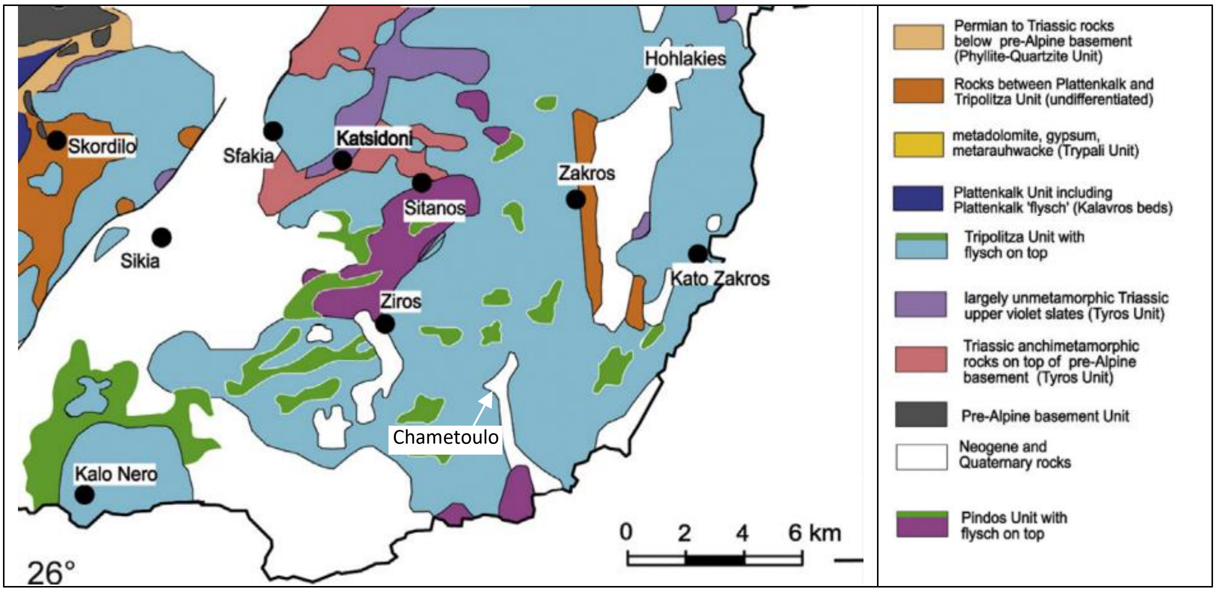
Tripoliza Flysch and Pindos Nappe at Chametoulo

View of Chametoulo village (left). A normal fault runs along the right side of the picture.

Compiled by George Lindemann, MSc.

Berlin, October 2023



Geological Map of south-eastern Crete [Source: Tonian basement in the eastern Mediterranean, W. Dörr, G. Zulauf et. al.]

Tripoliza Flysch and Pindos Nappe at Chametoulo

Overview showing the location of 1: Pindos Nappe, 2: Tripoliza flysch, 3: Normal fault [Source Google Maps]

Normal Fault

Normal fault within Tripoliza limestone (arrows)

Footwall of normal fault. 1: Slickenslide, 2: Cataclastic texture

1: The slickenslide indicates diagonal movement. Dashes lined indicates direction of movement

A slickenside is a smoothly polished surface caused by frictional movement between rocks along a fault. This surface is typically striated with linear features, called slicken lines, in the direction of movement.

2: The smooth slicken slide surface was formed on a tectonic breccia (i.e. cataclasite). Cataclasites are found where high shear strain causes fracturing at the contact of two rock surfaces, such as at fault and thrust planes.

Tripoliza limestone in its original state. It is normally darker than Pindos limestone.

The Tripoliza limestone contains large benthic foraminifers (probably Nummulites) indicating shallow water conditions.

Pindos Nappe

Pindos nappe thrust upon Tripoliza flysch. 1: Pindos limestone, 2: Tripoliza flysch. Dashed line indicates thrust plane

Pindos limestone.

Tripoliza Flysch

Overview of the Tripoliza flysch outcrop. 1: Pindos Nappe, 2: Shale – sandstone sequence, 3: Shale, 4: Sandstone, 5: Conglomerate


1: Highly sheared Pindos limestone at base of nappe and contact to flysch.

