The General and Structural Geology of a Portion of Moss Beach, San Mateo County, California

by

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A Report on the Structural and Sedimentary Geology of Moss Beach, California

by

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Geology of the Moss Beach Area

by

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of a portion of Moss Beach,

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The Geology of Moss Beach

Introduction

This project was undertaken as a field exercise for Geol. 110: Structural Geology, Stanford University. Its purpose was to provide experience with detailed geologic mapping as well as to make use of the descriptive tools developed in the course when analysing the structural features.

Moss Beach is located about 25 miles south of San Francisco on the Pacific Coast. Most of the area studied is a part of the James V. Fitzgerald Marine Reserve in San Mateo County, California. The area mapped is a small segment of the Montara Mountain Quadrangle, extending north along the coast about 600 meters from the Seal Cove Fault Zone. Mapping was accomplished via a plane table and alidade survey at a scale of 1:1000.

Special thanks to: Kent Keller, mapping partner and geologist extraordinaré, who managed to make the geology comprehensible; Mark Taguchi, a roommate and human alarm clock, who woke me up every Saturday morning despite my opposition to being aroused at that brutal hour; Robert Pacheco, provider of colored pencils and other forms of graphical assistance; Alison Okumoto, for all-around inspiration.

Previous Investigations

The earliest work in this area dates back to the late 19th century and general investigations of the geology of the San Francisco region. Most of this work has since been revised and is of too general a nature to be of use here, however, it is of interest to note that Lawson (1914) assigned the sediments in this area to the Merced Formation rather than the Purisima. On the basis of paleontological evidence, Glen (1959) reassigned the strata to the Purisima. Brabb and Pampeyan (1972) go further to point out that the Merced Formation in this area is confined to the east side of the San Andreas fault system, which is several miles inland at this point. The descriptions they provide of the Merced very closely match those at Moss Beach, however, and it is very easy to understand Lawson's misidentification.

Most of the work in the Moss Beach area before 1960 was confined largely to student reports and independent research, as well as several theses (See Bibliography for listing). Much of their analysis concurs with the present description, save for the interpretation of the contact between the Montara granites and the overlying folded beds at North Point. Early thought casts it as a fault contact whereas present intuition seems to imply that it is merely depositional (see Structure section).

Recent work in the area includes that by Glen (1959) and the mapping of Brabb and Pampeyan (1972). Several engineering studies have also been made, investigating fault activity, ground stability, and sea cliff erosion (Leighton, 1971). It appears that faulting has been commonplace in this area and the ground is largely unstable, being subject to both landslide and creep movement.

Descriptive Geology

The mapped section is a part of the Montara Mountain Quadrangle, an area dominated topographically and geologically by a mass of igneous rocks commonly referred to as the Montara Complex. In the mapped area we see outcrops of the granites themselves, as well as sediments which have been deposited on and deformed against this pluton.

Montara Quartz Diorite

At Moss Beach the Montara Complex locally appears as a quartz diorite of late Cretaceous age. It is composed largely of quartz, with significant fractions of plagioclase, hornblende, and biotite. Alteration of the biotite to a chlorite mineral accounts for the greenish-gray color which is characteristic of the rock in this area. There are occasional inclusions within the diorite as well as several pegmatite veins. The outcrops are all heavily jointed and fractured, with small displacements (on the order of several inches) on many of the cracks. No particular orientation of the joints seemed immediately apparent, however, the major fractures which were mapped seemed to trend in the same direction (approximately perpendicular to the syncline's fold axis. The extensive cracking results in a sharp, angular weathered surface, and where the cracks are frequent enough the rock appears to be crumbling.

Purisima Formation

The Purisima Formation is a marine sedimentary deposit of the Pliocene. Its type area is located along Purisima Creek about 5 miles south of Half Moon Bay. Locally it represents an accumulation of siltstones, sandstones, mudstones, and conglomerates several thousand feet thick, with the sediment supplied from an array of sources, including older Miocene sediments and the Montara Mountain granites. (Classen, 1958) The depositional and fossil record seem to indicate that the Purisima was laid down in a near-shore or shallow marine environment by transgressive seas (Brunego, 1974).

