Concretions, nodules and weathering features of the Carmelo Formation

The features that characterize a sedimentary rock can form at diverse times and under very different conditions. Geologists divide these features into four classes. **Depositional features** form while the sediment is accumulating. They can tell a much about the ancient environment of deposition and include many examples in the Carmelo Formation. **Diagenetic features** develop after the sediment has accumulated and can include the transition from sediment to rock. They typically have a chemical origin and include nodules and concretions. **Deformational features** result from the bending, buckling, or breaking of sedimentary strata by external forces. **Surficial** (**weathering**) **features** develop in a rock at or near the surface where it is subject to groundwater percolation. These features can reflect both physical and chemical processes. a number of examples exist in the rocks of Point Lobos. (See link to **The Rocks of Point Lobos** for further descriptions).

Depositional	Diagenetic	Deformational	Surficial
Features that form as the sediment accumulates	Features that form after the sediment was deposited until it becomes a rock	Features that develop anytime after deposition and reflect the bending, swirling, or breaking of the stratification	Features that form while the rock is exposed at or near the present-day land surface
Examples: Bedding (layering, stratification) Grain size Grain organization (grading, pebble orientation, imbrication) Ripple marks Ripple lamination Trace fossils Erosional scours Channels	Examples: **Nodules** **Concretions** Lithification (rock formation)	Examples: "Convolute lamination" Slump structure Tilting Folds Faults	Examples: **Iron banding** **Honeycomb weathering** **Color change**

Features of a sedimentary rock sorted according to their origin. Items in red are described in this link.

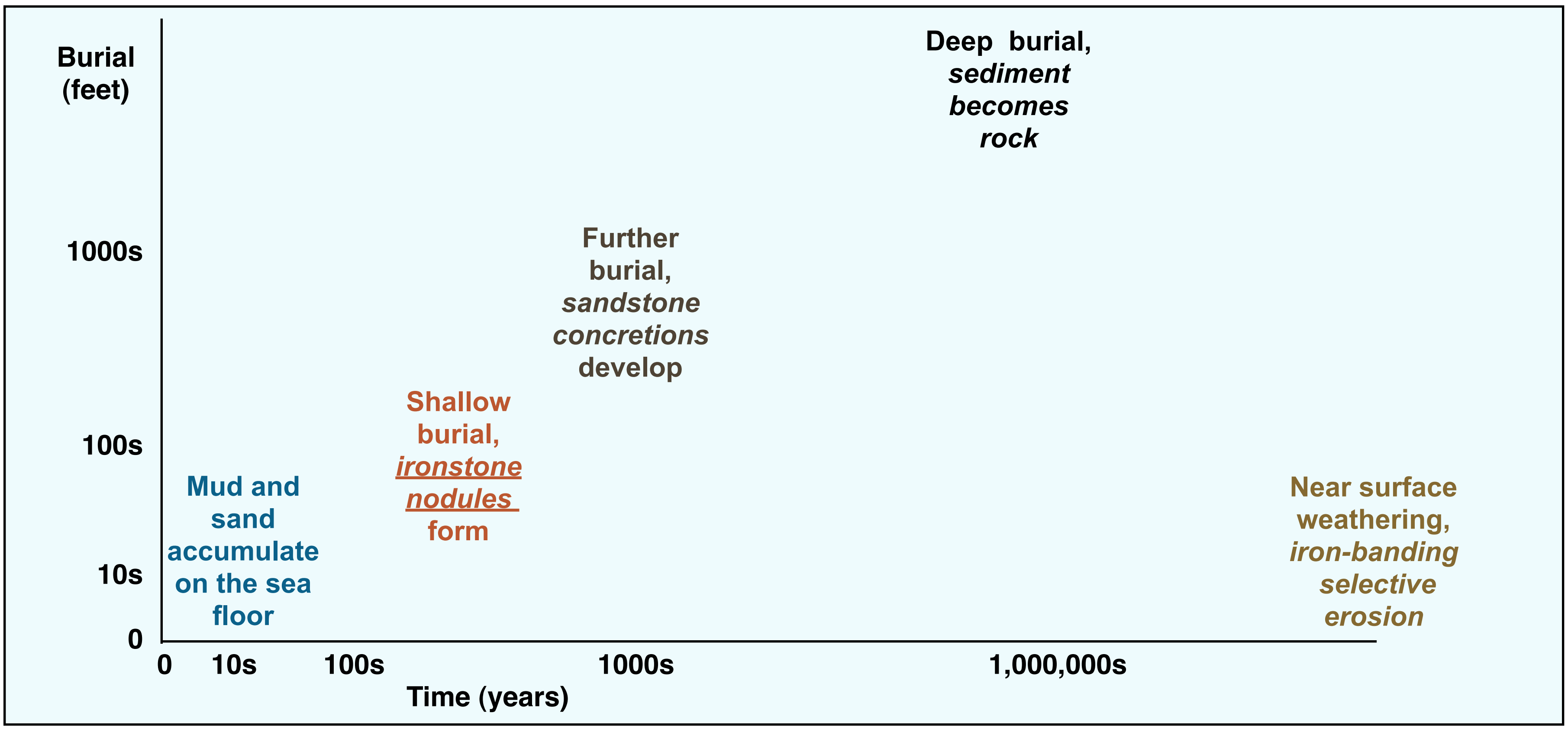
It can be helpful to consider these different classes of features in terms of where they form relative to the land surface and when they form relative to the time of deposition.

