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A virtual graphic log for clastic sediments

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ABSTRACT

Drawing a graphic log is a standard method to describe sedimentary rocks at outcrops or from borehole cores. Graphic logs give a visual impression of the rocks, their lithology, particle size, bedding contacts, sedimentary structures, palaeocurrents and fossil content as well as trends such as coarsening or fining upwards. The format of graphic logs and their styles vary. This paper includes outcrop photographs that were collected as part of a distance learning module in Sedimentology and provides an opportunity for students to practice drawing a graphic log without having to venture into the field, effectively bringing the field into the classroom. Instructions for drawing a graphic log are included. There is potential for virtual logs to provide a more open science approach to outcrop interpretation, enabling researchers to visit outcrops virtually and make their own descriptions and interpretations.

Key words: Sedimentology, fieldwork, field-class, outcrop, logging, strata

1. Introduction

Graphic logs are widely used to record details of sedimentary rocks from outcrops as well as borehole cores. They 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 (Nichols, 2009). Early records of sedimentary rocks and successions were recorded in text as tables describing bed thickness, colour and lithology (e.g., Dixon, 1921). Writing out descriptions of sediments bed-by bed is time consuming, can be repetitive and takes a lot of time to read and assimilate. Even with the use of short hand abbreviations for lithologies and facies codes the requirement to describe bed contacts and sedimentary structures makes for long sentences or a potentially confusing list of acronyms. 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. A complete graphic presentation of all sedimentary data of an investigated series is the best method of visualising the section (Bouma, 1962). Graphic logs are appropriately named because their construction resembles a graph with bed thickness on the vertical axis and grain size on the horizontal axis.

Graphic logs can be used for correlation between boreholes, and/or outcrops from equivalent stratigraphic sections at different locations, as well as correlation with wireline logs and geophysical properties (e.g., Myers and Bristow, 1989; Rider, 1996). They are also used to summarise typical vertical profiles in facies models, e.g., the fluvial fining upwards succession (Allen, 1964), coarsening upwards deltaic successions (Coleman and Wright, 1975), as well as the Bouma sequence in turbidites (Bouma, 1962). Multiple logs can be used to record lateral changes in thickness and facies and in the assessment of sand-body geometry and sedimentary architecture (e.g., Bristow and Myers, 1989; Dubiel, 1992; Willis, 1993). 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, and palaeocurrent directions.

Drawing a graphic log is an essential step in recording the details of sediments and sedimentary rocks. The process of recording the information and 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. These basic observations are the start of the tripartite field mantra 'observe, record, interpret'. I advocate a pictorial approach to drawing graphic logs because an accurate and detailed drawing of sedimentary structures and bedding contacts provides a better description than text or symbols, fulfilling the old adage that a picture paints a thousand words. However, I use symbols for small-scale features like ripple laminae, and yet still try to make the bedding and cross-strata as graphic and realistic as possible, aiming to create an accurate record of the rock that is easy to interpret, which is a key objective for all graphic logs (Nichols, 2009).

This paper presents a methodology of a virtual graphic log for clastic sediments using digital photographs, which was developed for distance learning modules in Sedimentology but can be used to develop skills in observation and recording sediments in the field as well as within a classroom environment. The aim of a virtual log is not to replace field work, except in exceptional circumstances, but to enable students to learn key skills before they go into the field. Learning how to make a graphic log in the classroom before venturing into the field should enhance experiential learning and enable students to make the most of their valuable field time. There are also advantages in creating virtual graphic logs for research, including open science, access, field-safety and legacy issues that are discussed briefly.

2. Properties of a graphic log

The graphic log is the standard method for systematically collecting and recording detailed observations of sedimentary rocks in the field and in borehole cores (Nichols, 2009; Coe, 2010; Tucker, 2011). However, as Tucker (2011, p. 14) observed, 'there is no set format for a graphic log, indeed, the features that can be recorded do vary from succession to succession'. A sentiment echoed by Collinson et al. (2006). The graphic log comprises a series of vertical columns. For a typical sandstone the features that must be recorded and therefore require a separate column are: lithology, bed thickness and contacts, texture (especially grain size), sedimentary structures, palaeocurrents and fossils, with an additional column for comments, and thumb-nail sketches. The required columns will change depending on the aims of the study and types of sediments, for example, volcaniclastic sediments use a modified grain size scale (Cas and Wright, 1988), and more bespoke schemes are available for carbonate rocks. A range of different proforma logging sheets are illustrated by Graham (1988), with further examples in Collinson et al. (2006), Nichols (2009), Coe (2010), and Tucker (2011). All follow the same basic layout with minor differences and an example is included here (Fig. 1). Having designated columns helps to ensure that all of the relevant information is recorded, empty columns show up very clearly and a missing piece of information such as the nature of a bedding contact or change in grain size is immediately apparent in the field. Logging sheets and proformas can be adapted to suit different sedimentary successions and the width and arrangement of the columns vary between different users and different purposes (Collinson et al., 2006). Graphic logs can also be recorded in field note books, especially those with squares, or graph paper pages that can be readily converted into columns for logging in the field. Further advice on what to record can be found in Nichols (2009), Coe (2010) and Tucker (2011).

2.1 Style and symbols

The original graphic logs published by Bouma and Nota (1961) and Bouma (1962) are highly stylised. 'The graphic presentation makes it necessary to use symbols and simple codes in the graph because extensive terminology would obscure the clearness of the picture' (Bouma, 1962, p. 3). It has been argued that the use of standard symbols is an advantage in communicating between different geoscientists, and has been adopted by oil companies where many people are involved in describing and interpreting logs from borehole cores (Anderton, 1985). In addition, graphic logs that are drawn with computer drafting packages tend to be stylised with a limited range of shapes or symbols for bedding contacts and sedimentary structures. Although it has been noted by Zervas et al. (2009) that computer-drawn logs offer little advantage over their hand-drawn predecessors, – they are just neater. In contrast, it has been suggested that graphic logs should be as detailed and realistic as the artistic abilities of the drawer will allow (Anderton, 1985). I endorse the pictorial approach, especially for cross-strata and bedding contacts and would add that it is more than a matter of personal taste (Anderton, 1985, Collinson et al., 2006), since there are epistemological reasons why we should be careful with the use of symbols, because some symbols require or imply a certain level of interpretation, and it is better to keep description separate from interpretation. In addition, the same symbol can be used to indicate different features by different authors, for example a lightning strike symbol can be used to represent roots (Anderton, 1985), as well as bioturbation (Tucker, 2011). Nichols (2009, p. 70) states that "The objective of any graphic sedimentary log should be to present the data in a way which is easy to recognise and interpret using simple symbols and abbreviations that should be understandable without reference to a key (although a key should always be included to avoid ambiguity).' We, professional geoscientists, and especially students, come across things that we have not seen before and therefore do not recognise, or worse still interpret incorrectly. If this unknown or incorrectly identified feature is represented on the graphic log by a symbol, that interpretation cannot be changed or undone. On the other hand, if the observer has made an accurate graphical representation of a said feature, for example an unknown trace fossil, then it is possible to research what it is later, or seek additional advice from someone else with relevant expertise so that it can be correctly identified. In addition, the use of symbols can limit the range of information that can be recorded on something as essential as a set of cross-stratification. While a set of symbols might include a symbol for trough cross-strata and planar cross-strata, they might not be able to record more subtle features such as the angle of dip, asymptotic toes, mud drapes, reactivation surfaces or tidal bundles, all of which need to be recorded because they contain essential information that is required for subsequent interpretation. The use of symbols and realistic drawings is not mutually exclusive, and I use a pictorial approach for bedding contacts and cross-strata, with symbols for ripple lamination and some trace fossils.

