THE ROCKS OF POINT LOBOS

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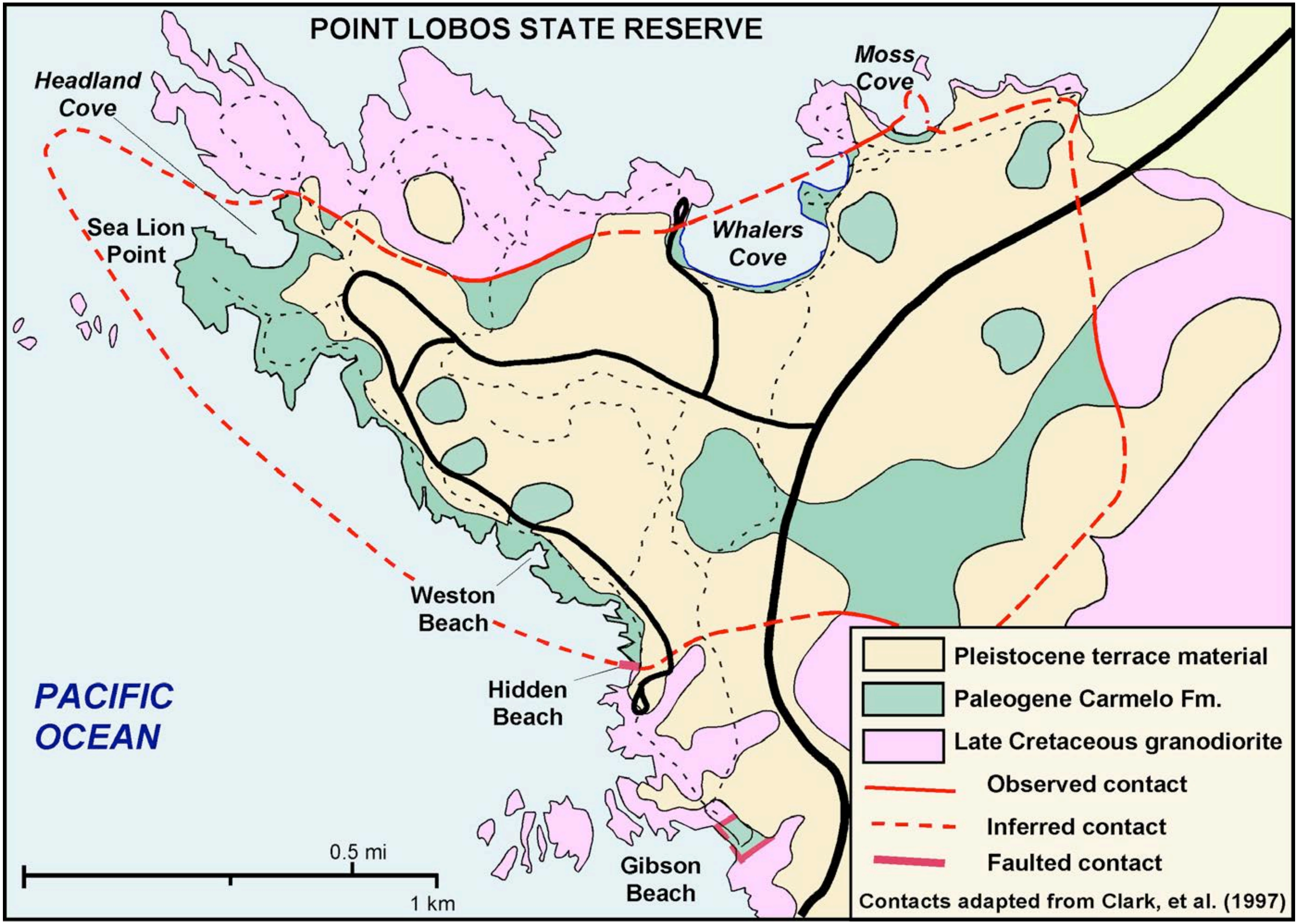
AN INTRODUCTION

Why do people visit Point Lobos? Many, perhaps most, come to experience "the greatest meeting of land and sea in the world". Others want to observe members of the more than 250 different animals and birds that make the Reserve their home. Many visitors find the Reserve an inspiration for art or poetry, or other creative activities. And some come primarily to examine the spectacular rocks that are so magnificently exposed in the Reserve.

Students of all ages marvel at crystals in the granodiorite or trace fossils in the Carmelo Formation. Professional geologists from many different nations come to the Reserve to study the superbly exposed, rare example of an conglomeratic filling of an ancient submarine canyon. This purpose of this link, the Rocks of Point Lobos, is to provide a general description of the features here that may be of interest to a wide spectrum of visitors.

Ed Clifton
September 2013



Distribution of geologic units, Point Lobos State Reserve

The Rocks of Point Lobos

I. Igneous rocks (Rocks that solidify from a molten material)

a) Granodiorite

Formal name: Once called the "Santa Lucia Granodiorite" it is now mapped in this area by geologists as "the porphyritic granodiorite of Monterey".

Characteristics: Typically light gray (Fig. 1) except on weathered surfaces where it is tan. Is composed of an interlocking mass of crystals of 5 different minerals: plagioclase feldspar, orthoclase feldspar, quartz, biotite mica and hornblende, each of which can be identified by eye with magnification (Fig. 2). Because the plagioclase (sodium and calcium) feldspar exceeds the content of orthoclase (potassium) feldspar, the rock is a "granodiorite". Were orthoclase dominant, the rock would be called "granite".

Figure 1. The porphyritic granodiorite of Monterey forming cliffs on the east side of Cypress Cove at Point Lobos.

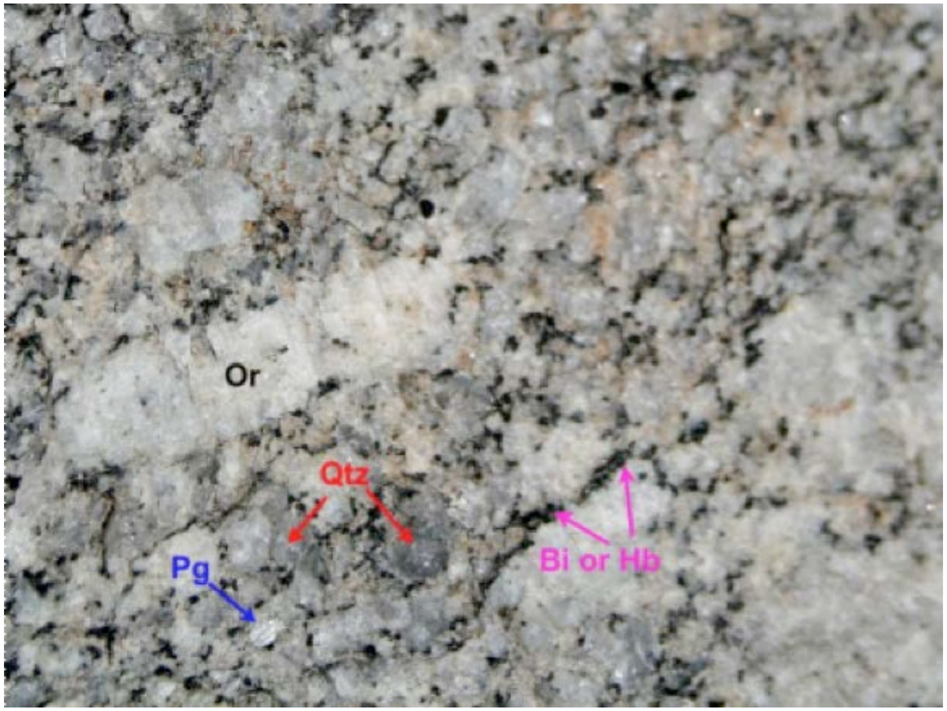


Figure 2. Close-up of the porphyritic granodiorite of Monterey at Point Lobos. The large crystals (OR) are orthoclase feldspar (potassium feldspar). Largest crystal is about 2 inches long. Small crystal faces that flash in the sunlight (Pg) are plagioclase feldspar (sodium-calcium feldspar). Gray amorphous mineral (Qtz) is quartz, and the fine dark minerals (Bi, Hb) are biotite mica and hornblende. Biotite is typically scaly, but both minerals have cleavage faces that flash in the sunlight.

Distribution: Crops out along the north shore of the Reserve, the south shore from Hidden Beach to the north end of Gibson Beach, Bird Island and associated offshore rocks, Sea Lion Rocks and the south end of Gibson Beach (see map showing distribution of geologic units, Introduction). The oldest bedrock at the Reserve, it forms the foundation on which all the younger deposits accumulated. At Gibson beach, adjacent to Gibson Creek, the granodiorite underlies the sedimentary rock whereas, at the northwest end of the beach, the contact is a thrust fault along which the granodiorite overlies Carmelo shale (Figs. 3, 4).

Origin: The granodiorite crystallized from a slowly cooling molten mass (magma) miles below the surface of the earth in southern California (or northern Mexico).

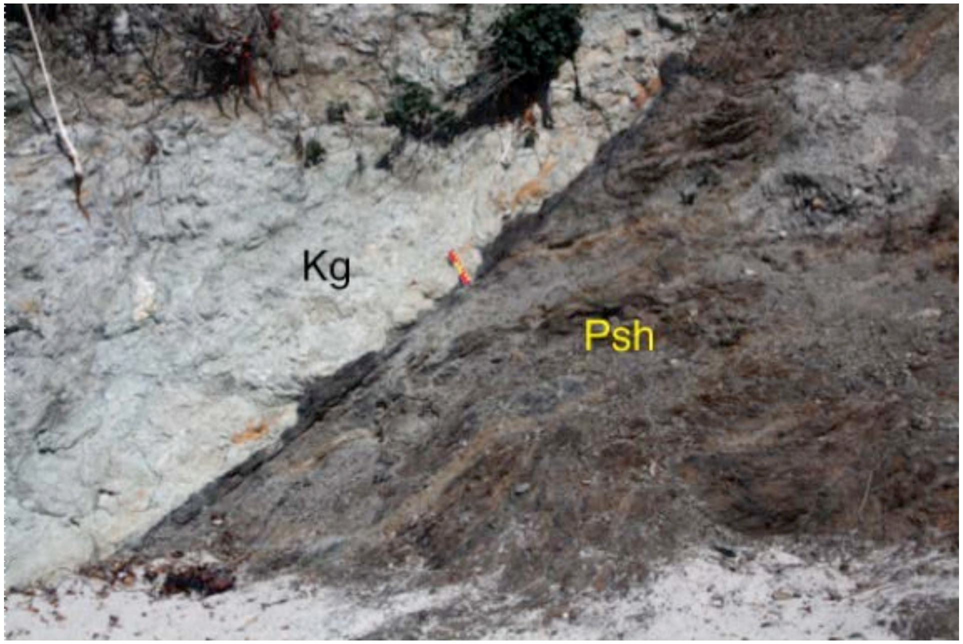


Figure 3. Fault on the northwest side of Gibson Beach separating light-colored granodiorite ("Kg", upper left) from dark shale ("Psh", lower right). Red and yellow scale at fault (near center of photo) is 15 cm (6 in) long. The fault extends from the base of the cliff under the beach sand toward the camera.

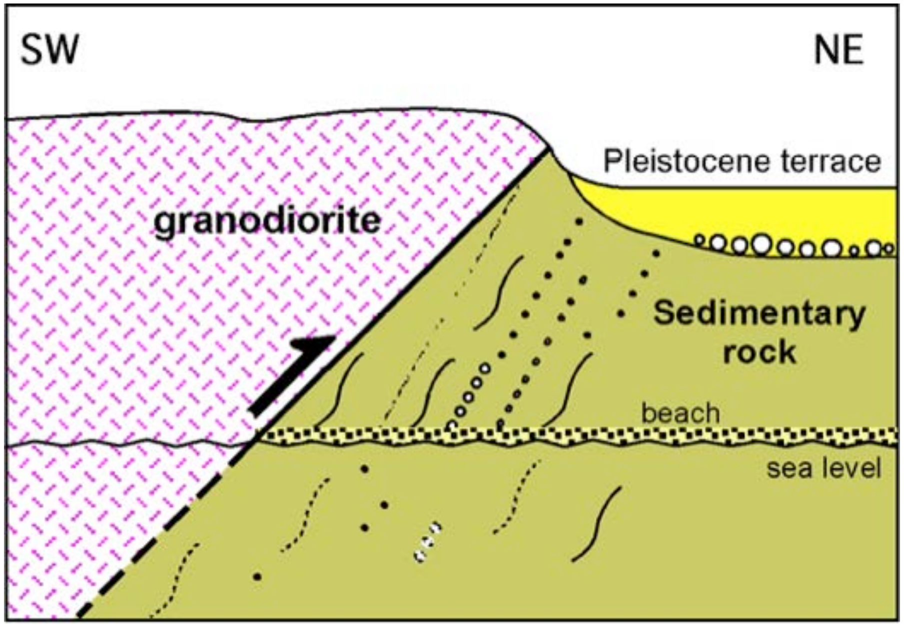


Figure 4. Sketch of inferred relations on the north side of Gibson Beach between the granodiorite and the Paleocene (?) sedimentary rock, looking toward the northwestern end of the beach.

Common Features in the granodiorite:

Phenocrysts. large orthoclase feldspar crystals notably larger than the other crystals in the rock) (Fig. 5). An igneous rock with such a disparity in crystal size is called "porphyritic", hence the current name. Orthoclase phenocrysts in the granodiorite at Point Lobos are long and typically lie in parallel alignment (Fig. 5) in contrast to the stubbier crystals in more or less random orientation in the granodiorite on the northern half of the Monterey Peninsula.

Veins: Light-colored "lines" that cross the outcrop are the surface manifestation of sheets of quartz, commonly mixed with feldspar. (Figs. 6, 7). The sheets represent cracks that developed in the rock as it cooled after crystallization, amd were filled with the minerals, quartz and feldspar, deposited from hot solutions of (probably) superheated water. A few of the thicker veins contain particularly large crystals ("pegmatite").

