Observe, Record, Interpret: some examples of teaching sedimentology by distance learning including virtual graphic logs

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ABSTRACT

In light of the COVID-19 pandemic, distance learning resources have become urgent. This paper provides distance learning examples that keep the sedimentary field class mantra 'Observe, Record, Interpret' at the forefront of the curriculum. These examples are intended to be a resource to other sedimentary geology educators. The approach taken here is based upon learning observation skills and recording sedimentary rocks with a progression from sedimentary lithologies, and basic properties like grain size, through sedimentary structures to graphic logs and facies analysis through experiential learning. Learning objectives for the module include synthesis of geologic data, integration with core concepts in geosciences, and development of coherent scientific interpretation of data. Outcrop photographs from the Cretaceous Woburn Sands that are used as part of a distance learning module in Sedimentology provide an opportunity for students to practice drawing a graphic log without having to venture into the field, effectively bringing the field into the classroom. Drawing a graphic log encourages observation and enables recording of sedimentary rocks in preparation for interpretation and facies analysis. This distance learning module has the added advantage of providing a mechanism to teach more inclusively to students with disabilities that prevent them from participating in traditional field experiences, thus promoting diversity and inclusion in geoscience.

INTRODUCTION

These three words: **observe, record, interpret,** are like a mantra for field work. Making good observations, recording those observations, and subsequently interpreting what has been observed and recorded are key steps in geoscience and are essential for field work. Becoming a trained observer is not easy, but it is a key learned skill; observational skills are at the heart of almost all geological data collection in the field. These skills generally start in the lab, for example, recording minerals in thin-section down a microscope, or drawing annotated diagrams of fossil specimens, see Genge (2020) for examples. There is less opportunity to work on the outcrop scale in the lab, and relevant skills such as making field sketches and mapping, are learned in field camp. This year, the coronavirus COVID-19 pandemic and resulting lock-down and social distancing has had a major impact on geoscience teaching with the cancellation of field camps and field classes around the world. To try and compensate for the loss of field training there has been an accelerated interest in virtual field classes including virtual outcrop geology (e.g https://www.see.leeds.ac.uk/virtual-landscapes/) as well as the use of 3-D models of outcrops (e.g. https://v3geo.com/) based largely on outcrop data from academic and industry collaboration http://www.virtualoutcrop.com/; in addition, there are teaching and learning resources available online through the newly created Seds Online teaching library https://sedsonline.com/sedimentology-teaching-library/ as well as the more established Teach the Earth https://serc.carleton.edu/teachearth/teach_geo_online/index.html.

In this article I would like to give some examples that are used to teach sedimentology by distance learning, as well as face-to-face. The virtual graphic logs were originally created years ago to bring the outcrop into the classroom. They are intended to introduce the concept of logging through experiential learning. The virtual graphic logs are not intended to fully replace field work but to supplement it. With the use of virtual graphic logs, students can make the most of their valuable field time because they have learned how to create a graphic log in the class and know what a graphic log is expected to look like. Learning how graphic logs are created will also aid students to analyze and interpret logs in textbooks and academic publications.

The virtual graphic logs were not intended to replace field work, but used only in exceptional circumstances. This year we find ourselves in just such exceptional circumstances due to the COVID-19 pandemic. This distance learning module can also be valuable towards creating a more inclusive learning environment to encourage a diverse student body, including those with

