2011

Discrete brittle to distributed shearing; Results from analysis of the deep portions of the Cajon Pass Drill Hole

James P. Evans
Utah State University

D Forand
Utah State University

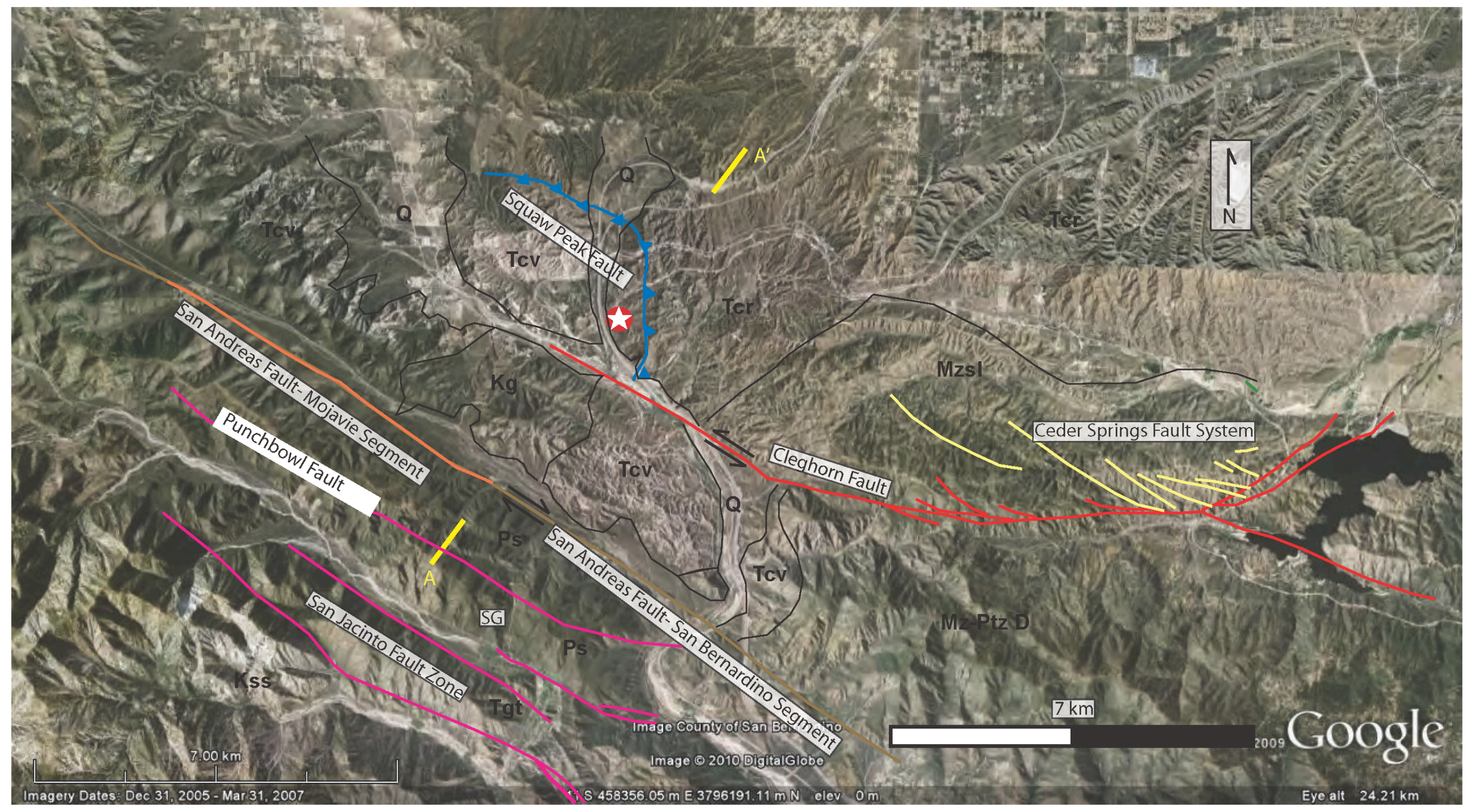
Recommended Citation

Evans, James P. and Forand, D, "Discrete brittle to distributed shearing; Results from analysis of the deep portions of the Cajon Pass Drill Hole" (2011). *Geosciences Presentations.* Paper 1.
https://digitalcommons.usu.edu/geology_pres/1