Fracture (shear) zones. The granodiorite is much fractured and broken. Many of the fractures are concentrated in "fracture zones (or "shear zones") that create closely spaced fractures in the rock shear. Waves preferentially erode the rock along these fractures, which played a major role in shaping much of the shoreline of Point Lobos (Figs. 7, 8).

Figure 5. Parallel orthoclase feldspar crystals (phenocrysts) in granodiorite at Whalers Cove. Poison oak for scale.

Figure 6. Veins filled with quartz and feldspar cutting across the granodiorite. Moss Cove.

Figure 7. Arch in granodiorite near Pelican Point. Waves have cut through beneath following a zone of weakness created by fractures (vertical cracks). Arrow indicates vein of quartz formed as the rock cooled.

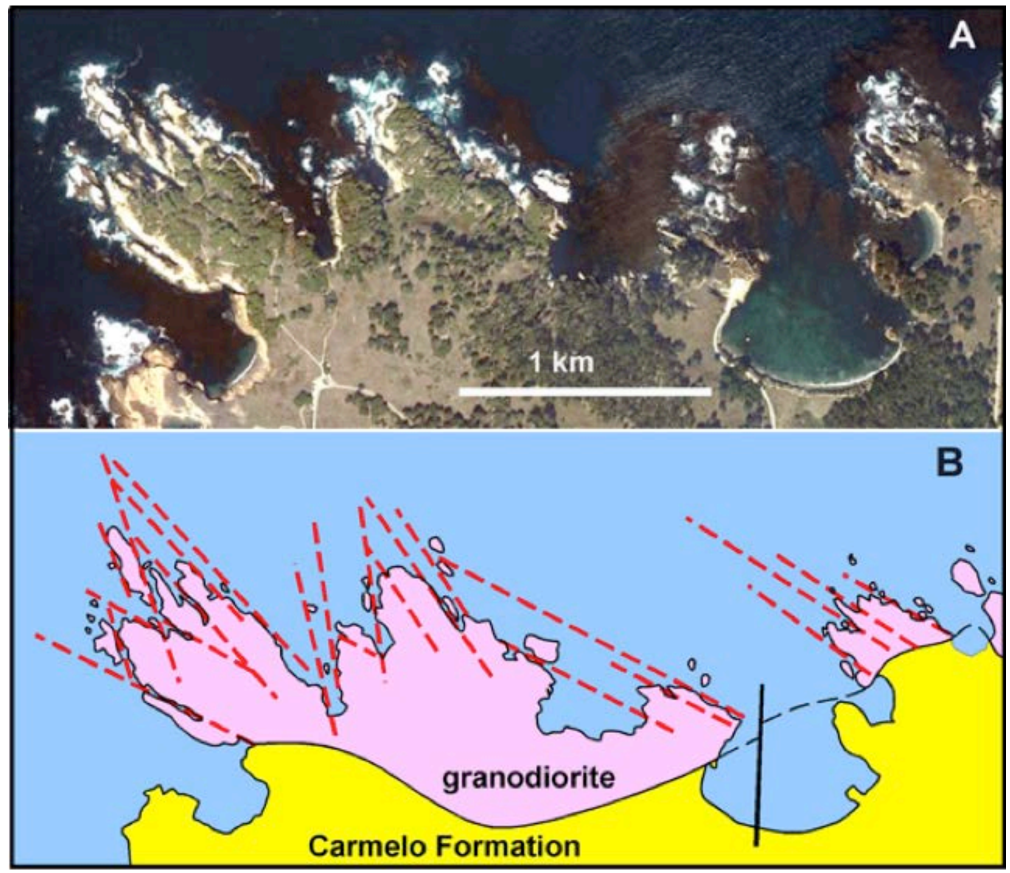


Figure 8. Fracture (shear) zones in the granodiorite on the north shore of Point Lobos control the location and orientation of reentrants in the shoreline.

b) Andesite and other volcanic rocks

Characteristics: Typically dark gray to maroon, with small light-colored particles, some with straight sides.

Distribution: Does not form bedrock at Point Lobo, but occurs as pebbles or cobbles (very large pebbles) in the sedimentary rocks (conglomerate or pebbly sandstone or mudstone) (Fig. 9).

Features: Small light-colored crystals or rock fragments set in a dark matrix of crystals too small to be seen without a powerful microscope.

Origin: The size of crystals in an igneous rock depends in part on the rate of cooling: Slow cooling promotes large crystals: rapid cooling produces small crystals, sudden cooling produces microscopic crystals, or as with a volcanic glass, no crystals at all. The size of the crystals in the andesite and similar pebbles indicates a volcanic origin. Some of the pebbles in the conglomerate have been tied chemically to Jurassic volcanic rocks in the Mojave Desert

Figure 9. Rounded clasts (cobbles) of volcanic rock (andesite) derived from conglomerate in the Carmelo Formation. Small crystals and or rock fragments form white to light gray flecks in the rock.

II. Sedimentary rocks (Rocks that accumulate on the surface of the earth)

Nearly all of the sedimentary rock at Point Lobos accumulated in a deep marine setting during the Paleogene Period (probably in the late Paleocene and early Eocene Epochs, some 50-60 million years ago). This rock is formally recognized as "The Carmelo Formation".

In order of increasing grain size

a) **Shale**

A fine-grained rock (individual component grains too small to be seen with a magnifying glass), typically dark and fissile (breaks into paper-thin sheets). (Fig. 10) Common only at Gibson Beach

Figure 10. Shale in outcrop at the northwestern end of Gibson Beach, Note near vertical foliation (splitting of the rock). Gray rock fragment near center of photograph is about 2 inches across.

b) **Mudstone**

A fine-grained rock (individual component grains too small to be seen with a magnifying glass), typically dark but not fissile (Fig. 11). Commonly includes thin layers and wisps of fine sand. Occurs locally of the main body of the Carmelo Formation at Point Lobos. Prominent in the upper part of the section at Weston Beach section. Rarely occurs as thin beds within conglomeratic intervals.

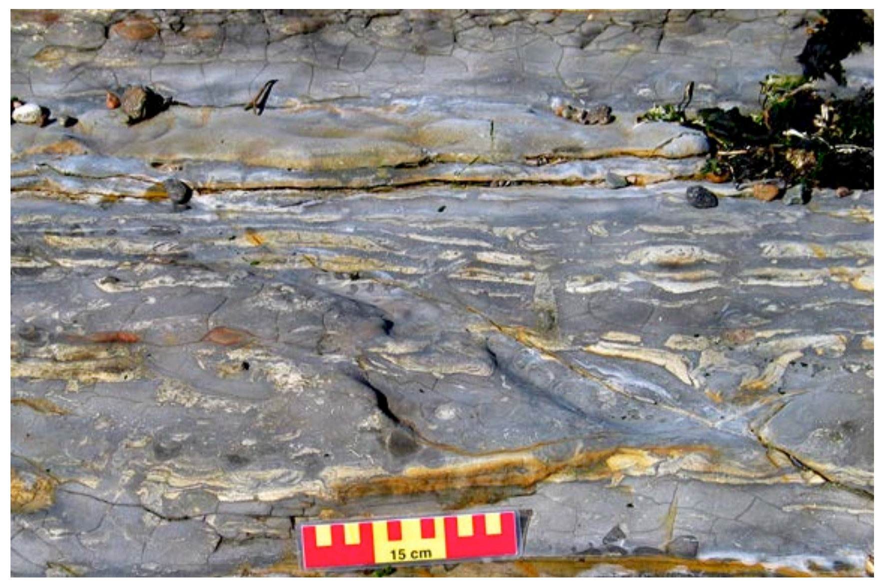


Figure 11. Mudstone (gray material) containing thin layers and wisps of sandstone (lighter colored material). The scattered, discontinuous character of the sandstone within the mudstone reflects the mixing action of animals that lived within the mud at the time of deposition. Weston Beach.

Common Features in the mudstone:

Trace fossils and bioturbation. Burrows and trails made by the organisms that lived in the ancient mud (Fig. 12) are prevalent features in the mudstone where associated with fine-grained sandstone but rare in the mudstone layers in the conglomerate, and are described in more detail in the link, "**Trace Fossils of the Carmelo Formation** ".

Ironstone nodules are common in the mudstone, particularly at Weston Beach. They form irregular masses, typically nor more than an inch or two across, composed of iron carbonate (the mineral siderite). On exposed surfaces, the iron oxidizes ("rusts") to a distinctive red color (Fig. 13). The origin of such nodules is not well understood. After the mud was deposited on the sea floor, iron carbonate completely replaced some of it below the surface. In a few places, the mud was eroded by later processes operating at the ancient sea floor. The nodules occur as fragments in the resulting deposit, indicating that they originated early in the depositional history. In a few places ironstone nodules are roughly tube-like and may be filling burrows. (See link to "**Concretions, nodules and weathering features of the Carmelo Formation**".

Origin of the shale and mudstone:

These rocks originated as mud on the sea floor, either deposited by the slow settling of fine particles onto the sea floor from overlying shallow water or by more rapid settling of mud in the aftermath of a turbidity current (underwater sand/mud "avalanche").

Figure 12. Filled tubes and general disruption (bioturbation)of the layers by ancient organisms are common in the Carmelo Formation mudstone (bedding surface view). Vertical tube at pencil point.

Figure 13. Ironstone nodules are prevalent in mudstone at Weston Beach. They weather to a distinctive rusty red on exposed surfaces (bedding surface view).

c. Sandstone

A rock composed of sand-sized grains that can be seen with the unaided eye or a magnifying glass, sandstone comprises 30-40 percent of the Carmelo Formation in the center of the Reserve. It is manifested as light gray or tan layers with a relatively smooth surface.

Several distinctive grades of sandstone exist at Point Lobos:

Very fine-grained sandstone: Individual sand grains 1/16 to 1/8 of a millimeter across. Visible only with magnifying lens

Fine-grained sandstone: Individual grains 1/8 – ¼ of a millimeter across. Largest grains may be visible to unaided eye

Medium-grained sandstone: Individual grains ¼ to ½ of a millimeter across barely visible with the unaided eye

Coarse-grained sandstone: individual grains are ½ to 1 mm across

Very coarse-grained sandstone: individual grains are 1-2 mm across.

Sand grain sizes scaled to actual size. The unaided eye can typically cannot see individual grains much smaller than about 0.25 mm without magnification.

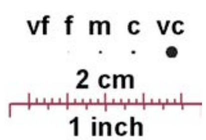


Figure 14 shows a sandstone bed in which the grains range from very coarse near the base to coarse or medium near the top.

Figure 14. Sandstone bed in which the sand grains range from very coarse at base of bed (arrow) to medium or coarse at the top (15 cm scale sits on top of bed). Individual grains are composed of quartz, feldspar the and possibly some rock fragments. Scale gradations are centimeters. Upper surface of sandstone bed displays iron banding,

Common features of the sandstone:

Beds. Sandstone typically occurs in layers ("beds") (Fig. 15), in which the sand accumulated in a depositional event under more or less the same conditions. Sandstone beds in the Carmelo Formation range from a few millimeters to more than a meter thick and can show any number of the additional features listed below.

Normal grading. An upward decrease in grain-size (Figs. 14, 16) characterizes the sandstone beds of the Carmelo Formation. As noted in the subsequent section on the origin of the Carmelo Sandstones, graded bedding typifies sandstone layers deposited by a passing turbidity current (undersea avalanche of a turbulent mixture of sand mud and water). Such layers are called "turbidites".

Figure 15. Sandstone beds (rotated to their initial horizontal orientation) at the northern side of Weston Beach. Each bed represents a separate depositional event. Lowest prominent bed (just below middle of photo) is about 6 inches thick. the five sandstone beds in the upper half of the photo are examples of fine-to medium-grained thick-bedded sandstone.

Figure 16. Normally graded bedding in a two medium/fine-grained sandstone beds in The Slot . Individual sand grains get progressively smaller upward within both beds.

Common features of the sandstone (ctd.)

Internal stratification. (Fig. 17) Sandstone beds commonly contain an internal layering imposed by differences in grain-size or composition. In the Carmelo Formation, this layering is confined to the upper part of many beds, a distribution typical of sandstones deposited by turbidity currents (see Fig. 16).

Ripple marks. (Fig.18). Ripples are common features in sand over which a fluid (water or wind) flows. In water, the velocity of the current is critical to ripple formation. In fine sand, velocities much below about 5 cm/sec are insufficient to generate ripples; velocities much above 25 cm/sec will wash away existing ripples into a flat bed. Ripple marks are preserved on the tops of sand beds where a layer of mud buries a rippled surface. If the sediment turns to rock and is later exposed to the elements, erosion pf the mudstone exposes the ripples, which not only tell geologists something of the fluid velocities, but also the direction in which the currents flowed.

Figure 17. Internal stratification within a sandstone bed. Dark lines at and above pencil tip represent thin layers of darker material within the sandstone.

Figure 18. Ripple marks on the upper surface of a sandstone bed, south side of Weston Beach. Ripple marks trend from upper left to lower right and are about 5 inches apart.

Common features of the sandstone (ctd.)

Ripple lamination. (Fig. 19). Active ripples on a sandy surface creep along the bottom in the direction of flow. Sand of different grain sizes and/or compositions slides down the steep faces of the ripples and the layers thus created are preserved as small surfaces in the sand bed that are inclined in the direction of ripple migration (and fluid flow). Ripple lamination is common in the finer sands of the Carmelo Formation.

