NORTHERN CALIFORNIA GEOLOGICAL SOCIETY

SILICA-RICH ROCKS IN THE BERKELEY HILLS

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Field Trip Leader:
Lin Murphy, Graduate Student
California State University, Hayward

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FIELD GUIDE TO SILICA-RICH ROCKS IN THE BERKELEY HILLS

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INTRODUCTION

The East Bay Hills of the San Francisco Bay area comprise a long (50+ miles), narrow (10-15 miles) range along the eastern margin of San Francisco Bay between the Hayward and the Calaveras faults. The Hills have an extremely complex geologic history, stratigraphy, and structure. In the Berkeley Hills are rocks of the Franciscan Complex, Jurassic Coast Range Ophiolite (CRO), Great Valley Sequence, and Cenozoic marine and nonmarine sedimentary and volcanic deposits. The Franciscan Complex includes shale, serpentinite, sheared matrix, and high-grade blocks, such as blueschist. The CRO includes gabbro, basalt, serpentinite, and keratophyre and quartz keratophyre. Keratophyres are altered silicic volcanics overlying the CRO. The Cenozoic volcanics, such as the Moraga volcanics located high in the Berkeley Hills, were erupted in the wake of the northward-migrating Mendocino Triple Junction. All these rocks have been complicated by faulting and folding. In addition, large landslides and residential development make it difficult to access good bedrock exposures. This field trip will focus on the silica-rich rocks preserved in and near parks in the Northbrae area of Berkeley. The Northbrae and Leona Rhyolites have until recently been interpreted as the same formation. With the exception of Cragmont rock, which Dibblee described as Franciscan chert, the other rocks in this guide have not been described or mapped.

HISTORY OF GEOLOGICAL INTERPRETATIONS OF THE NORTHBRAE AND LEONA RHYOLITES

- Lawson. 1914. USGS Geol. Atlas Folio. Names the rhyolites "Northbrae" and "Leona" after residential areas where they crop out; dates both rhyolites as Pliocene.

- Robinson. 1956. Geologic Map of the Hayward Quadrangle. Northbrae Rhyolite is not within his mapping area, but Robinson opines that Northbrae is likely a small intrusive related to the Leona and dates both as early to middle Pleistocene.

- Case. 1963. Geology of Berkeley and San Leandro Hills. Considers Northbrae and Leona to be Pleistocene keratophere.

- Radbruch. 1969. Engineering Geology of the Oakland East Quadrangle. Northbrae Rhyolite is not within her mapping area. Dates Leona as "Pliocene (?)".

- Knox [Bishop et al.]. 1973. Preliminary Geologic Map of San Pablo, El Cerrito, and Richmond. Mapped rhyolites north of U.C. Berkeley campus as Northbrae and dated them as Pliocene.

- Dibblee. 1980. Preliminary Map of the Richmond Quadrangle. Maps all rhyolites in this area as "Tertiary Rhyolite," and Cragmont Rock as Franciscan chert.

- California Division of Mines and Geology. 1990. Geologic Map of the San Francisco–San Jose Quadrangle. Maps both Northbrae and Leona as "rhyolite of uncertain age," "Mzv," and tentatively groups them as part of the Coast Range Ophiolite.

- Jones and Curtis. 1991. Guide to the Geology of the Berkeley Hills. Designates the Northbrae and the Leona Rhyolites as Mesozoic keratophyre belonging to the Coast Range Ophiolite based on depositional contact with Knoxville shale at Tunnel Road, near Highway 24.

- Graymer, Jones, and Brabb. 1995. Map of the Hayward Fault Zone. Maps the Northbrae and Leona as "Jsv," keratophyre belonging to the Coast Range Ophiolite.

- Murphy, 2001. Petrological and geochemical distinctions between the Northbrae and Leona Rhyolites, Berkeley, CA. Hypothesized that the Northbrae was an exotic block brought from Pacific trench/rift environment during period of subduction of Farallon plate.

- Murphy, Fleck, and Wooden. 2002. The Northbrae Rhyolite in the Berkeley Hills: A Rock Well-Misunderstood. Reports 11.5 million-year U-Pb age of Northbrae Rhyolite, which indicates that it is a heretofore unrecognized volcanic that erupted in the wake of the northward-migrating Mendocino Triple Junction.

