GEOLOGY OF TRINIDAD, CALIFORNIA

K. R. Aalto, Professor Emeritus
Department of Geology
Humboldt State University
Arcata, CA 95521

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Introduction

Within the relatively small area of the town of Trinidad, California one encounters geology that typifies that of much of the Coast Ranges of northern California (Fig. 1). The basement rock, the *Franciscan Complex*[1] of Late Mesozoic age (~145–100 Ma), is overlain by a succession of *Pleistocene* (less ~1 Ma) marine terrace deposits. Prior to deposition of these marine sediments the land surface suffered significant erosion, thus the contact is an *unconformity* (a buried land surface). A flight of terrace deposits exists in a stair-step pattern with terrace elevation and age increasing to the east (Figs. 2a, 5, 7). The terrace deposits flank and bury numerous rock monuments such as Strawberry Rock. These monuments are elevated and partially buried sea stacks that, at the time of terrace sediment deposition, were awash in waves much like modern sea stacks off Trinidad Beach. The presence of clam-borings and the stack margins attest to their burial in the surf zone. Their elevation reflects ongoing deformation of the North Coast along thrust faults, most of which are northeast-side-up, which account for the prevalent uplift of the northern coastal California. The coastal plains from Trinidad to Patrick's Point, in McKinleyville and at Crescent City are marine terraces that have been uplifted during and since the Pleistocene (Ice Ages). Thus the geology of Trinidad provides a model by which regional coastal geology may be interpreted.

Franciscan Complex Basement Rock

[1] Words in italics are defined in the glossary at the end of this paper. Figures are arranged in order at the end. Field photographs are presented at the end as Plate I: chiefly Franciscan Complex turbidite rocks, Plate II: Franciscan Complex oceanic plate rocks, Plate III: Pleistocene terraces and tectonics.

With the advent of *plate tectonic theory*, the late *Mesozoic* Franciscan Complex of California came to be considered a type example of a subduction complex, a highly sheared mixture of oceanic sediments and rocks that were deformed above an oceanic plate that slid beneath western North America (Fig. 6; Aalto, 1982). Franciscan rocks, which make up the resistant headlands and sea stacks along the Trinidad coast (Figs. 3, 4, 7; Plates I & II), consist chiefly of marine sandstones, with lesser amounts of *conglomerate*, biogenic ribbon chert, limestone, greenstone (metamorphosed oceanic plate volcanic rock), *ultramafic and mafic plutonic* rocks and *blueschist-facies* metamorphic rock (Aalto, 1976). These minor constituents exist chiefly as blocks in *mélange* units. Mélanges consist of mixtures of blocks of all different sizes dispersed in a sheared shale and/or serpentinite matrix in a 'plum pudding' assemblage. The blocks range in size from centimeters to kilometers across.

Chert is commonly thinly layered and red or green, although various tones of brown or yellow exist where thermal alteration occurred (Plate II). In microscope view, it is evident that chert is chiefly composed of the remains of unicellular siliceous plankton ('radiolarians') mixed with various amounts of clay. Red to brown coloration reflects oxidized iron minerals; green, reduced iron minerals; and gray, abundant mud. Blueschist blocks are those whose mineralogy reflects very high pressure, low temperature metamorphism, regardless whether the original rock (its 'protolith') was sandstone, chert or volcanic rock. On Trinidad Beach such blocks include silvery *actinolite schist* with a blue *glaucophane*-rich rind (Plate II), blue-gray metachert with a talc-serpentinite rind, and red-tan-yellow metachert with blue *crocidolite* veins ((Plate II; the 'Psychedelic Rock' of Humboldt Geology field trip renown). Geologists agree that blueschist metamorphic conditions only occur where a cold oceanic plate descends into the Earth's hot mantle, although disagree as to how such blocks have become later mixed with virtually unmetamorphosed rocks with a minimal history of subduction.

Greenstone (Plate II) exists in a variety of textures and forms depending upon whether it originated in submarine lava flows or as subaqueous volcanic ash (as lithified: 'tuff' or 'hyaloclastite'). Shearing before and during accretion of volcanic blocks into mélanges has resulted in complex mixes of volcanic rocks and marine sediments entirely within single sea stacks, constituting mélanges within a mélange (Plate II; Aalto, 1981). Trinidad Head is one extra large block of chiefly greenstone to the west and more coarsely crystalline oceanic volcanic arc rock (*metadiorite*) to the east (Plate I; Aalto, 1982). In one sea stack on Trinidad Beach, ribbon chert depositionally overlies pillow basalt, the depositional interface between ancient erupted seafloor and marine sediment (Plate II). Elk Head (Fig. 3b) consists of a western zone of greenstone (pillow basalt derived by undersea volcanic eruption associated with *seafloor spreading*, the creation of new oceanic crust at oceanic ridges) faulted against an eastern zone of interbedded sandstone, conglomerate and shale. The latter sedimentary rocks exist both in fairly coherent interbedded conglomerate/sandstone/shale sequences, termed 'broken formations', that are intercalated with mélanges, and as blocks in mélanges.

Broken formation units were deposited in basins on the Mesozoic seafloor (Fig. 6) by 'turbidity currents' [downslope mass flows of sediment-laden water engendered by earthquake-induced slumps]. Broken formation units along the Trinidad coast are unmetamorphosed and light to medium gray in color. The distinction of a sandstone/conglomerate mélange 'block' versus a broken formation unit is somewhat gradational and reflects map scale. Thus at the scale of figure 4, it might be reasonable to deem the north end of beach outcrop where basement rock is chiefly sandstone, a broken formation unit that extends into College Cove [note that the blueschist block in this zone is very likely not in place, but was rather transported or 'let down' to the Franciscan–terrace unconformity during land degradation]. Extensive coastal zones of broken formation (Fig. 3c) exist north of the Little River, between 'n' and 's' flanking Scotty's Point and at Patrick's Point (Aalto, 1976, 1981, 1989). Subduction-related deformation that occurred during the Late Mesozoic has resulted in pervasive fracturing of Franciscan rocks and localized development of large contractional faults and folds (Fig. 3c). Fossils are uncommon in broken formation units and sandstone blocks, although Late Jurassic (~145 Ma) clams have been found at Trinidad Beach. Other finds include traces and burrows made by a variety of deep sea organisms, and coalified plant debris (Miller, 1986, 1991, 1995; Plate I).

Slope Stability of the Terrace Margin

Where mélange blocks are small and mélange matrix is abundant, the mélange is susceptible to downslope mass movement as a debris flow. Similar flows can derive from broken formation units with abundant shale intervals (Fig. 2; Plate III). Debris flows front some 55% of the coast between Agate Beach and Moonstone Beach and should be factored into land use planning since they flow out from beneath terrace edges and produce slumped terrace margins (Aalto, 1977; Rust, 1982). For example, along the curves in Patricks Point Drive north of Seawood Drive and along most of Scenic Drive entire hillslopes are slowly creeping downslope [note the two meters of asphalt piled up at the curves]. Thus mélange blocks slowly creep downslope to be delivered eventually to the beaches. Terrace margin stability is greater where massive sandstone or greenstone fronts the ocean, or where (as is the case for Trinidad Beach) pocket beaches are developed between rocky headlands.