Depositional features (sometimes called "primary features" because they are the original features of a sedimentary rock) form while the sediment is accumulating. They reflect processes on or just below the surface of accumulation, such as the sea floor.

Diagenetic features (sometimes called "secondary features" because they following sediment accumulation) develop after the sediment is deposited and can include the transition from sediment to rock. They can develop a few years to millions of years after a sediment was deposited under a burial conditions of several feet to thousands of feet of additional sediment

Deformational features can develop at any depth, and any time after the sediment is deposited, even long after it has been converted to rock. They can occur within minutes of a turbidite sand accumulation or long after a sediment is converted to rock.

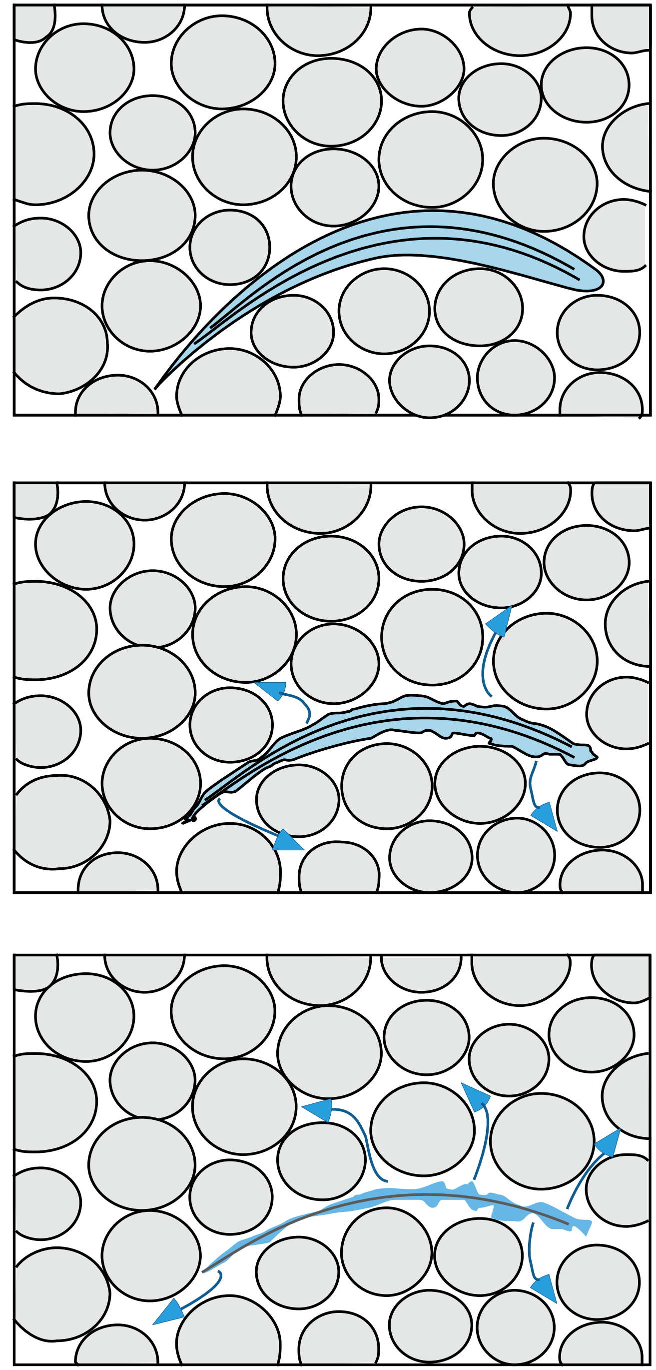
Surficial (or "weathering") **features** develop when rock is exposed at or near the surface and subject to oxidation and groundwater percolation.



