Sedimentary structures – sole marks

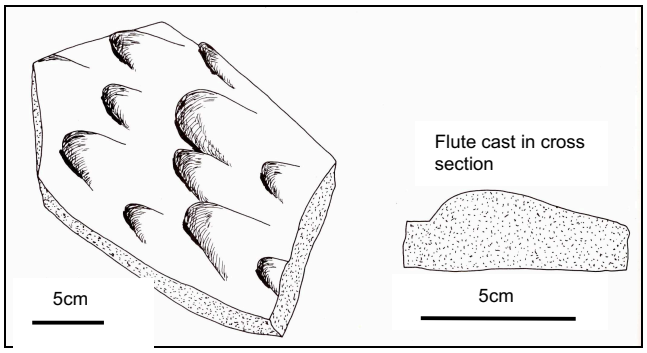
Evidence from the base of a sedimentary bed

In underwater areas that have strong currents at times, but have quiet periods in between, alternating layers of sand and mud are deposited. These later become sandstones and mudstones.

Conditions like these are typical of quiet deep sea areas where turbidity currents deposit turbidite sediments, but can also occur where there are storm surges in shallow seas and floods over river floodplains.

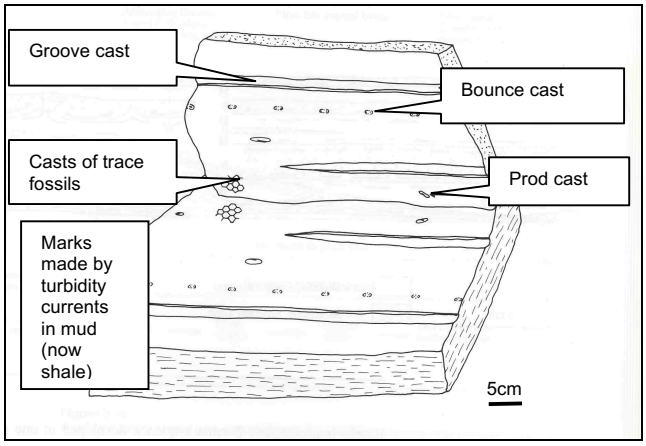
During the quiet times, fine particles settle out of suspension in the water building up a layer of mud. Then when a strong current flows over the mud surface, the surface of the mud may be eroded before depositing sand on top. The current may erode hollows and other marks in the mud, which are then filled up by sand,

When the sand becomes sandstone, casts of the hollows and other marks can be preserved on the bases of the sandstone beds and these are called 'sole structures' because they are found on the 'sole' of the sandstone beds. The sole structures can be seen when mudstone beneath the sandstone layers is eroded away. The sole structures may give evidence about which way the current flowed, helping us to interpret past environments..
The diagrams show some of the ways in which sole marks may be created. Ask pupils to study them and to answer the questions.



Flute casts on the base of a bed of sandstone (i.e. the specimens are drawn upside down)

Flute marks are made by strong eddies (vortices) in the current. These scour the underlying mud deeply at first, but then weaken and widen as they move on down current. In which direction was the current flowing which left these flute casts? (*A. from left to right*).



Tool marks, shown here as eroded hollows in the mudstone below and as bumps and ridges in the sandstone above.

Tool marks are produced when larger particles in the current scoured out the underlying mud. They include long **groove casts**, where fragments were dragged along, and **bounce casts** or **prod casts,** where debris bounced along, or hit the mud like a javelin landing on grass. The hollows formed in such ways were then immediately filled in with sand, which later turned to sandstone.
Work out what the trend of the current was which affected this example. Can you give its direction? If not, why not? (*A. The current flowed from left to right, or from right to left, but, in this case, there is insufficient evidence to state which. It is sometimes possible to decide the direction, if the prod marks are triangular, akin to the mark left by a javelin penetrating the grass, but then rebounding out again.*)

Now ask pupils to study the photographs of sole marks below. In each case, ask them: to name the type of sole marks shown; to work out the trend or direction of the ancient current; and to state if the sample is the right way up, or upside down.

