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MT. DIABLO AND BLACK DIAMOND MINE
REGIONAL PARK:
A STRUCTURAL PERSPECTIVE

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Preface

The joint Rock Fracture Project and Shale Smear Project Field Workshop 2000 consists of a one-day field trip to the East San Francisco Bay Hills. The purpose of the field trip is to see the remarkable antiformal uplift at Mt. Diablo and fractures and faults in Black Diamond Mine, which are probably related to this uplift and deformation.

On the way to our first stop at Mt. Diablo, we will see the Hayward and Calaveras faults and their linkage via the Mission Creek fault. We will drive to the top of Mt Diablo to view the structures within the mountain and surrounding it and discuss their role in the uplift of the mountain.

The last stop is at Black Diamond Mine Regional Park, where we will examine in detail the fractures and faults in an underground mine on the northern flank of the Mt Diablo structure. The underground provides an exceptional opportunity to observe fractures and faults without the impact of surface degradation. The rocks in the mine works have been well studied from the perspective of depositional environments. I was fortunate to find two theses work and several field guides primarily on the petrographic and depositional aspects of the Domengine Formation. However, I believe that this is the first publication on the fractures and faults and their formation processes in the Black Diamond Mine.

I received help from many persons during field work and preparation of this guide book: John Waters, the chief engineer of the mine has been extremely supportive throughout the work. John joined me for two days of field work in the mine and helped me to interpret mining-related features and to orient myself underground. Steve Graham provided copies of earlier publications related to the field trip area. Pat Raymond Sullivan of San Francisco State University joined me in the field for one day and helped me to evaluate the stratigraphy in the mine. Lidia Lonergan joined me for one day of field work and volunteered to be one of the guides during the field trip. Rangers Pat Dedmon and Bob Kanagaki were very helpful during my field work in the mine. Peter Eichhubl commented about the sections of the structures. Taixu Bai and Frantz Maerten helped with the visualizations. Phil Resor provided the satellite image. Victoria Doyle-Jones helped in the organization of the trip and reproduction of the guide book. Thank you all.

I hope that this field trip, just like the previous ones, will be considered to be an important mode of exchange between the projects and their member companies. As always, please don’t hesitate to let us know about your suggestions for future trips.

Atilla Aydin
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Introduction

San Francisco Bay Area Fault Architecture

The San Andreas Fault zone is the largest of a system of faults that make up the Pacific and North American plates transform boundary (Figure 2). A one-hundred km zone takes up about 90% of the motion (about 40 mm/year) of the Pacific plate relative to eastern US (Figure 3). The San Andreas zone proper is about 1300 km long and extends from the Gulf of California in the south to the Mendocino triple junction in the north. The present-day fault has been in existence for about 30 million years, although there is evidence for the existence of proto-San Andreas discontinuities. The sense of slip is primarily right lateral strike-slip; however, vertical components in both reverse and normal senses are common along the fault zone. The total amount of geologic slip along the fault may be as much as 560 km (Irwin, 1990) based on correlation of the offset basement rocks. However, a more reliable match is that of Eocene sedimentary rocks in the La Honda Basin and in the San Joaquin Basin, respectively. The offset of the depocenters of these basins right next to the San Andreas fault suggests a slip of about 305 km (Stanley, 1990). This magnitude of slip is consistent with that (330 km) inferred from matching early Miocene
(23.5 Ma) volcanic units on either side of the fault at the Pinnacles in central California and the Neenach volcanics in the Mojave Desert of southern California. It is also worthwhile to point out that limestone rocks within the Franciscan Formation along the western side of the fault show paleomagnetically tropical affinities, which suggests a northwesterly motion on the order of 2000-2500 km.

The San Andreas Fault in the San Francisco Bay Area is well-marked by its distinctive morphology of linear ridges and valleys, locally occupied by reservoirs with long and narrow dimensions paralleling the fault zone. A ~430km portion of the northern San Andreas fault from San Juan Bautista in southeast to the Cape Mendocino in northwest showed ground rupture associated with the April 18 California Earthquake of Ms 8.1. The maximum slip, about 6 m, was measured at Point Reyes, north of San Francisco. The slip tapered to zero near San Juan Bautista and was unobservable in the northernmost part of the fault under the ocean.

About 20 mm/year of the total relative motion is taken up by the San Andreas Fault (Figure 3). The Hayward/Calaveras/Greenville faults, the three major faults to the northeast (Figure 2 and 3), take an additional ~22 mm/year, and a few mm/year motion is spread to the east around the eastern boundary of the Sierra Nevada.

On the way driving to Mt. Diablo, we will see these faults but won’t make any stops because of time constraints.