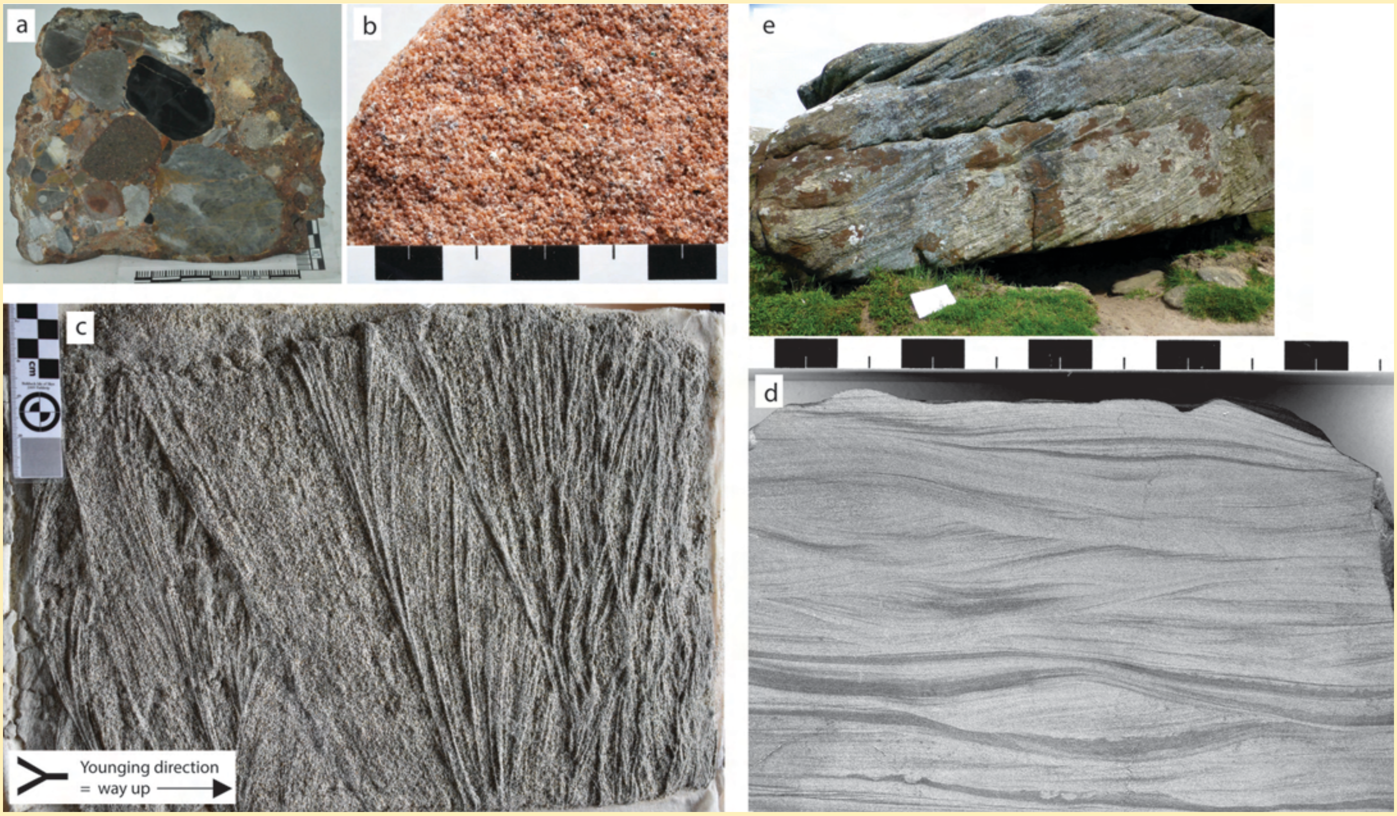

Figure 1: A) Example hand specimen photo of a cut surface of a polymict conglomerate, scale in mm and cm. B) Example photograph of a well-sorted aeolian sandstone, scale in cm. C) Example photograph of a sediment peel from a bar top in the Brahmaputra River, Bangladesh, scale in cm. D) Example photograph of a cut surface of a Carboniferous sandstone in black and white. Grey tones indicate grain size with pale fine grained sand and darker silt and clay sized particles. E) Outcrop photograph of a Carboniferous sandstone at Brimham Rocks in northern England. Note the bedding planes and sets of cross-strata. For scale, the white page is A4 about 30 cm by 21 cm.

disabilities that prevent participation in traditional field experiences.

This paper includes an example of a virtual graphic log from the Cretaceous (Aptian-Albian) Woburn Sands that are exposed in sand pits in England. This is set within the context of Sedimentology classes that have been developed for distance learning and includes some notes on how the virtual log might be used by geoscience teachers.

LITHOLOGY AND SEDIMENTARY STRUCTURES FROM PHOTO INTERPRETATION

For practical classes (labs), we start with polished slabs of rock and close up photographs of rock specimens such as the conglomerate, sandstones and limestones shown in figures 1a and 1b. Students are asked to make a sketch of the rock and describe the texture of the rock including: grain size, sorting, roundness, sphericity, and answer simple questions; “is it grain supported? Or matrix supported?” Following hand specimen descriptions we move to sedimentary structures using photographs of sediment peels, rock outcrops (Figures 1c and 1e). Again, sketching is a key part of the instructions: “Make a sketch of the sedimentary structures in the following photographs. Identify the different sedimentary structures that you can see in each photograph. Use your observations of the sedimentary structures to identify the ‘way-up’ for each picture. What is the ‘apparent’ palaeocurrent direction for each photograph?” We use the term ‘apparent dip’ and ‘apparent’ palaeocurrent direction because the sedimentary structures in the peels are only shown in 2-D. In order to measure the true dip direction you would need a 3-D outcrop.