2: Flysch consisting of shale-sandstone sequence

Closeup of previous picture showing plant fossils within the sandstone beds (greywacke)

The fining-up sequence is probably the result of a turbidity current. 3: Shale, 4: Sandstone, 5: Conglomerate

3: Silty shale. The weathered surface indicates some trough cross bedding

Fining-up sequence. 5: Conglomerate, 4: Sandstone (greywacke)

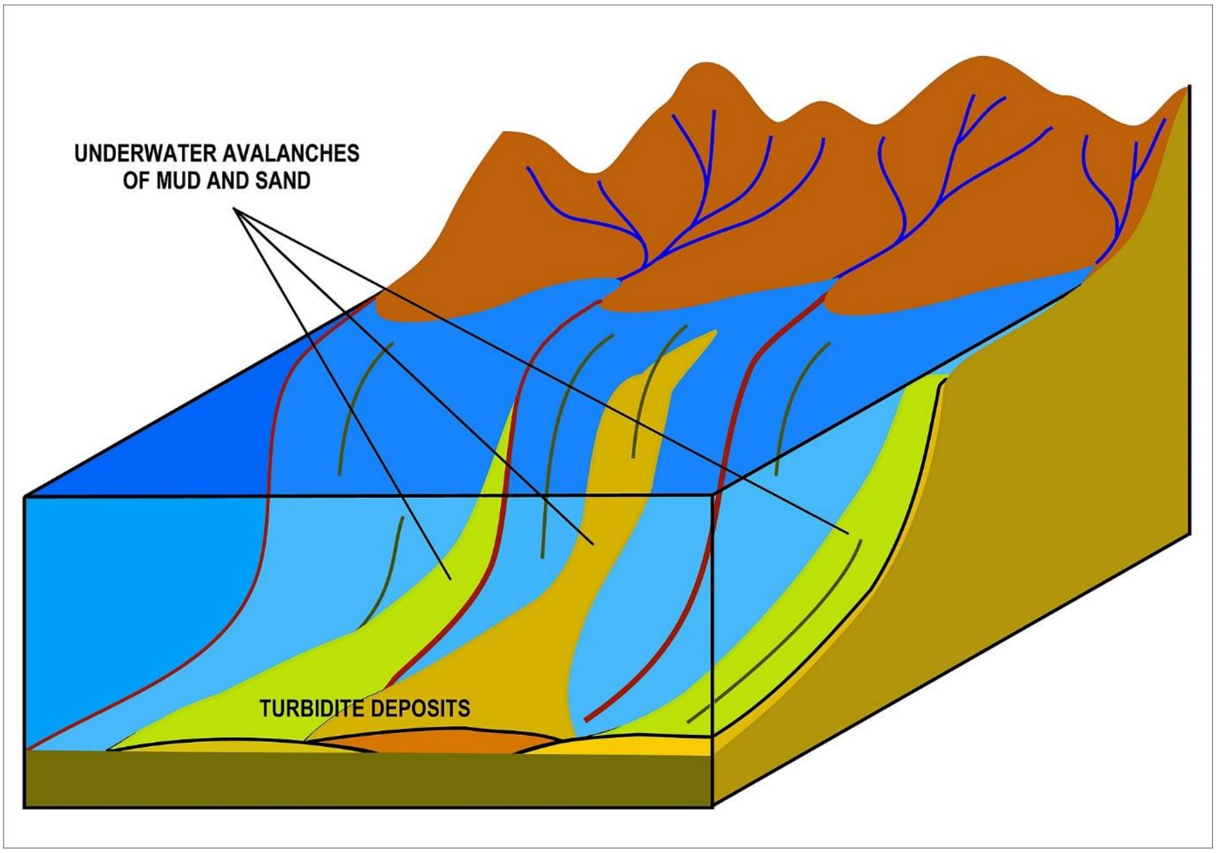

4: Sandstone (greywacke)

