

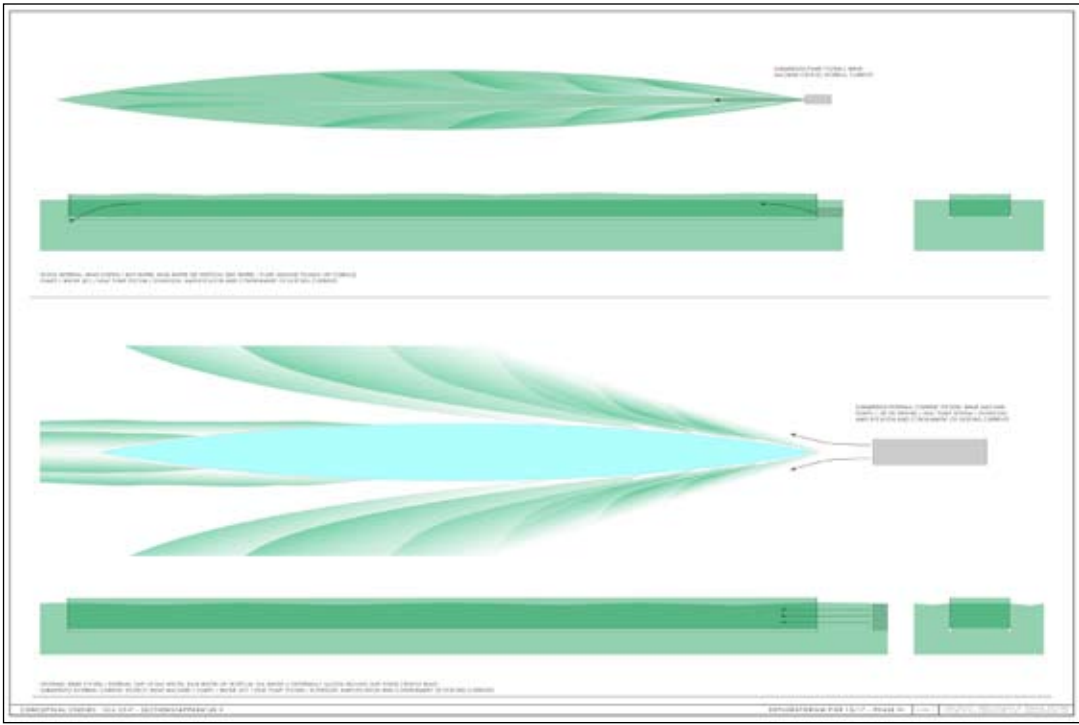
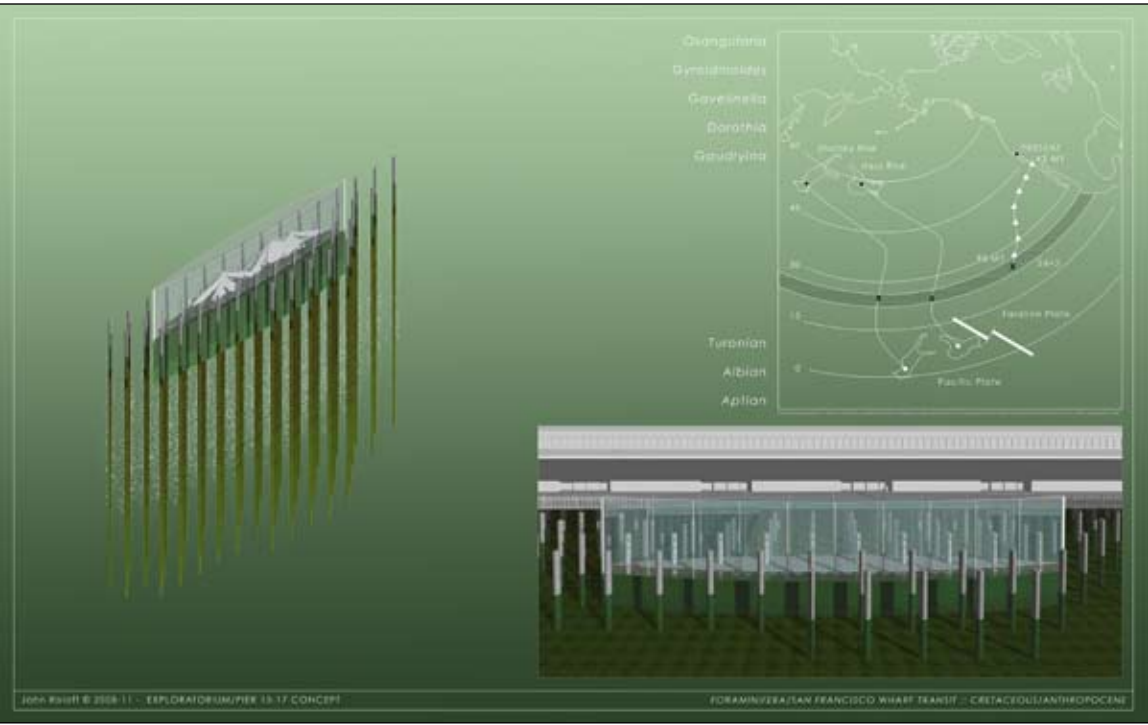
