NORTHERN CALIFORNIA GEOLOGICAL SOCIETY

"ANCIENT SUBMARINE LANDSLIDES IN A SUBMARINE CANYON FILL – THE CARMELO FORMATION AT POINT LOBOS"

NCGS FIELD TRIP – Saturday May 3, 2014

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Large-scale mass failures in Carmelo Formation submarine canyon fill,
Point Lobos, California
H. Edward Clifton, May 3, 2014

Introduction

The superb outcrops of the Carmelo Formation at Point Lobos State Natural Reserve provide an excellent view of a conglomeratic submarine canyon fill. Previous studies and field trips have dealt with different aspects of these deposits: sedimentary processes (Clifton, 1981; 1984), organization and architecture of the canyon fill (Cronin and Kidd, 1998; Lowe, 2004; Clifton, 2005; Sullivan and Campion, 2013), relation to similar deposits at Point Reyes (Burnham, 2005) and trace fossils (Hill, 1981; Bromley et al., 2003). This field excursion focuses on yet another aspect of these deposits: large scale mass failures of semi-consolidated sediment within the canyon. These failures created a number of enigmatic features within the deposits and greatly complicate attempts to interpret facies architecture and correlations within the canyon fill.

This field trip begins by examining Carmelo deposits in its exposures around Whalers Cove, Moss Cove and The Pit in the northeastern part of the Reserve (Fig. 1). We will meet at the entrance (park alongside the road near the park entrance) and follow the Carmel Meadow Trail to Whalers Cove for an overview of the Carmelo Formation.

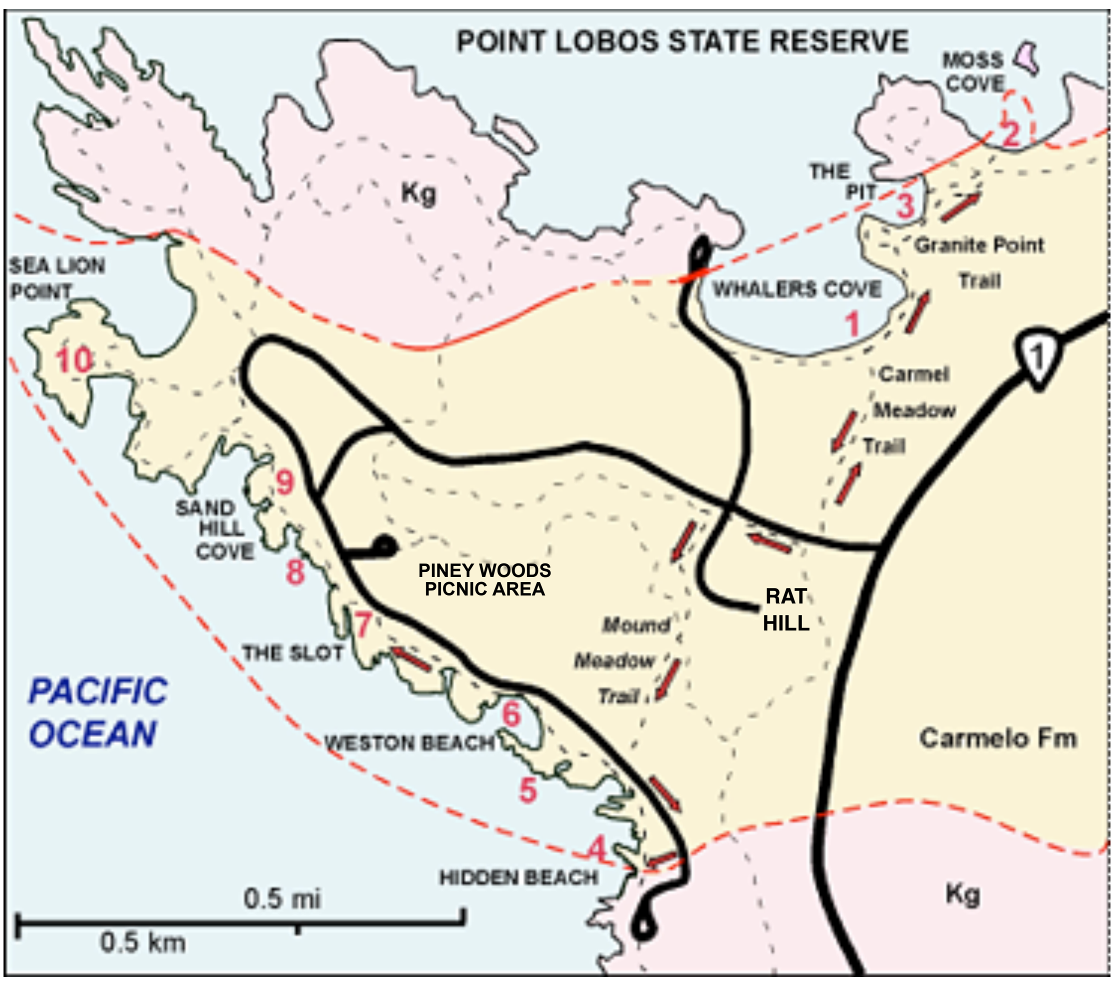

Figure 1. Distribution of Carmelo Formation at Point Lobos and location of field trip stops.

The trip continues to the shore of Moss Cove (Stop 2), where we will see the contact with the underlying granodiorite and consider implications of the attitude of the Carmelo strata there as it bears on the question of regional deformation. We will follow this with a stop at The Pit where we will consider evidence that the canyon fill was partly removed, perhaps abruptly, long after the initial filling (evidence for this also exists at Moss Cove).

The rest of the field trip focuses on outcrops on the Reserve's south shore (the stretch of coast between Sea Lion Point and Hidden Beach). We will retrace our course back to the Reserve entrance, walk down the road to the first intersection where we will take the Mound Meadow trail to the south. Upon reaching the road on the South Shore, we will follow it south to Hidden Beach to view a perplexing contact with the underlying granodiorite (Stop 4). We will then follow the South Shore Trail to the small cove south of Weston Beach (Stop 5) where we will examine an underwater slide that plowed into and disrupted a thick sedimentary succession. At Weston Beach (Stop 6) we will examine a set of unusual faults that may owe their origin to compression generated by that slide.

We will have lunch in the Piney Woods Picnic Area either before or after visiting Stop 7 (The Slot) depending on the time. The picnic area has restrooms and water.

At The Slot, we will examine a large submarine slide and discuss its origin. A short distance to the northeast, below the coastal parking area, our focus will be on some very complicated structural relations and faulting (Stop 8). Stop 9 provides another example of large-scale deformation of semi-consolidated sediment that appears to have resulted from large scale mass failure of the canyon floor deposits.

Stop 10 at Sea Lion Cove/Sea Lion Point (Fig. 1) is an optional stop that will depend on time and interest. A large slide is exposed in the sea cliffs around the Cove and its effects may extend onto Sea Lion Point itself.

Stop 1. Whalers Cove

The first stop, where the Carmel Meadow Trail intersects the Granite Point Trail, provides a view of the Carmelo Formation in its exposures around Whalers Cove. On the northwestern side of the cove the Carmelo strata dip to the south away from an apparently depositional contact. On Coal Chute Point, on the northeastern side of the cove, conglomerate and sandstone dip to the southeast. On the large rock island near the western side of the cove, strata dip to the east, but in the sea cliff deposits 50 m to the south, bedding dips to the southwest. In short, the attitude of Carmelo strata exposed around Whalers Cove is highly inconsistent (Fig. 2).