Diagenesis

The diagenetic process begins very shortly after a sediment is deposited. Initially the water between the sediment grains has the composition of sea water, but that quickly begins to change. Plant material within the sediment begins to decompose and the water becomes more acidic. Calcium carbonate, the stuff of most sea-shells, reacts with the acidic water by dissolving, releasing calcium and carbonate ions into the water between the sand grains. Decomposition of organic matter also reduces the dissolved oxygen in the water trapped between the sediment grains below the seafloor. As a consequence, iron in mineral grains becomes more soluble and leaches out, adding another component to the water trapped in the sediment.

With time, the chemistry of the trapped water becomes increasingly complex. It also can move as it is squeezed out of compacting clay rich layers and forced into sandy beds with more pore space. The dissolved materials, such as calcium, iron, and carbonate, may encounter a site within the sediment where they are less soluble and precipitate out either as cement between the grains or by replacing the existing sediment. This latter process is poorly understood, but there is evidence that in some cases the new material begins as a gel.



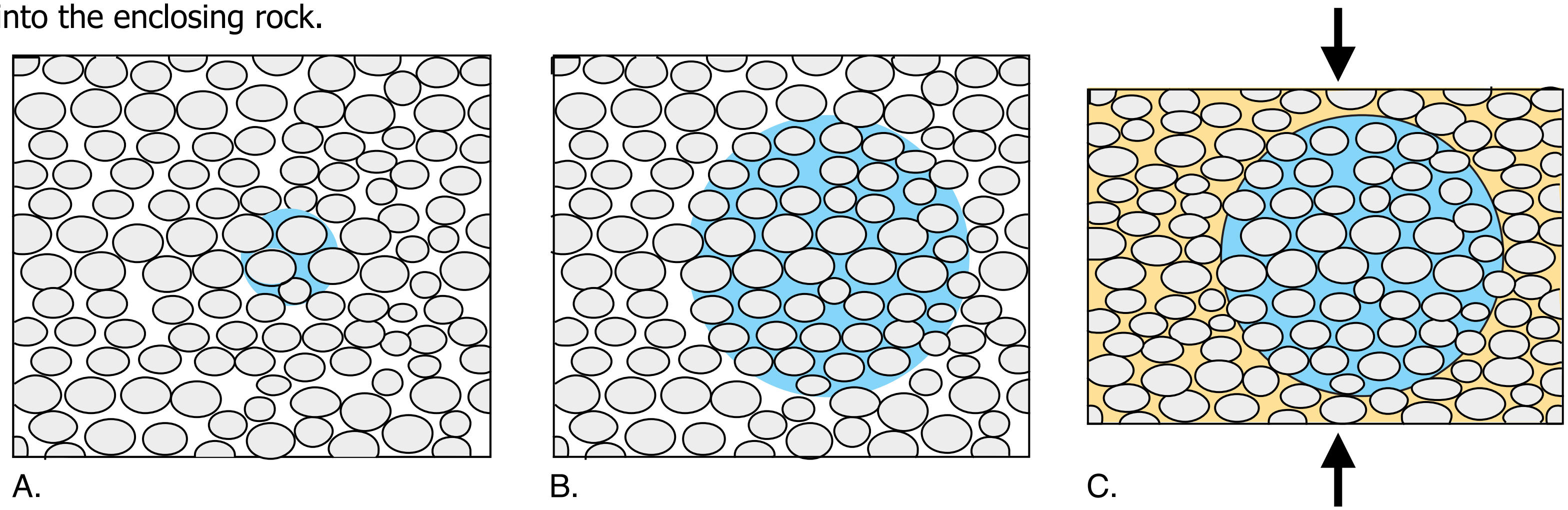
The causes of the initial chemical precipitation differ. In some cases, it appears to be due to the decay of organic matter. Many concretions have fossil remains at their cores. In other cases it may reflect variations in the pore water chemistry. Commonly we simply do not know the cause.