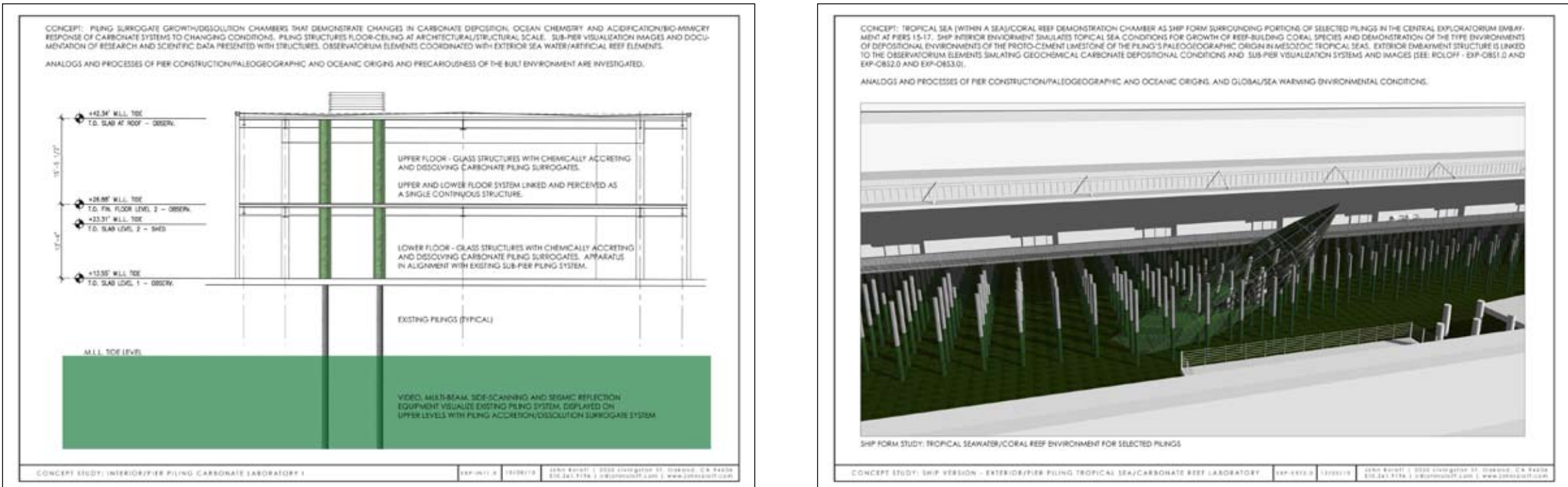
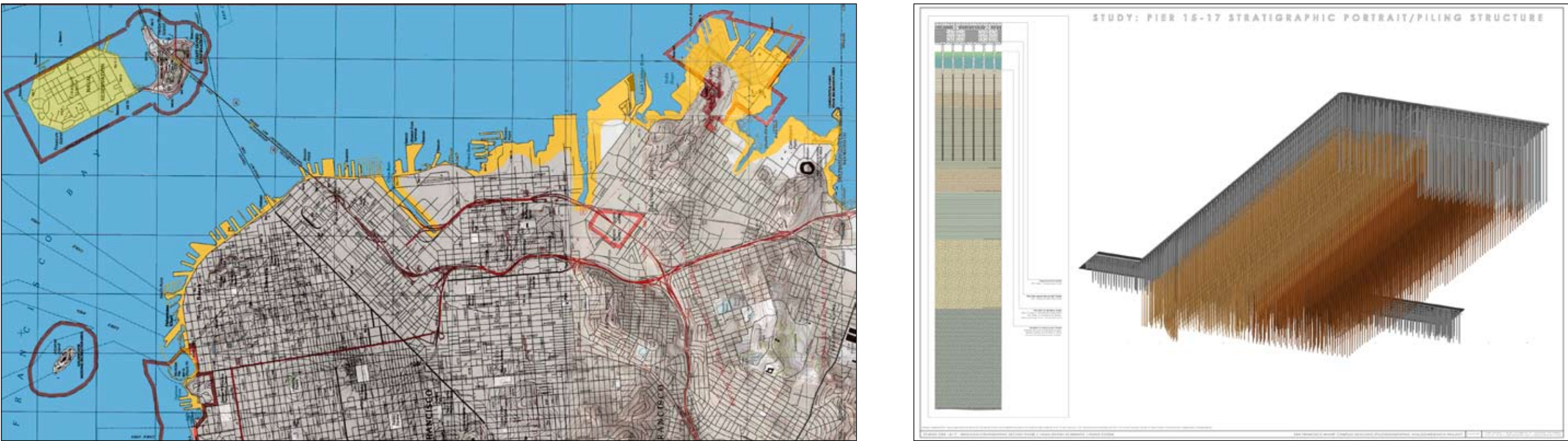
San Francisco Wharf Complex