5: Conglomerate

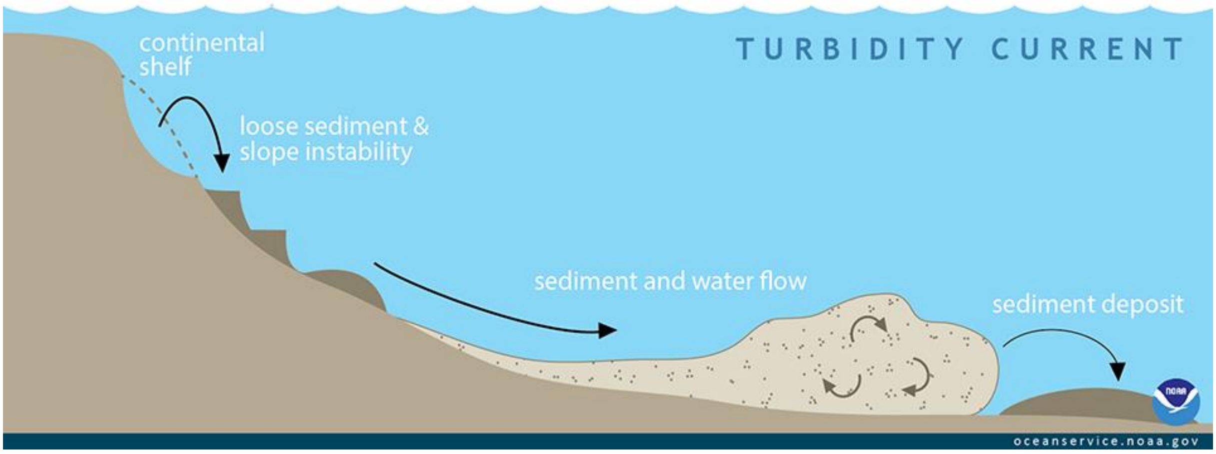
Flysch is the term used to describe sequences of marine clastic sediments that are formed, among other things, by the sliding of parent sediments previously deposited on the continental shelf over the continental slope into the deep sea. This sliding usually takes the form of avalanche-like turbidity or suspension currents. Since such slides are repeated relatively frequently during a mountain-building process that lasts millions of years, characteristic sequences develop in which layers of mudstone alternate with layers of coarser-grained material. The latter often have a very mixed mineral composition. Like sandstone, they consist mainly of quartz grains, but usually also contain larger amounts of lime or clay. Furthermore, they may contain a wide variety of minerals, including glauconite, mica and/or feldspar.

The layers of coarser material that are deposited by the suspension currents within a few hours or days are also called turbidites with regards to their formation. The layers of mudstone o shale in between are the result of an extremely slow, continuous sedimentation of clay particles (the so-called background sedimentation) in the deep sea.

The term flysch thus refers to a special sedimentary facies and a distinction can be made between a distal and a proximal facies, whereby the transition between the two facies is gradual. In typical distal flysch, the turbidites are represented by thin silt bands, which are characterised in the rock by a different weathering colour rather than by a difference in grain size visible to the naked eye. In typical proximal flysch, the turbidites are represented by sandstone beds, sometimes more than 1 metre thick, which may even contain plant remains [from Wikipedia].



Turbidites are deposited in deep ocean troughs below the continental shelf, or similar structures in deep lakes, by turbidity currents which slide down the slopes [Source: Wikipedia].



Longitudinal section through an underwater turbidity current [Source: Wikipedia].

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Website, Wikipedia: https://www.wikiwand.com/de/Flysch

Website, Geology is the Way: https://geologyistheway.com/sedimentary/turbidity-currents/