T33E-2461

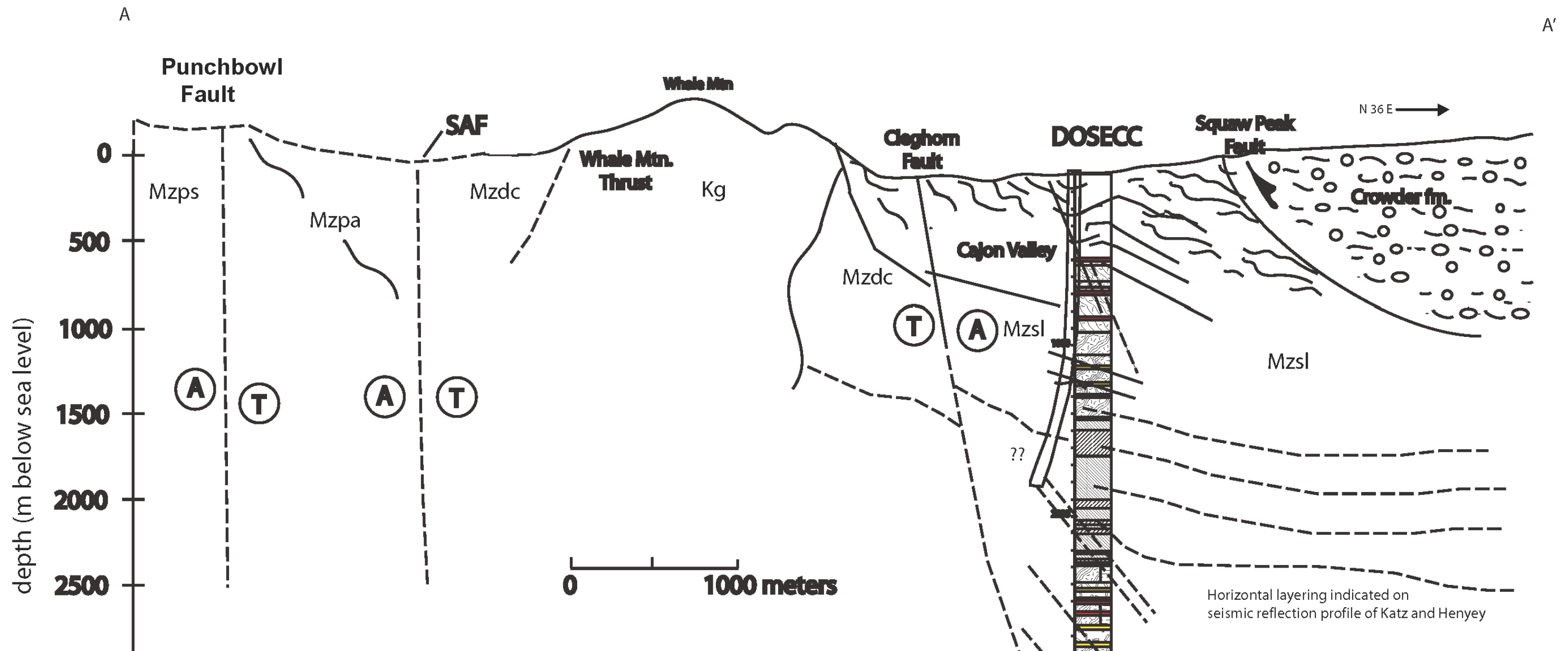
Discrete brittle to distributed shearing; Results from analysis of the deep portions of the Cajon Pass Drill Hole

James P. Evans, David Forand*
Department of Geology, Utah State University, Logan, UT 84322-4505
james.evans@usu.edu
* Now at: Chevron, Inc., Midland, TX



Geologic Setting

The right lateral strike-slip San Andreas fault transects Cajon Pass with a N60 °W strike, and many other subsidiary faults are located in the area, including the steeply dipping (85 °-vertical N) left lateral strike-slip Cleghorn fault. The CPDDH was drilled 4km NE of the San Andreas Fault and drilled through sandstones before reaching the basement rock at approx 500 meters depth. Gneisses, granites, grnaodiorites and granite gneisses are the dominant basement lithologies. The core intersected several small faults and captured fault related deformation throughout the core. The deepest level of deformation in the core is hypothesized to be the Cleghorn fault.