John Roloff 2008-2014

*San Francisco Wharf Complex* (SFWC) is a conceptual and physical site that consists of the structure, environment and history of the majority of the built San Francisco wharf/waterfront system and selected landfill areas, from approximately Pier 1 at Fort Mason to Candlestick Park, as well as research, studies and proposals for artworks related to this sea/landscape developed from 2008 to the present. Many of these concepts were developed during a multi-year relationship with the Exploratorium, San Francisco, CA, that included support from the National Science Foundation, Bernard Osher Foundation and the National Endowment for the Arts as well as the generosity of the Exploratorium and it's staff. Later projects, such as: *San Francisco Wharf Complex: Coral Orchid/Seamount*, 2012, and *San Francisco Wharf Complex: Sea Knot (Mesozoic/Holocene Seas)*, 2012, are examples of a multitude of proposals generated from this process. The video, *San Francisco Wharf Complex*, presents selected, generative images of earlier work and concepts from the mid-1970's to 2007, followed by representative images of the multi-phase research and proposal process for SFWC.

*San Francisco Wharf Complex* imagines the San Francisco wharf/waterfront system as a singular landscape/formation contextualized within the geologic and paleo-geographic history of northern and central California. This relationship of ideas and histories places the Anthropocene built environment within larger cycles of geologic time, natural change and landscape evolution. Research into the history and geologic relationship of the pier/wharf system to the underlying *Franciscan Complex* as well as more recent geologic structures, spawned numerous metaphors reflected in the concepts and proposals generated in SFWC. Site studies and project concepts such as: *Study: Pier 15-17 Stratigraphic Portrait/Piling Structure*, 2009 and *Concept Study: Observatorium/Pier Piling Carbonate Laboratory*, 2010 The idea of the piers as a landscape made of earlier landscapes through their paleo-geographic and geologic history unearthed special relationships of the San Francisco Bay Area to geologic time, ancient tropical seas, coral reefs, plate-tectonics, accreted terranes, ancient and contemporary climate change, as well as a host of poetic analogs and metaphors for those relationships. The majority of the concepts were developed as proposals for sculptural and environmental artworks for potential implementation at piers 15/17 and/or other waterfront sites.