The sediment peels (Fig. 1c) were collected from a sand bar in the Brahmaputra River in Bangladesh. The peels are made by digging a trench in a sand bar and cleaning the face to get a smooth surface. The surface is sprayed with resin. Sometimes the spray is not even, and this can give a blotchy or warty appearance to the sediment. It should be ignored because it is a feature of the spray and not a primary sedimentary structure. The resin causes the sand grains to stick together and highlights the lamination as it penetrates the sand. A layer of muslin is then pinned to the sand, with more resin sprayed to adhere the muslin to the sand. Finally a sheet of plywood is attached to the muslin and the peel is removed taking a thin layer of sand grains with it, preserving and highlighting the sedimentary structures present (Fig. 1c).

Similarly with the rock specimen (Fig. 1d.) students are asked to make a sketch and then annotate the sketch to show the sedimentary structures, name the structures, and determine which way the water was flowing when the sediment was deposited using arrows to show the apparent palaeocurrent directions. The photograph of the ripple laminae in figure 1d has been converted to black and white so that the grey tones represent grainsize. Darker tones are silts and pale tones are grey fine-grained sand. Removing colour simplifies the description and interpretation of the image allowing students to concentrate on the laminations and the truncations needed to define erosion surfaces. In addition, they are asked to show evidence for erosion using coloured lines e.g. red to show erosion surfaces; and erosional truncation surfaces are highlighted as a means for determining way-up. In addition, questions are posed such as; "How many erosion surfaces can you identify? And are there any other sedimentary structures visible in the photograph?"

Moving on to outcrop photographs, the selection of photographs is important to ensure that other features such as faults, fractures, plants and shadows are not present or are explained. For example the outcrop photograph in figure 1e shows a typical example of a cross-stratified sandstone exposure in northern England. An experienced geologist ignores the colour created by lichens living on the rock surface and will pick out sets of cross-strata, bedding planes and possibly some soft sediment deformation. An untrained eye will see the patches of brown and grey colours and the sub-vertical fracture and not realise that the colours are not relevant and nor is the fracture. Learning what to look for in an outcrop takes practice, practice normally gained in the field by drawing field sketches. But the lesson can also be achieved by observing and recording relevant information from field photographs. The quality of the sketch is less important than the observation and recording of relevant information. An annotated overlay constructed in a graphics package can be just as valuable as a hand-drawn illustration so long as the relevant information is observed and recorded.

GRAPHIC LOGS AND VIRTUAL GRAPHIC LOGS

Common best practices regarding constructing graphic logs is reviewed below, such that the reader can have a record of the basic approach taught to students in this particular exercise. It can be modified by the educator as needed based on their own approach to constructing graphic logs. The concept of a graphic log is to represent a large amount of data within a simple and comprehensive system (Bouma 1962), which has transformed the way in which details of an outcrop or borehole core are recorded. Bouma (1962) states 'a complete graphic presentation of all sedimentary data of an investigated series is the best method of visualising the section'. The graphic log should give a visual impression of the rocks that aids interpretation, facilitates the identification of rocks with similar characteristics (descriptive facies), as well as the identification of trends in particle size such as fining upwards, or coarsening upwards; or bed thickness, thickening upwards or thinning upwards. Drawing a graphic log is an essential step in recording the details of sediments and sedimentary rock outcrops, as well as logging borehole cores. Instructions for drawing graphic logs can be found in Collinson *et al.* (2006); Nichols (2009); Coe (2010); Tucker (2011) and Bristow (accepted). The format of the log varies between geologists and there is no set format for a graphic log, indeed, the features that can be recorded do vary from succession to succession, and with the aims of different studies (Tucker 2011). However, most graphic logs share the same basic layout. Completing a preformed logging sheet requires detailed observations to be made of lithologies, bedding thickness and contacts, textures (especially grain size), sedimentary structures, palaeocurrents and fossils. If any information has been missed, gaps on the log are immediately apparent. The process of recording the information is a precursor to interpretation using facies analysis. These basic observations are the start of the tripartite field mantra 'observe, record, interpret'.

The virtual graphic log shown here is one of five that were developed for teaching sedimentology via distance learning but can be used to develop skills in observation and recording sediments. Three key points are:
1) Graphic logs provide a systematic and reproducible way to record the details of sediments and sedimentary rocks in an efficient manner and present observations in a form that is easy to recognise and interpret.
2) 'The log should be as detailed and realistic as the artistic ability of the drawer will allow' (Anderton 1985, p.37). 3) Facies 'are units that will ultimately be given an environmental interpretation' (Middleton 1978).