Quaternary Geology

The Franciscan Complex is overlain unconformably by the Pleistocene marine terraces all along the Trinidad coast (Figs. 2, 5, 7; Plate III). The principal terrace ('Patrick's Point' terrace: Qtmpp), which constitutes the flat surface upon which the town built, is ~83,000 years old [=83 Ka] (Stephens, 1982; Carver, 1985, 1992; Carver and Burke, 1989). Rust (1982), however, assigns ages of ~60,000 and ~40,000 Ka to successively lower elevation stepped terraces (Qtml and Qtmtl) he has mapped along Trinidad Beach and Harbor terrace based upon soil development (Fig. 2a; Plate III).

At Elk Head and Trinidad Beach north of Mill Creek terrace Qtml unconformably overlies an older marine terrace ~370 Ka years old[2] (Stephens, 1982; Rust, 1982), with the contact marked by a buried soil (‘paleosol’). In the pocket beach adjacent to the Seascape Restaurant and Trinidad Head (Plate III), deposits of this older terrace are largely coarse grained sands and reworked shell rubble, with abundant mussels and barnacles. A sand dollar that occurs here and is fairly easy to find, called *Scutellaster*, was replaced in these parts ~300,000-400,000 years ago by the modern sand dollar, *Dendraster* (William Miller III, pers. comm., 2009). Kennedy (1978) suggested that most of the material was shed off the sides of the Head and reworked from sublittoral high energy sands that surrounded the base of this sea stack at a higher relative sea level. Reconstruction of the exact depositional setting is complicated by faulting. These beds have been tilted to the northwest at some 35° in association with down–drop to the west on the ‘Trinidad Head fault’. Rust (1982) interprets this fault as northeast-dipping, with the east side thrust over the west. However, my observations of small northwest-trending, east-side-

[2] Wehmiller *et al*. reported amino acid age dates of $500^{\pm}75$ Ka on *Saxodomus* shells from this deposit, thus placing it within the Middle Pleistocene.

down normal faults within this terrace suggests that Rust's Trinidad Head fault might itself be a southwest-dipping normal fault with the west side down. This would perhaps explain the existence of rooted redwood stumps (Plate III) that are buried on Trinidad Beach immediately north of Trinidad Head (west of the fault) and from which Stephens (1982) obtained a ~6 Ka radiocarbon age. These are occasionally exposed during major winter storms when the beach degrades, as it does each winter season.

Ongoing late Cenozoic crustal shortening has resulted in thrust faulting that has further disrupted Franciscan rocks. The rise in land north of the Trinidad Chevron station is the fault line scarp of the 'Anderson Ranch fault' (also called the 'Trinidad fault'); Figs. 2a, 5, 7; Plate III). This is one of many northwest-trending, east-side-up thrust faults that come onshore between Crescent City and Cape Mendocino, and whose genesis reflects the ongoing subduction beneath northernmost California of the Gorda oceanic plate (Carver, 1985, 1992). Carver (1992) gives an estimated slip rate of 1.9 mm/yr on the Trinidad fault.

Acknowledgements

Dr. Bud Burke, HSU Geology Department, provided insight on the age of the Trinidad marine terraces. Frederica Aalto and William Miller, III, reviewed the manuscript text.

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Glossary

actinolite schist–a foliated metamorphic rock rich in the amphibole mineral actinolite. Glaucophane is a blue, high-pressure, low-temperature mineral.
blueschist-facies–metamorphic conditions characterized by high pressures and low temperatures whereby an older rock undergoes textural and mineralogical reconstitution to achieve equilibrium in a new environment.
conglomerate–sedimentary rock made of gravel, pebbles, etc. cemented together.
crocidolite–a blue fibrous mineral belonging to the amphibole group.
Franciscan Complex–an assemblage of map-scale geologic terrains first described in San Francisco whose origin relates to convergence of oceanic and continental plates during the late Mesozoic Era.
Pleistocene–geologic epoch commonly thought of as the ‘Ice Ages’ (1.8–0.01 Ma = million years ago; note: Ka = one thousand).
plate tectonic theory–the ruling paradigm of the geological sciences which proposes that the crust and upper mantle of the earth consists of an array of some two dozen rigid plates. Plate boundaries can diverge via creation of new oceanic crust at oceanic ridges such as the Mid-

Atlantic Ridge or Gorda Rise, converge at oceanic trenches where old oceanic plate slides [is ‘subducted’] into the earth's mantle which leads to the formation of volcanic arcs such as the Aleutians or the Cascades, or slide by one another as is happening along the San Andreas fault system.

Mesozoic–a geologic era (249–65 Ma).

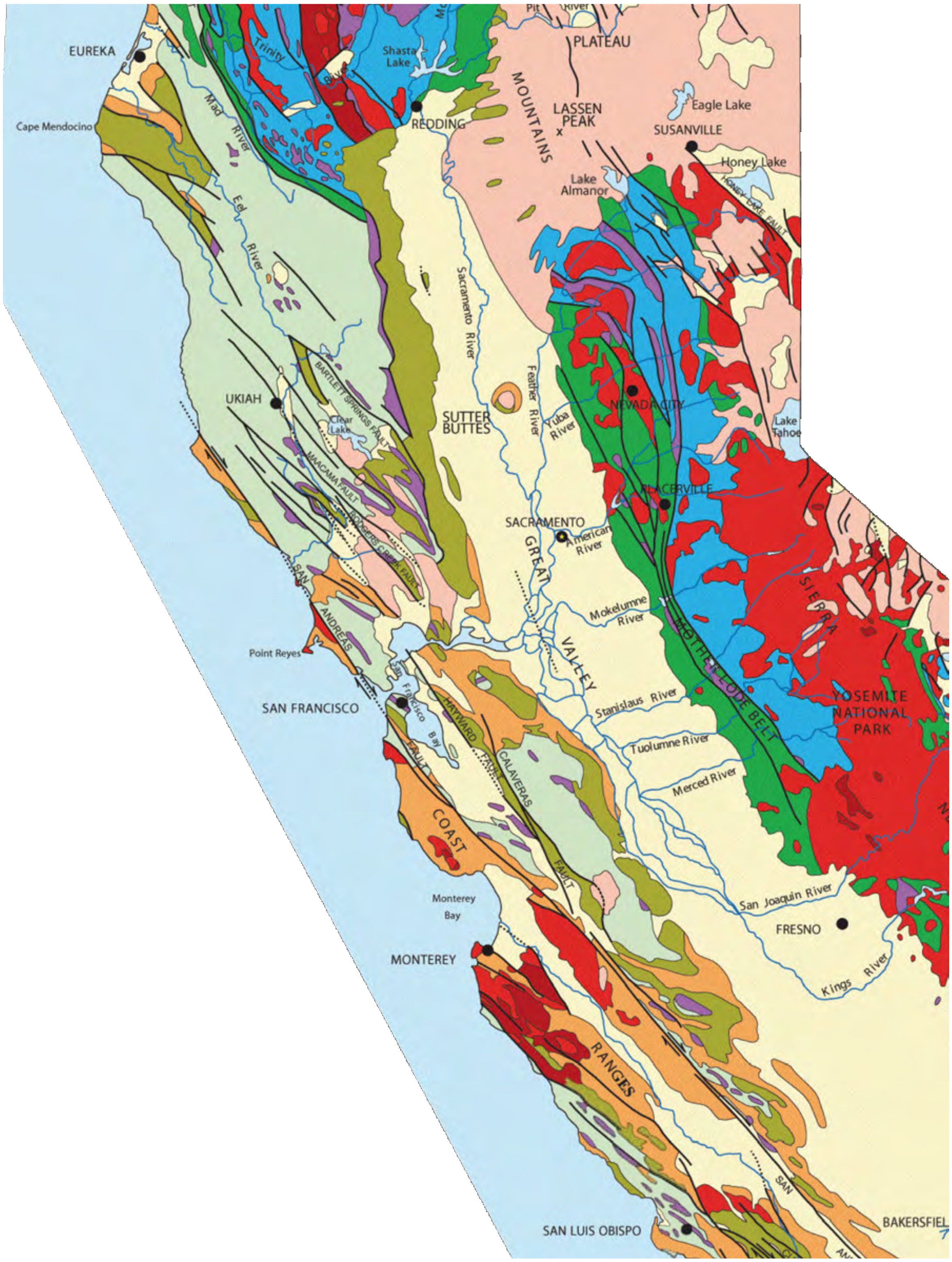
ultramafic and mafic plutonic–igneous rocks coarsely crystalline and very rich or rich in iron and magnesium which commonly formed at depth in the earth's mantle; common in oceanic plates.