The professional paper, *Franciscan Complex Calera limestones: accreted remnants of Farallon Plate oceanic plateaus* by Tarduno, McWilliams, Debiche, Stilter and Blake, among numerous other, similar documents, provided scientific narratives related to the material and historical provenance of the San Francisco wharf system. In particular, this paper, identifies the Calera limestone from the Permanente quarry, near Cuptertino, CA, as an allochthonous type-material/formation, exemplary of a range of potential geologic sources for the cement component of the *San Francisco Wharf Complex*. Tarduno, et. al., describe a narrative of a late Cretaceous mid-Pacific carbonate depositional system of reefs and oceanic plateaus that embarked on a 2500 km, 90 million year journey as part of the Farallon Plate ultimately transformed and emplaced as the Calera Formation limestone of the Permanente Terrane of the *Franciscan Complex*. In this narrative, the ship as a symbol for change and transformation is one of several metaphors for a land/sea-scape that has traversed time and space, creating new land/sea-scapes. As referenced in work since the 1970's and in addition to *San Francisco Wharf Complex: Coral Orchid/Seamount*, 2012 and *San Francisco Wharf Complex: Sea Knot (Mesozoic/Holocene Seas)*, 2012, through various phases of the development of the *San Francisco Wharf Complex*, the ship image, such as in: *Ship Form Study: Tropical Seawater/ Coral Reef Environment for Selected Pilings*, 2010, *Foraminifera/San Francisco Wharf Transit :: Cretaceous/Anthropocene*, 2011 and *Conceptual Studies: Sea Ship - Section/Apparatus II*, 2011, are exemplary of an analogs for orogenic, depositional, volcanic, turbidinal, ontological, psychological and related processes for the visualization and engagement of land and seascapes.



**Franciscan Complex Calera limestones: accreted remnants of Farallon Plate oceanic plateaus**

John A. Tarduno\*, Michael McWilliams\*, Michel G. Debiche\*, William V. Stilter† & M. C. Blake Jr†

\* Department of Geophysics, Stanford University, Stanford, California 94305, USA  
† US Geological Survey, Menlo Park, California 94025, USA

The Calera Limestone, part of the Franciscan Complex of northern California, may have formed in a paleoenvironment similar to Hess and Shatsky Rises of the present north-west Pacific<sup>1</sup>. We report here new palaeomagnetic results, palaeontological data and recent plate-motion models that reinforce this assertion. The Calera Limestone may have formed on Farallon Plate plateaus, north of the Pacific-Farallon spreading centre as a counterpart to Hess or Shatsky Rises. In one model<sup>2</sup>, the plateaus were formed by hotspots close to the Farallon-Pacific ridge axis. On accretion to North America, plateau dissection in the late Cretaceous (50–70 Myr) could explain the occurrence of large volumes of pillow basalt and exotic blocks of limestone in the Franciscan Complex. Partial subduction of the plateaus could have contributed to Laramide (70–40 Myr) compressional events<sup>3</sup>.

The Aptian to Cretaceous (115–85 Myr) Calera Limestone occurs in coastal California as a belt of blocks in the Permanente Terrane<sup>4</sup> (Fig. 1). In addition to the limestone, the terrane contains pillow basalt, radiolarian chert of lower Cretaceous (Valanginian) age and continentally-derived greywackes and shale. The limestone is dominantly pelagic, but rare shallow-water oolitic and bioclastic rocks are also found<sup>5</sup>. Pelagic limestone is interbedded locally with pillow lava, tuffaceous breccia, and volcanic sandstone.

The Calera Limestone has two facies, one a light grey limestone interbedded with replacement chert, the other a bituminous black facies. The black facies is lithologically similar to mid-Cretaceous anoxic zones seen on Manihiki Plateau, Hess Rise and Shatsky Rise. This observation led Jenkins<sup>6</sup> to infer a common depositional environment for the Franciscan and oceanic rocks, and to assign a provisional Cenomanian age to the anoxic part of the Calera Limestone. Together with Pacific plate reconstructions, results from the Deep Sea Drilling Project (DSDP) have led to suggestions that Hess and Shatsky Rises (on the Pacific Plate) had Farallon Plate counterparts, because the crust underlying Hess and Shatsky Rises is the same age as the basement of the respective plateaus<sup>7</sup>.