2.2 Scale

The vertical scale used on a graphic log depends upon the amount of rock to be recorded, the level of detail required, the complexity of the rocks, and the time available. As a consequence the vertical scale varies between users and localities. Ideally all sections would be logged in great detail but realistically this can be limited by practical constraints on the time available and associated costs. Bouma (1962) suggested a scale of 1:5 or 1:10 or even 1:1 or 1:2. However, Coe (2010, p. 119) suggested a scale of 1:100 or 1:500). I like to use a vertical scale of 1:25, which means that 1 m of outcrop is represented by 4 cm of log, 0.5 m is 2 cm, and 0.25 m is 1 cm. I find that this gives me enough space on the log to record most sedimentary structures, bedding contacts and textures, although very thin beds 1 or 2 cm thick are reduced to a single pencil line. Thus, if the succession comprises a large amount of very thin beds, a more detailed log would require a larger scale. Conversely, logging a very thick succession of thick beds in a limited time might require a smaller scale at possibly 1:50 or even 1:100 for a summary log.

The horizontal scale for grain size usually follows the Udden-Wentworth scale in which the boundaries between grains size classes or grades are defined by a logarithmic scale using 1 mm as the starting point (Udden, 1914; Wentworth, 1922). This scale emphasises the differences in particle size in the sand-sized range (0.0625 – 2 mm), and reduces the differences within conglomerates. As a consequence, additional grade boundaries have been suggested for conglomerates (Blair and McPherson, 1999), which would require additional grain size columns on the logging sheet.

3. **Testing the virtual outcrop approach**

The outcrop described here in order to test the virtual graphic log approach is a gravel and sand pit in the Bama Ridge, near the village of Ngomari on the southern outskirts of the town of Maiduguri in Borno State, northeast Nigeria (11° 45′ 54.3″S, 13° 13′ 57.8″E). The Bama Ridge is a low relief topographic feature standing at an elevation of 339 m that trends NW-SE and can be traced along strike for around 330 km from Cameroon, through Nigeria to Niger. The ridge marks a former shoreline of palaeolake Mega-Chad (Grove, 1959; Grove and Pullan, 1963; Schuster et al., 2005; Drake and Bristow, 2006). The River Ngadda has incised around 25 m and cuts through the Bama Ridge at Maiduguri. The outcrop is one of a series of artisanal sand pits that are excavated into the eastern edge of the valley cut by the river Ngadda. The total thickness of the section is around 20 m and outcrops extend down-valley for over 1 km but the exposures are discontinuous. The outcrop is oriented N to S at an angle of 40° to the palaeolake shoreline and oblique to the palaeocurrent direction. The view in Fig. 2 is facing towards the E, which is towards Lake Chad. This outcrop was selected because it has a range of particle sizes including sand and gravels and sedimentary structures that can be distinguished on the photographs.

3.1 Creating a virtual graphic log

The selection of a suitable site for the creation of a virtual logging exercise is not trivial. The outcrop needs to have a range of particle sizes that can be readily discriminated on a digital photograph which can be viewed on a computer screen, tablet or mobile phone. Sand-sized particles (0.0625 – 2 mm) are difficult to resolve without a very high resolution camera, thus it is useful to have either coarser grained gravel-sized particles and/or fine grained muds in a contrasting tone to pick out the sedimentary structures. 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 make it easier to measure bed thickness but can compromise access and safety. Good lighting is required for the photographs without shadows, which can mask some parts of an exposure. In this respect a flat light, e.g. a bright but overcast day, can be better than full sun. Outcrops that include faults, fractures or cleavage are best avoided because these can detract from observations of bedding and sedimentary structures. Successions with only sand-sized particles are difficult to distinguish on digital photographs. Coarse particles, e.g. gravel, are easier to distinguish on photographs and a range of grain sizes including sand and gravels provides an interesting and varied log. In this outcrop the sediments are unconsolidated, and the base of the section was cleaned and prepared with a trowel before being photographed using a 7 megapixel Olympus compact digital camera with a resolution of 3072 x 2304 pixels.

In this example, a set of outcrop photographs with a survey staff graduated in 1 cm, 5 cm, 10 cm and 1 m intervals is used as a scale bar in every photograph (Fig. 3 and supplementary data). The materials include a photograph that shows the outcrop with a person and survey staff for scale (Fig. 2) that provides context and shows the continuity of beds which could be used to draw a field sketch. Figure 3 shows the section with the survey staff in place, and the location of the detailed photographs as insets. Detailed photographs in the supplementary data each cover 70 – 90 cm, with some overlap between each photograph. The graduated scale on the survey staff is helpful because the 1 cm scale aids in the identification of clast size, while the 5 cm, 10 cm and 100 cm scales help to determine bed thickness and identify the location of the photograph within the vertical profile. The figure captions include notes on the sand-sized particles because the grain size is beneath the resolution of the digital camera.

4. Tips and advice for students

The aim of the graphic log is to record as much information as possible in a way that is easy to understand and interpret. The creation of the graphic log is the first stage in facies analysis, which leads to an interpretation of the depositional environment. Creating a graphic log of the outcrop will make you look at the outcrop in detail, and help you to observe and record the sedimentary structures. Having made the graphic log, you should be able to make an interpretation of the depositional environment of the sediments using facies analysis; grouping together those beds with similar characteristics as facies, that will ultimately be given an environmental interpretation; thus completing the field class mantra "observe, record, interpret". It is important to note that this is a three stage process and you should not jump straight to an interpretation. Interpretations need to be based upon accurate observations and good descriptions/records.

4.1 Site selection and scale

Before you start, take an overview of the outcrop, it is a good idea to make an outcrop sketch and pick out the major bedding planes and any erosion surfaces that define the sand-body architecture. Bedding is the most important feature to record in a sketch, and sedimentary structures, in particular cross-stratification should be drawn as accurately as possible (Genge, 2020). This advice applies to the virtual log as well as outcrops in the field. Identify a convenient place to start the log, usually at the base of the section or a prominent marker horizon. If in doubt, start at the bottom and work up. Choose a location where the best outcrop occurs or where access is most suitable. Do not put yourself or others at risk by climbing vertical cliffs. Select an appropriate scale that optimises the time available to record the log and the thickness of the section to be measured. The scale that you choose needs to provide plenty of space for the detailed recording of small-scale sedimentary structures and thin beds. A good scale for a detailed log is between 1:10, where 1 m of outcrop is 10 cm on the logging sheet, or 1:25 where 1 m on the outcrop is 4 cm on the log, the latter subdivides into easy units of 50 cm and 25 cm, per cm on the log.