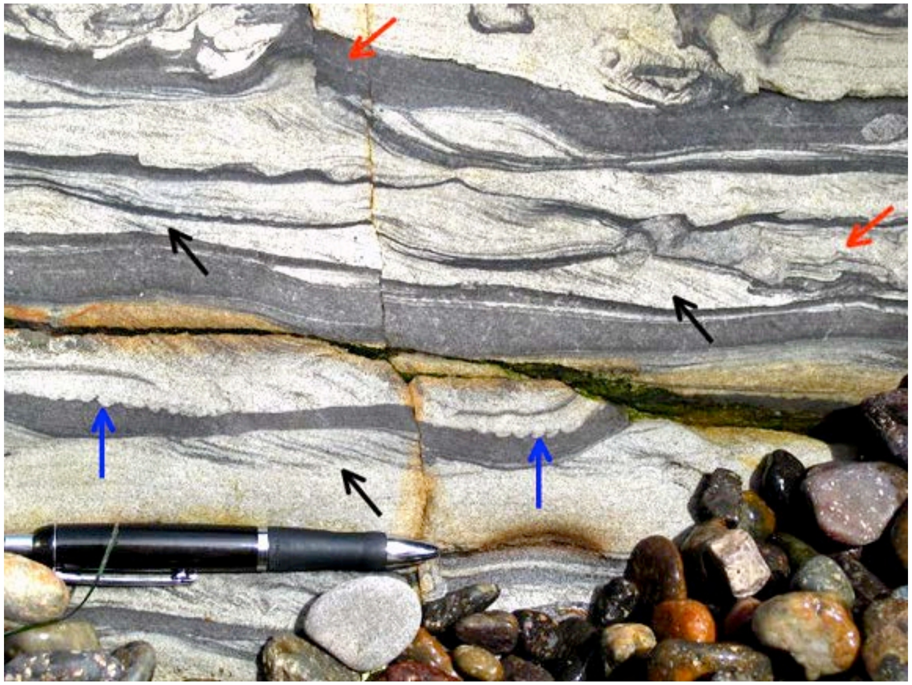


Figure 19. Ripple laminations (inclined to right, black arrows) at top of sandstone beds interbedded with gray mudstone, Weston Beach. Pen points in direction current was flowing. Also in photo: "flame structure" (blue arrows) where mud is pushed up into an overlying sand bed, and small deformational structures where the sand beds have been wrinkled or offset (red arrows).

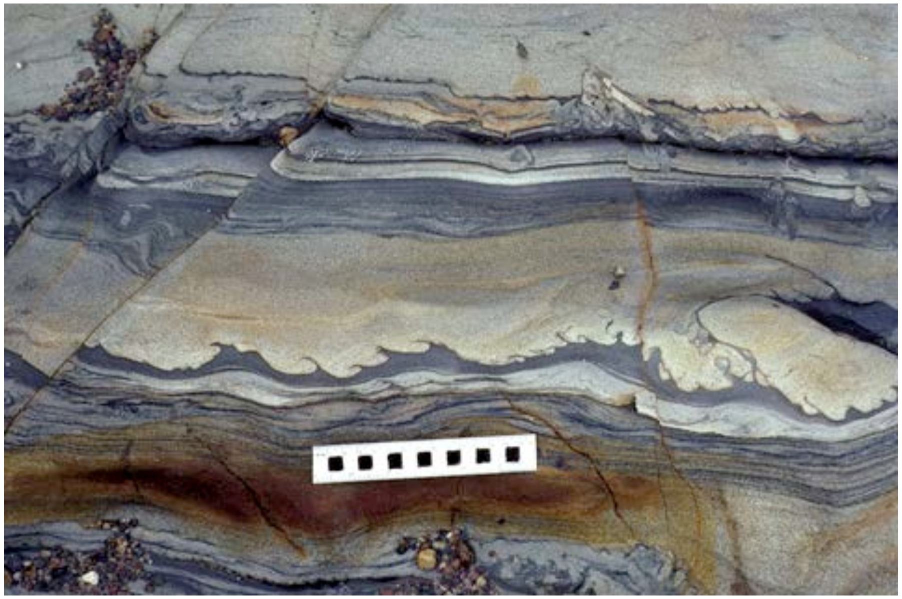


Figure 20. Mud injections (flame structures) into the base of graded sandstone bed (above centimeter scale).

"Flame structure". Injection of sediment from an bed of sand or mud into the base of the overlying bed is called "flame structure". Most commonly the material injected is mud (Fig. 20), although sand injections can also occur (see Fig. 31).

Flame structures result from the sudden emplacement of sand onto a rather fluid mud or sand substrate and are not uncommon in turbidity current deposits. The flames may take the appearance of a set of small breaking waves (Fig. 20) although waves have nothing to do with their formation. Some can be fairly complex. Geologists have tried to use flames as an indication of transport direction, but they have proved to be unreliable.

Common features of the sandstone (ctd.)

<u>Convolute lamination and soft-sediment faulting.</u> Some of the sandstone beds display wrinkled or highly folded intervals (Fig. 21) that denote movement within the bed during or shortly after deposition Others contain small faults that are truncated at their tops by an overlying bed, indicating that offset occurred during or just after accumulation.

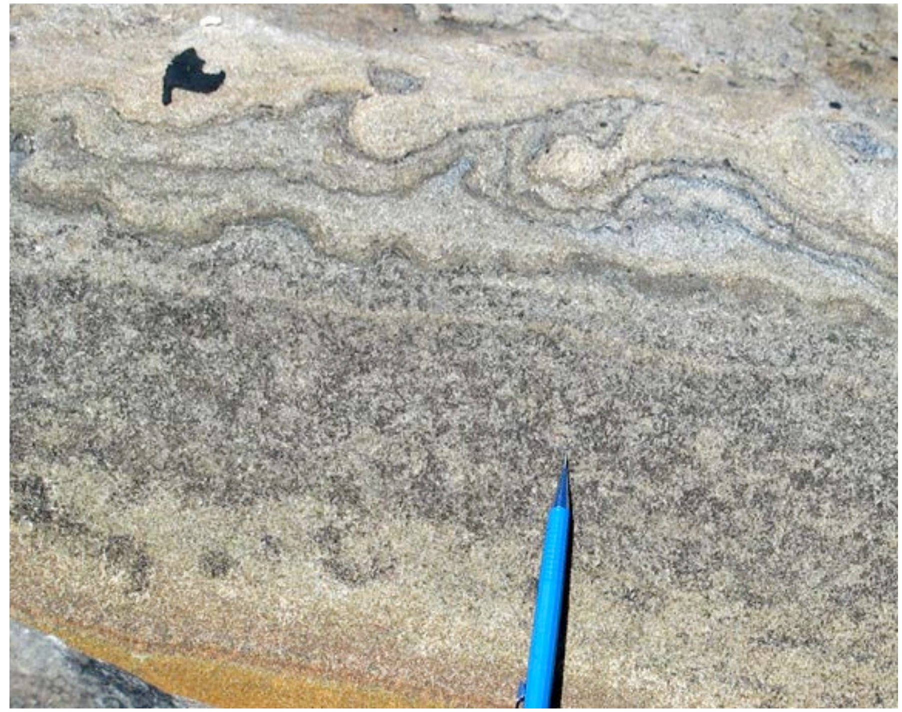


Figure 21. Convolute lamination (about 4 inches above pencil) in a sandstone bed, Weston Beach. This feature indicates remobilization of a sand layer after it was deposited.

Figure 22. "Dish structure" within sandstone bed north of the Piney Woods shoreline parking area, thought to be the result of dewatering of a newly deposited sand bed. Lens cap for scale.

<u>Dish Structure</u> (Fig. 22). A peculiar feature found in many deep-water sandstone beds. Seen in cross-section, this structure consists of a set of discontinuous, irregular, concave-up planes in the rock. Generally considered to be the result of dewatering of a rapidly deposited deposit layer of sand, dish structure is present on exposed sides of some sandstone beds in the Carmelo Formation. To be visible, it requires the right degree of weathering of the sand surface, and is probably more common than it
appears to be in the thicker sandstones at Point Lobos.

Common features of the sandstone (ctd.)

Trace fossils. Like the mudstones, many of the fine- to medium-grained sandstone beds in Carmelo Formation bear traces made by the organisms that lived on or beneath the ancient seafloor (Fig. 23). In contrast, few traces are evident in coarse-grained sandstone. For a fuller analysis of these features, follow the link to "**Trace Fossils of the Carmelo Formation**".

In general, the identity of the trace-maker is unknown, although inferences can be drawn as to the activity represented by the trace. As with the mudstone, traces tend to be rare in sandstone layers within conglomerate.

Figure 23. Three examples of trace fossils that transect or lie within Carmelo Formation sandstone: A. Sand-filled interconnecting tubes, B. Sand-filled vertical tubes lined with mud pellets (Ophiomorpha), C. Mud- and sand-filled horizontal tube lined with mud pellets (Ophiomorpha).

Trace fossils. (ctd)

One trace stands out in complexity - it was originally described as an imprint of fossil seaweed, no doubt because of a superficial similarity to the local feather boa kelp (Egregia menziesi) (Fig. 24). The three-dimensional character of this burrow (Fig. 24B) and the fact that the dark material is mud, rather than a carbonaceous film, demonstrate that it is a complex burrow, not a plant fossil.

The trace was named Hillichnus lobosensis by Bromley et al., (2003), who attributed it to the activity of a deposit-feeding snail. It's presence in the base of graded sandstone beds 10-20 cm thick imply development at least that deep below the sediment-water interface. The traces tends to occur where thin interbeds of mud intermingle with sandstone. It is generally absent in the muddier sections of the Carmelo Formation. Although this trace abounds in the Carmelo Formation, it has been found in only a few other places in the world, mostly California.

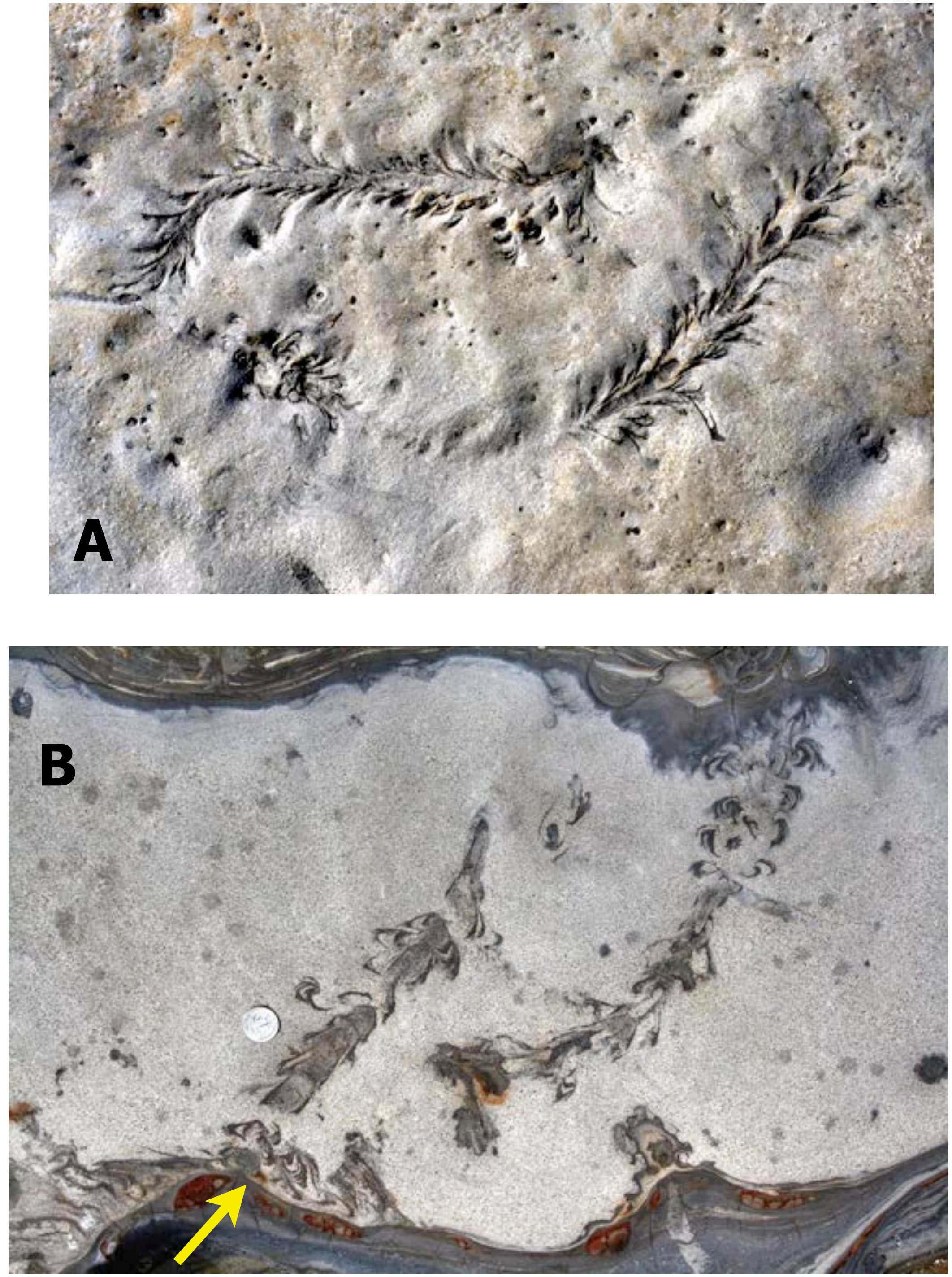


Figure 24. Two views of a complex trace fossils (Hillichnus) that is nearly unique to the Carmelo Formation. A. Feather trace on the surface of a sandstone bed, Weston Beach; B. Three-dimensional character of Hillichnus lobosensis. Quarter dollar scale is on the upper surface of a several-centimeters-thick sandstone bed in which Hillichnus is well-developed, Arrow points to lower part of bed, where trace continues, demonstrating the three-dimensional character of the trace.

Common features of the sandstone (ctd.)

Concretions. Strange circular patterns mark the exposed tops of many sandstone beds along the South Shore Trail. Called concretions by geologists, these features form during the transformation of loose sand into the rock (sandstone) (See link to "**Concretions, nodules and weathering features of the Carmelo Formation**".

For obscure reasons, some locations in the sand become sites of early mineral cementation, forming a typically round, hard lump in the otherwise unconsolidated sand. As sediment continues to accumulate, the increasing weight forces the rest of the sand grains to interlock, and the loose sand becomes sandstone. The resistance to subsequent weathering and erosion of the rock thus formed may differ from that of the concretionary lumps. These may form either spherical bumps on the sandstone or circular depressions (Fig. 25). Concretions grow in concentric rings (almost like an onion) and the different rings can commonly be seen on the sandstone surface where the concretions are weathering out.

