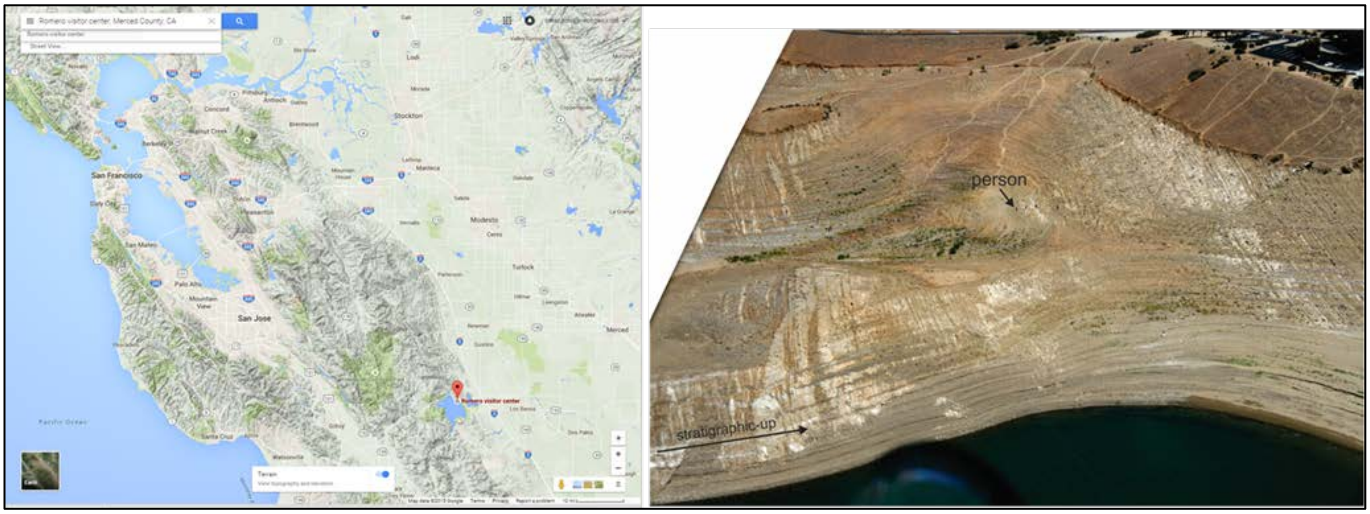

Field Trip: Anatomy and provenance of a deep-water boulder conglomeratic submarine canyon in the Upper Cretaceous Panoche Formation (Cenomanian), Great Valley Group, San Luis Reservoir, central California

Leader: Todd J. Greene, CSU-Chico

October 24, 2015

Field Trip for the Northern California Geological Society

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Abstract

The Great Valley Group (GVG) of western California contains forearc deposits (mostly deep marine) tectonically linked to Andean-style subduction of the Mesozoic-early Cenozoic Sierran continental arc and the Franciscan subduction complex. The San Luis Reservoir in the southern Diablo Range of Merced County

Acknowledgements & Disclaimer

Results from this project are still preliminary and have not yet been published at the time of this writing. Therefore, the data, interpretations, and ideas presented in this field guide should not be referenced in any journal article. My intention is to present background geologic information on the Diablo Range, as well as stratigraphic data on the Panoche Formation around San Luis Reservoir. Detailed interpretations of the data were purposefully left out to facilitate lively discussions on the outcrop.

I would like to thank the Chico St. Research Foundation for partially funding this work, as well as field assistants Michelle Melosh and Russell Shapiro. Kathy Surpless provided context for the geochemical interpretations and financial support for the detrital zircon analyses (both of which are not discussed in this field guide).

covers a profound faulted contact (Ortigalita Fault) between the Franciscan rocks to the west and the GVG rocks to the east. Low water levels in the reservoir have exposed a deep-water boulder conglomerate succession approximately 2.5 km thick along a 4 km transect within the Upper Cretaceous (Cenomanian) Panoche Formation of the GVG. We will visit many individual boulder conglomeratic units representing the thickest (up to 180 meters thick) and coarsest (up to 3.5 meter clasts) deposits ever recorded in the GVG. Fully characterizing these extraordinary deposits and placing them in a paleogeographic context adds to a steadily evolving history for the GVG in the San Joaquin basin.

Published geologic maps indicate Panoche-aged conglomerate may extend approximately 18 km along strike to the northwest, roughly parallel to northwest-to-southeast directed paleocurrent measurements recorded on imbricated clasts. Therefore, although no canyon wall exposures were observed, I interpret the entire section to represent a depositional dip-parallel submarine canyon exposure based on the style of deposition, thickness, continuity of deposits, and proportion of oversized boulder clasts.

Combined provenance data from conglomerate clasts, sandstone petrography, zircon geochronology, and mudstone geochemistry suggest sources at two difference scales. The oversized conglomerate clasts indicate a local ophiolitic source from nearby headlands. However, the dominant background source for the canyon is Sierran when compared to a more regional database. In addition, although Panoche-aged data generally overlap with San Joaquin basin GVG samples, our results fill a data gap that records a transition from Lower Cretaceous mafic trace element signatures to Upper Cretaceous felsic signatures.

Geology of the Diablo Range

The southern Diablo Range outcrops contain excellent examples of Late Cretaceous convergent margin tectonic elements as well as its later modification by transform tectonics (Figs. 1, 2, 3). This trip will visit outcrops that highlight the forearc deep-water clastics of the Great Valley Group at San Luis Reservoir,

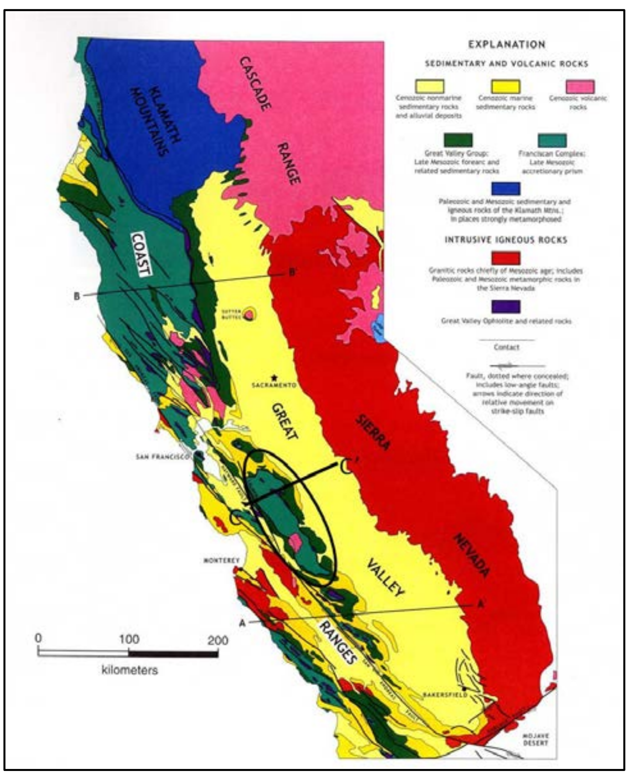


Figure 1. General geologic map of northern California (from Lowe, 2004). Circled area is the Diablo Range. See Fig. 4 for C-C' cross-section.

Late Cretaceous tectonics in central California consisted of east-dipping, west-facing subduction of the oceanic Farallon Plate beneath the active continental volcanic arc of the Sierra Nevada (Fig. 3). A simple east-to-west transect along the latitude of Pacheco Pass exposes all of the key elements of this convergent margin (Fig. 4): Sierran granites and metamorphic terranes of the continental arc, the thick sedimentary fill of the fore-arc basin deposits of the Great Valley Group, and the highly tectonized accretionary prism of the Franciscan Complex. The system persisted from at least Late Jurassic time (160-155 Ma) and probably consumed up to 10,000 km of oceanic crust (Ernst, 1984). Fast convergence of the Farallon Plate (10-15 cm/yr) persisted up until about 30-28 Ma when the collision of the East Pacific Rise with the trench system occurred in southernmost California (Atwater, 1970). Subduction progressively shut off as the Mendocino Triple Junction migrated northward arriving at Pacheco Pass between 15-5 Ma (Atwater, 1989) leaving a trail of right-lateral transform faults in its southern wake.

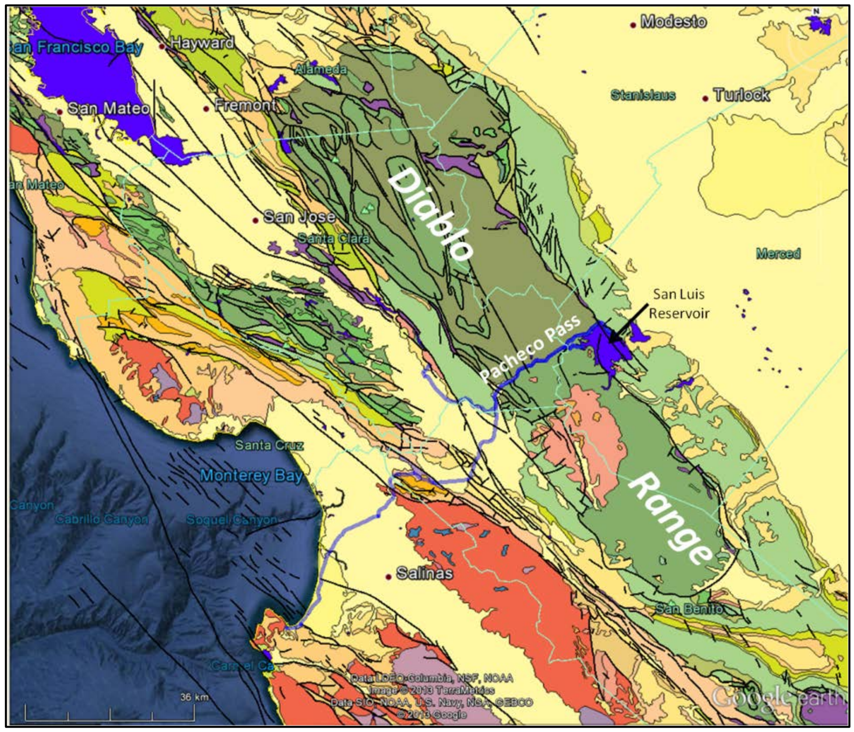


Figure 3. Geologic map surrounding the Diablo Range.