LOCATION and DIRECTIONS

Tour starts at Indian Rock Park, just north of Marin Circle in north Berkeley. **WALK** from Indian Rock Park. Follow the steps down Indian Rock Path. This path will lead to Arlington, Mendocino, and Contra Costa Avenues. Turn right on Contra Costa Ave and follow it to the intersection with Yosemite Road. Turn left on Yosemite to Great Stone Face Park. Walk to the right through the park along San Fernando Ave to Thousand Oaks Boulevard. Turn right along Thousand Oaks Boulevard to the intersection with Arlington Ave. Turn right on Arlington Ave to Southampton Ave. Turn left on Southampton to John Hinkel Park. Take the path uphill across John Hinkel to San Diego Road. Follow San Diego to the right to the intersection with Indian Rock Ave. Across Indian Rock Ave is Mortar Rock Park. Look for the depressions and holes interpreted as having been made by Ohlone Indians grinding acorns. Follow Indian Rock Ave back to Indian Rock Park.

DRIVE downhill on Indian Rock Ave to Marin Circle. Circle around to Marin Ave. Drive up Marin to Euclid. Turn right on Euclid and park near 971-972 Euclid. These are the addresses nearest to Easter Way Path.

WALK Climb the steps up Easter Way Path to Cragmont Park, which contains a rustic restroom and picnic shelter. Walk downhill on Regal Road around Cragmont Park to Pinnacle Path.

Follow Pinnacle Path uphill to Poppy Lane. Turn right and follow Poppy to Remillard Park.

SILICA-RICH ROCKS in and near NORTH BERKELEY PARKS

Indian Rock Park (Northbrae Rhyolite)

Petrology: The most striking features of Indian Rock are the flowbanding and brecciation textures. The flowbands vary in scale from millimeters to several centimeters. We interpret the flowbands as evidence that Indian Rock was emplaced as a viscous volcanic flow. We don't know whether the flow was subaerial or submarine. (Marine rhyolites are known from the IzuBonine and Suzmisu Rift in the west Pacific near Japan.) As the flow advanced, viscosity increased with cooling, and flow planes were bent and broken, forming autobrecciated clasts. The long low outcrop in the grassy area east of Indian Rock Ave (across the street) contains excellent examples of flowbands and autobrecciation.

On the wall by the stairs that leads west from Indian Rock Ave are two populations of clasts, (l) flowbanded autobrecciated clasts; and (2) clasts without apparent textures, formed possibly by another brecciation mechanism. Indian Rock also contains spherulites, which are radiating arrays of crystal fibers that form as the glass flow begins to devitrify (crystallize).

Primary textures of the original flow were silicified some time after eruption, resulting in a very hard rock. Due to its competence and to hand and footholds in the flowbands, Indian Rock has been a rockclimbing site since the 1930's. By contrast, the Leona Rhyolite is crumbly and broken. Its fractured, loose surfaces are totally unsuited for the sport of climbing.

Indian Rock also bears some extremely polished rounded surfaces. (We distinguish these surfaces from slickensides caused by movement along fractures and flow planes. Slickensides due to movement along flowplanes occur on the downhill side of the rock near Indian Rock Path.) The polished rounded surfaces are more apparent at Great Stone Face, another Northbrae Rhyolite block. Originally, we interpreted these rounded surfaces as possibly having been formed in an accretionary wedge or similar environment, where Northbrae blocks were tumbled, rounded and polished as exotic blocks in a melange. This interpretation was based. in part. on the similarity of Northbrae polished surfaces to rounded, highly polished Franciscan eclogite blocks on the Sonoma coast. High-grade Franciscan blocks on the Tiburon peninsula also have a rounded morphology and some polishing. The U-Pb date of the Northbrae (11.5 my) precludes its having been rounded and polished in an accretionary wedge. We now suggest that the rounding and polishing, as well as the secondary silicification, took place as the Northbrae blocks traveled northward in the Hayward–Calaveras fault zone. The Dibblee (1980) map shows that the Northbrae blocks outcrop in zones of serpentinite and sheared shale and sandstone within the Hayward fault zone.