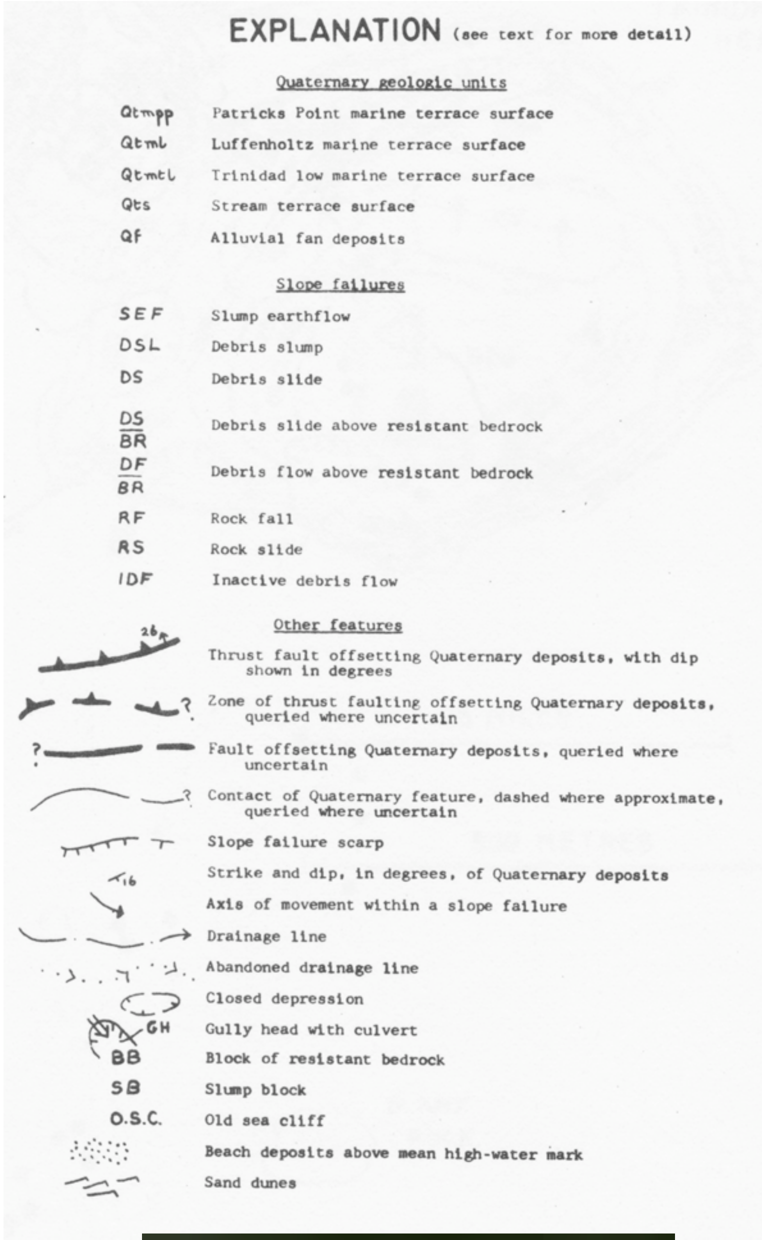
unconformity–a contact between two geologic formations that records an episode of erosion that occurred subsequent to the genesis of the older underlying unit, but prior to the deposition of the younger overlying unit, commonly marked by a fossil soil (paleosol).

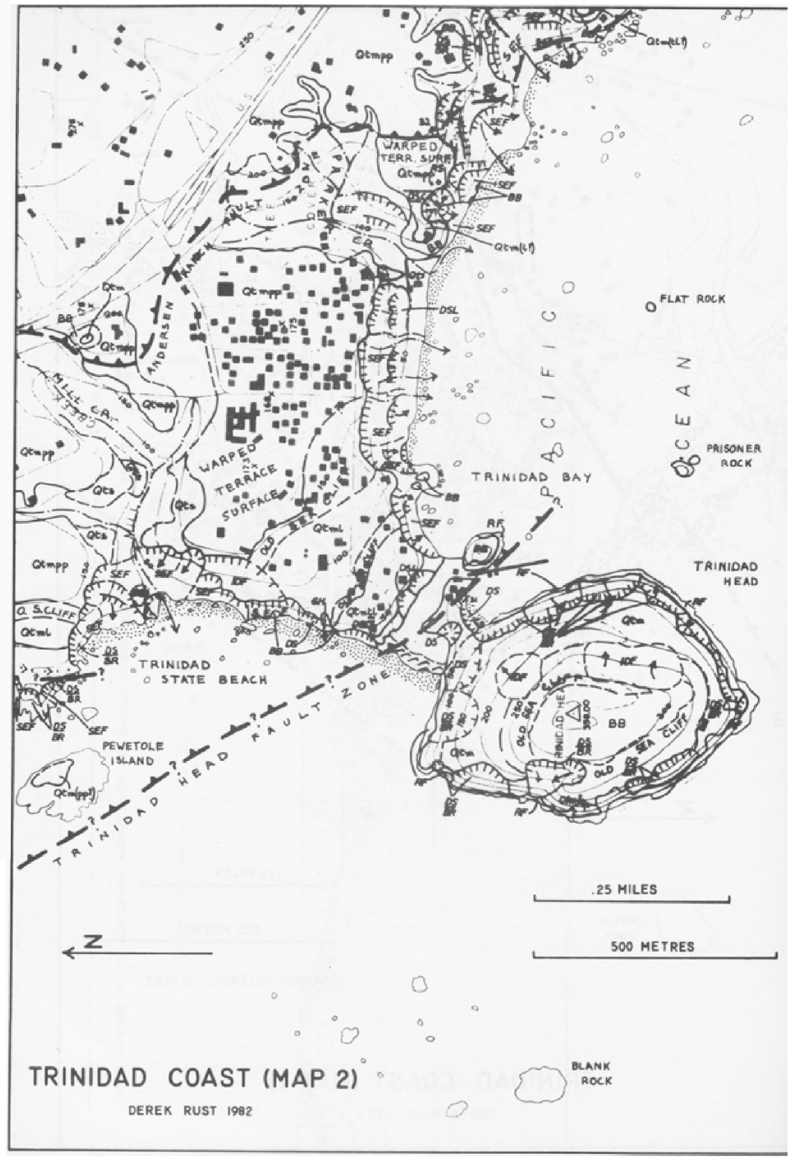
Web references to plate tectonics:
http://pubs.usgs.gov/gip/dynamic/dynamic.html
http://pubs.usgs.gov/gip/dynamic/understanding.html
http://vulcan.wr.usgs.gov/Glossary/PlateTectonics/framework.html
http://www.geosociety.org/science/timescale/