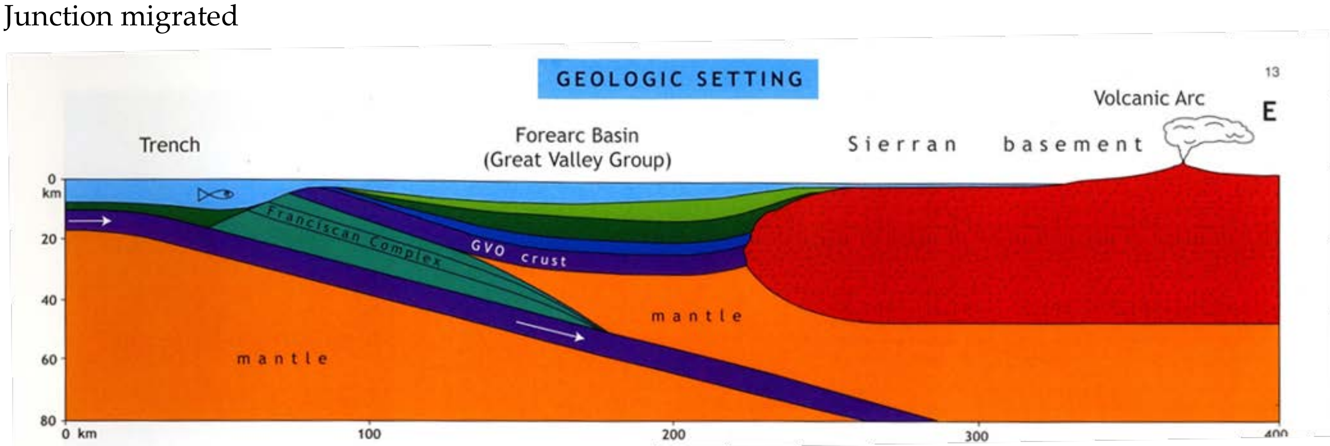


Figure 2. Simplfied Late Cretaceous cross-section across central California (from Lowe, 2004).

The Diablo Range is a general antiform with Great Valley Group (GVG) rocks flanking the Franciscan core along vertical faults (Figs. 2, 4). The two rock types' profound differences in metamorphic grade indicate at least 20 km of vertical offset along these fault zones (Ingersoll et al., 1999). Other significant features of the range include oceanic crustal fragments of the Coast Range Ophiolite (purple in Figure

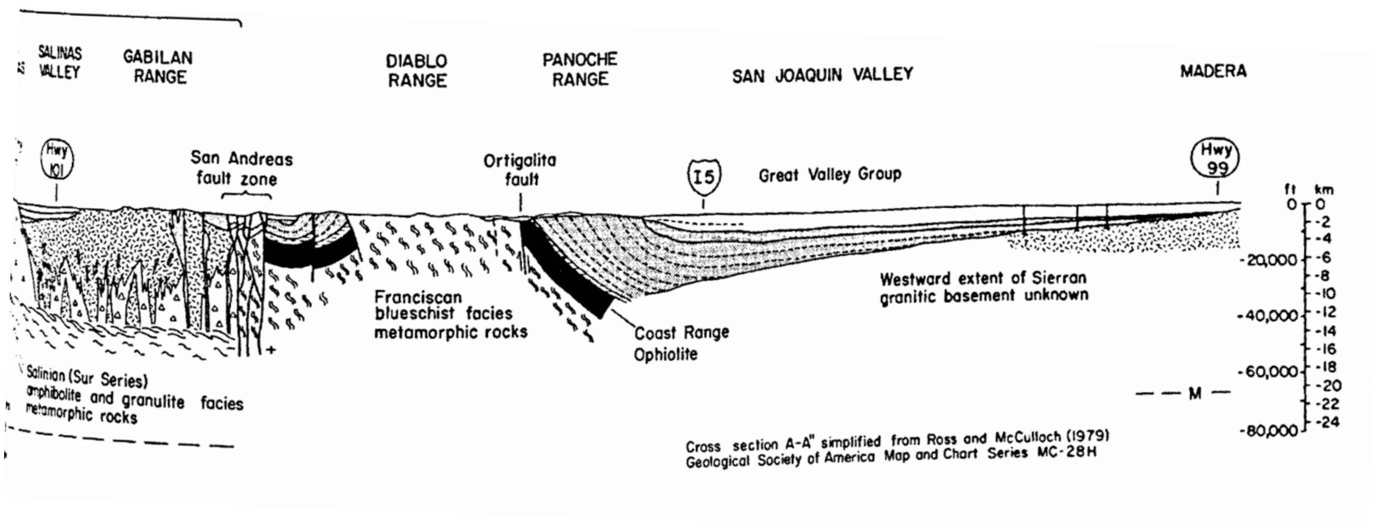


Figure 4. C-C′ east-west cross-section across central California showing Ortigalita Fault dividing Franciscan from the GVG (from Ingersoll et al., 1999). See Fig. 1 for approximate location.

2) and the more recent 11-9 Ma Quien Sabe Volcanics (salmon color in Figure 2). The Diablo Range has probably been a positive feature since at least Eocene time (Nilsen and Clarke, 1975). Uplift is still prevalent evidenced by high topography, rapid erosion, abundant coarse Franciscan debris, and consistent seismicity (Ingersoll et al., 1999).

The Pacheco Pass area juxtaposes two world-class examples of the convergent margin history: 1) the thickest examples of the coarsest deep-water fill of the GVG, and 2) jadeite-bearing meta-greywackes. Prior to transform tectonics, deposition of deep-water deposits in the accretionary complex led to fast and deep burial of Franciscan greywackes down to significant depths (20-30 km) leading to blueschist grade metamorphism, and then they were exhumed to later expose the best exposed and studied jadeitized meta-greywackes in North America, if not the world.

Panoche Formation near San Luis Reservoir

San Luis Reservoir is a major water storage facility built in 1967 designed to hold nearly 2,000,000 acre-feet of water as part of the California State Water Project and Central Valley Project. Its water is solely fed by water pumped uphill from the California Aqueduct and the Delta-Mendota Canal and then released back to aqueducts dictated by irrigation needs. The Romero Visitor Center beautifully documents the reservoir's history and its role in California's water delivery system.

The reservoir covers a faulted contact (Ortigalita Fault) between the Franciscan rocks to the west and the GVG rocks to the east (Figs. 5, 6). The best pre-reservoir geologic map of the area derives from Schilling's (1962) unpublished dissertation. Schilling documented up to 1.2 km thick of conglomerate in the Panoche Formation (Cenomanian) of the Upper Cretaceous GVG across 22 km of GVG strike ridges

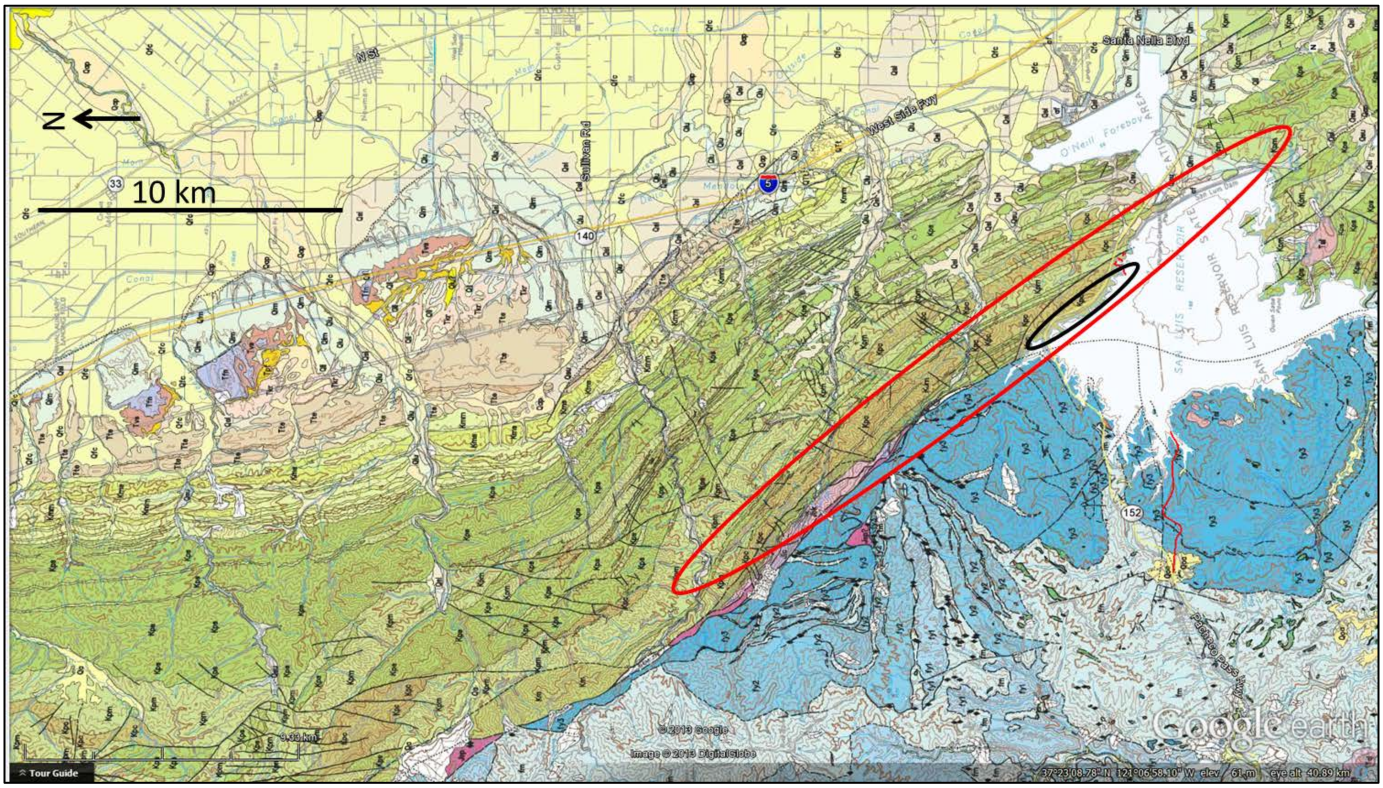


Figure 5. Geologic Map of the San Luis Reservoir. The olive colored Cretaceous (Kpc) is the conglomeratic portion of the Panoche Formation (Wentworth et al., 1999). The red oval marks Dibblee's (2007a,b,c) and Schilling's (1962) distribution of lower Panoche Fm. conglomeratic deposits. The black oval marks the outcrop visited during this field trip.

(Fig. 7). Mapping by Dibblee (Figs. 5, 8) also documented extensive Panoche-aged conglomerate along the ridges to the north of San Luis Reservoir (Dibblee, 2007a,b,c). Detailed unpublished maps by Vic Cherven (personal communication) documented 5 fan sequences to the north of San Luis Reservoir; his lowest fan, called the Crevison Peak Fan, is equivalent to the exposures that we visit during this trip.

Based on numerous publications of GVG deep-water outcrops and the summary publication by Lowe (2004) on GVG deep-water depositional systems, the section at San Luis Reservoir represents the thickest exposure of GVG coarse (cobble to boulder) deep-water deposits documented. Since 1962, however, very little, if any work has been conducted on the San Luis Reservoir outcrop.

For this study, 24 stratigraphic sections were measured along the shores of the San Luis Reservoir spanning approximately 4 km wide by 2.5 km thick (Figs. 9, 10, 11). Based on these detailed sections, 10 lithofacies and 6 facies associations were recognized. These are not defined in this guidebook, but they will be discussed during the trip on the outcrop. Facies associations mapped with sub-meter GPS for each outcrop exposure showcase the gross-scale architecture of the submarine canyon deposits along the reservoir (Figs. 9, 10). In addition, paleocurrent imbrication measurements at two localities and conglomerate clast counts at five localities were also collected.