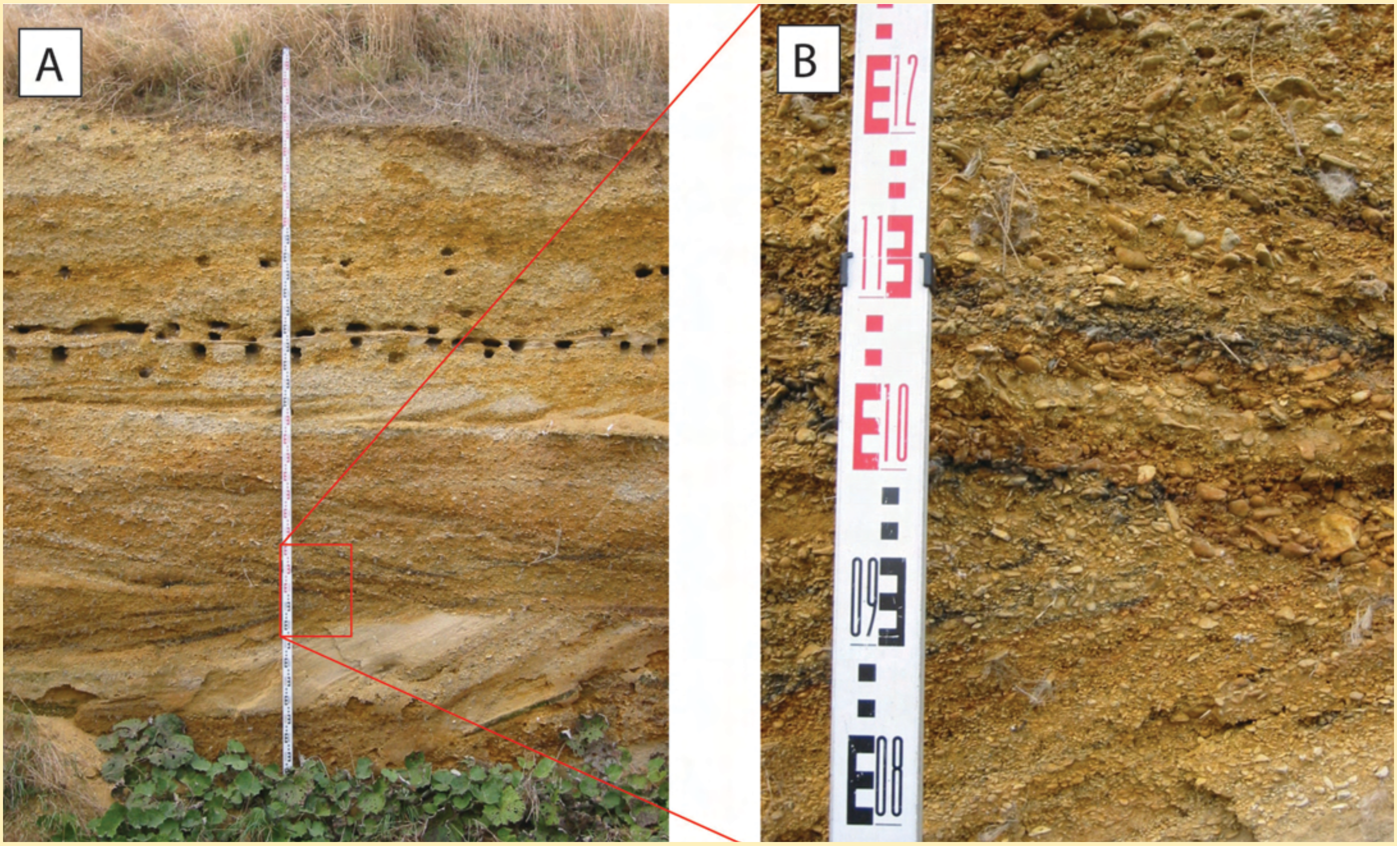

Figure 2: A) Outcrop of Thames terrace gravels with inset B) the sedimentary structures are quite subtle but the size of the pebbles can be determined using the graduated (cm) scale on the survey staff. Lecture notes and photographs can be downloaded from the SedsOnline teaching library https://sedsonline.com/sedimentology-teaching-library/ Files: Graphic logs lecture_1-2_Bristow_2020, Virtual graphic log 1-2_Bristow_2020

CREATING THE VIRTUAL GRAPHIC LOGS

Selecting a suitable site for a virtual logging exercise requires some planning. A primary requirement is that the outcrop should have a range of particle sizes, or sufficient contrast in tone, that can be readily discriminated on a digital photograph when viewed on a computer screen, tablet or mobile phone. One of the potential problems is the limited resolution of the digital photographs which means that it is not possible to resolve sand-sized and smaller particles because they are too small to be resolved in many digital photographs. This problem can be overcome by using high resolution images of sand grains or adding a written description of the sand size. A range of grain sizes, including sand and gravels provides an interesting and varied log. In addition, coarser grained particles, granules, pebbles and cobbles can be identified in the photographs and their size assessed with the graduated survey staff that is marked in cm, 5 cm, 10 cm and 1m intervals (Figure 2). A variety of primary sedimentary structures adds interest to the section and encourages observation and recording of relevant detail. A near vertical face and vertical scale makes it easier to measure bed thickness but can compromise access and safety. Good lighting is required to avoid shadows which can mask some parts of an exposure. Outcrops that include faults, fractures, cleavage or vegetation are best avoided because these can detract from observations of bedding and sedimentary structures. In the example presented in this paper pale coloured sands are interbedded with thin layers of contrasting, dark toned fine grained muds, allowing students to pick out the sedimentary structures (Figures 3, 4 and supplementary data a-v). The outcrop was photographed using a Canon Ixus 2 compact digital camera with a resolution of 1200 x 1600 pixels.