Strike-slip lineations on a fault surface


South-dipping cataclasite zone

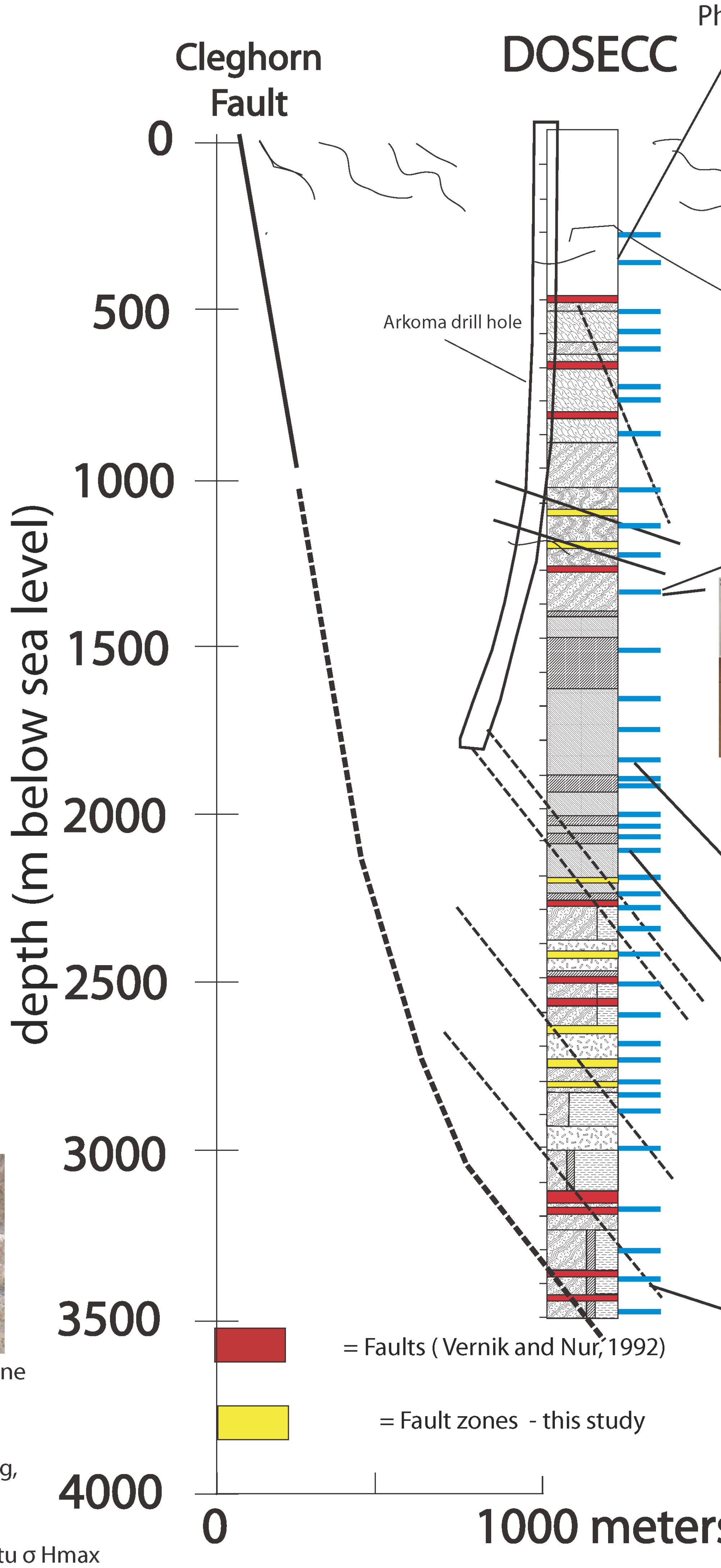
Objectives and Methods

The 3.5 km deep Cajon Pass Deep Drill Hole examined in-situ stresses, geochemical and geophysical logging, examination of the cuttings, and 53 spot cores . Though the drilling resulted in 106.87 meters of crystalline core at a varity of depths, little systematic structural analysis was performed incorporating descriptions or interpretations of deformation processes at depth. Analyses of the data from the CPDDH revealed that in situ σ Hmax is at moderate to high angles to the trace of the San Andreas Fault (Zoback and Healy, 1992; Shamir and Zoback, 1992; Day-Lewis et al., 2010). This work has lead to the well-known hypothesis that the San Andreas Fault is weak (Zoback et al., 1987) and likely embedded in a strong crust [Townend and Zoback, 2004). However, it appears that no systematic analysis examined the rocks, nor evaluated their structure in light of the wealth of borehole-based data from the project.

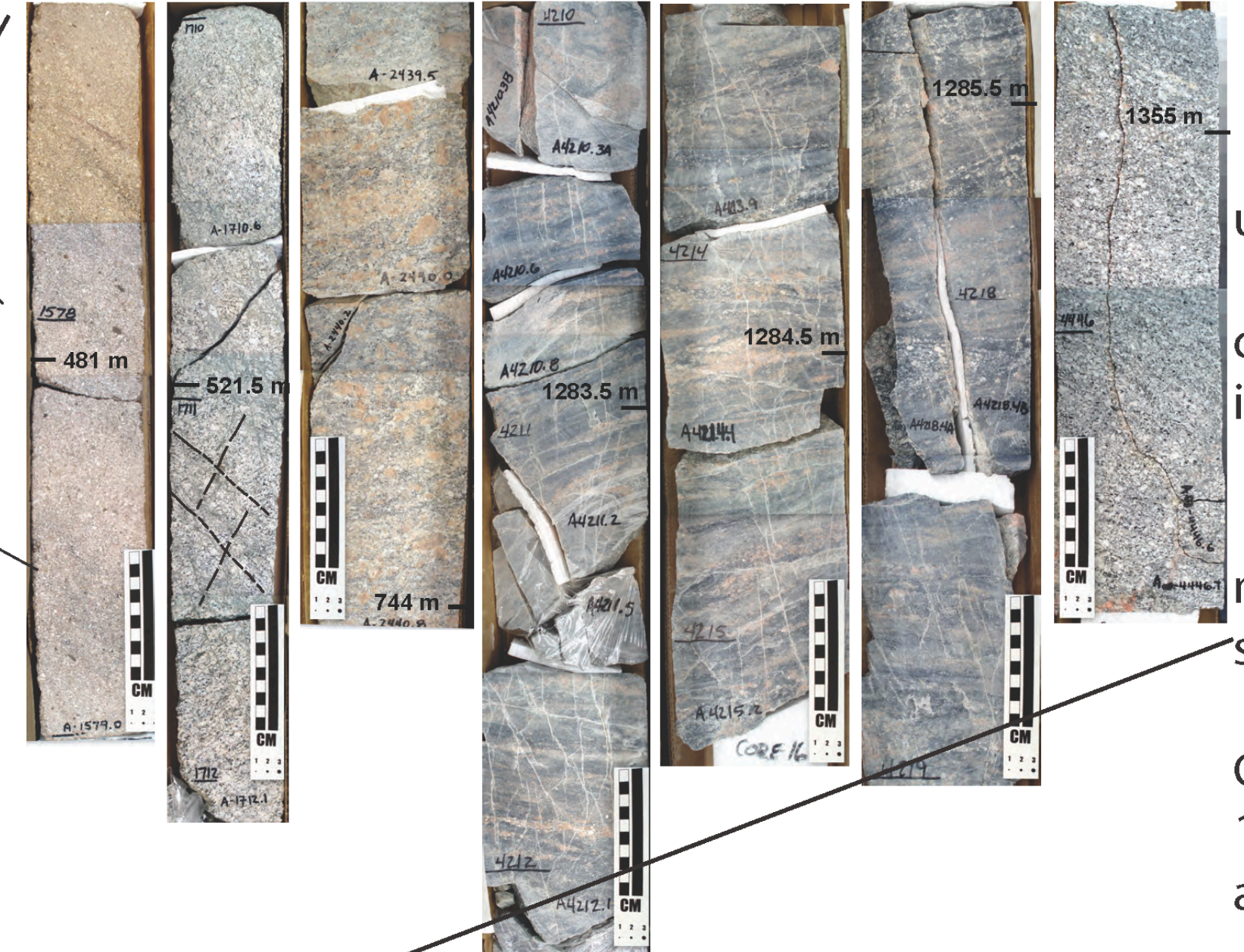
We performed a comprehensive systematical structural analysis of the entire Cajon Pass crystalline core. We adddress the following questions:

1. How does deformation vary with depth or with respect to location relative to fault zones?
2. What is the nature of deformation textures and alteration in cored faults?
3. How does deformation at depth compare with nearby exhumed faults?
4. What does the Cajon Pass drill hole reveal about the structural setting of the area?

Our methods included mesoscopic scale core logging, microstructurla analyses, X-Ray difrraction mineralogy, whole-rock geochemistry, and re-analyses of borehole geophysical data.

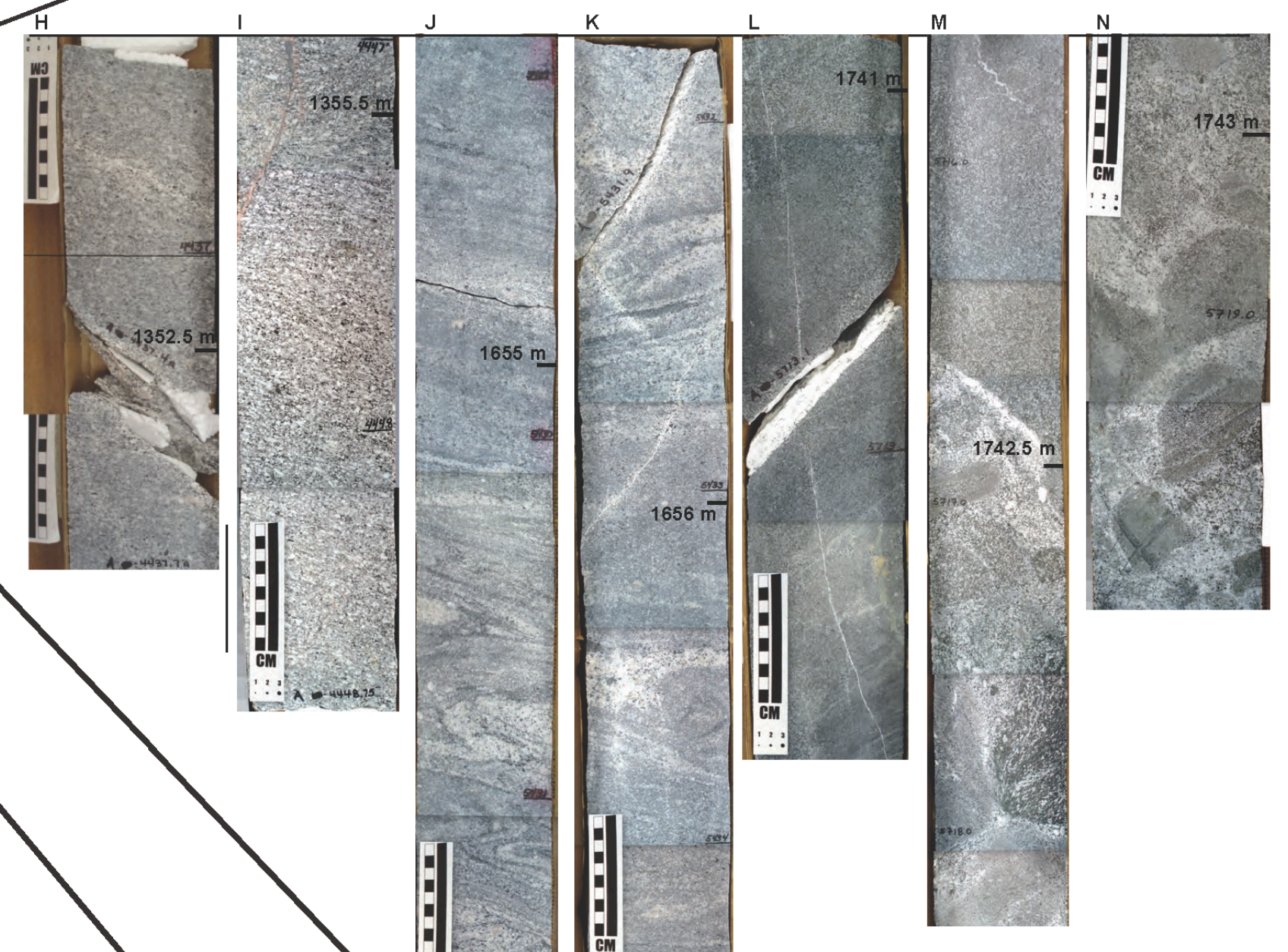


Photomosaics of selected core from the Cajon Pass drill hole.

