Development of an Engineering Geology field trip for Civil Engineering students

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Abstract

This paper describes and discusses the various elements of a one-week Engineering Geology field trip that has been developed for second-year undergraduate students studying Civil Engineering at Imperial College London. It is an essential component of the education of civil engineers and, as such, is a requirement of the accreditation defined by the Institution of Civil Engineers Joint Board of Moderators (ICE JBM). The trip is structured to develop the students' awareness of geological features and their ability to record and sketch key observations in the field. Having described the geological features, the students are prompted to think about consequent potential engineering hazards relating to them and also the influence of human activity, past and present, on the ground and environment. During the course of the week the students develop their observational and logging skills, with constant staff feedback both outdoors and during summary student presentation sessions in the evenings. A marked progressive improvement has been noted as a consequence of this approach. On the final day of the week the students have to map a coastal section, observing and recording the stratigraphy and significant features such as bedding, discontinuities and faulting, with the latter quantified by measuring quantities such as dip, strike and plunge, as appropriate. The students' work, assessed as part of the field trip, is completed by them and handed in just before final departure at the end of the week, most of it being completed in the field.

This paper, in the form of a photographic feature, describes a field trip that forms the key component in the teaching of Geology and Engineering Geology to undergraduate students of Civil Engineering at Imperial College London. The field trip has been developed over the past decade and the intention of this paper is to share both the experience gained during this time and also photographs of some of the spectacular geology and the work of some of the students. It is the first publication of its kind in QJEGH for 45 years since the papers by Cawsey & Francis (1970) and Dearman & Fookes (1974).

The purpose of the five-day field course is to introduce undergraduate Civil Engineering students to the importance and purpose of site investigation, by virtue of a walkover survey. Critical to this is developing the ability of students to identify hazards and to use their geological observations and insights to make predictive judgements about short- and long-term risks to various engineering scenarios. Those observations start with a classroom desk study using geological maps and borehole data, and continue in the field with sketches ranging from large-scale geomorphology to small-scale sedimentary processes and structural fabric. Supporting measurements include structural orientations of bedding and joints, rock strength data from Schmidt hammer tests, assessments of the soil profile and associated parameters, and identification of past human activity.

Given the large size of university classes in recent years and the pressure on student finances, the availability of suitable accommodation proved the critical factor in locating the trip, which is consequently based at Butlins in Minehead. Butlins proved to be affordable and the staff there are very helpful hosts, accommodating our need for an early breakfast by allowing us to use their staff canteen, and permitting us to stay during some of their special weeks. We hold our evening presentations at the Minehead Social Club, where we make use of their excellent function room and also enjoy their affordable fine ales.

The field trip course is designed to be self-contained, based entirely on student observations and staff guidance, with all data recorded in individual notebooks and a mapping exercise on the final day. Both are assessed at the end of the trip so that there are no post-trip reports to write. The week is structured to take students from the large scale to the small, and from the past to the present. Minehead provides access to a wide variety of sites within one or two hours by coach, each of which is tailored for a particular learning outcome. The first, Burrington Combe, makes an ideal stop just over half-way to Minehead on day 1, and illustrates the large-scale context and deep geological structure. These are evident in rather different materials 80 km to the SW at Woolacombe (day 2), where students see how rocks transform into soils and the far-reaching impact of the Ice Ages. The impact of human activity is everywhere at Meldon (day 3), from the obvious dam, reservoir and quarries to the subtle effects of undocumented early industrial mining. The final two days focus strongly on mapping and sketching, first around the coastal cliffs at Minehead (day 4) and then at Portishead, on the route back to London, where the geological maps produced form a key part of the assessment (day 5). Throughout the week, the purpose is to show how careful observations lead to useful, predictive insights, from which a ground model may be developed. Hence, after an early dinner at Butlins, each day's observations are reinforced with evening presentations by preassigned student groups and a final summary of the day using 3D computer models that put all the data collected into context.

