# Using three dimensional mapping to understand bedrock controls on the morphology of El Capitan, Yosemite National Park, California

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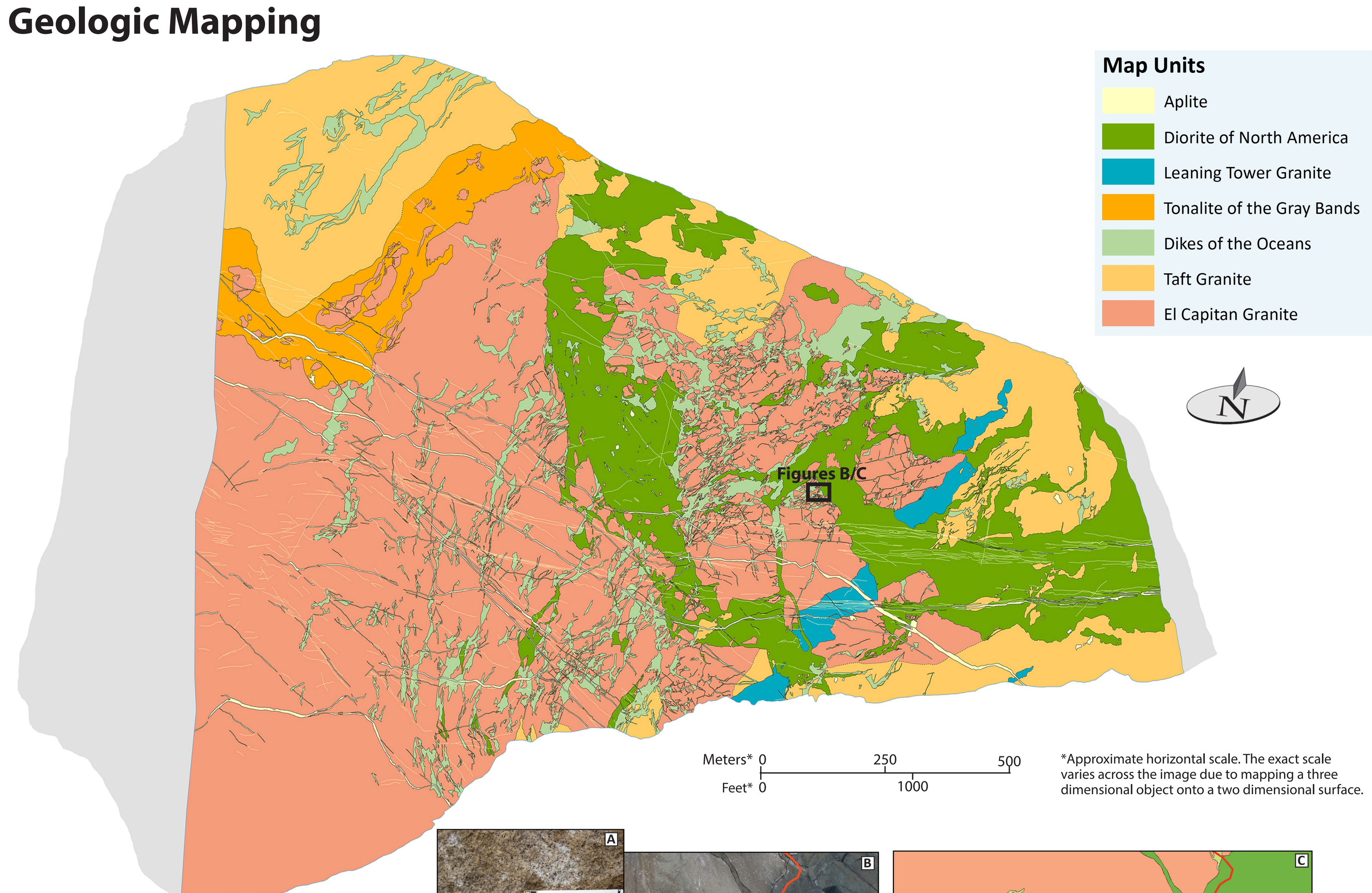
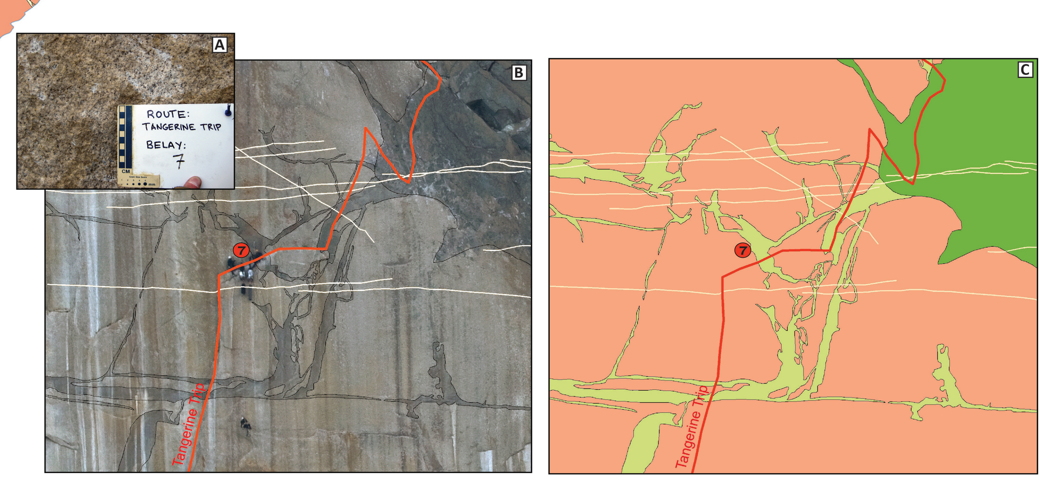
## Abstract