In general, the GVG outcrops exposed along San Luis Reservoir showcase boulder-conglomeratic intervals that sharply fine at their tops separated by thinner sections of sandstone and thin-bedded turbidites (Fig. 11). Each conglomeratic interval contains both clast-supported and matrix-supported conglomerate with a medium-grained sandy matrix. The conglomeratic intervals are commonly interspersed with lenticular 0.5-1.0 meter thick medium-grained, massive and planar-bedded sandstone beds which consist of up to 30% of the conglomeratic units. Conglomerate clasts are commonly greater than 30cm in diameter (boulder), rounded, and are composed

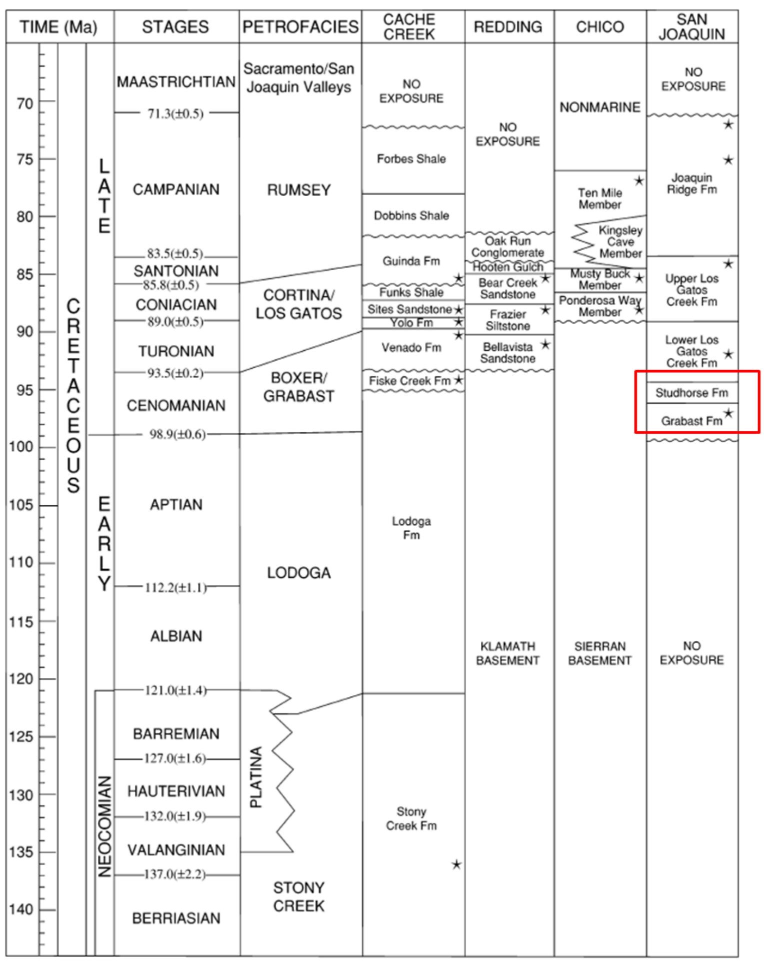


Figure 6. Stratigraphic chart of GVG formations in the Sacramento and San Joaquin basins (DeGraaff-Surpless et al., 2002) . This trip overs Cenomanian deposits equivalent to the Grabast Petrofacies of Ingersoll (1983).

of Sierran-type sources, as well as upper-plate island-arc sources such as quartz keratophyre, hornblende gabbro, and silicified pebble volcaniclastics. Imbricated clasts indicate S-SE paleocurrent directions.

Depositional environments are interpreted to be similar to those reported for the Juniper Ridge Conglomerate to the south near Coalinga (Lowe, 2004). Namely, the section represents large incised conglomerate-filled channels that could either lie within a proximal fan position or within a submarine canyon. The outcrop belt strikes parallel to depositional dip and therefore cannot be used to determine facies changes along depositional strike.

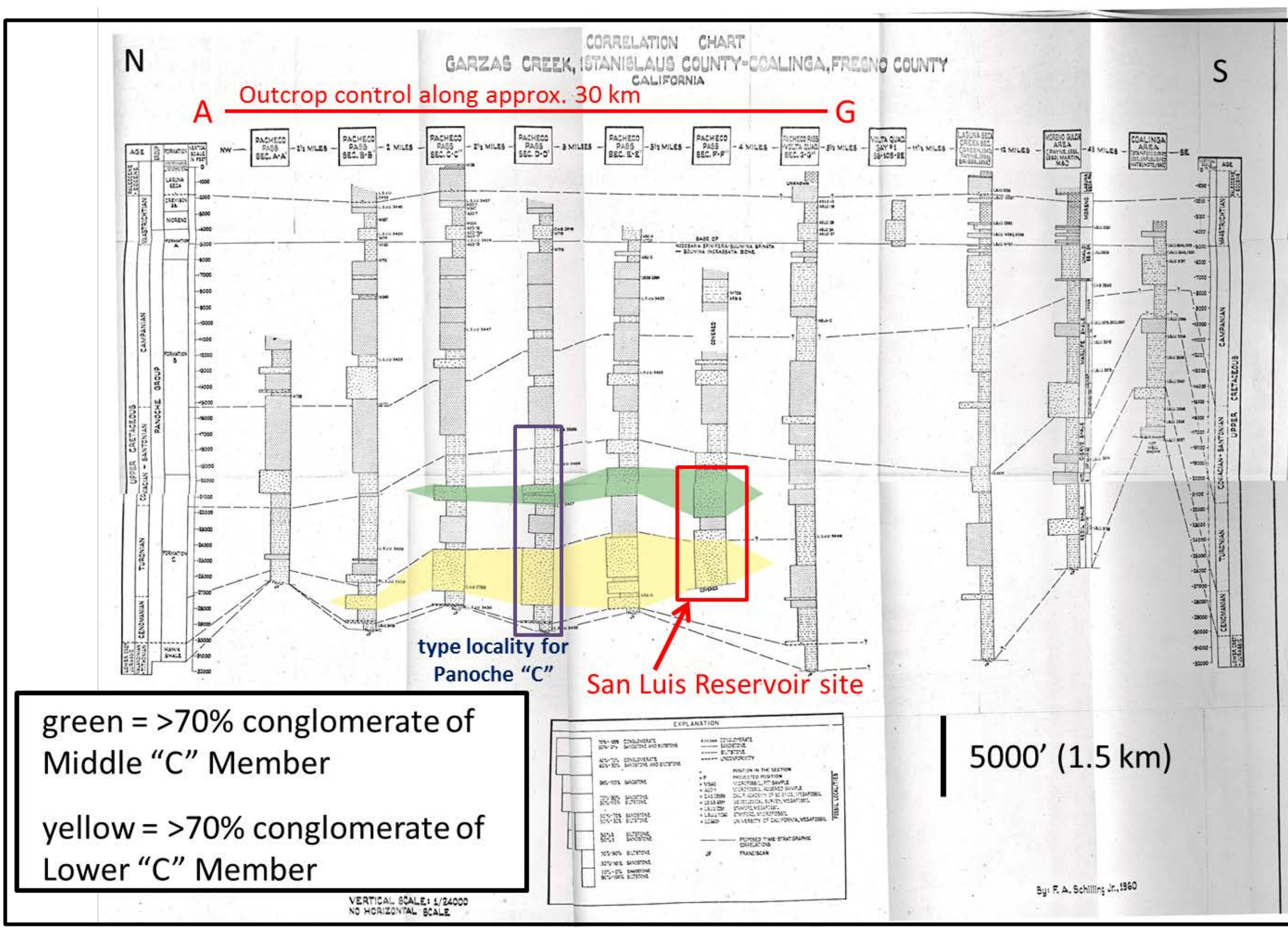


Figure 7. Stratigraphic chart from Schilling (1962) showing lateral distribution of conglomerate equivalent to the outcrops visited during this trip. See red oval in Fig. 5 for location of stratigraphic panel.

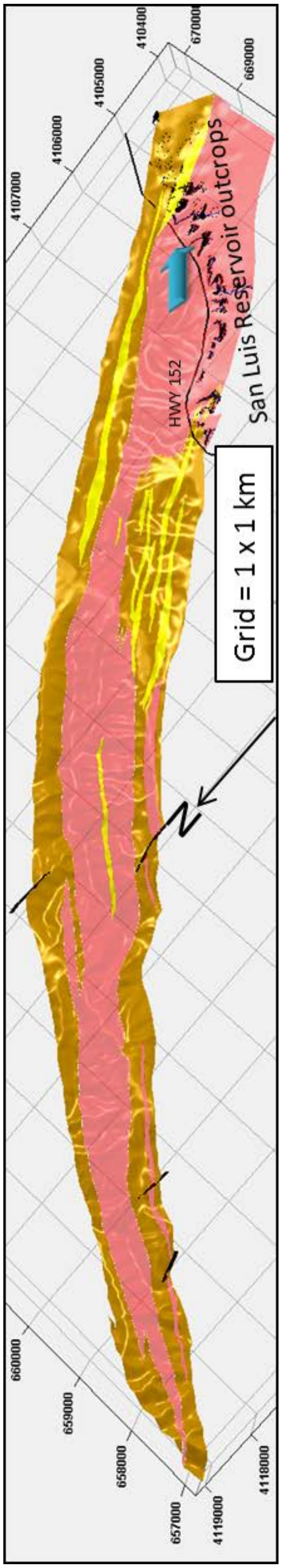


Figure 8. Lateral distribution of conglomeratic, sandy, and muddy lithofacies equivalent to the outcrops visited during this trip and the Crevison Peak Fan of V. Cherven (personal communication). General lithologies are from Dibblee (2007 a,b,c): red = conglomerate, yellow = sandstone, brown = mudstone. Paleocurrent arrow (blue) indicates NW-to-SE directed flow measured from imbricated clasts. Note how conglomeratic deposits (red) thicken and thin from north to south as the canyon meandered "in-and-out" of the outcrop