Figure 2. Carmelo Formation in exposures around the western side of Whalers Cove. Arrow denotes approximate location of Stop 1 on this field trip.

Stop 2. Moss Cove.

The Carmel Formation here apparently filled a reentrant or tributary to the main canyon. Contact with the granodiorite occurs on both the southwestern and southeastern sides of the cove (Fig. 3). The western contact (X) is steep and can be followed in rocks exposed in the cove. On the eastern side (Y), the conglomerate apparently overlies a southwesterly-plunging granodiorite ridge, east of which apparently lies the main body of the Carmelo Formation.

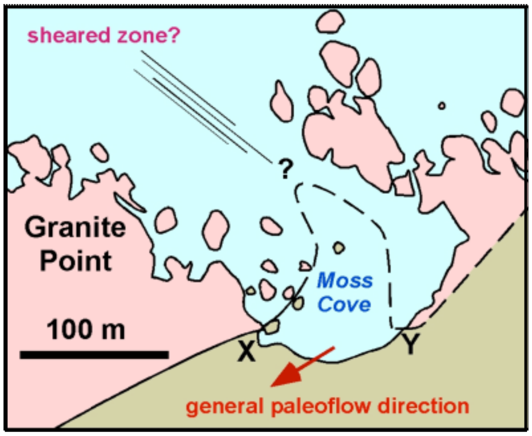

Figure 3. Distribution of the Carmelo Formation at Moss Cove.

On the western side of the cove, the Carmelo depositionally abuts a steep irregular wall of granodiorite. The Carmelo adjacent to the wall consists of about 8 meters of structureless conglomerate that grades upward into a couple of meters of pebbly mudstone and mudstone breccia (Fig. 4). Contacts within this unit dip away from the canyon wall at an angle of about 30°, as does its upper surface ("E" in Figures 4 and 5). Mudstone clasts near the top of the breccia are aligned parallel to the upper contact, documenting it as a depositional surface. Overlying gently dipping beds of conglomerate and sandstone apparently lap onto the mudstone breccia (Figs. 5 and 6).

The upward succession of unstratified conglomerate-pebbly mudstone-mudstone breccia appears to be completely transitional. Although the conglomerate shows no segregation into beds, pebbles display a crude alignment that dips about 30° away from the wall. The succession appears to result from a single depositional event, a slide of sand gravel and mud from the canyon wall. A block of steeply dipping (45°) interbedded sandstone and conglomerate several meters across adjacent to the contact (Fig. 6) appears to have slid down from the canyon wall.

The material that composed the slide presumably accumulated in an earlier phase of canyon filling, then slumped from the canyon wall into space created by a subsequent partial evacuation of the canyon fill. Subsequent deposits of sandstone and bedded gravel then covered (onlapped) the accumulation next to the wall.

EXPLANATION

A, Massive conglomerate with aligned clasts
B. Pebbly mudstone
C. Pebbly mudstone breccia large mudstone clasts
D. Mudstone breccia, very coarse sandstone matrix
E. Chaotic conglomerate
F. Organized conglomerate

Figure 4. Lithologies and sedimentary units adjacent to the granodiorite wall (just to right of photograph).

Figure 5. Bedding geometries at the top of the mudstone breccia. The overlying sandstone and conglomerate (upper two lines) dip gently to the south in an apparent onlapping of the more steeply-dipping top of the mudstone breccia (lower line "E"). Mudstone clasts below the contact are aligned parallel to it, indicating that it is a depositional surface sloping away from the canyon wall.

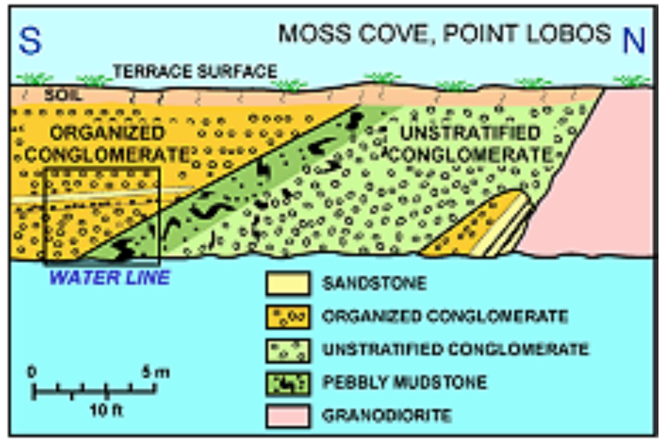

Figure 6. Representation of the basal Carmelo Formation on the west side of Moss Cove. Box shows location of Figure 5.

Sandstone strata in the central part of Moss Cove (Fig. 7), like those overlapping the slide, are nearly horizontal. Their attitude implies an absence of regional tilting of the Carmelo-granodiorite rock mass. Horizontal Carmelo strata elsewhere in the Reserve also argue against a regional tilting.

Figure 7. Nearly horizontal sandstone and conglomerate in the central part of Moss Cove.

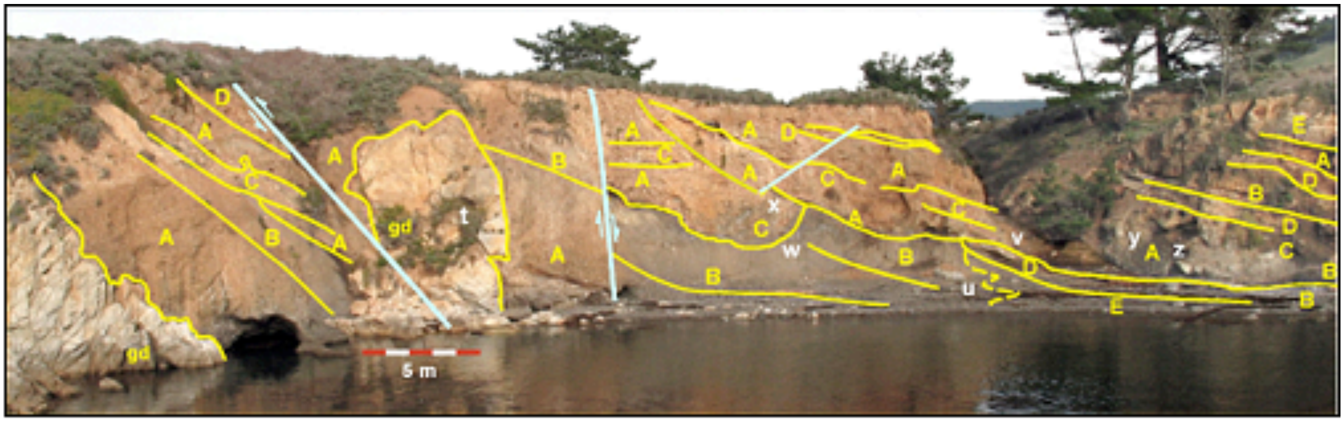

Figure 8. Eastern wall of The Pit, showing contact of the Carmelo Formation with the granodiorite (gd). Sedimentary lithologies: A = conglomerate, B = pebbly mudstone, C = conglomerate with large mudstone clasts, D = sandstone, E = interbedded sandstone and conglomerate. Light blue lines are faults. White arrows with lowercase letters refer to locations of features described in text.