4.2 Drawing the log

Working across the columns on the logging sheet (Fig. 1) from left to right; the first column on the left side shows where samples and photographs were taken. The second column shows the depth for borehole cores or height up the section for outcrops. This provides the vertical axis of the graphic log and is used to show bed thickness. If there is no exposure because the rocks are covered by soil I suggest that you put a large X in the lithology column, that fills the gap, and write 'No exposure' in the remarks column on the right.

4.3 Texture and sorting

The third column labelled 'texture and sorting' can be used to show the texture of carbonate rocks following the Dunham (1962) classification indicated by the initial letters: M for mudstone, W for wackestone, P for packstone, G for grainstone, B for boundstone, C for crystalline. If there are very coarse grained limestones separate columns can be added for Rudstone (R) and Floatsone (F) (Tucker, 2011). The texture column can also be used to distinguish between grain-supported and matrix-supported clastic sediments, and the degree of sorting e.g., well sorted or poorly sorted.

4.4 Lithology

The lithology column can be filled with standard symbols such as dots or stipple for sand and sandstone, horizontal dashes for mudrocks, and a brick-pattern for limestones. For coarser grained, conglomerate clasts, a pictorial approach drawing the clast is preferred. While this can be time consuming it does make a better record of the size, shape, sorting and packing of large clasts. Patterns introduce features into diagrams that do not exist, and also tend to obscure the detail of geological structures (Genge, 2020).

4.5 Bed contacts

In the outcrop photographs (Fig. 3 and supplementary data), cross-strata and bedding contacts are visible. If beds have irregular bounding surfaces, these should be recorded graphically on the log (Collinson et al., 2006). For example, erosive channel bases should be drawn cutting down into the underlying unit and lens-shaped beds should be drawn tapering at their ends (Collinson et al., 2006). If beds pinch out along strike use a mean thickness and add a note or thumb-nail sketch in the remarks column on the right to show how much the beds thin over what distance and direction, e.g., bed thins from 2 m to 1 m over 20 m towards the SW.

4.6 Sedimentary structures and bioturbation

The outcrop in the photographs includes a variety of primary sedimentary structures including planar lamination, current ripple lamination and cross-strata. I suggest that you draw these as you see them, and be as realistic as possible. Try to include the geometry of the bounding surfaces as well as the cross-strata. Some people prefer to restrict observations of sedimentary structures to a specific column, but I prefer to use the full width of the sedimentary structures and associated grain size columns to provide more room to record the details of sets of cross-strata.

Bioturbation is the disruption of sediment by the activity of plants and other organisms (Tucker 2011). This can take many forms from root disturbance to burrows created by animals living in or moving through the sediment or walking across the surface. The resulting tracks and trails are known as trace fossils and they record an animal's response to its environment including; feeding, walking, crawling, burrowing and boring traces. Trace fossils can help to reconstruct ancient sedimentary environments, the conditions at the time of deposition and what animals were doing there. Further information can be found in Collinson et al., (2006), and references therein.

4.7 Grain size

In the field, a hand lens and grain size comparator should be used to assess particle size. On the graphical log the grain size is displayed on the horizontal axis and represented by a line running up the page that moves to left and right with the grain size. Note that the vertical lines are the boundaries between the grain size classes or grades, medium grained sand is between 0.25 and 0.5 mm and the line should sit within the column and not on the line unless the grain size is either 0.25 or 0.5 mm. If the grain size fines-up the line should move gradually to the left across the boundaries. If the grain size coarsens-up the line should move to the right. Exceptionally large, outsized particles can be represented by a horizontal line extended to the right extending into the relevant column. Thin mud layers within sands can be represented by lines drawn to the left extending into the silt or clay size columns.

The particle sizes of the gravel layers can be identified on the photographs using the graduated scale. However, the size of the sand grains is beneath the resolution of the photographs and notes have therefore been added to the supplementary figures indicating the grain size of the sand particles which is also shown in Table 1.

4.8 Trends and palaeocurrents

Trends within sedimentary successions should include trends in bed thickness, thickening or thinning upwards successions, or in grain size, coarsening upwards or fining upwards successions. These can be depicted with an isosceles triangle within the column, widening in the direction that beds and/or grain size increase, and narrowing in the direction in which they decrease. Palaeocurrent data collected at outcrops may be presented as arrows pointing in the direction of palaeoflow. A useful convention on the graphic log is to orient the arrows as they would appear on a compass rose; pointing up the page towards North (0°) at the top, pointing right towards East (90°), pointing down to the South (180°), and pointing left towards the West (270°). This is not restricted to the cardinal points (North, East, South and West) but can accommodate all the other angles in-between. This graphical arrangement makes it easy to visualise palaeocurrent directions and identify any changes that occur within a succession. In this example, palaeocurrent directions will be relative, so although it is not possible to determine the true dip direction, it is still helpful to have an indication of the palaeoflow direction.

4.9 Fossils

Fossils can be drawn but are commonly represented by graphic symbols. Examples of the graphic symbols used for fossils are shown in Collinson et al. (2006, p. 270), Nichols (2009, p. 72), Coe (2010, p. 288), Tucker (2011, p. 16). Repeating the symbols two or three times can be used as an indication of their abundance. There are no fossils visible in the example illustrated here.

4.10 Facies

The term facies is used in many different ways in geology (Anderton, 1985), and its meaning has changed over the years (Middleton, 1978; Walker, 2006). Facies can be used for description as well as interpretation of sedimentary rocks. Anderton (1985, p. 32) distinguished between the two as follows; a descriptive sedimentary facies is ”a certain volume of rock that can be characterised by a set of features, such as grain size, geometry and sedimentary structures, that distinguish it from other rock units”. In contrast he defined an interpretive sedimentary facies as “a label summarizing the interpretation of the processes and environments of deposition of a certain rock unit”. A facies can be a single bed or more likely a group of similar beds. In addition, facies can be divided into subfacies or grouped together into facies associations. Facies can be given informal designations (‘Facies A’ etc.), or brief descriptive designations (‘laminated siltstone facies’), and it is understood that they are units that will ultimately be given an environmental interpretation, although the facies definition is itself objective and based on the total field aspect of the rocks themselves (Middleton, 1978). Nichols (2009, p. 84) notes that “There are no rules for the naming of facies but it makes sense to use names that are descriptive”. Facies names are often abbreviated with initial letters and short-hand abbreviations into codes that are devised to make descriptions quicker and more efficient (Tucker, 2011).
In this example the lithologies are sands and gravels, the sedimentary structures include planar lamination, ripple lamination, and cross-stratification. The bounding surfaces between the beds are sub-horizontal and locally erosive. All of these features of the outcrop can be grouped together into a descriptive facies of ‘stacked sets of cross-stratified sands and gravels with erosional bases, locally fining upwards on a metre scale’. This description encompasses the main features of the sediments, their lithology, sedimentary structures, grain size characteristics, bed contacts and geometry, and enables an interpretation to be made. The interpretation is that the sediments were deposited by dune bedforms and sand bars in shallow 1-2m deep rivers (Armitage et al., 2015). Because the exposure is only slightly oblique to the palaeocurrent direction, the basal erosion surfaces of the channel are quite subtle and the channels are best defined by gravel lags, the stacking of the cross-strata and fining upwards within the sands.