Old photos of Trinidad: http://trinidadbay.net/

Fig. 1. Geologic map of northern California. Franciscan Complex rocks of the Coast Ranges are in tones of green. (California Geological Survey, 1977)







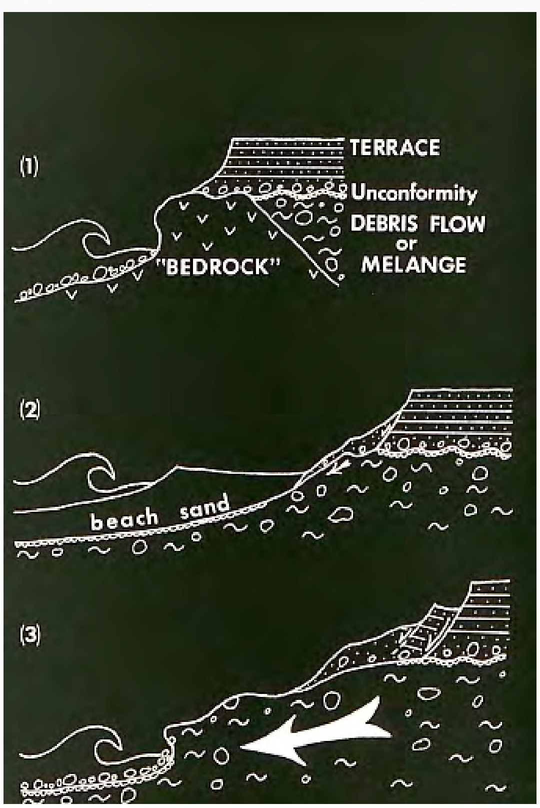


Fig. 2-

a) Quaternary geology (above; Rust, 1982);

b) Styles of terrace margin failure (to left; Aalto, 1977):

1) large rock mass facing ocean- most stable
2) mélange fronted by beach- less stable
3) mélange fronting ocean- least stable

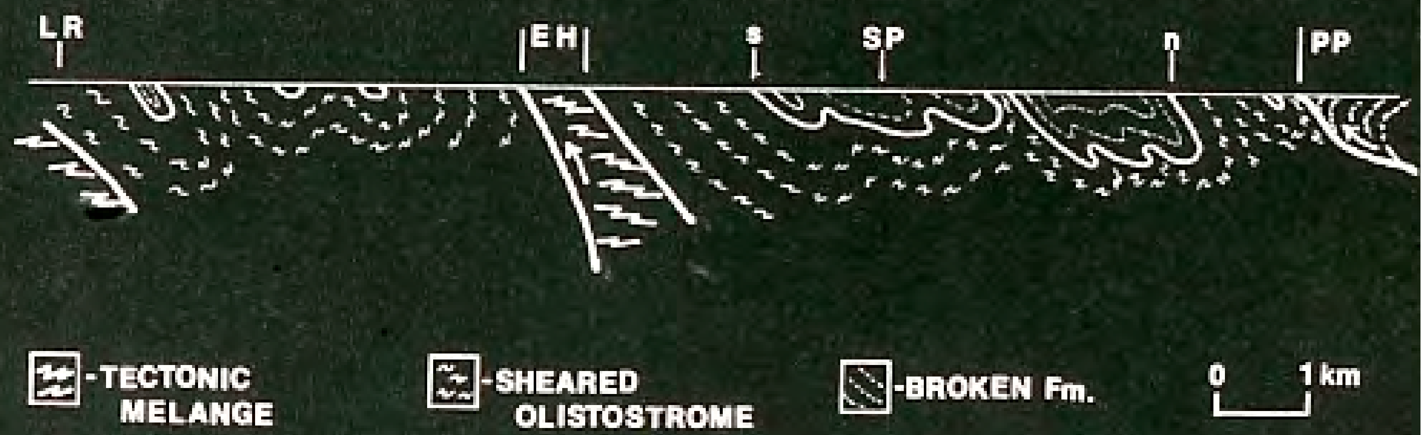


Fig 3b- Geologic cross section [looking west] from the Little River (LR) to Patrick' Point (PP). EH- Elk Head, SP- Scotty's Point (Aalto, 1981)

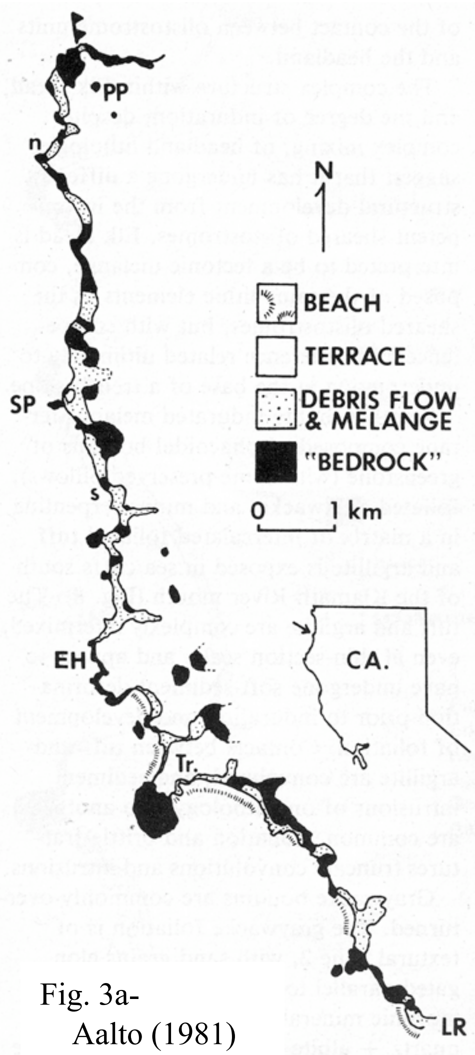


Fig. 3a- Aalto (1981)