Geochemistry: The REE (Rare Earth Element) plot of Indian Rock and all the other Northbrae Rhyolite blocks shows a LREE (Light REE) enrichment and a negative Eu (europium) anomaly. This REE signature indicates that the Northbrae has evolved through differentiation of its parent magma. (During differentiation processes, LREE are more likely than other REE to concentrate in the melt. A negative Eu anomaly indicates that plagioclase feldspar crystallized out of the Northbrae magma before it erupted.) In contrast, the REE plot for the Leona Rhyolite is flat, indicating relatively little evolution or differentiation of the magma.

The Northbrae Rhyolite contains intermediate values for potassium and sodium. This contrasts with the Leona Rhyolite, which has high sodium and low potassium values. On the Pearce [et al.] (1984) Ta-Yb tectonic discrimination diagram, the Northbrae Rhyolite plots in the field boundary between within-plate granite and anomalous ridge. The Leona Rhyolite plots as a volcanic arc, consistent with its interpretation as part of the CRO.

Great Stone Face Park (Northbrae Rhyolite)

Flowbanding and brecciated textures are present, although generally less obvious than at Indian Rock. Rounding and polishing of the primary flowbanded texture is more apparent at Great Stone Face Park. A low outcrop near the intersection of Yosemite Road and San Fernando Ave contains flowbands that terminate abruptly at a fine-grained zone of brecciated clasts. This feature may be interpreted as brecciation of the flow due to rapid chilling, perhaps as the flow encountered water. The clasts were incorporated into the flow. Rocky faces at Great Stone Face and at Indian Rock contain two populations of clasts: flowbanded from autobrecciation of the flow and nonflowbanded from another clastic process.

John Hinkel Park (silicified volcanic, geochemical affinity unknown)

Low. small gray outcrops exhibit flowbanding, silicified spherulites and lithophysae (irregular cavities in a volcanic rock). In thin section, Hinkel rock exhibits many small blocky feldspar microlites, which distinguish it from the Northbrae Rhyolite whose texture is primarily a recrystallized fine-grain mosaic with isolated feldspar phenocrysts. Hinkel likely erupted as a glass flow. We have no age or geochemistry on the rock at Hinkel Park.

Cragmont Park (silicified volcanic, possibly part of Northbrae Rhyolite)

The most striking feature of Cragmont Rock is its clastic appearance: poorly sorted, subrounded grey and white clasts float in a recessive matrix, which contains smaller angular fragments of quartz. These clasts may be silicified spherulites, lithophysae. autoclastic breccia, or sinter breccia. Cragmont may also represent a mass flow reworking of what originated as a lava dome or flow. We are not sure exactly how Cragmont was formed. In thin section one finds infrequent

crystals that have been replaced by microcrystalline quartz. These crystals suggest that Cragmont may have originated as the brecciated carapace of a silicic flow or dome. At Rock Lane, roughly equidistant between Cragmont and Indian Rock Parks, a house foundation exhibits clasts similar to those at Cragmont Park and flowbands similar to those found at Indian Rock Park. The exposure at Rock Lane suggests that Cragmont and Indian Rock are part of the same volcanic flow. Cragmont is >98% quartz which indicates that its original geochemistry has been significantly altered. The REE pattern is LREE depleted, just the reverse of the Indian Rock's LREE enrichment. It has a negative Eu anomaly, which is not as steep as Indian Rock's.

Although field observations, such as that at Rock Lane, suggest that Cragmont is part of the Indian Rock flow, this connection can neither be proved nor disproved by the altered geochemical signatures. Subsequent hydrothermal fluids have obliterated primary rock textures, as well as primary chemistry.

Remillard Park (Silica Carbonate)

The rock of this park is a silica-carbonate, formed by the hydrothermal alteration of serpentinite. Although serpentinite may form from high magnesium carbonates, the convergent margin history of the East Bay Hills suggests that this and other silica carbonates in the Berkeley Hills (for example, Founder's Rock on the UC Berkeley campus) likely derive from obducted peridotite, as sea floor and underlying mantle accreted to the North American continental margin during subduction.