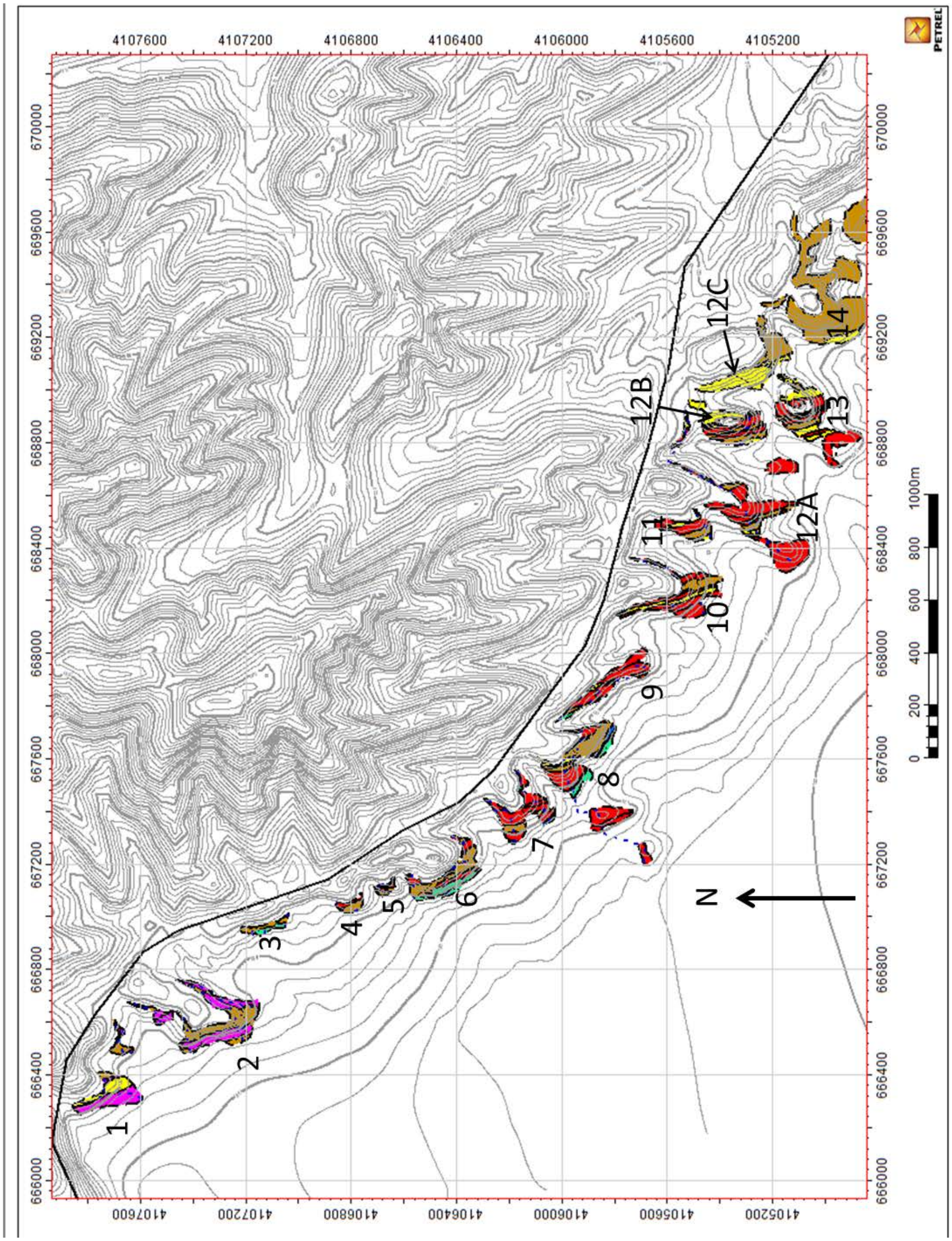


Figure 9. Topographic map (contour interval = 5m) and outcrop distribution of deposits surrounding San Luis Reservoir visited during this trip (sections are labeled 1-18). Colors refer to facies associations discussed during the field trip.

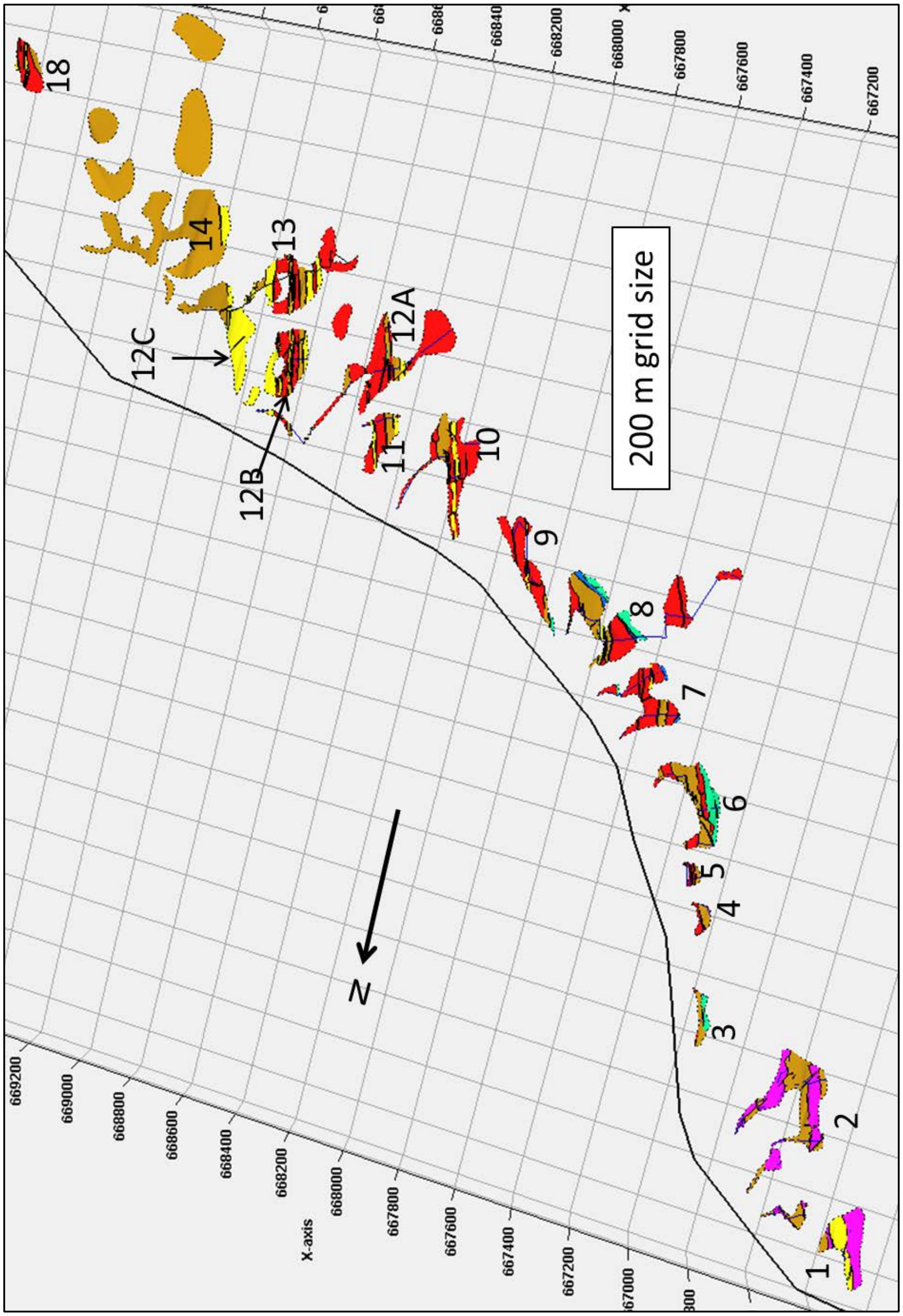


Figure 10. Outcrop distribution of facies associations surrounding San Luis Reservoir. Colors refer to facies associations discussed during the field trip.

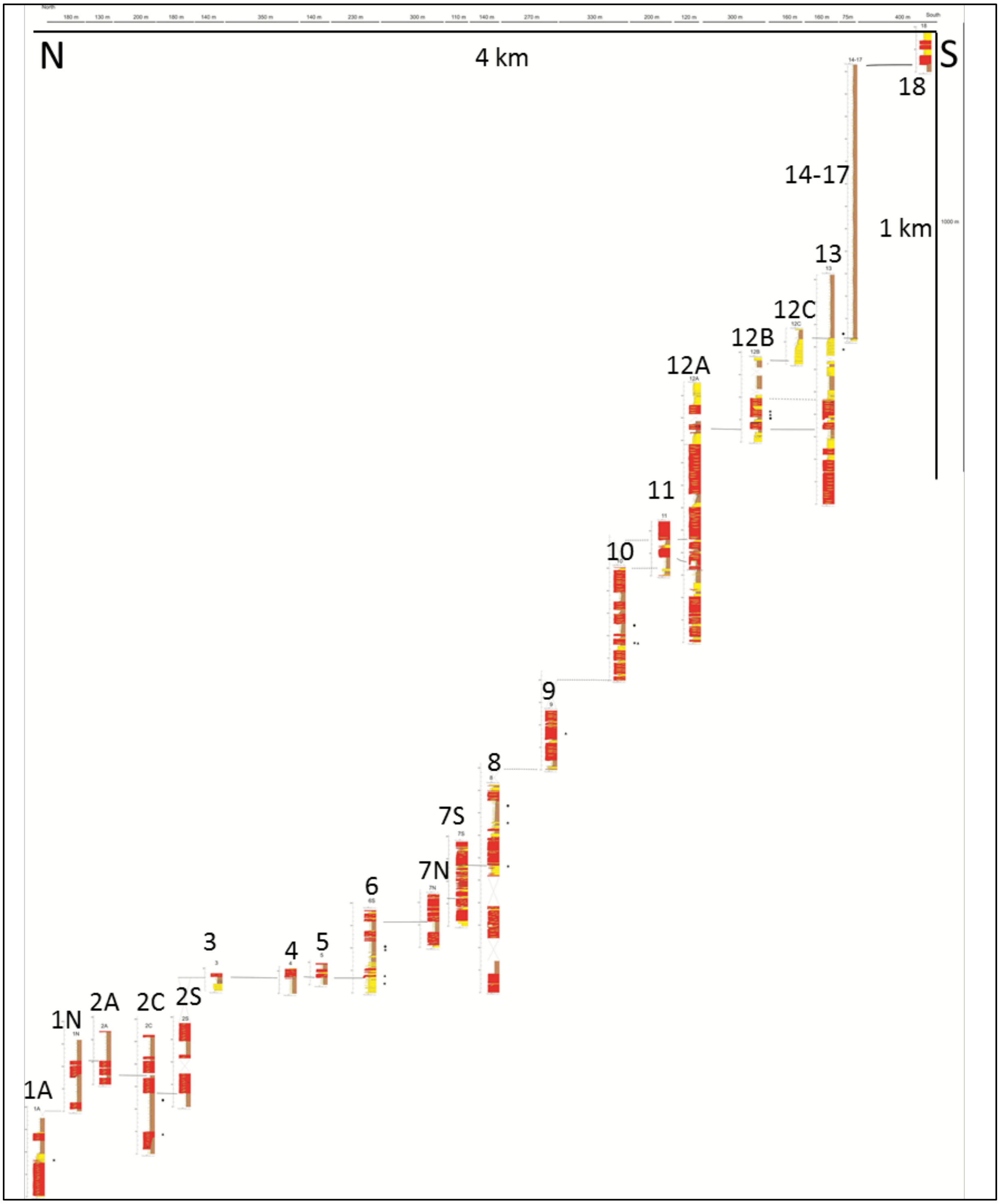


Figure 11. Complete stratigraphic panel of deposits surrounding the San Luis Reservoir. Colors indicate gross lithologies: red = conglomerate, yellow = sandstone, brown = mudstone. Section numbers are referred to in the text and during the trip.

