished PhD thesis, University of Oxford Brookes.

Chadwick, R A, Jackson, D I, Barnes, R P, Kimbell, G S, Johnson, H, and __ others. 2001. Geology of the Isle of Man and its offshore area. *British Geological Survey Research Report*, No. RR/01/06.

Chiverrell, R C, Thomas, G S P, and Harvey, A M. 2001a. Late-Devensian and Holocene landscape change in the uplands of the Isle of Man. *Geomorphology*, Vol. 40, 219-236.

Dackombe, R V, and Thomas, G S P. 1985. *Guide-book to the Isle of Man Excursion*.. (Cambridge: Quaternary Research Association).

Dackombe, R V, and Thomas, G S P. 1989. Glacial deposits and Quaternary stratigraphy of the Isle of Man. 333-344 in *Glacial deposits of Great Britain and Ireland*. Ehlers, J, Gibbard, P L, and Rose, J (editors). (Amsterdam: A A Balkema.)

Dawkins, W B. 1894. On the geology of the Isle of Man. Part I - the Permian, Carboniferous and Triassic rocks and the New Saltfield of the North. *Transactions of the Manchester Geological Society*, Vol. 22, 590-613.

Dickson. 1967. The structure and sedimentation of the Carboniferous rocks of the Castletown area, Isle of Man. Unpublished thesis, University of London (Queen Mary College).

Dickson, J A, Ford, T D, and Swift, A. 1987. The stratigraphy of the Carboniferous rocks around Castletown, Isle of Man. *Proceedings Yorkshire Geological Society*, Vol. 46, 203-229.

Downie, C, and Ford, T D. 1966. Microfossils from the Manx Slate Series. *Proceedings of the Yorkshire Geological Society*, Vol. 35, 307-322.

Farrant, A R, Jordan, C J, and Thomas, C W. 2001. A user requirement for Land Survey digital field data entry. *British Geological Survey Internal Report*, IR/01/137.

Fitches, W R, Barnes, R P, and Morris, J H. 1999. Geological structure and tectonic evolution of the Lower Palaeozoic rocks of the Isle of Man. 258-288 *in* 'In sight of the suture' the Palaeozoic geology of the Isle of Man in its Iapetus Ocean context. Woodcock, N H, Quirk, D G, Fitches, W R, and Barnes, R P (editors). *Geological Society of London Special Publication*, No. 160.

Geological Survey. 1898. Isle of Man Sheets 36, 45, 46, 56 and 57. Solid and Drift geology. 1:63 360. (Southampton: Ordnance Survey.)

Gillott, J E. 1954. Sedimentary petrology, metamorphism and structure of the Manx slates. Unpublished PhD thesis, University of Liverpool.

Gillott, J E. 1956. Breccias in the Manx Slates: their origin and stratigraphic relationships. *Liverpool and Manchester Geological Journal*, Vol. 1, 370-380.

Golledge, N R. 2001. A trial methodology for the digital capture of geological field data. *British Geological Survey Internal Report*, IR/01/186.

Gregory, J W. 1920. The Red Rocks of a deep bore at the north end of the Isle of Man. *Transactions of the Institution of Mining Engineers*, Vol. 59, 156-168.

Holmes, K, Sowerbutts, A, and Thomas, C. 2000. A BGS Structural Database: User Requirement. *British Geological Survey Technical Report*, WA/00/46.

Institute of Geological Sciences. 1982. Isle of Man Sheet 54°N-06°W. Solid Geology. 1:250 000. (Southampton: Ordnance Survey for Institute of Geological Sciences.)

Lamplugh, G W. 1903. The geology of the Isle of Man. *Memoir of the Geological Survey of Great Britain*.

Molyneux, S G. 1979. New evidence for the age of the Manx Group, Isle of Man. 415-421 *in* The Caledonides of the British Isles - reviewed. Harris, A L, Holland, C H, and Leake, B E (editors). *Geological Society of London Special Publication*, 8.

Molyneux, S G. 2001. Palynology of the Manx Group, Isle of Man. *British Geological Survey Commissioned Report*, CR/01/21.

Quirk, D G, and Burnett, D. 1999. Lithofacies of Lower Palaeozoic deep marine sediment in the Isle of Man: a new map and stratigraphic model of the Manx Group. 69-88 *in* 'In sight of the suture' the Palaeozoic geology of the Isle of Man in its Iapetus Ocean context. Woodcock, N H, Quirk, D G, Fitches, W R, and Barnes, R P (editors). *Geological Society of London Special Publication*, No. 160.

Simpson, A. 1961. The stratigraphy and tectonics of the Manx slate series. Unpublished PhD thesis, University of London.

Simpson, A. 1963a. The stratigraphy of tectonics of the Manx Slates Series. *Quarterly Journal of the Geological Society of London*, Vol. 119, 367-400.

Thomas, G S P. 1976. The Quaternary stratigraphy of the Isle of Man. *Proceedings of the Geologists' Association*, Vol. 87, 307-323.

Thomas, G S P. 1977a. The Quaternary of the Isle of Man. 155-178 *in* The Quaternary History of the Irish Sea. Kidson, C, and Tooley, M J (editors). *Geological Journal Special Issue*, 7.

Thomas, G S P. 1985. The Quaternary of the northern Irish Sea basin. 143-158 in *The geomorphology of North-west England*. Johnson, R H (editor). (Manchester: Manchester University Press.)

Thomas, G S P. 1999. Northern England. 179-193 *in* Correlation of Quaternary deposits in the British Isles. Bowen, D Q, McCabe, A M, Sutherland, D G, Bridgland, D R, Cameron, T D J, and __ others (editors). *Geological Society of London Special Report*, 4.

Thomas, G S P, Connaughton, M, and Dackombe, R V. 1985. Facies variation in a supraglacial outwash sandur from the Isle of Man. *Geological Journal*, Vol. 20, 193-213.

Woodcock, N H, and Barnes, R P. 1999. An early Ordovician turbidite system on the Gondwana margin: the southeastern Manx Group, Isle of Man. 89-108 *in* In sight of the suture: the geology of the Isle of Man in its Iapetus Ocean context. Woodcock, N H, Fitches, W R, Quirk, D G, and Barnes, R P (editors). *Geological Society, London, Special Publication*, 160.

Woodcock, N H, Fitches, W R, Quirk, D G, and Barnes, R P. 1999a. In sight of the suture: the geology of the Isle of Man in its Iapetus Ocean context. Woodcock, N H, Fitches, W R, Quirk, D G, and Barnes, R P (editors). *Geological Society, London, Special Publication*, 160.

Woodcock, N H, and Morris, J H. 1999. Debris flows on the Ordovician margin of Avalonia: Lady Port Formation Manx Group, Isle of Man. 121-138 *in* In sight of the suture: the geology of the Isle of Man in its Iapetus Ocean context. Woodcock, N H, Fitches, W R, Quirk, D G, and Barnes, R P (editors). *Special Publication of the Geological Society of London*, No. 160.

Woodcock, N H, Morris, J H, Quirk, D G, Burnett, D, Fitches, W R, and __ others. 1999c. Revised lithostratigraphy of the Manx Group, Isle of Man. 45-68 *in* In sight of the suture: the geology of the Isle of Man in its Iapetus Ocean context. Woodcock, N H, Fitches, W R, Quirk, D G, and Barnes, R P (editors). *Geological Society, London, Special Publication*, 160.