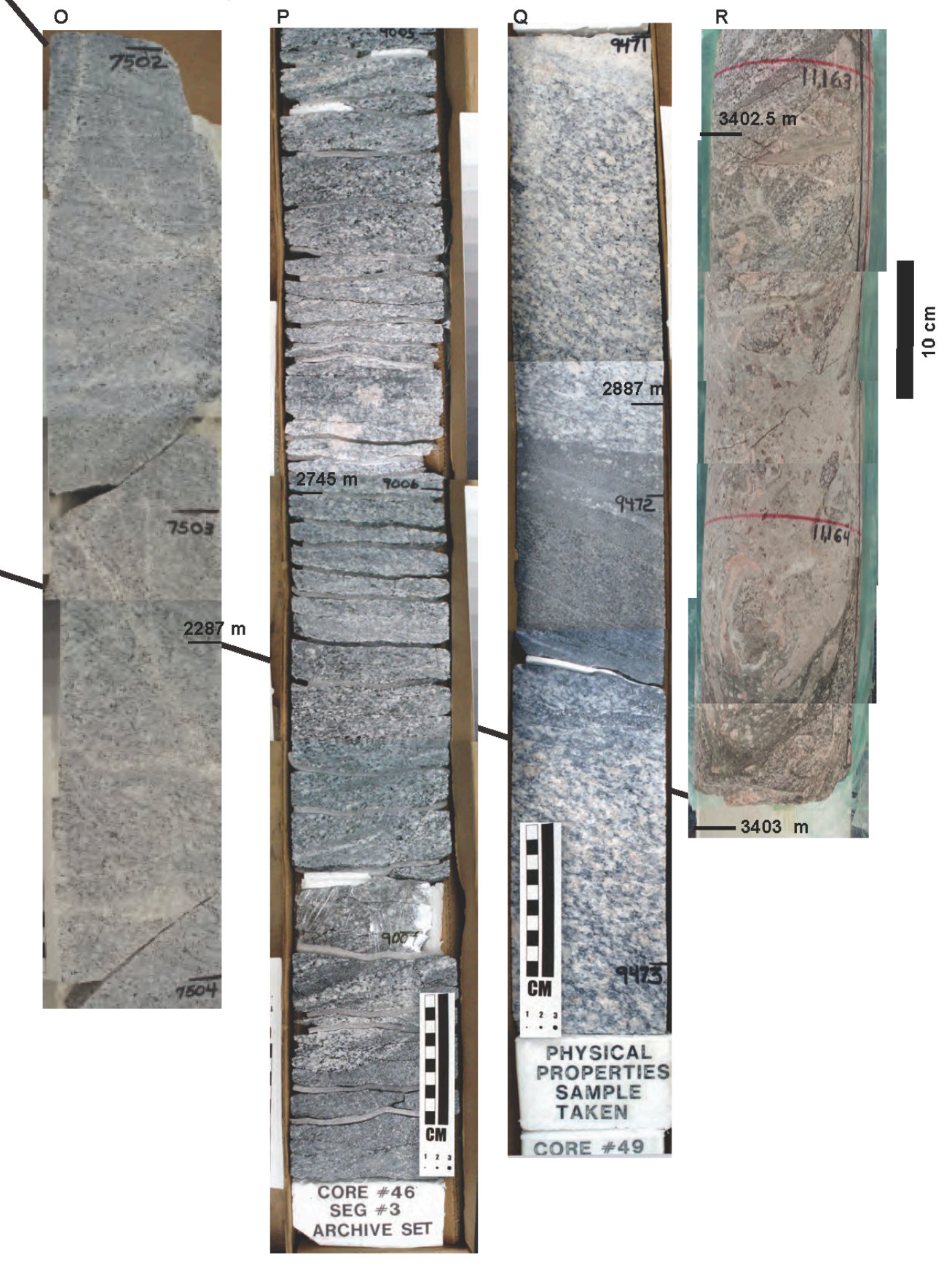


Depths in meters.