**El Capitan in Yosemite Valley, California is a 1 km-tall x 1.5 km-long cliff that displays the interior of the Sierra Nevada Batholith. This near-perfect exposure provides an excellent opportunity to study the emplacement and subsequent weathering of granitic rocks. Detailed mapping of the spatial extents of the different rocks used to be hindered by the challenge of performing field mapping on a 3,000 foot-tall cliff. However, recent advances in high-resolution photography and terrestrial LiDAR scanning technology allowed us to make the first comprehensive geologic map of El Capitan at decimeter scale. The timing and emplacement dynamics of the 7 rock types exposed on the face were evaluated using this unique, vertical geologic map.**

**Three dimensional mapping and remote sensing allowed us to test hypotheses about bedrock controls on the shape of El Capitan. Terrestrial LiDAR scans of El Capitan were color coded by slope-aspect in Coltop3D software by Terranum. Slope-aspect data, coupled with detailed understanding of the bedrock geology, allowed us to assess the fracture characteristics of the dominant rock types on El Capitan. Mafic rocks (e.g. the diorite of North America and the tonalite of the Gray Bands) have greater fracture density and tend to form smaller fractures than felsic rocks (e.g. the El Capitan and Taft Granites.) Since weaker rocks cannot accumulate large amounts of stress, they will often fracture easily; suggesting that the mafic rocks of El Capitan have lower rock-mass strength than their more silicic counterparts. Furthermore, the mafic rocks on El Capitan are often positioned at localized slope breaks. These results suggest that the distribution of granitic rock types on El Capitan may have a first-order control on its shape. This raises the possibility that subtle differences in the composition of granitic rocks affect their weathering characteristics and contribute to the geomorphic evolution of granitic landscapes.**