Health and safety and field equipment

Identifying hazards and assessing risk underlies the entire trip. In terms of health and safety, we advocate a continuous risk assessment approach to field safety. Although there are some essential requirements, particularly PPE (personal protective equipment), students are encouraged to assess continually the conditions around them, paying particular attention to others and to be self-enforcing. Woe betide a lecturer caught without a hard hat! This culture starts in the class: students quickly learn that their own health and safety starts with themselves, ensuring that they have sufficient food and water, and sleep the night before, as well as proper warm, waterproof clothing. The greatest hazard is a cold, tired, thirsty student whose brain no longer functions properly. Again, students are taught to identify these signs in each other and to help each other, before serious problems occur. However, working in a natural environment does carry particular risks unfamiliar to the urban student, and these are identified by the student group, with guidance from the staff, at the start of each site visit. Students are also reassured that there are no penalties for avoiding difficult terrain: if they don't feel confident, they don't do it.

A risk assessment is completed in class before the trip, where students discuss the hazards they might encounter, such as stones dislodged by ‘killer’ goats on the cliffs at Burrington Combe (humour raises awareness and aids memory), and the appropriate mitigations, such as wearing hard hats. No working sites are visited, so steel toe-caps are not needed, but ankle-supporting stout boots are essential, alongside a hard hat and reflective jacket (Fig. 1), as much for the benefit of staff locating students as it is for visibility on roads. All staff are fully qualified in first aid in the field and carry appropriate packs, but as airlines know well, repetition is the key to ingraining good practice and avoiding any significant incidents. Good behaviour is reinforced by reminding students that they are young professionals and treating them as such: a beer after the evening presentations is perfectly acceptable; drunken behaviour is not.

Fig. 1. (**a**) Group of students sketching in the field at Blue Anchor with appropriate and clearly visible PPE; (**b**) the geological feature being sketched (reverse fault through red Mercia Mudstone and grey Lias Clay).

Observing and recording the geology

The key to a worthwhile walkover survey is knowing what to look for and recording it. The purpose and structure of the field course is to guide students to make useful observations; the assessment is based for the most part on how well they record these observations. To help them, in preparatory classroom tutorials, students are given a basic introduction to field techniques, complete a desk study for the areas visited, and practise sketching. Key field measurements include dip and azimuth of bedding and principal joints, rock strengths (using a Schmidt hammer) and descriptions, and soil descriptions and a hand-auger log. Together with notes and sketches, these measurements are recorded in recently redesigned RSM (Royal School of Mines) notebooks, which include margins, alternating plain and feint-gridded paper, and a wide range of guidance notes at the rear, including soil and rock descriptions, making them an invaluable aid in the field. In this photographic feature several examples are included of sketches and observations from some of the best students' notebooks.

Assessing engineering aspects concerning the geology

An important point always relayed to the students is that their observations are factual and should be reasonably consistent between them whereas interpretations concerning the formation of the geology and any associated engineering risks may differ from one person to another. Thus accurate and representative factual observations are crucial.

Having recorded what has been observed, the next step is to think about interpreting these observations in relation to engineering scenarios. When doing this, often a different mindset is needed so as to use the recorded information to conceptualize potential engineering hazards. The students are constantly encouraged to think about how the various features they have observed might influence engineering design and construction; for example, the orientation of a system of joints has a profound effect on the stability of cuttings or tunnels. Gaining an understanding of the soil or rock mass strength is vital and can only be fully assessed by field observations; laboratory test results from a limited number of samples could be very misleading in the absence of the overall picture. The main intention is that the students think about the risks and hazards posed by what they see without dwelling extensively on the origin of the materials and features they observe.

Each evening the students are aided in this process through group presentations in which the selected students recap the day using hand-drawn posters and sometimes highly creative drama. These are followed by a short lecture using geological models (Fig. 2) to show the three-dimensional relationships between the observations and measurements made, to ensure that students understand their context and can identify hazards or other issues.