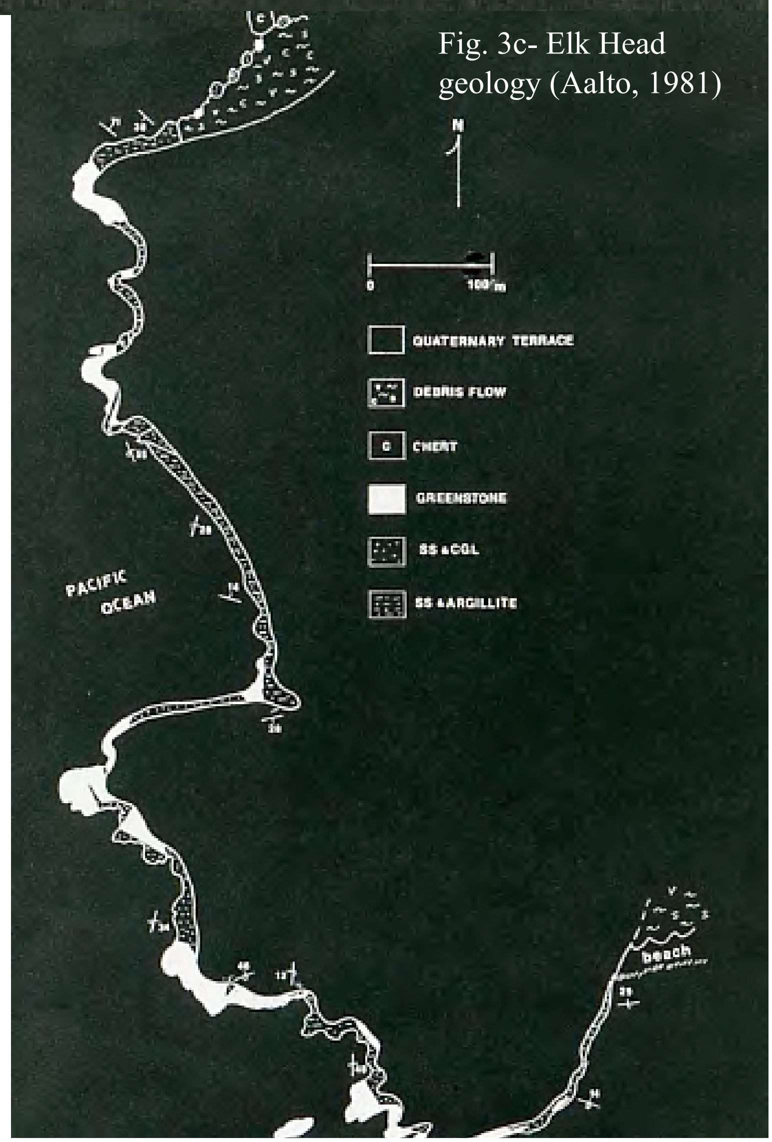
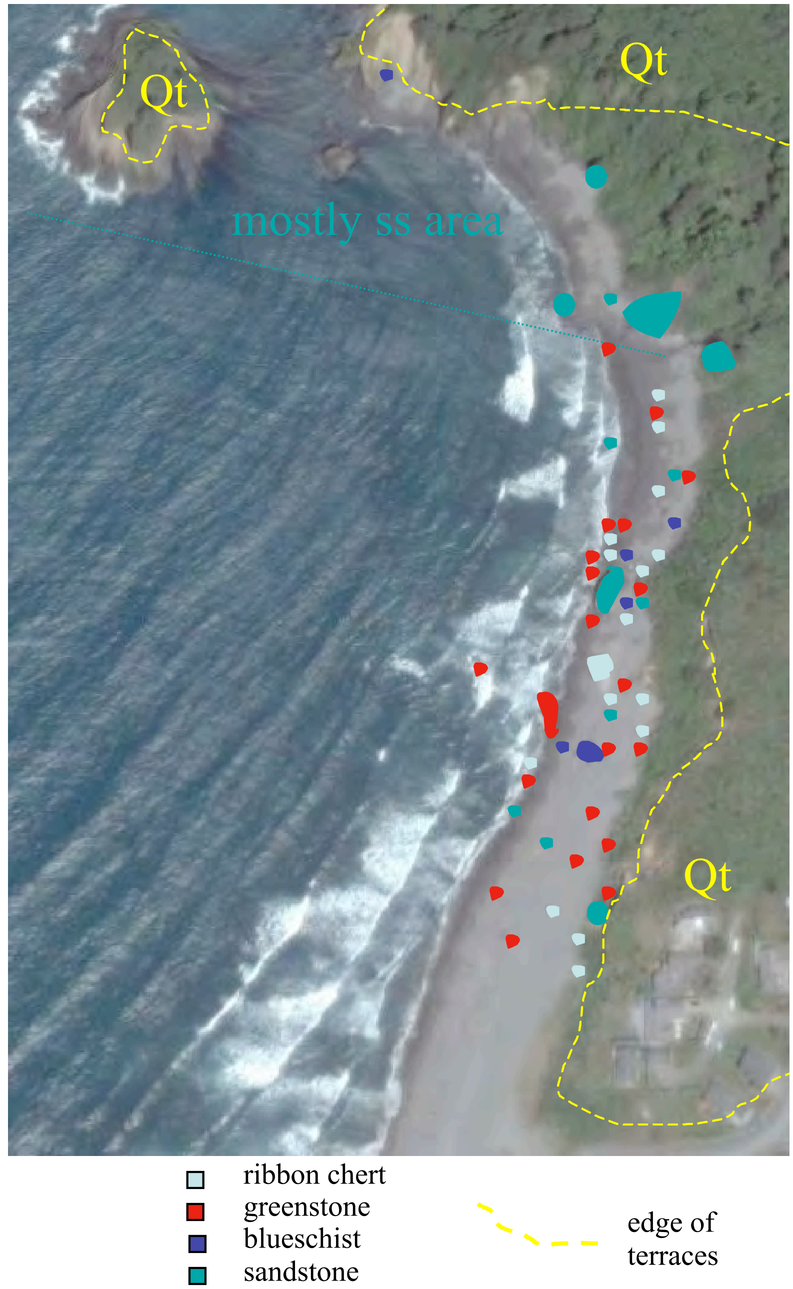


Fig. 3c- Elk Head geology (Aalto, 1981)

Fig. 4- Geology of Trinidad Beach

(Aalto, unpubl. data, 1976)



