British Geological Survey

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An integrated digital workflow for geological field surveying.

Integrated Geoscience Surveys (North)

Internal Report IR/02/180

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/02/180

An integrated digital workflow for geological field surveying.

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Key words

Digital field data capture; Compaq iPAQ; ArcPad; Cairngorms.

Bibliographical reference

GOLLEDGE, N. R. 2002. An integrated digital workflow for geological field surveying. *British Geological Survey Internal Report*, IR/02/180 21pp.

Keyworth, Nottingham British Geological Survey 2002

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Foreword

This report presents the results of a field trial investigating the use of a digital system for capturing geological data. The trial was carried out within the 'Digital Field Data Capture' (DFDC) (coordinated by C Jordan) part of the ongoing SIGMA (System for Integrated Geospatial MApping) project, which aims to establish whether the use of such technology can produce overall efficiency gains in the 'Land Survey' workflow.

The majority of time required for this trial was funded by the DFDC component of the 'SIGMA toolkit' project. Andy Howard (project leader, SIGMA) is acknowledged for the time that was provided. Additional thanks go to Clive Auton for the loan of the Dounreay project laptop PC for the period of the field trial.

Emma Bee and Nikki Smith were invaluable in assisting with the setup of both hardware and software, and Rhys Cooper provided assistance in later data manipulations. Thanks also to Colm Jordan for background text on SIGMA, and to Calum Ritchie for section 4.3, and for expert cartographic advice and assisting in establishing the integrated methodology.

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The digital capture of geological data in the field is not a new idea. However, it is only recently that hardware and software have become available that meet BGS requirements to a sufficient degree. The combination of hard and software used in this trial is one of several that are being tested in mapping domains in the UK and overseas (Jordan et al., 2002). This report describes the relative merits of this system in comparison with 'traditional' or manual mapping techniques.

The work was carried out during November 2002 on the northern flanks of the Cairngorm Mountains, intended to replicate typical geological surveying in an upland glaciated terrain. The methodology adopted at the outset was modified as required during the field trial, in order to find the most effective use of the equipment. However, the trial was not only an assessment of hardware and software functionality, but also of the practicalities of an integrated digital, rather than manual, methodology.

Collaborative efforts with members of Murchison House Cartographic Services have shown that this methodology does indeed work, and that a fully digital workflow is entirely possible. The system described here is, in addition, recognised as a considerable improvement on the last trial carried out by the author in 2001.

1 Introduction

1.1 BACKGROUND

The requirement for digital data has been formerly identified by Walton and Lee (2000). To this end, a number of trials have been conducted to assess the functionality of various hardware and software systems for digital field data capture (Aldiss et al., 1993; Golledge, 2001; Thomas, 2002), as well as the viability of the digital methodology as a whole (Barnes, 2002).

The 'Digital Field Data Capture' project was set up within SIGMA in light of recent hardware and software developments, whilst acknowledging previous evaluations of digital field data capture within BGS such as the MERLIN project. In order to fully evaluate the components of digital data capture in the field it was decided to obtain, customise and test several types of hardware and software. Combinations of these systems are being tested in the various mapping terrains encountered by BGS staff in the UK and overseas, to ensure usability across BGS (Jordan et al., 2002). This report describes one such set of trials.

BGS is not the only geological survey to be developing such systems. BGS hosted an international workshop (Keyworth, April 2002) and is in close contact with other organisations developing and testing these and similar systems.

1.2 FIELDWORK

The trial was conducted during November 2002 on the northern flanks of the Cairngorm Mountains. The field area was the northern half of 1:10 000 scale sheet NH80SE, and consists of low alluvial terraces, mainly used for livestock farming: flat-lying areas of deep peat; dense conifer forestry plantations on the lower hillslopes; and upland areas of peat-covered till slopes, or head-covered in their upper reaches. The equipment was therefore tested in a range of environments typical of Quaternary mapping in the Scottish Highlands.

The weather was changeable, from clear sunny spells to torrential downpours that lasted several hours. No snow was experienced, although at times the air temperature was very low. Similarly, the equipment was tested in a range of lighting conditions, from direct sun to early evening darkness.

2 Field Equipment

2.1 HARDWARE

The equipment used in the trial was the Compaq iPAQ 3950 Pocket PC. The iPAQ has 64 MB RAM and 32 MB ROM (Flash) internal memory, and was augmented by a Compaq PC-Card Expansion pack. This held both 128 MB CompactFlash card and an additional lithium polymer battery. An additional 'emergency' powerpack was also carried. This contains 4 standard rechargeable 'AA' batteries, and can be connected to the iPAQ for additional power supply if the internal batteries fail.

The iPAQ was securely housed in a rugged, shock-proof Compaq plastic case. This keeps the unit well protected from drops and knocks and is waterproof. The high-resolution colour screen is rectangular, measuring 240 x 320 pixels (width, height) and can be accessed by flipping the upper lid of the casing which itself conceals a rubber screen protector below.

Connected to the iPAQ using the serial cable slot on its lowest edge was a Garmin etrex handheld GPS (Global Positioning System). This is considerably smaller than the 12XL machines previously used, and besides being significantly lighter also uses only two 'AA' size batteries, rather than four.

Figure 1 (below) shows the iPAQ and etrex in use in the field.

Figure 1. The iPAQ and etrex in the field.

2.2 SOFTWARE

The iPAQ runs Windows CE v. 3.0 operating system (OS), and hosts standard Microsoft packages such as Pocket Excel and Pocket Word, Internet Explorer, Windows Media, and accessories such as Notes, Games and Calculator. Microsoft ActiveSync was also installed to enable communication via serial cable with a desktop PC, although this was not used during the trial. ArcPad 6.0 for Windows CE was installed on the iPAQ, allowing shapefiles generated in other Arc packages to be directly transferred to the ArcPad 'field map'. The version of the software used provided new and improved functionality over its predecessor, v. 5.0, and can be used in conjunction with the desktop version of ArcPad to transfer and display pre-defined ArcPad map projects.

3 Methodology

3.1 OFFICE PREPARATION

Prior to undertaking the fieldwork, an ArcMap project was set up within ArcGIS – Arcview, which contained two raster base maps and three shapefiles for geological data. The files were copied to the network from the desktop PC, and written to the CompactFlash using the laptop and its built in PC card slot. The card was then transferred to the iPAQ and a new map project opened into which the files were brought. In comparison with previous systems such as the Husky running PocketGIS (see Golledge, 2001), which required lengthy file translation via translation schemes, the method used in this trial organised all the data in an ESRI

(Environmental Systems Research Institute) product of one type or another. This provided a much more coherent and integrated approach to data transfer, one that is ultimately far more efficient.

3.1.1 Map preparation

One of the three vector files defined was a point shapefile set up to record point observations, and had attribute fields defined for 'Type', 'Details' and 'Other'. The 'Type' field was used to specify whether the point locality represented an observation or a notecard locality, or any other kind of point data such as outcrop measurements, auger holes and so on. The 'Details' field was set up with an auto-label function so that when notes were recorded in this field they would be visible on the 'map' face. The 'Other' field was used to record additional information that was relevant but was not required to be visible on-screen. Using the attribute fields in this way allowed systematic and organised data capture, whilst maintaining a high degree of flexibility for the user.