Website, Wikipedia: https://www.wikiwand.com/en/Bouma_sequence

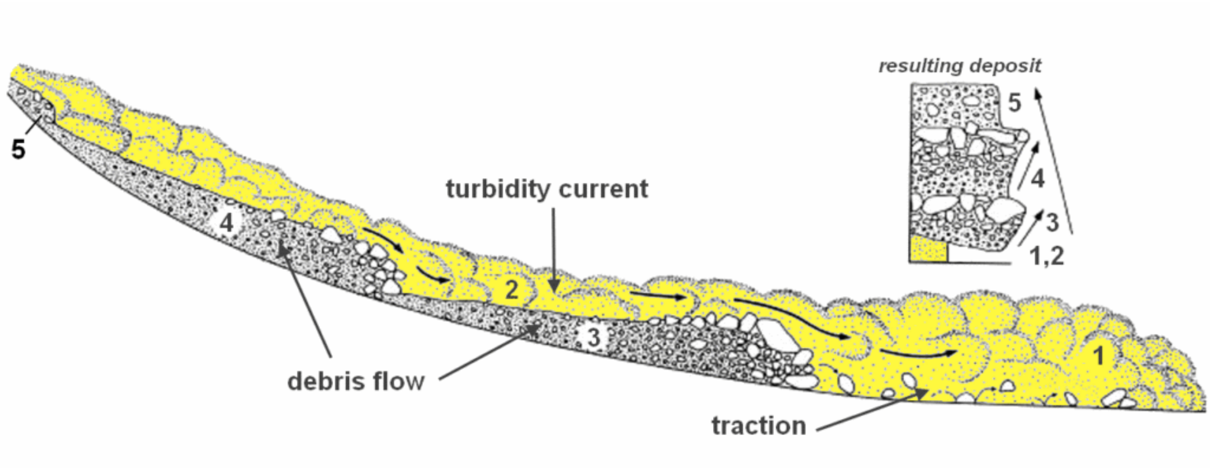
Appendix

Deep marine flysch deposits

Source: website Geology is the Way

https://geologyistheway.com/sedimentary/turbidity-currents/

Turbidity currents and turbidites



Example of depositional architectures related to turbidity currents and debris flows. Credits: Mikesclark (wikimedia.org)

Turbidity currents are underwater gravity flows triggered by the mobilization of sediments on a slope. These phenomena are common in deep marine environments close to the continental scarp, but can occur also in lakes and coastal environments or be associated with carbonatic sedimentation in deep water basins close to reefs. Their formation requires the presence of large amounts of loose sediments close to a scarp, for example next to a delta. Once triggered, turbidity currents may travel for tens to hundreds of kilometers and distribute millions of cubic meters of sediments on the seafloor, forming deep sea fans. The lithified product of a turbidity current is a turbidite, which is a graded layer that generally contains a coarse-grained base and a fine-grained top (conglomerate to coarse sandstone to mudrock).

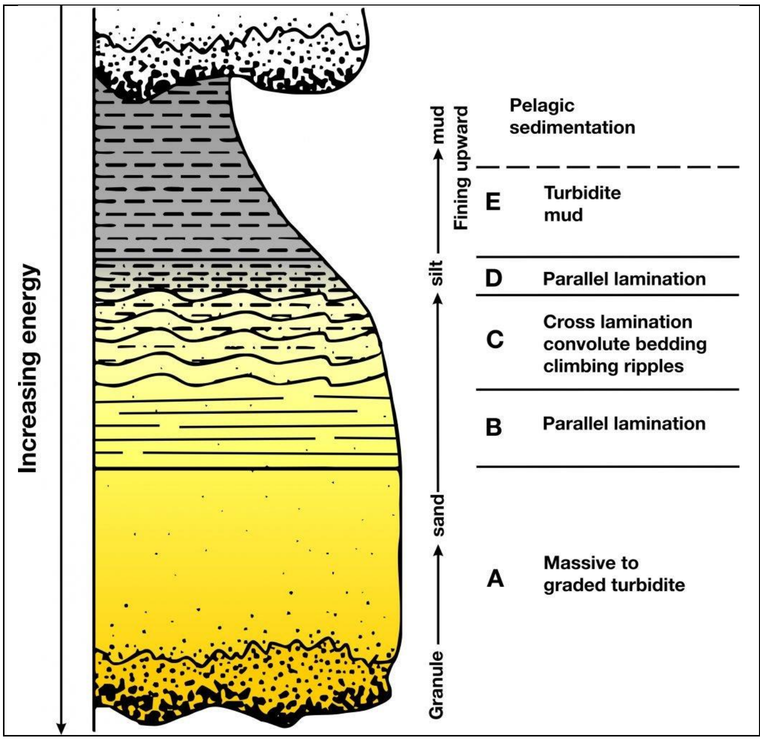
How turbidity currents form

Turbidity currents originate when water-rich clastic sediments are destabilized, for example by a submarine slump, and start to move downslope in underwater environment. As the sediment starts to slide on the seafloor, it incorporates water and progressively lose cohesion, becoming a mixture of water and suspended particles that move together in density flow.