Appendix 1 Point data capture

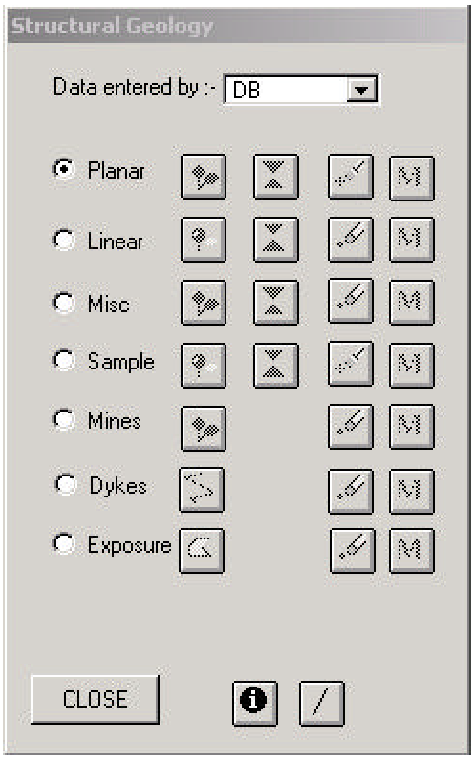
Most numerical observations made in the field relate to a specific spatial location and may change away from that location. These are here termed 'point data'. They may be new data recorded during field survey or existing data captured from records of previous work, in this case assumed to be a map or diagram which displays the location of the information.

Data entry is made via a two-level window system and the active view. Using a tool activated from the first level window, the location of a particular type of feature is identified in the view, either from a copy of whatever base map is being used or the raster image of a source document. The second level window then takes information appropriate to the nature of the feature. Data are stored in tables according to each primary feature type and represented in point shape files. The database structure was based on that defined for the BGS structural database (Holmes et al, 2000).

In general terms, rapid and accurate data entry is facilitated by the use of list boxes wherever possible. These were tailored for the Isle of Man project. In certain cases, list boxes only appear or became active and/or the list contents vary as appropriate for an entry selected in a previous box (e.g. 'Formation' lists vary according to selected group; 'Member' only appears if appropriate for the selected formation).

FIRST LEVEL WINDOW

The first level window, activated by a button on the button bar, allows the user to select the feature type (planar, linear or miscellaneous feature, sample location or mine entry) and identify the location of the feature from the active view. Note that two additional data types, relating to linear (dykes) or polygon (exposure) features, are described in the following section.



Point data entry – first level window

The list box at the top allows the initials of the person making the entry to be recorded. To begin entering or editing data, check the radio button against the appropriate data type. A data type can only be selected if the view contains a theme with the matching name. On selection, the three or four buttons to the right of the theme name become active. Their functions are as follows:

?? The first allows a new point to be added by clicking on the appropriate location on the view

?? The second allows a new point to be added at exactly the same location as an existing data point on the view

?? The third allows an existing data point on the view to be deleted

?? The fourth allows creation of a table of ‘promoted’ data, for example data from a 1:10,000 scale data set to be used on the 1:50,000 scale map.

At the bottom of the window, ‘**Stop editing**’ and ‘**Close**’ allow the data entry session to be terminated. Both return a message box asking if the edits are to be saved. ‘Stop editing’ leaves the first level window open, ‘Close’ closes it. The ‘**i**’ button yields information on an existing data point in the active theme. The button with a diagonal line can be used to return the orientation of a line. This is very useful when capturing data from a map on which orientated features are shown as symbols.

SECOND LEVEL DATA ENTRY

Clicking the appropriate location on the view with either of the first two buttons active automatically brings up the second level data entry window. This varies according to the data type, but in most cases contains common features as follows:

?? **Data source**: a list box allowing selection of one of the known data sources (in this case mainly the names of contributing authors).

?? **Source Info**: free text entry to provide additional information about a specific source document (e.g. for ‘Lamplugh’, whether field slip or clean copy)

?? **Lithostratigraphic data**: list boxes for Group, Formation and Member as appropriate.

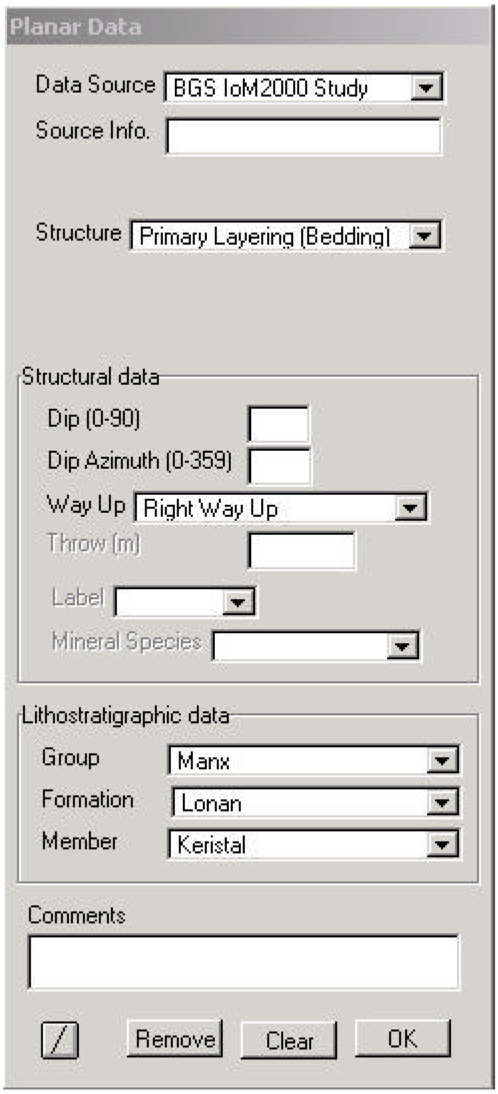
?? **Comments**: free text entry of any other pertinent information.

When entering multiple data of a particular type, certain data elements are automatically recalled from the previous entry, allowing more rapid data input if, for example, bedding from a number of locations in the same member are to be recorded from the same source document.

Four buttons at the bottom of the window allow the orientation of a line to be determined, the point currently being entered to be removed (‘**Remove**’), and the operation to be completed (‘**OK**’). ‘**Clear**’ was intended to remove all of the entries made in the current session, but in some cases does not function. The same effect can be achieved by selecting OK, then ‘Stop editing’ or ‘Close’ from the first level window, then ‘No’ in the message box.

Planar data

Can be used to record the location and attributes of primary layering (bedding), cleavage, foliation, stylolite, faults, shear zone, vein, dyke or fold axial surface.



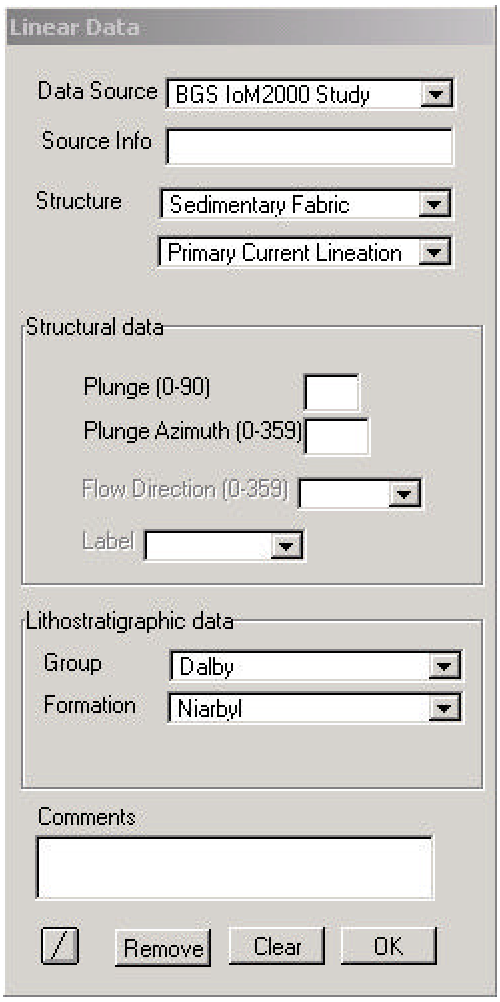
Point data entry – level 2 window for planar features

Structure: allows the structure type to be selected from the pre-defined list and defines the other data elements that can be recorded.