4.11 Remarks and Interpretation
As the log is being constructed you might develop hypotheses about possible interpretations of the sedimentary processes and environment of deposition and these can be recorded in the remarks and interpretation column (Collinson et al., 2006). In addition, you could include observations of features that are not recorded by existing columns such as colour, preferably using colour charts such as Munsell soil colour charts (Munsell Colour Company 2000), or the effects of weathering. Other features to note are authigenic minerals such as pyrite or glauconite (Tucker, 2011). In addition, this column can be used to highlight potentially significant features or things that you are not sure about "what is this?" as a reminder for further investigation. If you see something that you are not sure about you can make a sketch so that you have an accurate record of what you saw in the field/photographs, and then you can interpret it later with the aid of books, online images, or a supervisor. I like to record lateral changes in beds that occur either side of the measured section e.g., beds that thicken or thin, pinch out or are removed by erosion, with the addition of annotated thumb-nail sketches. In this case I noted the erosion surfaces at the base of channels.

5. Research applications

Virtual graphic logs can be a useful resource in the research environment. These days, the storage capacity for digital data is enormous. As a result, high-resolution digital images of outcrops can be stored and accessed online. One advantage of the virtual graphic log is that the virtual outcrop can be visited at any time, contacts can be checked, and details revisited for further investigation. In addition, the outcrop is available for other researchers to 'visit' and make their own descriptions and interpretations. This enables a more open science approach to outcrop description and interpretation. Furthermore, the virtual graphic log provides a record of temporary sections that might be removed due to excavation or burial, or where sites cannot be visited for safety or financial reasons.

6. Interpretation of the outcrop

The origins of the Bama ridge have been disputed (Zarma, 2016). Based on its location, and geomorphology, the Bama Ridge has been interpreted as a beach deposit marking the former extent of palaeolake Mega-Chad (e.g., Grove, 1959; Thiemeyer, 1992; Schuster et al., 2005; Drake and Bristow, 2006). In contrast, sedimentary studies of the sections exposed in sand and gravel quarries beneath the Bama Ridge suggest that the sediments are fluvial (Shettima et al., 2011; Armitage et al., 2015). The creation of a graphic log provides some of the observations and records required to make an interpretation of the depositional environment. It appears that the Bama Ridge is a beach ridge formed on the shores of palaeolake Mega-Chad, but the sediments beneath it were deposited by rivers, possibly a river that was deflected towards the north as it approached the lake shore during a lake highstand.

7 Conclusions

Virtual graphic logging is potentially a valuable resource for sedimentary research and teaching. One aim of a virtual graphic log is to provide training in key geological field skills in a classroom environment. Creating a graphic log involves observation, recording rock descriptions and is a precursor to facies analysis and the interpretation of depositional environments. Finding really good sections for virtual logging exercises is not easy, the outcrop has to be accessible, must show good exposures of a variety of sedimentary structures and a range of grain size that can be readily distinguished on digital photographs. 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, or coarsening upwards; or bed thickness, thickening or thinning upwards. While computer drawn graphic logs can appear neater, this neatness, and the use of symbols can come with a loss of information and the author supports a pictorial approach to be as realistic as possible when recording sedimentary structures on a graphic log. For research, online storage of digital photographs makes it possible to store and share digital photographs that form the data required to create virtual graphic logs. The virtual logs provide a more open science approach to outcrop interpretation, enabling researchers to visit outcrops virtually and make their own descriptions and interpretations.

8 Data availability statement

The data used for the construction of the virtual graphic log is available to download as supplementary data. Please ask the corresponding author for an outline answer if this is required.

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Figure Captions

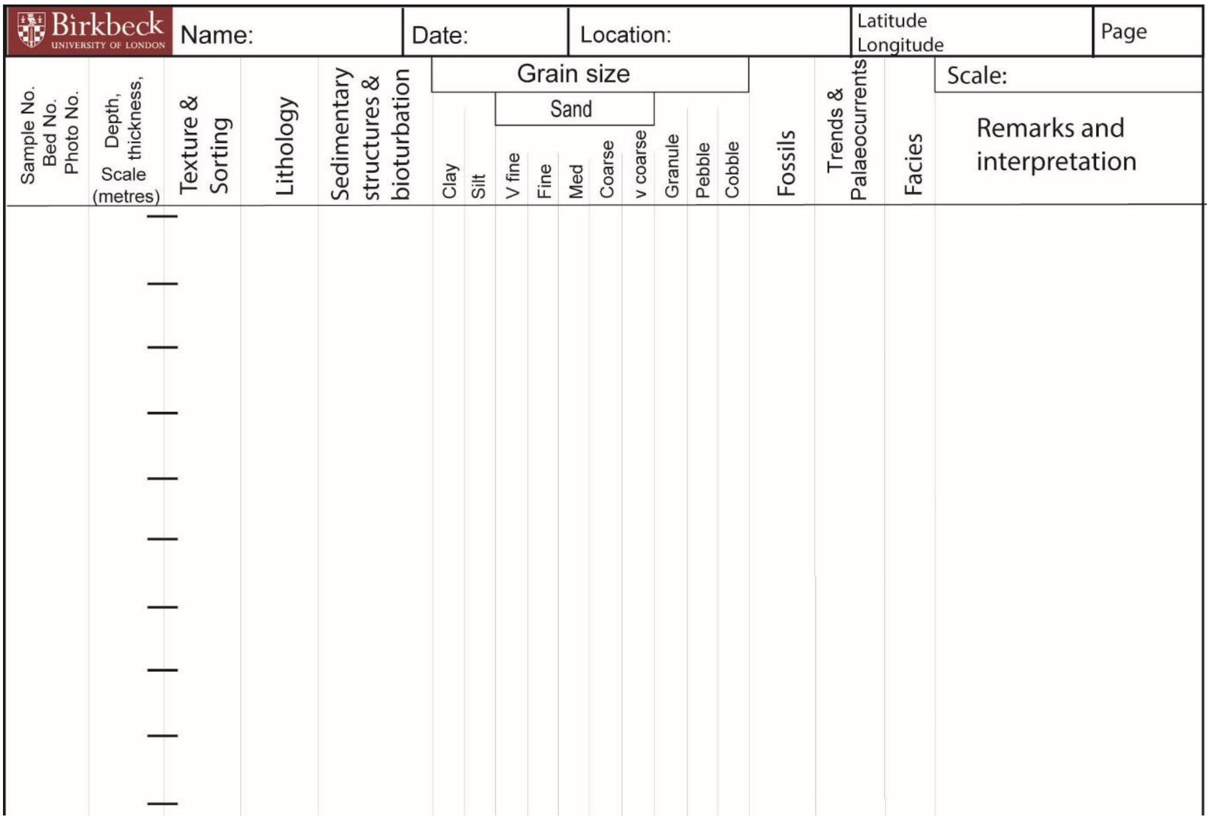


Figure 1. Example of a proforma logging sheet with vertical columns for lithology, sedimentary structures, textures including grain size, fossils, palaeocurrents, lithofacies as well as remarks and interpretation. The logging sheet and photographs can be downloaded from the supplementary data.