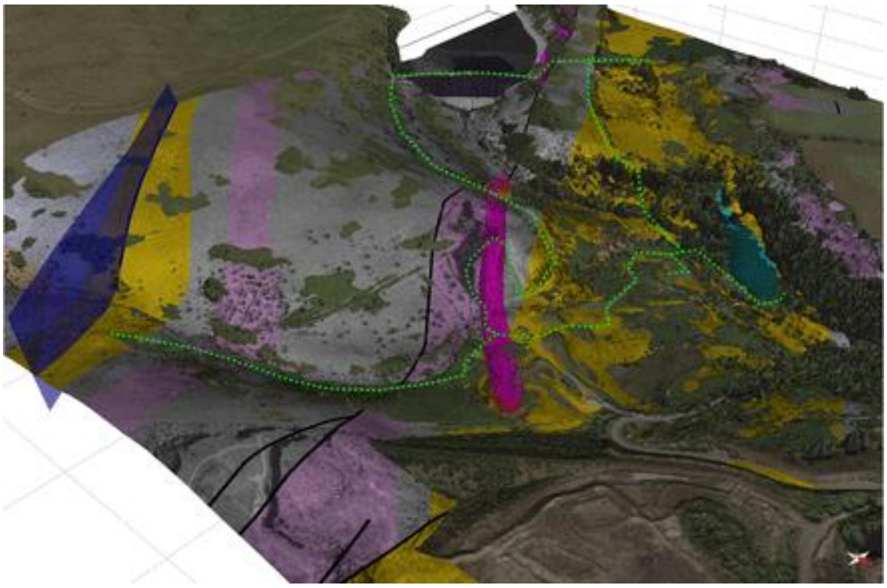

Fig. 2. Geological model of the Meldon area, showing the cooling joints (blue) that were exploited by tin and copper miners, oriented parallel to the aplite intrusion (purple). The route followed by the students is shown in green (starting close to the dam near the top centre of the image). Other geological units shown are: the Meldon Shale (pink) and Quartzite (grey) Formation; Teign Chert (yellow) and Limestone (cyan) Formation.

Localities visited

Five localities are visited during the trip: Burrington Combe on Monday, approximately midway on the journey to Minehead; Woolacombe on Tuesday; Meldon on Wednesday, Minehead on Thursday. The students complete their individual maps on Friday at Portishead, again about halfway back to London. These sites are chosen so that students start with the large-scale geological framework, and the oldest rocks, and progress through Quaternary processes to historical human activity. They are guided through a walkover survey at Minehead, completing a practice map, in preparation for their assessed map at Portishead. An overview of each of these visits is given below. Over the years that the field trip has run in this form (since 2010) there have been some changes in the sites visited. In earlier years visits were made to Charmouth, Blue Anchor (to see the spectacular reverse fault clearly visible with the red Mercia Mudstone beds on one side contrasting with the grey Lias on the other; Fig. 1b) and Aust Cliff to see the first and second Severn crossings. The locations described below form the current itinerary.

Burrington Coombe and Cheddar Gorge

A century-old disused limestone quarry is an ideal starting point for the trip: exposure is excellent, the application to engineering obvious, and there are significant site hazards to consider (Fig. 3a). The focus is on understanding the purpose and content of a walkover survey. In addition to identifying hazards, students are shown how to draw annotated sketches, record bedding and joint orientations using a compass and clinometer and measure their effects on rock strength with a Schmidt hammer, and understand the kinematic relationships that lead to rock slope failure (Fig. 3b and c). From Burrington the coach passes over the hinge of the anticline at Charterhouse, where students can see 'gruffy ground', created by former mine workings from Roman times until the early part of the twentieth century, exploiting mineralization in tensile joints parallel to the fold axis (Fig. 4). The Old Red Sandstone inlier is clearly demarked by gorse and pine, with the southern limb of limestone pockmarked with sinkholes. The gentle dip of the beds contrasts with the northern limb and creates an asymmetry to the spectacular cliffs of Cheddar Gorge. Finally, water resurfaces below the limestone, emerging from Gough's Cave in a dramatic illustration of the hazards posed by karst.