Structural data: orientation is entered in dip and dip azimuth format; entries that do not fall within the appropriate numerical range will not be accepted. For bedding, '**Way up**' can be entered as right way up, inverted or unknown. For faults, a value of throw can be entered if known. For cleavage and fold axial surface, the '**Label**' list box allows the generation of the structure (e.g. S1, F3) to be recorded if known. For a mineral vein, the '**Mineral species**' list allows the elements present to be recorded (e.g. Pb/Zn/Qz).

Linear data

Can be used to record the location and attributes of a wide range of linear features, including fold axis, sedimentary fabric, deformation fabric and fault fabric. For convenience, glacial striae and roche moutonnée were included in this category.



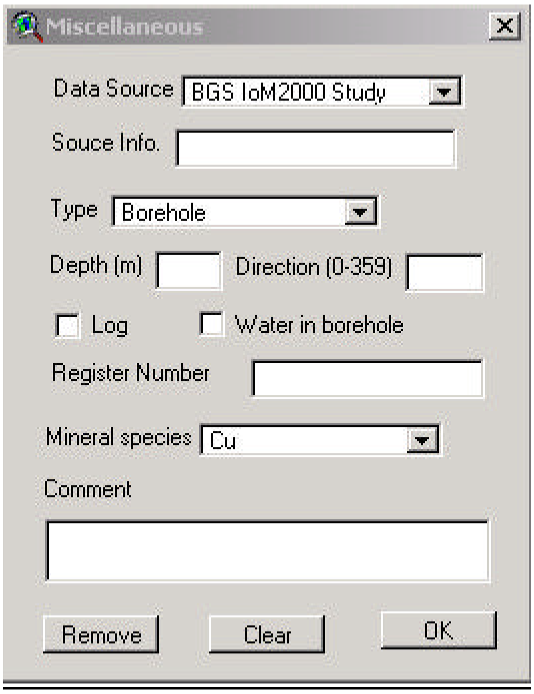
Point data entry – level 2 window for linear features

Structure: allows the structure type to be selected from the pre-defined list and defines the other data elements that can be recorded. Selection of some of these categories brings up a secondary list box, for example 'sedimentary fabric' allows a choice of ripple crest, flute, groove, PCL or imbrication.

Structural data: orientation is entered as plunge and plunge azimuth; entries that do not fall within the appropriate numerical range will not be accepted. In theory, '**Flow direction**' allows a direction of flow or movement (e.g. for flutes, ripples, slickensides) to be recorded, but in practice it does not work. For deformation fabric, the '**Label**' list box allows the generation of an extension lineation or the nature of the two surfaces forming an intersection lineation to be recorded if known.

Miscellaneous

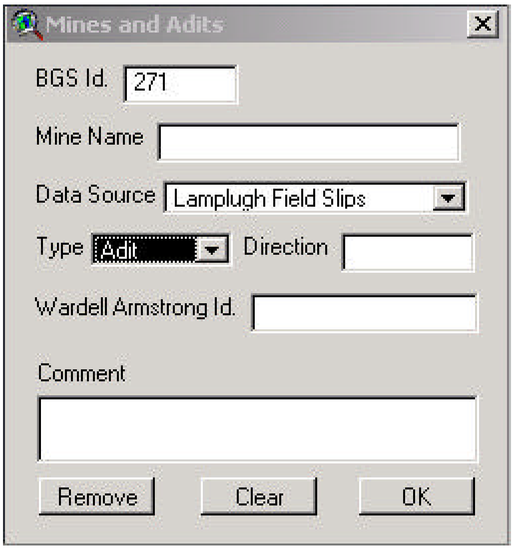
Initially developed to allow the location and details of mine entries, boreholes, wells and springs to be recorded but in practice only used for wells and springs shown on the 1860's six-inch topographical map used as a base by Lamplugh.



Point data entry – level 2: details of miscellaneous feature

Mines and adits

Designed to record the location and details of mine entries, superseding this aspect of the miscellaneous data entry form.



Point data entry – level 2: details of mine entry

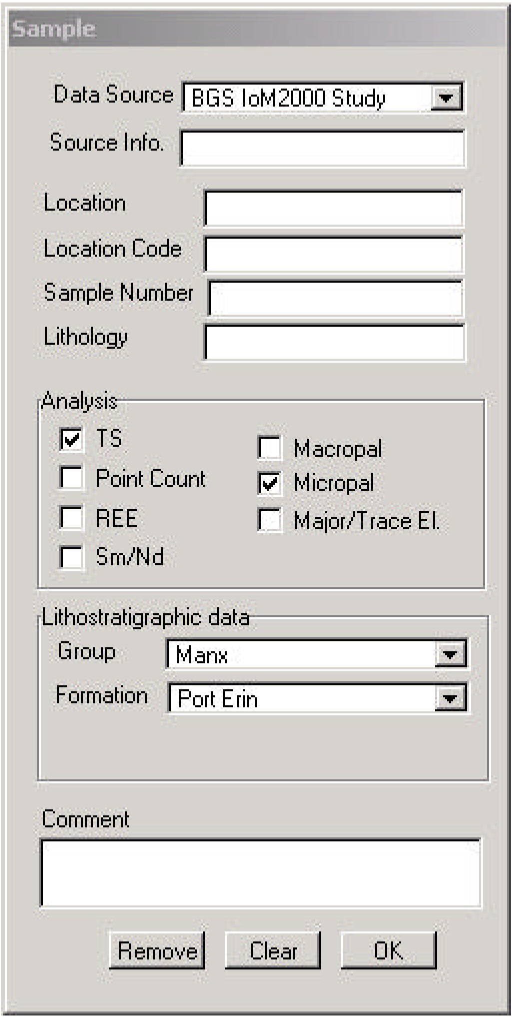
BGS Id is a sequential number of project significance attributed automatically to each new record

Type is shaft or adit, in the case of an adit the **Direction** box is shown for entry of the orientation of the adit (0-360°)

Wardell Armstrong Id was intended to cross-reference to a parallel dataset compiled previously by Wardell Armstrong but limited resources precluded correlation of the two datasets.

Sample

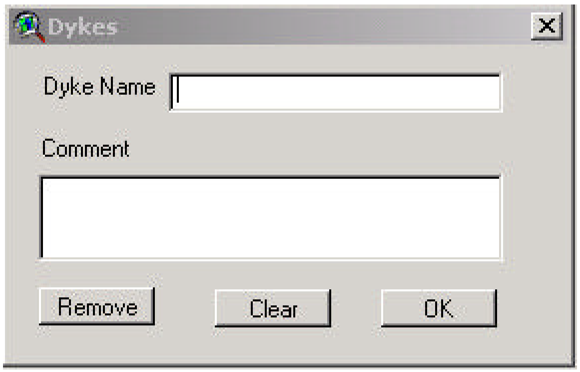
Simple record of the location, number and lithology of a sample and its intended uses



