Training the next generation of near-surface geophysicists: team-based, student-led, problem-solving field exercises, Cumbria, UK

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RUNNING HEAD: Training student near-surface geophysicists

ABSTRACT

Discussions with employers of graduate applied geophysicists (reinforced by recent literature) indicate a progressive reduction in the numeracy and literacy of graduating students. In particular, there is a perception that problem-solving and quantitative analysis skills are not being gained during University studies, which could be partly attributed to an emphasis on classroom lectures and timetable constraints rather than research-informed and active learning in the field.

This paper provides a pedagogic overview of a Masters level, student-led residential field exercise in the Lake District, Cumbria, U.K. that has run for eight years. The valley has a complex glaciated bedrock buried by recent sediments that poses a challenge for students to recognise, understand and quantify in three dimensions. Participating student 'companies' are set a competitive task to win a contract for a full geophysical valley survey to determine the route of a gas pipeline. Students initially complete a desk study, collating available multi-disciplinary (geology, remote sensing and geotechnical) datasets. The student-led field exercise then acts as a geophysical reconnaissance mission, with teams mapping depth to bedrock and estimating extents of any coastal salinity incursions. Full costings are produced to simulate a real work contract and the successful company is awarded the 'contract', based on 'client' presentations on the final day of the exercise.

Comments on the student learning outcomes are provided, including employability skills in team working, problem-solving, quantitative data analysis, project and budget management and client presentation skills. Recent student evaluations are discussed with very positive comments from graduate geophysicists who have entered related employment emphasising how the exercise has prepared them for the workplace.

INTRODUCTION

Informal discussions with both UK local and national employers of recent UK graduate geophysicists (British Geological Survey, Met Surveys Ltd., Reynolds International Ltd., RSK STATS Geoconsult Ltd., Terradat Ltd., Zetica Ltd.), have highlighted a general reduction in their numeracy, literacy and technical field skills along with a lack of familiarity with common near-surface geoscientific equipment and data processing software. This has been reinforced by recent literature on the subject (e.g., Manduca et al., 2008) and the issue is becoming a concern for industry-related graduate employers nationally (Loudin, 2004; 2007). A recent comprehensive review of geophysical education in the UK by the British Geophysical Association and the Royal Astronomical Society (Khan and Working Party, 2006), found that the most desired graduate skills were a sound theoretical and practical geophysical knowledge-base, some form of associated geoscience background, IT expertise and problem-solving skills.

Transferable skills, such as problem-solving, the ability to understand, analyse and interpret multi-disciplinary datasets, etc are all needed for the workplace and seem not to being gained during the course of current student studies (Loudin, 2004). This can be partly attributed to an emphasis on class-based lectures, which are driven by reduced course budgets and timetable constraints, rather than by research-informed learning, active learning and understanding (Biggs, 1999; Horton, 2001) and geophysical and surveying equipment familiarity in the field. Few Universities have direct access to the latest commercial equipment/software and their existing, in-house geophysical and survey field equipment base is becoming dated, primarily due to lack of University investment. Similarly, funding restraints mean that there are also limited 'real-world' quantitative geoscientific datasets for students to apply their theoretical skills to prior to leaving University, which would normally stretch student abilities and reinforce deeper learning and understanding (Hill et al*.,* 2004; Anderson et al*.,* 1991). Soreghan and Soreghan (2003) showed how a multi-disciplinary, student-led research project on course-relevant material can significantly aid student understanding and learning at the highest learning levels. We advocate this approach and present a review of a final year, M.Geoscience (level 4 undergraduate), five-day residential field exercise to the Lake District, Cumbria, UK that has been run by Keele University staff for eight years that has included a total of 42 students. By using a team-based, student-led, problem-solving field exercise, we aim to illustrate that participating students greatly enhance their employability skills including; team work, critical thinking, literacy and numeracy, problem-solving, multi-disciplinary data analysis, project and budget management, quantitative data analysis and interpretation and client presentation. The importance of these skills has been previously highlighted by a number of pedagogic studies (e.g. Chalkley, 2000; Macdonald and Bailey, 2000; HE Academy report 2005; Dalrymple and Miller, 2006; Loudin, 2004: 2007; Thomas, 2008) and are vital for graduate development in the geophysics industry.

STUDY AREA BACKGROUND

The Gilpin-Kent valley floodplain in the southern Lake District is located seven kilometres to the south west of Kendal in the Lake District, Cumbria, U.K. (Fig. 1). The bedrock dominantly comprises Silurian (Ludlow) Bannisdale Formation siltstones and mudstones with unconformably overlying Carboniferous (Dinantian) limestones that are massive in character (Taylor and Wilson 1997). A small outcrop of Silurian Kirkby Moor Flagstone Formation is observed in the north-east of the study area (dipping 80º eastwards) whilst the Carboniferous limestones dip 30º eastwards. Predominantly northwest-southeast trending transverse faults separate the two bedrock types into typical fault block distributions. The limestone forms the high ground either side of the north-south trending Gilpin valley, as it is more resistant to erosion than the softer Silurian sediments that predominantly form the valley floor (Fig. 2a). A mixture of Quaternary (Late Neogene) sand, clay and gravel deposits, formed by glacial and/or fluvial processes, overlie the bedrock in most of the valley (Fig. 2b). In the south, there are Holocene tidal flat deposits formed by coastal processes and the Gilpin River becomes a tidal estuary with associated saline water incursions observed in places (see later). These recent sediments have resulted in a very flat modern surface topography across the whole valley, bounded by rocky outcrops to the north, east and west and the estuary to the south (Fig. 3). Valley land-use is predominantly agricultural, with isolated villages on the valley edges and a main trunk road (A590) running east-west across its centre.

Early reconnaissance seismic surveys (Gresswell, 1958) and geotechnical boreholes (Knight, 1977) showed the middle part of the valley to have been subjected to significantly deep (40m+) glacial erosion (Fig. 4). Taylor and Wilson (1997) presented five valley traverse interpretations that revealed a complex bedrock valley floor topography that has been mostly overlain by the recent deposits (Fig. 4b). Observed bedrock depth varies from 0 to 60 m below present ground level, depending upon position within the valley. These traverse interpretations were created from a combination of multiple refraction surveys and regional micro-gravity data (the bedrock having a higher density than the recent sediments) and they concluded that this apparently complex buried bedrock topography would be difficult to identify from surface information alone.

Current remote sensing and historical datasets of the study area at various scales (1:1,250 up to 1:250,000) can be downloaded by subscribers from the EDINA Digimap

UK national academic data centre and include the British Geological Survey digital solid and drift geology maps, a Digital Terrain Model (DTM) and topographic maps (Fig. 2). EDINA is funded by the Higher Education Funding Council for England and the resource allows participating students to access industry-quality, high-resolution digital data. This facility is an important part of developing the students' quantitative data analysis/presentation skills and significantly enhances their learning experience.

As the study area is topographically flat, with a variety of quiet country lanes, footpaths and wide verges on main routes, it is an ideal environment for students to undertake micro-gravity, magnetic and electrical (electrical resistivity imaging and vertical electrical sounding) surveys safely without too much disturbance. The complex bedrock valley floor, a variety of available multi-disciplinary datasets and nearby field centre accommodation makes this an ideal study area for participating students to develop the required 'real-world' employability skills.

STUDENT FIELD EXERCISE INFORMATION

Students were initially given a project exercise overview that detailed the exercise's aims and objectives (Table 1), a basic background geological/geographical description of the study area, an introduction to relevant near-surface geophysical technique theory, practical demonstrations of the available equipment and basic instructions on how to use the available data processing software (Table 2). The overview emphasised how it would be a student group-led, problem-solving exercise and would be competitive, with 'client presentations' forming the basis of deciding which 'company' would be awarded the surveying 'contract'. The exercise deliberately included the typical pre-survey processes that a near-surface geophysical company would be involved in including a 'job specification' with further information (Table 1) and the requirement that a desk study needed to be completed before undertaking the field-based surveys. During the field exercise, the students' were expected to undergo a 'reconnaissance survey', then 'full surveys' (with logistical/organisational activities of both personnel and equipment agreed in advance) before the exercise culminated with the 'client' presentation rather than a written report being required. The background information presented in this paper (including Figs. 2-4) was not provided to the students beforehand, however, they were given borehole co-ordinate positions and basic survey area information, as well as being directed to the EDINA website and the Taylor and Wilson (1997) cited paper.