In sandy sediment, calcium carbonate may fill the pore spaces, creating a small hard lump in the semi-consolidated sand. With time, this lump may grow as additional calcium carbonate accumulates. Eventually, with sufficient burial, the weight of the overlying sediment compresses the relatively loose sand into rock as the sand grains interlock.

Because the concretion and the native rock are cemented by different processes, they behave differently under physical stress. The native rock has a bit of flexibility that the concretions lacks; when an external stress is imposed, the concretion can crack independently form the enclosing rock. The concretions in the Carmelo Formation commonly display "independent" fractures that may extend for only short distances into the enclosing rock.

The rock around the margin of the Carmelo sandstone concretions commonly seems more prone to erosion than either the native rock or the concretions. With sufficient erosion, concretions are often washed away, leaving holes in the rock some of which can be several feet across. Partly eroded concretions are common features in the Carmelo.

A large sandstone concretion in the Carmelo Formation. Erosion of the sandstone around the concretion created the trough.



Origin of sandstone concretions. A. Dissolved calcium and carbonate in pore water of unconsolidated/loosely consolidated sand precipitate around a nucleus, forming a mass of calcium carbonate that cements the sand grains together into a concretion (blue area). B. The cemented area forms an expanding sphere of as more calcium carbonate precipitates in the space between the sand grains. C. The weight of overlying sediments compacts the sand into rock (sandstone) as the sand grains interlock (yellow matrix). The concretion, already cemented, forms a hard mass around which the rest of the rock develops.

Concretions also develop in shales and mudstone by a similar process. Concretions in fine sediment can be huge – more than 10 feet across! Although commonly spherical, concretions can take a variety of shapes. Many have fossil plant or animal remains in their core, apparently the material that initiated concretionary growth. They can also contain some strange features . Some seem to have gel core that contracted or expanded as it consolidated, forming cracks in a solid outer rind. If these cracks are filled by cement of another composition, they create septarian structures much favored by rock collectors. A peculiar mass in the Carmelo Formation south of The Slot appears to be a septarian ironstone mass that grew in a large mudstone chunk after it was deposited.

Figure 6. The Moeraki Boulders, South Island, New Zealand. Giant (<3 m) concretions have weathered out of underlying mudstone.