Fig. 25. Different manifestations of concretions in the Carmelo sandstone. More brittle than the enclosing rock, concretions can fracture independently, and weathering along these fractures produces some strange internal patterns.

Common features of the sandstone (ctd.)

Weathering features. The Carmelo sandstones display some intriguing weathering features such as iron banding (Fig. 26) and honeycomb weathering (Fig. 27), both of which result from ongoing processes at the present or in the very recent past (see Link to "**Concretions, nodules and weathering features of the Carmelo Formation**".

Fig. 27. Honeycomb weathering, like this example from Sea Lion Point is common on sandstone surfaces in the Reserve.

Fig. 26. Iron banding in sandstone near the Piney Woods coastal parking area. Groundwater percolating into the sandstone form nearby cracks seems to generate these features.

Types of Sandstone in the Carmelo Formation

Sandstones in the Carmelo Formation tend to fall in 3 categories based on their thickness and sand grain size: thin-bedded sandstone, fine thick-bedded sandstone, and coarse thick-bedded sandstone

Thin-bedded sandstone (Fig. 28) occurs in normally graded beds typically less than 20 cm (8 in) thick that tend to maintain a relatively uniform thickness across the outcrop. Sand grain-size typically is fine to very-fine, and the beds commonly contain an upward transition from structureless sand to laminated sand to ripple-bedded sand (Fig. 29). Such a transition, called a Bouma sequence after the geologist who first described it, is characteristic of turbidites. Trace fossils are common.

Figure 28. Thin-bedded sandstone layers interbedded with mudstone. Trace fossils are common.

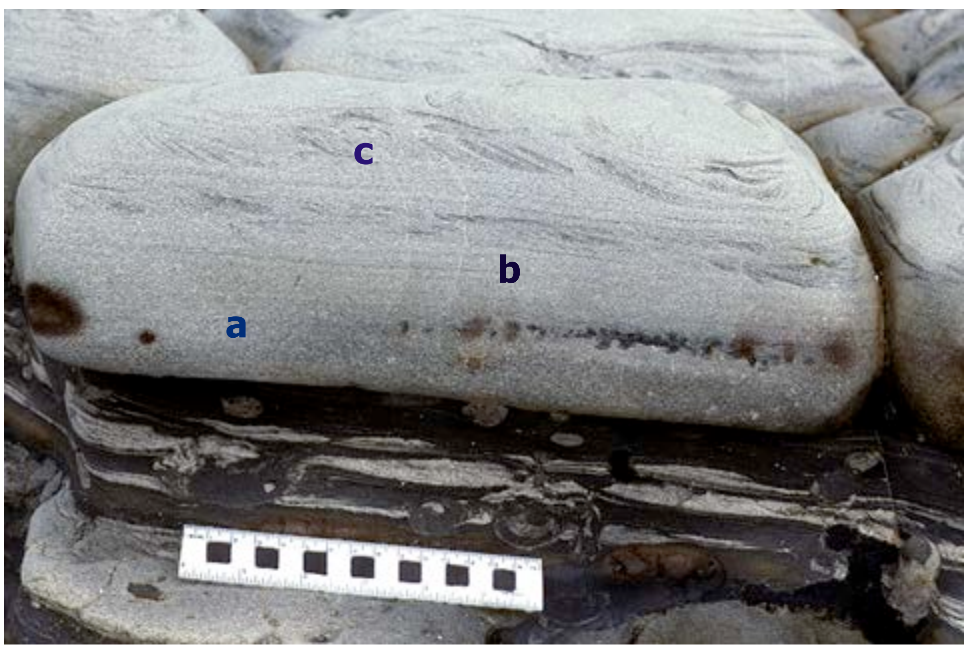


Figure 29. "Bouma sequence" within a fine-grained sandstone bed in The Slot, a characteristic of the deposits of sandy turbidity currents. "a" is a lower structureless interval, "b" an intermediate flat-bedded zone, and "c" an upper ripple-laminated interval. The "d" interval, where bedding again is flat, is not visible here.

Thick-bedded sandstone forms beds that are tens of centimeters to more than a meter (1-4 ft) thick. Two distinct types of thick-bedded sandstone occur in the main body of the Carmelo Formation at Point Lobos.

i. Medium- to fine-grained thick-bedded sandstones tend to be graded only in the upper few cm (in) and many display parallel lamination, particularly in their upper part. Dish structure is evident on certain weathered surfaces. Basal contacts of these finer beds are generally planar and appear to be non-erosional (Fig. 30). The beds can be lenticular, and consistent thickness changes can prevail in a succession of beds.

ii. Coarse- to very coarse-grained thick-bedded sandstone typically displays normal grading (Fig. 14). Some beds bear a thin, commonly discontinuous layer of conglomerate near or at their base or scattered fragments of mudstone in their upper middle parts. These sandstones commonly scour into the underlying strata (Fig. 31)

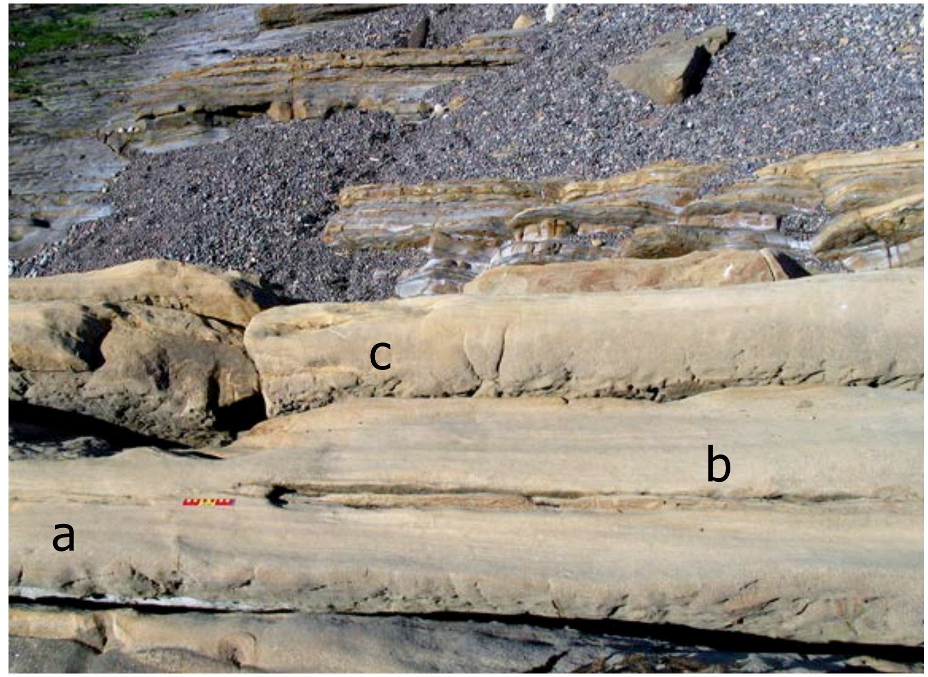


Figure 30. Fine-grained thick-bedded sandstone layers (a, b, c), Weston Beach. Note flat bases to sandstone beds and flat-lamination within the beds. These beds pass upward into a section dominated by thin-bedded sandstone.

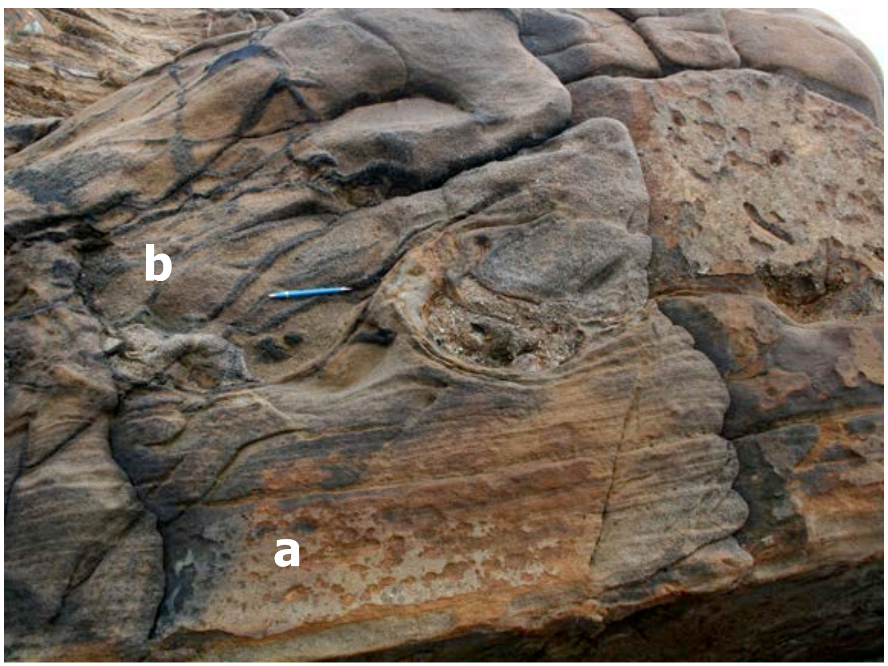


Figure 31. Fine-grained thick-bedded sandstone (a) overlain by coarse-grained thick sandstone (b). Note scoured, irregular contact marked by a large flame structure (at end of pencil).

Origin of the Carmelo Formation Sandstone

The pervasive occurrence of graded bedding, as well as the other features in the sandstone indicates that most, if not all, of the beds were deposited by turbidity currents, underwater avalanches of mixtures of sand, mud, and water (Fig. 32). Because the mixture has a greater fluid density than sea water, it cascades down submarine slopes and flows along the sea floor. As it loses energy, the coarsest suspended grains settle out first, followed by successively smaller grains; the result is a graded bed.

A classic turbidity current should produce a bed of relatively uniform thickness, and some of the fine-to medium-grained thick-bedded sandstones are highly lenticular. One 60-cm thick bed, on the southern side of Weston Beach, pinches out within 5 m in the down-transport direction (Fig. 33). Such beds may be the result of "collapsed" sandy turbidity currents that crept across the seafloor in their final movement.

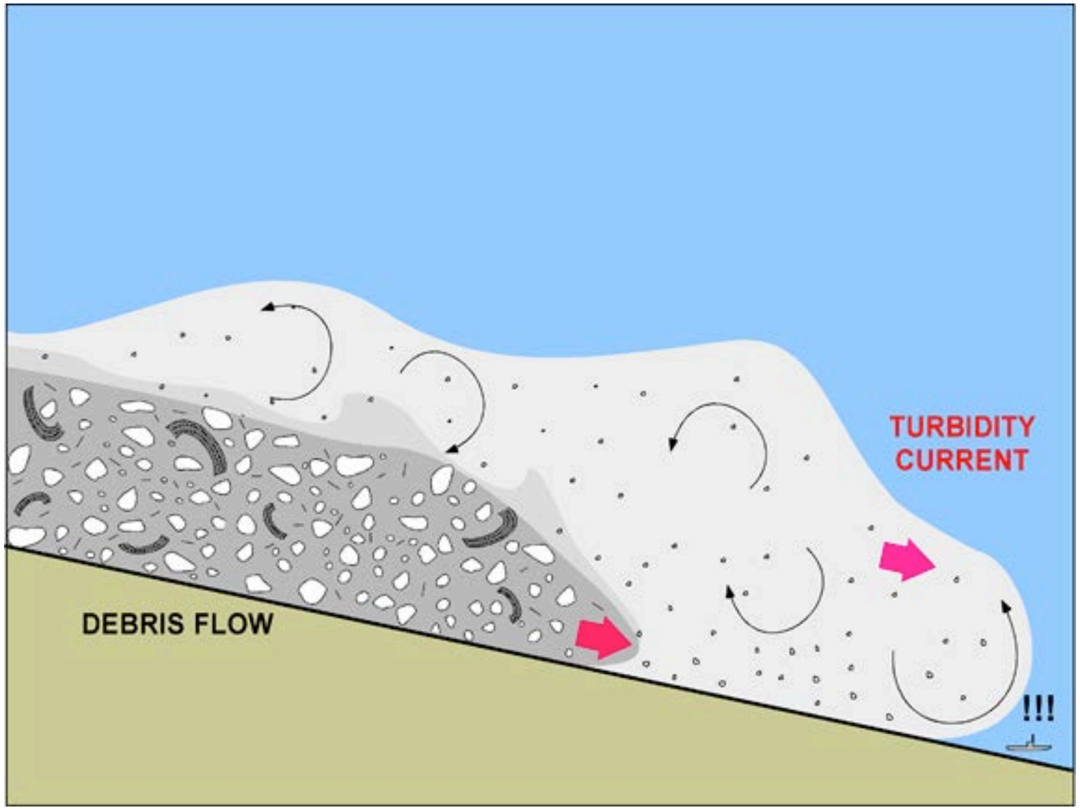


Figure 32. Cartoon showing a large turbidity current associated with a big debris flow (a moving mass in which the strength of the matrix supports the larger blocks). Submarine for fanciful scale.

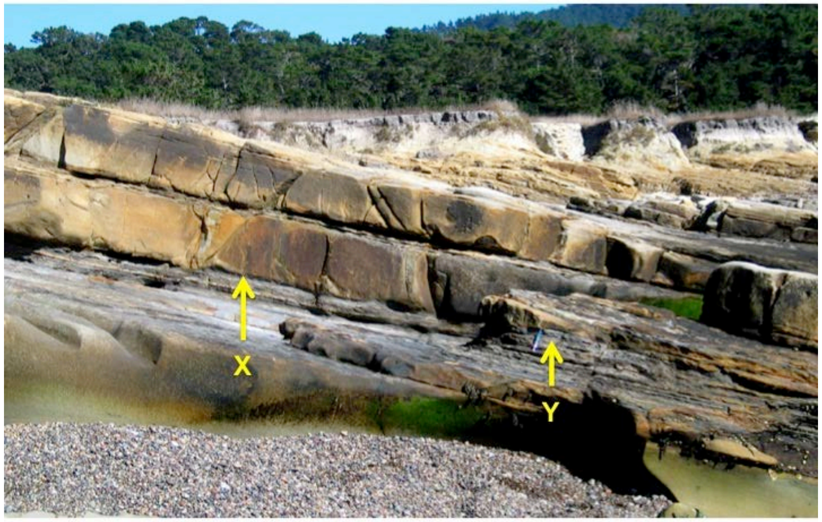


Figure 33. Fine-grained thick-bedded sandstone bed (above arrows) pinches out from thick sandstone (x) to little or no sandstone(y). Transport direction was to the right.