A line shapefile was also set up with the same three attribute fields. This was designed for capturing linear landforms such as crestlines, breaks of slope, and meltwater channels. No label field was used in this instance, as it was not deemed necessary. In fact only the 'Type' field was used for the majority of records. Additional data was entered for a few features, for example, where it was necessary to record that a channel was one-sided rather than two-sided, or where a break of slope coincided with a geological boundary such as an alluvial terrace.

The third shapefile defined was another line file, used for capturing geological boundaries. From the outset, these lines were only regarded as being sketch lines that would be used as guidelines for later polygon capture in the fieldbase or office. Consequently, no attributes were defined for the features. It became evident in earlier trials that there is little value in attributing a geological boundary line in the field, as each line fragment needs two attributes, and it is difficult to define how each relates to the line (Golledge, 2001). Instead, the point theme was used to provide 'labels' within the delimited area to identify the lithology, much as would be done on a hand-drawn map by writing, for example, 'till' across an area.

Two raster base maps were used, one was a scanned fieldslip of NH80SE(S), the other a scanned clean 1:10 000 scale topographic base of the whole of NH80SE. These were originally created as .tif files, but were converted to Mr-Sid (.sid) files by Colm Jordan using ERDAS IMAGINE. This was necessary because ArcPad does not support .tif files, (although with C^{++} programming this functionality could be added).

3.2 FIELDWORK

Fieldwork was undertaken between 4^{th} – 8^{th} November 2002 in the area bounded by sheet NH80SE(N). The ground is located on the northern flanks of the Cairngorm Mountains, a granite massif in the Central Highlands. The highest elevation in the area was approximately 800 m O.D.; the lowest, approximately 250 m O.D. Much of the middle slopes of the field area are forested with plantation conifers, with substantial areas of alluvial deposits on the lower ground from the River Feshie, and glacial and paraglacial deposits higher up in the smaller valleys such as the Coire Allt a' Mharcaidh. A large area of flat-lying peat exists below the forestry, and one or two fields (used for stock grazing) exist along the River Feshie, mainly on alluvial and glaciofluvial terraces.

A typical field day involved working in at least two of these three 'zones', and as a result, the equipment was tested in a realistic and varied environment. Flat-lying field areas are easy to map and presented little problem, whereas the dense conifer plantations presented significant obstacles to walking in the form of felled trees, thick brash, or uneven rutted ground. Progress in these areas was consequently slower. Upland areas were typified by till slopes overlain by waterlogged peat, or in the upper reaches, head deposits generally derived from translocated glacial deposits such as till admixed with rock debris if a free face was present nearby.

The greatest problem encountered was the density of the forest, which made strong GPS signals hard to find. However, this was usually possible to overcome by moving a few metres or by allowing a little extra time for the receiver to locate more satellites. In general, on open ground, a horizontal accuracy of between 5 and 11 m was achieved, equivalent to one mm or so on a 1:10 000 scale map. This was considered sufficiently accurate for mapping purposes. Where such accuracy could not be achieved, the base maps were used to refine the location. It was noted on one or two occasions and also in earlier trials, however, that the Ordnance Survey topographic base (particularly with old base maps) might not be entirely accurate at showing tracks through forestry or fence boundaries, for example. This should be borne in mind when deciding to over-rule the GPS location.

3.2.1 Hardware - general use

The iPAQ and etrex GPS together are a small and compact combination, as described above. With the etrex hung around the neck, the iPAQ can be handheld easily when in use, and stowed in a pocket when not. The weather necessitated numerous layers of clothing, and on several occasions gloves were worn throughout the day. None of these impaired usage of the iPAQ in any way.

3.2.1.1 Hardware connections

The serial port on the lowest side of the iPAQ unit (when handheld) was used to connect with the Garmin etrex GPS. The connector fitted snugly through the port in the case, though this could be quite fiddly at times. This was also the only ‘break’ in the otherwise complete seal of the plastic case, which would make it the only place where water could penetrate, given severe conditions. A flexible rubber sleeve could be attached to prevent this, if deemed necessary.

3.2.1.2 Portability

The iPAQ is small (150 x 100 x 50 mm when in the case), and light (approximately 560 g including case and cable). This means that it can be slipped into a jacket pocket easily, or belt mounted if desired. A shoulder strap could also be fitted if required. With the iPAQ linked to the GPS (hung around the neck), just enough cable length was left free to allow sufficient movement. The remainder was duct-taped to the back of the case.

3.2.1.3 Data capture

The pen tool provided for use on the touch-sensitive screen worked well and was often used without problem whilst wearing gloves. The pen can be pushed into one of the loops on the case, or stowed anywhere else that is immediately handy. Using the pen through the rubber screen-protector was easy and did not restrict data capture greatly. The sole exception was when trying to capture data right up to the very edge of the screen, which was awkward. However, this is a minor and easily avoidable issue.

The biggest difference between the iPAQ and systems such as the previously used Husky (Golledge 2001) is that the former has no integral keyboard. For the purposes of recording short notes, this was not considered a significant drawback, and typing with the pen on the onscreen keypad was reasonably quick after a little practice. For longer notes it might be better to use handwriting recognition software or to use an external keyboard that slots into the serial port at the base of the unit. Whilst these keyboards can be very useful, and enable ‘proper’ typing, their use would necessitate detaching the GPS serial connection, which would be an inconvenience for frequent use. External keyboards would also be of limited use in wet weather and in exposed areas in windy conditions.

3.2.1.4 BATTERY LIFE

A fully charged battery lasted the entire working day, assuming normal use over approximately 8 hours. Typically 70 – 80 % of the battery life was used on most days, however, during the summer when field days are longer, it may be necessary to use the emergency battery pack. Battery life will also be influenced by the type of terrain being mapped, and the type of mapping being carried out, insofar as upland plateau areas require less frequent note-taking, as does outcrop (bedrock) mapping, and so the machine can be powered-off in between data capture points. During this trial, a significant amount of the mapping was carried out on very complex morainic topography where individual crestlines were being recorded more-or-less constantly. This meant that the iPAQ was rarely turned off during the day.

3.2.2 ArcPad software - general use

Belonging to the new ArcGIS 8.2 suite of software, ArcPad 6.0 has a Graphical User Interface (GUI) that is similar to many of the other ESRI products (Figure 2), and as a result is intuitive and easily navigable with a small amount of familiarisation. One clear advantage of ArcPad over PocketGIS is that screen refresh is considerably quicker, even when switching between layers.