EXAMPLE FROM THE WOBURN SANDS NEAR LEIGHTON BUZZARD, ENGLAND

The Woburn Sands are exposed in sand pits near the town of Leighton Buzzard in England. They are Cretaceous (Aptian-Albian) in age and there are several publications that describe the sands and interpret their sedimentary environments, facies and sequence stratigraphy (Johnson and Levell 1995, Wonham and Elliot 1996, Yoshida *et al.* 2004). The outcrop shown in Figure 2 is from Nine Acre Pit (SP

Figure 3: Outcrop photograph of the Woburn Sands in Nine Acre Pit. The strata are part of the silver sands 3 unit of Wonham and Elliot (1996) and the heterolithic sands of Yoshida et al. (2004). The orange colour is due to iron oxide minerals that are interpreted to be formed by oxidation reactions during weathering. The photograph is taken facing towards the south and the outcrop is oriented E-W with east on the left. The survey staff is 5m long.

940 277), which is locality 10 in Johnson and Levell (1995), locality D in Wonham and Elliot (1996). The section exposed in Nine Acre Pit is part of the silver sands 3 unit of Wonham and Elliot (1996), and the heterolithic sands of Yoshida *et al.* (2004). Photographs of the outcrop are shown in figures 9 and 10 of Johnson and Levell (1995), as well as figure 12 in Yoshida *et al.* (2004). Summary stratigraphic logs for Nine Acre Pit are shown in Figure 13 of Wonham and Elliot (1996) and Figure 7 of (Yoshida *et al.* 2004), with more detailed sedimentary logs in Figure 13 of Yoshida *et al.* (2004). The outcrop shown in figure 2 trends E-W and the photograph is taken facing south so that east is on the left and west is to the right. Cross-strata dipping towards the left have an apparent dip towards the east, and cross-strata dipping towards the right have an apparent dip towards the west. This is important to note because it means that palaeocurrent directions shown as a compass rose will point in the opposite directions to the cross-strata in the outcrop. The true palaeocurrent directions from this unit are towards the NE and SW due to reversing tidal currents (Yoshida *et al.* 2004), with the ebb current direction towards the SW (Johnson and Levell 1995).

THE VIRTUAL GRAPHIC LOG

The outcrops of the Woburn Sands are a good location for creating a virtual graphic log because the sedimentary structures and trace fossils are picked out by layers of mud that show up on the photographs due to the contrast between dark muds and pale sands (Figure 3 and supplementary data a-v). Students are advised to make an outcrop sketch first using the outcrop photograph (Figure 3), so that they can identify the bedding geometry and pick out any erosion surfaces that control sand-body geometry. Then use the detailed photographs (a-v) in the supplementary data to identify sedimentary structures and draw a graphic log.

There are 22 photographs in the virtual log (supplementary data a-v) each of which covers around 30 cm of section (supplementary data a-v). The grain size of the sand is not resolved in the photographs but the students are informed it is fine to medium sand as described by Yoshida *et al.* (2004), and that the darker grey layers are silty clay mudstones. They are also informed that orange colour on parts of the outcrop is due to iron oxide minerals that are interpreted to have formed by oxidation during weathering. The example shown in figure 3 uses a vertical scale of 1:25, where 1m of outcrop equals 4 cm on the log, a scale of 1:10 or 1:20 would enable more detail to be added.