The geochemistry of Remillard shows high levels of nickel and chromium, consistent with a mantle origin. Silica carbonates are spatially associated with fault zones of both the Franciscan Complex and Coast Range Ophiolite; however, they are a much later development. Silica carbonates develop in low-dipping fault zones that channel fluid flows. Plastic serpentinite focuses strain and seals fluids, which allows fluid overpressures to develop from groundwater containing dissolved silica and carbonate. An event such as fault-rupture may temporarily lower overpressures, allowing precipitation of dissolved minerals (Mel Erskine, personal communication 2001).

Remillard exhibits dissolution features such as resistant silica veins that stand out from the recessive rock into which they were originally intruded. Some surfaces also contain patches of euhedral quartz crystals. Thin sections exhibit carbonate vein fill and silica chalcedony.

SUMMARY

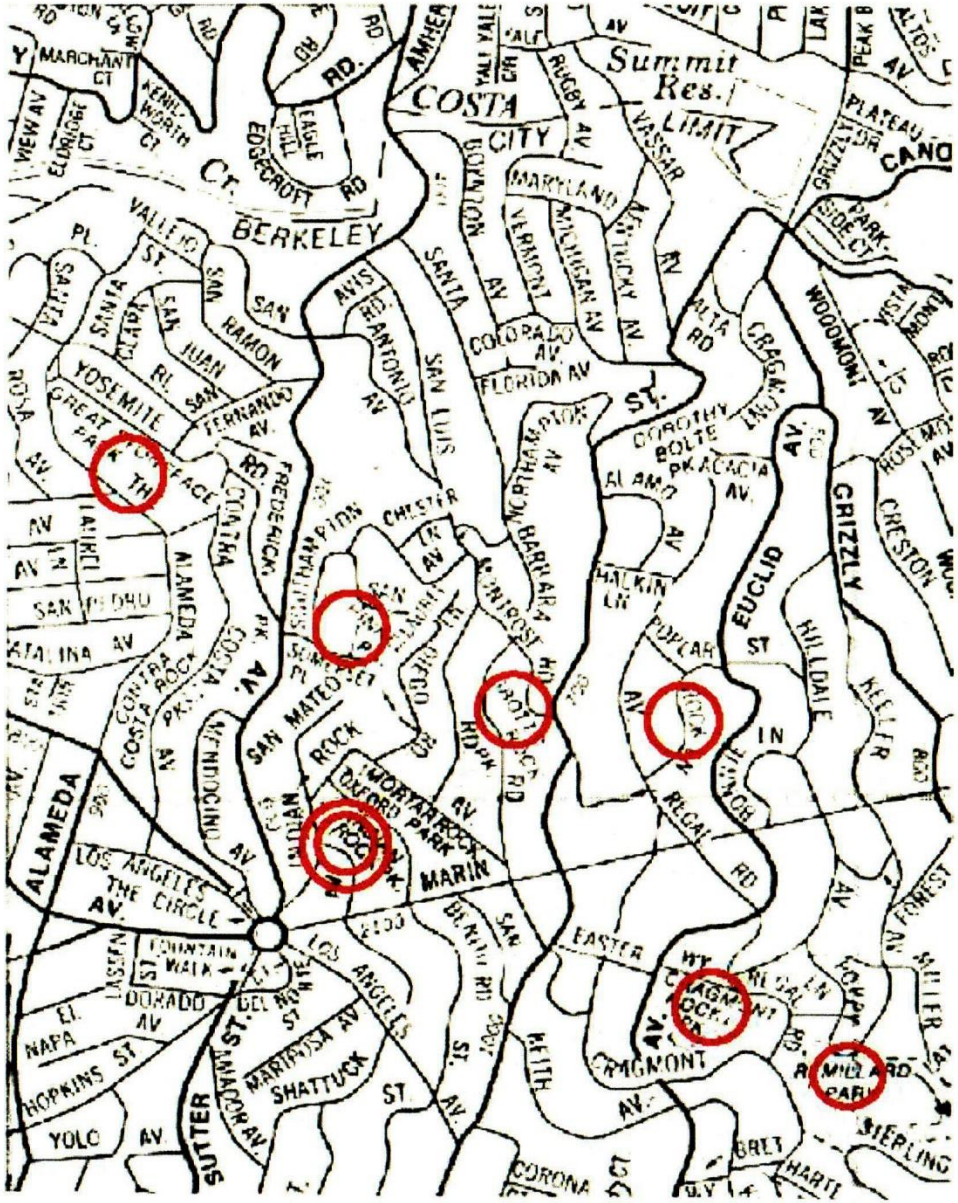
Current mapping of the silica-rich rocks in the Berkeley Hills identifies all the above rock outcrops as CRO keratophyres. Many researchers believe that the Northbrae Rhyolite is just part of the Leona Rhyolite. The Leona Rhyolite outcrops from Richmond to San Jose, along the Hayward Fault. One can visit it at Alvarado Park in Richmond, Tunnel Road in Berkeley near the Claremont Hotel, the quarry on I-580 (Leona Heights), near Lake Chabot, and on the Cal State Hayward campus. Our geochemistry indicates that the Leona sandwiches the Northbrae, which appears to be areally limited to Berkeley. We have no sure answer why the Leona and Northbrae Rhyolites are distributed in apparent mutual exclusivity. One explanation may be that in the Northbrae neighborhood the Leona was removed by developers who left the more resistant Northbrae in place.