Participating students were usually divided into two companies (by the tutors) a couple of day before the start of the exercise, with each group having roughly the same skills set, based on previous taught module experiences, commercial placements and individual research projects. Each company was encouraged to democratically select a project leader who directs the work schedule for the duration of the project. Information on fieldwork logistics, accessibility, responsible working and the relevant health and safety advice were given to students before allowing them to undertake the fieldwork. The specification (Table 1) detailing the available equipment and personnel daily hire rates were also provided (Table 2). Rates included equipment, software, sundries and advisor personnel rates; the latter for both consultants and electronic engineers required for any onsite equipment repairs. Rates on commercially used equipment were periodically checked with U.K. hire companies to maintain an up-to-date context to the exercise. A budget of £10,000 was given for 2006-10 companies.

FIELD EXERCISE

The residential field exercise took place over a five-day period in April with area familiarisation and further equipment instruction occurring in the first morning (Fig. 5a/b). Client presentations were scheduled for the morning of the last day, therefore allowing students three and a half days of ‘planned field time’ for data acquisition, processing and interpretation (Table 3). Staff members organised logistics, charged and repaired equipment where necessary (this incurred a cost to student companies) and initially advised the student companies on how to plan their fieldwork. However, it was emphasised to the groups that this was a student-led field exercise and, therefore, they were left to their own devices for planning and carrying out field data acquisition.

Ideally, the latest in commercially available equipment should be available for the exercise (in order for students to gain familiarity with state-of-the art geophysical instrumentation). However, restricted University budgets have meant that although the equipment used in the field is modern, the very latest in equipment types could not be purchased or used on a year-by-year basis. Nevertheless, the main commercially relevant near-surface geophysical survey techniques, equipment and software were available to the students (Table 2 and Fig. 5) and they were given ‘free choice’ on what to use. In summary, the principle techniques used were;

Gravity surveys

The gravity surveys in this area were used to determine bedrock topography (Tønnesen, 1995) with higher density values being associated with the shallow buried limestone bedrock (~2.6 – 2.8 Mg m^{-3}). This contrasted with lower density values of ~1.8 - 2.2 Mg m^{-3} associated with the thick (up to 60 m) recent drift deposits (see Fig. 6). In their surveys, most student companies used the Worden gravimeters (rather than the Scintrex instrument) as they felt more confident using a manual instrument that was relatively robust and simple to operate (it was also cheaper to hire). The students measured three values at each sampling position (averaging the result) and recording the time of collection (i.e., following standard methodologies – Milsom, 2007). Regular revisits to a base station position corrected for temporal changes in the Earth's gravity. Terrain and above-ground structure corrections were not undertaken due to the comparatively flat topography found within the survey area. There was usually limited time for the students to undertake comprehensive gravity modelling, as commercial companies would normally do, but some of the better students did attempt to quantify the observed gravity differences, or determine bedrock depth, through quantitative methods and/or simple modelling. Despiked processed gravity datasets were graphically plotted using ArcGIS v.9.1 software and a contoured surface created for the survey area (see Fig. 6 for examples).

Magnetics Surveys

The magnetic surveys were used to spatially map the outcropping bedrock and drift deposits in the valley (Baltassat et al., 2005) with typical values of 49,250 nT being recorded for the very near-surface, shallow bedrock and <49,100 nT associated with thick drift deposits, although this did vary across different student cohorts (Fig. 7). In their surveys, most student companies used the proton precession magnetometer to measure the total magnetic fields as it was simple to operate, less cumbersome than the potassium vapour magnetometer and, of course, cheaper. Interestingly, they quickly realised that the additional accuracy of the potassium vapour magnetometer was unnecessary for this application and that extensive data coverage was more beneficial for the mapping task. At each recording position, an average of three total field values was recorded, along with the time of collection (Milsom 2007). Although regular revisits to a base station position can adequately correct for temporal magnetic variations, the student groups opted to use a separate magnetometer to log total field values continuously at one 'base point' for more accurate drift corrections. Despiked processed magnetic data were graphically plotted and a contoured surface created for the survey area (see Fig. 7 for examples).

Electrical methods

Generally, the non-fractured rock types in this area were shown by resistivity surveys to have relatively high values (~500+ Ω.m), when compared to the much lower resistivity drift deposits (~1 - 25 Ω.m). These values contrasted with the intrusive, conductive saline waters ~0.5 Ω.m, in the southern extent of the valley where tidal estuarine conditions prevail. The student companies were able to choose from a range of electrical resistivity survey configurations and equipment (Table 2) and had free reign on how to undertake the investigation work.

Vertical Electrical Sounding (VES) surveys: the students used the expanding VES technique, using a Wenner array geometry (Milsom, 2007), mainly in the south of the study area in order to detect coastal saline intrusion (Fig. 8). Sounding sites were usually located on grass verges beside minor roads with typical electrode spacings ranging from 0.25 – 7 m (the maximum spacing was limited to ~8m by cable lengths). From 2007-2010 the student companies used IPI2Win v.3.0.1 software to create vertical resistivity models to match the VES observed data (see Fig. 8).

Electrical Resistivity Imaging (ERI) surveys: In these surveys, the students usually used either 32 or 64 electrode, Wenner-based ERI array profiles to determine the depth to bedrock (Reynolds, 1997) with electrode spacings of 3 or 5 m. Again, survey locations were chosen beside minor roads and on grass verges where there was adequate space to leave the accompanying equipment vehicle (Fig. 8). Nearly all groups chose to orientate the surveys East-West across the valley in order to determine the bedrock depth and form ‘across strike’. Geotomo RES2DINV™ v.3.4 software was used to invert the measured apparent resistivity values to true resistivity (Loke and Barker 1996) and because of the relatively flat topography, elevation corrections were not required (Fig. 8).

Surveying methods

Although the Leica™ 1200 differential Global Positioning System (dGPS) system was available for students to locate their geophysical data sampling positions (Table 2), all students used a combination of hard copy Ordnance Survey (OS) maps of the area and Garmin (hand held) GPS units to locate their data. These were not only cheaper to hire than the dGPS system but, again, were perceived as being simpler to operate. As the valley topography was relatively flat with unrestricted views it was straightforward for the students to orientate/locate themselves to a reasonable degree of accuracy (i.e., within ~3m on the Ordnance Survey maps).

DISCUSSION

Student Data Collection Experiences:

Gravity: Most student companies collected gravity data for the full period of the field exercise (see Fig. 6 and 9a). Overall, there were increasingly more gravity positions collected during successive days and in succeeding years (Table 3). More points should improve the resulting contoured plots, although this was not always the case as anomalous readings were sometimes left in student data. Observing the spatial extent of the gravity data collected, most student groups kept to the minor roads within the survey area, with a few groups also collecting data along footpaths (Fig. 6). This was mostly due to perceived access difficulties, although a few groups did ask permission of farmers/landowners to collect data on their land to fill in perceived data ‘gaps’. The valley edges were also usually avoided, mainly due to perceived concerns about data being affected by terrain affects. In general, gravity data were collected throughout the survey area in days 1 and 2, with later days used for filling in perceived ‘gaps’ as the groups became focused on obtaining a good quality gravity dataset. Position density also varied; the 2004 ‘S’ group data were more than 500 m apart, whereas the 2009 ‘G’ group’s data were ~200 m spaced and day 1 of the 2009 ‘M’ group data was spaced at a distance 50 m. Most companies presented gravity as their primary technique for determining the depth to bedrock and its large-scale variations (Fig. 6).

Magnetics: Most student companies collected magnetic data for the full period of the field exercise, although the 2010 company did not (see Fig. 7). Observing the spatial extent of the magnetic data collected, most student groups kept to the minor roads within the survey area, with a few groups also collecting data along footpaths (Fig. 6). The magnetic data required significant processing as, initially, students were unfamiliar with the need to avoid above-ground sources of magnetic ‘noise’. As a consequence, there was a ‘lack of confidence’ associated with this technique when compared to gravity. As data could be collected relatively quickly, (e.g., the 2008-9 companies collected over 200 data points - Table 3), the spatial spread of data showed a lack of decisive pre-field planning, with several areas being revisited or ‘unexplainable’ gaps being present in the coverage (Fig. 6). It was also interesting to note that some groups failed to recognise the ‘non-geological’ sources of noise in the field (e.g., metal fences, gate, pylons, etc) and were oblivious to their effects during data collection.