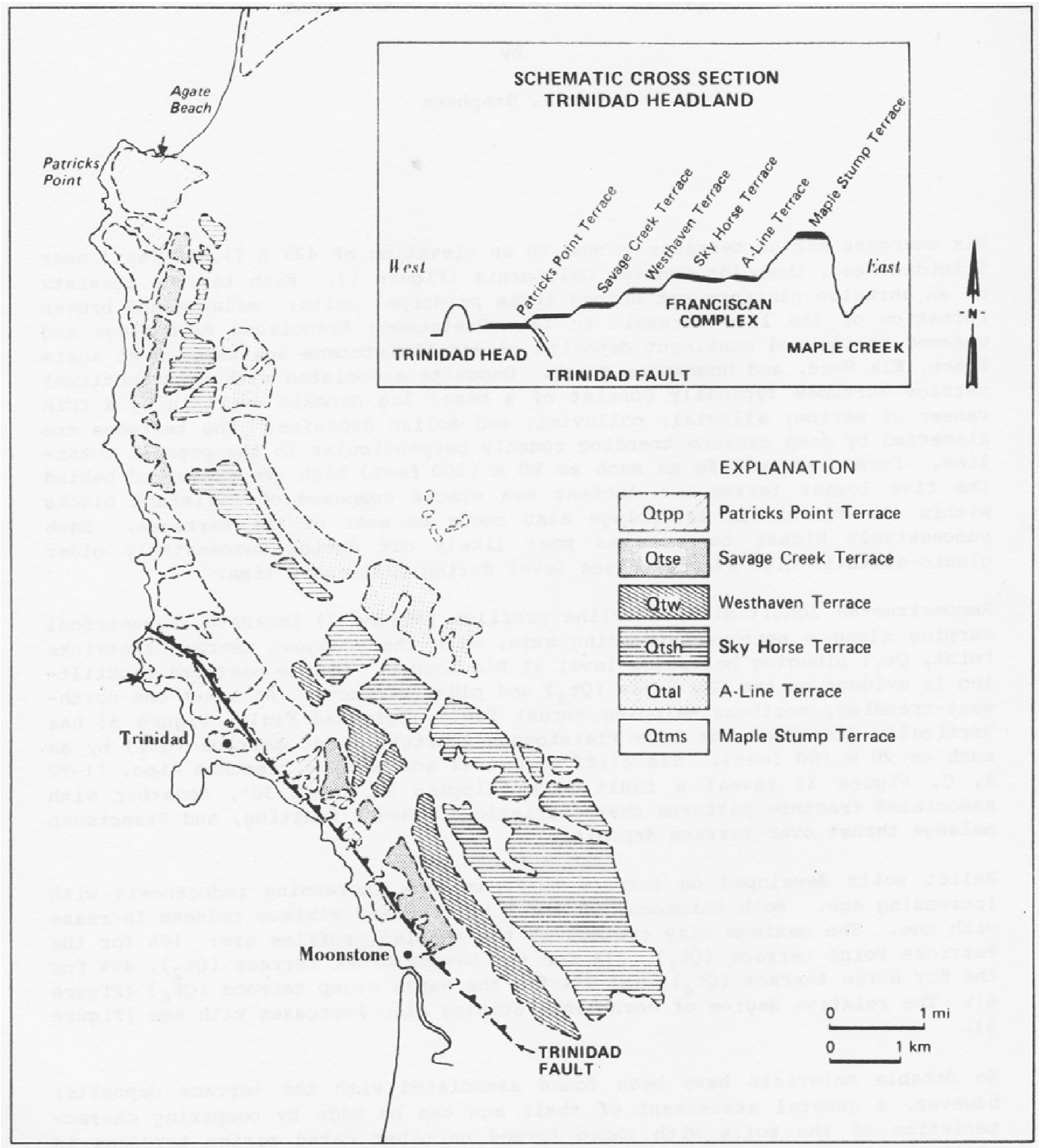


Fig. 5- Terrace stratigraphy (Stephens, 1982). Small arrow indicates Elk Head.