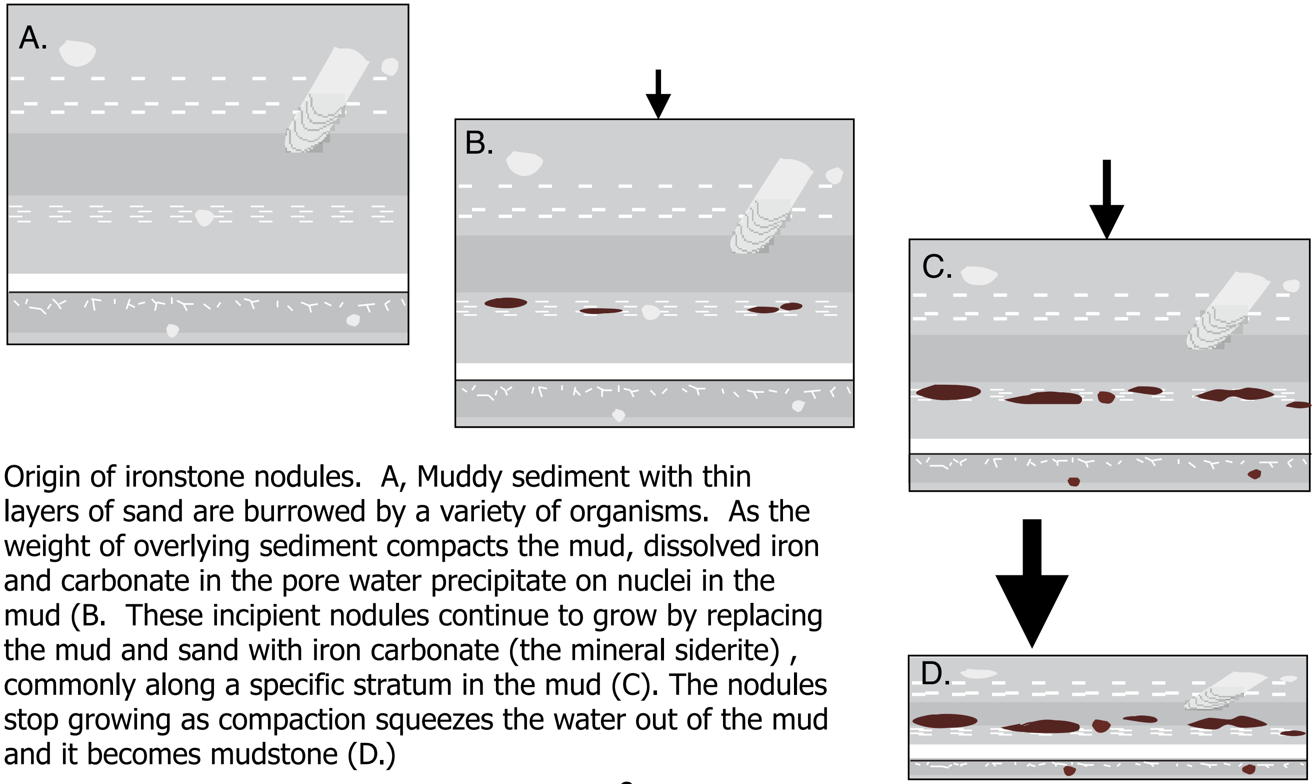
Large septarian concretion on the beach at Moeraki, New Zealand.

Septarian structure in a large mudstone mass largely replaced by iron oxide . Carmelo Formation, south of The Slot

Another common diagenetic feature in the mudstone layers of the Carmelo Formation are ironstone nodules). These small (typically a few inches across) irregular masses are composed of iron carbonate (the mineral siderite). Exposed to the air on the outcrops of Weston Beach they oxidize ("rust") to a bright red that enhances the photogenic quality of these rocks.

Nodules, unlike concretions, form by replacing the original sediment. They may originate shortly after deposition. Some, in coastal marshes of England contain World War II shells and metal in their cores. The Carmelo Formation contains local accumulations of sediment formed by local erosion of the sea floor. Some of these contain nodules that apparently were eroded from pre-existing deposits of mud within the submarine canyon. Some nodules in the Carmelo appear to fill tubular burrows within the sediment. Others follow no apparent pattern. Certain layers are more likely to contain nodules, perhaps reflecting the optimal organic matter content for nodule formation. The large septarian feature shown on the previous page probably a large nodule that was eroded elsewhere from the sediment and carried to its resting site on the sea floor.