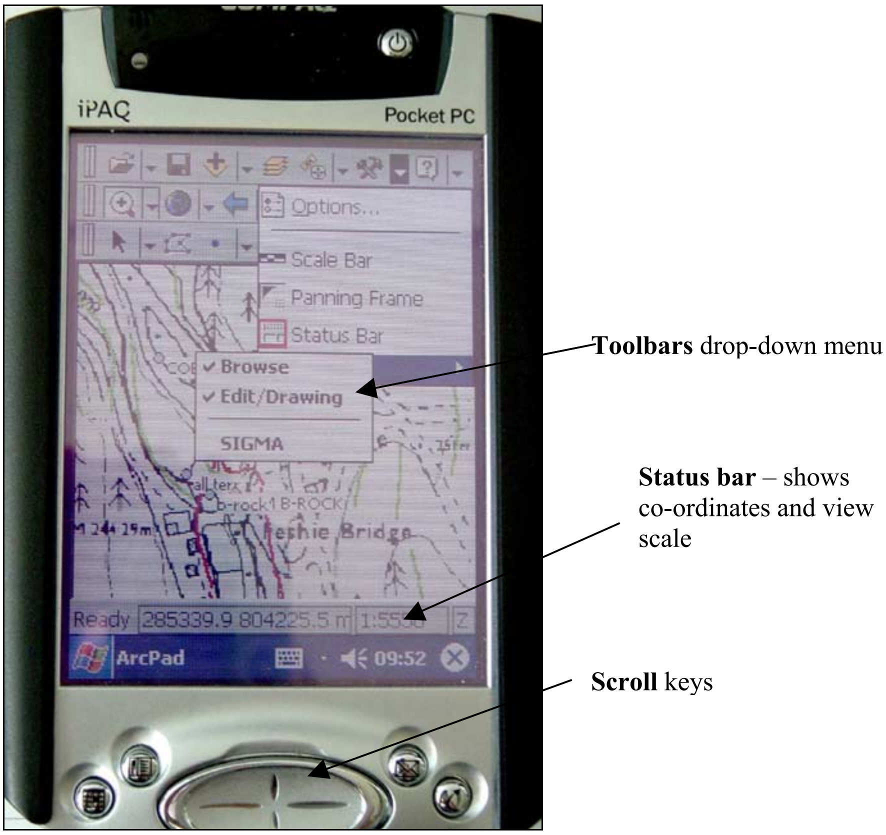

Figure 2: The ArcPad GUI on the Compaq iPAQ

Unfortunately the desktop PC version of ArcPad is not included in the standard installation of ArcGIS 8.2. This would be useful as it allows symbology to be defined for datasets and exported with an ArcPad map project for use on the Pocket PC. This would enable, for example, different linestyles to be used for differently attributed line features, making quick identification in the field much easier. It may be that in future, users wishing to set up their ArcPad maps in this way could get access to the desktop version of ArcPad.

3.2.2.1 Basic tools

Three toolbars are displayed in the ArcPad window, each of which can be moved, and two of which can be hidden if required (custom toolbars can be designed using ArcPad Application Builder if required, although this is unfortunately only available as an expensive additional desktop package).

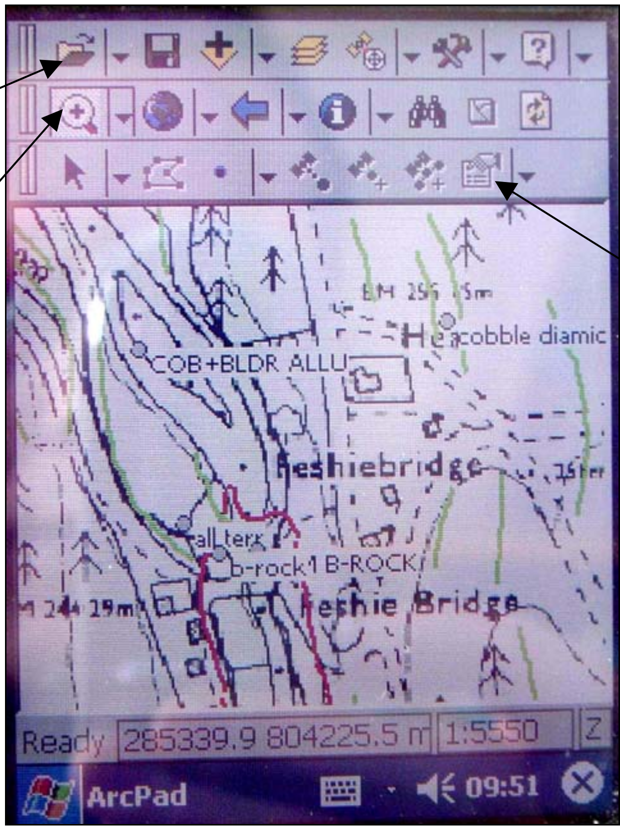

Figure 3: The three main 'Toolbars'

The main toolbar

The uppermost toolbar displayed organises the following functions, from left to right:

- **Open map** – Opens an existing map project. The dropdown menu next to the button provides the following options: New Map / New Layer / Open Map / Save Map / Save Map As… / Map Properties / Recent Maps / Recent Layers / Exit.
- **Save map** – Saves the current map project.
- **Add layer** – Adds an existing layer to the current map. The dropdown menu next to the button provides the following options: Add layer / Add internet server / Geography network…
- **Layers** – Opens the 'Layers' dialogue box.
- **GPS position window** – Displays the GPS position window. The dropdown menu next to the button provides the following options: GPS position window / GPS Active / GPS tracklog / GPS debug.
- **Tools** – Opens the ArcPad 'Options' dialogue box. The dropdown menu next to the button provides the following options: Options… / Scale bar / Panning Frame / Status bar / Toolbars…
- **Help** – Opens the online help menu. The dropdown menu next to the button provides the following options: Help topics / About ArcPad.

The 'Browse' toolbar

The second toolbar displays buttons for navigating around the map:

- **Zoom in** – Zoom in on the map by defining an area with the pen. The dropdown menu next to the button provides the following options: Zoom in / Zoom out / Pan.
- **Zoom to full extent** – Zooms to the full extent of the current map. The dropdown menu next to the button provides the following options: Fixed zoom in / Fixed zoom out / Zoom to selected / Centre on GPS / Zoom to full extent.
- **Go back to previous extent** – Redraws the map at the extent previously viewed. The dropdown menu next to the button provides the following options: Go back to previous extent / Go to next extent / Set view coordinates / Set map scale / Create bookmark / Manage bookmark / Zoom to bookmark.
- **Identify** – Activate the identify tool. The dropdown menu next to the button provides the following options: Identify / Measure / Radial measure / Freehand measure / Hyperlink / Go to / Advanced select.
- **Find** – Opens the 'Find' tool.
- **Clear selected** – Unselects the selected feature or features.
- **Refresh** – Redraws the map.

The 'Edit / Drawing' toolbar

The third toolbar shows the tools required for data entry and editing:

- **Select** – Activates the 'Select' tool. The dropdown menu next to the button provides the following options: Select / Select at GPS position.
- **Vertex Edit** – Allows editing of the vertices of selected features.
- **Point** – Enables the point feature capture tool. The dropdown menu next to the button provides the following options: Point / Line / Polyline / Freehand line / Rectangle / Polygon / Ellipse / Circle / Freehand polygon.
- **Capture Point using GPS** – Captures the current GPS position as a point feature in the editable layer.
- **Add GPS vertex** – Adds the current GPS position as a vertex in the current line or polygon feature.
- **Add GPS vertices continuously** – Captures vertices in the current line or polygon feature using streaming GPS positions.
- **Feature properties** – Opens the 'Feature Properties' dialogue box. The dropdown menu next to the button provides the following options: Feature properties / Zoom to selected feature / Centre on selected feature / Go to selected feature / Delete feature.