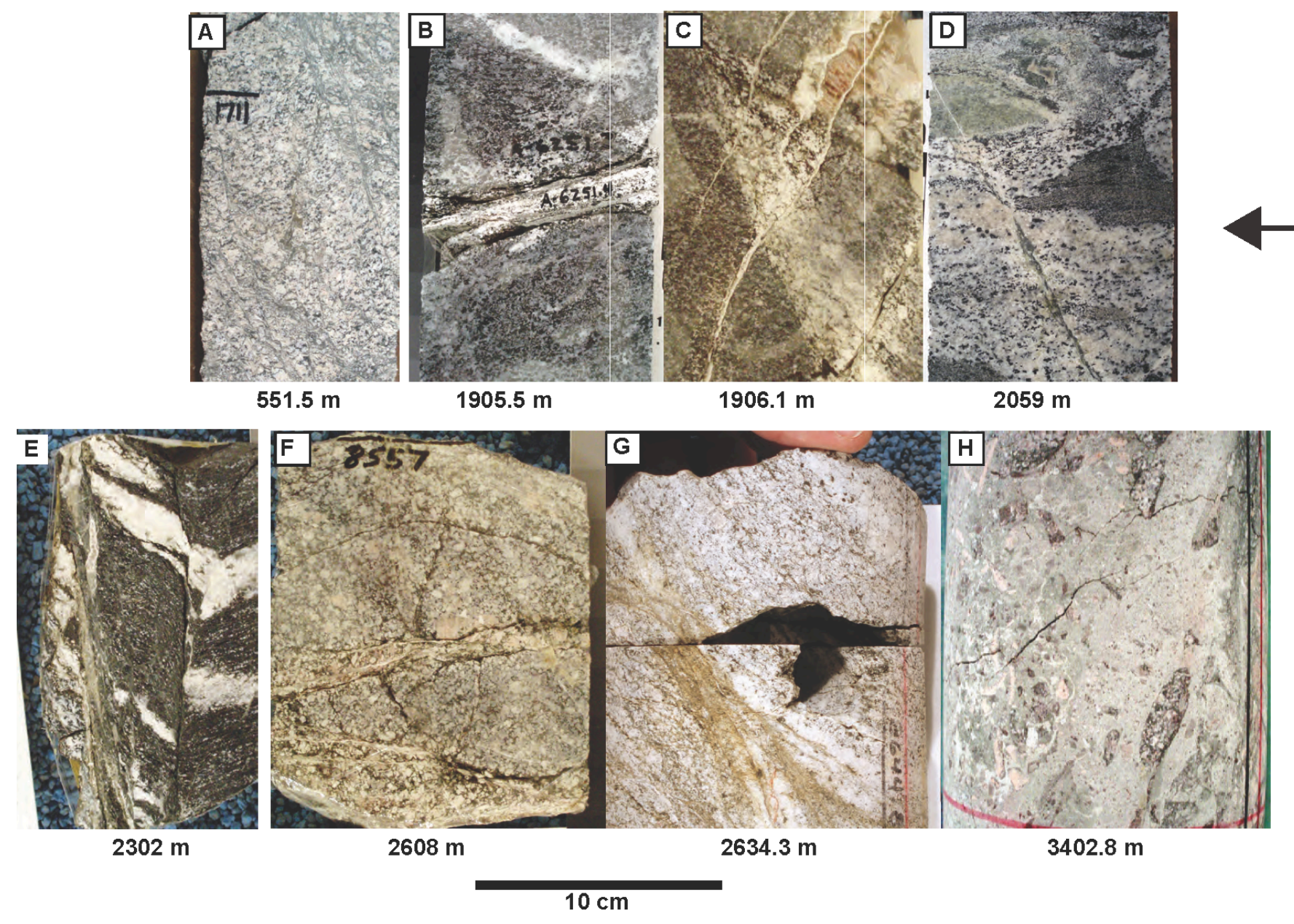
A. Arkosic sequence from the upper 500 m of the core.
B. Granodiorite gneiss with chloritic shear zones, indicated by dashed lines.
C. Granitic gneiss from 744 m md.
D-F – core run from ~ 1283 to 1286 m md in gneisses, with abundant subvertical mode I fractures with white laumontite coatings.
G. Well defined Mode I fracture at 1355 m md with pink and white alteration halo.



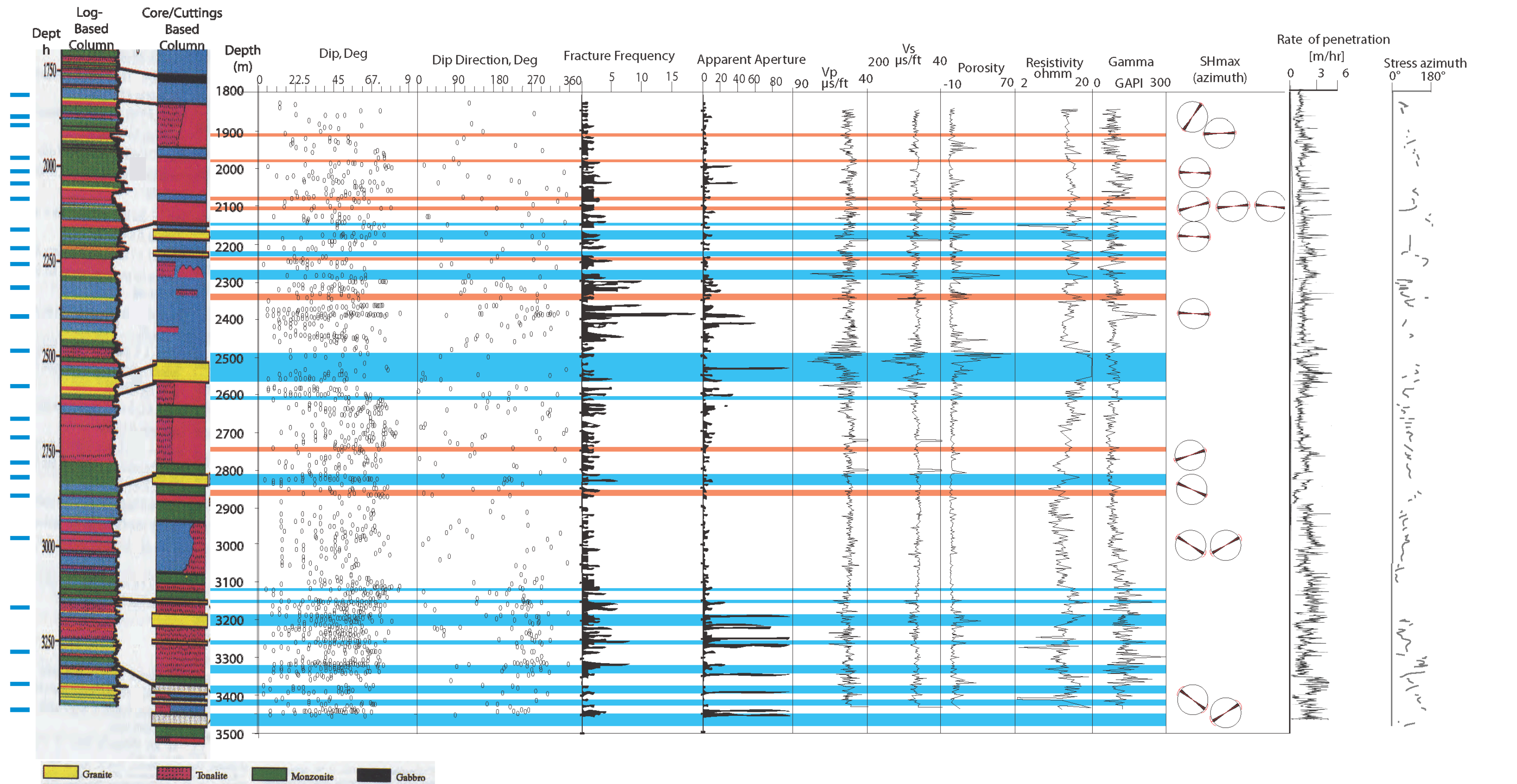
H. Moderately dipping brittle fault at 1352.6 m md.
I. Subvertical pink and white mineralized fracture near the top of the core at 1335.5 m md.
J. Sequence of relateively undeformed migmatite
K. Migmatite cut by steeply dipping laumontite coated mode I fractures.
L. Dark diorite cut by Mode I mineralized fracture.
M and N – sequence of gneisses