Turbidity currents are density flows driven by the difference in density between the turbulent sediment-loaded water and the surrounding marine water. For this reason they can travel on the seafloor for tens to hundreds of km at speeds like 10 to 30 km/h before stopping. A nice story that led to the discovery of these processes years later is related to the M 7.1 earthquake that struck Newfoundland on November 18, 1929. After the earthquake, the telegraph cables laid on the Atlantic floor were progressively sheared off, one after another, over the next 13 hours and 17 minutes, up to some hundreds of kilometers away from the epicenter. Today, we know that the seismic event triggered a submarine landslide that produced a turbidity current that travelled on the abyssal plains of the Atlantic, interrupting all communications.

Turbidites and Bouma sequence

Turbidites were first described in the field by Arnold H. Bouma (1962), who defined what today we call Bouma sequence in deep water marine sediments. Bouma recognized that many of the layers he was investigating consisted of typical intervals with homogeneous structures. In particular, he recognized five characteristic intervals from the base to the top of the turbidite



E – laminated to homogeneous mud.

D – laminated silt to mud

C – sandstone with cross-lamination and convolute lamination

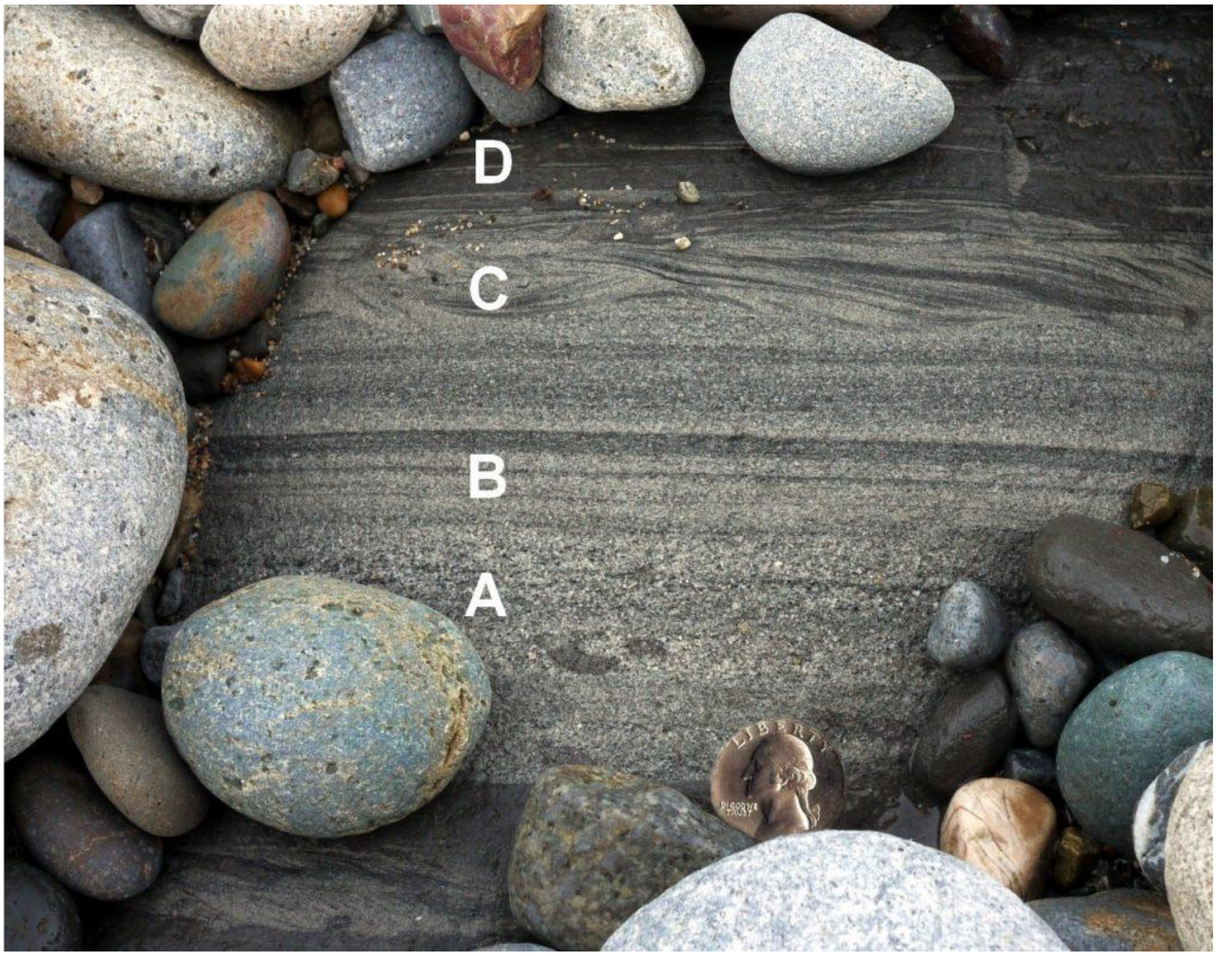
B – sandstone with plane parallel lamination