Point data entry – level 2: details of sample

Dykes

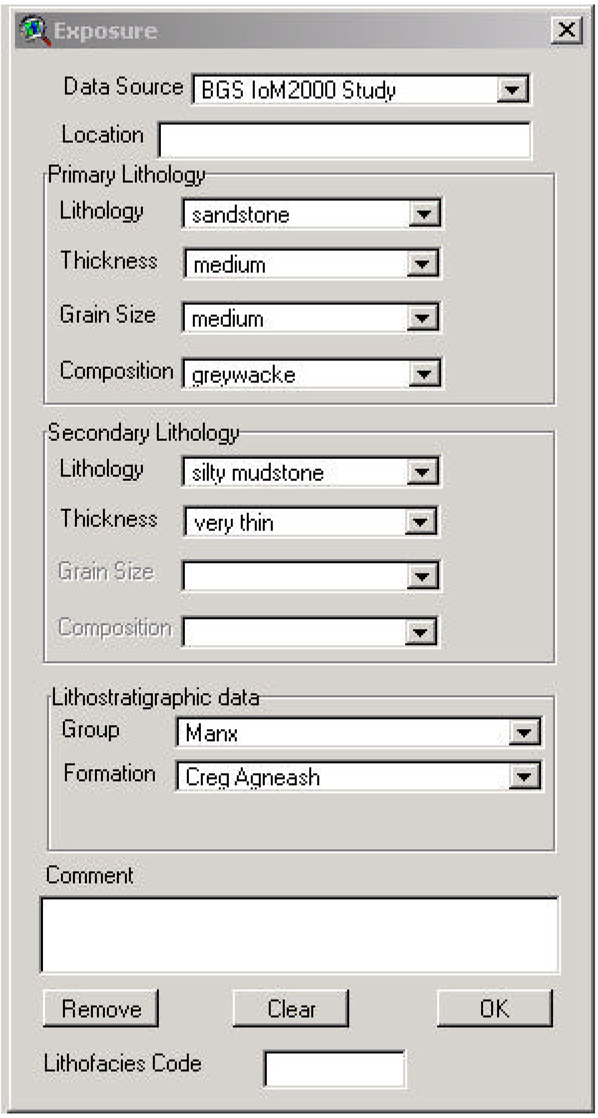
Simple input to a line shapefile used to abstract dykes from Lamplugh's field maps. Selecting the dykes data type offers a polyline tool to trace the outcrop of the dyke and the lithology is entered under **Dyke Name**.



Point data entry – level 2: details of dyke

Exposure

Selection of the 'Exposure' data type activated the polygon tool and allowed definition of the limits of an exposure. The polygon could then be attributed with information relating to lithology and lithostratigraphy. **Lithofacies code** referred to a scheme developed by Oxford Brookes University in their own research on the Isle of Man. This was an experimental idea to allow validation of the interpreted geological map against outcrop observations.



Point data entry – level 2: details of exposure

Appendix 2 Raster images

The following sections provide a description of the source documents captured as raster images.

LAMPLUGH FIELD SLIPS

Identifier/file names: Field slips are numbered after the original six inch map sheets (Figure 1) (e.g. 12), which were quartered (e.g. 12NW, 12NE, 12SW & 12SE) and then each quarter cut in half vertically (e.g. 12NEW & 12NEE) for use in the field.

Originator: G W Lamplugh for the Geological Survey of the United Kingdom

Abstract: Data comprise raster images of manuscript County Series maps (c. 1850) at six-inch (1:10560) scale, anotated with observations made and geological linework interpreted by G W Lamplugh during his field survey of the Isle of Man for the Geological Survey of Great Britain. This is the only survey of the Isle of Man at this level of detail and the observations remain valid, although the interpretation of the geology has changed subsequently. Minor intrusions, mineral veins and mine entries, glacial striae and roche moutonnée, and upland till boundaries were extracted from the field slips/clean copies and a selection presented on the 2001 version of the geological map without addition or modification other than the nomenclature of the dyke rocks. Other data, such as bedding and cleavage measurements, were extracted and used in areas where more recent data are lacking.

Period of data capture: 1892-1897

Data update: None in same style or of comparable completeness; variable new observations are available from more recent research; interpretations are in part superseded culminating in the revised 2001 version of the geological map at the time of writing.

Scale: six-inch (1:10,560).

Data extent: Field slips are available for the entire area of the Isle of Man with the exception of part sheet 16SEE (northern Langness) which is missing. Those for the northern, drift-covered part of the island (1-3 and northern parts of 4 & 5) were not captured as raster images.

Data accuracy: Original accuracy of positioning of information by Lamplugh will vary according to topographical detail; i.e. locations will be more accurate when near features easily identified on the map compared with those situated, for example, on open moor land. The scanned maps were georeferenced by matching features to a scan of the 1:25,000 scale topographical map of the Isle of Man. Minor errors in this process and distortion of the original manuscript maps leaves a variable mismatch when compared with the 1:10,000 scale digital (MANNGIS) map. This is generally less than 10 m on the ground and was compensated for when data were extracted.

Data format: Colour raster images (.tif) of monochrome topographical maps with hand-written notes in pencil and various coloured inks and associated ArcView files.

5.1 LAMPLUGH CLEAN COPY MAPS

Identifier/file names: Field slips and files are numbered after the original six inch map sheets (Figure 1).

Originator: G W Lamplugh for the Geological Survey of the United Kingdom

Abstract: Data comprise 19 raster images of manuscript County Series maps (c. 1850) at six-inch (1:10560) scale, anotated with observations made and geological linework interpreted by G W Lamplugh. The clean copies provide the final version of Lamplugh's interpreted linework and other data selected from those compiled on the field slips (described above).

Period of data capture: 1892-1897 (original data capture on field slips) interpretation made prior to publication of the one-inch map published in 1899.

Data update: None in same style or of comparable completeness; variable new observations are available from more recent research; interpretations are in part superseded culminating in the revised 2001 version of the geological map at the time of writing.

Scale: six-inch (1:10,560).

Data extent: Clean copies are available for the entire area of the Isle of Man. The entire set was captured as raster images.

Data accuracy: Accuracy of positioning of original information will vary according to topographical detail; i.e. locations will be more accurate when near features easily identified on the map compared with those situated, for example, on open moor land. Boundaries between geological units will vary in accuracy depending on control from exposure or landforms as appropriate. The scanned maps were georeferenced by matching features to a scan of the 1:25,000 scale topographical map of the Isle of Man. Minor errors in this process and distortion of the original manuscript maps leaves a variable mismatch when compared with the 1:10,000 scale digital (MANNGIS) map. This is generally less than 10 m on the ground and was compensated for when data were extracted.

Data format: Colour raster images (.tif) of monochrome topographical maps with hand-written notes in pencil and various coloured inks and geological units coloured with watercolour wash, with associated ArcView files. Note that due to the size of these maps they were scanned at lower resolution than the field slips.

5.2 PREVIOUS PUBLISHED 1:50,000 SCALE GEOLOGICAL MAP

Identifier/file names: Raster image ‘Lamp_50k’.tif and associated ArcView files

Originator: Institute of Geological Sciences by reconstitution at 1:50,000 scale of Lamplugh’s one-inch map.

Abstract: The geological map, originally published at one-inch scale, was republished at 1:50,000 scale in 1975 without significant modification.

Period of data capture: 1892-1897 (original Lamplugh survey), reprinted at 1:50,000 scale in 1975

Data update: Superseded by the 2001 revision of the geological map

Scale: 1:50,000

Data extent: Isle of Man.

Data accuracy: Variable as data transfer from six-inch clean copies to the original one-inch map (Geological Survey 1898) was by eye with respect to the topography.

Data format: Colour raster (.tif) image of the colour-printed map and associated ArcView files.

5.3 PUBLISHED MAPS FROM DICKSON *ET AL.* (1987).

Identifier/file names: Raster images ‘jd_ygs_fig3’, ‘jd_ygs_fig8’, ‘jd_ygs_fig11’, ‘jd_ygs_fig14’ and ‘jd_ygs_fig17’ as .tif and associated ArcView files.

Originator: PhD mapping by Dickson (1967) modified and published by Dickson et al. (1987); reproduced with the permission of the Yorkshire Geological Society

Abstract: Published paper describing the outcrop of the Carboniferous rocks preserved in the south of the Isle of Man around Castletown and providing modern stratigraphical subdivision. A map at 1:25,000 scale of the entire outcrop (Figure 17) provides the basis for the information displayed on the revised 1:50,000 geological map, although the stratigraphy has been modified in the light of more recent developments in north-west England. More detailed maps of the coastal exposures (Figures 3, 8, 11 & 14 in Dickson *et al.* 1987) provide structural data.