Resistivity: VES data collection was predominantly restricted to the south of the valley (Fig. 8) with a few companies timing data collection for high tide to maximise their chances of observing a saline intrusion. The resulting VES three-layer models did indeed indicate saline intrusions (in the south) for some cohorts but not others, most likely due to tide and/or locally varying soil moisture content (Fig. 8). A few companies appropriately related these VES results to areas needing saline resistant cement (as indicated in specification) but many groups failed to grasp (or at least adequately explain) the linkage between resistivity, conductivity and pore-water salinity. Almost surprisingly for the U.K., weather conditions have been similar each year with generally dry, yet cool, conditions and only short periods of rainfall.

ERI profiles were predominantly used to determine the depth to bedrock, and its local morphology, which changed considerably from north to south (Fig. 8). Students rapidly became familiar with the equipment and the need for obtaining appropriate electrode contact resistivity values to obtain optimal images. Some companies just showed the Geotomo RES2DINV™ software inversions with their default display setting whilst others made the effort to set a common scale to visually highlight their interpretations; this was usually commented upon, positively, by the clients! A few companies showed the measured resistivity values to indicate their inversions were realistic (and/or related them to published values), but most just presented the inverted results with no other collaborating information. Disappointingly, only one group from the entire eight years attempted to correlate the ERI and VES data together and constrain their inversion routines. That said, the 2009 'M' group did use the Geotomo RES2DMOD™ resistivity modelling software to validate the measured field data with a 'modelled' stratigraphy which significantly improved their interpretations.

Tutor Observations

This field exercise had the advantage of having the same tutors for the eight years with student datasets being fully archived together with student evaluation forms and course marks (see later).

Student companies have generally collected more and better quality datasets in the last few years (Fig 9c), which could be partly attributable to better pre-planning, higher student expectations and increasing competitiveness. Generally companies performed better with a strong leader, which was often not previously experienced by students during the course of their studies, whereas democratically run companies usually lacked focus. Although every effort was made to make respective competitive ‘companies’ equal, one company was usually stronger in the field. However, this did not always transfer to winning the contract due to lack of sensible data interpretations. For example, the 2008 ‘PA’ group, who performed very well in the field, interpreted the gravity as being related to a 1000 m wide void in the valley centre, despite the contrary magnetic and resistivity evidence - something that did not instil the clients with confidence! Usually one team member was tasked to monitor finances from the beginning, who often made key survey decisions on the basis of cost alone, illustrating that the students were fully aware of the financial considerations from day one – a particularly important employer requirement.

There has been a general trend towards students working harder and for longer during the eight year period. Although field equipment has improved, this has not resulted in significantly more data being collected (Table 3). Student company magnetic data point totals have generally remained static whilst the total number of VES survey data points have reduced during 2002-2010, although it could be argued that students have become more focused on the task, rather than collecting as much data as possible during the available field time. The 2010 group for example were collecting VES data at 06:00 on day 3 in order to have optimal conditions to monitor any saline intrusions in the south of the area. Time spent on data processing has increased (as has its complexity) although it is arguable if this has had any real benefits in data quality. There has been observed more time and effort spent on digital data integration, especially since the EDINA data resources have been available for them to utilise. Laptop PCs have also become more powerful, allowing the integration of both desk study and field data within the 3D visualisation software.

During the latter years, particularly from 2008 to the present, students have been bringing their own GPS positioning equipment, laptop PCs and specialist software as they perceive that this gives them ‘the edge’ on other groups (although they all do it). There has also been an increased level of personal ‘stress’ exhibited by some students, either perceived or real, perhaps generated by the competitive nature of the exercise. A few rare vocalised disagreements have occurred, but these are normally resolved quickly, and the students quickly realise that working as a team is the best approach.

Client presentations were universally feared but subsequently all commented on it being a very positive experience, especially for future employment. More recent groups have also been spending significant time on presentation visuals, rather than necessarily on content, which may reflect the students’ perceived anxiety of producing a professional presentation for the ‘clients’. There has also been a corresponding increase in the professional approach of students to the exercise, probably as a result of them being more engaged, having increasingly higher quality data (both desk study and field material) and spending more time on the project. In many cases, the presented information would not look out of place in a commercial geophysical survey report.

Student Evaluation

The student company groups’ marks have been consistently high, averaging 73% (Table 3), which reflects the high degree of student engagement in this exercise and the quality of their work. The total marks include sensible subdivisions of field effort, data interpretation, recommendations to the 'clients' and their ability to justify costs and keep close to budget. In one case, the company with the higher mark did not gain a contract, due to the client-perceived interpretational error.

Pre- and post-course focus groups were conducted in 2010 with pre-course responses indicating that the students were nervous beforehand, not sure what to expect, not familiar with geophysical equipment (other than during an initial 'familiarity' session) and queried the field course validity. Comments included "why are we doing geophysics?" and "could we just use mapping skills?". However, the post-course focus group revealed that students were very positive about the course with universal approval of the field experience, the 'client' presentations and the multi-disciplinary and student-led focus of the residential exercise. Comments included "Real-world style assessment is very helpful, especially in the 4th year" and "a professional exercise but staff kept atmosphere friendly and fun" (Table 4).

Evaluation of the eight years of course questionnaires, based on the Higher Education Funding Council for England (HEFCE) commissioned National Student Survey, reinforced the overall very positive student experience of the field course (Figure 9). 86% of evaluated students agreed or strongly agreed with Q.1 that 'the aims and structure of the whole field course were explained at the start' and, 84% agreed or strongly agreed with Q.2 that 'introductory material was sufficient to prepare me for the fieldwork'. For the field course itself, 97% agreed or strongly agreed with Q.3 that 'the equipment and materials provided were adequate for the tasks set' and for Q.4 74% stated 'the amount of time allocated to this field course was' just right. 75% of students agreed with Q.5 that 'the amount of time students were without direct staff supervision' was just right. Overall 95% agreed or strongly agreed with Q6 that 'the field course had been worthwhile'. Questionnaire scores for successive courses showed an overall improvement that probably reflected improved pre-course assistance and in-course refinements (Table 3).

Evaluation of the last 3 years of the questionnaire's open comments showed students were very positive about the field course especially its student-led 'real-world' nature, the professional residential environment and the practical experience gained using geophysical equipment, data processing and interpretation software (Table 4). They associated this with an improvement in transferable employability skills. Students also liked the professional 'client presentations', although were universally dreading it beforehand. Negative comments included a lack of help in the field and limited geophysical knowledge prior to undertaking the field course. Whilst it was the students who were driving the schedule, the authors would suggest it was not crucial for all members to know about geophysics – it was a rapid learning curve for some students but having a mix of background experience was key to a successful exercise. Anecdotal evidence from students (42 in total) who gained related employment (~10 in geophysical/exploration companies and the geotechnical industry) have commented how well the exercise prepared them for the workplace, particularly the teamwork and student-led aspects. These comments included the positive outcomes on developing teamwork and inter-personal skills, their effective planning and time management of the project, as well as their fieldcraft and technical skills. Sample comments included: "it made us work effectively, even with people we didn't work with normally", 2008 student, and "it was hard work, but showed us what it was like in the real-world", 2009 student.

Student Learning Outcomes

In the handbook for the module, it was stated that students successfully completing the exercise would: (1) gain experience in the planning and implementation of an integrated geophysical and applied geological field-based study, which makes use of equipment and techniques that are at the forefront of professional practice; (2) have demonstrated self-direction and originality in tackling and solving problems and; (3) further develop skills to a high level in report writing, problem-solving, computing and team-working. Student evaluation evidence supports these outcomes (see above). Participating students became competent at geophysical field craft, data analysis (including processing) and interpretation. Undertaking these stages during each field day and planning the next days' data acquisition made this learning curve even more steep and satisfying to observe. The need for careful data collection, spatial positioning and data processing soon became apparent to the student cohort. Thinking for themselves and fixing problems (as calling out an 'engineer' incurred a cost!) also all rapidly improved. The importance of multi-disciplinary data integration was also recognised by students, using available resources and desk studies to aid interpretations to give sensible client recommendations. Effective project, time and team management were all rapidly learnt. The need to develop new skills, and apply them in a dynamically changing environment, was rapidly learnt and the concentrated, focused effort (often with long hours to deliver the task) has given the participants some idea of what will be in store for them upon employment.