At Moss Beach the Purisima appears as bedrock in the "Reefs" and "Bathtub" area. The contact at North Point seems to indicate that it is resting unconformably on a basement of the Montara granite. The sediments consist of indurated siltstones, granular sandstones, and bouldery conglomerates. For mapping and descriptive purposes, we have divided these sediments into 10 units, using outcrop expression as a criteria for differentiation rather than any particular sedimentary relationship.

Tp_1: The oldest of the mapped sedimentary units, this member is a fossiliferous, blue-gray, sand/siltstone. The exact thickness can not be determined as the beds are truncated by the Seal Cove Fault, but the unit extends at least from that boundary to the outer rib of the Bathtub. Tp_1 forms the Reefs, which are believed to be an extension of the syncline whose northeast counterparts lie buried beneath the beach and terrace (see down-plunge profile). Within the unit, sand-silt lenses devoid of fossils are interbedded with fossiliferous (mollusc shells and fragments) lenticular bodies. The former exhibit excellent jointing perpendicular to the bedding lamination, whereas the latter are structurally "stirred" mixtures of shell fragments and siltstone pebbles in a fine sand matrix grading upwards into bedding planes defined by oriented shell fragments. As a whole, Tp_1 includes cobbles up to 30 cm in diameter near the Seal Cove Fault and grades upward into thicker layers of sand/silt showing fewer lenses and no cobbles.

Tp_2: A granular rich sandstone, massively bedded and of variable thickness (0.5 - 1.0m), this unit is best described as a poorly sorted, blue-gray sandstone riddled with very angular, quartzo-feldspathic clasts up to 10mm in diameter. On exposed surfaces and along fractures it weathers to a rust brown color. The percentage of sand/granule is approximately 60/40. The contact with Tp_1 is very sharp, whereas the transition upward into Tp_3 is gradational. Possibly the sands of unit 3 became available for deposition before 2 had appreciably consolidated.

Tp_3: This blue-gray sand/siltstone is massively bedded for the most part and contains occasional fossils and inclusions. Burrow holes indicate bioturbation and some areas show clear interlamination of silt and sand in subdued ripple forms. The unit is capped by a 10 - 20cm thick zone of shearing and cracking, where the sand/silts are contorted into incompetent fissile chunks which weather recessively.

Tp_4: This unit can essentially be considered a combined Tp_2-Tp_3 sequence, a granule rich material grading into a sand/siltstone layer, but mapped as a single unit since the upper layer rarely appears in map-view due to excessive weathering. The description is analogous to those older members. It is also of interest to note that this unit lenses out along the northeast limb of the syncline.

Tp_5: This is the lower of the two conglomerates which define the Bathtub. It consists of cobbles and boulders in a silty to very poorly sorted sand matrix resting on a thin layer of granule rich sandstone (about 10cm thick). The contact with the sand/siltstone of Tp_4 is very sharp. This layer is essentially only one boulder thick, but it is very resistant to weathering and has good continuity on the limbs of the syncline. Most of the cobbles/boulders are granitic, some are sand/siltstone, and all are well rounded. Locally, the matrix can be fossiliferous.

Tp_6: Representing another influx of fine sediment, a cross section showing units Tp_5 and Tp_6 would show the upper surface of the boulders encased in the blue-gray sand/siltstone of this unit. Locally cross bedded, this bed also shows some minor dune forms. A fossiliferous bed as a whole, it also includes lenses comprised almost wholly of shell fragments. The bed is only moderately indurated and weathers recessively out of the limbs of the syncline.

Tp_7: Another granule-rich sandstone - sand/siltstone sequence analogous to Tp_4, this unit is characterized by well developed dune and ripple forms in the granular units and crossbedding in the sandstone. The granule unit is similar to those encountered before, however, the sandstone is gray-brown and medium grained rather than the blue-gray siltstone of Tp_4. Again it is possible to recognize the sharp contact in moving from the finer sandstone into the granule unit, and then the transitional grading from the granule unit into the next finer unit above.