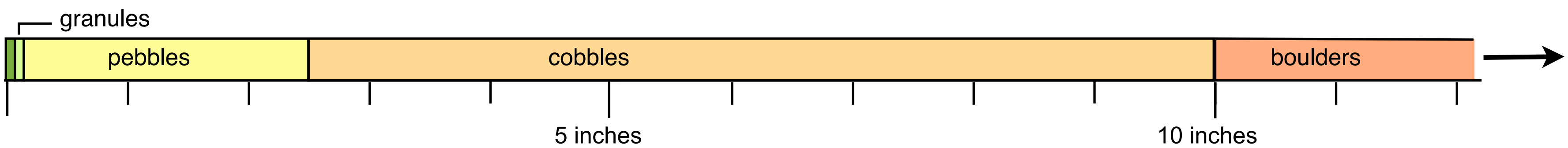


Figure 34. Standard classification of clast (rock fragment or particle) sizes in a coarser sedimentary rock (conglomerate). Sand sizes lie in the small green area at left end of scale

d. Coarse clastic rocks: Conglomerate and breccia.

Conglomerate and breccia are terms for sedimentary rock in which the size of the clasts (rock fragments) exceeds those of sand. Sedimentary particles larger than sand grains are called granules (2-4 mm or 1/12-1/6 inch), pebbles (4-64 mm or 1/6-2.5 inches), cobbles (64-256 mm or 2.5-10 inches), and boulders (>256 mm or 10 inches) across (Fig. 34). Conglomerate contains rounded clasts (Fig. 35); in breccia the clasts are sharp and angular (Fig. 36).

On most of Point Lobos, conglomerate composes 40-50 percent of the Carmelo Formation. At Gibson Beach, pebbly beds like those elsewhere in the Carmelo are essentially absent, although a few pebbles exist in some of the mudstone breccia beds. The Gibson Beach exposures also contain a few beds of limestone conglomerate, a rock not seen elsewhere at the Reserve.

Figure 35. Conglomerate, Moss Cove. 15 cm scale.

Figure 36. Mudstone (gray fragments) breccia, South Shore. 15 cm scale.

Types of conglomerate in the Carmelo Formation.

Conglomerate in the Carmelo Formation tends to be either chaotic or organized.

Chaotic conglomerate (Fig. 37) occurs in units that range from a meter to more than 10 m thick and lacks any coherent internal organization. Pebbles and cobbles show no alignment, and clasts of different sizes occur with no degree of segregation into beds. Chaotic conglomerate can also contain large masses of sandstone and mudstone blocks and appear as a jumbled mixture of lithologies (Fig. 38). In places (Sea Lion Point and the upper end of The Slot), masses of chaotic conglomerate push into and deform the underlying strata. About half of the conglomerate in the Carmelo Formation at Point Lobos is chaotic.

Figure 37. Chaotic conglomerate, Sea Lion Point Cove, lacks any degree of internal organization. 15 centimeter scale.

Figure 38. Chaotic conglomerate, The Slot. Note mudstone block (blue arrow) and discontinuous large mass of sandstone (white arrow). Blue backpack for scale.

Organized conglomerate. The other half of the conglomerate at Point Lobos shows some degree of organization, particularly stratification (Fig. 39). Pebbles of certain sizes may be concentrated into specific layers within the rock, and the conglomerate can contain interbeds of sandstone (Fig. 40). Sandstone that is interlayered with organized conglomerate tends to show a parallel lamination and contain cobbles that are larger than the pebbles in the enclosing beds (Fig. 39, 41). Additionally, the pebbles and cobbles in organized conglomerate may be aligned. In cross-section, many pebbles either lie parallel to stratification (Fig. 42) or imbricate (shingled), where the long axes are inclined into the up-transport direction (Figs. 43, 44). On bedding surfaces, pebbles with an organized conglomerate bed tend to be aligned parallel to the transport direction (Fig. 44).

Figure 39. Stratified (organized) conglomerate, Sea Lion Point. Some conglomerate beds also display inverse grading (arrows). Note large isolated cobbles in the central sandstone bed.

Figure 40. Organized conglomerate Sea lion Point (pebble layers, sandstone interbeds).

Figure 41. Sandstone within organized conglomerate. Note size of pebbles and the parallel stratification in the sandstone. 15 cm scale.

Figure 42. Large cobbles and small boulders lie preferentially with long axes sub-parallel to bedding in this coarse organized conglomerate on Sea Lion Point. Notebook and pencil scale..

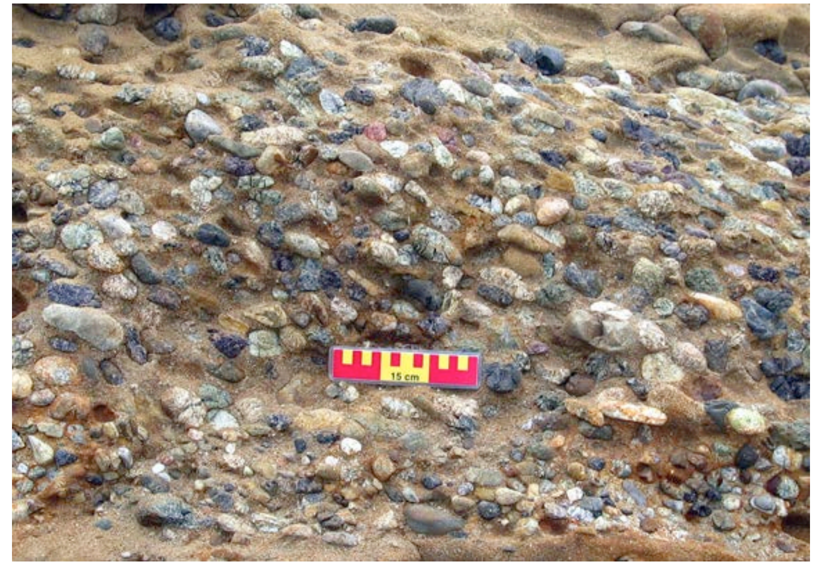


Figure 43. Organized conglomerate on Sea Lion Point. Long axes of pebbles above 15-cm scale preferentially dip to the right, indicating sediment transport to the left.

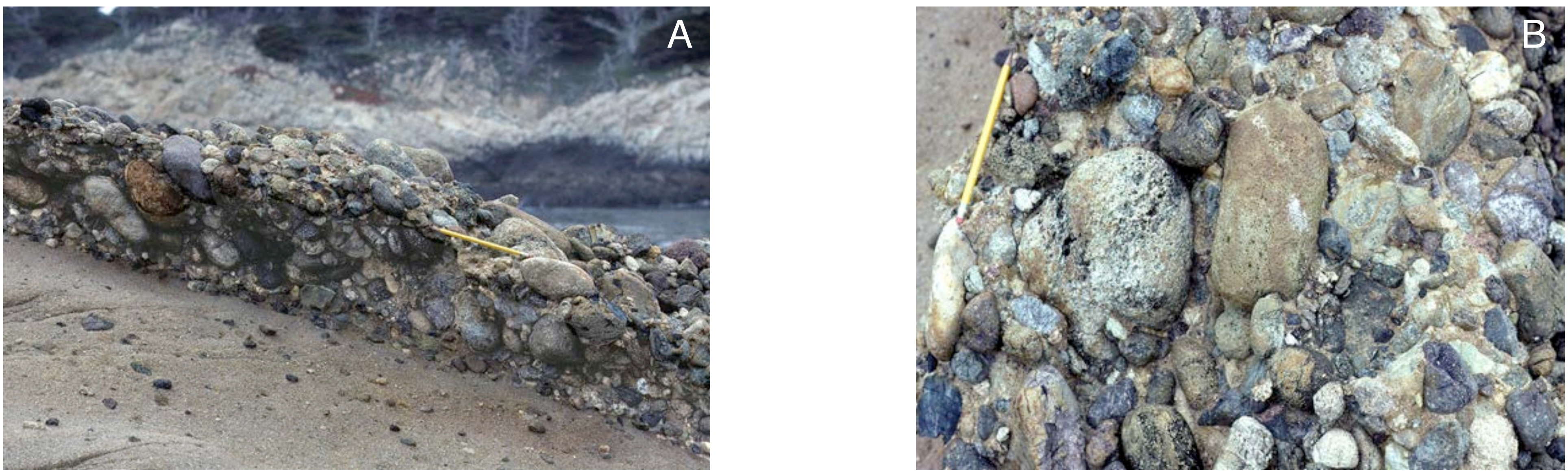


Figure 44. Organized conglomerate on Sea Lion Point. A) Cross-section of conglomerate in which pebbles are inclined to the right dip to the right, indicating sediment transport to the left. B) Bedding plane view showing alignment of pebble long axes (parallel to pencil and to flow direction. Pencil scale is in same location in both photographs.

Organized conglomerate (ctd.)

Although normal grading (upward fining) is characteristic of the Carmelo sandstone beds, it is rare in the conglomerate. Instead, where the top and base of a conglomerate are clearly defined (as occurs where a conglomerate layer is encased in sandstone), pebble size increases toward the top of the bed, producing an inverse grading (Figs. 39, 43, 45), Although it can be difficult to see in beds encased in conglomerate, inverse grading seems to be a common motif within the organized conglomerate.

In addition to inverse grading, some lenticular conglomerate beds show an obvious increase in pebble size in the down-transport direction (Fig. 46). The largest cobbles in a conglomerate are likely to be those at its down-transport terminus.

Figure 45. Inverse grading in conglomerate beds, Sea Lion Point. Upper sandstone bed is about 50 cm thick. Note big pebbles and parallel stratification in sandstone interlayers.

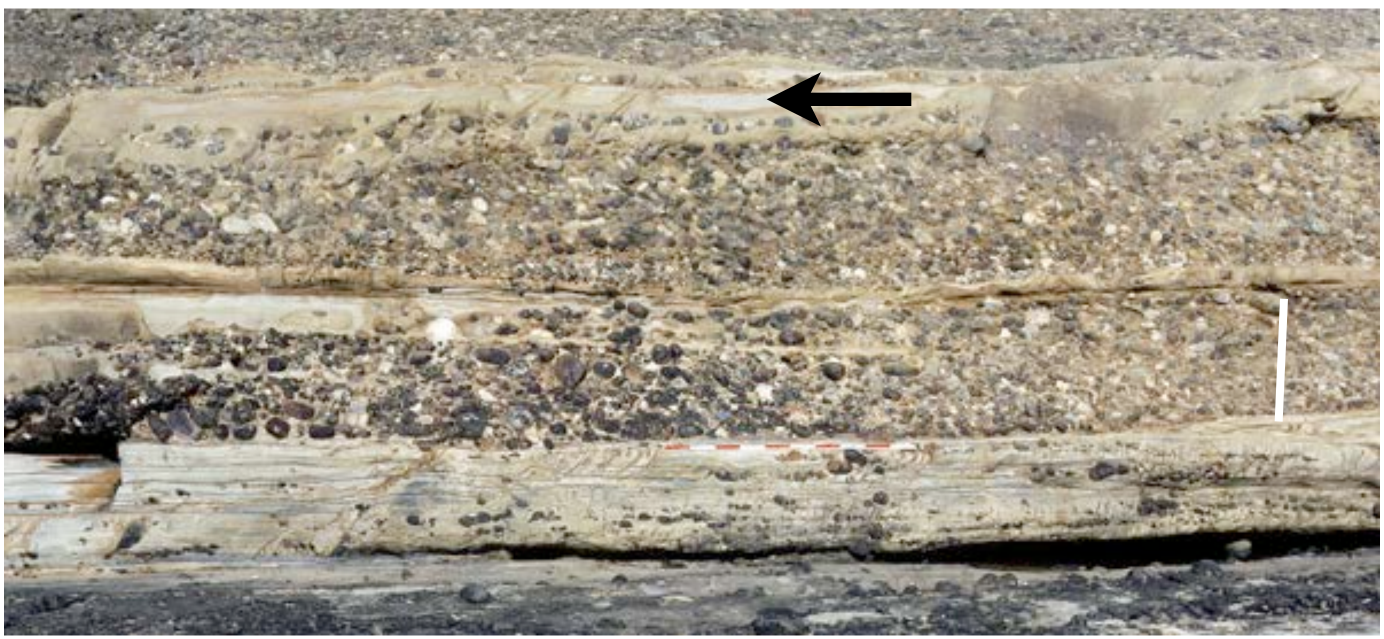


Figure 46. Organized conglomerate on Sea Lion Point. Long axes of pebbles above 15-cm scale preferentially dip to the right, indicating sediment transport to the left. Note layer of finer pebbles below scale and sandstone beds within (and above) conglomerate.

Not only are the pebbles largest at the down-transport end of a gravel layer, they also take a different orientation. Unlike the pebbles in the main body of a organized conglomerate lens, which are aligned parallel to flow direction (Fig. 44), pebbles at the down-transport end lie with long axes transverse to the transport direction (Fig. 47).

A transverse orientation is also characteristic of the isolated large pebbles and cobbles isolated within the sandstone beds associated with organized conglomerate (Fig. 48, 49).

Figure 47. Pebbles at the down-transport end of a conglomerate lens transverse to flow direction (pointed to by pencil).

Figure 48. Pebbles within sandstone beds associated with organized conglomerate are preferentially aligned transverse to flow direction (pointed to by pencil).