CONCLUSIONS

This is the most important learning exercise in geophysics that Keele University's M.Geoscience students encounter during their degree studies, and the students take the task extremely seriously, sometimes worryingly so! Student questionnaire evaluation and focus group discussions have shown that participants experience the normal highs and lows that occur in real-life work situations. Disputes, such as personality clashes and differences of opinion, were encountered; however, the reality of having to deliver a presentation to a sceptical and informed client meant that these had to be resolved or put aside. The transferable skills acquired include a real working knowledge of geophysical equipment, data collection, processing, integration and interpretation. This was learnt in a much more meaningful way than lectures, laboratory practicals or even one-day field trips could ever deliver. Students experience the pressures of working to strict deadlines and soon discover that it is possible to deliver challenging and difficult tasks on time, in adversity and under budget. They also, surprisingly to them, found the real thrill and camaraderie which working in a team can bring. Ultimately, it is hoped that this paper can provide an example of best practice that other institutions could adapt for their own courses and, therefore, improve the geophysical student learning experience, gain them vital employability skills and enthuse graduates with a career in geophysics.

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Figure Captions:

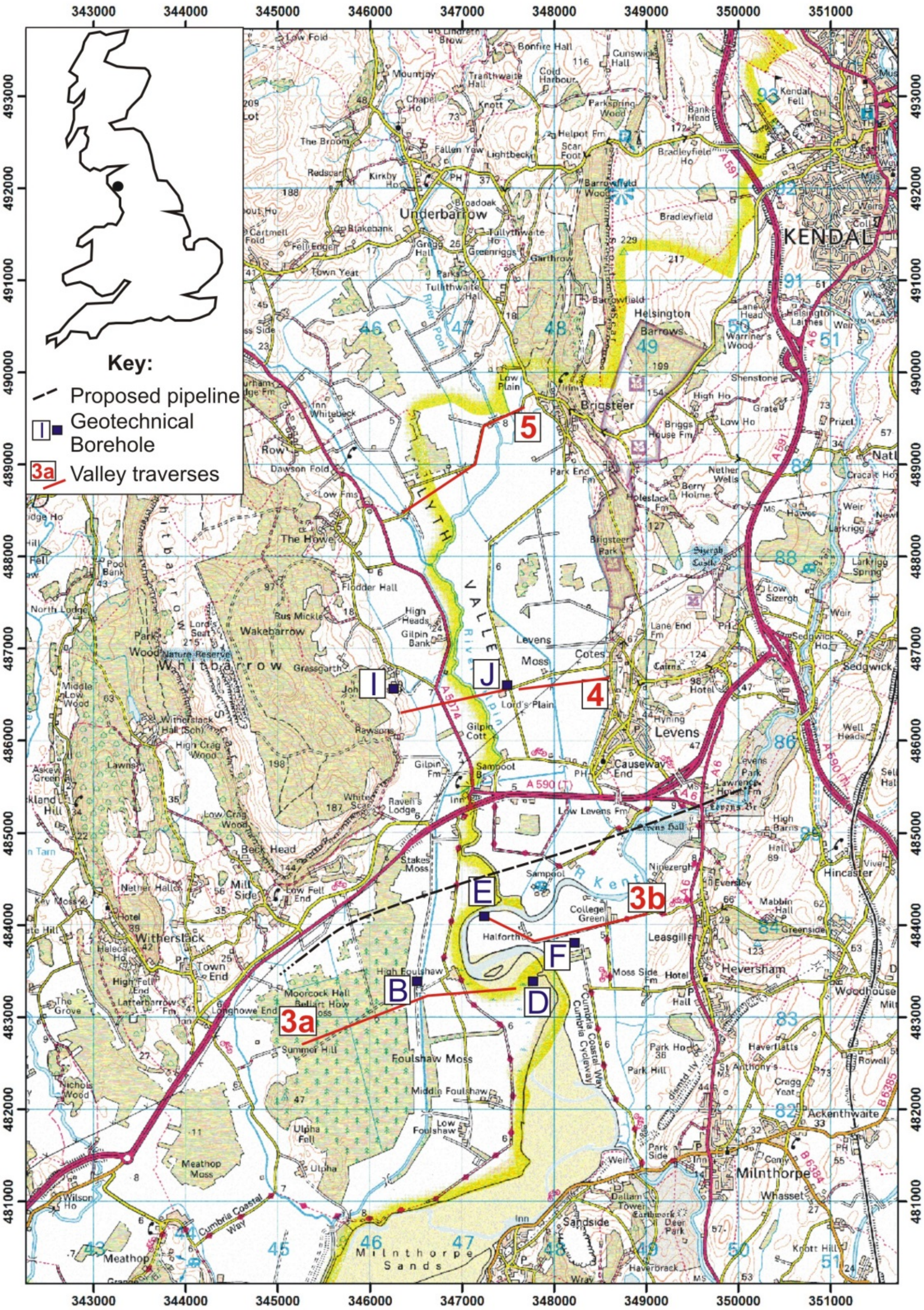
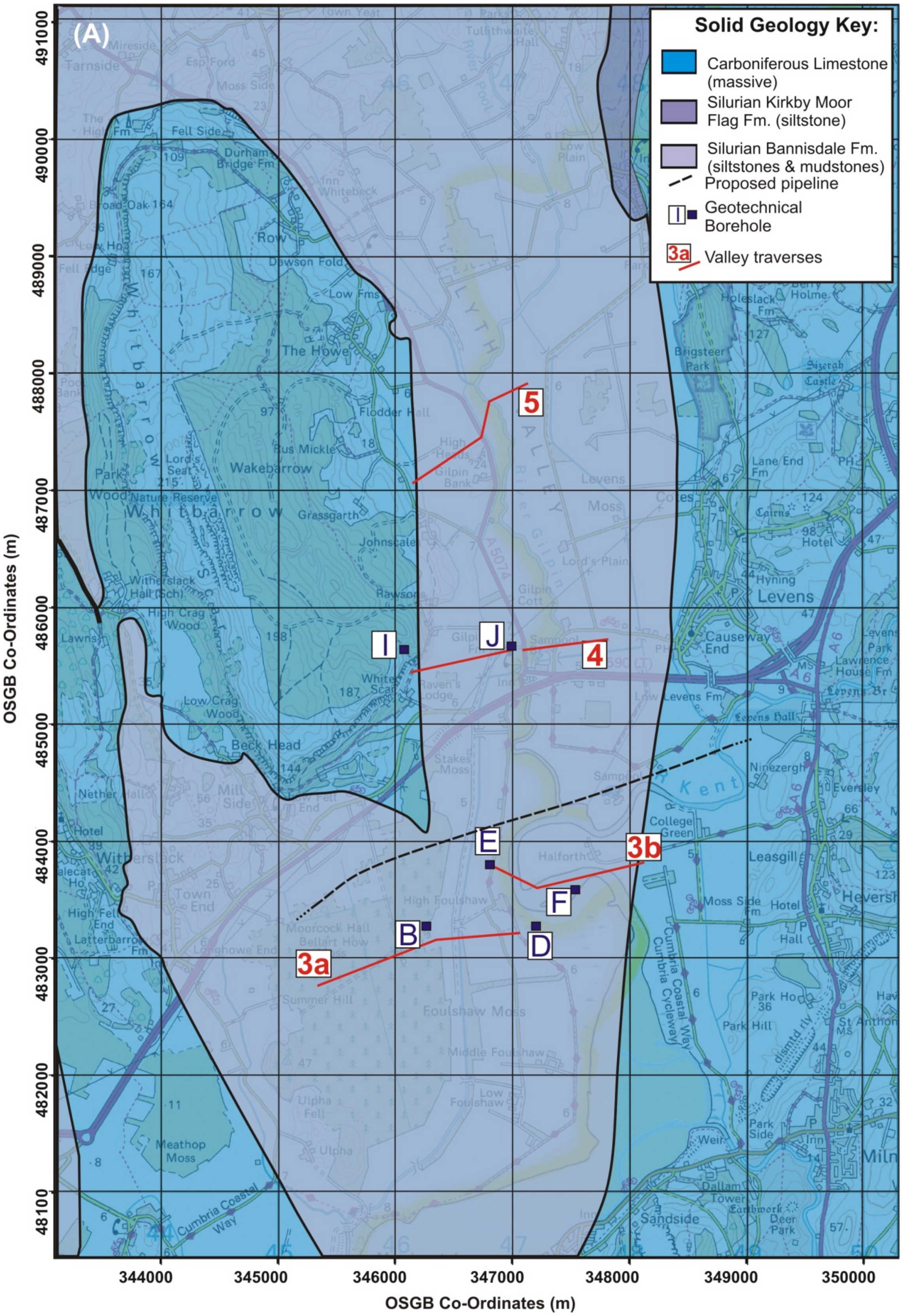


FIGURE 1. 1:50,000 scale topographic map of the study area (UK location inset). Student available geotechnical 1D borehole records, 2D valley traverse interpretations and the proposed 'Manx' gas pipeline route are shown (see text).