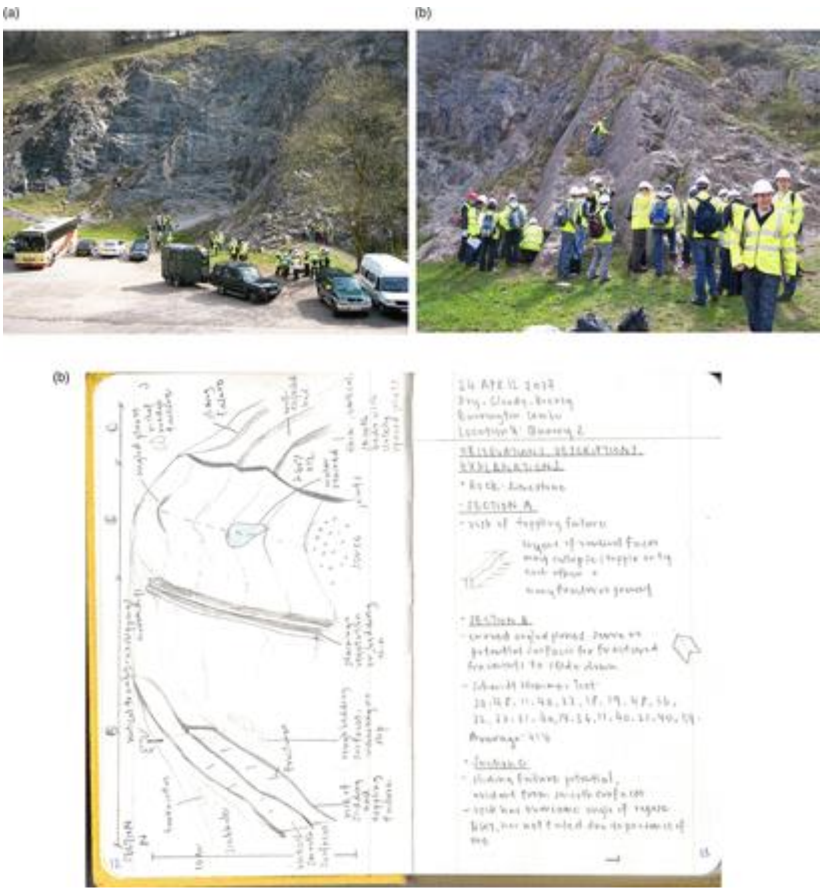

Fig. 3. Burrington Coombe: (**a**) view of quarry face; (**b**) accompanying sketch and notes (courtesy of A. Law); (**c**) first field measurements of dip and dip direction.

Fig. 4. 'Gruffy ground' at Charterhouse: general view of area of former bell-pit mine works.

Woolacombe

The Minehead trip is marked by long but beautiful coach journeys, the first over Exmoor to Woolacombe, a usually warm and sunny expanse of sandy beach popular with surfers and dog-walkers. We start above the beach with a hand-auger assessment of the soils on a gentle slope up to the rounded sandstone hills. Over the years, we have been able to reach depths from as little as 30 cm to more than 1 m. The soils, predominantly sands, are described and discussed in detail from an engineering perspective and a borehole log is compiled. Most of the day is in fact spent investigating the sand. The next stop is to view and sketch the ancient sand dunes (Fig. 5) and here and on the beach it is explained that the sand is composed of fine, rounded grains of Dartmoor granite and local Old Red Sandstone originating not from the beach but from inland, brought on prevailing Ice Age northeasterlies, which swept dunes far out across the Bristol Channel, exposed by lowered sea-level. Great fun is had in a competition involving student groups testing sandcastles to destruction (Fig. 6), following which the theory and elements controlling the sand strength are described and debated. Later on the beach, students discover that the soil encountered in the hand-auger borehole overlies vertically dipping and deeply incised thin beds of shale (Fig. 7), folded in the same orientation as the Cheddar anticline, but here closer to the core of the ancient Variscan mountain range. The day ends with an explanation of the morphology and history of the area and sketching of the landforms surrounding the bay (Fig. 8).