## Geologic Mapping



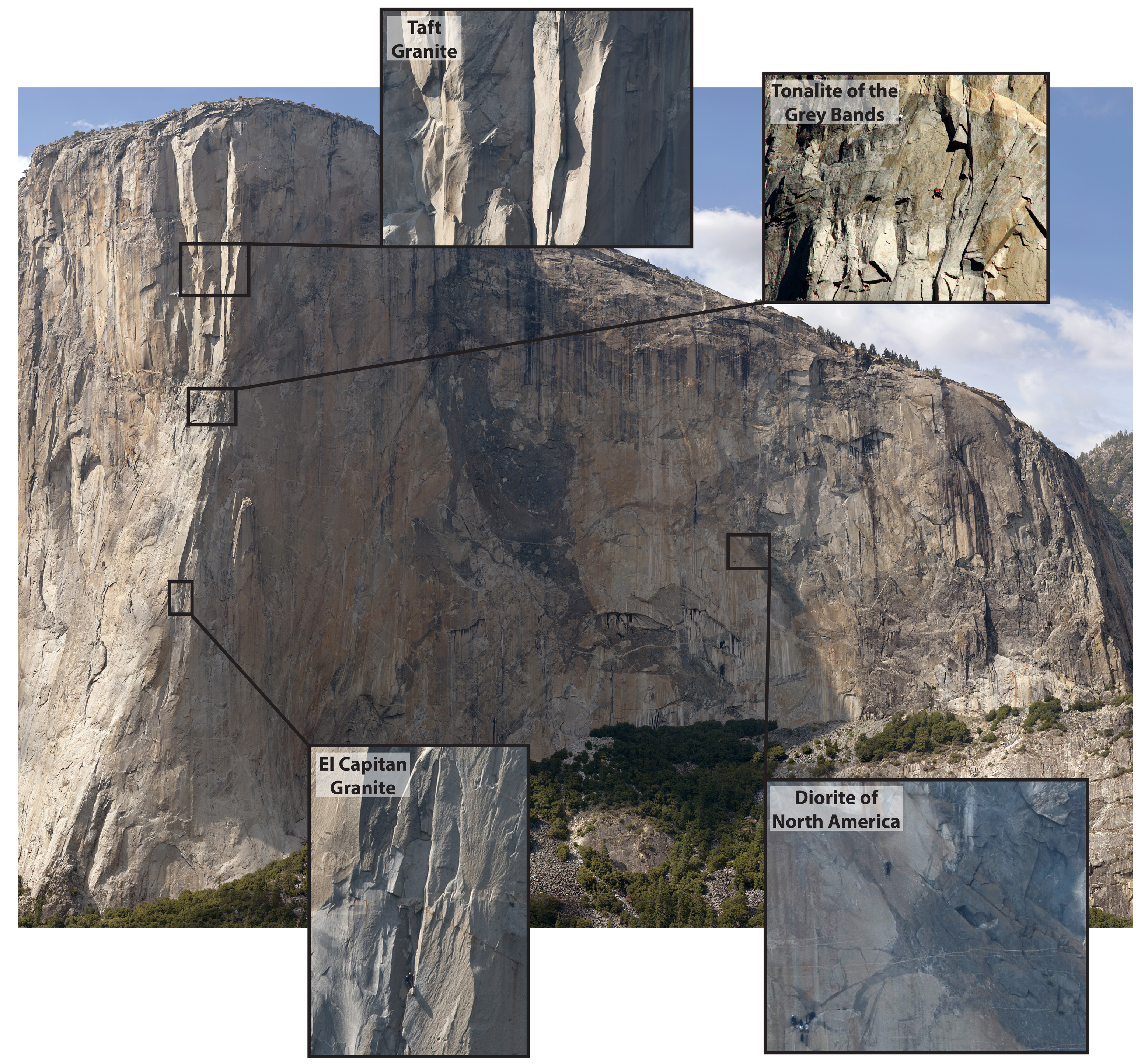

We used geologic mapping of El Capitan accomplished by Putnam et al. (2014) that built upon mapping by Calkins (1985) and Peck (2002). The map was initially drafted using ESRI ArcGis software in which contact lines of different units were manually digitized over a gigapixel image of the southeast face (www.xrez.com). Contact lines were identified by examining LiDAR point cloud and intensity data, single high-resolution photographs of selected areas, and the gigapixel images. These contact lines form polygons that were assigned rock types using scale photographs taken by climbers who passed through those areas of the cliff. Mapping was ground-truthed by climbing and rappelling.