(A)
Solid Geology Key:
Carboniferous Limestone (massive)
Silurian Kirkby Moor Flag Fm. (siltstone)
Silurian Bannisdale Fm. (siltstones & mudstones)
Proposed pipeline
Geotechnical Borehole
Valley traverses
3a
3b
4
5
B
D
E
F
I
J
OSGB Co-Ordinates (m)
OSGB Co-Ordinates (m)
344000
345000
346000
347000
348000
349000
350000
491000
490000
489000
488000
487000
486000
485000
484000
483000
482000
48100

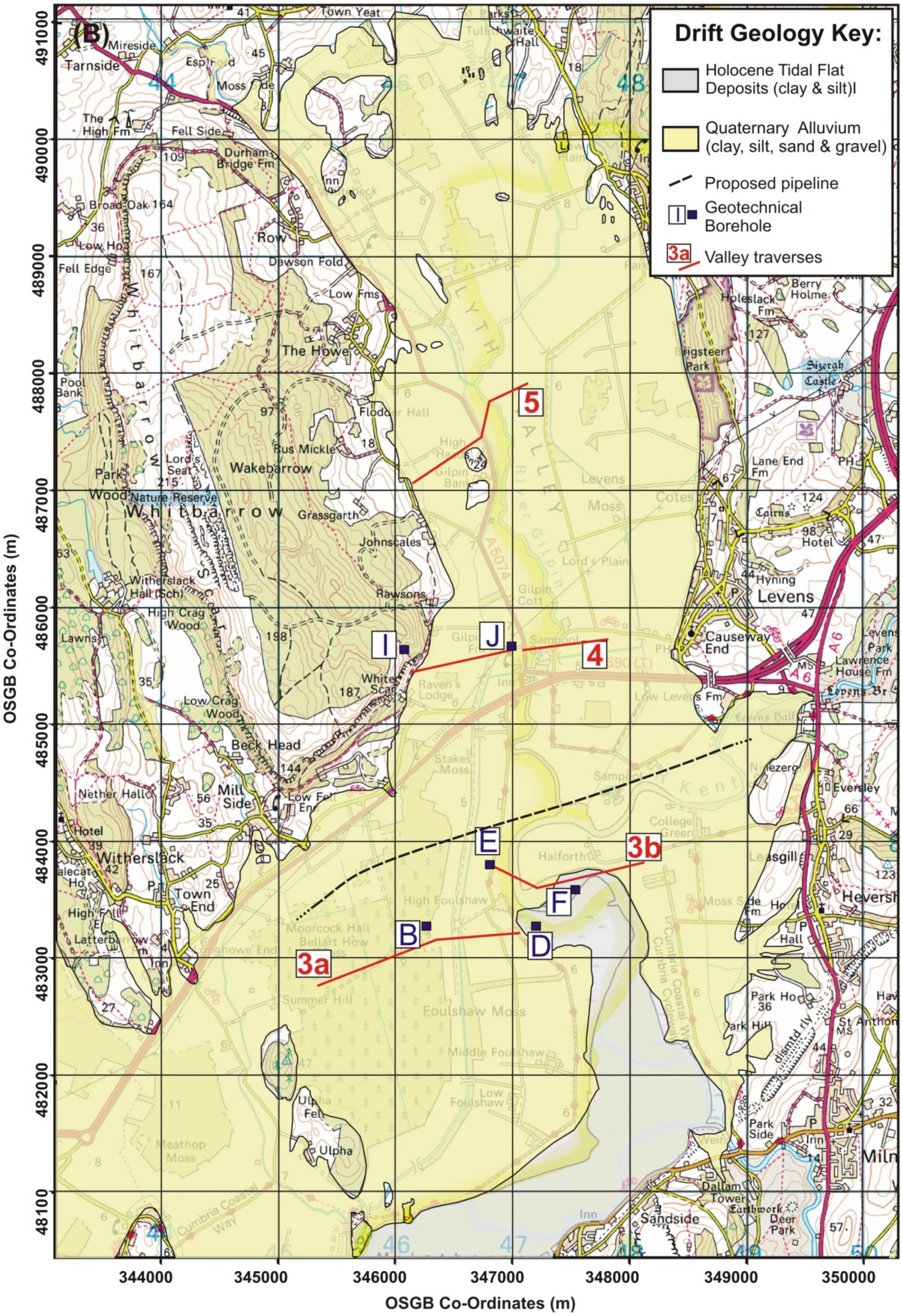


FIGURE 2. (A) Solid and (B) drift digital geology maps of the study area (see respective keys) © British Geological Survey/EDINA supplied. Basemaps are © Crown Copyright/database right 2007. An Ordnance Survey/(Datacentre) supplied service.

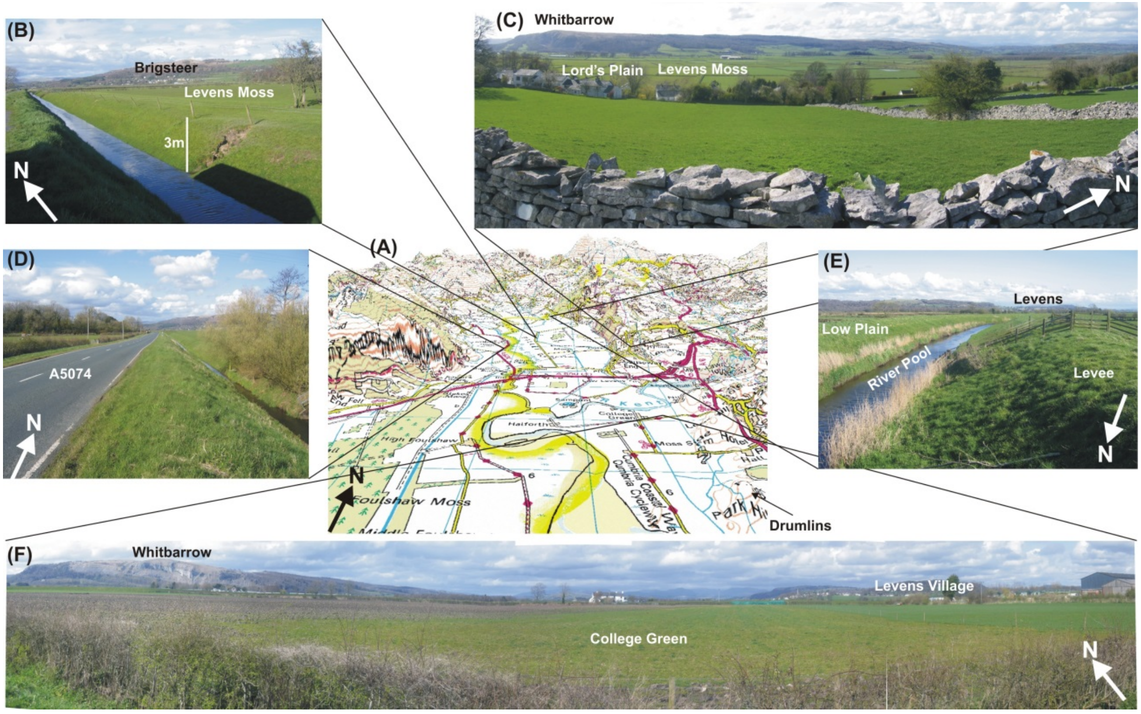


FIGURE 3. (A) Digital 3D 'draped' view of the Gilpin Valley © Crown Copyright/database right 2007, An Ordnance Survey/(Datacentre) supplied service; (B) Deep drainage ditch at Levens Moss in the valley centre; (C) View across Valley (looking west) from Levens; (D) A5074 road; (E) The Pool River in the north at Low Plain (note extensive levee) and; (F) View looking north up the Gilpin Valley from College Green.