Period of data capture: 1964-1987

Data update: Some aspects of the stratigraphy were modified by BGS during preparation of the revised (2001) geological map, as described in Chadwick *et al.* (2001, chapter 5)

Scale: Map of the entire outcrop (Figure 17) published at 1:25,000 scale; more detailed maps of the coastal exposures published at larger scales.

Data extent: Castletown and Ballasalla area in the south of the Isle of Man, extending from Port St Mary in the west to Langness and Cass ny Hawin in the east.

Data accuracy: Assumed to be as appropriate to original survey at the scale of the published maps.

Data format: Monochrome maps as raster (.tif) images with associated ArcView files.

5.4 'CLEAN COPIES' AT 1:25,000 SCALE OF RECENT RESEARCH MAPPING

Identifier/file names: Data supplied by R P Barnes for the north-eastern part of the Isle of Man - 'rb_data' and 'rb_gs_fig8'; by N H Woodcock for the south-east coast and part of the north-west coast of the island - 'nw_iom_se' and 'nw_iom-nw' respectively; and by J H Morris for the western coast of the island - 'jm_iom_white', all as .tif and associated ArcView files.

Originator: R P Barnes, J Morris & N H Woodcock as part of the NERC Small Grant funded research project carried out in the mid-1990's (Woodcock *et al.* 1999a).

Abstract: Detailed structural and lithological mapping redrafted by the authors as 'clean copies' on a 1:25,000 scale map base provided by DOLGE. Linework and structural data (bedding, cleavage etc, represented using standard map symbols), were extracted into ArcView shape files during the 1:50,000 map revision project. Simplified versions of some of these data were published as Figure 8 in Fitches *et al.* (1999) (rb_gs_fig8), Figure 1 in Morris *et al.* (1999) and Figure 2 in Woodcock and Morris (1999), these papers and Woodcock and Barnes (1999) providing a detailed account of the geology in the respective areas.

Period of data capture: 1995-1998.

Data update: Some aspects of the geological interpretation were modified during compilation of the revised (2001) version of the 1:50,000 scale geological map

Scale: Original mapping at 1:10,000 scale.

Data extent: RPB – the north-east of the Isle of Man from Maughold Head south to Port Cornaa and extending inland to the outcrop of the Barrule Formation; NHW – the south-east coastal area from Clay Head to Cass ny Hawin and the north-western coast from Will's Strand to Glen Mooar; JHM – the west coast from Fleshwick Bay to Peel.

Data accuracy: As appropriate to original survey at 1:10,000 scale and compilation at 1:25,000 scale.

Data format: Monochrome maps as raster (.tif) images with associated ArcView files.

5.5 SATELLITE IMAGE

Identifier/file names: Raster image 'iom_sat.tif'

Originator: BGS by display of data from the European Space Agency (ESA).

Abstract: The image is a false colour composite, displaying infrared wavebands 4, 5 and 7 in red green and blue. Red in the image is vegetation (healthy green crops, thick grass, etc), with forested areas being a dark reddish brown colour. Pale orange on slopes is thin grass, whilst the uplands moor land areas are pale shades of blue and greenish blue. Otherwise, the different shades of blue are bare areas of different types (soil, rock, tarmac, etc) and built up areas are dark blue.

Period of data capture: 17 April 1987.

Data update: 2001. Landsat data are acquired continually. It is now possible to obtain 15 m resolution Landsat data.

Scale: The image can only be viewed at small scale (1:50,000 or less) due to the large (30 m) pixel size.

Data extent: Isle of Man.

Data accuracy: 30 m (an image can only be georeferenced to within one 30 m pixel)

Data format: Georeferenced colour raster (.tif) image and associated ArcView files.

5.6 GENERALISED OFFSHORE GEOLOGY

Identifier/file names: Raster image 'Outcrop' as .tif and associated ArcView files.

Originator: R A Chadwick & H Johnson for offshore; R P Barnes onshore

Abstract: The map was published as Figure 1 in Chadwick *et al.* (2001) and combines the onshore solid geology from the revised (2001) geological map (described below) with a revised interpretation of the solid geology of the area around the Isle of Man. The offshore area of the map represents a compilation of published data (BGS 1994, 1996), locally modified by interpretation of confidential seismic data (provided by TotalFinaElf Exploration UK PLC).

Period of data capture: 2000-2001

Data update: None

Scale: Offshore map sources are at a scale of 1:250,000. The onshore area was compiled from data at a range of scales as described below.

Data extent: Isle of Man plus offshore region

Data accuracy: Original

Data format: Colour raster image of published diagram.

5.7 BASE PERMO-TRIAS STRUCTURE CONTOURS

Identifier/file names: Raster image 'P-T' as .tif and associated ArcView files.

Originator: R A Chadwick

Abstract: The map, published as Figure 16a in Chadwick *et al.* (2001), represents generalised depth contours (below sea-level) to the base Permo-Triassic surface. Major faults are also shown, their mapped locations corresponding to where they cut the Base Permo-Triassic in the subsurface. The mapped contours are based principally on a compilation of confidential structure-contour maps produced by TotalFinaElf Exploration UK PLC in the period 1990–1998 (these based on interpretation of regional seismic datasets). Significant inconsistencies between maps of differing vintages were resolved by professional judgement. Areas not covered by the TotalFinaElf Exploration UK PLC mapping, and specific structural details are based on additional seismic interpretation by R.A. Chadwick. Outcrop limits are based largely on BGS (1994), modified locally by additional seismic interpretation.

Period of data capture: 1999-2001

Data update: None

Scale: TotalFinaElf maps at a range of scales from 1:25,000 to 1:1000,000. BGS (1994) map is 1:250,000.

Data extent: Isle of Man plus offshore region

Data accuracy: Close to original. Some loss of accuracy due to re-scaling.

Data format: Colour raster image of published diagram.

5.8 BASE MERCIA MUDSTONE GROUP STRUCTURE CONTOURS

Identifier/file names: Raster image 'MMG' as .tif and associated ArcView files.

Originator: R A Chadwick

Abstract: The map, published as Figure 16b in Chadwick *et al.* (2001), represents generalised depth contours (below sea-level) to the base Mercia Mudstone Group stratigraphical surface. Major faults are also shown, their mapped locations corresponding to where they cut the Base Mercia Mudstone Group in the subsurface. The mapped contours are based principally on a compilation of confidential structure-contour maps produced by TotalFinaElf Exploration UK PLC in the period 1990–1998 (these based on interpretation of regional seismic datasets). Significant inconsistencies between maps of differing vintages were resolved by professional judgement. Areas not covered by the TotalFinaElf Exploration UK PLC mapping, and specific structural details are based on additional seismic interpretation by R.A. Chadwick. Outcrop limits are based largely on BGS (1994), modified locally by additional seismic interpretation.

Period of data capture: 1999-2001

Data update: None

Scale: TotalFinaElf Exploration UK PLC maps at a range of scales from 1:25,000 to 1:1000,000. BGS (1994) map is 1:250,000.

Data extent: Isle of Man plus offshore region

Data accuracy: Close to original. Some loss of accuracy due to re-scaling.

Data format: Colour raster image of published diagram.

5.9 BASE ?PENARTH GROUP STRUCTURE CONTOURS

Identifier/file names: Raster image 'Penarth' as .tif and associated ArcView files.

Originator: R A Chadwick

Abstract: The map, published as Figure 16c in Chadwick *et al.* (2001), represents generalised depth contours (below sea-level) to the approximate base of the Penarth Group. Some uncertainty is attached to the stratigraphical calibration, particularly in the Solway Basin where the mapped surface may actually lie within the upper part of the Mercia Mudstone group. Major faults are also shown, their mapped locations corresponding to where they cut the base ?Penarth Group in the subsurface. The mapped contours are based partly on a compilation of confidential structure-contour maps produced by TotalFinaElf Exploration UK PLC in the period 1990 – 1998 (these based on interpretation of regional seismic datasets), and partly on additional seismic interpretation by R A Chadwick. Outcrop limits are based partly on the TotalFinaElf Exploration UK PLC mapping, partly on additional seismic interpretation and partly on BGS (1994)..