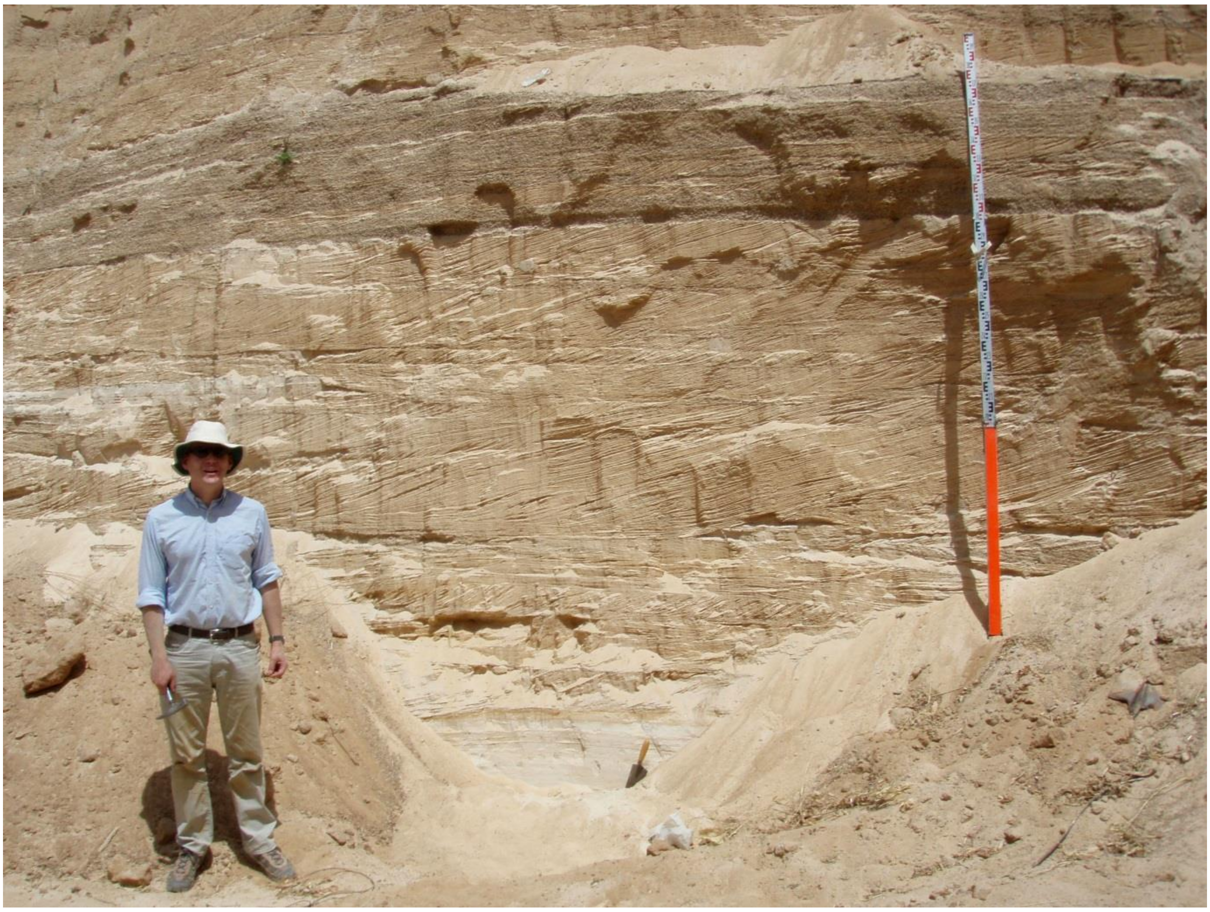


Figure 2. Outcrop photograph with person and survey staff for scale. The section photographed in detail for the graphic log is to the left of the trowel and the outcrop is 3.8m high. The outcrop is oriented North to South with South on the left and North on the right.

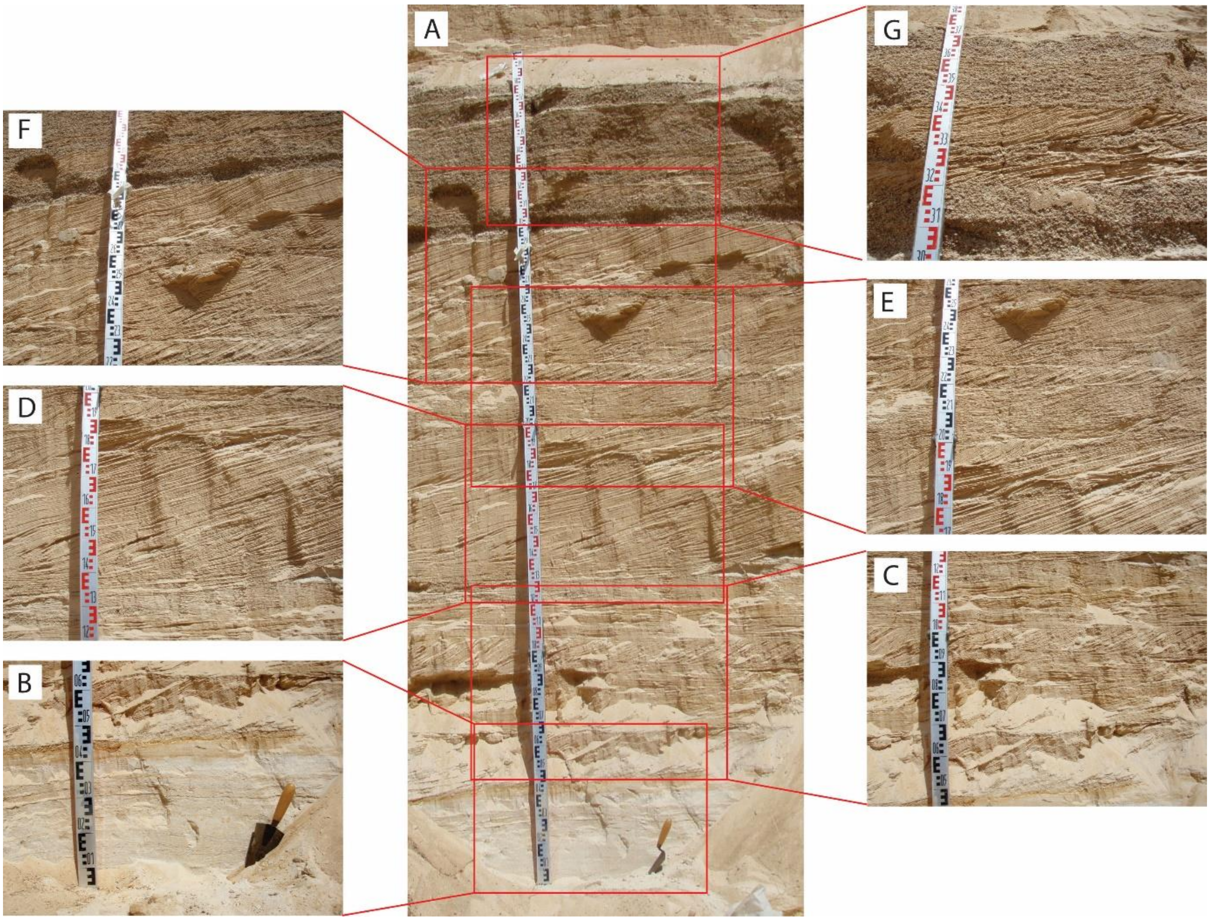


Figure 3. A) The section to be logged with the survey staff in place has a well exposed vertical face. B) Base of section, 0-0.68 m, the first 5 cm are covered by loose sand. C) 0.45 to 1.28 m. D) 1.2 to 2.0 m. E) 1.73 to 2.68 m, note the different sized sets of cross-strata. F) 2.22 to 3.35 m, the lower half of the photograph repeats the section shown in E. G) 3.0 to 3.8 m, the top of the accessible part of the section. The inset photographs B to G can be downloaded from the supplementary data.