Tp_8: This is the upper of the two conglomerate pavements and like Tp_5 consists of cobbles and boulders in a poorly sorted, brown sandstone matrix, resting on a granule rich sandstone. The unit thickens markedly as you approach North Point as does the size of the boulders. The contact with the underlying Tp_7 is very sharp, as the base of the granule rich layer truncates cross-bedded sands. The conglomerate is essentially one boulder thick (some of the boulders are more than one meter in diameter), these megaclasts consisting mostly of granite boulders (some Montara quartz diorite) with some sandstone boulders and cobbles.

Tp_9: A green-brown to gray-brown, medium grained, moderately sorted sandstone, through which large boulders extrude from the conglomerate below. Some granules appear in the unit, generally subangular quartzo-feldspathic fragments. This member is massively bedded, without cross-bedding or lamination, and is somewhat fossiliferous.

Tp_{10}: This fine, well-sorted, gray sandstone is the youngest of the units in the Bathtub area, appearing only on the stacks in the middle of the syncline. It exhibits some bedding, but it is not cross-bedded, nor does it contain any fossils.

Purisima deposits also outcrop on a small wave cut bench on the beach north of North Point. This bench unit is exposed only at the base of the sea cliff. The bedding appears to represent a syncline plunging

12, N 49 W, which means it is converging with the fold exposed in the Bathtub at an angle of approximately 18°. Data for this second fold was considerably limited by the nature of the exposure and all interpretations must be considered approximate. It is composed of layers of conglomerate, siltstone, and granular sandstone, all of indeterminate thickness and extent. Five separate members were sketched out for purposes of mapping and correlation:

Tp_A) A massively bedded conglomerate consisting of granitic cobbles and pebbles in a sandy-silty matrix.

Tp_B) A blue-gray sand/siltstone capped by a granule rich unit (similar to Tp_3 - Tp_4). It is extensively jointed with some shearing apparent. As seen in the units at the Bathtub, the contact between the siltstone and the granule cap is very sharp, whereas the transition from conglomerate to siltstone and then from the granule unit to the next bed are both gradational.

Tp_C) A conglomerate sequence wherein some layers consist primarily of cobbles and boulders in a granule rich matrix, exhibiting massive bedding, and other layers are predominantly granitic fragments and pebbles in a finer sand/silt matrix which exhibits planar bedding. The material is all fairly angular.

Tp_D) A granule rich member, grading down into silty sandstone.

Tp_E) Conglomerate of abundant granitic boulders in a sandy matrix. Although no connection was made in the field, it appears from the down plunge profile and the descriptions that we might consider units A and E to represent the same layer as exposed on different limbs of the syncline, and similarly for units B and D.

The Purisima deposits as exposed at Moss Beach imply relatively sudden changes in the environment of deposition. The alternating layers of sandstone, siltstone, and conglomerate suggest deposition amid fluctuating sea level, the fluctuation being dependent on regional uplift or eustatic changes worldwide. The recurrences are rhythmic and suggest a small, quick (note sharpness of contacts in going from finer to coarser material) drop in sea level which allowed coarse material to be laid down in a near-shore environment. The area then subsided or sea level rose slowly (gradational contact into finer material) during which sub-littoral sand/siltstones were deposited. This cycle was apparently repeated several times, as recorded by the rocks in the syncline.

It is also of interest to note the facies changes within the individual members as they are traced out to North Point. The separate layers increase in thickness and their individual components increase in size and angularity. The change is especially apparent if one considers the units exposed on the bench north of North Point. Here the bedding is much more massive and poorly sorted, and the boulders and cobbles are considerably more angular. This increase in sediment size and angularity to the north might be interpretted as an indication that the source area originally lay in this direction. The source rocks include older sedimentary beds as well as Montara granites.

The Sea Cliff: Quaternary Terrace Deposits

Unconformably overlying the Purisima rocks in this area is a late Pleistocene interglacial terrace composed primarily of feldspathic/arkosic sand with some lenticular conglomerates. The interbedded coarse and fine layers, as well as obvious cross bedding, indicate a swash zone or near-shore environment of deposition. The cliff itself ranges from 10 to 20m high and in section one recognizes a general coarsening upward of the terrace material. Stream reworking of the sediment is evident near the top of the terrace. Retreat of the sea cliff has been approximately one foot per year since 1900; however, since 1965 erosion has claimed 3'-4' yearly, threatening local homeowners (Leighton, 1971). The cliff is weakly indurated and subject to slumping.