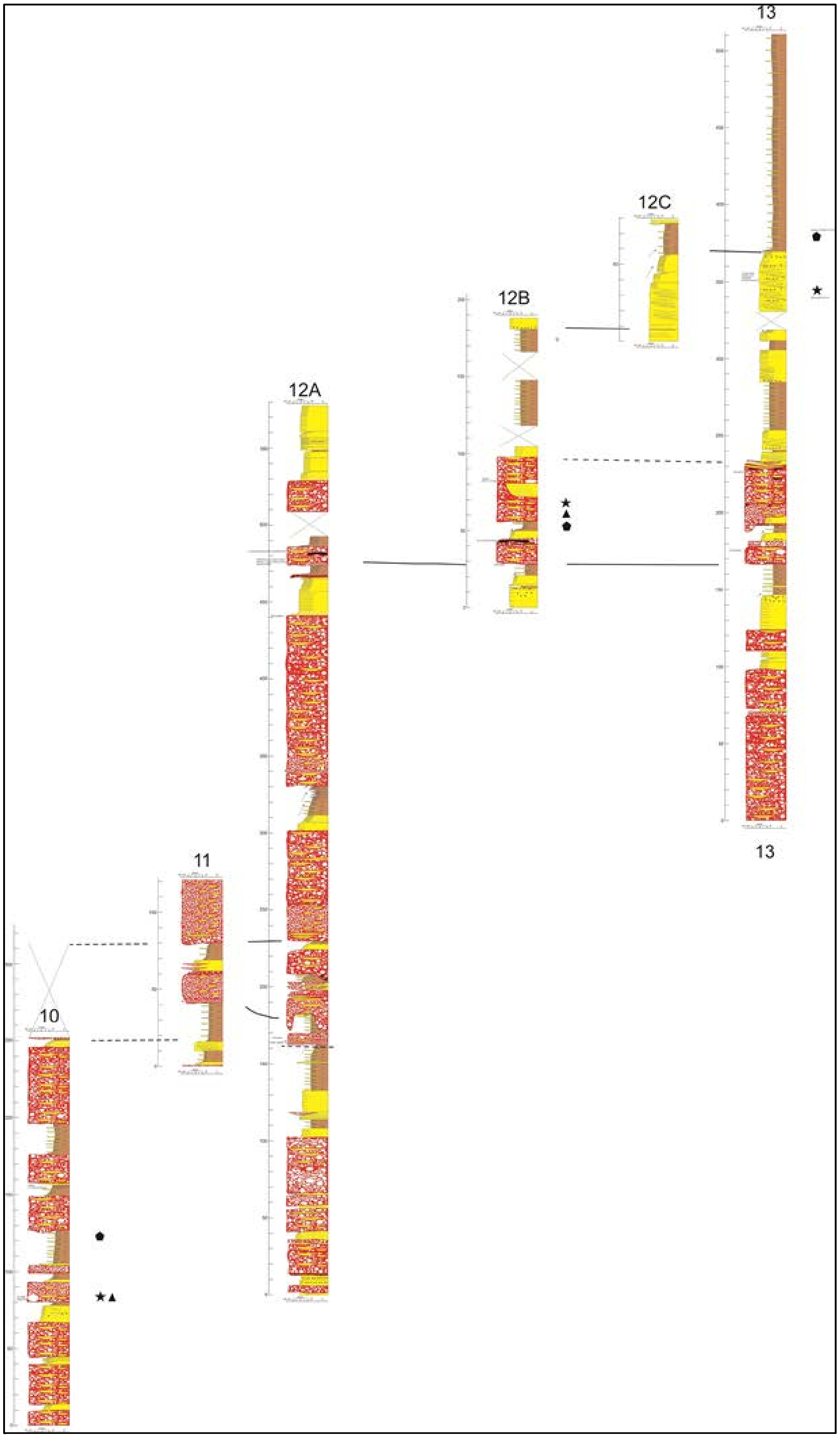


Figure 12. Stratigraphic correlation panel for sections 10-13 (thickness in meters). Colors refer to dominant lithology: red = conglomerate, yellow = sandstone, brown = mudstone.

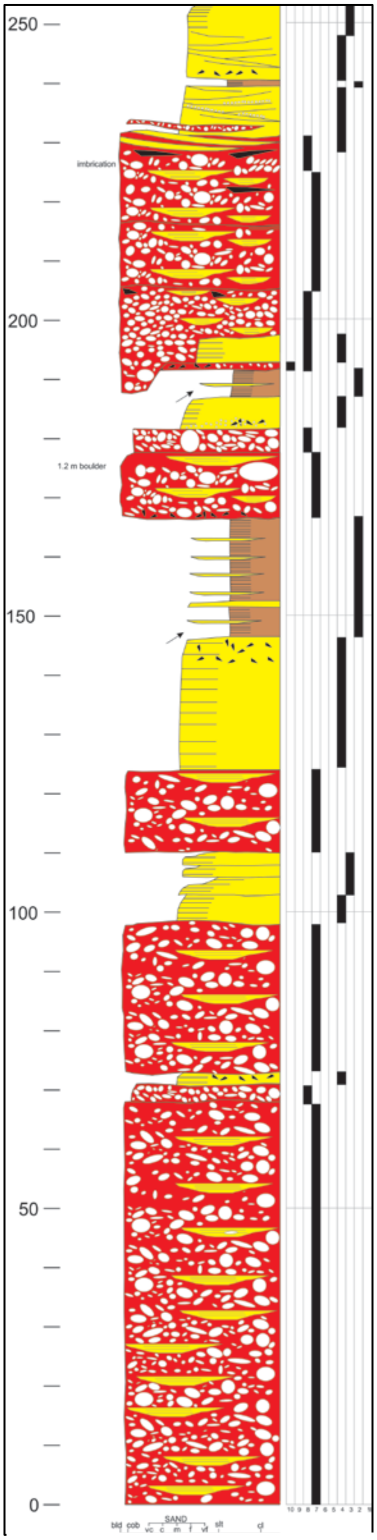


Figure 13. Portion of stratigraphic Section 13 (thickness in meters). Lithofacies 1-10 are marked on the right.

Stop 1

The first outcrops to be visited are exposures nearest to the Romero Visitor Center. The deposits represent the youngest coarse-grained sequence in what Vic Cherven calls the Crevison Peak Fan (Fig. 8). It is possible to see most of the lithofacies within these outcrops. Section 12A, 12B, 12C, and 13 (Fig. 12) represent the longest, continuous exposures in the field area. There are numerous small faults that have m-scale offset. Correlations between sections are relatively straightforward due to their similar lithostratigraphic features.

Figure 14. Photo of channel-fills near the 230 m mark on Section 13. Arrow indicates scale and stratigraphic-up direction.

Section 13 (Figs. 13, 14, 15) contains good examples of erosive channels, outsized boulders, varying degrees of clast-support and matrix-supported conglomerate, and sand lenses within the conglomerate. Section 12B contains excellent examples of clast imbrication, with the mean direction pointing 121° (SE). In addition, clast counts in Section 12B can be viewed in Figure 16. Clasts indicate a mixed source, including silicified pebble volcaniclastics, mafic volcanics, and felsic plutonics.

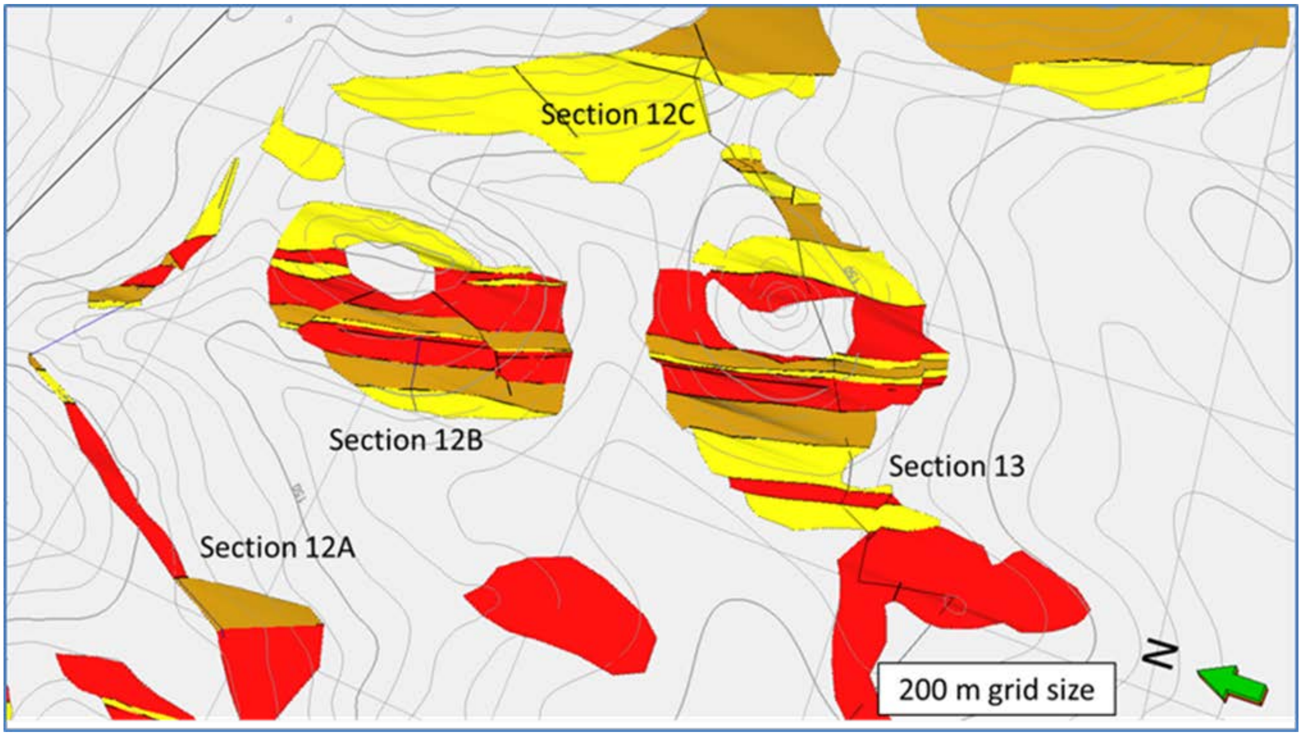


Figure 15. Perspective view of facies associations map for sections 12A, 12B, 12C, and 13. Facies associations colors will be discussed during the field trip. Contour interval is 5 m.

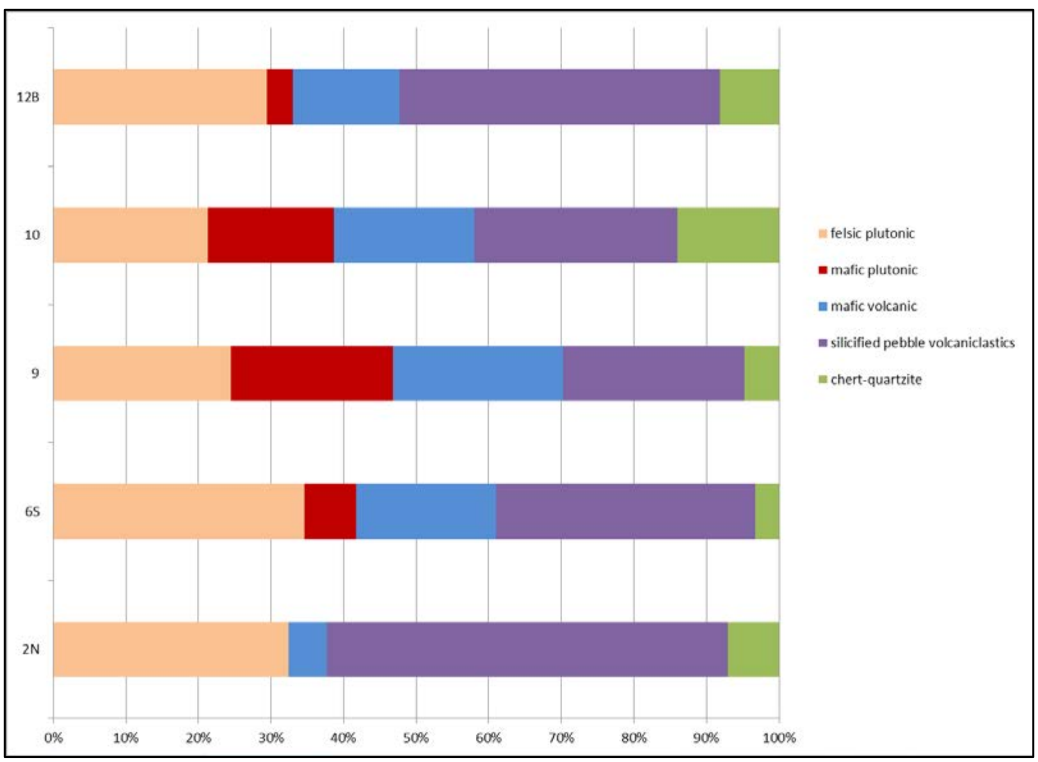


Figure 16. Conglomerate clast count data from 5 sections located throughout the field study. Section numbers are listed to the left of the bar chart. Note the gross similarity in counts with the possible exception to Section 2N.