## Petrology of Major Rock Types

| | El Capitan Granite | Taft Granite | Tonalite of the Grey Bands | Diorite of North America |
|---|---|---|---|---|
| **Texture** | Commonly porphyritic, containing phenocrysts of potassium feldspar <2 cm in length. Biotite typically comprises 10 vol% and locally defines a weak magmatic foliation. | Finer-grained and more equigranular than the El Capitan Granite. Biotite averages about 3 vol% and is the only mafic constituent. | Fine-grained, biotite-rich, hornblende-poor tonalite. Biotite defines a strong magmatic fabric. | Medium-grained biotite-hornblende gabbro and diorite. Heterogeneous texture and composition. |
| **$SiO_2$ (wt%)** | 73.78 | 75.3 | 66.08 | 53.1 |
| **$Fe_2O_3^{T*}$ (wt%)** | 2.04 | 1.47 | 4.51 | 9.95 |

Data drawn from Putnam et al. (2014), Putnam et al. (In review), Nelson et al. (2012) and Ratajeski et al. (2001). Major elements compositions express total Fe as Fe2O3 and have been normalized 100 wt% anhydrous.

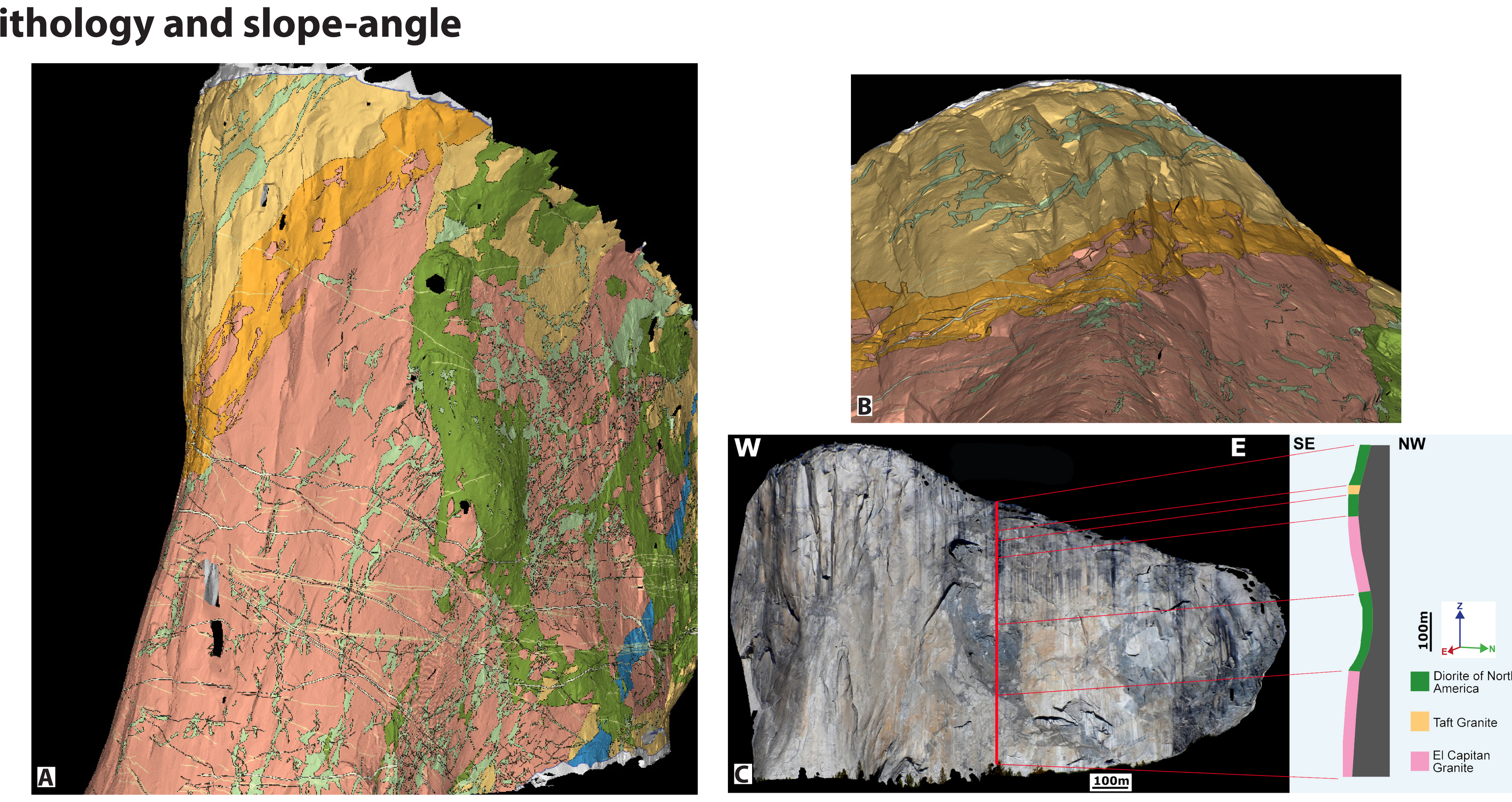
## Macroscopic Rock Characteristics




Gigapixel photography, high-resolution photography, and field work suggests different rock types on El Capitan have different weathering characteristics.

- El Capitan Granite: Fractures are rare. When present, they form long, linear, steep crack systems
- Taft Granite: Fractures are rare, but more abundant than the El Capitan Granite. Fractures form corners. Often forms large "shields" (overhanging featureless bulges).
- Tonalite of the Grey Bands: Fractures more common. Forms flakes and short cracks.
- Diorite of North America: Fractures are very abundant. Apparently random in orientation.