Henderson *et al.*<sup>8</sup> suggested that Hess and Shatsky Rises were formed by hotspot activity coincident with the Farallon-Pacific spreading ridge. By analogy with present ridge-coincident hot-spots such as the Iceland hotspot which formed paired plateaus, it is possible that 'mirror images' of Hess and Shatsky Rises formed on the Farallon Plate. The Calera Limestone might then represent obducted slices of carbonate caps deposited on the plateaus.

Well-exposed outcrops of Calera Limestone at Permanente and Pacific Quarries (Fig. 1) allow models of the origin of the Calera Limestone to be tested. At Permanente Quarry several large limestone sections are repeated by a complex series of faults. At Pacific Quarry, a continuous 75-m section is exposed in a single block. A black shale horizon is present midway through the section, below which bituminous limestone is interbedded with thin tuffaceous horizons.

The light-grey facies of the Calera Limestone at these quarries dated by planktonic foraminifera as 'at least Albian to Turonian'<sup>9</sup>, is now known to extend to the Aptian. Foraminifera from the same sections suggest bathyal depths (200–1,500 m), similar to Hess and Shatsky Rises. Genera present include *Oranulularia*, *Cyroidinoides*, *Gavelinella*, *Dorothia* and *Gaudryina*. Sponge spicules, agglutinated foraminifera, and fish debris

© Macmillan Journals Ltd., 1985

Fig. 1 Location map showing sample localities and regional relations between the Permanente Terrane, other Franciscan terranes, the Great Valley sequence, and the Salinian terrane.

Fig. 2 A terrane model for the Calera Limestone palaeomagnetic data using the plate motion models of Engenbreton *et al.* (1973) and methods of Debiche *et al.* (1973). The northern option for the initiation of Kula/Farallon spreading has been chosen. Palaeolatitude versus age is shown for 30 palaeontologically dated palaeomagnetic cores (small circles) of Calera Limestone from Permanente Quarry. Scatter in the data probably represents *in situ* slumping. The computed terrane model and the present location of the Calera Limestone on North America are also shown. From 106 to 63 Myr, the Calera Limestone rides on the Farallon Plate converging with North America. At 63 Myr, accretion to North America takes place. From 63 to 10 Myr, the Limestone is driven tangentially along a small circle representing the palaeo-Californian margin with 50% of the coast-parallel Farallon Plate velocity. Pacific Plate motion from 10 Myr to present takes up the final amount of northwards displacement.

quarries, evidence of shallow water debris is found in the older bituminous limestones. Nearby outcrops of Calera Limestone at Baldy Ryan Canyon near New Almaden also contain oolitic and bioclastic limestone of Albian age, indicating shallow water deposition<sup>10</sup>.

A comparison of stratigraphic columns from Shatsky and Hess Rises, the mid-Pacific Mountains (DSDP Legs 32 and 62 respectively)<sup>9,10</sup> and the Calera Limestone reveals a similar