The Leona Rhyolite too has been altered: Robinson (1953) discusses the sulfide mineralization of the rock at Leona Heights, south of Oakland. However, the Leona's silica content is well within the range of other CRO quartz keratophyres (Bailey [et al.], 1974), and its textures do not bear the obvious signs of silicification found at Indian Rock, Cragmont, Hinkel, or Remillard Parks. Not only do geochemistry and petrology of Northbrae, Cragmont, Hinkel, and Remillard indicate a petrogenesis different from the Leona's, secondary silicification of the former indicates a different environment after emplacement. Rounded, polished morphology suggests alteration and travel within the Hayward-Calaveras fault zone.

In Spring 2002, Fleck and Wooden of the USGS, Menlo Park, dated zircons from two different outcrops of the Northbrae Rhyolite. Their data indicate that the Northbrae Rhyolite is a newly recognized unit of the Cenozoic volcanics that erupted in the wake of the northwestward-migrating Mendocino triple junction. These Cenozoic volcanics are believed to be the result of the "asthenospheric window" (McLaughlin [et al.], 1996) or "slab gap" (Dickinson, 1997) that developed from the interaction of the East Pacific Rise and the Farallon trench. See Fox et al., 1985; McLaughlin et al., 1996; and Dickinson, 1997, for discussions of northwardly younging Cenozoic volcanic rocks in western California.

Similar radiometric ages suggest that the Quien Sabe, north of Hollister, and the Northbrae in Berkeley are part of the same volcanic field. As of the writing of this guide we are trying to gain access to the Quien Sabe volcanic field. There is no published trace element chemistry for these rocks, which would help establish a connection with the Northbrae. Drinkwater [et al.]'s (1992) map of the Quien Sabe volcanic field shows flowbanded rhyolites capping Cathedral and Mariposa peaks. There is significant hydrothermal mineralization in the area, which includes a number of silica carbonate blocks. Northbrae's greater proximity to Mendocino Triple Junction represents its movement along the Hayward-Calaveras fault system. The Moraga volcanics located high in the Berkeley Hills are younger than the Northbrae (9–10.2 Ma, Graymer, 1995), east of the Hayward Fault, and distinct from the Northbrae in lacking secondary silicification textures. Recognition of the Northbrae as a slab-gap volcanic may provide a new constraint for movement along the Hayward-Calaveras faults.

Street map of the Northbrae Area, Berkeley, CA



The Northbrae Rhyolite is areally limited to the Northbrae residential subdivision, north of the University of California campus. Outcrops are all clustered within 1/2 mile of Indian Rock Park, with the exception of Madera School, ~2 3/4 miles north of Indian Rock. The Madera School exposure has been greatly diminished in size since 1980: only occasional flowbanding identifies it as Northbrae, rather than Leona.

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