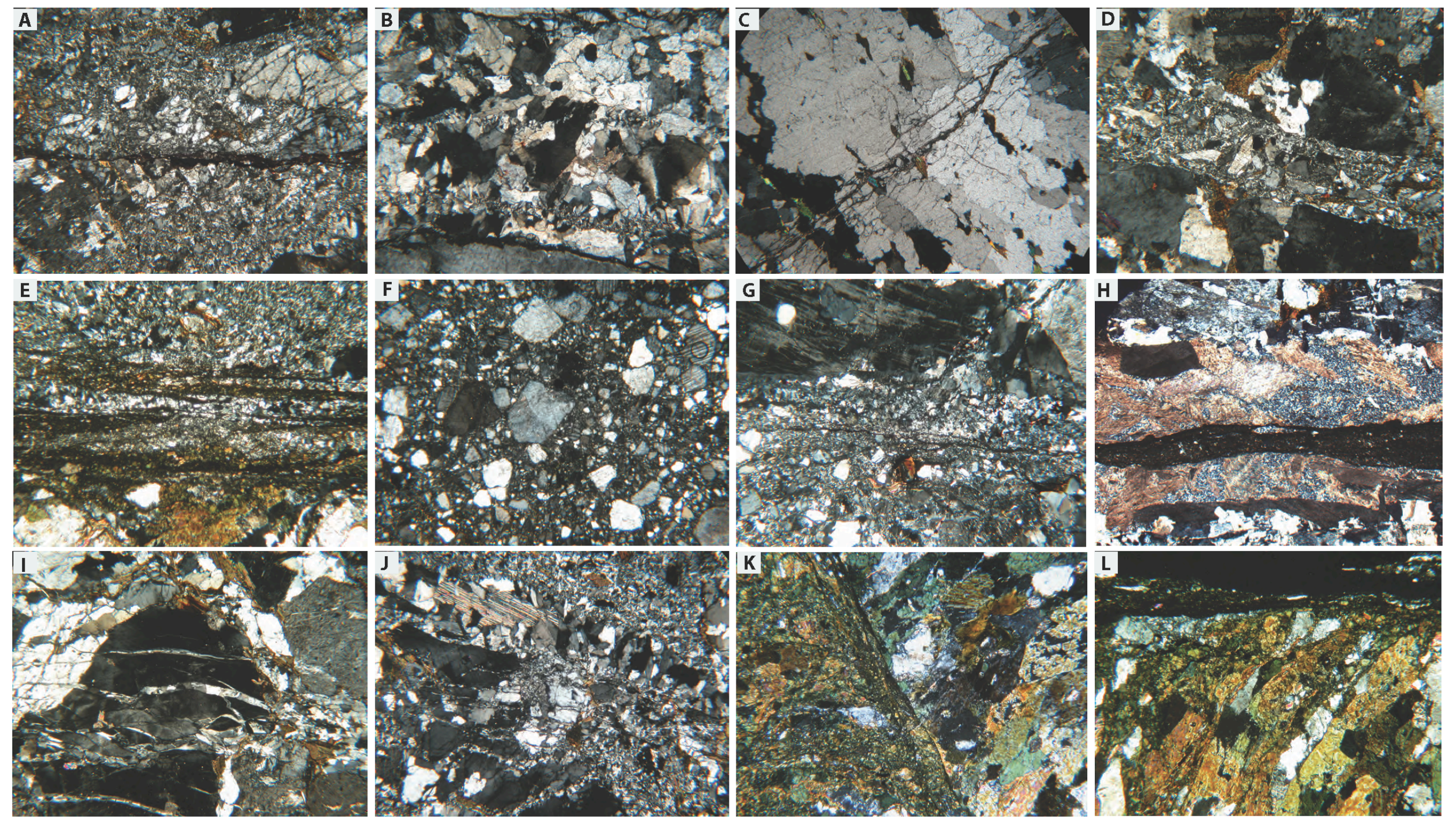
O. Fractured coarse-grained gneiss at 2287 m md.
P. Subhorizontally fractured sequence at 2745 m md with chloritic shearzone near base of core
Q Relatively intact gneiss at 2887 m md.
R. Highly sheared and altered gneiss at 3402.5 to 3403 m md. White to light pink sequence of sheared and altered zeolite ± chlorite rich sheared rock.