Stop 3. The Pit

The Pit, which derives its name from gravel extraction here in the early 20th Century, provides an excellent exposure of the basal contact of the Carmelo Formation. Figure 8 depicts the eastern wall of the inlet showing the lithologies exposed in the sea cliff and location of features described in the text. Two prominent faults cut the outcrop. One, which intersects the beach about 10 m from the basal contact, is inferred to be a reverse fault that probably repeats the section (Lowe, 2004). Figure 8 shows an inferred reconstruction of the section across the faults.

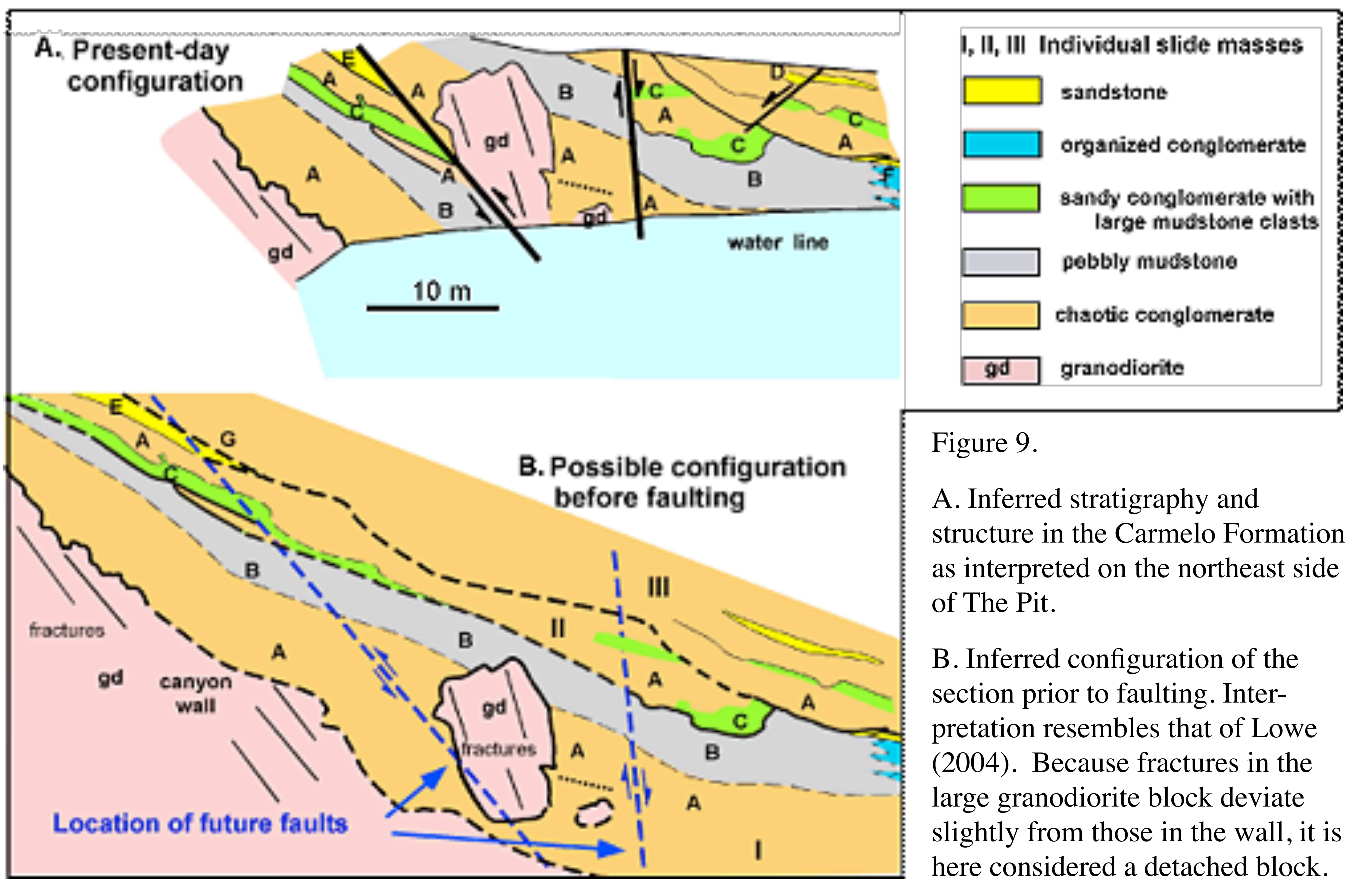

Figure 9.

A. Inferred stratigraphy and structure in the Carmelo Formation as interpreted on the northeast side of The Pit.

B. Inferred configuration of the section prior to faulting. Interpretation resembles that of Lowe (2004). Because fractures in the large granodiorite block deviate slightly from those in the wall, it is here considered a detached block.

The Carmelo Formation here, as in Moss Cove, abuts a wall of granodiorite, but the stratigraphic and structural relations are more complex. The granodiorite is repeated in a giant block ("t", above the scale in Figure 8), that is probably either an up-faulted spire or detached block (see Figure 9). The section above the basal contact appears to consist of a series of large slides off the granitic wall.

As in Moss Cove, unstratified conglomerate abuts the granite wall and passes upward into pebbly mudstone. The long axes of many pebbles in the conglomerate, like those in Moss Cove, dip roughly parallel to the underlying contact. In The Pit, the pebbly mudstone is not overlapped by gently inclined sandstone and conglomerate. Rather, if the pre-fault reconstruction (Fig. 9) is accurate, the pebbly mudstone laterally abuts a mass of stratified conglomerate ("u", Fig. 8) that is capped by a prominent sandstone bed that underlies the trail where it enters the beach ("v", Fig. 8). The contact between the stratified conglomerate and the pebbly mudstone is gradational, suggesting that the conglomerate and overlying sandstone are part of a large disintegrating slide block encased in the pebbly mudstone.

The pebbly mudstone (shown as "B: in the central part of Figure 8) underlies a coarse conglomerate. Locally this conglomerate seems to have "plowed" into the mudstone ("w", Figure 8). This conglomerate is sharply overlain by another mass of coarse chaotic conglomerate, which contains intervals of large mudstone clasts. I infer that 3 large sidewall slides are present here: the lowest ("I", Fig. 9B), capped by pebbly mudstone, a middle slide ("II", Fig. 9B) which plowed into the pebbly mudstone "II", and an upper slide ("III", Fig. 9B) that truncated the middle one (conceivably, the middle and upper units are part of the same slide).

Near the trail entry to the cove, slide mass III truncates the prominent sandstone bed noted at "v" in Figure 8, Repeated thrust faults in this sandstone bed (Fig. 10) indicate that the overlying slide moved to the southeast. A set of prominent striations on the base of slide III where it overlies slide II ("x", Fig. 8) supports this slide direction.

In summary, the basal Carmelo at The Pit consists of series of large sidewall slides. The presence of blocks of finer (and in one case bedded) conglomerate ("y" and "z", Fig. 8) suggests that the slides occurred after the sand and gravel had become partly cemented, implying substantial time between the initial deposition of the coarse sediment and its incorporation into a slide mass. As at Moss Cove, the question remains: what process could have exhumed the canyon fill to allow such large sidewall slides?