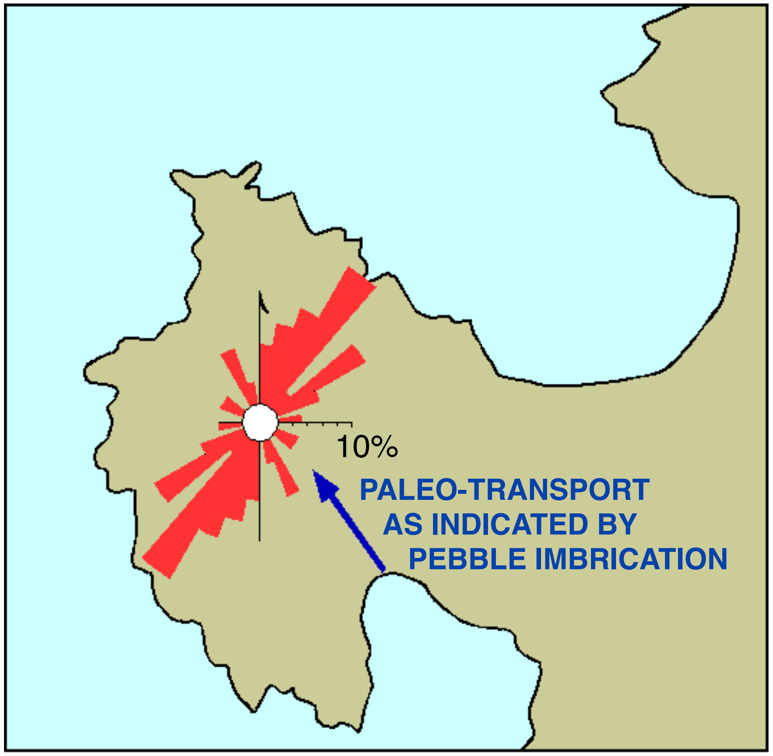


Figure 49. Long-axis orientation of 36 pebbles on a sandstone surface at Sea Lion Point relative to paleo-transport direction indicated by pebble imbrication in adjacent beds.

Other types of Carmelo conglomerate.

Conglomerate adjacent to the contact with the granodiorite in The Pit and Moss Cove is unusual in that the pebbles show a well-defined alignment parallel to the canyon wall (Fig. 50), but no other manifestations of organization such as internal stratification, or associated sandstone layers. In both cases the conglomerate lies in the lower part of a succession that grades upward into pebbly mudstone.

Exposures in the sea cliff of Gibson Beach display a different type of conglomerate, one not seen elsewhere at Point Lobos. In this rock, the pebbles are mostly composed of limestone (Fig. 51). Mollusk shell fragments, including a few dentalium (tusk shells) occur in this rock, which tends to lack other kinds of pebbles.

Figure 50. Pebbles within conglomerate adjacent to the canyon wall in The Pit are preferentially aligned, dipping to the lower right. 15-cm scale is horizontal,

Figure 51. Conglomerate composed of rounded pebbles of limestone, Gibson Beach.

Mudstone conglomerate and breccia: Although most of pebbles and cobbles in the Carmelo conglomerate consist of volcanic or other hard rock material, layers containing mudstone fragments are fairly prevalent. Most of these form a rock called "mudstone breccia" (Fig. 36) (breccia is a term used for coarse clastic rocks in which the fragments are angular or only slightly rounded). In other layers the mudstone fragments are rounded, implying some wear during their transport (Fig. 52). Commonly the mudstone conglomerates (or breccias) lie a matrix of very coarse sandstone. Many of the mudstone clasts likely originated as mud rip-ups by sandy turbidity currents; others developed as debris eroded from channel margins.

Figure 52. Mudstone conglomerate in a coarse sandy matrix.

Pebbly mudstone (Fig. 53) is consists of pebbles and/or cobbles floating in a mudstone or sandy mudstone matrix that may also contain mudstone clasts. It is prevalent only near the canyon walls in The Pit and Moss Cove where it seems to have originated in slides of previously deposited materials off the walls.

Figure 53. Pebbly mudstone. Mudstone clasts and rock pebbles in a muddy matrix.

Deposition of the Carmelo Formation conglomerate:
For the first half of the 20th Century, geologists believed that sand and gravel could only accumulate in rivers or the very shallow marine environment. An experimental study in the early 1950's, however, showed that mixtures of sand and water formed a distinctly separate fluid that could flow down subaqueous slopes. This revolutionized the study of sedimentary rocks as we discovered that immense quantities of sand had accumulated at great depth over geologic time.

Today we recognize 3 general types of "sediment gravity flow" that move mixtures of sand and gravel down submarine slopes. These types are defined by the dispersal mechanism that keeps the particles suspended within the flow (Fig. 54). The three are 1) debris flows where the strength of the matrix supports the larger clasts (submarine landslide), 2) turbidity currents in which fluid turbulence supports the particles (“submarine avalanches”), and 3) grain flow, where the particles are suspended by their internal collisions (as in dry sand flowing down the steep face of a sand dune).

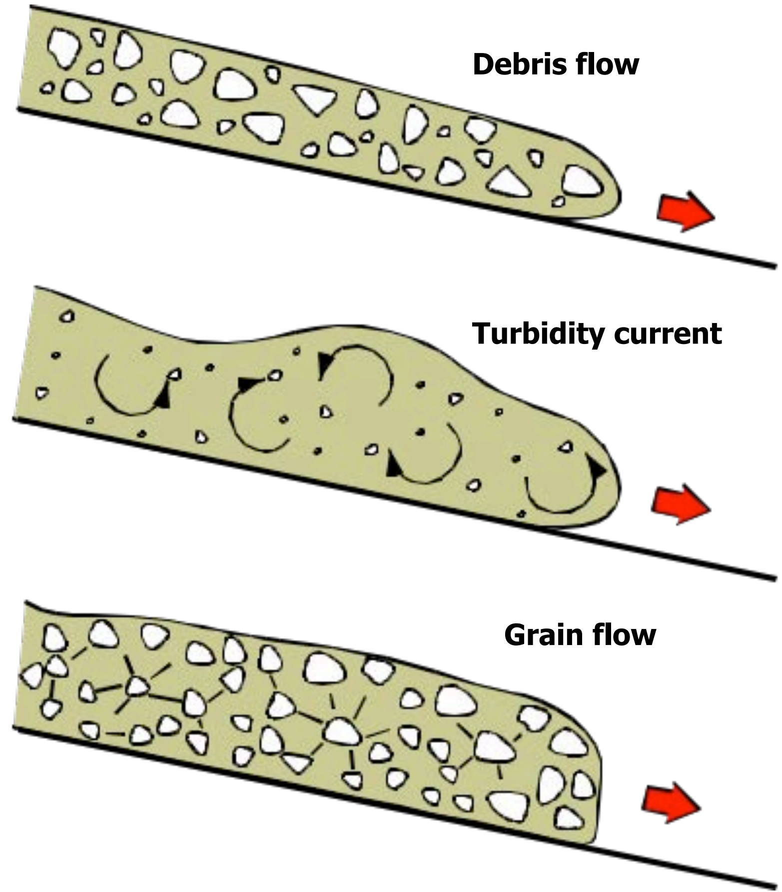


Figure 54. Types of sediment gravity flows capable of transporting gravel into deep water.
Debris flows are maintained by the strength of the matrix (the material between the larger clasts), which doesn’t allow them to sink to the bottom.
Turbidity currents are underwater “avalanches” of a mixture of sand , mud, and water, Turbulence within the flow precludes the settling of particles.
Grain flows are dense concentrations of particles in which the energy imparted by intergranular collisions keeps the particles moving within a flow. The avalanching of dry sand down a dune face is an example of grain flow.

Each process leads to a distinctive deposit (Fig. 55). The chaotic conglomerate in the Carmelo Formation is readily explained as the product of submarine debris flows or landslides, some of which were quite large. The organized conglomerate requires another explanation.

Normally-graded conglomerate is rare in the Carmelo Formation, indicating that few of the pebbles were being carried in suspension in a turbidity current. Inverse grading, however, is common, suggesting that collisional sorting, as occurs in grain flows, was an important process. Moreover, the fabric of the organized conglomerate beds, including pebble imbrication, the flow-parallel clast alignment, pebble imbrication and increase in pebble/cobble size at the down-transport end of the conglomerate lenses are all consistent with deposition from grain flow (Fig. 56).

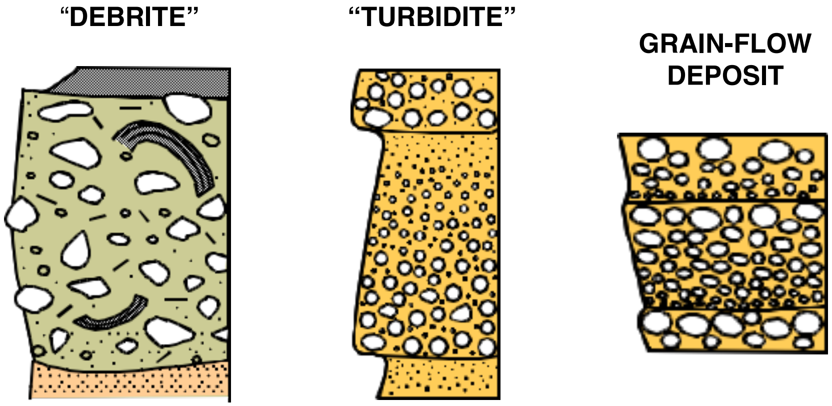


Figure 55. Nature of the deposits produced by the three types of sediment gravity flow. The deposits of debris flows are sometimes called "debrites". The deposit typically is chaotic, and the larger clasts "float" in a finer matrix. Deposits of turbidity currents, called "turbidites" by geologists, show normal grading (upward-fining) that reflects the accumulation of progressively smaller particles as the energy of the turbidity current wanes. Grain-flow deposits typically show an inverse grading wherein the particle size increases upward within the bed (much as a shaken bag of popcorn tends to force the largest kernels to the top and the smallest to the bottom).

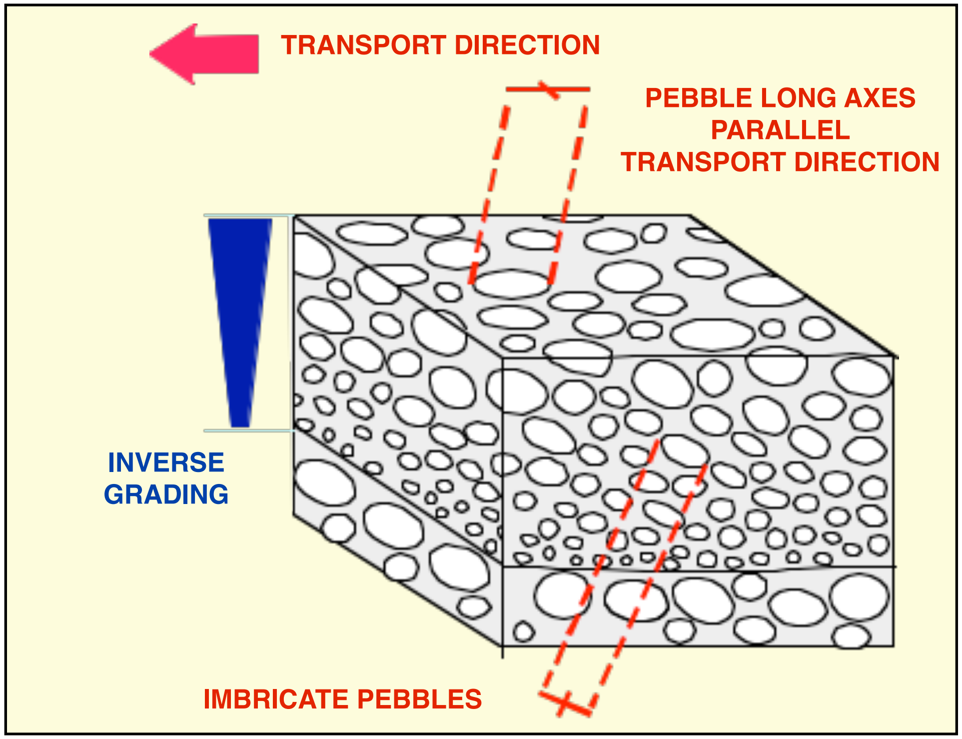


Figure 56. Three-dimensional block diagram showing the idealized fabric of an organized conglomerate layer. The inverse grading, pebble imbrication and long axis alignment parallel to transport direction are consistent with the fabric produced by grain flow.

Sedimentologists, however, generally agree that pure grain flow, as occurs in dry sand flowing down a dune face, is an inefficient transport process, requiring steep slopes and typically moving only a thin layer of grains. Collisional sorting, however, can also occur in "modified grain flows", where the impetus for movement lies beyond the simple pull of gravity on the grains. Such a flow occurs on beaches during wave backwash, where a dense carpet of sand grains is pulled seaward along the bottom, producing an inversely graded layer of sand. The sorting process results from inter-granular collisions, but the impetus for flow is the water returning to the sea.

What could have been the driving force propelling the gravel "grain flows"? A hint lies in the isolated cobbles and large pebbles in the associated sand beds. As shown in Figures 48 and 49, these lie transverse to the general transport direction. This fabric is produced where pebbles and cobbles roll along the sea floor driven by a relatively powerful current (Fig. 57).

Figures 58 and 59 illustrate a possible origin for the organized conglomerate in the Carmelo Formation. A large sandy turbidity current drives a jostling mass of gravel along its base. When the energy of the turbidity current drops below a certain level, the gravel ceases to move and forms a lens of gravel on the sea floor. The sandy turbidity current continues to flow down-slope, with enough energy to roll the large pebbles that have accumulated at the top and front of the gravel lens along the seafloor, depositing sand as it does so. Figure 60 shows in cartoon form the idealized resulting conglomerate deposit.