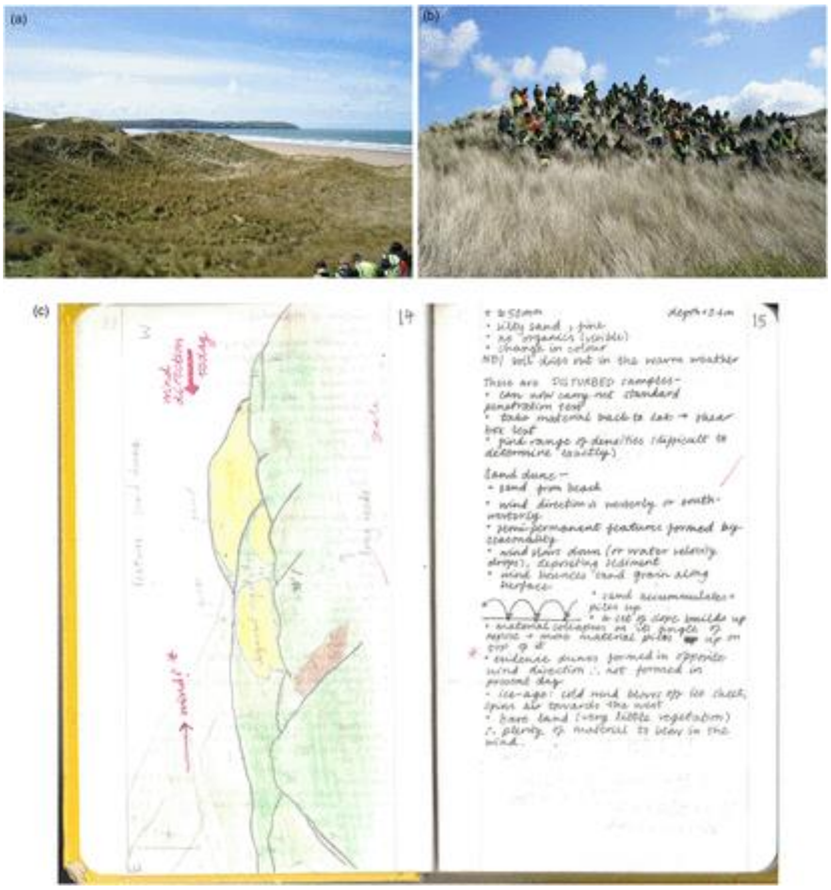

Fig. 5. Ancient sand dunes at Woolacombe: (**a**) photograph of dunes; (**b**) students sketching them; (**c**) accompanying sketch of dunes (courtesy of A. Jackson).

Fig. 6. Woolacombe bay sand castle competition: (**a**) testing the sand castles; (**b**) explaining the theory behind what was observed; (**c**) sketches and accompanying notes relating to the test (courtesy of A. Jackson).

Fig. 7. Woolacombe bay: (**a**) discussing the shale beds (dipping almost vertically with major joint sets); (**b**) students taking measurements.

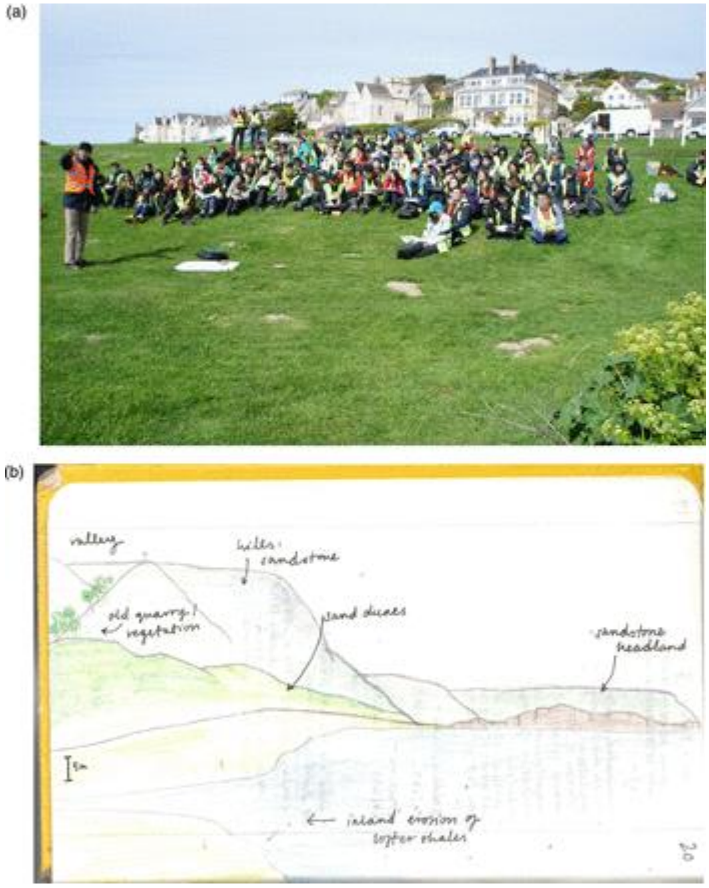

Fig. 8. Woolacombe: (**a**) students sitting on upper level of Fig. 5a, sketching view across bay (see background horizon of Fig. 4a); (**b**) sketch of view (courtesy of A. Jackson).