Figure 10. Thrust in sandstone bed adjacent to the trail (note asphalt pavement on right side) in The Pit. Strata below the sandstone consist of mudstone and conglomerate. Overlying the sandstone is chaotic conglomerate at the base of Slide III in Figure 9B. Thrust fault is one of several in the sandstone bed, all with the same sense of offset. I interpret the faults to result from imposed at the base of the overlying slide mass as it moved toward the southeast.

Stop 4. Hidden Beach

The contact exposed at Moss Cove and The Pit crosses the Reserve and enters the sea on the north side of Headland Cove (the cove north of Sea Lion Point) (Figs. 1, 11). As in the exposures to the east, the contact dips steeply (±30°) to the south and is depositionally overlain by conglomerate. Beneath the sea the contact turns to the south (landward of the granitic Sea Lion Rocks) and crosses the shoreline at Hidden Beach (Fig. 11). Maps provided by the Bay Area Underwater Explorers (BAUE) show that the seafloor beneath the granodiorite has a distinctive pattern that helps resolve the location the contact with the Carmelo Formation. If my interpretation of that pattern (Fig. 11) is accurate, the contact lies near the shoreline off Sea Lion Point and the southern part of the South Shore.

Hidden Beach marks the southern limit of the Carmelo Formation on the South Shore. It is also the site of a geological puzzle. The contact (Fig. 12) between the granodiorite (on the southeast side of the beach and the Carmelo Formation (on the northwest side) is covered by sand on the beach and by

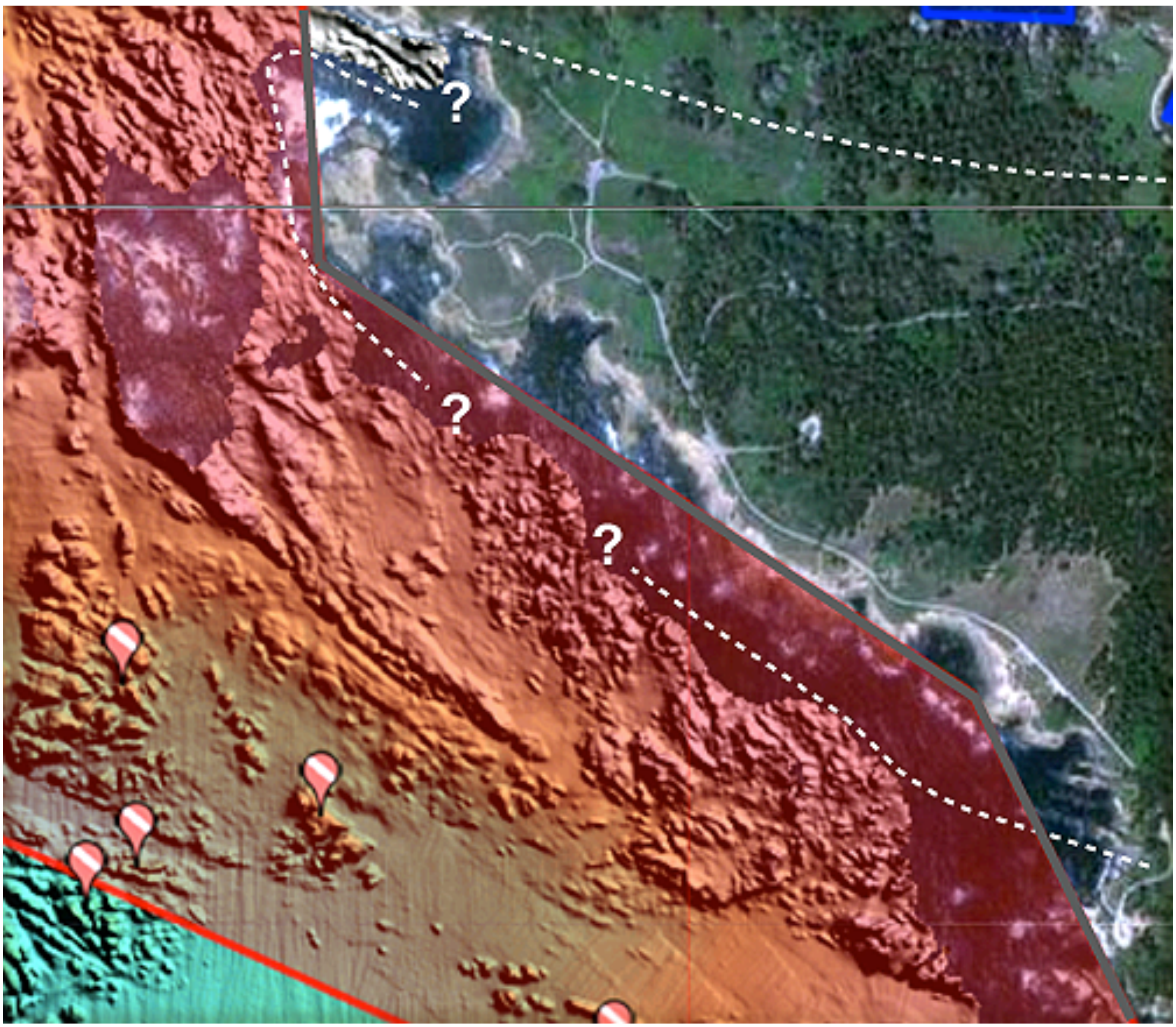

Figure 11. Ocean floor seaward of the South Shore of Point Lobos State Reserve. Image provided by the Bay Area Underwater Explorers (http://www.baue.org/lobos_maps/). Note pervasive northwest/southeast fracture pattern in the inferred offshore granodiorite.

rubble in the sea cliff. It has been mapped as a fault by previous workers (Nili-Esfahani, 1965; Clark et al,,1997) and it probably is. The conundrum derives from the orientation of the Carmelo strata, which are parallel to the nearly vertical contact.

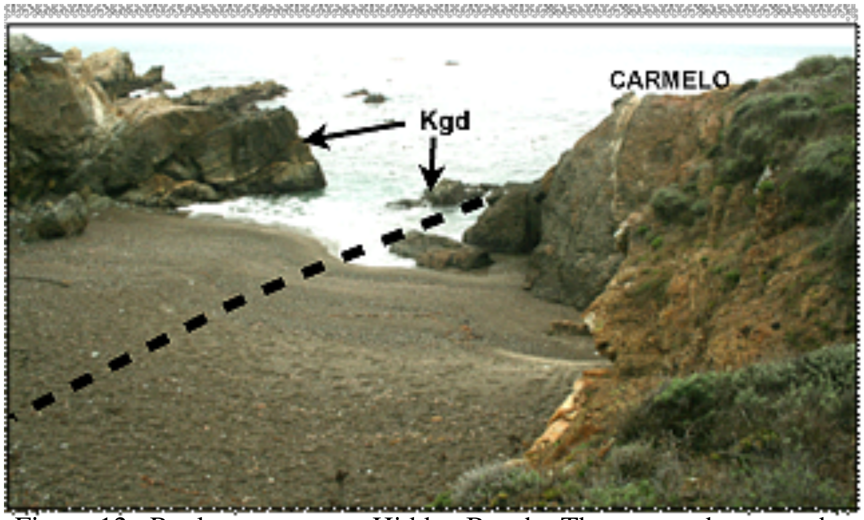

Figure 12. Rock exposures at Hidden Beach. The contact between the granodiorite (Kgd) and the Carmelo Formation approximately follows the dashed line. Note nearly vertical strata in the Carmelo.

