Vein Structures And Intrastratal Microfractured Zones Interpreted In Cores Of Late Miocene Diatomite, Midway Sunset Field, California*

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Abstract

Silty diatomaceous mudrock from the Belridge Diatomite Member, Reef Ridge Shale, Monterey Formation preserve small-scale veins and microfaults. This study compares vein, fracture, and fault geometry and mineralogy from four whole cores of argillaceous diatomite in Midway Sunset Field to what has been described in both outcrop and modern offshore diatomaceous sediments. Thin section petrography using both standard and reflected ultraviolet light was combined with scanning electron microscopy (SEM) on standard and argon ion-milled samples to document the microfabrics, fracture styles, mineralogy and paragenesis of events. Formation and evolution of vein structures as fluid escape features, and microfault development at vein sites, is reported in diatomaceous muds cored from active margins during the Ocean Drilling Program and Deep Sea Drilling Project. A diffuse type of vein structure observed in the core of Miocene diatomite compares well with what are termed 'ghost veins' in modern offshore Peru sediments, which develop preferentially in more diatom rich laminae. Preservation of primary vein networks, grain alignment, and fill mineralogy observed in the cores of Miocene diatomite are relict signatures of fluid expulsion that occurred early in the unconsolidated diatom ooze lamina within diatomaceous muds. The sigmoidal en echelon tension gash fracture sets are recognized in whole core by their distinct geometry, darker color, and reduced porosity and permeability relative to the surrounding matrix. They form subparallel en-echelon arrays whose terminal projections are aligned along common bedding planes or other distinct geomechanical boundaries. In SEM, the material within tension gash structures, relative to the surrounding diatomite, is composed of highly comminuted diatom fragments and minor clay and organic material. Multiple crosscutting sets of 'ghost veins' and en echelon structures are observed. Both features are observed in finely laminated diatomites as well as in more thickly bedded intervals and their manifestations vary with the clay content of the bed. Vein structures, fracture styles and their relationship from observations in the cores of Miocene diatomite of the Midway Sunset Field supports outcrop- and modern sediment-based interpretations that syn-sedimentary to early post-depositional downslope movement of highly porous and low permeability, organic-rich sediments drives their formation.

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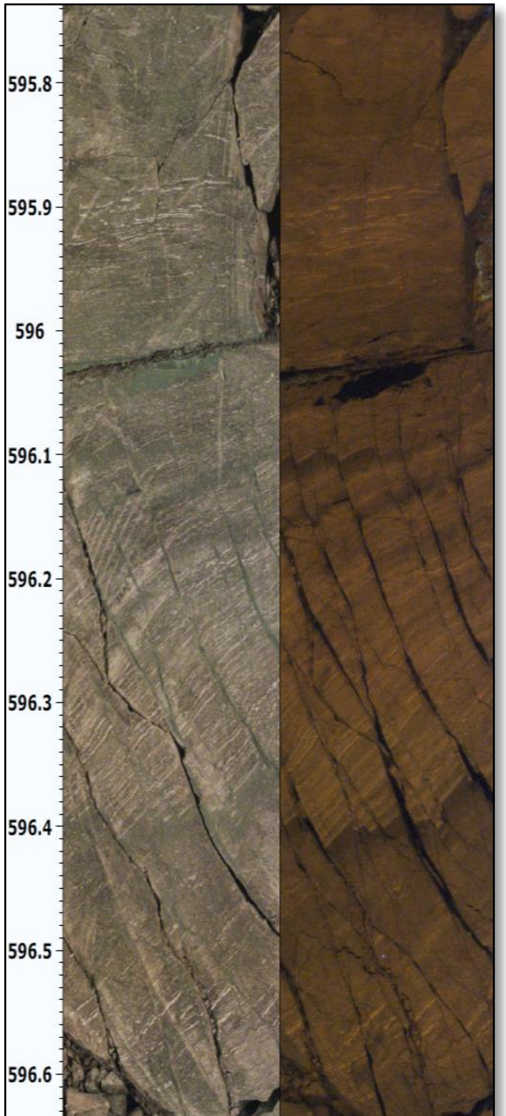