In addition to the button functions on the toolbars it is also possible to use the large oval button below the screen to scroll around the 'map' (Figure 2). This can be particularly useful if you don't want to have to interrupt data capture to select the pan tool from the toolbar.

3.2.3 Capture of geological data

Making geological maps is a complicated task. Not only does it involve the collection of a large amount of highly diverse data types with numerous attribute variables, but there is also a very large part of the process that is largely subjective. Very rarely can a geological boundary, for example, be placed with absolute certainty. As a result, map-making is an iterative process, usually involving the sketching of lines which are edited or redrawn numerous times before the final position of the line is established. In developing a digital system that allows this kind of flexibility, it must be appreciated that sometimes 'less is more'. That is, a less structured approach allows greater user flexibility, which ultimately allows the most effective data capture. For this reason, geological boundaries were treated as sketch lines only, intended to provide a guide during the later creation of geological polygons. Having a system that allows a natural way of drawing such lines is essential, and was identified by Farrant et al., (2001) as one of the key requirements for digital field data capture systems.

One aspect of digital data capture that was not attempted during the trial was the use of 'digital field notecards'. Instead, the traditional method of section descriptions sketched onto paper notecards was used, as it was believed to be still the most efficient way to do it. Digital drawing tools are simply not flexible enough to create sketches as quickly and easily as a pencil and paper, particularly not on handheld or Pocket PC's. Whilst the benefits of XML-tagged text notes are appreciated, this may be an example of where the digital methodology does not actually produce an efficiency gain *in the field*. Further trials being planned within SIGMA specifically to address this issue may find otherwise, and future hardware and software may in fact resolve the issue entirely.

3.2.3.1 DIGITISING NEW DATA

The most useful feature provided by ArcPad is the 'freehand line' tool. This is exactly what is required in the field to enable linear data to be captured quickly and naturally. On completion of the line the attribute dialogue box opens and details can be entered as required. If the line drawn is unsatisfactory it can be quickly and easily deleted and redrawn, much like rubbing out a pencil line and sketching it back in more carefully. In most instances it was found to be quicker to redraw a line than to modify its geometry by moving individual nodes. If a perfectly straight line is required instead, the polyline tool is used to place nodes one at a time at the desired locations.

GPS streaming can also be employed with the polyline tool to capture points automatically at a user-defined frequency from the attached GPS. This was found to be particularly useful when mapping moraine crestlines over rough ground, when the IPAQ could be stowed in a pocket to leave both hands free but yet also continue data capture. The user is then at liberty to concentrate on where he or she is going.

The GPS can also be used to capture point features, such as section localities, outcrop data, or general observations. The auto-label function can be set up to use one of the attribute fields for labelling, so that after making notes, they could be seen on the map face. This is of great importance in the creation of a geological model in the users head, and was a failing of earlier systems. Being able to define the displayed size and visible scale range means that when zooming out, the notes can be turned off to make the map less cluttered. Attribute tables with a series of pre-defined fields may suit some users, and could save a certain amount of time if correctly configured.

One aspect of data capture that was not available with earlier systems is the ability to capture three dimensional data. That is, streaming data from the GPS may be recorded in a 3D point, polyline or polygon shapefile, where the z-value is captured in addition to the x and y coordinates. Whilst GPS z-values are notoriously inaccurate from handheld devices, this function could be of great use if small-scale surveys using differential GPS were to be carried out. This tool may also be of use overseas, where a lack of high resolution topographic data may make the relative inaccuracies of the GPS more acceptable, particularly if the z-values were captured only every few tens of metres. A degree of experimentation may be required when configuring the GPS streaming interval to ensure that sufficient points are captured to accurately represent the feature, without too many being generated, which might make the dataset overly cumbersome. In this way it is possible to build up a dataset that can be added directly to a project in ArcScene and viewed immediately, and with no user intervention, in 3D. The 3D point, polyline or polygon shapefile can be converted to a TIN (Triangulated Irregular Network) quickly and the surface viewed and manipulated as required.

3.2.3.2 MODIFYING FEATURES

Once data has been created it is possible to edit the lines, points or polygons as required. Node editing is perhaps the most likely requirement, and can be done relatively easily by selecting the desired feature and clicking the 'Vertex edit' button, then hold down the pen on the screen until a menu appears. Under 'Options' are the possibilities for moving individual vertices, or entire features if required.

In the field it was found that such operations were generally more time consuming than redrawing the original feature. However, if the dataset to be modified is, for example, existing DigMap linework, then it is more practical to move individual nodes. The procedure is easy and considerably more user-friendly than previously used systems.

In some instances it may be necessary to reattribute a feature, rather than change its geometry. This is also a relatively simple operation, requiring the user to select the desired feature and click on the 'Feature properties' button on the Drawing Toolbar. The attribute table (or custom form) can then be amended as necessary.

3.3 DATA TRANSFER AND INTEGRATION

It has been demonstrated above that digital geological data in the form of attributed points and lines can be easily and efficiently captured in the field using readily available hardware and software. In order that an integrated workflow from field data collection to office compilation and ultimately cartographic output may be defined, the field data must be efficiently brought into a corporately compatible GIS.

3.3.1 Data Transfer

During the field trials described in this report, a MESH laptop PC was used at the field base to allow data download / upload from / to the iPAQ on a daily basis. The CompactFlash card was removed from the iPAQ and inserted directly into the PCMCIA slot of the laptop. The memory card is then easily read as an 'additional drive', enabling fast data transfer to, for example, the PC hard-drive. This technique is considerably faster than using a plug-in card reader. After copying the files to the required directory, overwriting the old versions of the file if desired, the data can be viewed instantly on screen by opening the ArcGIS - Arcview project already set up. The shapefiles and their updated .dbf files are read in on opening, ensuring that the entire days field edits are present in the Arcview project. (When opening the ArcMap project, the new data may not be immediately visible. This is most likely because the map is not editable when first opened. Under the 'Editor' drop-down menu, select 'Start editing'. Then select each theme to be updated one at a time from the toolbar at the top of the screen that identifies the theme into which new data is to be added. The new data should now be visible).

For the purposes of data compilation, the preferred software platform for this trial was ArcGIS 8.2, not Arcview 3.2. The reasons were simply that experience has shown the former to be far more capable in terms of data manipulation and integration, and may well represent efficiency gains over Arcview 3.2.