A – a graded interval with gravel to sand size particles lacking any structure, starting with an erosional surface

The interpretation of this structure is related to the progressive decrease in speed that turbidites experience as they travel on the seafloor. When the turbidity current is not fast enough anymore to hold all its sedimentary load in turbulent suspension, the coarser grains begin to settle all at once generating the first graded bed (A). Finer-grained sand can continue to move by traction while there is still a current flowing and speeding down: this forms first parallel lamination (B), then cross lamination with ripples and climbing ripples (C). Laminated fine-grained silt and mud (D) deposit when the flow is very slow and close to stop.

Finally, layer E deposits when the turbidity current is over and the mud particles that remained suspended in water start to slowly decantate. This layer represents also the inter-layer between two turbiditic events, as it contains also the mud that slowly settles down from the water column in underwater environments. Therefore, while layers A to D represent a single event that may have occurred in less than a few hours, layer E testifies both the settling of the mud from the tail of the turbidite and the slow pelagic sedimentation of mud from the water column that takes place between a turbiditic event and the next one. The resulting architecture of a turbidite is characterized by a fining upward sequence, with sediments that are progressively more and more fine-grained towards the top, as a result of decreasing velocity and energy of the flow.

Fining-upward bed of sandstone showing grading from coarse to fine sand (layer A of Bouma). Cala del Leone, Quercianella, Italy. Photo Samuele Papeschi/Geology is the Way.