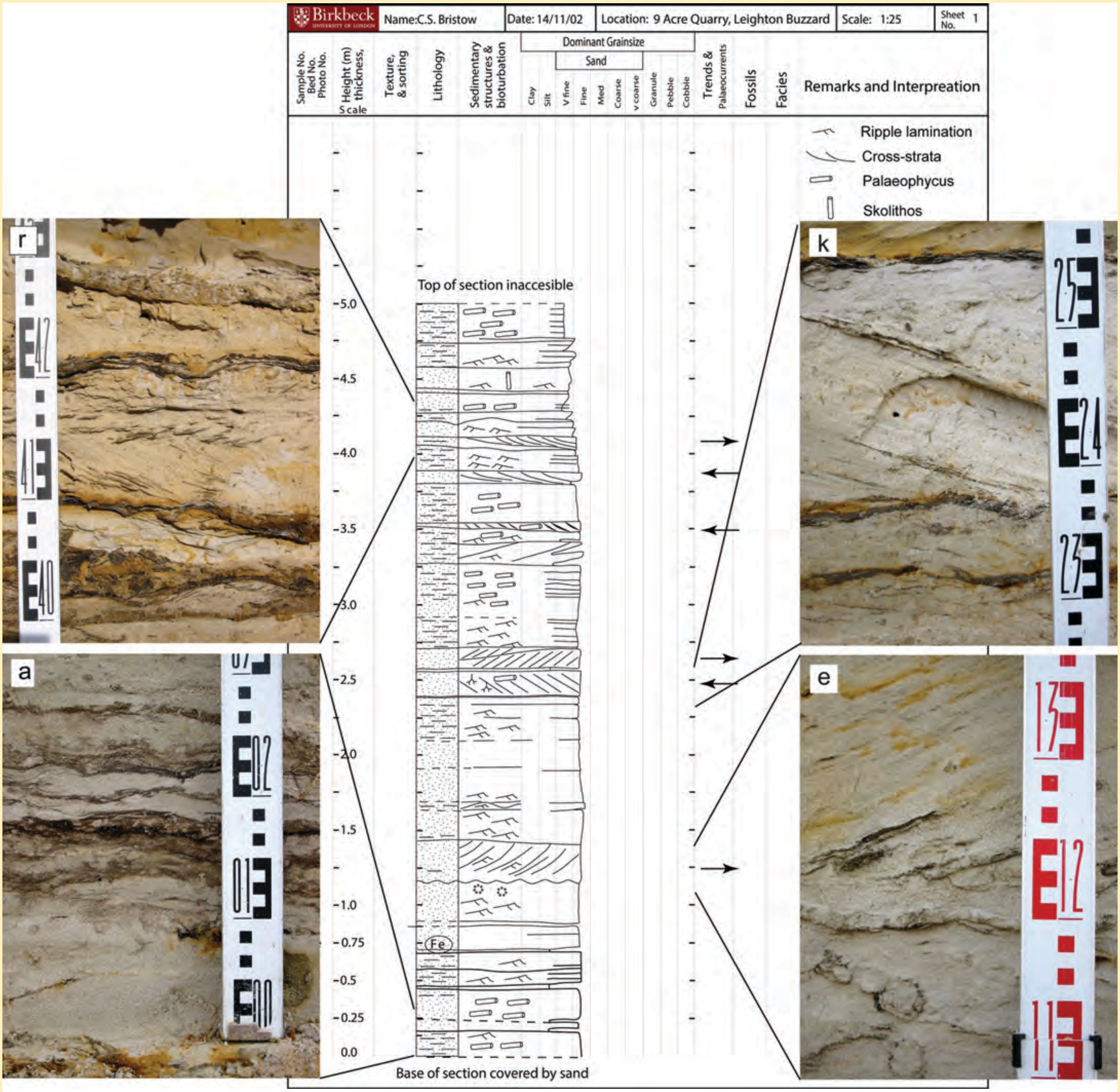

Figure 4: Example of a graphic log with selected photographs showing sedimentary structures that are commonly picked out by darker silty clay layers within the pale coloured sands. The letters on the photographs a, e, r and k, correspond with the photographs in the supplementary data a-v that show the full 5 m section.

ASSESSMENT AND GRADING

An assignment of this type can be formative or summative. As stated earlier, the log should be as detailed and realistic as the artistic ability of the drawer will allow (Anderton 1985), and the ultimate objective is to make an environmental interpretation using facies analysis. In drawing their own graphic log students should have noted the different sedimentary structures, apparent palaeocurrent directions and trace fossils. They can then use their observations to conduct a facies analysis and interpret the environments of deposition. Marks can be assigned for accuracy of observation, as well as description, presentation and interpretation. The published interpretation by Yoshida *et al.* (2004) places the heterolithic sands within a large and thick tidal sand bank in a tide dominated marine embayment. If this assignment must be graded then identifying one facies, heterolithic sands, is the best answer. The student should support the facies