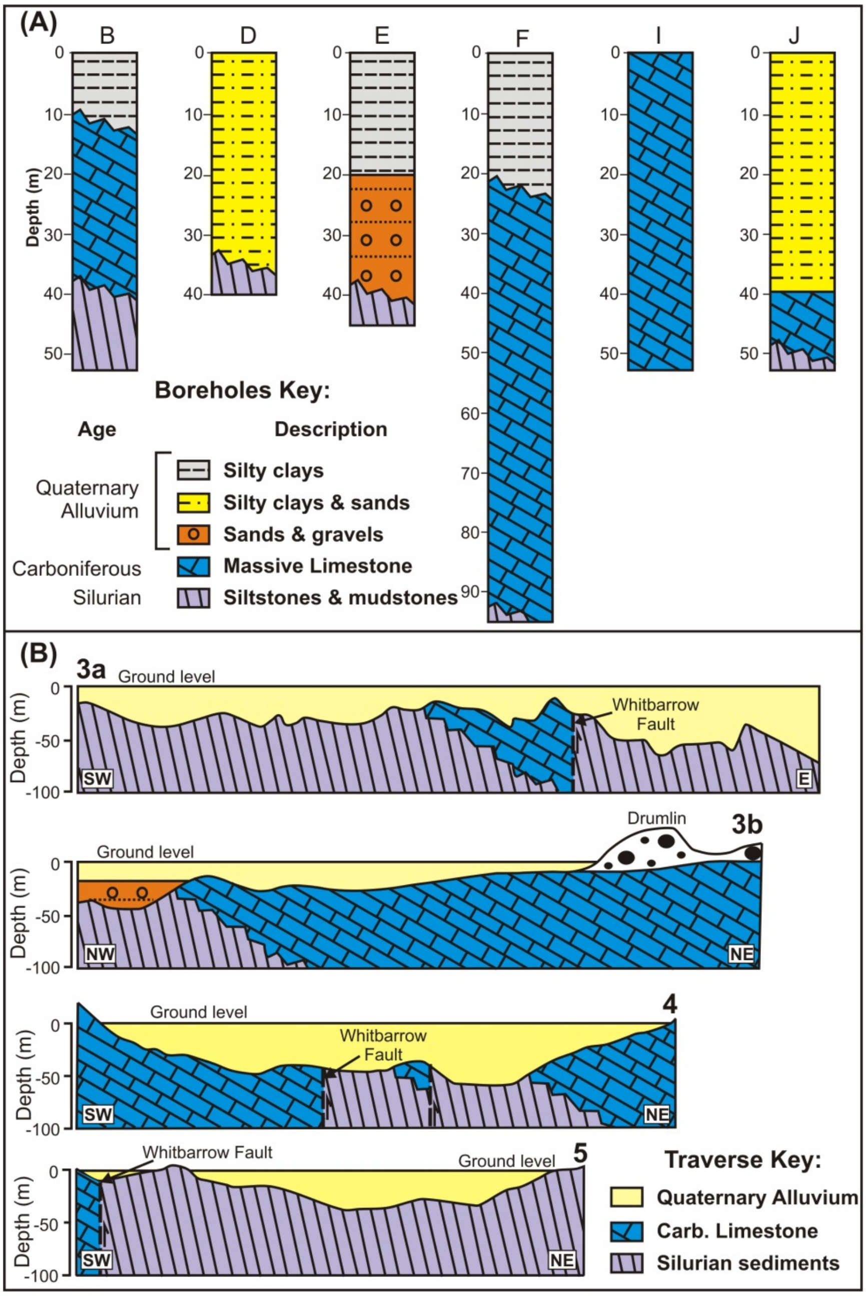


FIGURE 4. (A) Geotechnical 1D boreholes and (B) valley traverse interpretations produced from seismic and micro-gravity data (same lithology key as Fig. 2). See Figure 1 for respective locations. Both have common vertical scales. Modified from Taylor and Wilson (1997).

FIGURE 5. Various field exercise photographs. (A) Student introduction to field area; (B) equipment instruction (usually on Day 1). (C) Micro-gravity data acquisition; (D)

proton precession magnetics data acquisition (with control magnetometer inset); (E) Vertical Electrical Sounding (expanding Wenner) data acquisition; (F) Electrical Resistivity Imaging (ERI) data acquisition. (G) Residential field data processing/project management and; (H) company client presentation.

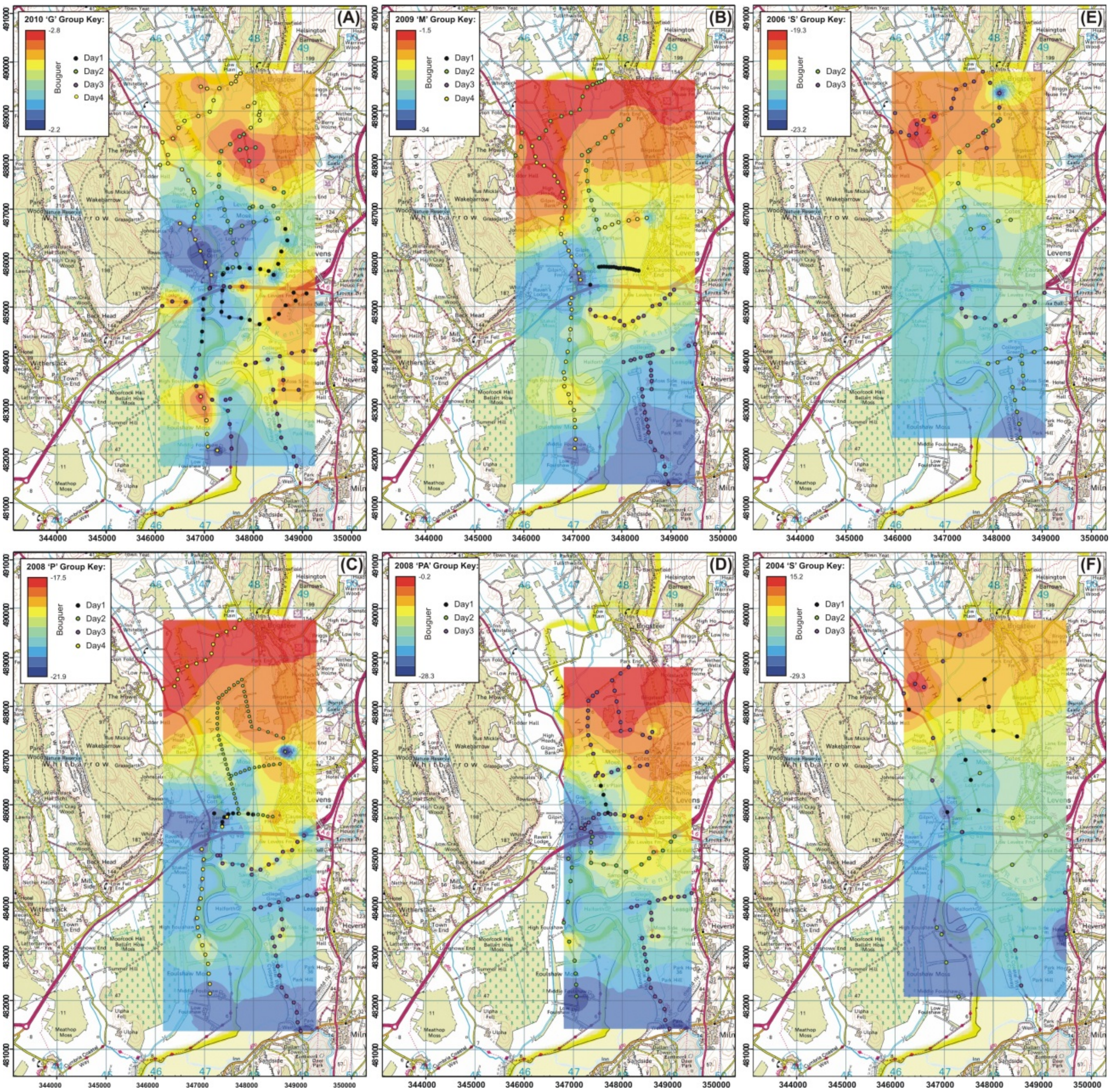


FIGURE 6. Bouguer reduced, processed micro-gravity data sampling positions (different days shown as coloured dots) and resulting contoured surfaces for selected 2004-2010 companies (see keys). Relative highs to the north and lows to the south were observed, with a high, representing shallow bedrock, orientated east-west across the estuary at High Foulshaw and College Green (see text). (A) data collected by both Worden instruments and normalised; (C) & (E) collected using the 769 Worden and

(B), (D) & (F) using the 841 Worden. Basemaps are © Crown Copyright/database right 2007. An Ordnance Survey/(Datacentre) supplied service.