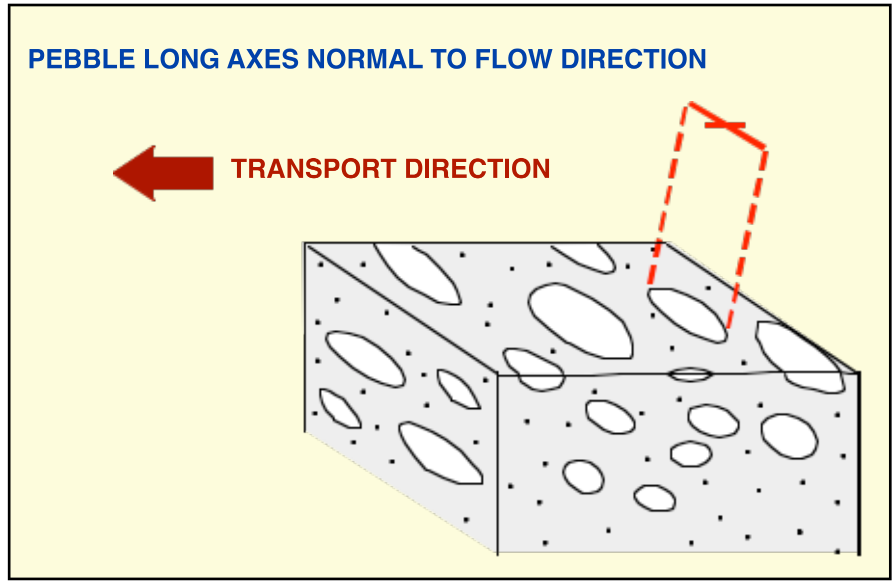


Figure 57. Three-dimensional block diagram showing the idealized fabric of coarse pebbles and cobbles in a sandstone layer associated with organized conglomerate. The long axis alignment transverse to transport direction is a fabric resulting from clasts rolling along the sea bed.

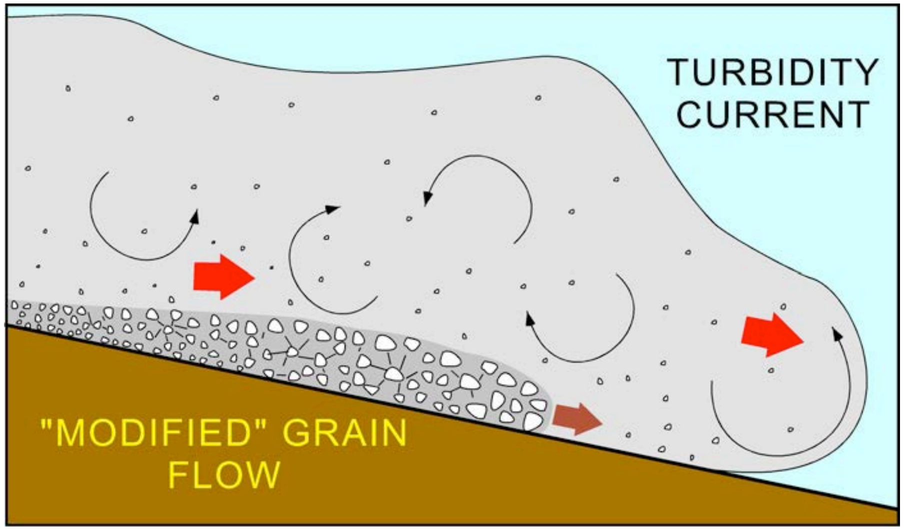


Figure 58. Cartoon showing the movement of a concentration of gravel in a jostling, colliding mass at the base of a large sandy turbidity current.

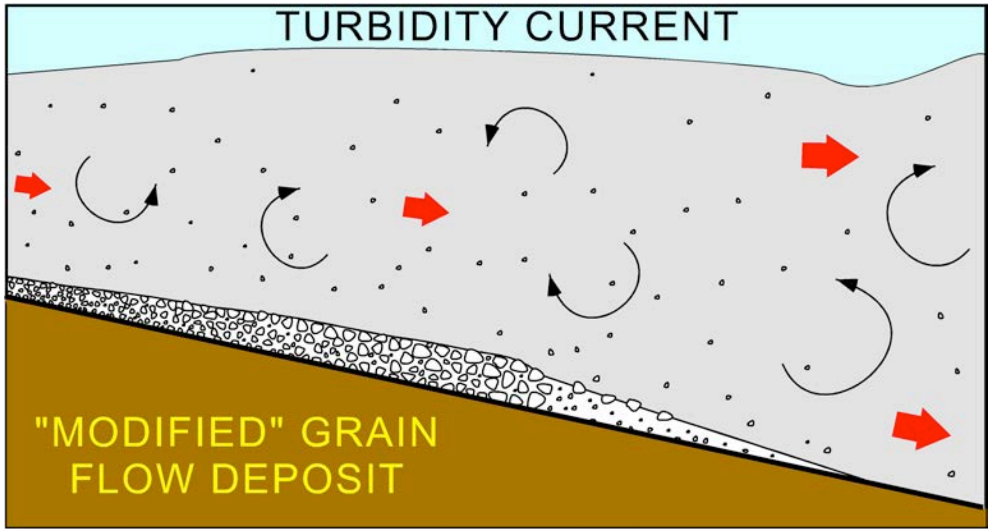


Figure 59. Cartoon showing the deposition of an inversely graded gravel as the large sandy turbidity current continues to move down slope, rolling the largest clasts along the sea floor.

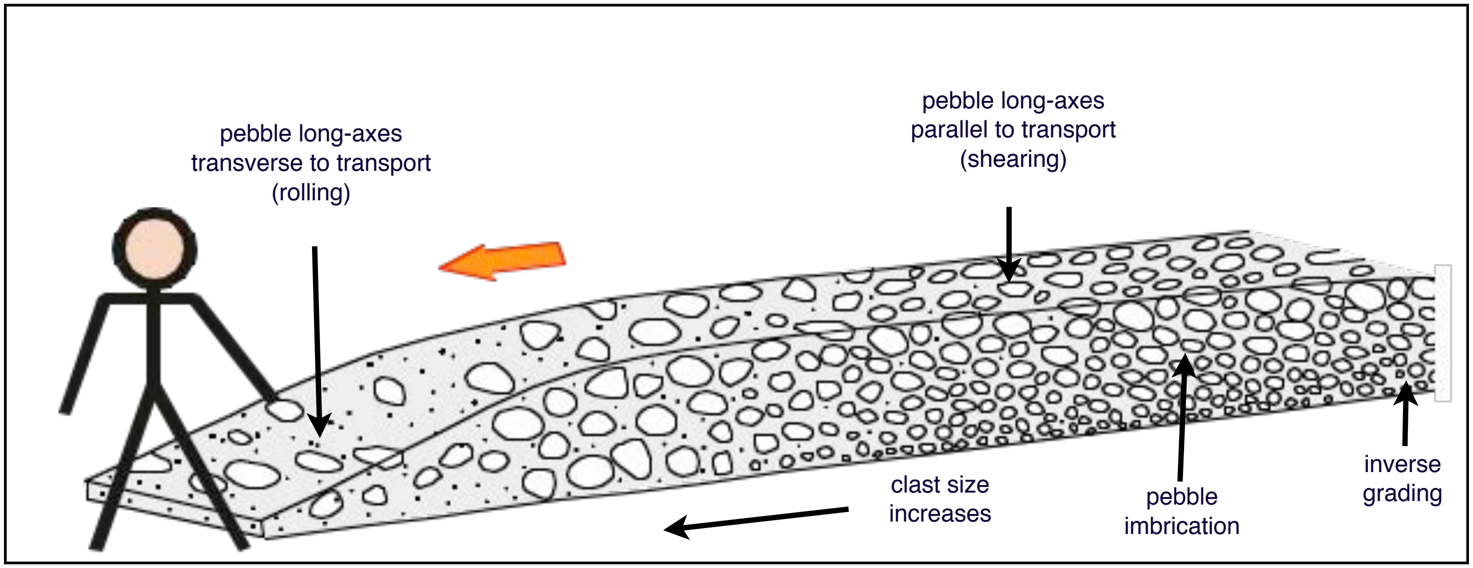


Figure 60. Cartoon illustrating the idealized character of an individual modified grain flow deposit of organized conglomerate in the Carmelo Formation at Point Lobos.

Pleistocene conglomerate: A much younger conglomerate crops out sporadically on the rocky platforms along the South Shore as well as in the upper part of some sea cliffs around the Reserve. This rock is more loosely cemented than conglomerate of the Carmelo Formation and the matrix tends to be a red-orange coarse sandstone (Fig. 61). In some places, such as south of Weston beach or on Sea Lion Point, this conglomerate occupies grooves or other recesses cut into the Carmelo Formation, where the less resistant Pleistocene conglomerate is somewhat protected from erosion. The red-orange color as well as the poor sorting suggests that some of this material formed where subaerial slope wash accumulated over the top of the Carmelo Formation. Loosely aggregated conglomerate, which overlies the more highly cemented Carmelo Formation in the sea cliffs around Whalers Cove, probably accumulated on the Pleistocene sea floor when sea level stood relatively higher than it does today (see section on marine terraces in "The Assembling of Point Lobos").

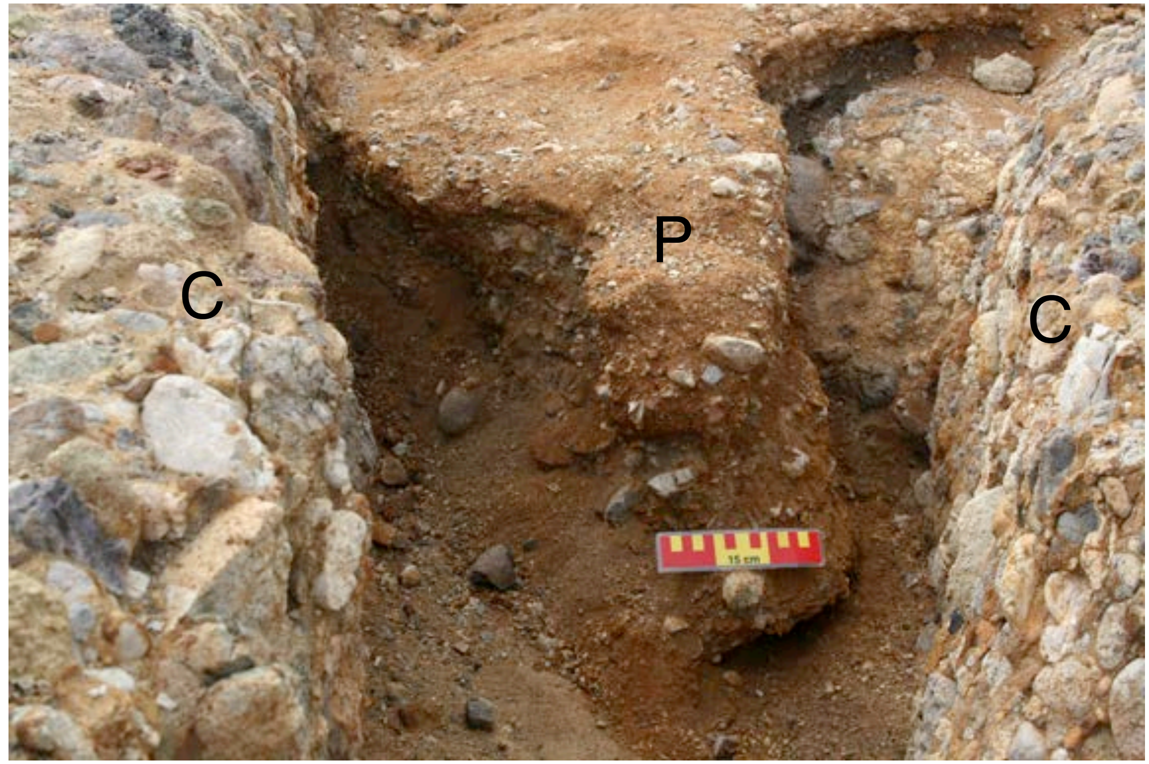


Figure 61. Mass of red-orange sandy Pleistocene conglomerate (P) lying within a small trough on top of the Carmelo Formation (C), just north of Weston Beach.

Depositional setting of the Carmelo Formation:
Basal contacts, outcrop pattern and paleocurrent indicators indicate that Carmelo Formation fills a submarine valley cut into the granodiorite. The contact with the granodiorite on the north side of the Reserve is steeply inclined (Figs. 62, 63) (on the south side the contact itself is not exposed; at Hidden Beach the Carmelo Formation is presumed to be faulted against the granodiorite). Nearly horizontal sandstone and conglomerate in Moss Cove, a short distance (150 m) from the contact shown in Figure 62 indicate that the steepness of the contact reflects an unrotated erosional surface.

Figure 62. Contact between the Carmelo Formation and granodiorite in The Pit, where the Carmelo conglomerate appears to be "plastered" against a relatively steep granodiorite wall.

Figure 63. Steeply-inclined contact (arrow) between the Carmelo Formation and granodiorite on the northeastern side of Headland Cove. Stratification in Carmelo beds on right side of photograph dips gently away from the camera, indicating that, as in The Pit, The Carmelo Formation was deposited against a steeply inclined erosional surface on the granodiorite.

Outcrop pattern and paleocurrent indicators (Fig. 64) suggest that Carmelo Formation fills a submarine valley that trends into the Reserve from the east or northeast and bends to the northwest along the South Shore (the stretch of coast between Sea Lion Point and Hidden beach, see map of geologic units, Introduction). The few body fossils found in the Carmelo Formation indicate deposition in water depths in the range of 600 to 2000 feet (200-600 m), which is consistent with the trace fossil assemblage and the abundant evidence that turbidity currents were instrumental in the deposition of the sandstone (and conglomerate). A poorly constrained cross-section (Fig. 65) of the rocks across the central part of the Reserve (dotted line, Figure 64) is consistent with cross-sections in the upper reaches of the present-day Carmel Submarine Canyon which lies a few miles north of the Reserve. The Carmelo Formation appears to represent the filling of an ancient submarine canyon that existed in the early Paleogene Period in Southern California (see link to the **Geologic Evolution of Point Lobos**).