Stop 2

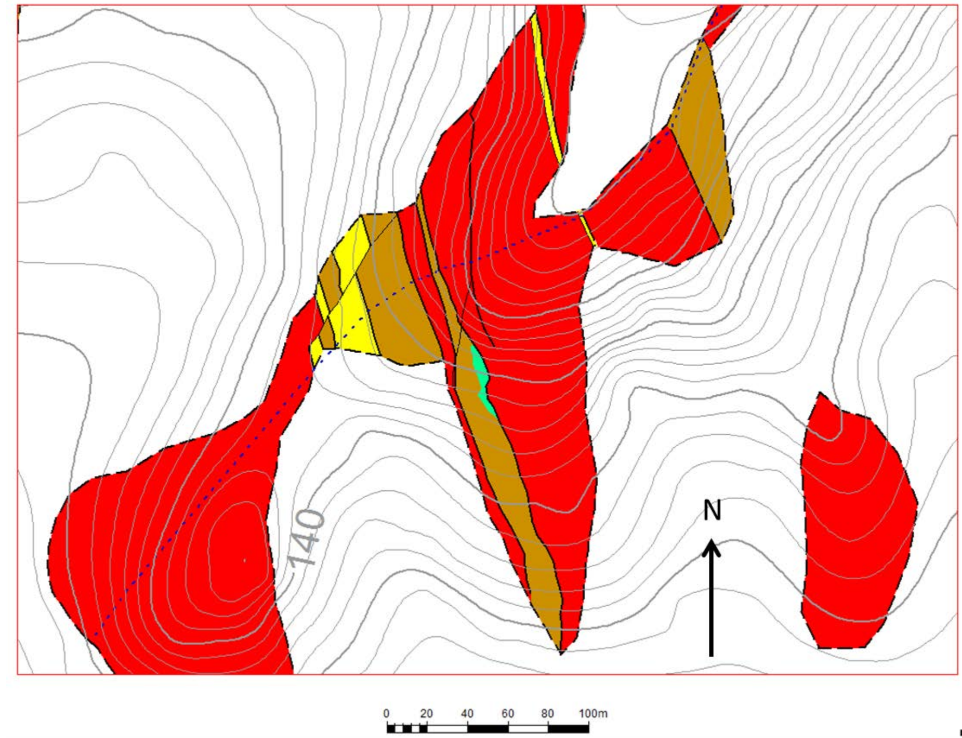
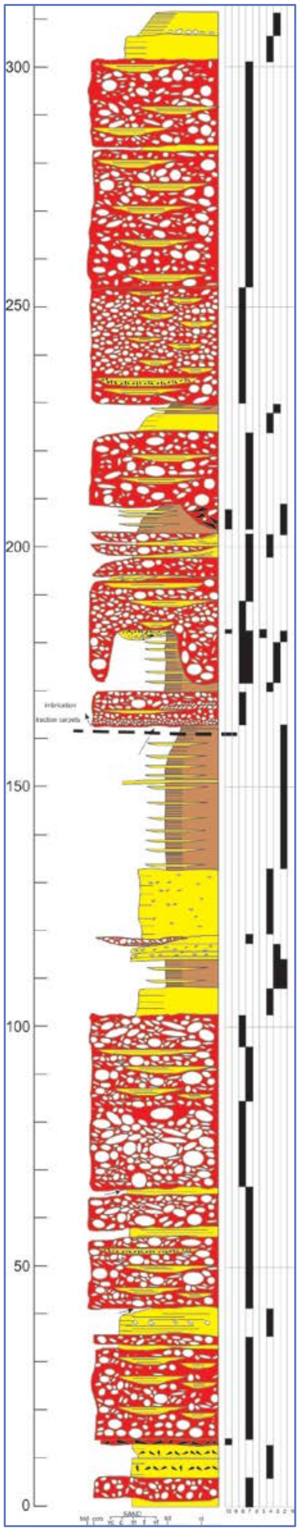


Figure 17. Facies associations map with faults (thin black lines) of lower portion of Section 12A. Colors of facies associations will be discussed during the field trip. Contour interval is 2m. Blue dotted line marks the path of measured section.



We will walk down towards the base of Section 12A (Figs. 17, 18). Here, it is possible to see amalgamated channel fills and erosive surfaces, as well as a multitude of faults. This also affords the opportunity to visit the base of one of the thickest conglomerate units in the field area. However, the lowest conglomerate's base has yet to be identified due to lake levels.

Figure 18. Lower portion of stratigraphic Section 12A. Thickness in meters. Lithofacies 1-10 are marked on the right.

Stop 3

We will continue walking along strike and down section to Section 10. In addition to this outcrop being an excellent example of widespread conglomeratic fills, Section 10 also hosts the largest clast seen in the field (see white star, Fig. 19). This mega-clast (Fig. 20) measures 3.5 meters in diameter, and can hold an entire class of students (i.e. "class-clast"). The clast is a brecciated basalt with vacuole-filled prehnite. These types of clasts strongly suggest a nearby mafic source mixed in with Sierran-type clasts.

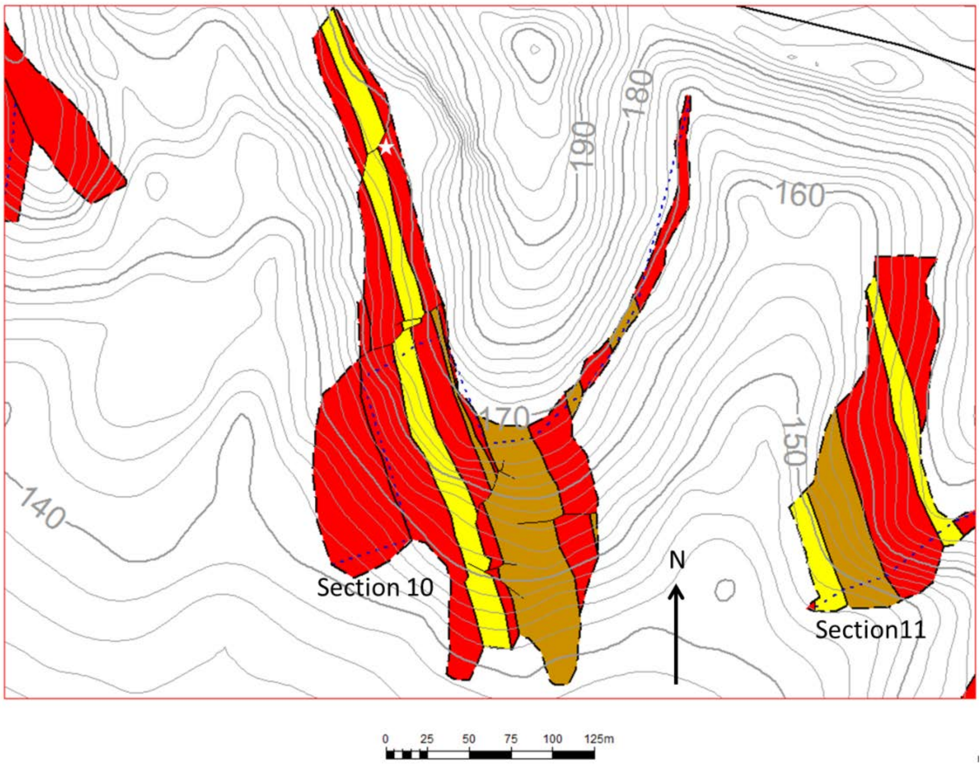


Figure 19. Facies associations map of sections 10 and 11. Note the white star as the location for the mega-clast. Colors of facies associations will be discussed during the field trip. Contour interval is 2m. Blue dotted line marks the path of measured section.

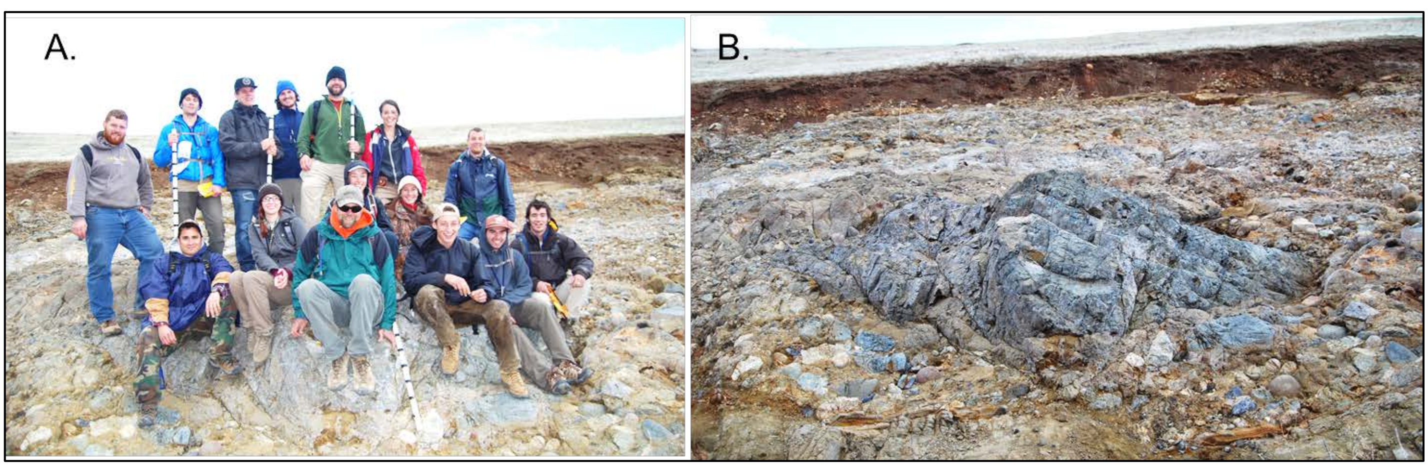
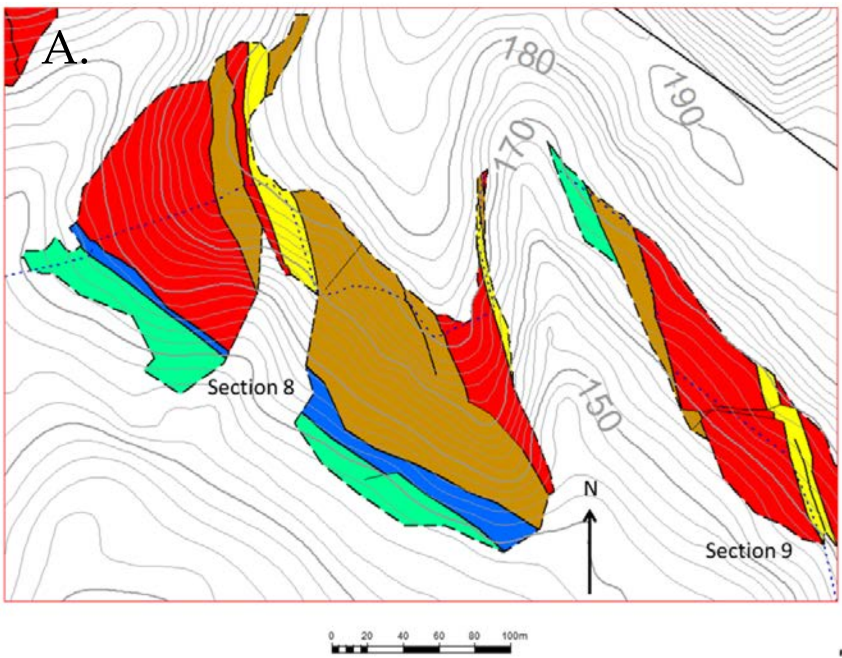


Figure 20. A. "Class-clast" on a 3.5 meter diameter brecciated basalt clast. B. Same as in A but without the class.