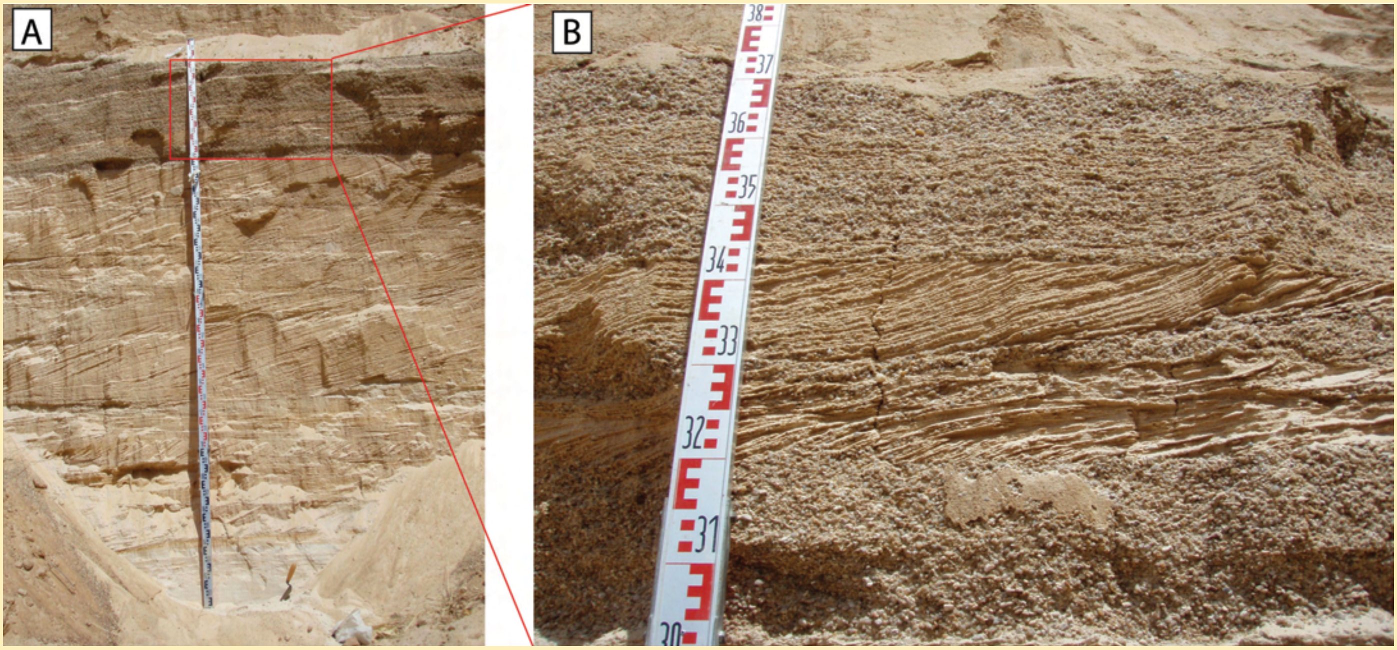

Figure 5: A) photograph of sand and gravel pit at Ngomari, NE Nigeria, and B) cross-strata and different grain size which makes for a more varied and interesting graphic log, modified from Bristow (accepted).

scheme by a well justified explanation of observations distinct to the facies. Additionally, the student should show how the sedimentary structures and bioturbation have been used to interpret the depositional processes and reconstruct the sedimentary environment, e.g. mud drapes on sets of cross-strata, and ripple lamination together with bimodal palaeocurrent directions is indicative of tidal currents (Yoshida *et al.* 2004). The trace fossil assemblage including *Ophiomorpha* and *Palaeophycus* is consistent with a shallow marine interpretation. Two facies is also acceptable, but needs to be justified as to why the facies has been subdivided and what is the palaeoenvironmental justification. Answers of three, four, or more facies suggests a lack of understanding of facies analysis.

Alternatively, the assignment is a good subject for class discussion, starting with a poll of the number of facies each student has identified. The poll could be an anonymous online poll, or a traditional show of hands. Followed by an online or classroom discussion of what is the best answer, concentrating on the ultimate objective which is the environmental interpretation. Questions to consider include: are there significant difference in environment between the cross-stratified sands, ripple laminated and bioturbated sands? What do the sedimentary structures tell you about the palaeocurrent directions? What do the mud drapes on cross-strata and ripple laminae tell you about palaeoflow velocities? What do the trace fossils Ophiomorpha and Palaeophycus tell you about the environment of deposition?

Summative assessment

The summative assessment for the module includes a graphic log that the students have to interpret with the aid of photographs of thin sections, hand specimens and outcrop photographs. The log includes both carbonates and clastic rocks in a succession that invokes of changes in sea-level, climate, tectonics and provenance. The grading is divided 60% for description of the thin sections, rock samples, and facies; and 40% for interpretation of depositional environments and a reconstruction of the geological history including a discussion of likely controls on sedimentation based upon all of the available information. This makes for a challenging final assessment that tests students' abilities to describe and classify sedimentary rocks (60%), as well as their abilities to construct a cogent and well justified interpretation of the geological history and controls on sedimentation (40%). The grading reveals a strong differentiation in students' knowledge, skills and ability to synthesize geologic data and integrate with core concepts and skills into a cohesive temporal scientific interpretation. The examination is open book, students can take reference books into the examination, and complete the assessment remotely under a timed release on line where the exam materials are made available at time X and the window for online submission of answers closes five hours later. The use of open-book and an extended time window reduces the exam stress and provides students with time to develop their ideas, and allows exams to be sat at remote locations without supervision.