Meldon

At Meldon Dam (Fig. 9), students think about the following aspects: (1) its purpose (drinking water storage), with consideration of the balance between storage supply, flood protection and river compensation (maintaining natural river flow downstream); (2) location (geology and geography; drought periods control drinking water supply, so catchment location is determined by that demand); (3) design (concrete arch, mainly owing to local resources with insufficient soils for an earth dam but readily available supplies of limestone and aggregate for concrete production); (4) construction, relating the geology to the engineering from both analytical and practical perspectives.

Fig. 9. Meldon dam and reservoir: (**a**) students on crest learning about geology, background and engineering aspects; (**b**) downstream view of dam.

Moving on to a disused aplite quarry (Fig. 10), the observational skills of students are tested to their limits to identify the interfingering nature of the aplite intrusion into the shales (mudstones), metamorphosed by the great body of the Dartmoor granite into hornfels, and to decide which of the many fracture planes might be bedding, and what other joints may be observed (e.g. clearly visible circumferential contraction joints running around the granite batholith).

Fig. 10. Former aplite quarry at Meldon: (**a**) students reconnoitring the quarry, sketching and measuring dip angles and direction of bedding and joints; (**b**) receiving explanation of geology and what they observed.

The cooling joints observed in the aplite quarry controlled the movement of hot, mineral-rich waters that deposited copper and tin, of great value to early industrial revolution-era miners. Much unmapped industrial archaeology remains, providing an ideal opportunity for a walkover survey to assess the influence of the Anthropocene epoch. However, lecturers beware! During many of the earlier field trips, the first author stood at the bottom of the now-collapsed bowl around the Red-a-ven mine main shaft, pointing out the potential risks of doing so, but never really expecting it to one day fail. The students draw a sketch map of the area (Fig. 11), marking features and artefacts they can identify (with the help of an illustrative sketch provided in their field trip handout booklets), and discuss potential risks (stability, contamination).

Fig. 11. Meldon mine workings: (**a**) sketch of remains of former mine and ancillary works with accompanying notes (courtesy of H. Slack); (**b**) students receiving briefing about history of site.

Quarrying of one form or another continued in Meldon until 2001, when the British Rail quarry was mothballed, finally closing in 2012. A relatively small outcrop of limestone (actually a displaced reef fragment) lies within the hornfels, and was worked in the early 19th century for lime fertilizer and more recently for the concrete of Meldon Dam. This quarry is now flooded but evidence of overlying hornfels bedding is clearly visible (Fig. 12). The hornfels overburden was disposed of on ground across a small nearby river; how this was achieved is another mystery for students to solve.

Fig. 12. Former limestone quarry at Meldon.

Minehead

Burrington, Woolacombe and Meldon provide students with the background necessary for their site investigation, taking them from the large scale to the small, from deep geological forces to surface processes, and from the distant past to yesteryear. At Minehead, on their penultimate day, they are walked through a site survey, applying all that they have learned to understanding the ground conditions on a coastal transect that just happens to pass through all of those times and events. During the walk to the start of the transect, various features are pointed out and discussed, including the engineering of the sea defences constructed to protect the town in recent years, the town refuse tip (now disused and covered with topsoil and vegetation) and tree-induced slides on the steep wooded slopes at West Quay. Students are given a brief revision session about how to record data on a map as well as in their notebooks, to provide detailed knowledge of the ground across the site. As the students walk around the headland, they appreciate the cobble and boulder foreshore deposits, the difficulty in walking and the benefit of their boots with ankle protection. They pass obliquely through the processes of orogenic folding and orthogonal extensional collapse faulting evident in the Old Red Sandstone of Culver Cliff (Fig. 13), discover spectacular S-, M- and Z-folding (Fig. 14), and end the day realizing the importance of the Ice Age in generating steep, unstable colluvial slopes and how these are modified by pedogenesis (Fig. 15).

Fig. 13. Minehead coast: (**a**) observing faulting; (**b**) dipping folded strata; (**c**) measuring dip and dip direction.