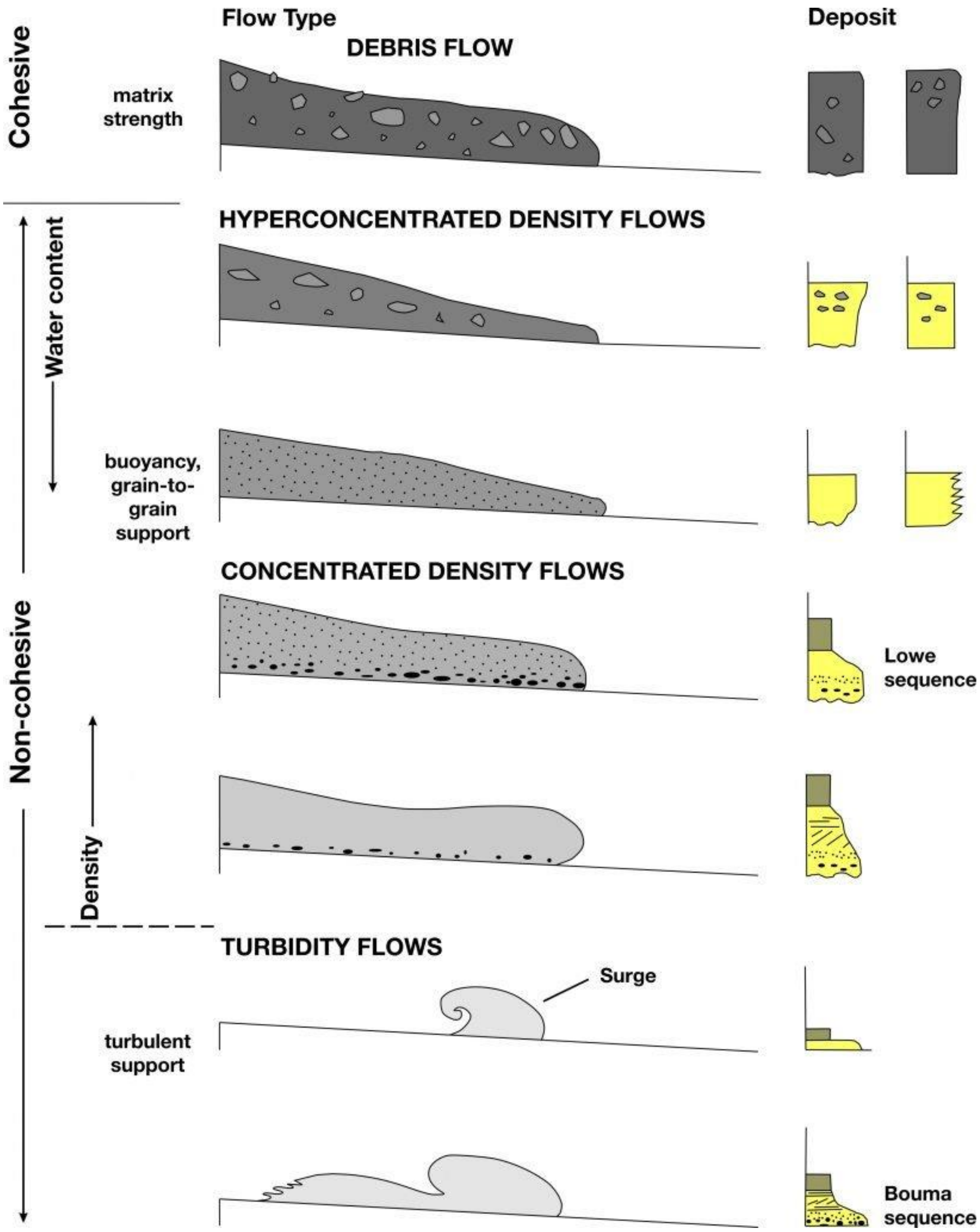


Bouma A, B, C & D layers in a turbidite from the Cretaceous Pigeon Point Formation, Pescadero Beach, California. Photo by Mikesclark.

Turbidite with thick graded base (A), laminated layer (B), and convolute laminations (C). The base of the turbidite is the dark layer close to the bottom, where load structures are visible. Cozy Dell Formation, Eocene. Tapatopa Mountains, Ventura Co., California, USA. Photo by Mikesclark.

Other types of turbidites and associated deposits

Turbidites in nature show a wide range of structures, beyond the Bouma sequence. In first order, Bouma sequences themselves may be incomplete, as some grain sizes can be missing and therefore do not develop the associated layers. More generally, mixtures of water and sediments produce a wide range of non-cohesive density currents, with different viscosity and active mechanisms that allow the mixture to flow. Finally, turbidites may evolve an incorporate more water as they flow and this causes lateral variations in depositional facies and structures.



Types of turbidity currents and associated deposits. Redrawn based on Mulder & Alexander (2001).

Hyperconcentrated and concentrated density flows

High density currents like hyperconcentrated and concentrated density flows are sustained by buoyancy and grain- to grain support. Their relatively high viscosity and density hinders the development of Bouma sequences, since grain sizes are not free to move and separate within the flow. Hyperconcentrated flows are still chaotic and poorly organized, while in concentrated density flows we may see graded beds (to a certain degree) topped with cross and parallel laminae, even if the separation of the various grain sizes is not perfect.