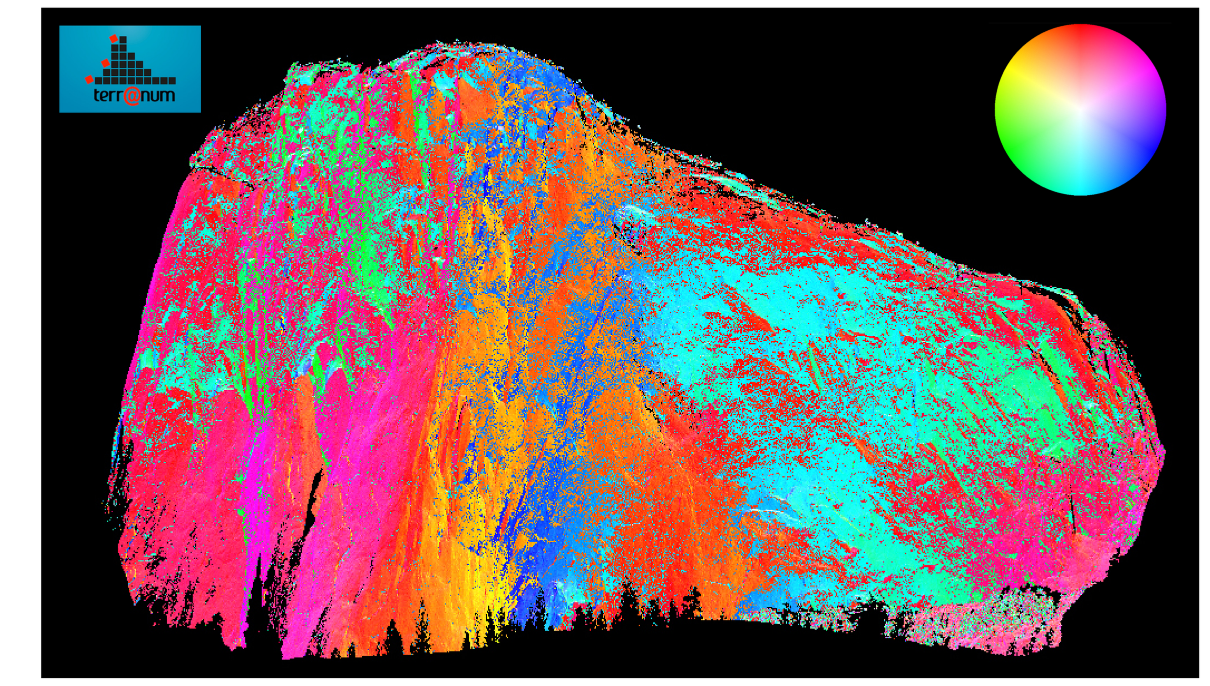
## Lithology and slope-angle




Using Reshaper 3D[tm], the geologic map was overlain over terrestrial lidar scans of El Capitan. This gave a general picture of the slope in areas occupied by different rock types. Several correlations are evident:

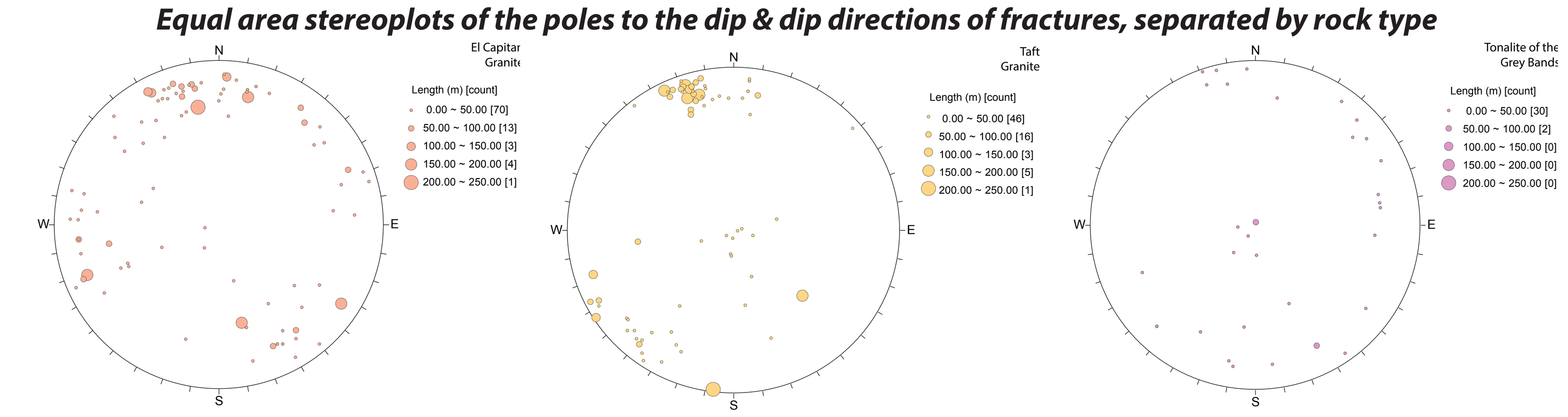
- The tonalite of the Grey Bands forms a significant slope break 600 m up the prow between the southeast and southwest faces (Figure A).
- The Taft Granite indeed appears to form more steep corners than the other rock types (Figure B)
- The Diorite of North America appears to preferentially weather out of the surrounding granites, creating hollows and overhangs. The southeast face, where the mafic rocks are concentrated, locally overhangs up to ~35 m with a typical slope of ~87˚ compared with the southwest face, which has a typical slope of ~80˚ (Figures A, C)