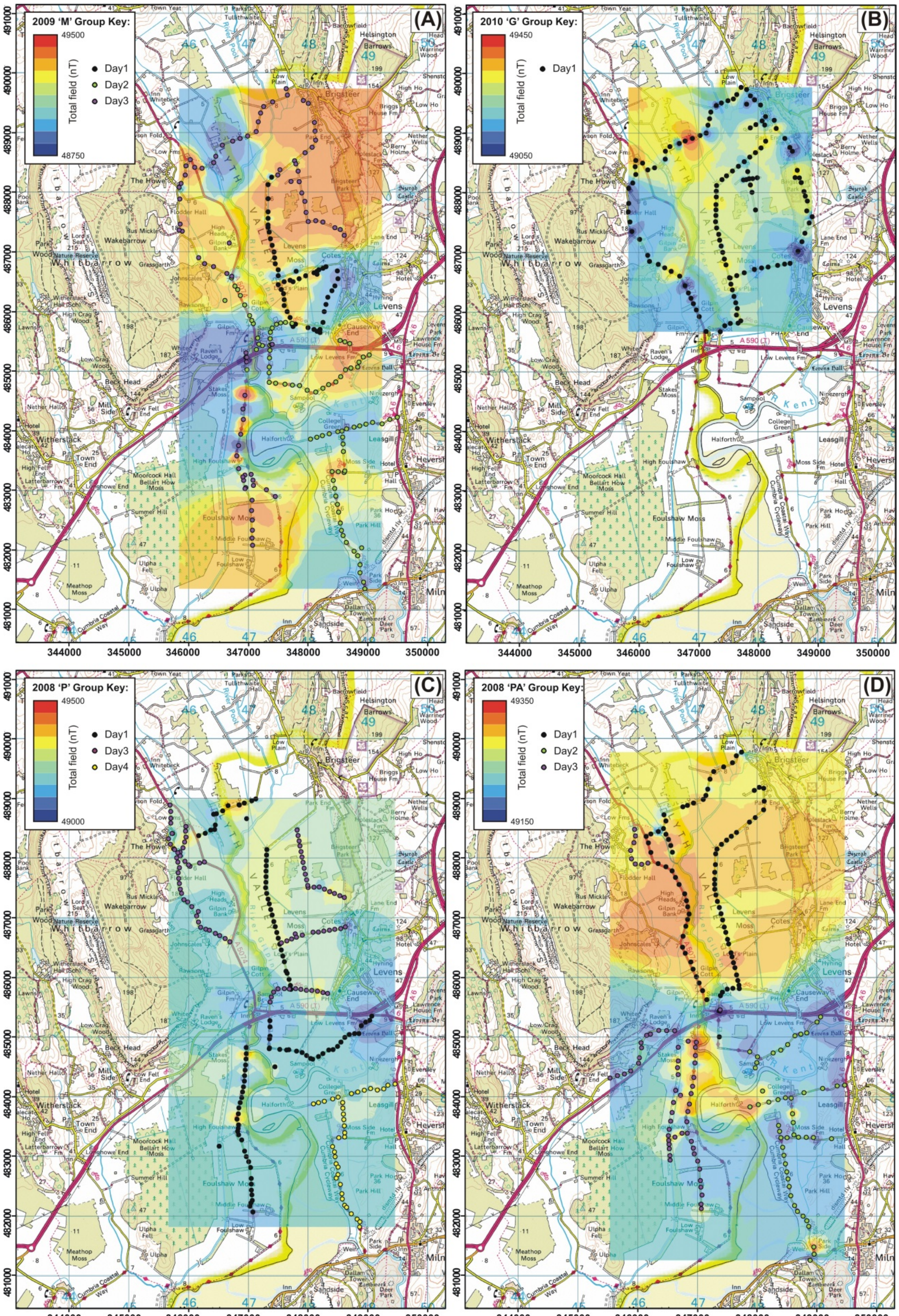


FIGURE 7. Total field processed magnetic data sampling positions (different days shown as coloured dots) and resulting contoured surfaces for selected 2008-2010 companies (see key). A relative high in the north was observed with isolated highs in the south near Halforth, and a low beneath the A5097 bisecting road suggested shallow bedrock. Basemaps are © Crown Copyright/database right 2007. An Ordnance Survey/(Datacentre) supplied service.

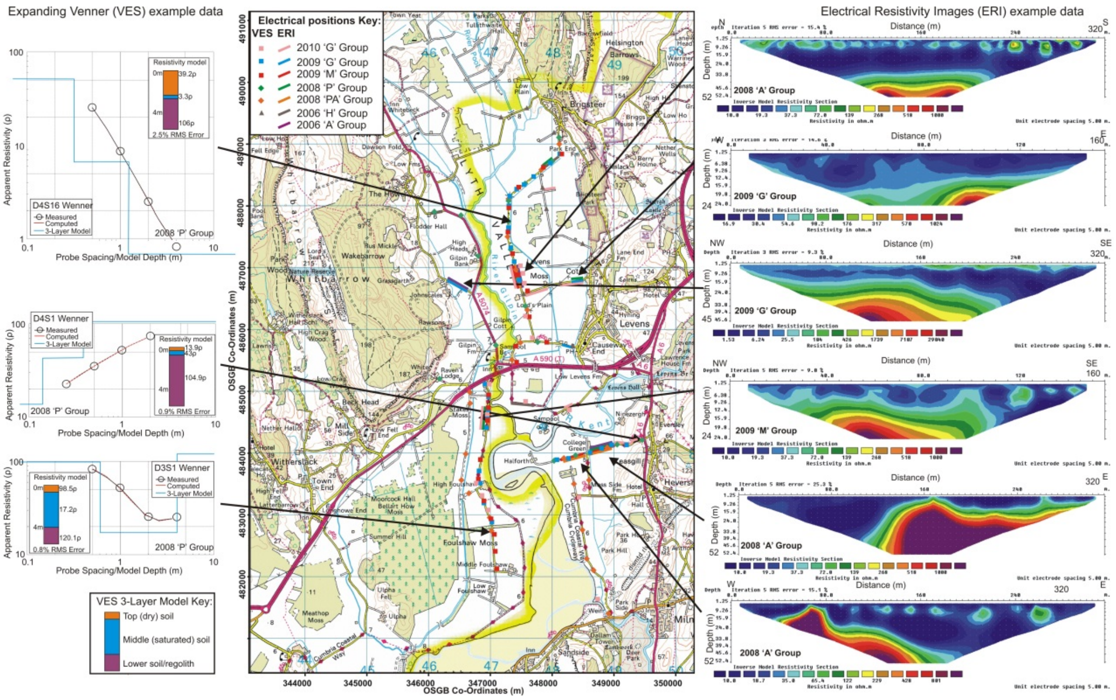


FIGURE 8. Resistivity selected processed VES and ERI data and full data location map for 2006-2010 companies (see key). VES data models showed some saline intrusion in south for some cohorts, probably due to tide and / or soil saturation variations. ERI 2D profiles showed varying bedrock depths bgl throughout the valley, suggesting preferential pathways for southward-moving glaciers.