**STOP 1: Mt. Diablo Area Fault Architecture**

Mt. Diablo (elevation 3849 feet) is the highest mountain in the Bay Area. It is believed that it provides the broadest view in all directions in the world! At the summit, we will view the enigmatic structure of the mountain and place the Black Diamond Mine district in a regional frame.

Things to see:

- Franciscan rocks in the core of the mountain.
- Cretaceous and Tertiary sedimentary rocks that form the antiformal rim.

The mountain is made up of a diabase in fault contact with the surrounding rocks, which are made up of typical mélange components: serpentine, graywacke, chert, shale and schist. The Great Valley sequence of detrital rocks overlies the diabase-mélange (the Franciscan complex with oceanic affinity), and it is followed by the early Tertiary detrital rocks.

- The East Bay Hills contractional domain of Aydin and Page (1984),
- Segmentation along the Calaveras Fault,
How thrust/reverse faults in this domain are connected to the contractional side of the segments’ ends.

Concepts to think about:

- Why the East Bay Hills domain is structurally higher?
- What is the age of this uplift? The Calaveras fault is quite young, certainly post Miocene. The bulk portion of the uplift took place in the last 2-3 million years (Aydin and Page, 1984).
- What is the relationship between the orientation of the Calaveras Fault segments and the thrust faults?
- Are there any normal faults associated with the Calaveras fault segments?
- If yes, where are they located and in what orientation?

Let’s turn to the Mt. Diablo structure:

Things to think about:

- Is the diabase core an intrusion or stock as suggested by Pampeyan (1964) and many other earlier workers?
- Given the Franciscan rocks forming the core of the mountain and their subduction affinity, is it possible that the uplift of the mountain and the broad antiform surrounding it are just relics of the subduction process and the following erosion?
- Why would the subduction-related uplift be so localized?
- Given the age of the uplift in the East Bay Hills domain, is it possible that the NE side of the fault stood still while all hell broke loose on the NW side?
- Is it possible that the Concord and Mt Diablo/Greenville faults configuration has no consequences with regard to the vertical component of displacement in Mt. Diablo?

Well, you will have to make up your own mind regarding the origin of the Mt. Diablo uplift. However, I would like you to think about the origin of the faults in N and NE direction to the south and north of the mountain (Figure 4) in order to better interpret the faults in Black Diamond Mine. The point is that if these faults are related to the strike-slip faults bounding the Mt. Diablo structure, then what we will see in Black Diamond Mine Regional Park regarding fault sense (normal with lateral component) and orientation (N to NE) are selfconsistent: They are extensional counterparts of the Mt. Diablo contractional structure.
Stop 2. Black Diamond Mine: A Structural Perspective

When we get to the parking lot in the park, we will gather in the underground meeting room at the Hazel-Atlas entrance to the mine (Figure 5). We will have two short introductions: One on the Mt. Diablo mining history by John Waters, the chief engineer for the park, and the other on structures that this author will show you.

Domengine Formation

The Domengine Formation of Eocene age and other lower Tertiary rocks are exposed in the northern flank of Mt. Diablo (see the schematic section in Figure 6a). As mentioned in the Preface, this formation and its depositional environment are well studied. Bodden (1981) described the rocks and interpreted the depositional environment. He provided many of the detailed sections. He concluded that the white sandstone member of the Domengine Formation was deposited in a complex of barrier-beach environments: marshes, lagoonal back-barrier sands, tidal inlets, and shoreface sands. Sullivan et al. (1994) recently reinterpreted the depositional features of the rocks and concluded that they formed in NE-SW-trending incised valleys as estuarine back-fill sands and muds. Regardless the distinction between the two interpretations, the sequence apparently has thick, clean, sand bodies, organic matter, coal and shale (Figure 6). There are three main coal bodies: The Clark, Sully (formerly unnamed) and Black Diamond (Figure 6b and c). See the detail of the Sully vein structure in Figure 6c for reference.

Things to see in the B-level tunnel:

- Clark vein
- Sand-filled burrows
- Various fossil plants
- Mud drapes on foreset laminae
- Truncated Sully vein
- Chemical reaction fronts (liesegangen) in porous sandstone
- Mud-filled ripples.
- Impact of shale laminae on constraining fluid flow
- Various faults (we prefer not to spend a long time on these).

Take the stairs to the upper level into the B-level machinery tunnel.

Things to see:

- Joints with precipitant fill (Figure 7a)
Joints occurring in clusters
Joint orientation is often perpendicular (in this locality) to and parallel (in some other localities) to bed strike
Evidence for shearing on these fractures (offset, tail-splay cracks?)
A white seam within these structures is crushed sand within or surrounded by opaque infill.
Asymmetric diagenetic precipitants (brown staining on one side only)
Note that this staining diminishes from the level of sandstone, which is characterized by orange reaction fronts (Figure 7b)

Things to think about:

- When did the joints form?
- What was the timing of the opaque infill?
- When did the shearing occur?
- What is the role of joints in fluid flow?