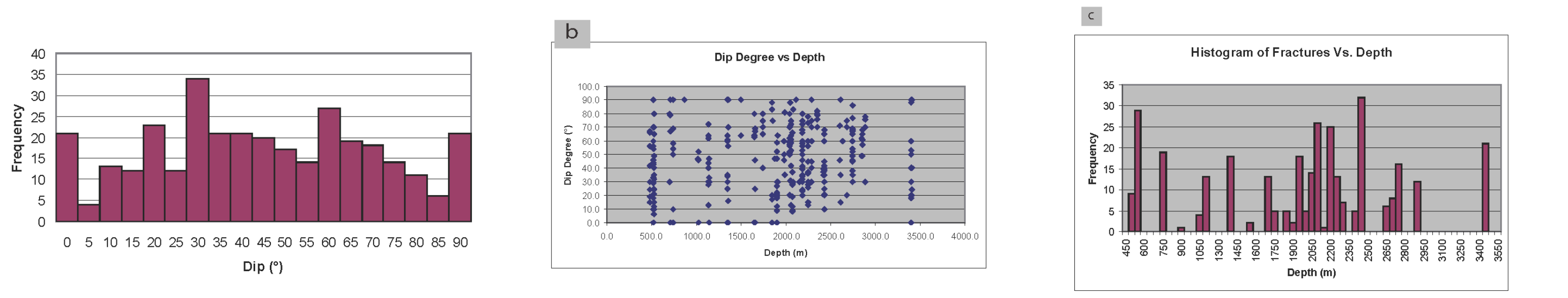
Expanded views of key mesoscopic structures in the core.
A. Thin chloritic shear zones that dip steeply.
B. Shallowly dipping zeolite-chlorite shear zone
C. Narrow steep dipping laumonitite veins
D. Narrow chlorite shear zone.
E. Nearly vertical chlorite + zeolite + epidote decorated shear zones that cut the white and green banding in the gneiss.
F. Laumontite – chlorite shear zones at a low-angle to the core axis from 2608 m md.
G. Moderately dipping semi-brittle shear zone
H. Indurated shear zone at 3402.8 m md.



Lithologic column of the crystalline core and Cajon Pass borehole from depths 1800 m to 3500 m with wireline log data, structural data from this work and that of previous workers, stress orientation data, and rate of penetration data. Revised lithologic column, dip and dip direction, fracture density, apparent fracture aperture, Vp, Vs, porosity, resistivity, gamma logs are from Barton and Zoback (1992). The σHmax data are from Zoback and Healy (1992), Shamir (1990), Shamir and Zoback (1992) and Day-Lewis (2007). The rate of penetration data are digitized from Shamir (1990). North is marked at the top of the column and the red lines around the circles represent associated error with each measurement. Orange lines mark locations of newly identified faults from this study. Blue lines represent previously identified faults. We infer the presence of two fault-damage zone complexes at ~ 2500 m and 3500 m, the lower one perhaps related to the Cleghorn fault.



Microstructures from representative sections of the core. A. Narrow Fe-oxide filled fault cuts large intragranually fractured feldspar grains from 1467 m md. b Narrow horizontal fractures cutting quartz-rich gneiss at 1534 m md. c Single large transgranular fracture with adjancent subparallel fractures cutting quartz-hornblende gneiss from 1653 m md. d 2493 e Narrow chlorite-biotite shear zones that cut a zone of cataclasite from 2634 m md; f. Highly indurated cataclasite from 2607 m md; g. Sheared cataclasite from 2741m md; h. Calcite-laumontite filled vein with dark cataclasite shear zone cutting it from 2472 m md. i 3401 j. Examples of multiple deformation mechanisms at depth. Brittle fractures that cut quartz grains are decorated with neomineralized quartz grains, and plastically deformed grains are visible at 3402 m md



Distribution of fractures in the core examined in this study.. A. Fracture frequency as a function of fracture dip. We assume that the borehole is approximately vertical over its trajectory, such that the core axis – fracture angle approximates dip. Most fractures sampled by the core dip between 10° and 80°. B. Fracture dip as a function of depth in the core. No systematic dip can be seen as a function of depth. C. Fracture frequency as a function of depth in the core. The increased in density in the region 2000 -2500 m correspond to the increase in fracture frequency determined by Barton and Zoback (see above) and corresponds to the presence of a fault inferred from the borehole data (see Barton and Zoback, 1992; Figure 6).

This work was funded by a Southern California Earthquake Center Grant, grants to Forand from the Society of Professional Well Log Analysts, ExxonMobil, and a McKillop scholarship through the Department of Geology at Utah State University. A manuscript based on this work is currently in review in Lithosphere.