Additional resources and alternative approaches

An introductory lecture on graphic logs and a simple example of a virtual graphic log are available online at https://sedsonline.com/sedimentology-teaching-library/. The relevant files are Graphic logs lecture_1-2_Bristow2020, Virtual graphic log 1_1-2_Bristow2020, and Virtual graphic log 1_answer_Bristow2020. This includes an example from the Thames terrace gravels (Figure 2) that can be used to show the principles involved in creating a graphic sedimentary log. The example from the Woburn Sands, shown here, has limited grainsize changes and is best suited for identifying sedimentary structures and making a palaeoenvironmental reconstruction. A third example from a sand and gravel pit in Nigeria shows both particle size changes and sedimentary structures (Figure 5). As a consequence, drawing the log is more demanding, but the results can be more interesting and the environmental interpretation is more challenging (Bristow accepted). The use of these three examples with increasing complexity should reinforce skills through experiential learning.

An alternative approach to learning about graphic logs would be to start with a set of written rock descriptions in a tabular form that students have to convert into a graphic log. Students learn to draw the lithologies, contacts and sedimentary structures described by filling in the columns on the graphic log before advancing to identifying the structures and bedding contacts in the photographs used for the virtual logging exercise.

Extension

The virtual graphic log could be extended by creating correlation exercises using published data from the paper by Yoshida *et al.* (2004), or creating synthetic logs to demonstrate lateral changes in facies for a palaeogeographic reconstruction, or a hypothetical proximal-distal section from fluvial to coastal, shallow marine and offshore facies belts.

CONCLUSION

Observational skills are at the heart of geological field work and need to be taught through observations of thin-sections, hand-specimens, and outcrop sketches. Drawing a graphic log aids observational skills and recording of sedimentary rocks through experiential learning. This is an essential field skill that can be enhanced with the use of virtual graphic logs. The aim of a virtual log is not to replace field work, except in exceptional circumstances such as the current COVID-19 pandemic, but to enable students to learn key skills before they go into the field. The exercise also has the added long-term benefit of accommodating students with disabilities to cultivate a more inclusive classroom environment and diverse student population.

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REFERENCES

ANDERTON, R., 1985. Clastic facies models and facies analysis. In Brenchley, P.J., and Williams, B.P.J., (eds.) Sedimentology: recent developments and applied aspects. Geological Society Special Publication 18, 31-47.

BOUMA, A.H., 1962. Sedimentology of some flysch deposits: A graphic approach to facies interpretation. Elsevier, Amsterdam, pp.168.

BRISTOW, C.S., accepted, A virtual graphic log for clastic sediments. Sedimentary Geology.

COE, A.L., 2010. Recording features of sedimentary rocks and construction of graphic logs. In Coe, A.L., (ed.) Geological Field Techniques, Open University, 102-138.

COLLINSON, J.D., MOUNTNEY,N.P., THOMPSON, D.B., 2006. Sedimentary structures, third edition. Terra Publishing, Harpenden. 292pp.

GENGE, M.J., 2020, Geological field sketches and illustrations: a practical guide. Oxford University Press, Oxford 293p.

JOHNSON, H.D., AND LEVELL, B.K., 1995, Sedimentology of a transgressive, estuarine sand complex: the Lower Cretaceous Woburn Sands (Lower Greensand), southern England. In Plint, G.A. (ed.) Sedimentary Facies Analysis: A tribute to the research and teaching of Harold G. Reading. IAS Special Publication 22, p.17-46.

NICHOLS, G., 2009. Sedimentology and Stratigraphy, 2nd edition. John Wiley and Sons, Chichester, 419pp.

TUCKER, M.E., 2011, Sedimentary Rocks in the Field: a practical guide fourth edition. John Wiley and Sons, 275p.

WONHAM, J.P., AND ELLIOT, T., 1996, High resolution sequence stratigraphy of a mid-Cretaceous estuarine complex, the Woburn Sands of the Leighton Buzzard area, southern England. Geological Society Special Publication 103, 41-62.

YOSHIDA, S., JOHNSON, H.D., PYE K., DIXON, R.J., 2004. Transgressive changes from estuarine to marine embayment depositional systems: the Lower Cretaceous Woburn Sands of Southern England and comparison with Holocene analogs. AAPG Bulletin 88, 1433-1460.

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