Period of data capture: 1999-2001

Data update: None

Scale: TotalFinaElf Exploration UK PLC maps at a range of scales from 1:50,000 to 1:1000,000. BGS (1994) map is 1:250,000.

Data extent: Isle of Man plus offshore region

Data accuracy: Close to original. Some loss of accuracy due to re-scaling.

Data format: Colour raster image of published diagram.

Appendix 3 Vector data

PLANAR STRUCTURAL DATA

Identifier/file names: 'Planar' as .shp and associated ArcView files

Originator: Data extracted from the sources listed above by D J Burnett and R P Barnes; including data contributed by D Burnett from his PhD mapping (Burnett 1999) and new data acquired during the BGS fieldwork during 2000 as part of the 1:50,000 scale map revision project.

Abstract: Data comprise details of planar structural elements from the Palaeozoic rock formations at the location of the exposure in which they were recorded. Generally these are measurements of the orientation of the primary depositional layering or bedding within the sedimentary rocks and the tectonic fabrics or cleavage. The orientation of a plane is represented in these data by the dip (the maximum inclination from the horizontal) and the direction of dip (measured as a compass bearing from 0 to 359°). Many of these data were captured in ArcView from the raster images of contributing information on which they are represented by standard symbols and a number denoting the dip amount. Whilst modern data are recorded with a compass and clinometer, they may be generalisations of wavy or irregular surfaces. Lamplugh's planar data are typically in 5° increments, suggesting possibly that they were estimated by eye although this generalisation may reflect the necessary approximation. Unfortunately many of Lamplugh's measurements lack the dip value.

Period of data capture: Original data 1892-2000, captured in ArcView format 2000-2001.

Data update: None

Scale: Variable depending on source.

Data extent: Data cover the entire area of solid rock outcrop on the Isle of Man. They stem from exposure and therefore are most abundant in coastal areas and vary inland depending on the level of exposure and the nature of the rock (Barrule mudrocks for example rarely preserve evidence of bedding but cleavages are well developed.

Data accuracy: Location s appropriate to original survey at 1:10,000 scale; dip and dip azimuth variable, generally better than ????

Data format: Original information on maps (included as georeferenced raster images, see above) and from new field work. Data captured as point file in ArcView. Location information is embedded within the ArcView data and not immediately apparent. Other fields (in the .dbf file) are as follows:

?? Shape – always polygon

?? Structure – structure type, generally 'bedding' or 'cleavage' indicating first (S1) second (S2) or third (S3) generation cleavage where known.

?? Dip_azimuth – direction of dip, measured 0-359° clockwise from north

?? Point_dip – dip amount, from 0° (horizontal) to 90° (vertical). A value of 99° indicates that no dip value is available (generally derived from Lamplugh maps).

?? Way_up – with reference to bedding, describing the direction of sedimentary younging as 'R' right way up (younging in same direction as dip), 'O' overturned (younging in opposite direction from dip) and blank or 'U' unknown.

?? Orig_data – originator of data

- ?? Comments – free text comment
- ?? Data_loc – locality name
- ?? Group – assignment of the exposure at stratigraphical group level
- ?? Formation – assignment of the exposure at stratigraphical formation level
- ?? Member – assignment of the exposure at stratigraphical member level
- ?? 50k_scale – denotes whether the data is represented as a symbol on the revised (2001) 1:50,000 map ('Y') or not ('N')
- ?? New_azi – Dip_azi recalculated to allow ArcView to plot symbols rotated to the correct orientation.

LINEAR DATA

Identifier/file names: 'Linear' as .shp and associated ArcView files

Originator: Data extracted from the sources listed above by D J Burnett and R P Barnes; including data contributed by D Burnett from his PhD mapping (Burnett 1999) and new data acquired during the BGS fieldwork in 2000 as part of the 1:50,000 scale map revision project.

Abstract: Data comprise details of linear structural elements (typically fold axis) from the Palaeozoic rock formations and the orientation of glacial striae or roche moutonée at the location of the exposure in which they were recorded. Both include an azimuth denoting the direction of plunge or direction of ice flow (measured from 0-359°), and structural elements include the plunge (the dip from the horizontal) in degrees. Many of these data were captured in ArcView from the raster images of contributing information on which they are represented by standard symbols and a number denoting the plunge amount. All of the glacial striae and roche moutonée orientations are derived from Lamplugh's field slips/clean copies.

Period of data capture: Original data 1892-2000, captured in ArcView format 2000-2001.

Data update: None

Scale: Variable depending on source.

Data extent: Data cover the entire area of solid rock outcrop on the Isle of Man.

Data accuracy: Variable, generally better than ????

Data format: Original information on maps (included as georeferenced raster images, see above) and from new field work. Data captured as point file in ArcView. Location information is embedded within the ArcView data and not immediately apparent. Other fields (in the .dbf file) are as follows:

- ?? Shape – always point.
- ?? Structure – structure type, generally 'fold axis' denoting whether anticline or syncline ('ant' or 'syn') and first (F1) second (F2) generation where known
- ?? Point_azimuth – direction of plunge of structural fabric or ice-flow orientation, measured 0-359° clockwise from north
- ?? Point_plunge – plunge amount, from 0° (horizontal) to 90° (vertical). A value of 99° indicates that no dip value is available (generally derived from Lamplugh maps)
- ?? Orig_data – originator of data
- ?? Comments – free text comment
- ?? Data_loc – locality name

- ?? Group – assignment of the exposure at stratigraphical group level
- ?? Formation – assignment of the exposure at stratigraphical formation level
- ?? Member – assignment of the exposure at stratigraphical member level
- ?? 50k_scale – denotes whether used on 2001 1:50,000 map (‘Y’) or not (‘N’)

DYKES/MINOR INTRUSIONS

Identifier/file names: ‘Dyke_data’ and ‘Dykes50k’ as .shp and associated ArcView files

Originator: Dyke data were derived from Lamplugh’s maps by D J Burnett. A parallel investigation of thin sections cut from Lamplugh’s samples by G M Power provided a modern dyke-rock terminology for a subset of the dykes. The samples were located by D J Burnett and correlated with the mapped dykes by R P Barnes and the rock classification extrapolated to all of the dykes presented on the revised (2001) 1:50,000 map.

Abstract: Dykes of a range of compositions are abundant within the Ordovician, Silurian and Carboniferous rocks of the Isle of Man. They generally range from a few centimetres to a few metres in thickness, although a few thicker examples occur, and they may extend for a few tens of metres to a few hundreds of metres in length. They are best seen in the coastal exposures where the majority have been recorded. Lamplugh’s data provides the only complete survey of the dykes on the Isle of Man and have therefore been used for the revised (2001) 1:50,000 map. However, the dyke rock terminology used by Lamplugh is out of date and it was necessary to derive a new nomenclature consistent with modern terminology. BGS holds the thin sections cut from Lamplugh’s samples at the time of his survey and the majority of these are of dyke rocks. These thin sections were examined and classified by G M Power. Based on correlation of the sample locations with mapped dykes this classification was extrapolated to all of the dykes presented on the revised (2001) 1:50,000 map.

Period of data capture: 1892-2000

Data update: None

Scale: Mapped at six-inch (1:10,560) scale.

Data extent: Data cover the entire area of solid rock outcrop on the Isle of Man.