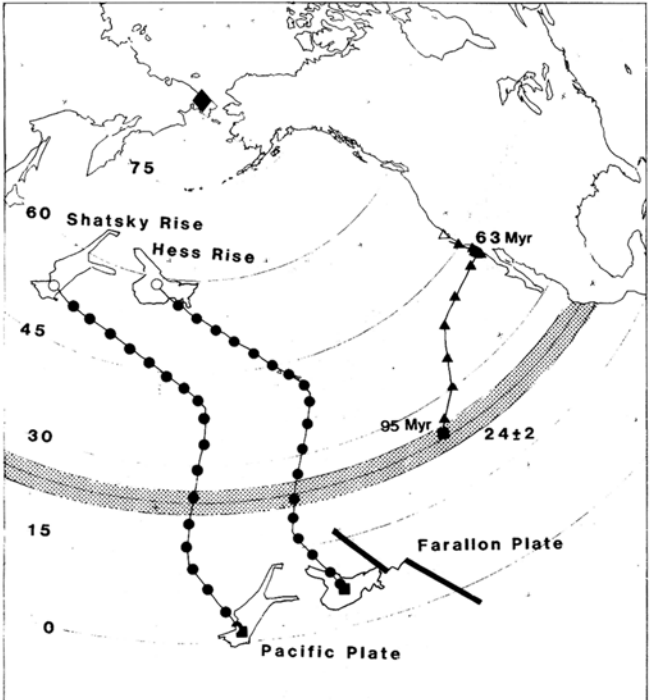


Fig. 3 Oceanic plate reconstruction in fixed North America coordinates is shown for 92 Myr. The small circles represent latitude and longitude coordinates, and the present coastline of Eurasia is shown for reference. Open symbols represent present-day locations while the filled squares represent positions at 92 Myr. Hess and Shatsky Rise are reconstructed back to 92 Myr on the Pacific Plate. The black circles represent 5-Myr increments. The computed terrane trajectory is shown by solid triangles. The stippled region represents the palaeomagnetic constraints for 92 Myr based on a 6-Myr averaging window. This model predicts the crust on which the Calera Limestone was deposited formed during chron M21 (153–154 Myr)<sup>15</sup>. Assuming an accurate location of the Farallon-Pacific ridge and symmetrical spreading, this reconstruction suggests that the Calera Limestone originated on a Farallon Plate analogue of Shatsky Rise.

The oldest part of the Calera Limestone, dated by foraminifera from Pacific and Permanente Quarries, is of Aptian age (115 Myr). By extrapolating sedimentation rates measured above the black shale marker horizon in Pacific Quarry, we infer that the anoxic sediments below the horizon denote the Barremian-Aptian anoxic zone. As these outcrops probably predate the oldest recovered sediments from Hess Rise (early Albian to late Aptian), it is likely that Pacific and Permanente Quarries are coeval with Shatsky Rise. The stratigraphy of Site 463 from the mid-Pacific Mountains is most similar to that of the Calera Limestone quarries. A distinctive sequence of Aptian carbonaceous limestone interbedded with tuffaceous and chert is present in the Calera Limestone, but it's absent in DSDP sites from Hess and Shatsky Rises.

Samples were taken at Permanente Quarry by Courtillot *et al.*<sup>11</sup> for palaeomagnetic investigation. In that study, a positive 'mega-conglomerate' suggested that the magnetizations predate block tilting (the palaeomagnetic inclinations are in significantly better agreement after correction to the palaeohorizontal). New palaeomagnetic results from Permanente Quarry which confirm this interpretation are reported below. The age of the sections sampled falls within the Cretaceous normal polarity superchron. Therefore, with facing directions provided by foraminiferal dating, a unique determination of palaeolatitude can be established, assuming that the magnetizations were acquired shortly after deposition.

Thermal and alternating field demagnetization experiments reveal stable magnetizations with blocking temperatures of 500–580 °C, and median destructive fields of 30–40 mT. Magnetiz-

ations from 30 palaeontologically-dated samples suggest 7° of poleward translation over the depositional interval of 105–90 Myr (Fig. 2). Palaeolatitudes range from ~18°N at 105 Myr to 25°N at 90 Myr. The palaeolatitude change implies plate speeds of at least 5 cm yr<sup>-1</sup>, in accord with estimates of Farallon Plate motion.

Using these new palaeomagnetic data, northern Pacific Basin plate motions<sup>12,13</sup>, and geological accretion ages, a model terrane trajectory<sup>14,15</sup> can be computed for the Calera Limestone (Fig. 2). Our preferred model involves the following sequence: (1) Deposition of the Calera Limestone on the Farallon Plate from 105 to 90 Myr between 18° and 25°N. (2) Accretion to North America at 63 Myr. (3) Northward translation relative to North America, driven by oblique subductions of the Farallon Plate from 63 to 10 Myr. (4) Transfer to the Pacific Plate from 10 Myr to the present, after development of the San Andreas transform system.

The palaeopositions of Hess and Shatsky Rises during the known interval of Calera Limestone deposition can be found by reconstructing the Pacific Plate (Fig. 3). If the location of the Farallon-Pacific ridge is accurate, and if spreading is symmetrical, the symmetry between the Calera Limestone and Shatsky Rise astride the Pacific-Farallon ridge suggests that the plateau carrying the Calera Limestone formed as a mirror image of Shatsky Rise.