Lowe sequence

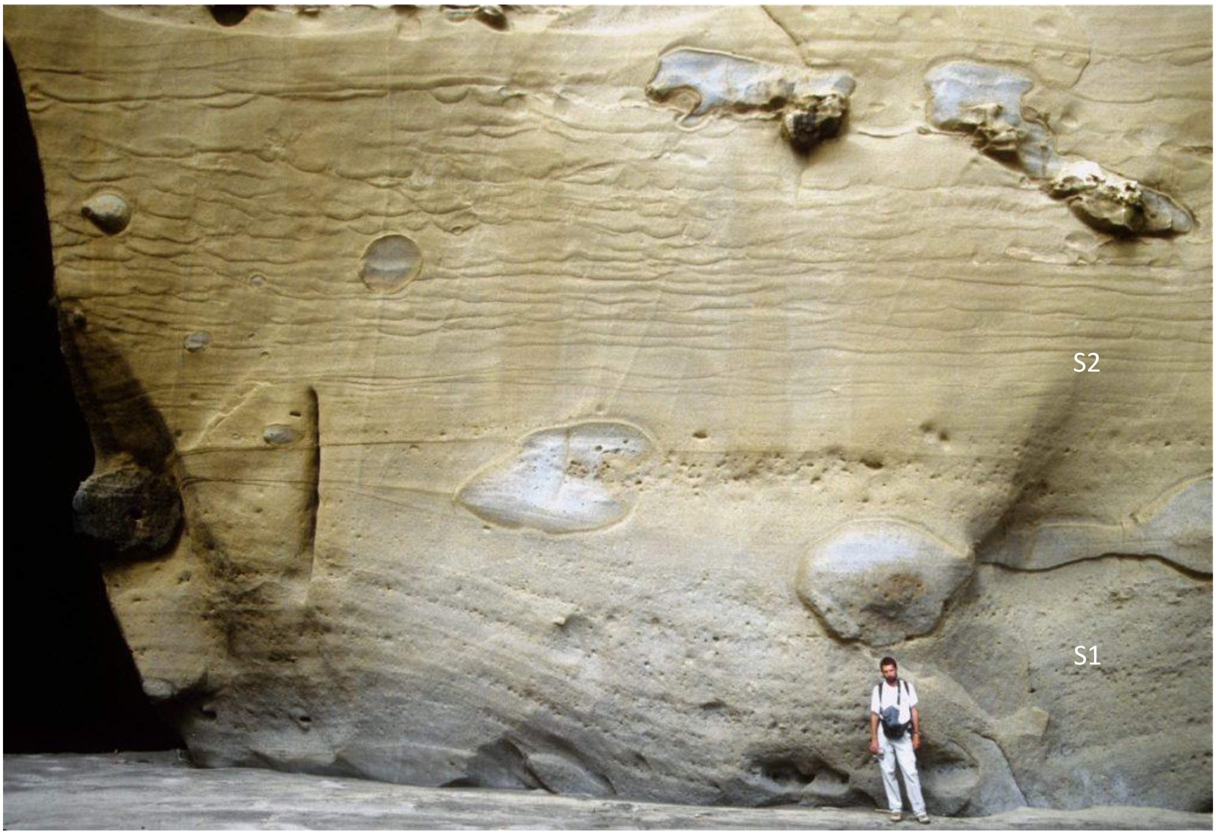
The Lowe sequence describes a set of sedimentary structures in turbidite sandstone beds that are deposited by high-density turbidity currents. It is intended to complement, not replace, the better known Bouma sequence, which applies primarily to turbidites deposited by low-density (i.e., low-sand concentration) turbidity currents.

The Lowe sequence adds three layers labelled S1 through S3 to Bouma's terminology, with S1 being at the bottom and S3 at the top of a sandy turbidite bed. As with the Bouma sequence, each layer has a specific set of sedimentary structures and lithology. And like the Bouma sequence, the layers become finer grained from bottom to top. The layers are described as follows.

S3 - Massive to graded, fine- to coarse-grained sandstones that overlie the S2 layer represent deposition from a turbulent suspension. Sometimes dish structures and dewatering pipes are present. This layer is essentially the same as the Bouma A layer.

S2 - Inverse (reverse) graded, fine- to coarse-grained sandstone layers that overlie the S1 layer represent deposition as traction carpets, where grain-to-grain collisions are an important process.

S1 - Sandstone to conglomerate that are at the base of the turbidite and display parallel-laminated to cross-laminated beds that indicate traction deposition, wherein the current moves grains, pebbles and large clasts by rolling and sliding them across the surface beneath the flow. [Soucre: Wikipedia]



Lowe sequence: thick deposit of a concentrated density flow with coarse-grained laminated sandstone at the base and massive sandstone at the top. The wavy surfaces are dish-structures, formed by soft-sediment deformation of the turbidite. Talara, Peru. Photo by Zoltan Sylvester via wikimedia.org.

Debris flows

Debris flows (which are not turbidity currents) are cohesive flows where sediments move suspended in a muddy/sandy matrix, producing unsorted, massive, and chaotic deposits. When a certain amount of water starts to be present in the flowing sediment, water infiltrates between grains reducing the overall matrix strength and making the flow non-cohesive.

Debrite: a chaotic deposit with blocks in a muddy matrix. This deposit is produced by a debris flow. Black Mill Bay. Isle of Luing, Scotland. Photo by Anne Burgess via Geograph.uk.