Proceed to the narrow tunnel.

Things to see:

- Fault with shaly fault rock (Figure 8a)
- Offset shale layer, its thickness (1.8 m) and its internal architecture (Figure 8b)
- Many small faults with apparent normal offset within the shale layer as well as within the fault zone
- Deformation of the sandstone on the footwall (Figure 9a that shows deformation bands and their impact on compartmentalizing the sandstone based on the staining distribution)
- See the intensity of the structures in sandstone at the far end of the tunnel

Things to think about:

- What do the details of the shaly fault rock tell you about the faulting process? Is this shale smearing?
- The shale layer in the tunnel is on the hanging wall side but which way should one look for its counterpart based on the smearing geometry?
- If the answer is up in the footwall, is there any evidence for it? How about the shale appearing in a small opening on the roof about 40 m to the east?
- If this shale is the same as the offset shale, can we determine the offset? How does 25 feet or 8 m sound based on the assumption that the apparent normal offset is actually throw, i.e., normal faulting?
How would you evaluate the offset/shale thickness ratio and continuity and integrity of the smeared shale?

Go back to the stairs and proceed to the west in B-Level haulage tunnel.

Things to see:

- Fault with shaly fault rock (Figure 10a)
- A piece of a shale layer appearing through a roof opening
- Deformation bands with apparent normal faults in the hanging wall side (Figure 10b)
- Faults with apparent normal offset on the footwall side (Figure 10b)
- Go to the far end side of the narrow tunnel and see the apparent conjugate normal faults both on the wall and on the roof (Figure 9b)
- See also thin shale lenses offset and cut by faults with cm-scale offset

Things to think about:

- If the shaly fault rock is smeared and it came from the shale layer appearing in the roof, where is its counterpart?
- What does this imply in terms of possible sense of offset?
- Reverse? Okay, is there any evidence for reverse faulting here? Remember, you aren’t in Mt. Diablo or the East Bay Hills!
- Normal? What is the evidence? According to Raymond Sullivan, the sand to the west is the same as the sand with tidal bundles, and therefore, the fault is likely to be of normal kind, though he at some point entertained the idea of a reverse fault. John Waters believes that the miners are smarter—they know where to go to find good, clean mineable sand that they were following until they encountered the fault. So the tunnel geometry is suggestive of the offset of the mined sand level. The 3-D spatial relationships are visualized in Figure 11 based on B-level tunnel geometry that John provided and on the measured attitudes of the fault N 35° E and 70° NW and bedding nearly E-W and 30° N.
- The configuration doesn’t actually prove that the sense is normal. It, however, constrains the possibilities. Given the offset of the tunnel axis for about 40 feet (13 m), the pure slip along the strike of the fault is about 46 feet (~15 m), and pure dip-slip along the dip of the fault is about 28 feet (9 m).
- If this is a normal fault, given the fault’s orientation, can the shale in the fault rock be the same as the exposed shale?
- If not, where should one look to locate the continuity of the shale layer on the other side of the fault? Is there such a layer there?
- If the shaly fault rock isn’t the same as the exposed shale, where are the shale beds from
which the fault rock was driven out?

Does this require another shale bed to the west? Is there another shale bed down section? Well, there is. However, it is much lower stratigraphically and doesn’t appear to be exposed in the footwall side!

In both the machinery and haulage tunnels the faults with shale smear have the same attitude. They appear to be the same fault, but this needs to be established unambiguously. Is it possible that the shale layers in both tunnels are the same one?

Conclusions

The view from Mt. Diablo provides a good reference frame for the rocks and structures in the Black Diamond Mine Regional Park. One represents a remarkably focused uplift and contraction, and the other displays mostly extensional structures. I would like to suggest that both of these behaviors are consistent with the major right lateral strike-slip faults and their configuration in the region.

We have seen a number of interesting features with a focus on joints, sheared joints, deformation band faults, and shale smearing in the Hazel-Atlas workings. Judging from chemical reaction haloes and their distribution, joints, sheared joints, and deformation band faults have a strong influence on fluid flow.

Joints occur in clusters both perpendicular and parallel to the structural grain. Many of them are sheared to become sheared joints with both brownish opaque infilling material, apparently precipitated within the fractures, and fine-grained sandstone incorporated into the fault rock by friction and wear.

We have seen some excellent examples of shale smear incorporating shale into the fault rock. However, ambiguities still exist due to limited exposures and inadequate understanding of the process of incorporating shale into fault zones. Towards this end, I would like to name the fault with shale smear as the Hazel-Atlas Fault and suggest that its understanding will never be complete without knowing the process responsible for the faulting in the presence of shale layers.

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