Beach Material

The beach is composed of well sorted arkosic sand with occasional clusters of large cobbles and boulders. The sand is well sorted in each wave environment, and ranges from medium to very coarse in grain size depending on the exposure to wave movement. The grains are subrounded for the most part. Compositionally, the sand has a high lithic fragment content with some biotite and heavy minerals present. Scattered across the beach are occasional large cobbles and boulders, ranging in composition from sandstone to granite and in size from cobbles to boulders several feet across. Cobbles can also be found in the swash zone of the more energetic parts of the beach front.

Structural Geology

The central California coast exhibits a wide variety of geologic deformation. Many examples of folding and faulting can be found in the area and at Moss Beach we find two good examples of these features: the Seal Cove Fault and the Bathtub Syncline.

The Seal Cove Fault is an important structure which has stirred considerable interest in the Moss Beach area. The fault parallels the trend of other nearby faults and is considered by some to be an extension of the San Gregorio Fault (Leighton, 1971). In the Half Moon Bay area, the fault trends N 18-35 W and dips 65-80E. At its exposure on the beach, the fault essentially parallels the southwest limb of the Bathtub.

Predominantly right lateral with a large component of vertical displacement, the offset as exposed in the sea cliff at Moss Beach has Purisima siltstones faulted against younger marine terrace deposits. The Seal Cove Fault introduces a major lithologic change in the coastal bedrock, bringing fine grained siltstone into contact with the interbedded sandstone/conglomerate of the Bathtub area. The southern block is upthrown relative to the northern block with a net vertical displacement calculated at 12 to 15m.

Secondary faults and fracture zones characterize the area immediately adjacent to the fault plane. The fault is actually a zone of shearing and faulting several meters wide. Near the main fault in the Reefs area, several auxilary faults appear. These faults are predominantly strike slip, with offsets generally less than one meter, and they appear to be related to drag movement along the Seal Cove Fault.

There have been two known movements along the Seal Cove Fault, one before folding of the sedimentary beds and one after which displaced the overlying marine terrace. Both moved the southern block up relative to the northern block. It is probable that a third movement, with an opposite sense of direction, preceded these movements (Nelson, 1972). Recent work indicates the fault is still active and much of the area is considered unstable (Leighton, 1971).

The dominant structural feature of the mapped area is the Bathtub, a slightly asymmetric syncline plunging 10, N31W. It is expressed topographically within the tidal range by resistant conglomerate ribs (Tp_5 and Tp_8). The fold is parallel as the layers largely maintain their thickness from limb to limb, however, the down plunge profile reveals the fold's asymmetry (the northeast limb dips about 20° to 30° less than the southwest limb). Due to the asymmetry, the hinge axis is not parallel to the trend of the plunge. Most of the information about the syncline and its sedimentary character was gathered from the more accessible northeast limb.

The layers are competently folded for the most part, but instances of jointing, shearing, and faulting also accompanied folding. Thrust faults in sand/siltstone beds have been mapped near the nose of the synform, which corresponds to the trace of the hinge axis. These faults strike roughly parallel to the trace of the fold axis and are most likely a result of axial compression in folding. Occasional low-angle thrust faults appear elsewhere in the less competent units, also probably related to stress in folding.

Shear zones, cracking and distorting the bedding of the sand/siltstone layers immediately beneath the contact with the overlying granule rich units, appear to indicate slippage of the layers during folding. As the layers folded they slipped past one another; frictional drag resulted in shear failure in the less competent sand/siltstone units.

Several long joints trending approximately perpendicular to the fold axis also characterize the northeast limb of the Bathtub. These nearly vertical joints are best exposed in the more competent layers, but can be traced through the bedding sequence. The trend of the joints is somewhat perplexing. If the joints are related to deformational stress and if the folding is a result of compression more or less perpendicular to the fold axis, then one would normally expect failure at about a 45° angle according to a simple stress model. Their present trend indicates that something else may be happening. Several interpretations appear possible: 1) It is impossible to use a simple stress model given the limited information; 2) The joints might reflect some other type of deformation not related directly to the folding incident; 3) The joints are behaving along the lines of a simple stress model, which implies the compression is not perpendicular to the fold axis. It then becomes necessary to explain the fold shape as a product of both compression and interaction with the underlying granitic basement. It might also be possible to explain the syncline's asymmetry by a model of this nature; 4) One can not establish precisely what the joints imply.