Data accuracy: Assumed to be appropriate to the scale of mapping

Data format: Original information on Lamplugh’s maps (included as georeferenced raster images, see above). Data captured as line file in ArcView. Location information is embedded within the ArcView data and not immediately apparent. Other fields (in the .dbf file) are as follows:

- ?? Shape – always line.
- ?? Dy_name – dyke rock name attributed by Lamplugh (a detailed account is given in Lamplugh 1903)
- ?? Comments – free text comment
- ?? L_samp_no – Lamplugh sample number collected from dyke location
- ?? GMP_name – modern rock name attributed to thin section of Lamplugh sample in ‘Dyke_data’, extrapolated to all of the dykes in the subset used on the revised 1:50,000 map (‘Dykes50k’).
- ?? GMP_qual – additional comments by GMP on thin section determination
- ?? 50k_scale – denotes whether used on 2001 1:50,000 map (‘Y’) or not (‘N’) in ‘Dyke_data’, this field having been used to separate the data in ‘Dykes50k’.

MINE ENTRIES

Identifier/file names: 'Mine_data' as .shp and associated ArcView files

Originator: Data extracted by D J Burnett and R P Barnes from Lamplugh's six-inch maps, either from locations recorded on the original maps or notes made by Lamplugh.

Abstract: Some of the mines were still active at the time of Lamplugh's work on the Isle of Man and plans or other records of many others were available to him. His dataset is therefore one of the most comprehensive available. Whilst every effort has been taken to transfer these data accurately, there are possible errors in location. The accuracy with which Lamplugh recorded the locations is uncertain and limited by the scale of the maps used. In some cases the precise location noted by Lamplugh is unclear or uncertain. Consequently the .shp file must be taken as an index only, the user referring to the source documents for the 'precise' location of a particular feature. Some information was taken from Lamplugh's memoir (Lamplugh, 1903) which includes very detailed accounts of many of the mines. Details of the depth and direction of underground workings originating from the shafts and the length of the adits may be of particular value.

This dataset has not been correlated with that reported by Wardell Armstrong on behalf of the Isle of Man department of Trade and Industry in 1996 and 1998. Lamplugh's field slips are not listed by Wardell Armstrong as one of their data sources and brief comparison suggests that many of the mine entries identified by Lamplugh are not recognised in their data. On the other hand, the 1:2500 scale base maps used by Wardell Armstrong include more mine entries than the one-inch maps used by Lamplugh and some of these (and others of unknown origin) do not appear in the Lamplugh dataset.

Period of data capture: During survey by Lamplugh in 1892-1897 (in part from pre-existing mine or mineral exploration plans).

Data update: A separate compilation of mine entry data was made by Wardell Armstrong on behalf of the Isle of Man Department of Trade and Industry in 1996 and 1998 (Wardell Armstrong report numbers SAC/ADE.1/W3351/20 and RJG/JLH.02/W3351/20). The 1998 report includes a set of maps at 1:2500 scale showing the locations of mine entries or areas in which mine entries are thought to occur.

Scale: Original mapping at six-inch scale

Data extent: Isle of Man

Data accuracy: Presumed as appropriate to the six-inch map scale from which some of the data were derived and upon which all of the data were presented, although some locations may have been derived by Lamplugh from smaller scale or otherwise inaccurate plans.

Data format: Original information on maps at six-inch scale (included as georeferenced raster images, see above), and from the detailed accounts given by Lamplugh 1903. Data captured as point file in ArcView. Location information is embedded within the ArcView data and not immediately apparent. Other fields (in the .dbf file) are as follows:

?? Shape – always point

?? BGS_id – sequential number attributed as data were captured (some numbers are missing, representing spurious records subsequently deleted)

?? Orig_data – source of record, generally Lamplugh Field Slip, Lamplugh Clean Copy or six-inch series topographical map

?? Reference – Page number in Lamplugh (1903) where further details may be available

?? Mine_name – as shown on field slip/clean copy maps or taken from Lamplugh (1903)

- ?? Two types of mine entry are noted: ‘shaft’ referring to a near vertical entry, and ‘adit’ referring to a horizontal or gently sloping entry.
- ?? Direction – direction of adit measured 0-359° clockwise from north. A value of 999° is recorded where the direction is unknown and for shafts.
- ?? Comments – brief details from map or Lamplugh (1903), also notes if the location is uncertain.
- ?? On_6_(inch) – Y if shown on six-inch topographical map, N if not
- ?? On_fs Y if shown on Lamplugh’s field slip, N if not
- ?? On_cc – Y if shown on Lamplugh’s clean copy, N if not
- ?? Manngis – Y if evidence of location on the 1:10,000 MANNGIS data (generally uncertain), N if not.
- ?? Mineral – mineral species present/worked
- ?? Direction2 – direction recalculated to allow ArcView to plot adit symbols rotated to the correct orientation.
- ?? 50k_scale – denotes whether used on 2001 1:50,000 map (‘Y’) or not (‘C’).

WELLS AND SPRINGS

Identifier/file names: IoM_other as .shp and associated ArcView files

Originator: Data extracted from six-inch topographical maps by D Burnett.

Abstract: Originally intended as including any ‘miscellaneous’ information extracted from Lamplughs maps, in the event data are largely the locations of wells and springs represented on the six-inch county series maps used as a topographical base by Lamplugh. The locations of a few boreholes noted by Lamplugh are also included, although no other details are given.

Period of data capture: Springs and wells mainly prior to date of map survey; others recorded by Lamplugh 1892-1897.

Data update: None

Scale: Six-inch scale

Data extent: Isle of Man

Data accuracy: Presumed as appropriate to the six-inch map scale.

Data format: Original information on monochrome maps (included as georeferenced raster images, see above). Location information is embedded within the ArcView data and not immediately apparent. Other fields (in the .dbf file) are as follows:

- ?? Shape – always point
- ?? Type – Well, spring or borehole
- ?? Orig_data – always Lamplugh’s maps.

ROCK SAMPLES

Identifier/file names: ‘IoM_sample’ as .shp and associated ArcView files

Originator: Compilation of sample localities from Lamplugh’s original collection and material collected recently by G M Power, D J Burnett and the map revision project.

Abstract: Data comprise the locations of samples collected by G W Lamplugh, G M Power, D J Burnett and the BGS.

Period of data capture: 1892-1897 and 1992-2000.

Data update: None

Scale: Samples were located on maps at six-inch or 1:10,000 scale other than some of the BGS samples which were located on maps at 1:25,000 scale.

Data extent: Isle of Man

Data accuracy: As appropriate to scale of maps on which sample locations were identified.

Data format: Data captured as point file in ArcView. Location information is embedded within the ArcView data and not immediately apparent. Other fields (in the .dbf file) are as follows:

?? Shape – always point.

?? Sample_no – in collectors format

?? Locality – locality name

?? Loc_no – Locality number

?? Lithology – rock type collected

?? Group – assignment of the exposure at stratigraphical group level

?? Formation – assignment of the exposure at stratigraphical formation level

?? Member – assignment of the exposure at stratigraphical member level

?? Micropal – Y if processed for micropalaeontology

?? Comment – free text comment

?? Orig_data – originator of data

GEOLOGICAL MAP – SOLID GEOLOGY LAYER

Identifier/file names: 'IoM_solid' as .shp and associated ArcView files.

Originator: R P Barnes and D J Burnett based on data as described above.

Abstract: This layer must be read in conjunction with the faults layer (described below). Together they represent the re-interpretation of the solid geology of the Isle of Man south of the Quaternary covered northern plain (BGS 2001, and described by Barnes *et al.* in Chadwick *et al.* 2001). It is based on the information sources described above, in particular the original mapping by G W Lamplugh. The interpretation of the Lower Palaeozoic rocks draws on the results of the 1995-1998 research study published in Woodcock *et al.* (1999a) and detailed contributions from N H Woodcock and J H Morris. It includes new biostratigraphical data derived during the map revision project by S Molyneux (2001). The stratigraphy of the outcrop of Carboniferous rocks in the Castletown area is based on Dickson *et al.* (1987) with modifications by Jones & Riley (in Chadwick *et al.* 2001). The boundaries between adjoining polygons are interpreted to be stratigraphical contacts unless marked by a fault.