A 90° rotation of the entire succession, including the basement rock (A, Fig. 13) is hardly conceivable. Prominent northwest-southeast trending fractures in the granodiorite shape much of the north shore of the Reserve (Fig. 1). At Moss Cove, Carmelo conglomerate fills a fissure made by such a fracture, evidence that the fracturing preceded the deposition of the Carmelo. The northwest-southeast fracture pattern is visible in the subsea rocks off Sea Lion Point as well as in those exposed on the seafloor south of Hidden beach (Fig. 11). A 90° rotation of the entire section at Hidden Beach seems impossible,

Drag of the sedimentary beds along a fault could create vertical dips (B, Fig. 13), but drag is not a likely explanation for the approximately150 m of contiguous Carmelo section to the north with similarly steep dips.

A third possibility is that a giant slide within the canyon fill ramped up the strata against a steep canyon wall (C, Fig. 13). The Carmelo Formation in the Reserve seems to have filled a undersea valley that curved to the northwest on the South Shore. The imbrication of pebbles in the conglomerate exposed on the South Shore indicates paleo-transport to the northwest, approximately parallel to the offshore canyon wall. Conceivably, a massive slide of the canyon fill could drive the strata in the slide up against a very steep, locally nearly vertical canyon wall.

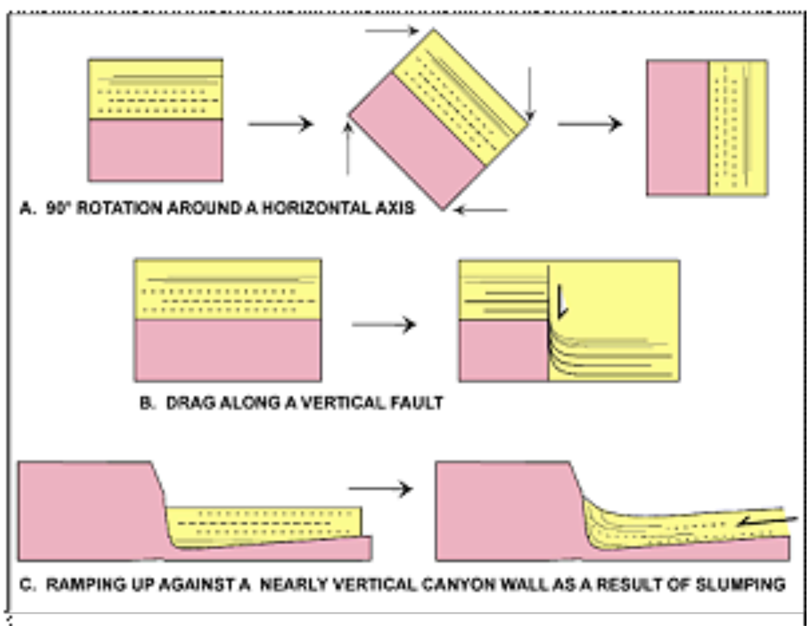

Figure 13. Possible explanations for the strange contact at Hidden Beach, where the contact between the granodiorite and the Carmelo formation is a nearly vertical fault and the basal Carmelo strata are approximately parallel to the contact.

Stop 4. The shoreline between Stop 4 (Hidden Beach) and Stop 5 (“nightmare cove”).

The Carmelo section north of Hidden beach consists of about 150 m of steeply dipping strata organized into a series of upward-fining successions (Cronin and Kidd, 1998, Clifton, 2007). The configuration of the shoreline in part reflects these successions with alternating projecting headlands of conglomerate and narrow coves following intervals of mudstone.

Two of the recesses (A and B, Fig. 14) follow a fault zone composed of sheared fine-grained material. The attitude of the strata changes across these faults: North of A in Figure 14, the beds are still dip very steeply, but the strike differs by about 12 degrees. North of B, the strata inside the cove display a variety of attitudes.

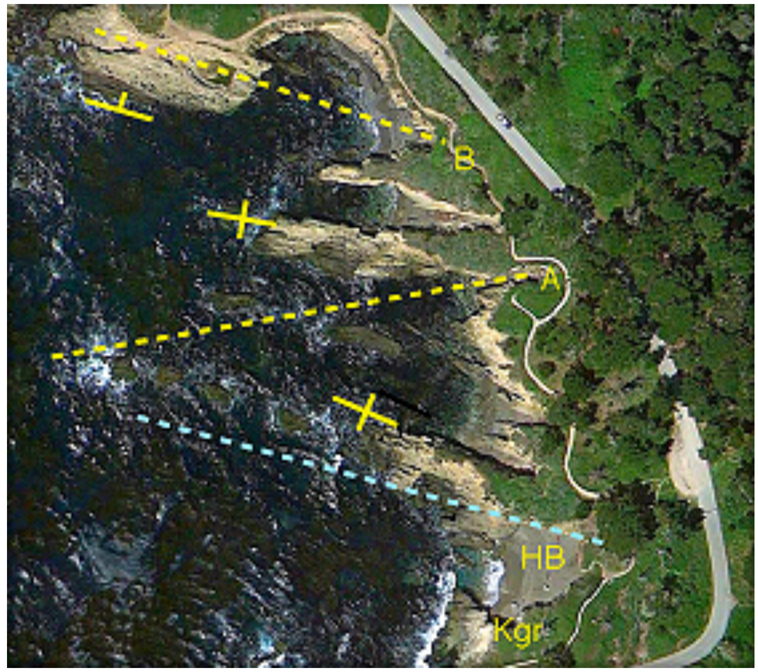

Figure 14. Shoreline between Hidden Beach (HB) and “nightmare cove” (very top left of photo). Arrow marks a fault (sheared zone) across which the strike of the nearly vertical beds changes. Blue dashed line shows approximate Carmelo-granodiorite (Kgr) contact.

Stop 5. “nightmare cove”

I bestowed the informal name “nightmare cove” on the otherwise unnamed small cove south of Weston Beach (Fig. 1) because of its stratigraphic and structural complexity. Although less than 10 m across at the entrance, the cove displays striking contrasts in its rocks (Fig. 15). A thick chaotic conglomerate containing contorted and discontinuous beds of sandstone occupies most of the south wall. The northeastern side of the cove is underlain by upward fining of conglomerate, sandstone and mudstone. A poorly exposed fault separates the conglomeratic section on the south from the sandy section on the north (“F”, Fig. 16). Strata exposed near the middle of the cove lie in seemingly unrelated attitudes (Fig. 16) and a large block of steeply-dipping thick- and thin-bedded sandstone is wedged what appears to be a continuous section of thick-bedded sandstone that contains pebbles pebbles in its lower part (Figs. 15-17). This wedge is broken by many small faults, and near its northern terminus, the beds are crumpled (Fig. 18). Some sandstone within the wedge displays evidence of soft-sediment deformation (Fig. 19).