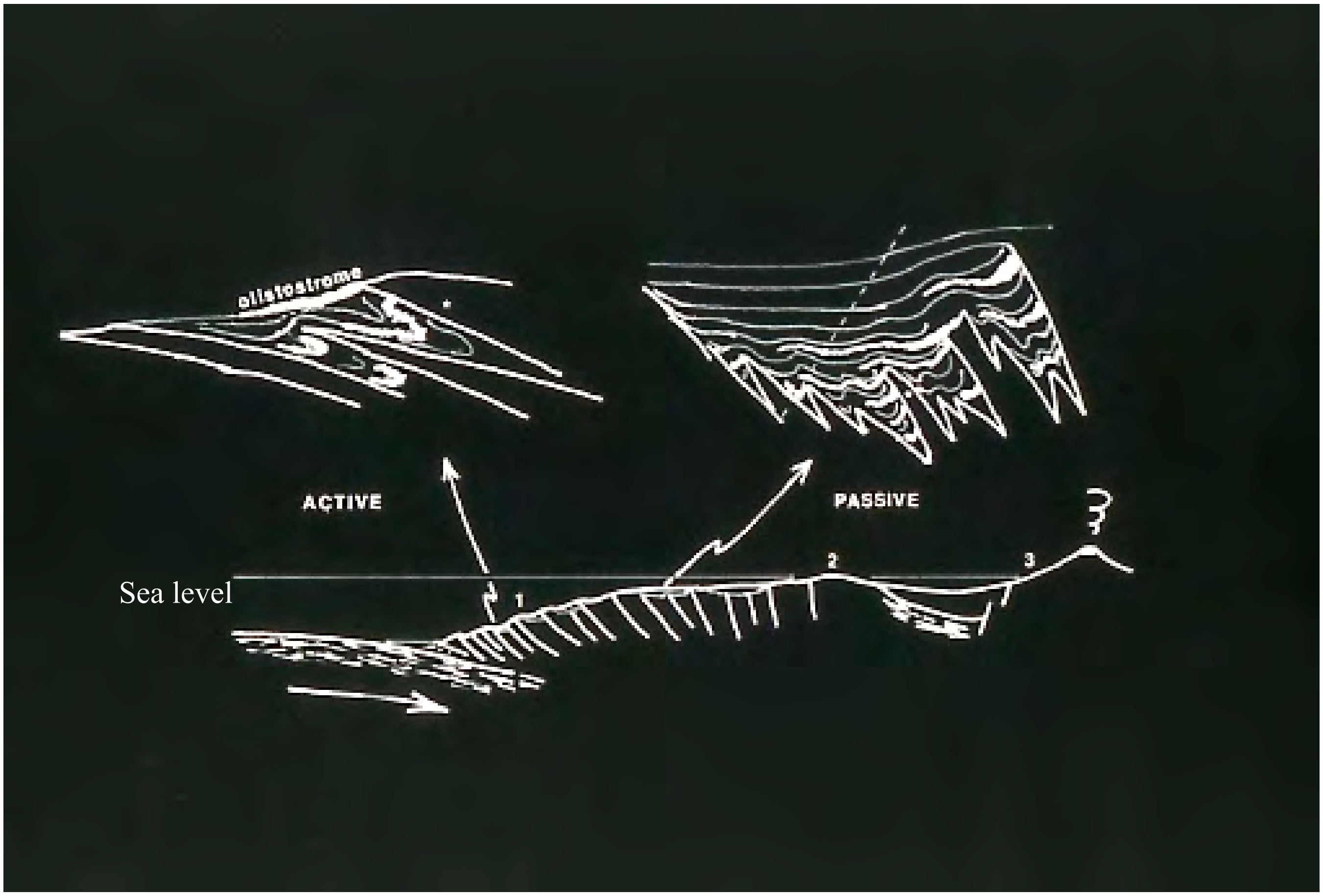


Fig. 6- Sedimentary tectonic model for the Franciscan Complex of northern California (Aalto, 1982). At the bottom is a profile across an active convergent plate margin, commonly some 200 km across. An oceanic plate is subducting at a trench; a volcanic arc exists far to the east formed by rise of magma where the subducting plate has reached ~100 km depth. The upper sketches are blowups of small basins developed on the trench slope at locations shown by the arrows. Note how adjacent to the oceanic trench (active mode) large submarine debris flows ('olistostromes')are being actively deformed into large folds in associating with motion on thrust faults (heavy white lines). With continued seaward growth of the subduction accompanying offscraping and underplating of trench sediments and oceanic plate rocks this basin will be uplifted into an upper trench slope setting (passive mode) and, while continuing to receive turbidite and pelagic sediments from source areas 2 and 3, will no longer be an area of active fault-related deformation. The dashed line represents a cross sectional view of Franciscan Complex geology across the Coast Ranges at the Humboldt – Del Norte County line.

Fig. 7- Geologic map of Trinidad (Aalto, Kelsey et al., 1982, unpublished).