The northeast limb of the Bathtub syncline is exposed along the shore up to North Point, where it sits unconformably on the Montara quartz diorite. It was originally thought (Weber, 1958, and Nelson, 1972) that this was a fault contact, the fault running through the small cove between the Point and the knob of Montara granite. An exceptionally low tide uncovered the contact and revealed it to be depositional. There was no evidence of a fault plane or shear zone and the Purisima sediments appear to merely abut against the granitic knob. The appearance of the small cove is solely an erosional feature, with wave action undercutting the less resistant beds beneath the upper conglomerate.

Continuing north around North Point, a wave-cut bench is exposed at the base of the sea cliff. This bench essentiallypresents in section the profile of a syncline plunging approximately 12, N49W. The bench is nearly two meters high and is unconformably overlain by terrace deposits. At its northern end, the bench is truncated by a fault, as evidenced by vertical displacement and considerable shear deformation, into contact with the Montara diorite. The southern contact is beneath a concrete walkway, but as no evidence could be found for a fault here (signs of shear or slickensides), the contact might be assumed to be depositional as was the case at North Point. Earlier interpretations (Weber, 1958) had cast this bench as a graben which had been downdropped by faults at both ends. If we assume the southern contact is depositional rather than a fault contact, we can then establish a continuous system of folding for the area: the two synclines being joined by an anticline which at one time extended over the granitic knob at North Point. Erosion has removed the anticline and left only the two synclines.

The plunges of the two folds are not parallel, but instead converge at an angle of 18°. The failure of the folding pattern to be simply cylindrical as well as the asymmetry of the Bathtub Syncline might indicate a complex compression and folding pattern, or it may simply reflect the interaction of the sedimentary beds with the underlying pluton. Since the sediments lie unconformably on this massive igneous body, any major deformation of the strata is going to affect and be affected by the underlying basement. We might reasonably explain the lack of symmetryor cylindrical nature of the folds to interaction with the granitic basement.

Jointing within the Montara rocks might be indicative of fold strain, however, no particular orientation of the joints appears to stand out, nor can the joints be related to any particular type of deformation. That the granitic rocks must have somewhat deformed in the process of folding a cover of sedimentary rocks appears obvious, but the nature and extent of this deformation could not be ascertained.

Geologic History (after Brunego and Nelson)

The oldest rocks encountered in the Moss Beach area are the Montara granites of late Cretaceous age. They represent an igneous intrusion into Mesozoic sediments of the Franciscan Formation, which in this area have largely been eroded away. Large crystals within the diorite suggest intrusion at great depth and slow cooling, followed by isostatic uplift.

Unearthing of the batholith in the early Cenozoic was accompanied by sedimentary deposition against the Montara Mountain Complex. The Miocene epoch witnessed the development of the Seal Cove Fault (perhaps correlating with early movement along the San Andreas), along with extensive folding and faulting of the sedimentary beds. Uplift and erosion of these beds characterized the late Miocene. There are no local expressions of these beds near Moss Beach, however, some may still exist beneath the Purisima.

The Pliocene was characterized by quiet deposition of the Purisima sediments in a basin which lapped against Montara Mountain. At the end of the Pliocene a major orogeny resulted in large scale deformation of the coast ranges and was presumably responsible for the main structures we presently observe at Moss Beach. Compressive forces apparently pushed the deposits against the unyielding Montara batholith; the resultant deformation seems to reflect both this compression and the interaction with the underlying basement.

The early Pleistocene witnessed the planing down of these folds, followed by mid-Pleistocene rejuvenation of folding and faulting , and late-Pleistocene formation of the interglacial terrace. All activities have been accompanied by fluctuating sea levels. The last major movement in the area was movement along the Seal Cove Fault, which displaced large portions of the interglacial terrace.