Photo 1. Sole casts, Aberystwyth Grits, Aberystwyth, Wales (coin is 2cm in diameter)

Photo 2. Sole casts, Mam Tor Beds, Mam Tor, Derbyshire

Photo 3. Sole casts, Aberystwyth Grits, Moriah, mid- Wales.
(*All photos by Peter Kennett*)

The back up

Title: Sedimentary structures – sole marks

Subtitle: Evidence from the base of a sedimentary bed

Topic: An activity based on diagrams and photographs of sole marks, where pupils are asked to look for evidence of past environments and the orientation of the samples.

Age range of pupils: 14 – 18 years

Time needed to complete activity: 15 minutes

Pupil learning outcomes: Pupils can:

- relate photographs of sole marks on the undersides of beds to diagrams of their origins;
- appreciate that sole marks may often be used to determine the direction in which an ancient current (palaeocurrent) flowed;
- use the presence of sole marks on rock sequences at outcrop to determine if the beds are the "right way up" or not.

Context: The activity is part of a series on sedimentary structures and the ways in which they can be used to interpret past conditions.
Answers to the questions relating to the photographs are:
Photo 1: *Flute casts, with the deeper, narrow part on the left, showing a current flowing from left to right. The specimen is upside down.*
Photo 2: *Flute casts, groove casts, prod casts. The groove casts indicate a current flowing from left to right, or from right to left. The flute casts show that the current flowed from left to right. Prod casts appear to point to the left, confirming that the current came from that direction. The specimen is upside down.*
Photo 3: *Groove casts and possible prod casts. The groove casts show a current flowing from left to right or from right to left. The prod marks appear to narrow toward the right, indicating a current flowing from that direction. We are looking at the base of the bed, so the strata are inverted. The "way-up" of a bed may sound to be only of academic interest, but such evidence enables the geological structure of whole regions to be unravelled, such as in this example from mid-Wales.*

Following up the activity: Try modelling the original flute marks, groove marks and prod marks in mud using modelling clay, to match the diagrams, using a spoon or similar implement. It will not be possible to replicate the original vortex, but the outcome may at least resemble the diagrams. Then make a rim round the clay and make a cast of the "sole marks" using Plaster of Paris. Pupils can be challenged to work out the "ancient current flows" from the casts when they have dried out.

Underlying principles:

- Some areas have very quiet times, when mud layers are deposited, followed by very active sand-depositing currents.
- These currents can erode the previously deposited mud. If the mud is cohesive enough, it will retain the shape of the eroded feature, such as a flute mark or tool mark.
- Coarse sand is deposited rapidly as the current passes and fills up the eroded hollows, to leave sandstone casts of them.
- Flute casts and some tool casts may provide evidence of the direction of flow of the current.
- Sole casts may indicate whether a sequence of the beds is the right way up, or if it has been inverted by Earth movements.

Thinking skill development:
Thought processes of construction are involved when relating the photographs of sole casts to the diagrams. Upside-down structures may involve cognitive conflict, and metacognition is used when pupils discuss the activity. Bridging skills are needed to relate the observations to the real world.

Resource list:

- access to the photographs and diagrams above – either projected or on paper

Optional –

- modelling clay or Plasticine™
- dessert spoons, or similar implements
- Plaster of Paris
- mixing pots and stirrers
- water

Useful links: www.earthlearningidea.com

"Sedimentary structures – graded bedding: make your own graded bed – one depositional event, but with coarse to fine sediment", and "High flow. Low flow? - atmosphere and ocean in a tank: hot, cold and particle-filled density currents as they flow in the atmosphere and ocean".
+ ref to load casts, when written?

Source: Written by Peter Kennett of the Earthlearningidea Team, with diagrams, by permission from King. C. (1991) Sedimentology Book 2: The Depositional Environments. Longman.