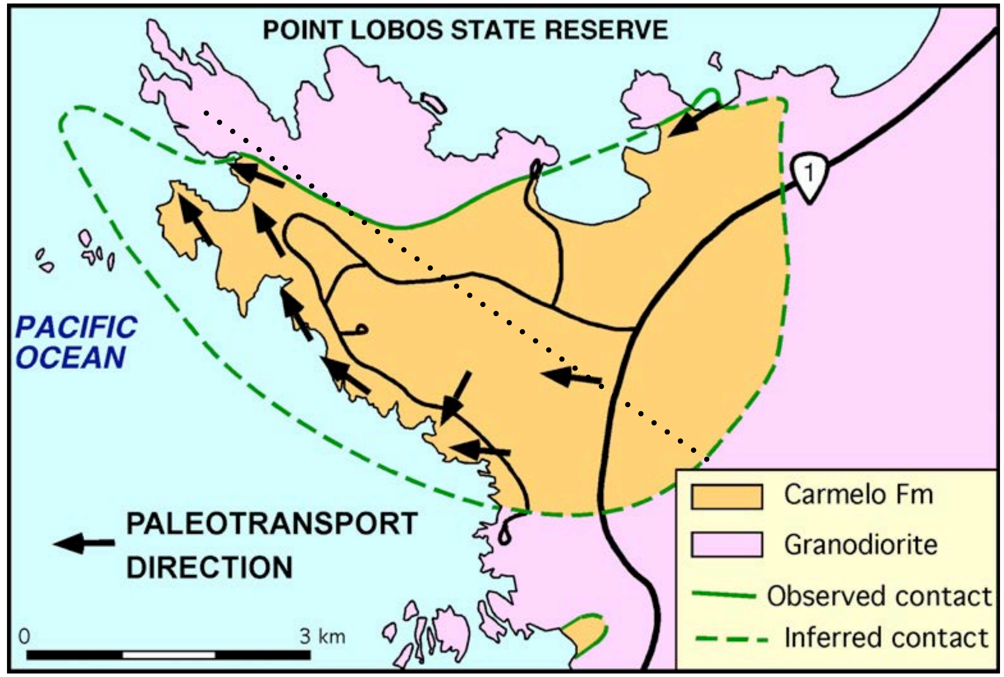


Figure 64. Distribution of the Carmelo Formation at Point Lobos and inferred direction of paleocurrents based on pebble imbrication and ripple marks and ripple lamination. Dotted line shows location of cross section shown in Figure 65.

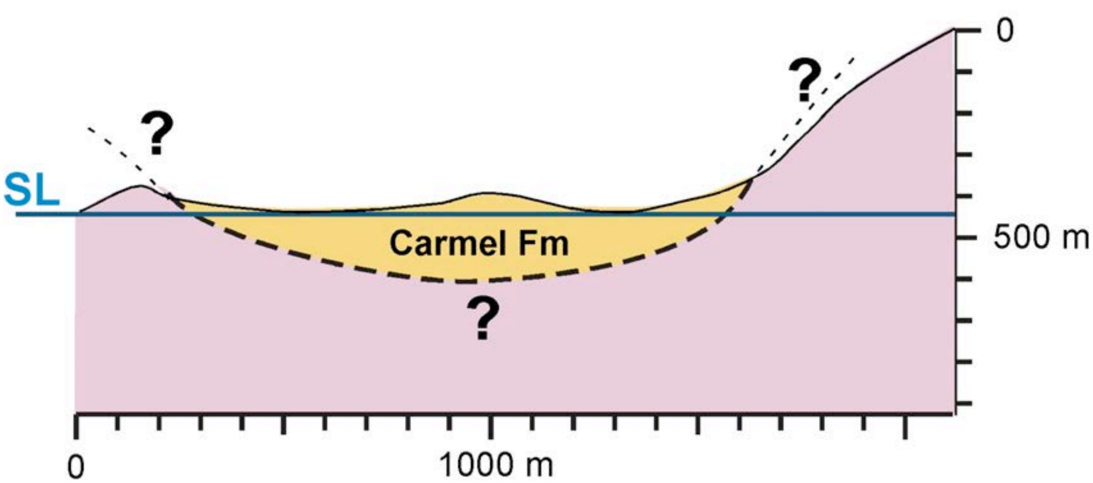


Figure 65. Inferred cross-section through the central part of Point Lobos State Reserve. The depth to the underlying contact with the granodiorite is unknown, but based on the thickness of the section along the south shore, probably is on the order of at least 100-200 m.

e. Deformation of the sedimentary rocks at Point Lobos

Folding: Most of the Carmelo strata were deposited in quasi-horizontal beds. Since their deposition, nearly all of the Carmelo strata has been rotated, in some places by 90° (Fig. 66). Much of the strata exposed on the South Shore is inclined in a landward direction (Fig. 67). Very few of the sedimentary layers retain their original attitude (example: sandstone beds exposed along the shoreline of Moss Cove about 40 m from the contact with the granodiorite, Fig. 68).

Figure 66. Nearly vertical sandstone and conglomerate beds between Hidden Beach and Weston Beach.

Figure 67. Inclined strata, Point Lobos South Shore.

Figure 68. Nearly horizontal sandstone and conglomerate beds, Moss Cove between Hidden Beach and Weston Beach.

Some of the folding appears to be the product of instability within the sediment as it filled the ancient submarine canyon, such as local sliding of masses of unconsolidated sediment from the sides of channels or other high areas within the canyon (Fig. 69). Some deformation appears to be the product of large landslides within the canyon fill (see following section).

The northeasterly tilting of the strata along most of the South Shore (Figs. 67, 70) may be due to giant mass failure within the canyon or to later tectonic processes that accompanied the Carmelo Formation's transit from Southern California (see link to "**The Geologic Evolution of Point Lobos**").

Figure 69. Inclined deformed interbedded sandstone and mudstone between beds that were initially horizontal (at shadow and above 15-cm scale. Filling of depression (marked by scale) demonstrates that failure of the sand/mud interbeds occurred on the ancient sea floor.

Figure 70. Visitors walking on landward-dipping beds of conglomerate and sandstone, south side of Weston Beach. Sea Lion Rocks on distance, far right.

Fractures: Many fractures break the sedimentary rocks at Point Lobos. Some, merely cracks in the rock with little or no displacement of the strata on either side, are called joints. Commonly joints occur in parallel sets and, in sandstone, may show a spectacular iron banding (Fig. 71). Joints commonly develop when overlying rock is removed by erosion and the release of pressure resulting by the overburden causes the rocks to crack.

Faults, fractures across which the strata are offset or displaced, abound in the Carmelo exposures (Fig. 72). Although the offset across many faults is small enough to permit the correlation of the displaced strata, the amount and direction of offset across many others cannot be determined.

Figure 71. Joints with prominent iron banding, north side of Weston Beach.

Figure 72. Prominent faults cutting across a rock platform on the South Shore between Weston Beach and The Slot. The eastern fault (blue arrow) displaces a couple of meters of strata: offset on the western fault (yellow arrow) is unknown, but may be in the range of 10 or more meters. Image from Google Earth.

Faults through the Carmelo along the South Shore display a wide variety of orientations. Most cut the strata at a high angle, but others lie nearly parallel to the bedding in the Carmelo. No consistent patten of displacement exists. Some faults transpose rock types in a given horizon, but do no displace overlying or underlying strata.(Fig. 73), presumably as a consequence of strikeslip or lateral offset. Others terminate abruptly against a bedding surface (Fig, 74). Either the fault broke the section while sediment was accumulating and was buried by subsequent deposition or the fault plane abruptly turns and follows a bedding plane surface. The geometry and displacement of many faults remains enigmatic.

Figure 73. Fault transposing sandstone (left) against conglomerate (right) without displacing the underlying strata (Below the scale's right hand).

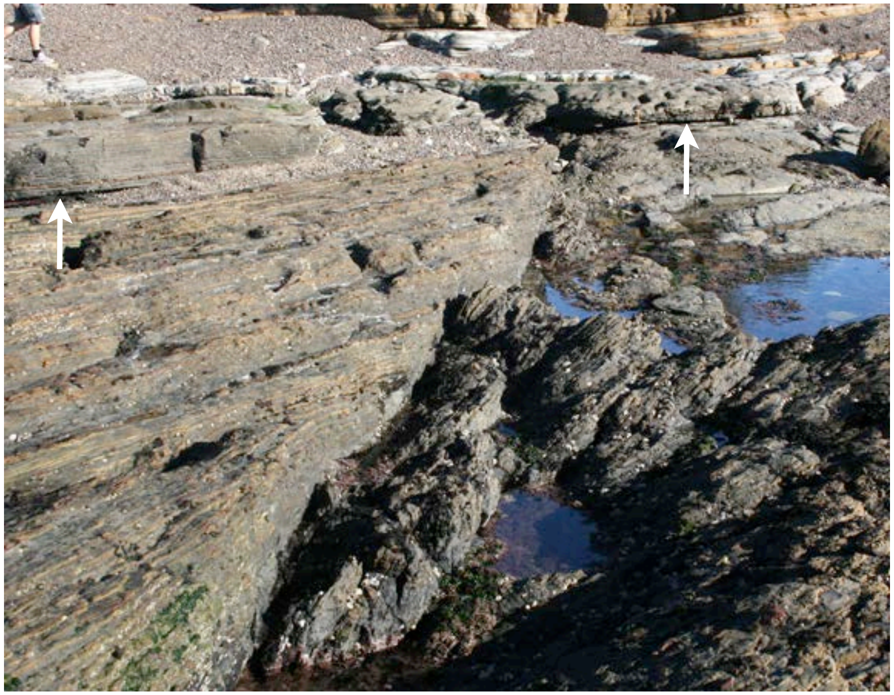


Figure 74. Fault (yellow arrow) cutting a fine-grained section on the south side of Weston Beach terminates abruptly at a bedding-plane surface (white arrows). Person, upper left, for scale

Faults that parallel bedding planes in the strata they transect may represent the soles of large subaqueous slides within the ancient submarine canyon. A probable example occurs in the small cove just southeast of Weston Beach (Fig. 75). The attitudes of strata in this cove are highly variable, presumably due to deformation at the front of a large slide. Another example exists in the sea cliffs just northeast of the Piney Woods area, where a prominent break in the section is accompanied by pre-consolidation deformation of the underlying and overlying sediment (Fig. 76).

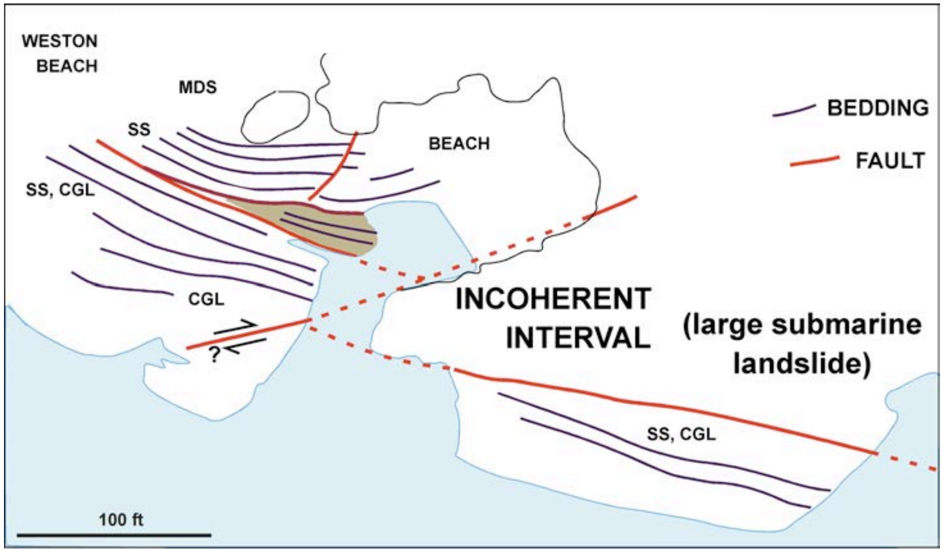


Figure 75. Deformation of strata in the small cove just southeast of Weston Beach is probably due to the impact of a large submarine slide that was moving in a northwesterly direction across the canyon floor. This deformation (the bending and breaking of the beds in the cove shown by the red and black lines inside the cove) occurred before the whole section was tilted to the northeast by another process. The fault that roughly parallels the shoreline appears to be the sole of the slide. It appears to have been subsequently offset by another fault on the southwest side of the cove.

Figure 76. Prominent fracture through the section in the sea about 100 m northwest of the Piney Woods coastal parking area. Dark line (arrow) is a break in the section that approximately parallels the stratification. Overlying fine-grained strata displays large-scale deformation and appears to be crushed into conglomerate at the far left of the photo. Underlying sandstones appear to been locally highly deformed before the sediment was fully consolidated.

Incoherent intervals: A number of outcrops of the Carmelo Formation at Point Lobos lack any obvious stratigraphic or structural organization and are referred to here as "incoherent intervals" (Figs. 77, 78, 79). Some, if not most, of these may have been created by internal movements in very large mass-failures of the sediment that occurred in the ancient submarine canyon. The material noted as "Incoherent Interval" in Figure 75 is a disorganized jumble of conglomerate and sandstone (Fig. 79).

Figure 77. Incoherent interval, southeast side of Moss Cove. Rock in cliff behind figure has neither stratigraphic continuity nor coherent structural organization.

Figure 78. Large scale incoherent interval, northeastern side of Sea Lion Cove. Stratification and structure lack evident organization.

Figure 79. Incoherent interval shown in Figure 75 on the south side of the small cove southeast of Weston Beach appears to be part of a large submarine mass failure that slid into and deformed the rocks on the northwestern side of the cove.

III. METAMORPHIC ROCKS (Rocks that have been changed by heat and pressure into a form different from their original character)

No metamorphic rocks crop out at Point Lobos, but many pebbles in the Carmelo conglomerate show a degree of metamorphism. In his Masters Thesis on the Carmelo Formation, Alireza Nili-Esfanhani analyzed 2,300 pebbles from 23 different conglomerate outcrops and determined that a quarter of the andesitic volcanic pebbles showed some degree of metamorphism (Masters Thesis, UCLA, 1965, 228 p.).

The End