Structural activity has continued throughout the Recent, with continued fault action and broad warping. In summary, the region has gone through several cycles of deposition, folding and faulting, uplift and erosion. The present Moss Beach merely represents the latest cycle.

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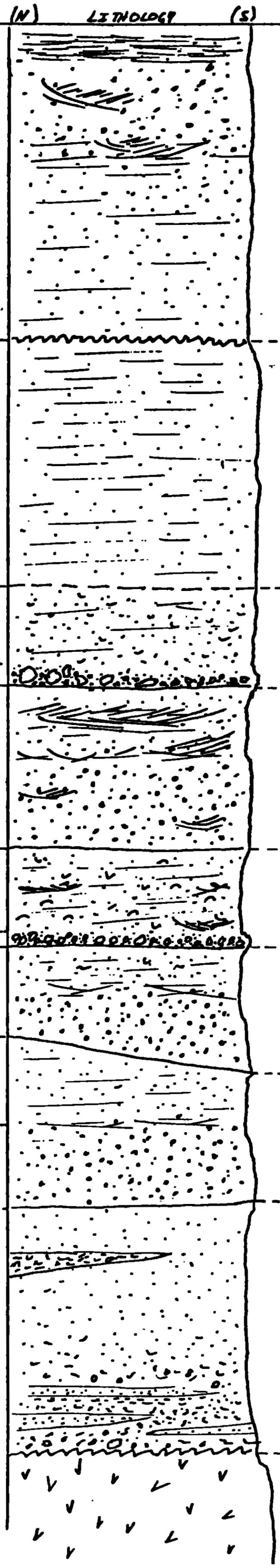
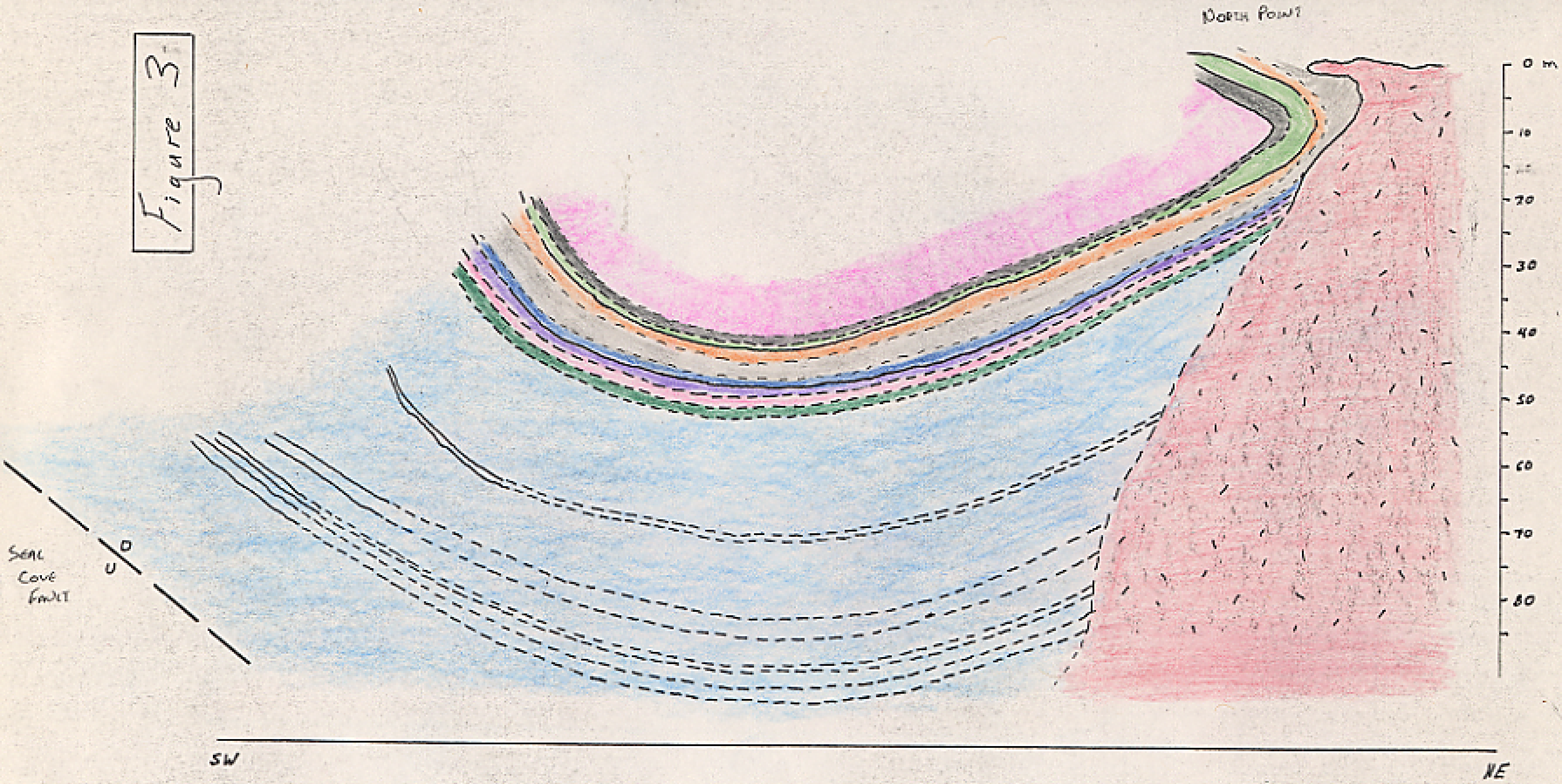
Figure 1:

Rock Units of Moss Beach Study Area



UNIT	THICKNESS	(N) LITHOLOGY (S)	DESCRIPTION
			Beach sands.
Qt			Marine terrace sands and gravels. Fine, massively bedded, grades up into poorly sorted sand and granitic lithics. Some fluvial reworking near top.
T_{p10}			Gray, fine, well-sorted sandstone. Laminar bedding. Homogeneous and undisturbed; no fossils or bioturbation.
T_{p9}, T_{p8}			Conglomerate → sandstone sequence. "Upper" conglomerate of granitic boulders up to ~3m. in brown sand matrix, overlain by green-brown fossiliferous sandstone.
T_{p7}			Granule-rich sandstone → sand/siltstone sequence. Quartzofeldspathic porphyroclasts up to 8 mm in fine matrix, overlain by heavily cross-bedded gray-brown sandstone with prominent dune and ripple forms.
T_{p6}, T_{p5}			Conglomerate → sandstone sequence. "Lower" conglomerate overlain by fossiliferous blue-gray sand/siltstone.
T_{p4}, T_{p3}			Granule-rich sandstone → sand/siltstone sequence. Coarse (up to 20mm.) porphyroclasts; overlying blue-gray sands/silts contain occasional fossils.
T_{p2}			Granule-rich sandstone → sand/siltstone sequence. Bioturbation, occasional fossils in overlying T_{p3}.
T_{p1}			Blue-gray sand-siltstone. Interbedded fossil- and pebble-rich lenses decrease in frequency towards top.
K_{gr}			Montara Quartz Diorite.

Figure 3



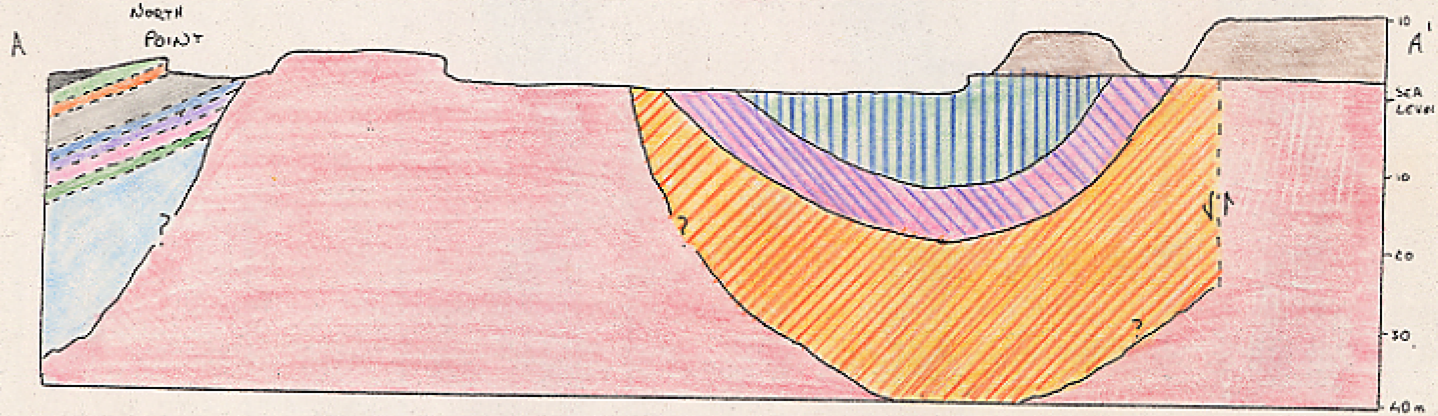
Down-Plunge Profile: The "Bathtub" Syncline