## Lithologic Controls on Fracture Frequency

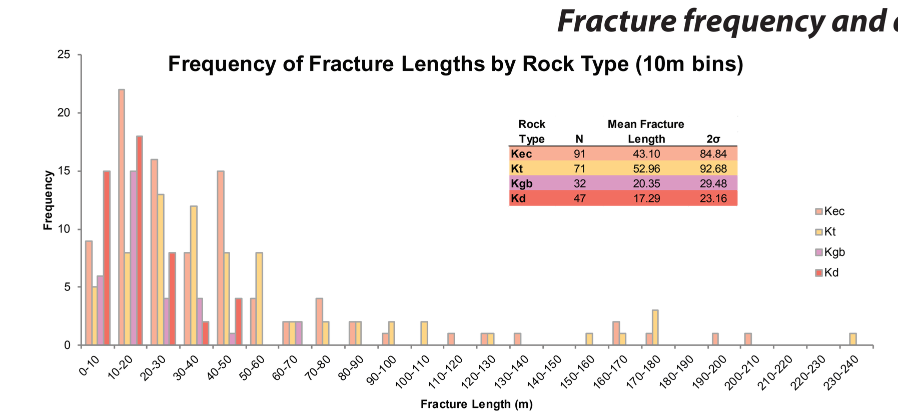



The TLS point cloud of El Capitan was colored by the extrapolated slope angle of each point using Coltop 3D by Terranum[tm]. Coltop 3D calculates the slope angle of each point by interpolating a surface created by each point and the nearest 9 points. Each point is colored according to the dip and dip direction on the colored equal-area stereoplot shown above. By looking for areas of stark color contrast, we could evaluate the orientation of fractures. Fracture lengths were measured in Reshaper 3D[TM]. Surface area occupied by each rock type was estimated by using Adobe Photoshop[tm] to count the number of pixels of each rock type on a JPEG of the geologic map.

***Equal area stereoplots of the poles to the dip & dip directions of fractures, separated by rock type***




***Fracture frequency and density data***




| Rock Type | Pixels | % of area evaluated | Fracture count | Fractures/ % area |
|---|---|---|---|---|
| El Capitan Granite | 21069133 | 53.0 | 91 | 1.7 |
| Taft Granite | 10939780 | 27.5 | 71 | 2.6 |
| Tonalite of the Grey Bands | 2673362 | 6.7 | 32 | 4.8 |
| Diorite of North America | 5080117 | 12.8 | 47 | 3.7 |

- The El Capitan Granite has the lowest fracture density. Its fractures are steeply dipping and long compared with the more mafic units.
- The Taft Granite forms long, steeply dipping corners. It has greater fracture density than the El Capitan Granite, but lower than the mafic units.
- The tonalite of the Grey Bands' fractures are more disorganized and shorter than the felsic units. It also has the greatest fracture density.
- The diorite of North America's fractures are the smallest. It also has a higher fracture density than the felsic units.

## Discussion

- Mafic dikes have a greater abundance of weaker minerals, particularly biotite, and finer grain size, resulting in a lower rock-mass strength than the host granites. Fracturing is more intense in the diorite of North America than in the surrounding granite, resulting in smaller joints of high density. The tonalite of the Grey Bands is not only more mafic than the host granites, but it also has a well-developed magmatic fabric. These factors contribute to both mafic units being more easy to weather. Preferential weathering of weaker rocks can provide surfaces from which joints can propagate, creating topographic features such as overhangs and slope breaks (Schmidt and Montgomery, 1995; Korup, 2008).
- The more felsic units form much longer fractures than the mafic units. This is likely because they are composed of harder minerals, giving them greater rock-mass strength and allowing them to accumulate larger amounts of stress before failure (eg. Eberhardt et al., 1998).
- The Taft Granite is the most silicic of the units studied. It has long fractures, yet has a greater fracture density than the El Capitan Granite. This is perhaps because of its smaller grain size and smaller grains often provide more weaknesses from which microcracks can form and initiate joints (Ehlen and Zen, 1986). The high amount of corners is likely related to the cooling history of the pluton as there is no foliation or other petrographic reason to explain this property.
- **Our data suggest that rock types have a significant control on the morphology of El Capitan. Perhaps subtle differences in petrology have a greater control on the weathering of granitic landscapes than previously assumed.**
- Kinematic tests of these rock types is ongoing at the University of Lausanne.

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