Although the stratal relations in the cove (Fig. 20) initially appear nightmarish, they provide the key to interpreting the succession. The section below the fault on the south side of the cove (pebbly sandstone atop a massive conglomerate section) closely resembles that in the lower part of the section on the north side of the cove. I infer that the fault at the base of the chaotic conglomerate on the south side of the cove originally aligned with the fault at the base of the wedge on the north side of the cove and was subsequently displaced by movement along the fault that follows the southeast side of the cove (Figs. 20, 21). This fault coincides with the front of a large submarine landslide in the canyon that plowed into a fining-up succession (Weston Beach), deforming the beds and forcing a detached wedge of sandstone into the strata on the north side of the cove. The slide predated the tilting of the beds; the attitude of the deformed beds suggests that it was moving toward the west-southwest.

Figure 15. "Nightmare cove" (inlet crossing center of photograph), looking north. Rocks on south side consist of a thick chaotic conglomerate overlying, in fault contact (F), steeply dipping organized conglomerate with sandstone beds. Rocks on the north side of the cove lie in an upward-fining succession from conglomerate (1) to thick-bedded sandstone (2) to thin-bedded sandstone (3) to interbedded sandstone and mudstone (4). A large wedge of internally faulted thick/thin-bedded sandstone (w) abuts thick-bedded pebbly sandstone between numbers "2" and "3" on photo. Weston Beach in background.

Figure 16. North side of "nightmare cove". Note differences in bedding attitude (1, 2, 3, 4, 5), wedge of displaced thick and thin-bedded sandstone (w) and fault (F) at back edge of the cove

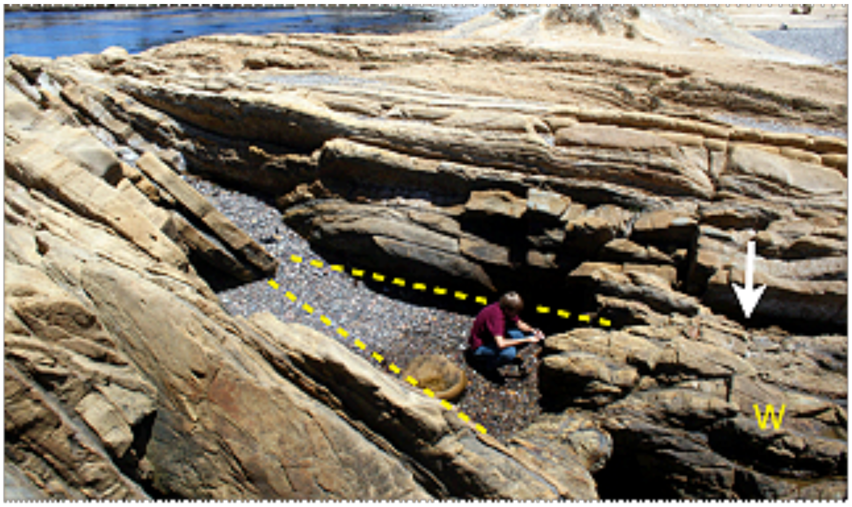

Figure 17. Landward end of the wedge (w). Dotted lines indicate upper and lower surfaces. Arrow points to location of Figure 18.

Figure 18. "Crumpled" Interbedded sandstone and mudstone near the northern "nose" of the wedge ("w" in Figs. 15-17). Fine gravel (right side for scale.

Figure 19. Faulted sandstone bed within the wedge. Note apparent soft-sediment deformation of overturned thin sandstone and mudstone layers below pencil point.

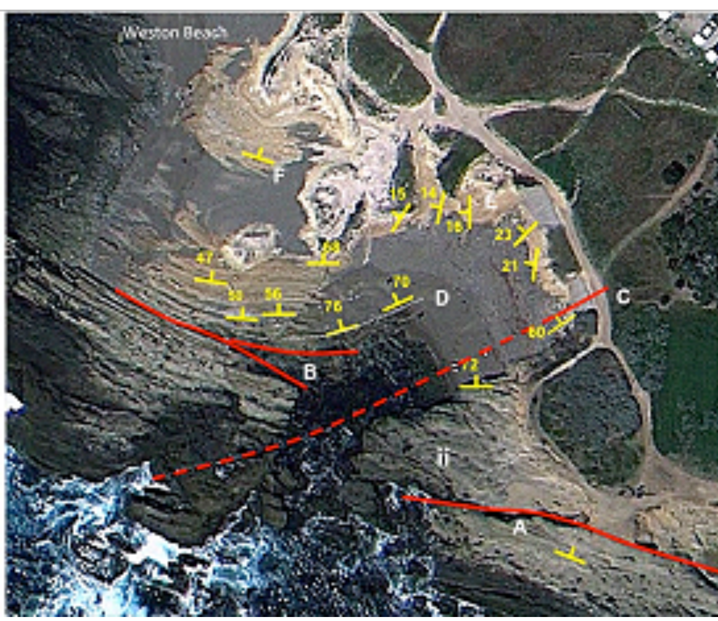

Figure 20. Structural relations at "nightmare cove". A: fault separating chaotic conglomerate from underlying organized conglomerate; B. sandstone wedge; C. fault separating fine beds section from conglomeratic section; D. steeply dipping sandstone beds; E: moderately inclined fine-grained strata; F. nearly horizontal fine-grained strata. ii: incoherent interval of conglomerate and sandstone
Red lines: faults