KJfm–mélange; Qm–Pleistocene marine terraces

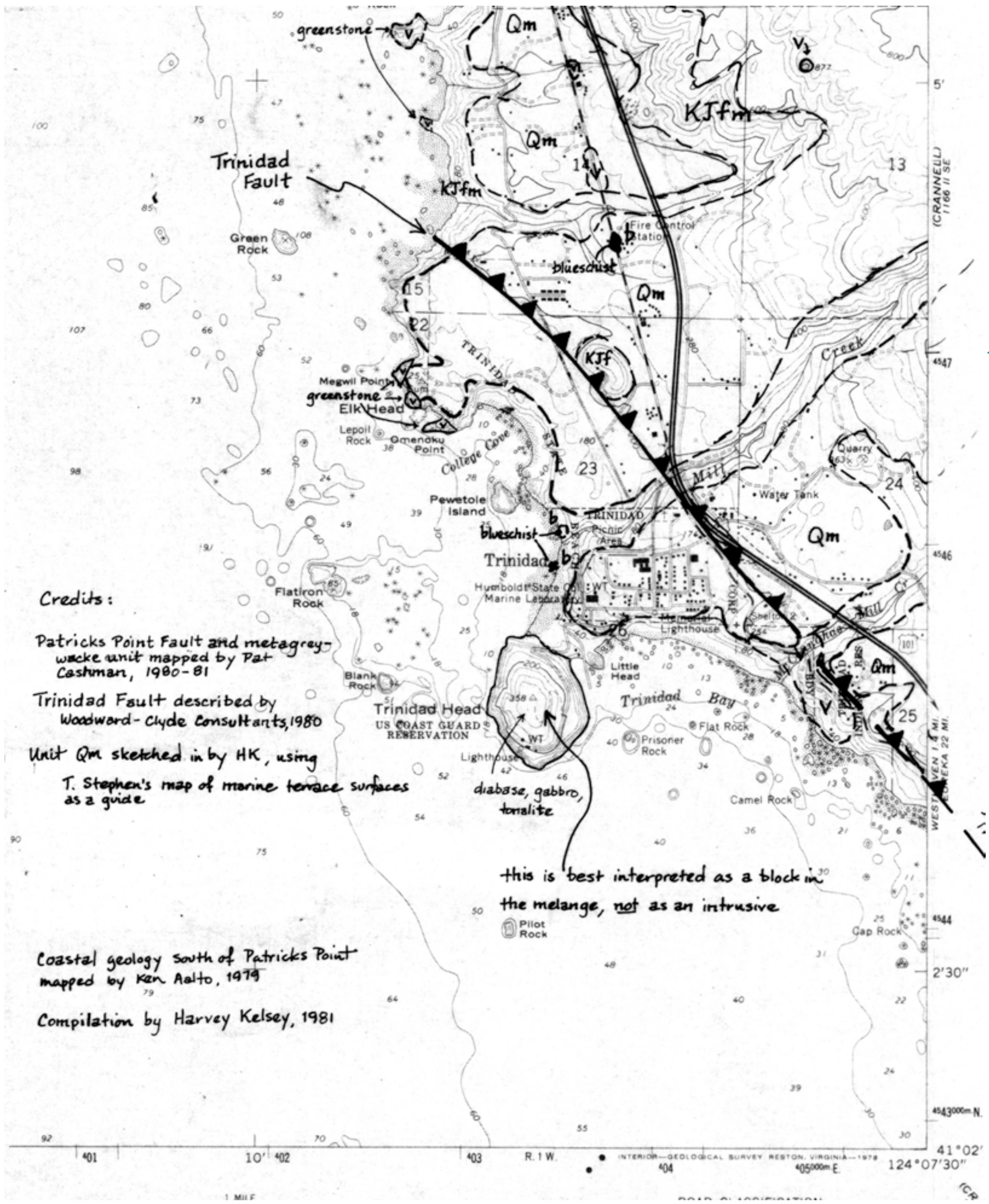


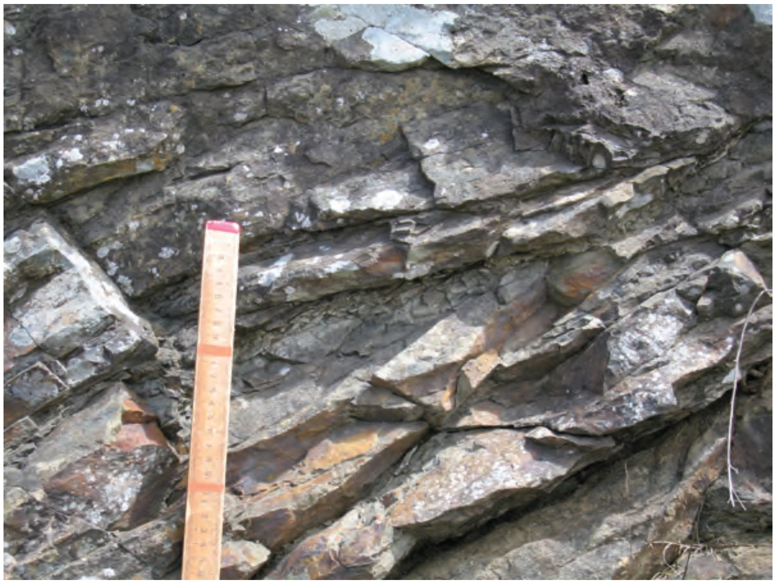
Plate I

Burrows and flute casts

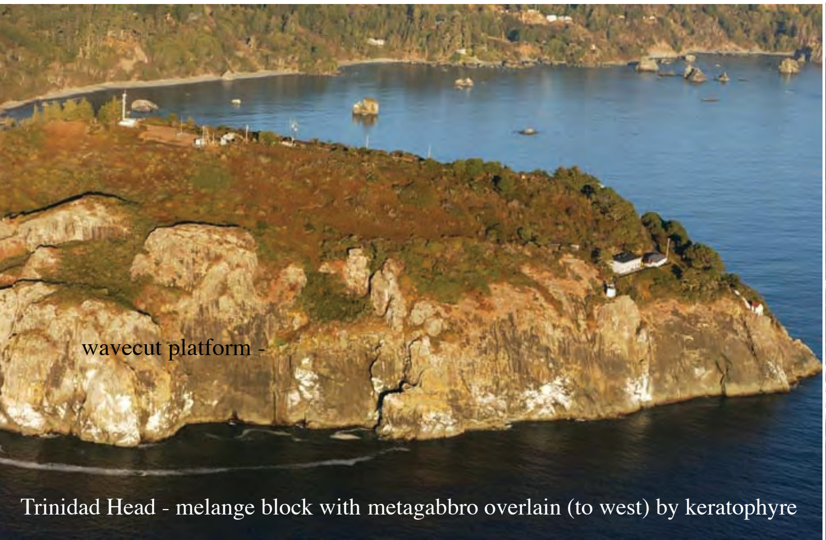
Casts of trace fossils

Terrace paleochannel over sandstones

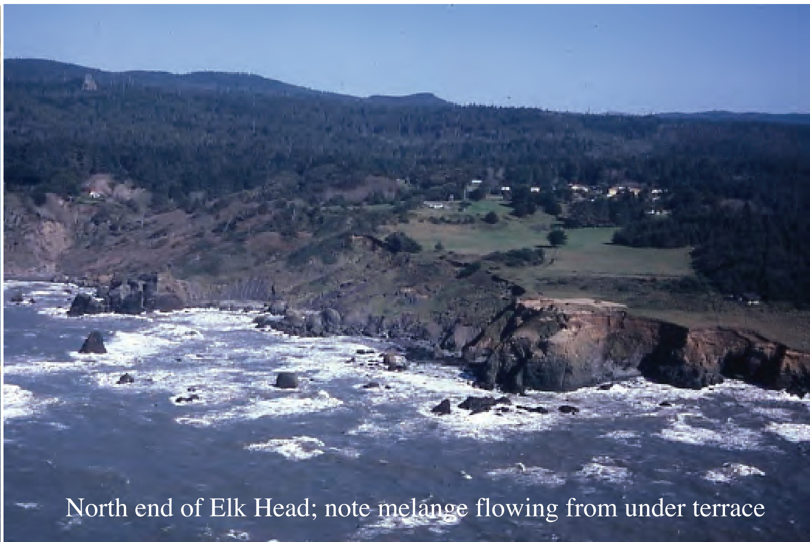
Turbidite sandstone beds north of Elk Head, up is to the right



Upright turbidite sandstone beds showing sheared bedding



Trinidad Head - melange block with metagabbro overlain (to west) by keratophyre



North end of Elk Head; note melange flowing from under terrace

Plate II

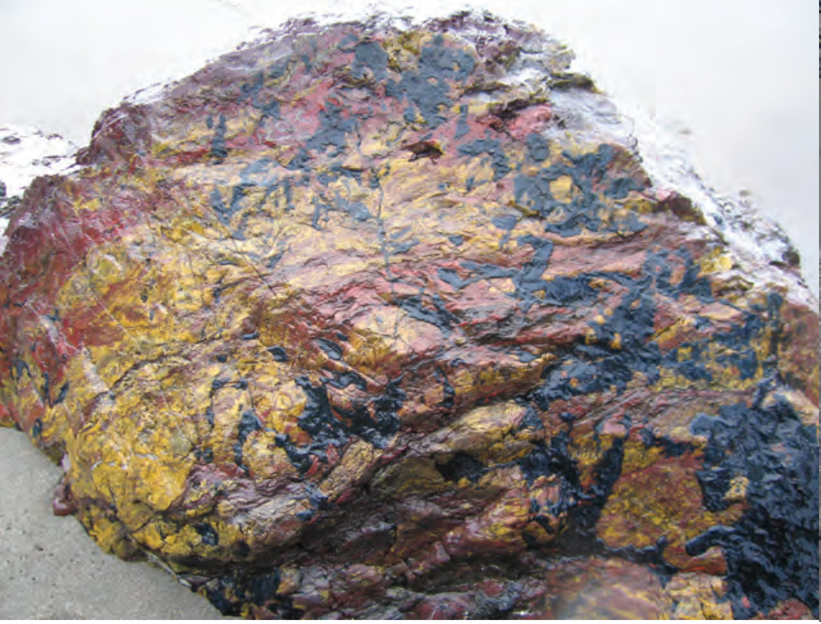

Pillow basalt block on beach, Trinidad


Fractured ribbon chert


Chert deposited upon basalt

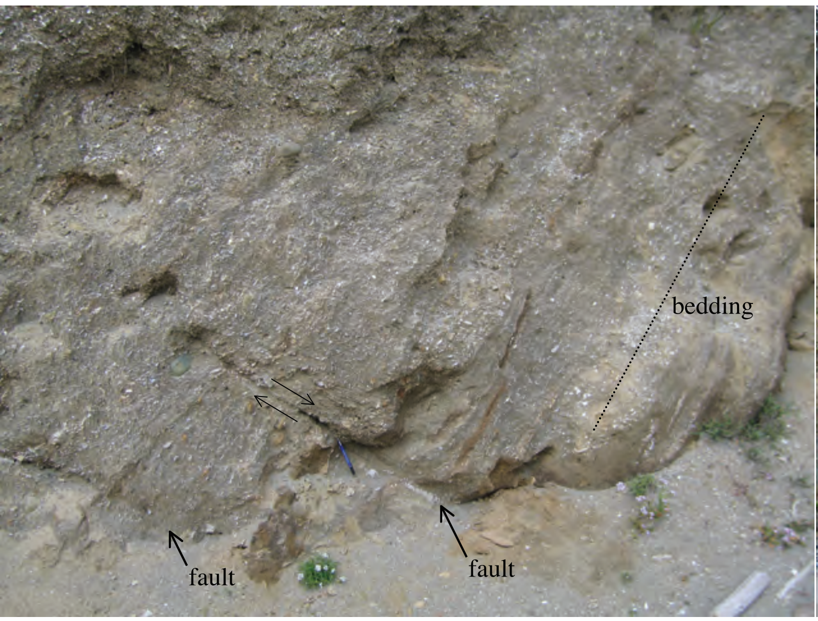

Mixed basalt, sandstone & tuff


Green ribbon chert


The ‘Psychedelic Rock’ with blue crocidolite


Actinolite schist with blueschist rind

Young fault behind Chevron Station: field and trench views



Tilted marine terrace deposits (370,000 BP?) near the 'Seascape'

60,000(?) BP marine terrace burying Franciscan sea stacks, Trinidad

~6,000 year old stumps exposed on Trinidad Beach - 1997 El Nino

Clam (surf zone) borings on sandstone sea stack