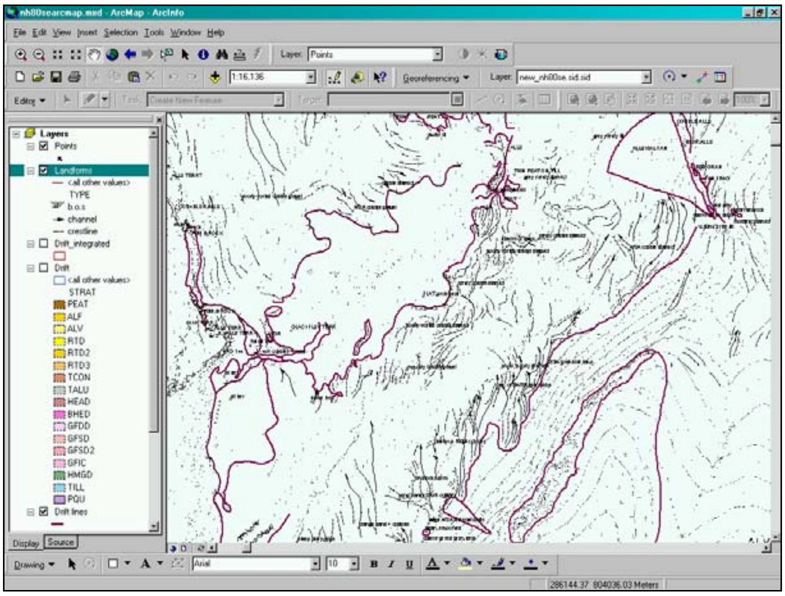

Figure 4: Field data displayed in ArcMap - ArcInfo

With the three themes captured in the field immediately editable on-screen, preliminary data checking was undertaken to ensure that all the data was where it should be and attributed correctly. The 'Observations' point theme required little, if any, editing, showing clearly all the point observations made during the field trial. The label field defined in the ArcPad map transferred directly and without user intervention to the ArcGIS project, allowing the details of the notes to be viewed easily.

The line theme constructed for linear landforms held in the region of 500 attributed lines, mainly being undifferentiated crestlines, meltwater channels, and breaks of slope. Using a 'Unique value' legend symbology in ArcGIS, the lines could be shown more clearly than on the iPAQ, using colours and linestyles to differentiate them. Although a small number of features may need 'tweaking', or minor adjustments, the majority of linear data can be directly copied into the required map project.

The line theme set up for capturing geological boundaries was defined as an unattributed layer for the reasons outlined in 3.1.1 above. Capturing polygons in the field has proved to be inefficient (Golledge, 2001) and consequently lines were collected for the purpose of generating polygons later. When these geological boundary lines were brought into the ArcGIS project, labelled point observations identified the lithologies that they bounded.

3.3.2 Data Integration

The auto-labelled point theme and the linear landform line theme needed very little post-capture processing to integrate them into a typical GIS map project, as stated in 3.3.2 above. Constructing the geological polygons, however, is more involved.

The technique employed for generating geological polygons from the geological boundary lines was nonetheless relatively simple, and by experience the most efficient. Rather than join all the line fragments required to construct a polygon into one closed polyline, which needs to then be converted to a polygon, copied into the required theme and attributed, the lines were used as a digital sketch line only. This is because it is far quicker to simply draw a new polygon into the desired theme using the geological boundary lines as a guide, than clean the lines by moving, adding or deleting nodes. This technique allows the user flexibility in deciding where to put the line, whilst also providing sufficiently accurate guidance to maintain data quality. A smoother line can be drawn using this method, particularly if use is made of the freehand 'streaming' digitising mode.

In order to get smooth lines, the ‘streaming’ option should be enabled (under the ‘Editor’ drop-down, then ‘Options’). A streaming tolerance setting of 8 – 10 appears to produce lines of sufficient quality without too many superfluous vertices. One advantage of using streaming is that nodes are placed at equal intervals along a line, regardless of the level of zoom at which the line is captured. This is useful for maintaining a consistent level of line ‘smoothness’. In practice, most of the polygons were digitised at approximately 1:3 000 scale, although more complicated areas were captured at scales down to 1:1 000. It is worth noting that streaming mode does not restrict the user in any way. If a greater number of nodes is required in a segment of the line, for example, a particularly tight curve, these can be placed *in addition* to the automatic nodes by simply clicking the mouse or tapping the pen at the required spot, as would be done for manual node placement. In fact, the only restriction on the scale at which the streaming mode can be efficiently used is the degree of handshake of the user, which may produce less smooth lines above about 1:4 000 scale.

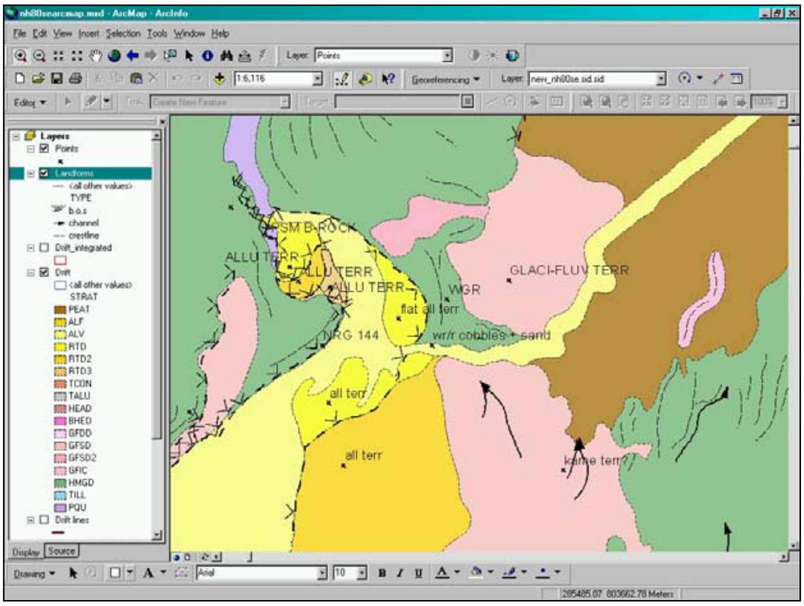

Figure 5: Geological ‘map’ compilation in ArcMap - Arcinfo

4 Discussion - An integrated methodology?

In order to really achieve the efficiency gains aspired to by the SIGMA project, geological mapping needs to be approached in an holistic manner, considering the process from an endpoint backwards. That is, a geologist producing a digital 1:10 000 scale standard map needs to know how Cartographic Services (CS) will use their data, what file formats are preferable and so on. Data can then be compiled in the most appropriate manner. For digital capture of data in the field, it is necessary to consider the above, and to think about how to undertake the capture process. This may involve realigning the ‘established’ field mapping techniques in order to accommodate the differences between digital and analogue data handling.

4.1 PHILOSOPHY

In attempting to create a digital geological ‘map’, fundamental questions need to be asked about currently accepted methodologies. Since the inception of the Microstation-based Digital Map Compilation System (DMCS), and its Arcview-based descendant the Geological Spatial Database (GSD), digital map compilation has focussed on capturing individual polygons from a scanned fieldmap raster base. These polygons are created with a variable ‘snapping tolerance’ employed to ensure that edges and vertices join together to make a seamless ‘map’. To this end, the GSD has a number of specifically designed tools to allow the user any number of polygon modifications.