Height up the section (m)	**Sand grain size** (Udden Wentworth grades)
0 - 0.4	Fine grained sand
0.45 - 1.28	Mostly coarse grained sand
0.7	Sand size fines to medium grained sand
1.0 and 1.2	Medium grained sand
1.2 - 1.33	Fine to medium grained sand
1.33 - 1.75	Fines up from coarse grained to medium grained sand
1.75 - 2.0	Coarse grained sand
2.0 - 2.2	Fine to medium grained sand
2.2 - 2.55	Fines up from coarse grained to medium grained sand
2.6 - 2.9	Fines up from coarse gained to medium grained sand
3.2 - 3.25	Medium grained sand
3.3 - 3.4	Coarse grained sand
Above 3.7	Medium grained sand

Table 1. Grain size information for sand grains that cannot be resolved on the photographs.

Supplementary figures

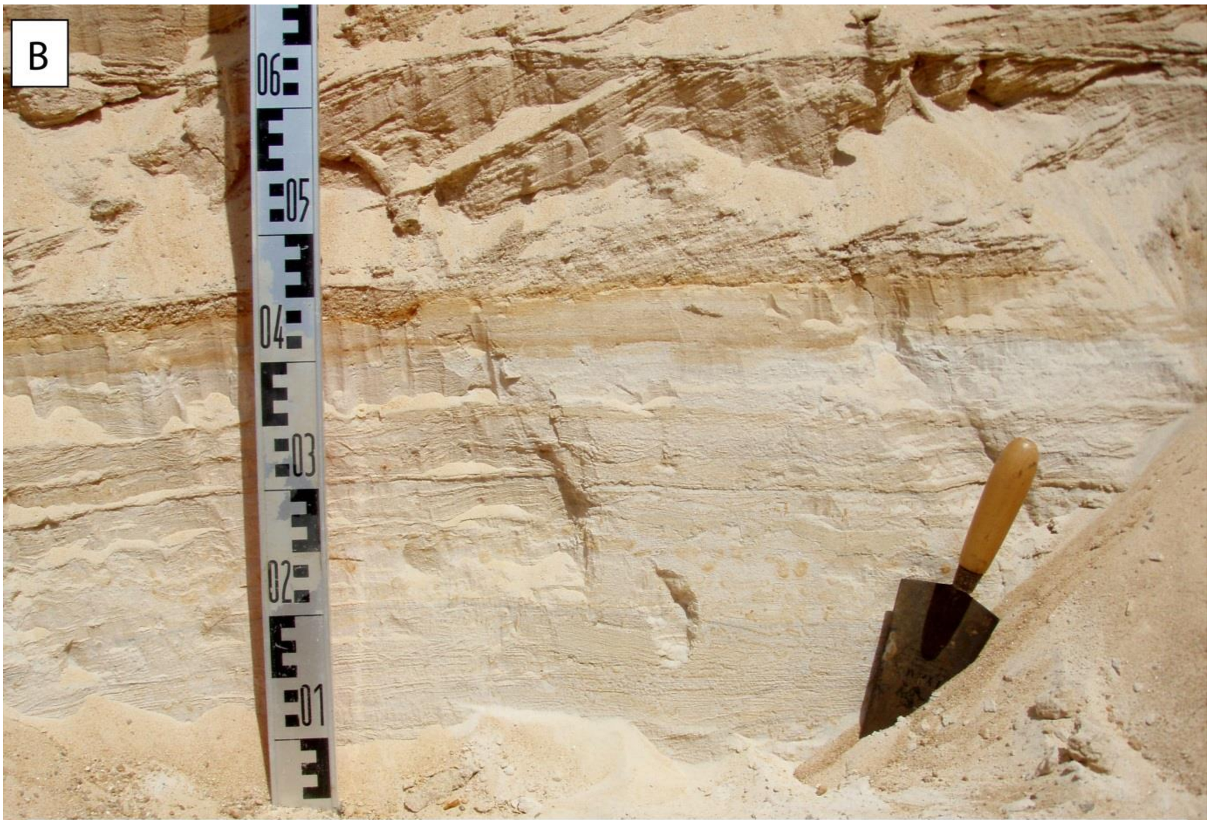
Birkbeck UNIVERSITY OF LONDON

Name:	Date:	Location:	Latitude Longitude	Page

Sample No. Bed No. Photo No.	Depth, thickness, Scale (metres)	Texture & Sorting	Lithology	Sedimentary structures & bioturbation	Grain size										Fossils	Trends & Palaeocurrents	Facies	Scale: Remarks and interpretation
							Sand											
					Clay	Silt	V fine	Fine	Med	Coarse	v coarse	Granule	Pebble	Cobble				

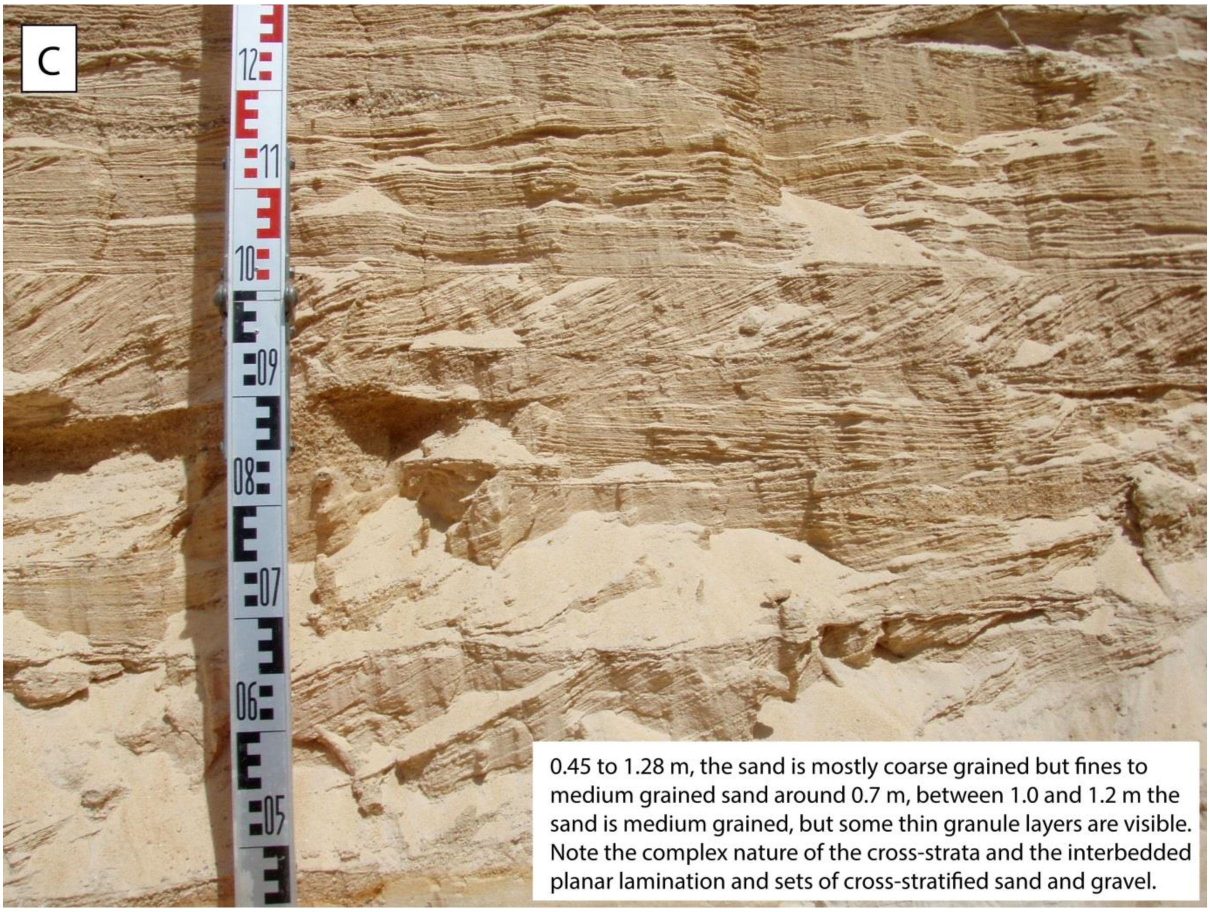
Example of a proforma logging sheet with columns for lithology, sedimentary structures, textures including grain size, fossils, palaeocurrents, and facies as well as remarks and interpretation.