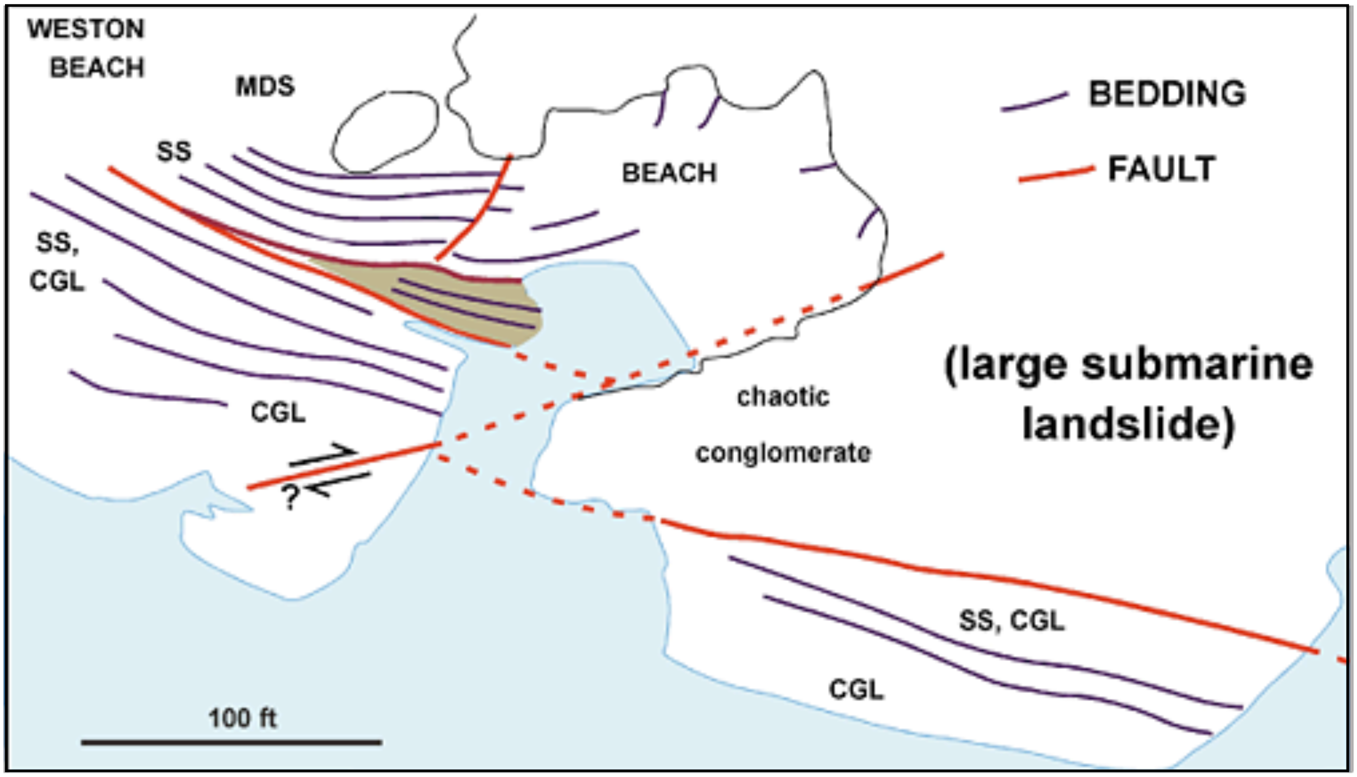

Figure 21. Interpretation of the strata at "nightmare cove". Chaotic conglomerate represents a large submarine landslide on the ancient canyon floor, moving to the southwest, crushing into and deforming an upward-fining succession of conglomerate, sandstone and mudstone. Fault contact at the base of the chaotic conglomerate on the southwest side presumed to form the base of the "wedge" (in brown).

Stop 6 (Weston Beach)

Weston Beach (Fig. 1) is one of the more geologically significant locations in the Reserve. In addition to displaying a thick complete upward succession from conglomerate to mudstone, the rocks provide a plethora of beautifully exposed deep-water trace fossils. Our focus is, however, on some very strange faults that cut the section and may relate to the large slide in "nightmare cove".

The strata at Weston Beach form a shallow syncline, the axis of which lies on the southwestern side of the cove (Fig. 22). Separating the two limbs of the syncline is a prominent fault characterized in the upper intertidal by a 4-m-wide fault zone filled with vertical strata that strike slightly obliquely to the fault (A, Fig. 23). The fault zone narrows to seaward, where the strata adjacent to both sides of the fault bend slightly upward as they

Figure 22. Weston beach showing attitudes, syncline axis (dashed line) and location of Figure 23 (white square).

approach the fault (Fig. 24), even though the fault broadly defines a synclinal axis of a syncline. To landward, the fault zone is covered by beach sand and gravel. The southern bounding fault aligns with a fault through the bedrock exposed on the beach (B, Fig. 23). The landward extent of the northern bounding fault is uncertain: it is constantly buried under beach sand and gravel and the material underlying the sea cliffs is intensely weathered. At "B" (Fig. 23), sandstone adjacent to the fault forms irregular streaks (Fig 25); it appears to have been unconsolidated at the time of faulting.

A second obvious fault (C, Fig. 23) crosses the intertidal rocks about 10 m south of the fault zone at "A" (Fig. 23) in a trend parallel to that of the southern bounding fault at "A". Strata adjacent to this fault locally dip steeply into the fault plane (Fig. 26). The fault terminates abruptly at bedding surface in the overlying

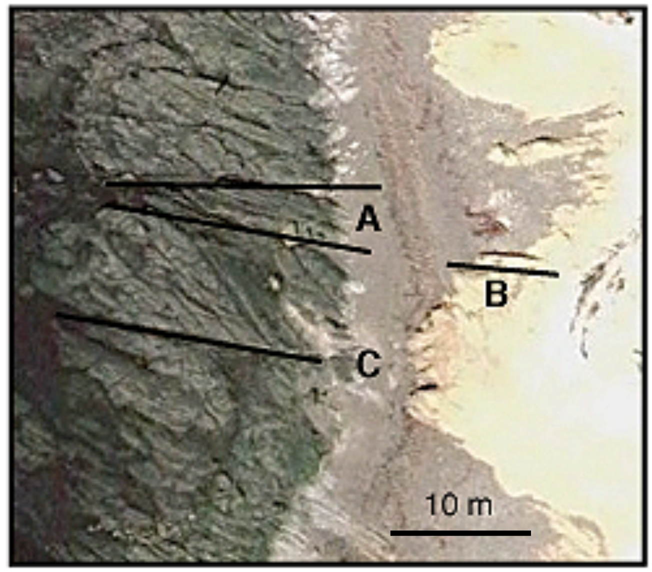

Figure 23. Enlargement of Figure 22, south side of Weston Beach. A. Fault zone containing large block of nearly vertical strata. B. Fault through rocks exposed on beach, on line with the southern bounding fault of the fault zone. C. Single fault through interbedded thin-bedded sandstone and mudstone of the Carmelo Formation.

Figure 24. Fault zone (A, Fig. 23) viewed from seaward side. Arrows delineate fault zone boundaries. Note that beds at either side of the fault zone in foreground are bent upward adjacent to the fault.

thinly bedded strata (large yellow arrow, Fig. 26). Strata on the south side of this fault dip steeply into the fault plane as they approach it, but the fault appears to be a simple single break.

Steeply dipping strata within a fault zone as with faults A and C (Figs. 23, 24 and 26) require a special explanation. Figure 27 offers a possibility based on lateral compression. Fault C represents stage 3 in the compression and the more complex fault A represents stage 4.

How could this much compression occur without involving the overlying section? A possible explanation is that compression displaced the fractures along bedding planes in the sediment above the faults. Bedding plane faults are common in the Weston Beach thin-bedded sandstone and mudstone intervals (Figs. 28, 29). Typically no evidence exists of differential erosion along these contacts suggesting that they did not break an ancient sea floor.

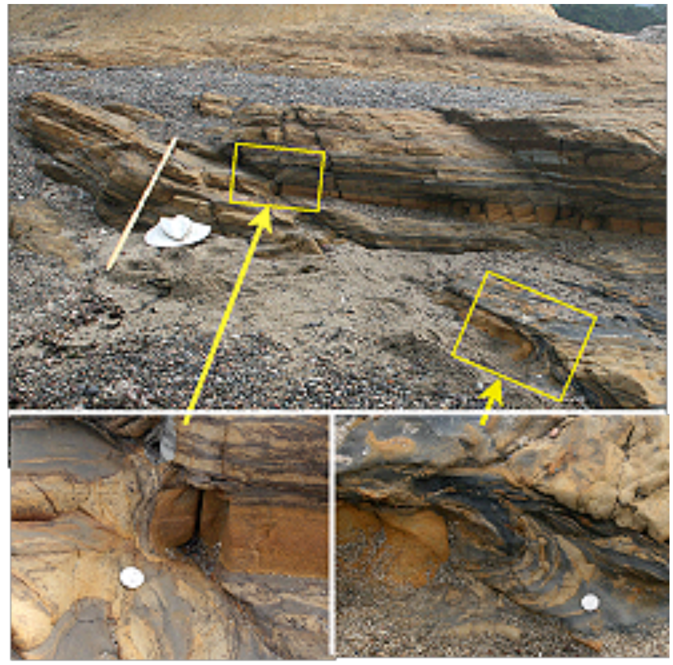

Figure 25. Fault zone (B, Fig. 23) above hat. Note streaked nature of sandstone adjacent to the fault, implying a lack of complete consolidation at the time of movement. Quarter dollar for scale in bottom photographs.