However, practice has shown that no matter how experienced at digitising the user may be, this method of snapping polygons together invariably creates ‘slivers’ in the final output. This is a function of capture methodology. Two polygons may look like they are snapped together, and therefore share a coincident boundary, whereas, the nodes defining their respective boundaries are not identically placed, and as a result, the clean ‘snapped’ appearance is simply the way in which the data is displayed. Such problems have become particularly evident when Arcview data has been imported into Microstation and has had line-cleaning procedures performed on it. The result is that Cartographic Services staff need to spend a certain amount of time ‘cleaning’ the linework before it can be useful employed in map production. The reality is that often it is quicker to *re-digitise* the lines from a scaled plot. This somewhat contradicts the motivating force of digital data capture, which is ‘efficiency gains’.

At a philosophical level, the above method of ‘snapping polygons’ can be simplified into saying, ‘there is no geology here until I create it’. That is, the user systematically defines an area of one particular lithology, and joins it to another, eventually producing complete geological cover for the required standard map.

A more logical approach may be, ‘we have a 5 km x 5 km square of *undefined* geology’, (since fundamentally there is geology there, but its nature is uncertain). That square can then be cut into areas that are known to share a common lithology. As these areas are progressively defined, they can be attributed as normal by entering the required value into the attribute table. By defining a ‘Unique value’ legend symbology it is possible to gradually create coloured geological polygons.

4.2 METHODOLOGY

This philosophy was translated into a working methodology as follows: firstly a 5 km x 5 km square polygon was generated by capturing four nodes in a polygon theme called ‘Drift.shp’, and by using the right-click tool the required x, y corner coordinates for the map were entered. This ensures that the ‘master polygon’ is *exactly* square and in the correct geometric space. This polygon was simply defined in the attribute table as ‘master polygon’, and was given a transparent light grey shading so that it could be seen, but did not obstruct the view of the base map. Using the geological boundaries as guides, and the streaming tool to automatically capture evenly-spaced nodes, the ‘Cut polygon’ tool was used to digitise a *line* that cut the master polygon. The area that was cut-off was then attributed as necessary. The master polygon was then dissected again, using the same cutting tool, to produce another polygon of a different lithology. This was also attributed. The procedure was repeated until all the major geological polygons had been created.

It is also necessary to create polygons within other polygons, particularly where small areas of certain lithologies exist, for example as isolated moraines, or small peat-filled hollows. This is also simple to do. Using the ‘Create new feature’ tool, the polygon is captured as required. With the polygon still highlighted, the ‘clip’ tool under the ‘Editor’ drop-down was used to cookie-cut this from whatever polygon it overlies. This can be done on the master polygon, or any other polygon cut from the master polygon. A dialogue box triggered by the ‘clip’ tool presents two options regarding the function – to keep the overlapping area or to discard it. The default is to discard it, which is the preferred option.

Using these two simple tools, the entire map can be created from one master polygon. The advantages over the ‘snapping polygon’ are immediately obvious.

- The technique is considerably quicker, as any one boundary line need only be digitised once. The GSD requires the user to complete each polygon by digitising every boundary, even if previously captured, at the bare minimum by creating nodes within existing polygons to which the new feature would 'snap'.

- Cutting from a master polygon ensures that each boundary is created from *only one line*. This means that although ArcGIS creates two lines in order to define the polygon, the nodes and the lines that connect them are *identical*. This is of fundamental importance in creating a dataset free of 'slivers' that can be efficiently integrated into the Cartographic Services workflow. The ArcInfo 'Integrate' tool (under the 'Editor' drop-down) provides a rapid method for producing a fully integrated, topologically clean dataset requiring the minimum of post-processing by CS.
- The streaming tool allows for standardisation in the frequency of node-placement, and hence the smoothness of the line, without compromising user flexibility.
- Polygons can be easily modified. Using the 'shared edit' tool from the main toolbar, nodes on boundaries of coincident polygons can be moved in one go, and both polygons are adjusted accordingly. If a polygon needs to be modified to take into account new data, say an area of peat that was previously undefined, the 'clip' or 'cut polygon' tools can be used to do exactly that.
- By starting with a square covering the whole 1:10 000 scale map sheet, the order in which the polygons are captured makes little difference. If the largest polygon is left until last, it needn't be captured at all, because it already exists as the remainder of the master polygon, so it simply needs to be reattributed.

At the end of the process, the original 5 km x 5 km square polygon has been divided into numerous smaller polygons of attributed geologically-similar areas which share **truly coincident** boundaries. A simple process of integration then produces a shapefile of topologically 'clean' linework that is of a quality useful to CS. This methodology has only been used for the capture of superficial polygons, but it should be easily transferable to bedrock map compilation. In other areas of the UK geological mapping is carried out not by creating new polygons, but by modifying existing linework (e.g. Barnes, 2002). In cases such as these it would still be beneficial to use the 'Shared edit' tool to move coincident boundaries.

4.3 CARTOGRAPHIC SERVICES PERSPECTIVE - EXPORTING ARC DATA TO THE CARTOGRAPHIC PRODUCTION ENVIRONMENT

4.3.1 Overview

The standards for topological data capture within the Bentley Microstation-based DMPS97 (Digital Map Production System) have been set to ensure there is edge to edge coverage of non-overlapping polygon data within each theme. This has been achieved by using a single boundary line to produce matched polygon boundaries. The Bentley Geographic Information System (GIS) provides a good selection of tools to validate and correct the topological data. The data is held as parcels and centroids within the DMPS97, unlike ArcMap where it is held as polygons. Previous data sets from Arc have proved to be extremely time consuming to incorporate into the DMPS97 data structure. These earlier datasets have exhibited mismatched polygon edges resulting in slivers and polygon fragments. When broken down for incorporation into the DMPS97 system, the data produces mismatched near duplicate boundaries and inappropriately fragmented areas that are difficult and time consuming to correct.

4.3.2 Incorporating Test Data Into The DMPS97

An import test to the DMPS97 system was performed on the 'integrated_drift' shapefile provided. The shapefile was imported into the Bentley GIS environment using the GeoExchange plug-in, creating graphics with attribute data. This boundary data was then cleaned, with no automatic correcting performed, and then tested for errors. This revealed **no problems** with the boundary linework. The centroid data was then checked with a topological validation, which produced one area with no attribution. This was traced to a user error in the original data capture and can be discounted as a problem with this test. The attribute data imported with the polygons was then used to link the centroids to the correct Lex-Rock tables within the 'Geol_CartJ' Cartographic Production database. The linework for the drift boundaries and the sheet extent are then separated and the appropriate features attached.

This test data set was a **vast improvement** on the quality of the material normally supplied to Cartographic Production unit. It was run through the procedure that all Carto data is subjected to, (in order to check and verify the topology), but **no manual correction work** was required. This test dataset was incorporated into the DMPS97 system standard with **greatly reduced time and effort**.

Some areas of the sheet extent in this test data were found to deviate slightly from the correct 10k sheet boundary. Subsequent investigation has shown this to be a result of automatic 'snapping' within the original dataset in Arc, reaffirming the need to employ a data capture methodology that obviates the need for snapping.