10, N31W

mapped contact

inferred contact

- Overhang @ North Point = Lose Cylindrical



Scale:
1:1000

No Vertical
Exaggeration

Vertical Cross Section of Bench Syncline

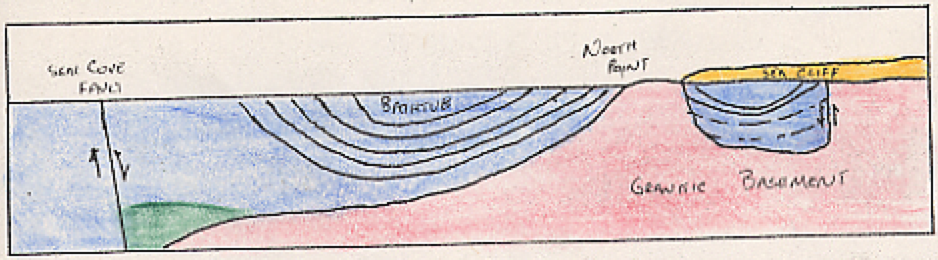
-Syncline plunges 12, N49W

-Down -plunge profile not possible given limited map contacts.

-See map for location and unit explanation.

Interpretive Cross Sections

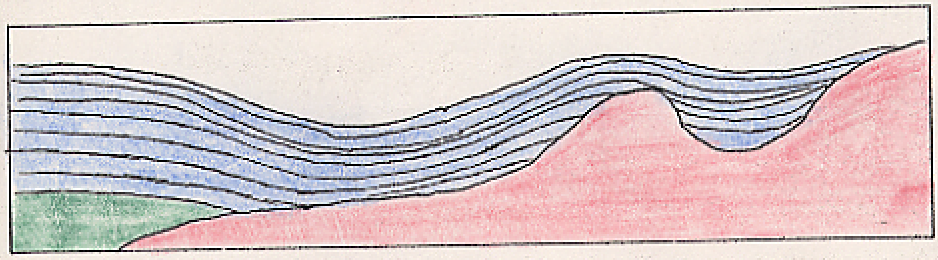
-see geologic history



Pleistocene - Present

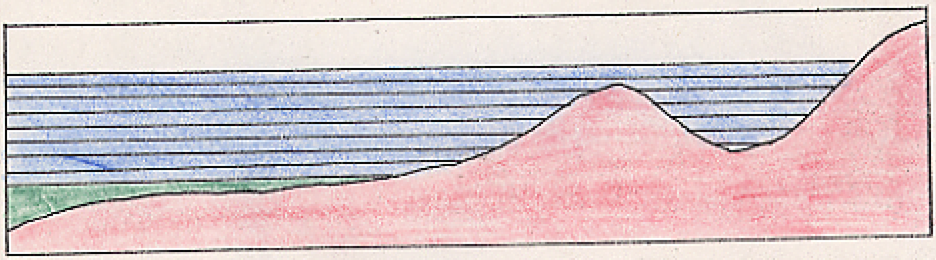
Fault Movement, Erode Folds

Terrace Deposition



Late Pliocene

Deformation of Purisima



Early Pliocene

Deposition of Purisima

Miocene

Erosional remnants of Miocene sediments

Montara Batholith

SW NE

- Not to Scale