Stop 4

As we continue down section and along strike, Section 8 offers an excellent opportunity to view lithofacies that directly underlie a conglomeratic fill (Fig. 21). A chaotic, mudstone-brecciated facies and a well-sorted, coarse-sand to gravel-dominated, highly-organized facies (Fig. 22) can both be observed at Section 8.

These facies continue through to Section 7 and 6 as well (Fig. 23).



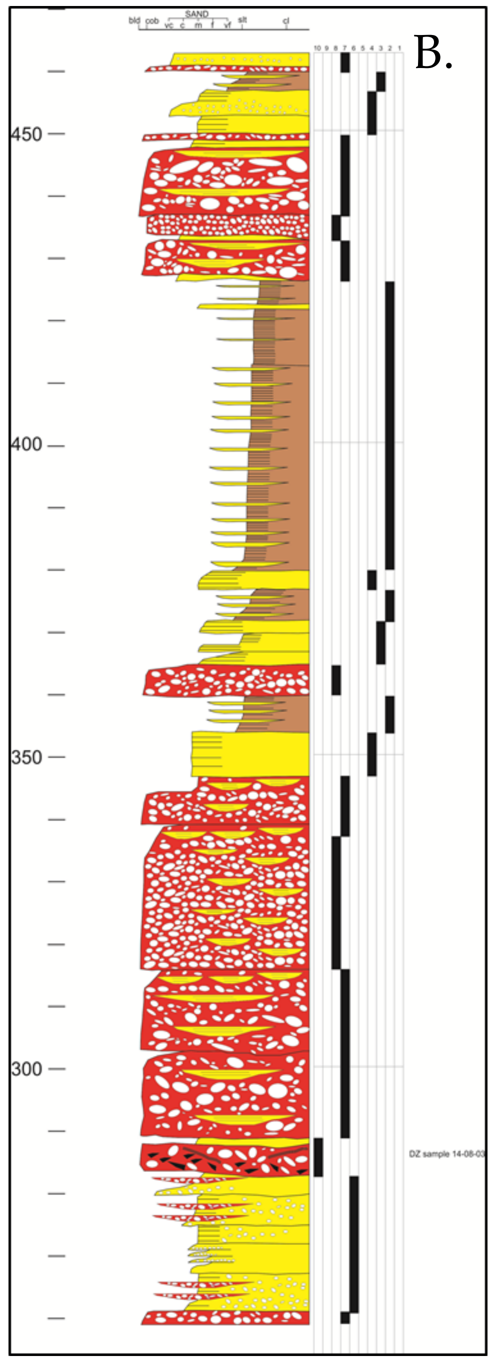


Figure 21. A. Facies associations map of sections 8 and 9. Colors of facies associations will be discussed during the field trip. Contour interval is 2m. Blue dotted line marks the path of measured section. B. Stratigraphic section of Section 8. Thickness is meters. Lithofacies 1-10 are marked on the right.

Figure 22. Photo of gravel-coarse sand lithofacies below conglomeratic fill (~280 m mark on Section 8).

Stop 5

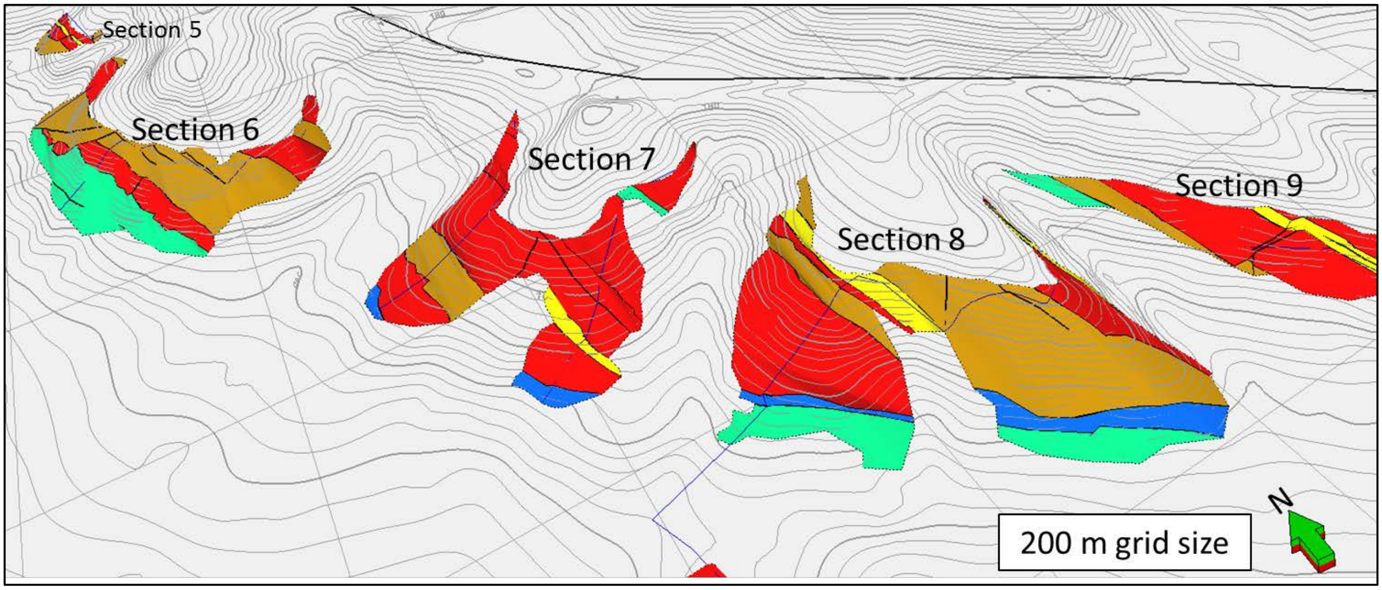


Figure 23. Perspective view of sections 5-9. Note the general trend of the blue and turquoise pattern. Colors represent facies associations that will be discussed during the field trip. Blue dotted lines mark the path of the measured sections.

We will continue to Section 6 for Stop 5. As we continue downsection and along strike to Section 6, try tracing the two facies associations (blue and turquoise colors on Fig. 23) you just visited in Section 8 to Section 7 and finally to Section 6. These facies appear to be precursors to the boulder conglomerate seen in Section 6, 7, and 8. In addition, it appears these facies trace the base of a channel-complex that has its apex in Section 6 (Figs. 24, 25), where the consistently largest boulders appear. We will be stopping at these boulders in Section 6.

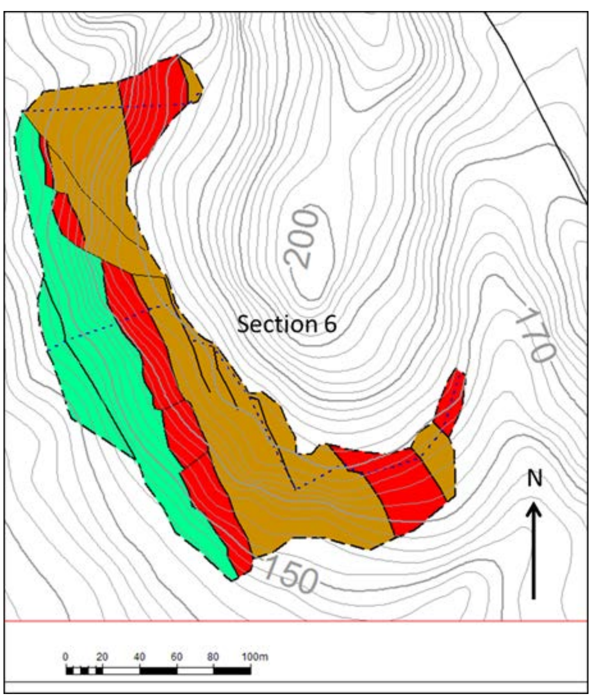


Figure 24. Facies associations map of Section 6. Colors of facies associations will be discussed during the field trip. Contour interval is 2m. Blue dotted line marks the path of measured section.