4.3.3 Importing Graphics From Arc Into Adobe Illustrator (AI)

ArcGIS 8.2 can directly export a 'map' to Adobe Illustrator as vector elements, preserving the layer structure of the original display. This would be used to supply graphics-only to the Cartographic Production unit for plate making and printing, or e-publishing for example, or for anything where the performance of an industry-standard high quality graphics package is required.

There are a few problems to be aware of when exporting from ArcGIS 8.2 to an AI file:

- Raster components of the 'map' should be separated from vector data when exporting. Their inclusion can result in vector elements being rasterised as part of the raster component. The raster can be supplied instead by way of a separate export operation, for subsequent cropping, or as the original file if the full extent is required. A layer with a box of the raster extents should be included in the vector export for registration.
- Polygon themes should be set to solid fill, rather than semi-transparent, as transparency appears to result in the vector layer being rasterised on export, rendering the dataset useless.
- Line styles should be avoided for the themes to be exported. Use only a continuous plain line, since a pecked linestyle results in individual elements being created for each peck, and not the entire length of the line. Consequently the resulting A.I. file would be unnecessarily large and difficult to edit. Brushes can be applied to the linework within Illustrator to give the correct appearance. To distinguish different lines on one layer use different colours of continuous lines in the display symbology. A group selection on the display attributes can be made and brushes applied globally in Illustrator.
- Repeated symbols are an area that would have to be evaluated on an individual basis. It may be better to import the graphic from Arc or recreate the symbols from a library in Illustrator.

Cartographic Services also have the MAPublisher 5.0 plug-in for Illustrator that gives it GIS capabilities. This will handle Arc files of graphics and attribution, with many of the capabilities of Arc available within the Illustrator environment.

4.3.4 Cartographic Production Consultation

There is knowledge within the Cartographic unit of ArcGIS 8.2 as well as it's own systems. Members of staff are available to discuss any requirements for importing data from Arc into the Cartographic Production systems or for quality publishing.

5 Conclusions

A field trial conducted in the northern Cairngorms during November 2002 has shown that a combination of a Compaq iPAQ Pocket PC with ESRI ArcPad 6.0 software is both capable and suitable for geological mapping in Scottish Highland terrains. This trial follows on from earlier field-testing that employed a different combination of hardware and software, and demonstrates that the iPAQ / ArcPad system is far superior to the Husky / PocketGIS system for the following key reasons:

- The iPAQ is smaller and lighter, making it easier to carry than the Husky.
- The iPAQ screen is easily readable in varied lighting conditions, with good resolution.
- ArcPad 6.0 is fully compatible with other ESRI products used throughout BGS, whereas PocketGIS requires data translation to read ESRI files.
- ArcPad 6.0 provides greatly superior functionality over PocketGIS, in particular it meets the user requirement of freehand line capture and can also capture 3D data.

The system used allowed the user to transfer data on a daily basis to a laptop PC at the fieldbase, ensuring that data was integrated into the ArcMap project quickly and incrementally. This could be seen as the equivalent of 'inking in', except that in this system, once the 'map' is completed, the output product is the 'clean copy', rather than the fieldslip. The issue of whether or not a fieldslip is necessary for archiving purposes should be discussed before wide usage of such technology is adopted. Essential to such a discussion is the recognition that decreasing funding for field mapping will impact on either the amount of ground mapped, or the number of outputs produced. Digital compilation and the obsolescence of traditional fieldslips may therefore be regarded as a cost-saving exercise.

Issues like that of 'digital field notecards' highlight a fundamental aspect of what we are trying to achieve. We should not simply try and replicate digitally what we do manually for the sake of it. A certain amount of thought needs to go into the process to assess what is best done in which manner. In terms of data capture, geological data is so diverse that restrictive pro-forma's for recording attributes in boxes will not be the best method for everyone. For some types of data, such an approach may be useful. For others it will lead to frustration and may compromise data quality. In developing a digital system we need to 'build in' a degree of flexibility for the user. This may actually accelerate the uptake of digital systems, rather than impede it.

Whatever field data capture tools are used, it is of absolute importance that the geological mapping process is approached in an integrated and holistic manner, where the end product is considered right from the outset. In this way we can implement systems that allow standardisation where practicable, flexibility where necessary, and that produce efficiency gains where we most need them. Initial results this year have been constructive and have helped to direct further testing.

By working closely with Cartographic Services staff, and by being flexible in the approach to the 'map'-making process, it has been demonstrated that holistic thinking can lead to efficiency gains. This exercise has proved that an integrated **digital** workflow can be established from original field data capture to Cartographic Services output, and has proved to be superior to previous attempts in terms of data quality and time-efficiency.

Appendix 1 – Downloaded datasets

Drift lines.shp – a polyline file of geo-boundaries, unattributed.

Points.shp – a point file for observations, defined fields for ‘type’, ‘details’ and ‘other’.

Landforms.shp – a polyline file for linear landforms, fields as for point.shp.

New_nh80ses.sid – a raster image of a coloured-up fieldslip, converted from .tif to .sid.

New_nh80se.sid – a raster image of a greyscale 10k base map, converted to .sid.

Appendix 2 – Data entry pro-forma

(This pro-forma was completed on return to the office (Nov ‘02) in order to provide rapid feedback to project managers in a structured format).

DIGITAL FIELD DATA ENTRY TRIAL
REPORTING PRO-FORMA

The ‘Spatial Data Handling’ project, in support of SIGMA, is carrying out a series of trials on Land Survey digital field data entry. Last year the project developed a user requirement (IR/01/137) which identified distinct geological terrains with distinct mapping requirements. This, modified as necessary to accommodate the SIGMA design brief, forms the basis of the trialling programme. The trialling programme is designed to assess different combinations of hardware and software in the different geological terrains identified. Not all hardware/software combinations will be appropriate in all terrains.

Although not all of the identified user requirements will be relevant in all terrains or for all hardware/software combinations it is nevertheless important that each trial is carried out in as consistent a manner as possible, and in particular that the same factors (where relevant) are assessed in each trial. Without this it will be very difficult to make sensible comparisons of the trial results. This pro-forma is designed to provide this consistent framework for recording information derived from the trials. It is based on the use of free text fields which allow the assessor to give their views of particular aspects of the hardware and software in the circumstances of the particular trial. It thus aims to strike a balance between a highly structured approach which would be likely to miss key aspects that the assessor considered relevant, and a wholly ‘open’ unstructured approach that would make comparisons impossible.

In carrying out the trials and making the assessments it should be borne in mind that in the context of SIGMA and the DGSM the primary purpose of fieldwork is to gather data and make interpretations that will be used to populate a spatial database and make models. The database and models will be used subsequently to produce various products, of which the geological map is one. Digital field data entry should not therefore be seen as being primarily about making maps, but rather gathering the data that can be used to make maps. This obviously has a bearing on the requirements of the hardware and software, in particular in terms of their cartographic capabilities.