Siderite nodules exposed on Weston Beach. Oxidation has caused the exposed surfaces of the iron carbonate that composes the nodules to turn red ("rust").



Origin of ironstone nodules. A, Muddy sediment with thin layers of sand are burrowed by a variety of organisms. As the weight of overlying sediment compacts the mud, dissolved iron and carbonate in the pore water precipitate on nuclei in the mud (B. These incipient nodules continue to grow by replacing the mud and sand with iron carbonate (the mineral siderite) , commonly along a specific stratum in the mud (C). The nodules stop growing as compaction squeezes the water out of the mud and it becomes mudstone (D.)

Surficial (weathering) features

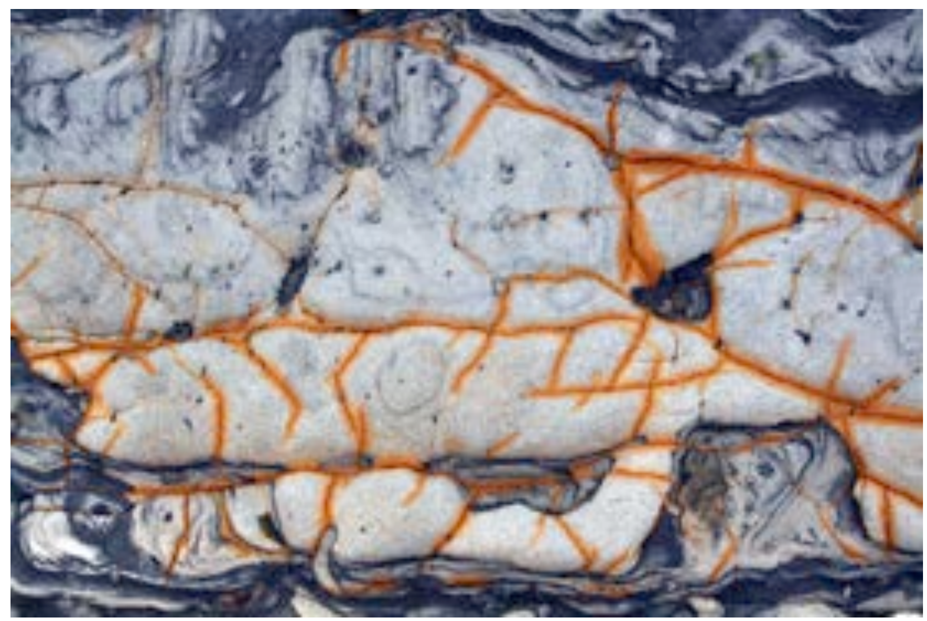
Other peculiar features of the Carmelo Formation formed much later, as a consequence of the rock being exposed at or near the present-day land surface.

As it was uncovered by erosion, the rock was subjected to oxidation by the atmosphere or ground water that permeated from above. As the the overlying rock was worn away, cracks developed in response to the release of pressure, into which ground water could seep. Commonly the ground water carried mineral salts that could precipitate into any pore space left between the grains of the sandstone. As a result the margins of the cracks are more resistant to weathering and erosion and stand in relief on the rock surface.

Seepage of mineral-rich groundwater along cracks into the rock can also produce spectacular staining and/or chemical banding patterns on the rock surface parallel to the crack. Typically the pigment in this banding results from different concentrations and oxidation states of the iron precipitated in the rock.. This iron banding (or "liesegang structure") can be a striking feature in the rocks.

Another weathering feature of the Carmelo sandstone occurs on exposed sandstone surfaces where a pattern of ridges and holes develops. The origin of this "honeycomb weathering" has been the subject of a number of scientific papers, most of which attribute it to weathering that involves wind and salt.

Ridges on a Carmelo sandstone surface produced by additional cementation along fractures in the rock



Modern-day staining of a sandstone along cracks, Weston Beach.

Iron banding along fractures in Carmelo sandstone.

Iron banding in sandstone near the Piney Woods coast parking area.

Honeycomb weathering on a sandstone surface, Sea Lion Point.

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