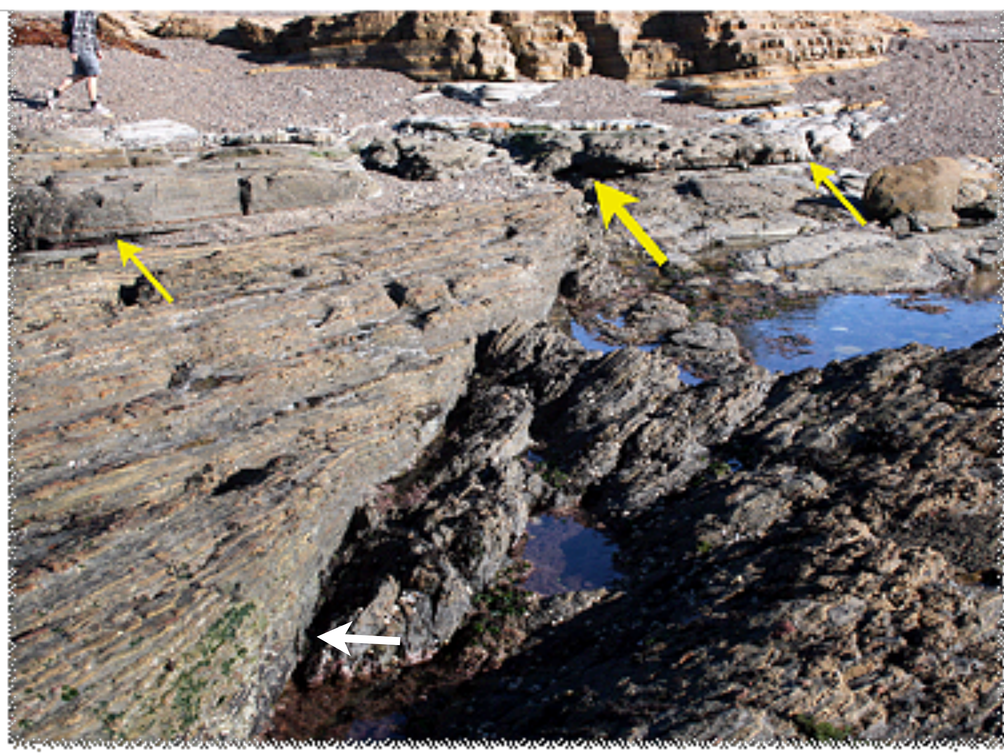

Figure 26. Fault C in Figure 23. Fault (white arrow) is truncated by overlying nearly horizontal sandstone and mudstone at the point of the large yellow arrow. Smaller yellow arrows identify the same surface in rocks to either side. Note steep inclination of strata into the fault beneath the white arrow. Figure, upper left, for scale.

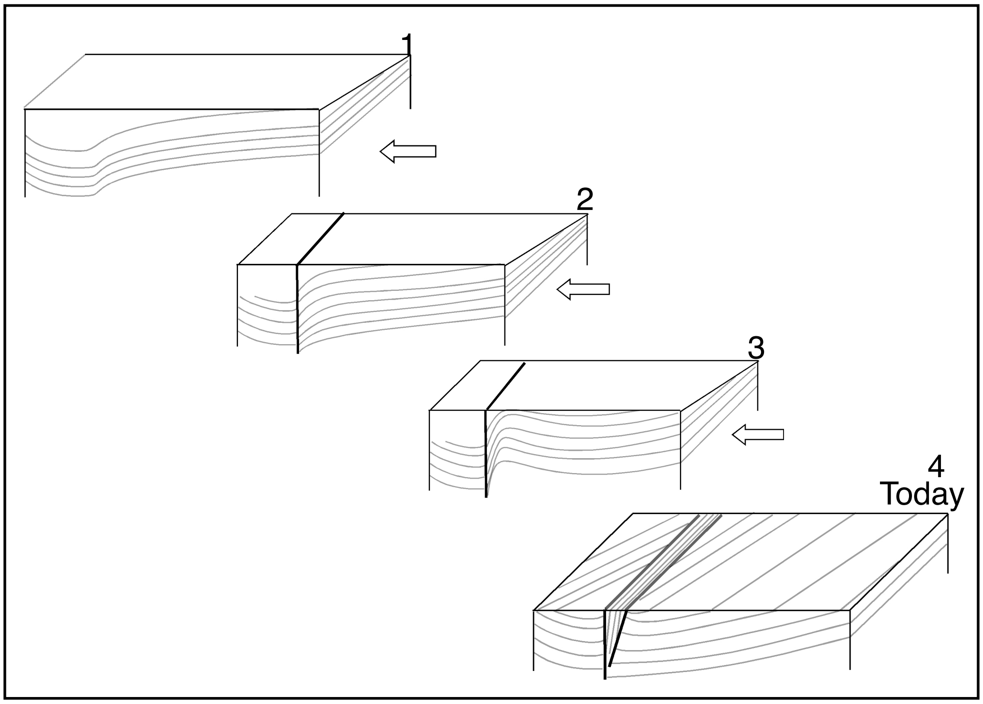

Figure 27. Possible origin of the faults at the south end of Weston Beach.

1: Lateral compression bends the strata into a syncline;

2: The strata fracture along a "kink" in the resulting fold;

3: Further compression sharply bends the strata into the fracture;

4: The rocks fracture again, creating a zone of steeply dipping strata bounded by faults.

It seems reasonable to attribute the peculiar faults on the southern side of Weston Beach to compression generated by the impact of the large landslide that disrupted the strata in "nightmare cove". In both places the strata appear to have been deformed while cohesive enough to fracture, yet sufficiently unconsolidated that sand could behave plastically.

The pattern of bedding attitudes shown in Figure 22 suggests that the Weston Beach syncline could have resulted from the impact of the slide in "nightmare cove" The strange faults on the south side of Weston are part of the overall deformation created by the landslide.

Figure 28. Small fault of unknown displacement (to right) of lens cap terminated at a horizontal surface (marked by arrow). South side of Weston Beach.

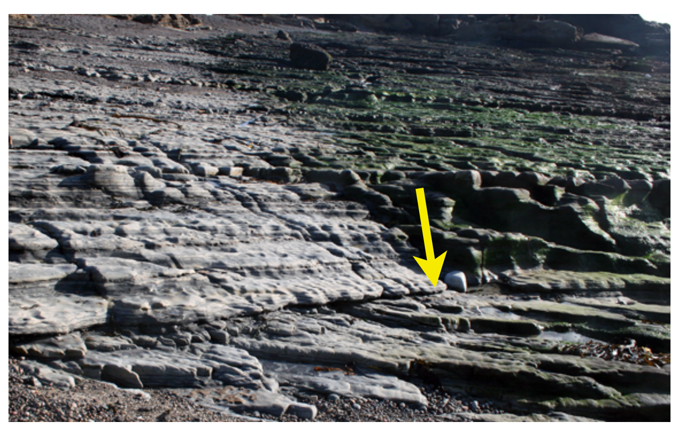

Figure 29. Bedding plane fault (arrow) in strata on the central east side of Weston Beach. Strata immediately above the contact show no sign of differential erosion as might be expected if the contact represented the ancient sea floor below which the strata were tilted.