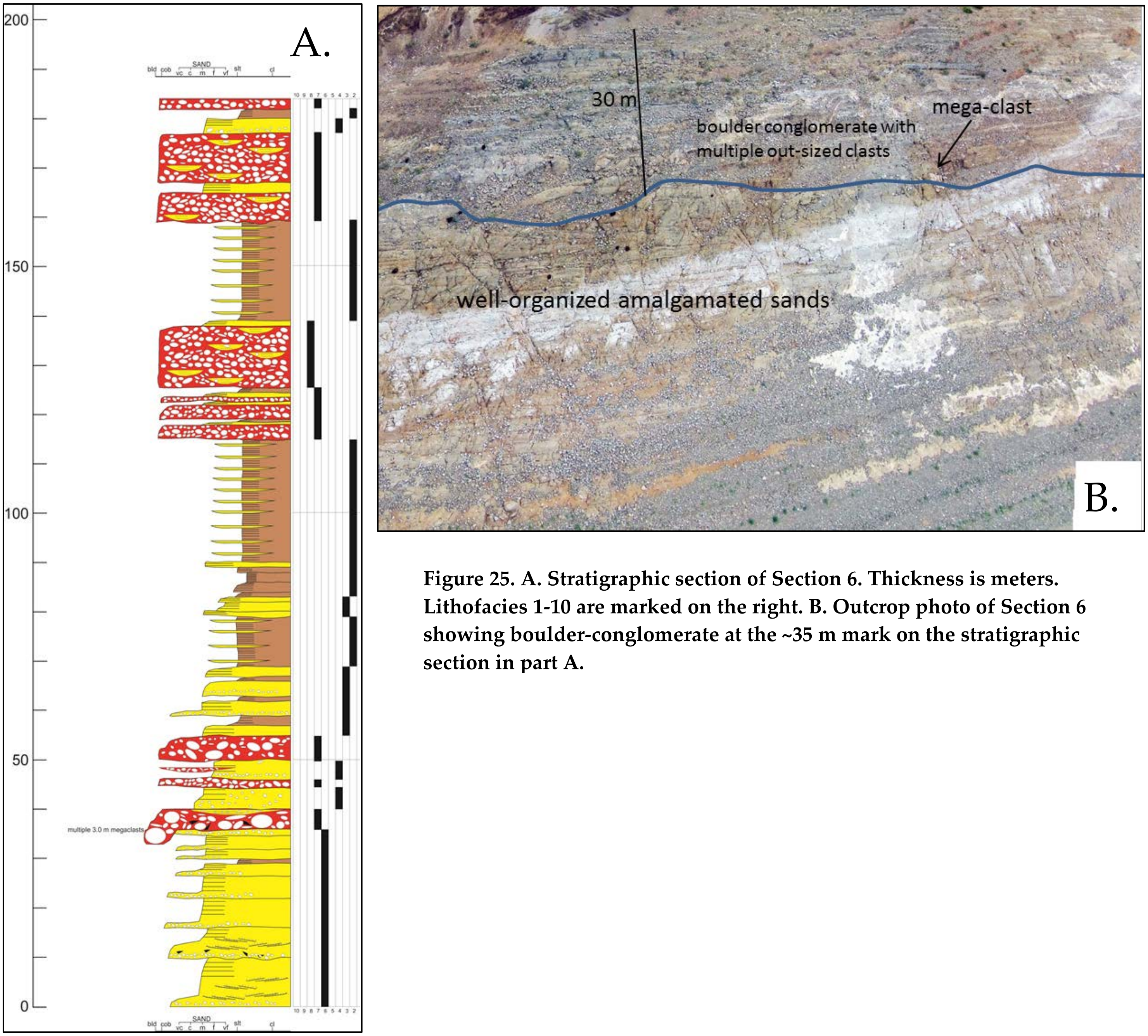
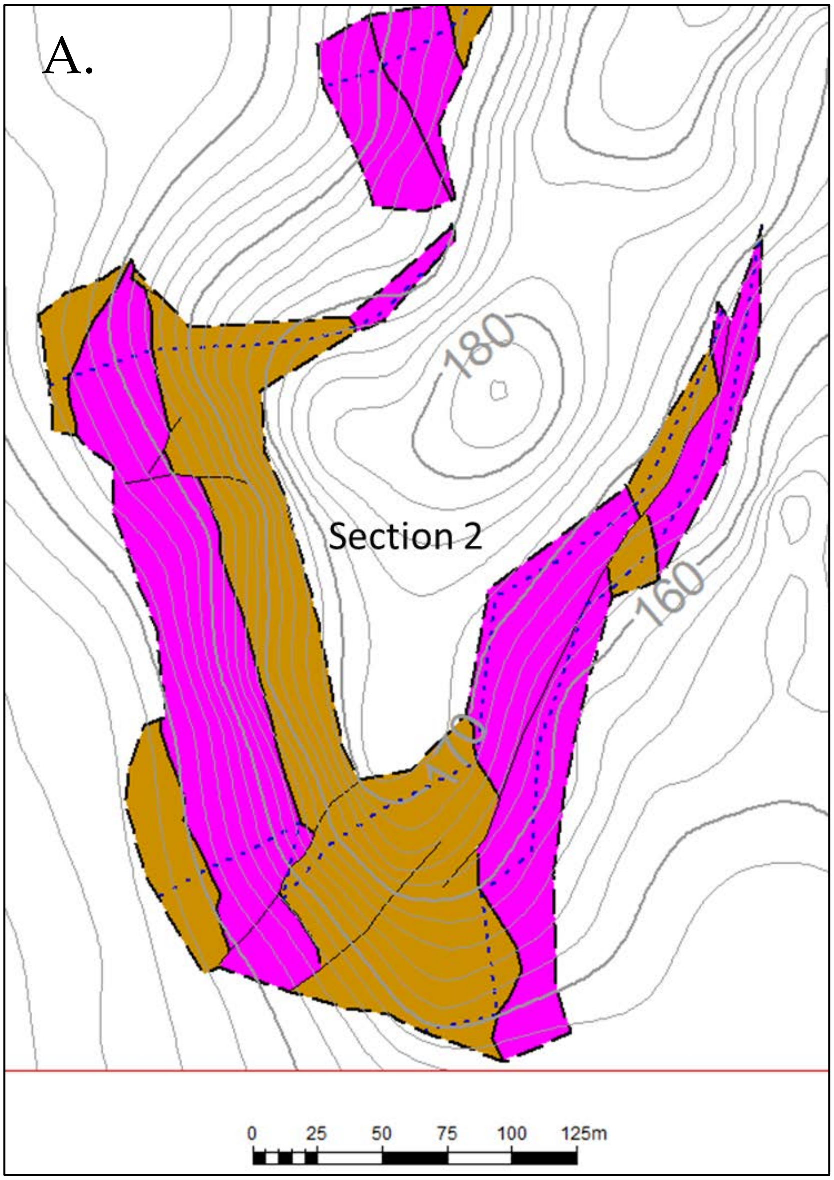


Figure 25. A. Stratigraphic section of Section 6. Thickness is meters. Lithofacies 1-10 are marked on the right. B. Outcrop photo of Section 6 showing boulder-conglomerate at the ~35 m mark on the stratigraphic section in part A.

Stop 6

Our final stop of the day will examine the most proximal outcrops of the field area: Section 2 (Fig. 26). Notice a distinct change in character of the conglomerate. They are exclusively clast-supported and are generally cobbles instead of a mix of cobbles and boulders.



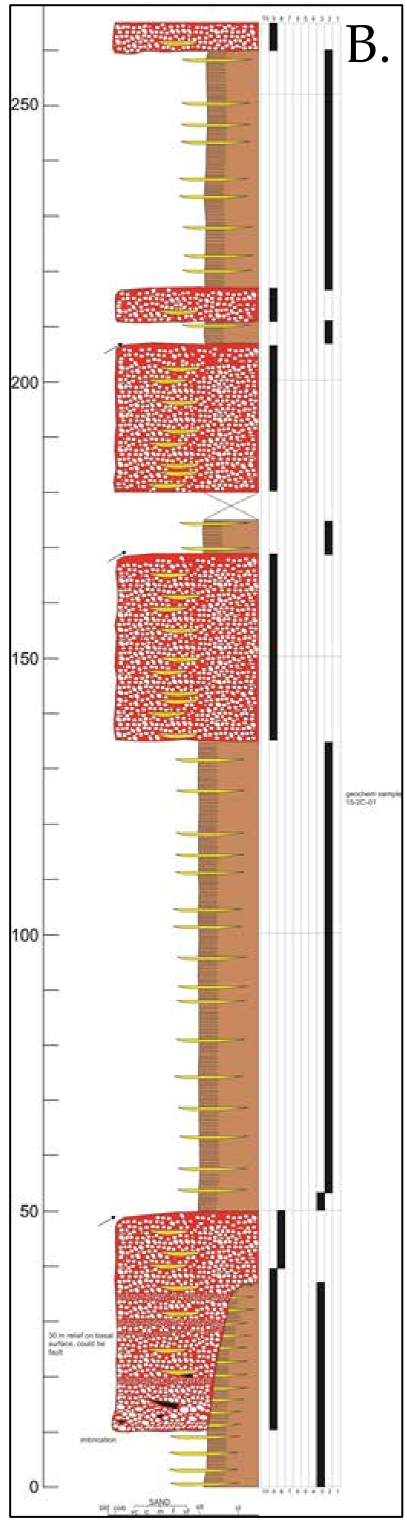


Figure 26. A. Facies associations map of Section 2. Colors of facies associations will be discussed during the field trip. Contour interval is 2m. Blue dotted line marks the path of measured section. B. Stratigraphic section of Section 6. Thickness is meters. Lithofacies 1-10 are marked on the right.

In addition, an excellent erosional surface with up to 30 m of relief on the north section of Section 2 is well-exposed placing clast-supported cobble conglomerate on top of finer grained units (Fig. 27). Clast-imbrication is well-developed at the base of the lowest conglomerate (heading of 140°). Since sections 1 and 2 (Section 1 also has similar characteristics to Section 2 and may be visited depending on time) are the northernmost exposures, I interpret the facies change and the erosive nature of the conglomerate as representing proximal positions within the submarine canyon.

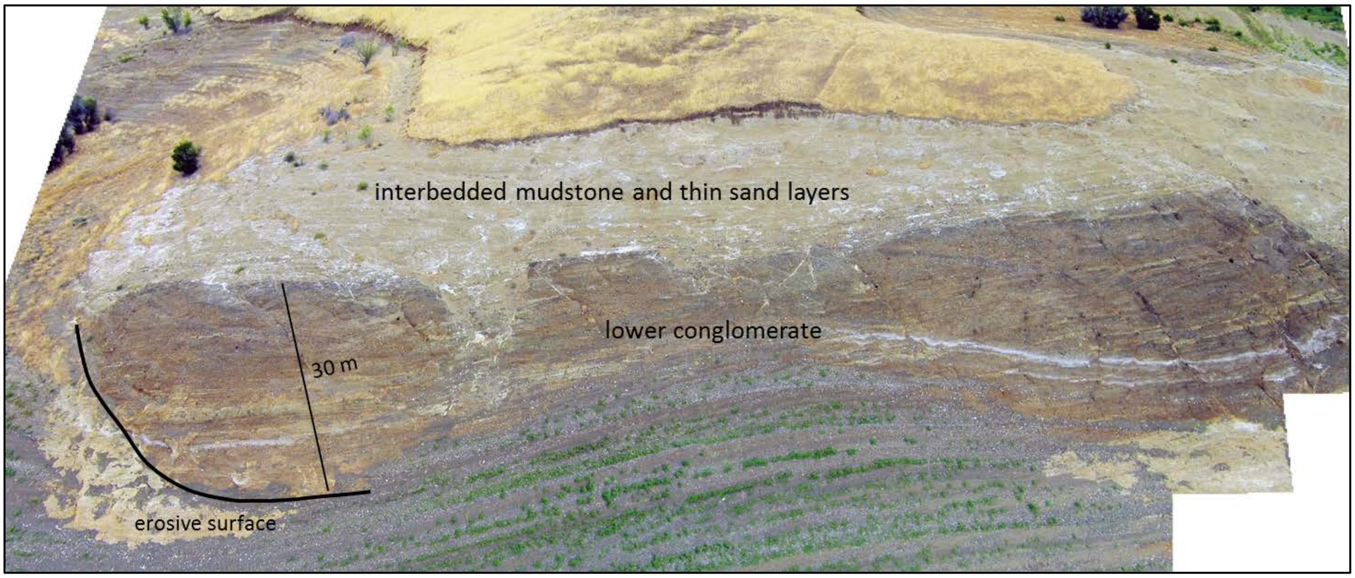


Figure 27. Outcrop exposure of Section 2. Note the erosive surface with 30 m of relief with overlain clast-supported cobble conglomerate.

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