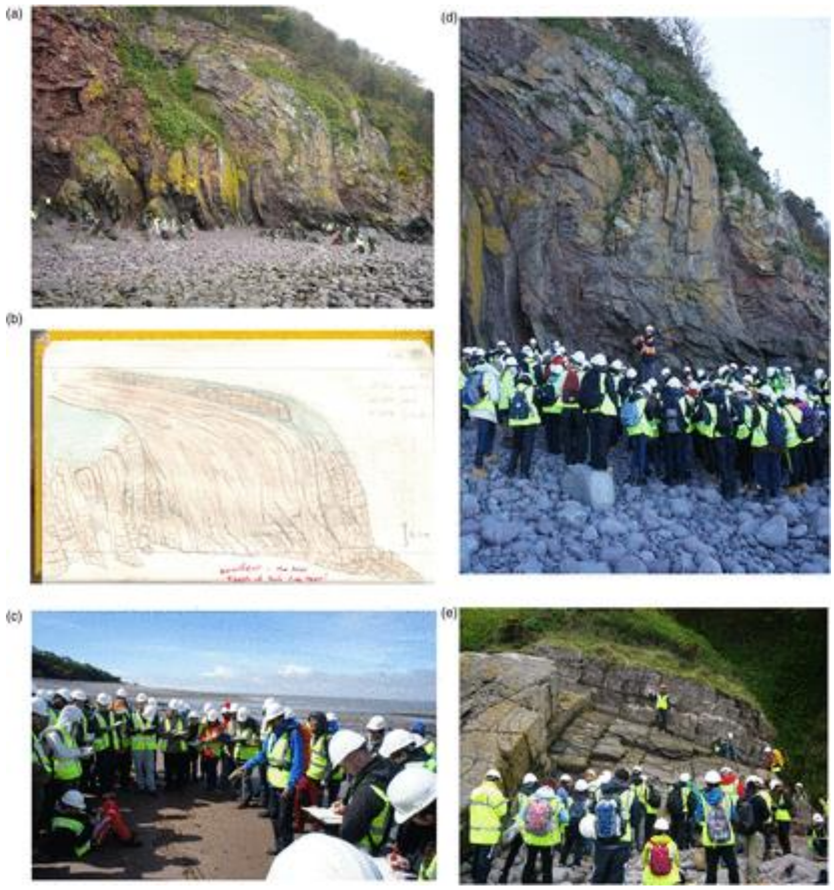

Fig. 14. Minehead coast: (**a**) spectacular S-fold in sandstone cliffs; (**b**) sketch of S-fold feature (courtesy of A. Jackson); (**c**) explaining origin of S- and Z-fold features; (**d**) discussing engineering risks involved with such features; (**e**) detailed appraisal of smaller scale S-fold feature further along coast.

Fig. 15. Ancient soil horizon (colluvium at base of slope) at Minehead: (**a**) students sketching salient features; (**b**) example of sketch and accompanying notes (courtesy of H. Slack).

Portishead

Armed with everything they have learned and practised, we stop at Portishead on our return to London for a final assessed site survey along this classic coastal section (Fig. 16). The exercise starts with a briefing and description of the geology present at the site, which is extended as the day progresses and different formations are encountered (Lower and Upper Old Red Sandstone, Woodhill Bay Conglomerate and finally Woodhill Bay fish beds). Students work in pairs taking measurements of dip and dip direction, sketching and transcribing their measurements and observations to their maps. Time management is important as there is a strict deadline to meet, especially if the tide times are not favourable. Collecting maps and notebooks at the end of the section provides us with a true record of the students' observations and interpretations.

Fig. 16. Portishead on final day: (**a**) briefing at the start of the mapping exercise; Lower Old Red Sandstone (note the second Severn Bridge in background); (**b**) further explanation of geology in vicinity of Woodhill Bay Conglomerate exposure; (**c**) end of exercise where Woodhill Bay fish beds are distinctly visible.

Conclusions

At the start of the week very few of the students have much appreciation of making field geology and engineering field observations or taking field measurements. By the end of it they have a much wider in-depth understanding of Geology and its implications for and application to Civil Engineering, gained through their detailed field observations and measurement and continuous staff explanations and discussion throughout the course of the week. They have certainly learned to 'get their eye in'. They also have a much better appreciation of the use of materials for Civil Engineering purposes (e.g. aplite for railway ballast; limestone for cement manufacture) and equally the potential hazards associated with the interventions such as former mine workings. We are always amazed and delighted by the ability and enthusiasm of our Civil Engineering students after just 5 days in the field (Fig. 17), and hope that wherever their careers take them, they always recognize the importance of the ground and fondly remember their remarkable achievement in understanding it.

Fig. 17. Final visit en route home: (**a**) observations at Aust cliff; (**b**) group photograph of happy students with first Severn Bridge in background.

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