This overview, together with palaeontological and palaeomagnetic information, suggests a model for the evolution of the Permanente Terrane as a whole. In Kimmeridgian to Albian times (154–105 Myr), topographic highs (a seamount province) were formed on the Farallon Plate, possibly by a hotspot coincident with the Farallon-Pacific ridge. Although the distinction between plateaus, aseismic ridges, and seamounts is partly artificial<sup>16</sup>, it is possible that such Farallon Plate topographic expressions attained the dimensions of present oceanic plateaus (800–1,200 km<sup>2</sup>). General subsidence marked the Albian to Turonian interval (105–90 Myr), with the deposition of pelagic limestones and sporadic off-ridge volcanism.

Accretion in the Franciscan Complex took place in the late Cretaceous to Eocene, marked by the influx of continentally derived greywacke. The partial subduction of buoyant oceanic plateaus and seamounts could have contributed to the shallowing of the angle of subduction which was manifested by the trench, the limestone, basalt, and greywacke were obducted and imbricated by thrust faulting. Further northward translation by proto-San Andreas motion, driven by oblique subduction of the Farallon Plate, dissected the obducted limestones and juxtaposed other exotic blocks of limestone, greenstone and chert originally located on more distant parts of the Farallon Plate.

We thank Steve Kupferman and Kaiser Permanente Cement Co. for providing access to Permanente Quarry and helpful information. This research was supported by NSF grant EAR-8408035 and Petroleum Research Fund grant 13646-AC2 to McWilliams.

Received 16 March; accepted 25 July 1985.

1. Jenkins, J. C. *J. geol. Soc. Lond.* **137**, 171–188 (1980).
2. Henderson, L. J., Gordon, R. G. & Engenbreton, D. C. *Tectonics* **3**, 121–132 (1984).
3. Lirio, R. F., Burke, K. G. & Seng, A. M. C. *Nature* **289**, 276–278 (1981).
4. Blake, M. C., Jr., Howell, D. G. & Jordan, A. S. *Proceedings of the American Geophysical Union* (Am. Geophys. Union, Washington, DC), **65**, 423–437 (1984).
5. Blake, M. C., Jr. *J. geol. Soc. Lond.* **137**, 171–188 (1980).
6. Bailey, E. H., Irwin, W. P. & Jones, D. L. *Calif. Div. Min. Res.* **183**, 68–77 (1964).
7. Irwin, W. P. *Pacific Sci.* **20**, 489–492 (1966).
8. Irwin, W. P. & Seng, A. M. C. *Geology* **13**, 107–110 (1985).
9. Irwin, W. P. & Seng, A. M. C. *Geology* **13**, 107–110 (1985).
10. Irwin, W. P. & Seng, A. M. C. *Geology* **13**, 107–110 (1985).
11. Courtillot, V. *et al.* *Geology* **13**, 107–110 (1985).
12. Engenbreton, D. C., Gordon, R. G. & Cox, A. *Geol. Soc. Am. Spec. Pap.* (in the press).
13. Engenbreton, D. C., Gordon, R. G. & Cox, A. *Geol. Soc. Am. Spec. Pap.* (in the press).
14. Debiche, M. G., Cox, A. & Engenbreton, D. C. *Geological Soc. Am. Spec. Pap.* **286**, 23–30 (1985).
15. Debiche, M. G., Cox, A. & Engenbreton, D. C. *Geological Soc. Am. Spec. Pap.* **286**, 23–30 (1985).
16. Jenkins, J. C. in *Sediments, Environments and Facies* (ed. Reading, H. C.) (Elsevier, New York, 1979).
17. Dickinson, W. R. & Snyder, W. S. *Bull. geol. Soc. Am.* **153**, 337–366 (1978).
18. Irving, E. & Irving, G. A. *Geophys. Surv.* **1**, 141–150 (1982).
19. Hartnall, W. B. *et al.* *Geological Time Scale* (Cambridge University Press, 1982).