The section to be logged with the survey staff in place has a well exposed vertical face.

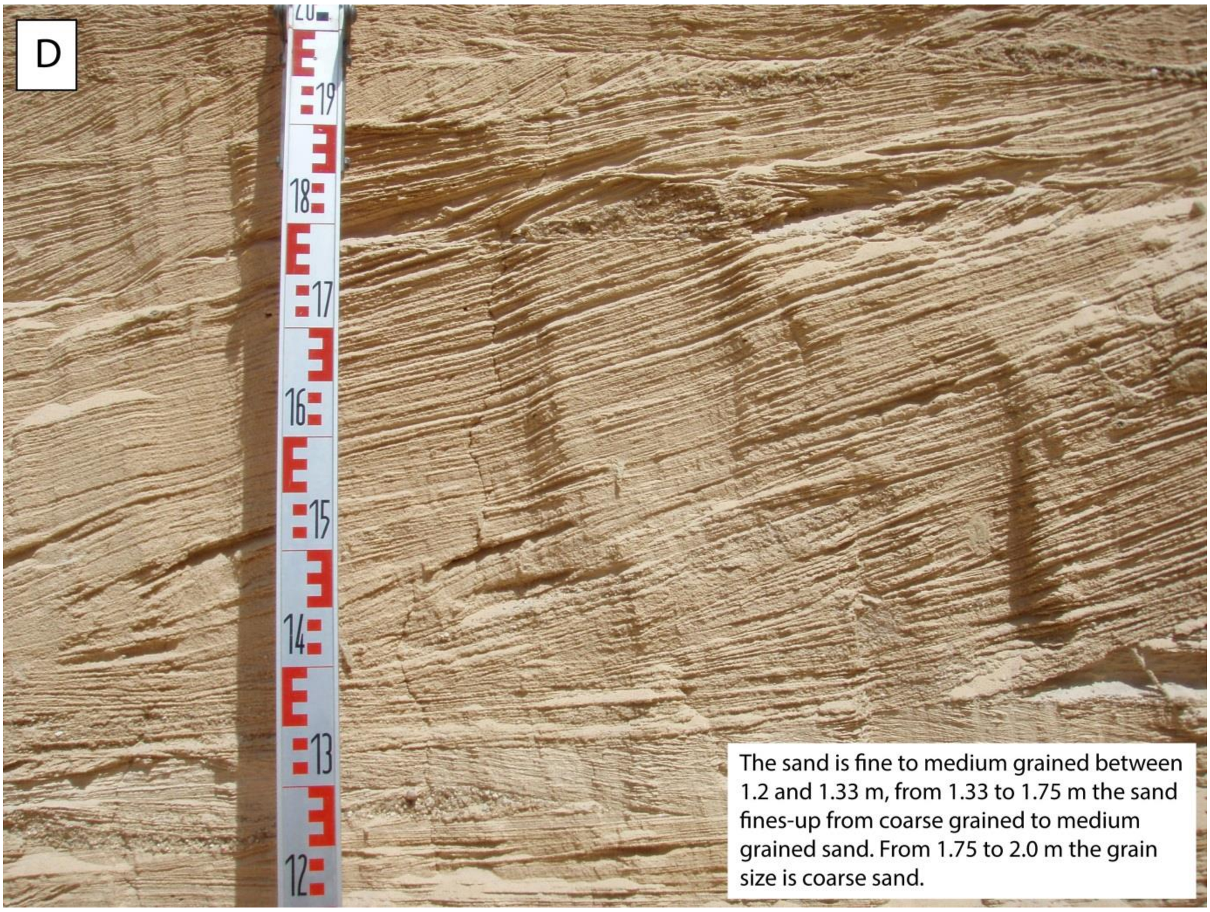


Base of section, 0-0.68 m the first 5 cm are covered by loose sand and the laminae in the first 0.3 m are a bit faint but some discontinuous low-angle lamination should be visible. The grain size of the sand between 0 and 0.4 m is fine grained sand.