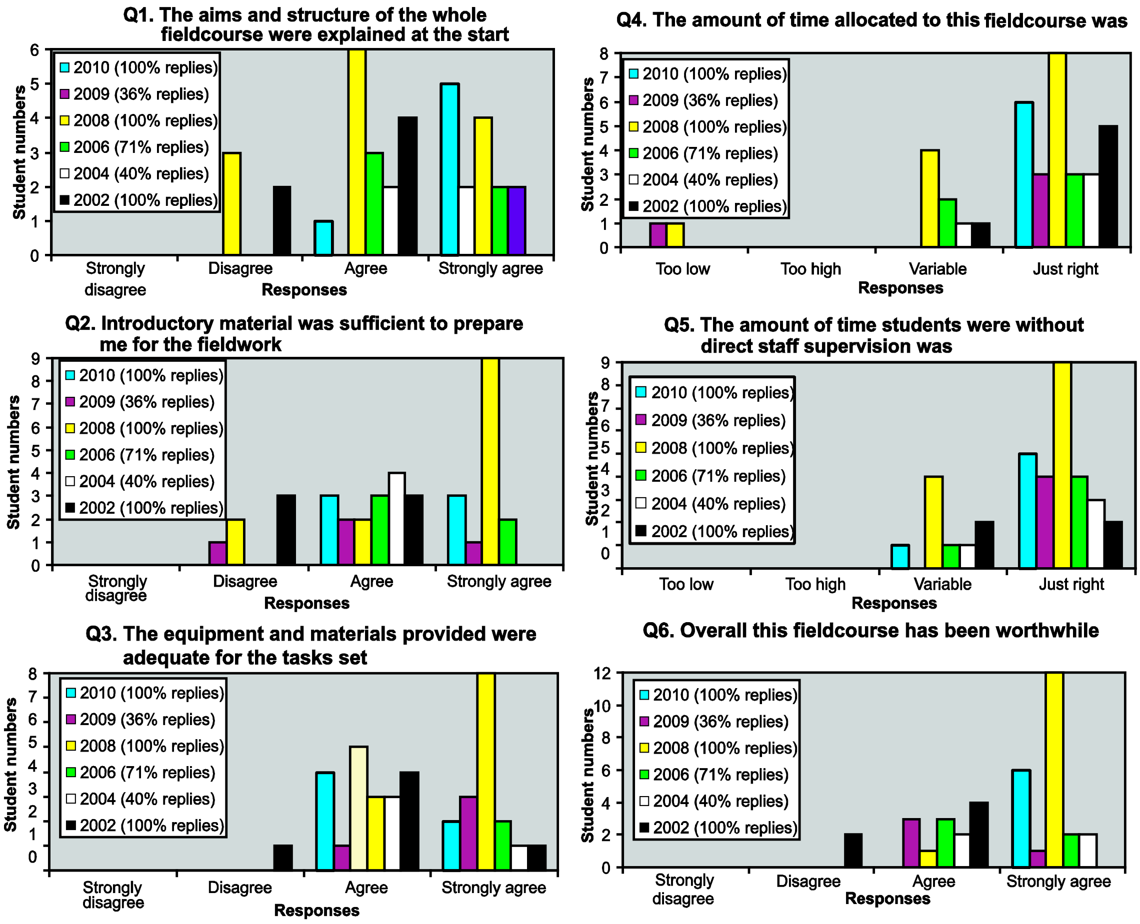


FIGURE 9. 2002-2010 bar graph summaries of selected questions from end-residential field course evaluation questionnaires (see key and text).

Table Captions:

Project Outline:
The client (Manx Gas) proposes to construct a main gas pipeline from Morecambe Bay to Leeds. The pipeline must cross the glaciated Gilpin Valley. Some site background is given in the accompanying notes. A route has been proposed but the Lakeland County Council requires further information regarding bedrock and drift depth and constitution before approving the route. Before approving the contract for a near-surface geophysical site investigation of the full pipeline route, those tendering for the contract are requested to participate in a quality-verification project study. Each participating group will have a maximum budget of £5,000 (or equivalent) to offset pre-field exercise desk study datasets, available field equipment hire and repair (if necessary), consultant advice and transport/accommodation. Read the accompanying safety information carefully. You will also be asked to account for costs.
Project Aims & Objectives:
1 Undertake a study site desk study pre field exercise. There will be opportunity to buy some data from a previous geophysical contractor, although this may be of dubious quality. You are encouraged to find study site information from other sources. 2 Participating companies should design and execute a reconnaissance geophysical survey from 'dates' to determine the suitability of the proposed route across the Gilpin Valley and, if necessary, suggest a better alternative. 3 You must submit a daily plan of work for logistical purposes. 4 Bedrock depth below ground level and drift thickness must be determined in order to optimise pipeline position. Information on the geo-technical characteristics of both the bedrock and drift must be provided. There may be the presence of saline water which would require the use of expensive sulphate-resistant cement. Information on pore-water salinity is therefore required. 5 Finally you will give a short presentation of your company's findings and recommendations and a justification of the incurred costs to the Clients. The winning company will then be awarded the full contract.
Additional Notes:
(i) *You cannot automatically assume permission is available for farmland access.* (ii) *Tides may control your access to certain areas. You will therefore need to obtain tide tables in order to plan your fieldwork.* (iii) *A list of available near-surface geophysical equipment (with hire rates) is provided in the accompanying notes.* (iv) *Accommodation will be provided by Manx Gas.* (v) *The ability for companies to work efficiently as a team is viewed as a high priority.*

TABLE 1. Information provided to the student companies before the residential field exercise is undertaken.

	Daily Rates (£)	Availability
Hardware		
Worden Gravimeter	50	2
Scintrex™ CG-5 Micro-gravimeter	200	1
Proton Precession Magnetometer	50	3
GSMP-40™ Potassium vapour gradiometer (& accessories)	100	1
Megger™ VES Resistivity equipment	50	1
Campus™ TIGRE ERI Resistivity equipment	175	1
GPS hand-held receivers	15	6
Leica™ 1200 RTK dGPS system	150	1
Distance measuring wheel	10	2
Software		
Laptop PC & Microsoft™ Office	100	2
In-house gravity processing (reduction)	50	2
Grav2D (modelling)	25	2
Geotomo™ Res2DINV (inversion)	50	1
Ipi2win (VES processing)	50	2
Geotomo™ Res2DMOD (modelling)	50	1
Mag2D (modelling)	25	2
ArcGIS™ suite (visualisation)	100	2
Golden™ Surfer (visualisation)	50	2
The Mathworks™ Matlab	100	2
Personnel Rates		
Consultant geophysicist	500	3
Electronics Engineer	300	1
Sundries		
Commissioning/ Decommissioning (inc. travel)	250	N/A
Accommodation & subsistence	At client cost	N/A

TABLE 2. List of available student near-surface geophysical equipment, software, sundries and hire rates (see text).

Groups	Student numbers in team	Company Marks (%)	Overall Questionnaire score (100 = max)	Day1				Day2				Day3				Day4			
				Grav-ity pts.	Mag-netic pts.	VES pts.	ERI (El. no.)	Grav-ity pts.	Mag-netic pts.	VES pts.	ERI (El. no.)	Grav-ity pts.	Mag-netic pts.	VES pts.	ERI (El. no.)	Grav-ity pts.	Mag-netic pts.	VES pts.	ERI (El. no.)
2010 'G' Group	6	78	98.5	29			64	55	138	6	128	15		2	96	30		8	96
2009 'M' Group	6	75	92.7	17	51		128	33	83		128	44	83	13		41	0	10	
2009 'G' Group	6	72	92.7	10	83	13		25	46	13		28	55		64	40	23		64
2008 'P' Group	6	73	99.2	10	102	10		60	0	8		39	90		98	31	37		98
2008 'PA' Group	7	75	99.2	5	86		128	24	52		128	69	64	17		0	64	6	
2006 'H' Group	5	73	89.0	0	33	7		26	93	6		27	98		64				64
2002 'M' Group	6	72	74.0	5	24			12	28	4		13	50						
Averages	6.0	74.0	92.2	10.9	63.2	10.0	107	33.6	62.9	7.4	128	33.6	73.3	10.7	80.5	28.4	31.0	8.0	81

TABLE 3. Summary statistics of 2002-2010 student companies, marks and geophysical data acquired. Note only gravity data was available from the 2004 group so is not included and the ERI equipment was not available for 2002 groups. There was also only one 2010 company who had access to all equipment.

POSITIVE ASPECTS of Field Course:	NEGATIVE ASPECTS of Field Course:
• Supporting staff (8) • ‘Real-world’ exercise (5) • Pre-fieldwork sessions on equipment & software (3) • Student-led (2) • Professional environment (2) • Improved employability skills (2) • Client presentation experience (2) • Practical experience of geophysical equipment (2) • Assistance with data interpretation (1)	• Lack of help in field (3) • Clarity of equipment hire costs (3) • Lack of geophysics knowledge (2) • Staying up to 1 am working (1) • Fieldtrip costs (1)

SUGGESTED IMPROVEMENTS:

- More geophysical background theory beforehand (3)
- A night off (2)

OTHER COMMENTS:

- ‘Professional exercise but staff kept atmosphere friendly & fun’, 2010 student.
- ‘Demonstrators useful in evenings for data advice’, 2010 student.
- ‘‘Amount of preliminary work required about right for trip and timing in relation to exams/dissertation’, 2009 student.
- Well planned & supported fieldtrip’, 2008 student.
- ‘Really increased knowledge of geophysics’, 2008 student.
- ‘Real-world style assessment is very helpful, especially in the 4th year’, 2008 student.

TABLE 4. Summary of 2008-10 student questionnaire course evaluation comments.