Period of data capture: 1999-2001

Data update: None

Scale: Original mapping work was carried out at 1:10,000 and 1:25,000 scale.

Data extent: Isle of Man

Data accuracy: As appropriate to scale of mapping

Data format: Data interpreted as a polygon file in ArcView. Fields (in the .dbf file) are as follows:

?? Shape – always polygon

?? BGSref – unique number for each geological unit

?? Group – assignment of the polygon at stratigraphical group level

?? Formation – assignment of the polygon at stratigraphical formation level

?? Member – assignment of the polygon at stratigraphical member level; also used to indicate sandstone-dominant units within certain formations as 'Sandstone'.

GEOLOGICAL MAP – FAULTS

Identifier/file names: 'IoM_faults' as .shp and associated ArcView files.

Originator: R P Barnes and D J Burnett based on data as described above.

Abstract: This layer is complementary to the solid geology layer in representing the re-interpretation of the solid geology of the Isle of Man south of the Quaternary covered northern plain as described above. The interpretation of a boundary between geological units as faulted draws particularly on new biostratigraphical data derived during the map revision project by S Molyneux (2001). Faults in the outcrop of Carboniferous rocks in the Castletown area are based on Dickson *et al.* (1987).

Period of data capture: 1999-2001

Data update: None

Scale: Original mapping work was carried out at 1:10,000 and 1:25,000 scale.

Data extent: Isle of Man

Data accuracy: As appropriate to scale of mapping

Data format: Data interpreted as a line file in ArcView without other attribution.

GEOLOGICAL MAP – QUATERNARY LAYER

Identifier/file names: 'BGS' as .shp and associated ArcView files

Originator: R C Chiverrell and G S P Thomas based on data as described above.

Abstract: The data in this layer represents a re-interpretation of the drift geology of the Isle of Man based on the original mapping of G.W. Lamplugh and subsequent revision and re-mapping by G S P Thomas and R C Chiverrell in 2000. The upland drift deposits are presented largely as mapped by Lamplugh (based on his field slips rather than the published one-inch (or 1975 1:50,000) map which was an inaccurate representation of this information), with the addition of solifluxion terraces mapped by R C Chiverrell in parts of the northern uplands. The lowland drift deposits have been largely reinterpreted based on the results of published work in the period 1977-2001 by Dackombe and Thomas (1985, 1989) Thomas (1976, 1977a, b and c, 1984, 1985 and 1999), Thomas and Dackombe (1985), Thomas *et al.* (1985) and Chiverrell *et al*. (2001).

Period of data capture: 1999-2001

Data update: None

Scale: Original mapping by Lamplugh at 1:10,000, which has been revised and remapped by Thomas and Chiverrell at 1:10,000 and 1:25,000.

Data extent: Isle of Man

Data accuracy: As appropriate to scale of mapping.

Data format Data interpreted as a polygon file in ArcView. Fields (in the .dbf file) are as follows:

?? Shape – always polygon

?? Id – numerical descriptor referring to landform type

?? Morphotype – text descriptor describing the geomorphology that includes: solifluction terraces, solifluction deposits, ridges (morainic), till (ground moraine), humpy bumpy (till ice disintegration topography), sandur (proglacial outwash), alluvial fans, alluvium, lake (sediment), marine lagoon (sediment), peat, raised beach and blown sands.

?? Formation – empty field

?? Lith_code – text descriptor giving the formation and additional information defining significant sediment-landform assemblages that have discrete surface expression and which broadly equate both with members within the formations (e.g. Shellag Formation – ice-marginal moraines).

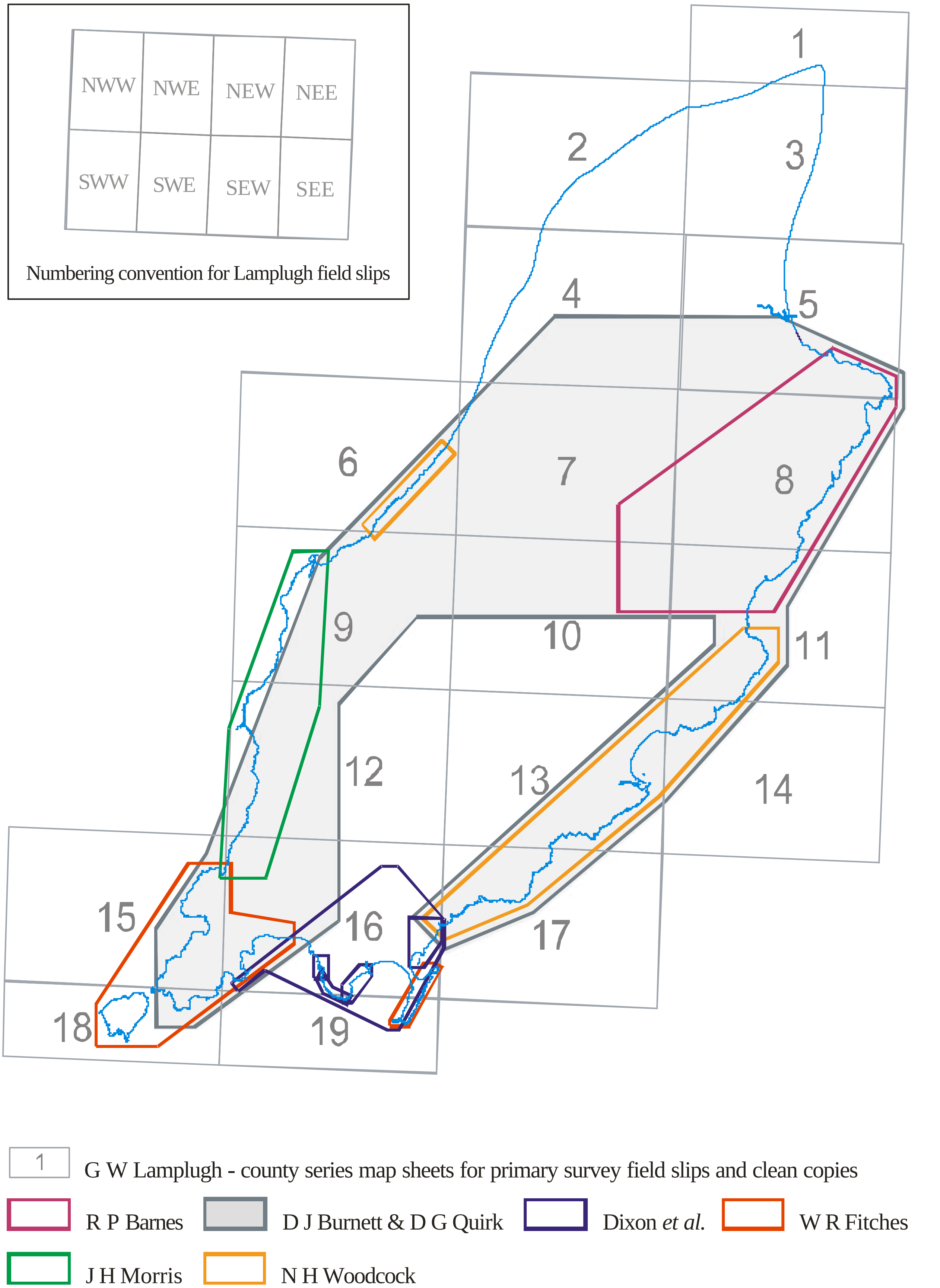


Figure 1 Map of the Isle of Man showing the county series map sheets and the other areas for which information was captured as raster images and data extracted. Inset shows numbering convention for segments of the county series maps used as field slips.