It also should be borne in mind that there is an important difference between the hardware and software aspects of the trial. The hardware is as it is – for example if a piece of kit is unacceptably heavy for fieldwork there is nothing that can be done about it and it may therefore simply not be suitable. Software on the other hand can be customised. The software being trialled is either off the shelf (eg Pocket GIS) or pre-existing BGS software developed for other purposes (eg the GSD). We do not therefore expect the software to be wholly suitable as it wasn't designed for the particular requirements of BGS digital field data entry. What we want from the trials is an assessment of how nearly suitable the software is and what would need to be changed to make it wholly suitable.

Form 1: Hardware assessment

Name of hardware being assessed:	**Compaq iPAQ**
FEATURE	**ASSESSMENT**
Was the hardware sufficiently robust? Indicate any problems.	Yes
Was the hardware sufficiently reliable? Indicate any problems.	Yes
Weight – was any difficulty experienced carrying the kit?	No
Weather resistance – how did it compare with paper methods? Was it waterproof?	Coped well with extended periods of torrential rain, often being soaked all day.
Screen readability – was this satisfactory in all natural light conditions?	Screen was easy to read, even in bright sun.
Screen size – was this big enough and did it have sufficient resolution?	Screen is a far better shape than that of the Husky, much more useful for mapping. Resolution was good, but would ideally need a smaller scale map base when zooming out to allow the map to be readable.
Battery life – was this sufficient? Was recharging easy?	I used up to 80% of the battery in an 8 hour day. Longer summer days would require more, so having the emergency backup pack is a great idea.
Was the kit ergonomically satisfactory? eg was the keyboard big enough, was the pen/pointer readily accessible etc?	Perfectly acceptable, though no keyboard. I didn't need one, but others might.
Did the machine 'wake-up' sufficiently quickly at each new location?	Yes.
Did you have any problems saving data or with data loss?	No.
Were you able to load all the software you needed? What software did you use?	Yes. ArcPad v. 6.0.
Did you connect and use external data capture devices such as range finders or digital cameras? If so were these satisfactory?	Only had GPS connected. This worked fine.
Was there any hardware functionality that you needed which was not provided?	No.
What was your overall assessment of the hardware in this trial?	Robust, reliable, easy to use, small, good screen, good case.

Form 2: Software assessment

Name of software being assessed:	**ESRI ArcPad v. 6.0**
FEATURE	**ASSESSMENT**
Were you able to load all the data sets you needed? What data formats did you use (.shp, .tif, etc)?	Yes .shp, .sid
Did you find the data/software loading process easy / complicated, slow / sufficient?	Reasonably straightforward, manual is very good, detailed. Data transfer (via PCMCIA slot) v. quick.
Were you able to able to access/view all data sets sufficiently rapidly?	Yes, switching between layers was easy and screen refresh in general was quick.
Was the software interface easy to use and intuitive?	Yes, after a day or so it is quite straightforward.
Was the software reliable with no 'crashing'?	Yes, very reliable.
Was it easy to enter and edit point data?	Very easy.
Was it easy to enter and edit text data?	Yes, slightly slow to start with using the pen to tap on the 'keyboard', but otherwise fine.
Was it easy to enter and edit linework?	The freehand tool is excellent and essential. Vertex editing was simple and far better than PocketGIS
Was it easy to enter and edit polygons?	I didn't attempt this, but there is a freehand polygon tool, which would be useful.
Did you want to sketch lines and then generate polygons from them, and if so was this possible?	I sketched lines and used them as a guide to create polygons later. Worked very well.
Was it easy to add attribution to points, lines and areas?	Yes.
Was it easy to add symbolisation to points, lines and areas?	Would be useful to have desktop ArcPad in order to define symbology files.
Was it easy to capture sketches?	Didn't attempt this.
Were you able to attach sketches and drawings to a point?	Didn't attempt this.
Could you record all the information/data you needed to? If not what extra was required?	No problems.
Was it easy to export data to other corporate software, such as ArcView and/or Access or Oracle?	Data is easily transferred to Arcview or ArcGIS as it is in .shp format.

Was it easy to download or back-up data in the field base?	Very easy if the laptop at the fieldbase has a PCMCIA slot.
Did the software have the facility to access directly all necessary constraint dictionaries eg the RCS or Stratigraphic lexicon?	Don't know.
Did you use the kit as a standalone PC in the field base and if so was it satisfactory for this?	I used a laptop at the fieldbase so I never tried using the iPAQ for things if not in the field.
Did you use GPS and if so was there a satisfactory link to the software?	Yes, the GPS worked well and was essential in delineating moraines.
Did the software perform any field calculations you needed eg gradient to angle of dip? If not what extra is required?	Didn't try it.
Did you use or need handwriting or voice recognition software; did the software provide this functionality?	Didn't really need it.
Was there any software functionality that you needed which was not provided?	I had all I needed I think.
How could the software be improved?	Being able to design customised forms within expensive Application Builder software would be good.
What was your overall assessment of the software in this trial?	Excellent.

Glossary

GSD The 'Geological Spatial Database', a BGS customisation of Arcview 3.2 designed for the capture of attributed geological data to populate corporate databases and from which can be produced hard-copy 'maps'.

DMCS 'Digital Map Compilation System' – Bentley Microstation-based software intended to enable geologists to capture their data in the office in a cartographic way, for integration into DMPS97 by Cartographic Services. The trials of the system stopped after approximately one year, as the software was deemed overly complicated and did not support the level of attribution required by the geologist.

DMPS97 The current system for all cartographic output from Cartographic Services, which supports a lower level of attribution than the GSD but one that is suitable for most purposes.

IGSN Integrated Geoscience Surveys North – the Murchison House former 'Land Survey'.

SIGMA 'System for Integrated Geospatial MApping' – a project currently under the management of Andy Howard investigating the use of digital spatial data within BGS to produce efficiency gains.

TIN A 'Triangulated Irregular Network' – a 3 dimensional surface representing the x, y, and z values of a dataset.

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.

ALDISS, D. T., LAWRIE, K. I. G., LEWIS, P. M. 1993. The MERLIN project. Investigation of digital field data acquisition. Report on pre-prototype trial. *Unpublished*.

BARNES, R. P. 2002. Application of ArcView GIS to geological mapping. *British Geological Survey Internal Report*, IR/02/121. 38pp

FARRANT, A.R, JORDAN, C.J, THOMAS, C.W. 2001. A user requirement for Land Survey digital field data entry. *British Geological Survey Internal Report*, IR/01/137. 21pp

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

JORDAN, C. J., BEE, E., LAWLEY, R., NAPIER, B. R. 2002. Digital Field Data Capture, interim evaluations and recommendations. *British Geological Survey Internal Report*. IR/02/190. 68pp

THOMAS, C. W. 2002. Digital Field Data Capture: a trial in West Greenland, July – August, 2001. *British Geological Survey Internal Report,* IR/02/066

WALTON, G. AND LEE, M. K. 2001. Geology for our diverse economy: *report of the Programme Development Group for Onshore Geological Surveys.* (Keyworth, Nottingham: British Geological Survey.)