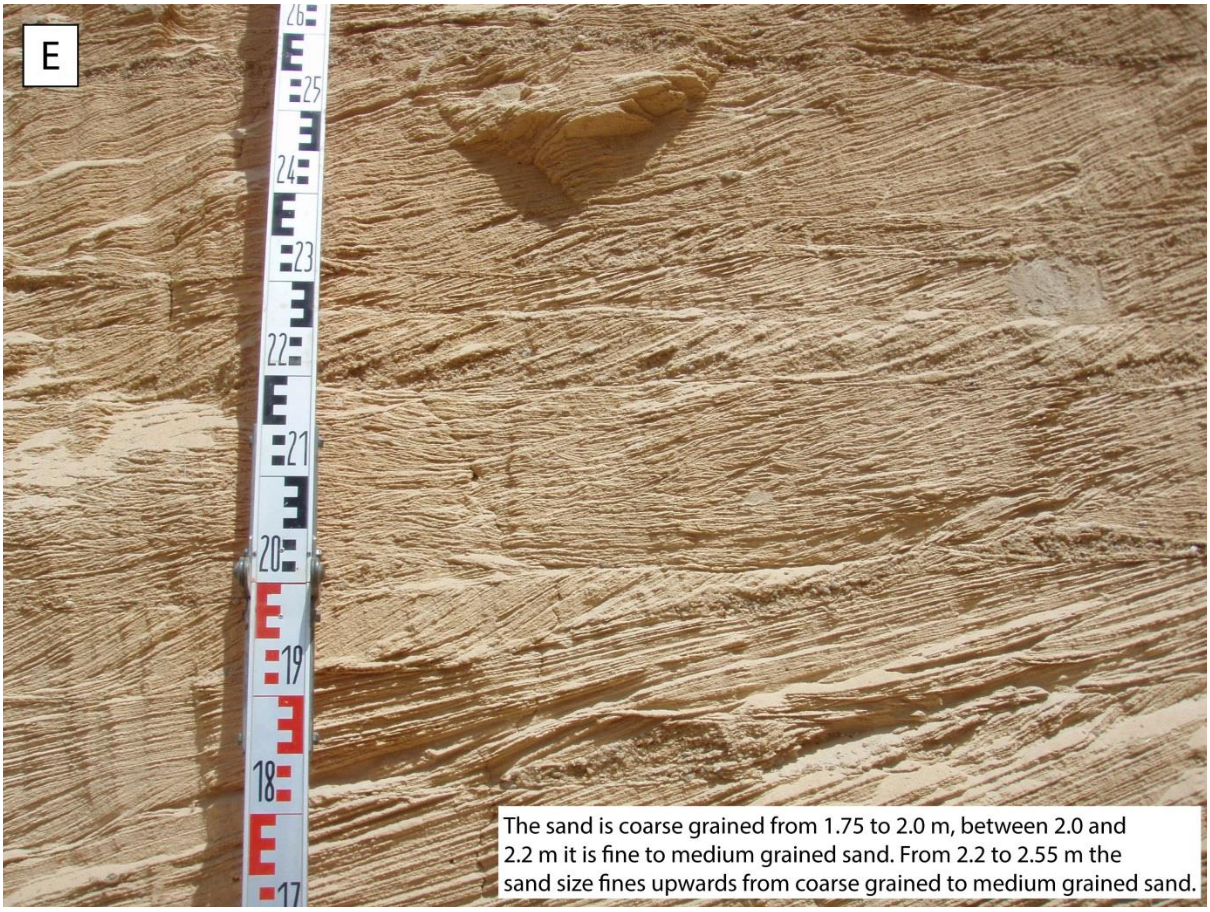
figure B. Base of section (0-0.68 m), the first 5 cm are covered by loose sand and the laminae in the first 0.3m are a bit faint but some discontinuous low-angle lamination should be visible. The grain size of the sand between 0 and 0.4 m is fine grained sand.



C. 0.45 to 1.28 m, the sand is mostly coarse grained but fines to medium grained sand around 0.7 m, between 1.0 and 1.2 m the sand is medium grained, but some thin granule layers are visible. Note the complex nature of the cross-strata and the interbedded planar lamination and sets of cross-stratified sand and gravel.

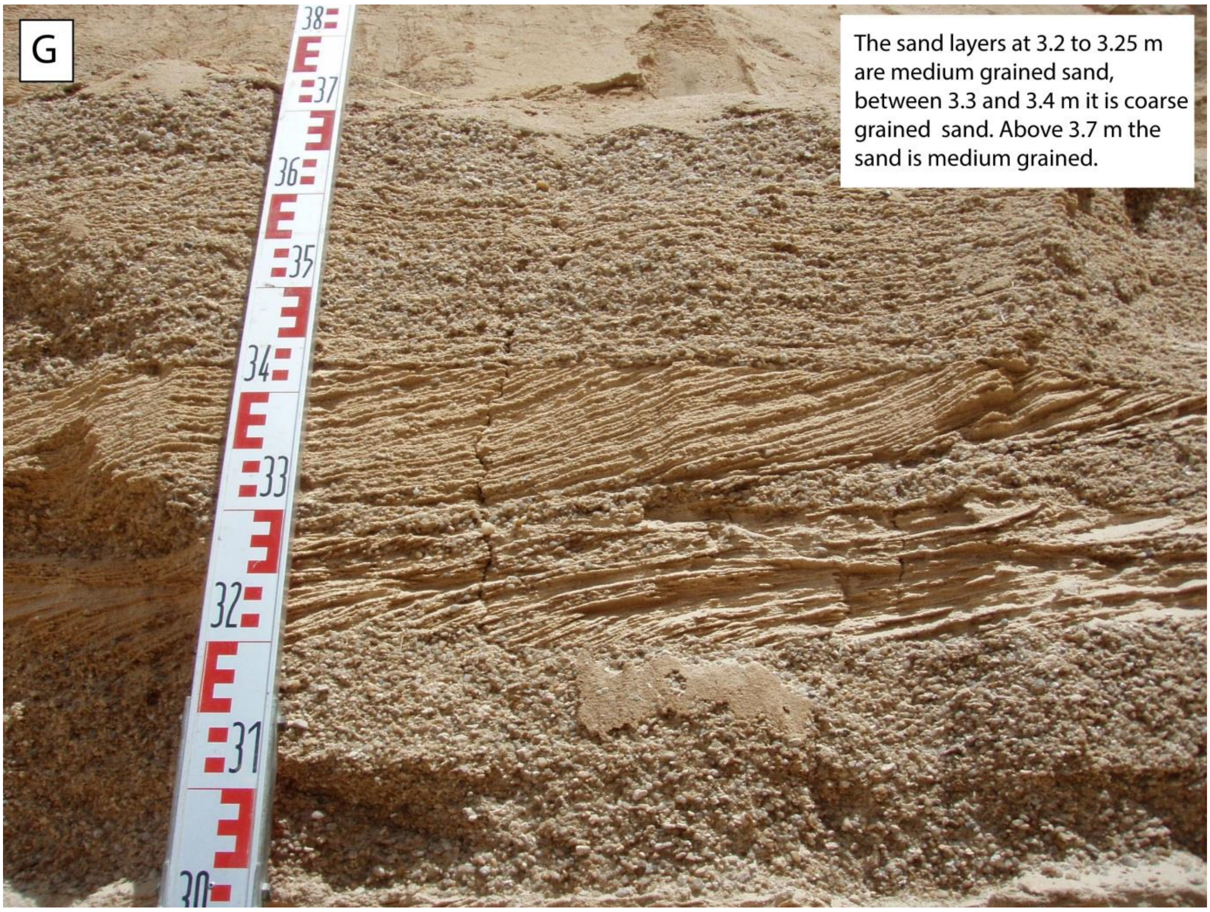


D. 1.2 to 2.0 m, well exposed sets of cross-stratified sand, field observations shows that the sand is fine to medium grained between 1.2 and 1.33, from 1.33 to 1.75 the sand fines up from coarse grained to medium grained sand. From 1.75 to 2.0 m the grain size is coarse sand.



E. 1.73 to 2.68 m, note the different sized sets of cross-strata. Field observations indicate that the sand is coarse grained from 1.75 to 2.0 m, between 2.0 and 2.2m it is fine to medium grained sand. From 2.2 to 2.5 m the sand size fines upwards from coarse grained to medium grained sand.

F. 2.22 to 3.35 m, the lower half of the photograph repeats the section shown in figure 7. From 2.6 to 2.9 m the sand size fines upwards from coarse grained to medium grained sand.



G. 3.0 to 3.8m the top of the accessible part of the section. The grain size is mostly granules (0.2 to 4 mm) with some small pebbles. The sand layers at 3.2 to 3.25 m are medium grained sand, between 3.3 and 3.4m it is coarse grained sand. Above 3.7m the sand is medium grained.