Why a macro and microscopic evaluation of rock properties is paramount for an integrated geologic and engineering understanding of opal-A diatomite

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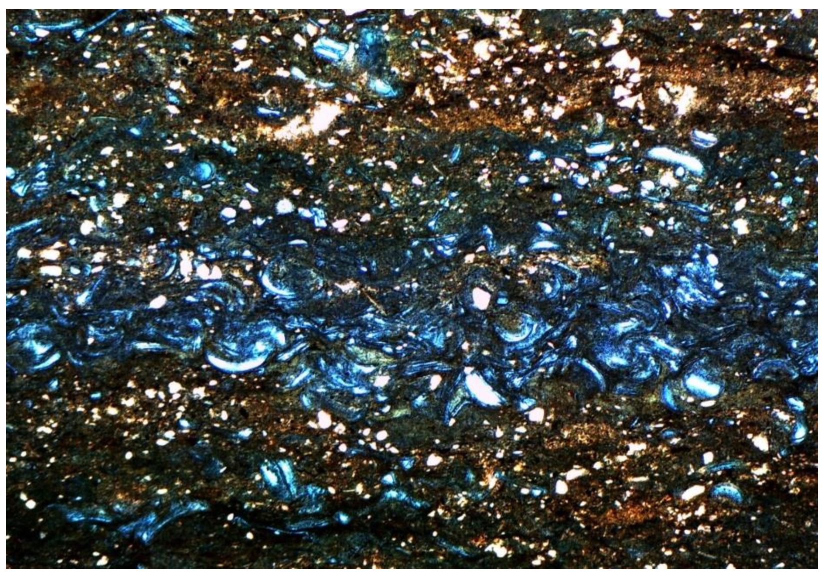
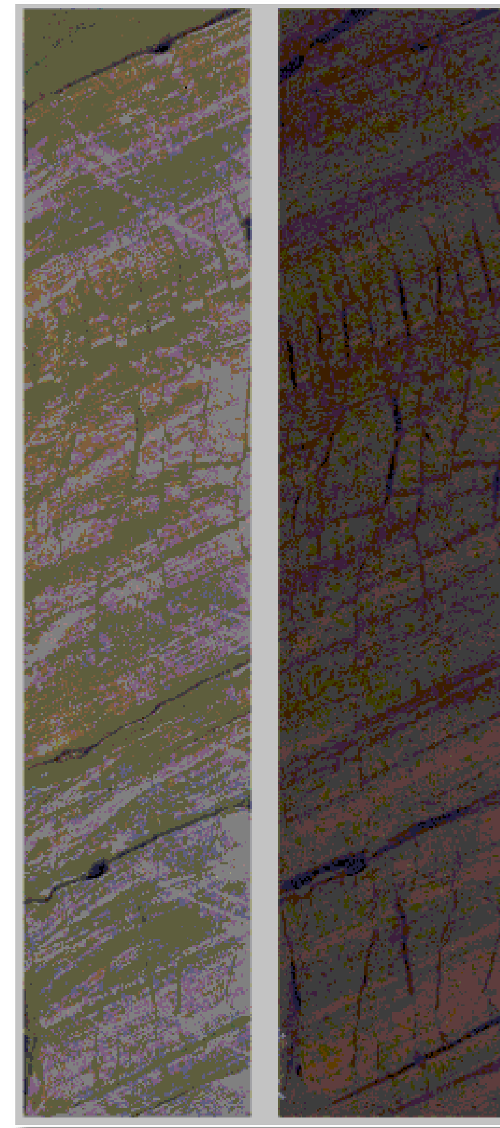
Mary Nelis, Core Laboratories

Pacific Section AAPG, Bakersfield

April 28, 2014





What are vein structures and Intrastratal Microshear Zones (IMZs)? Why the need to understand natural vein systems in opal-A?

- **Veins** are defined as < 2 mm mud-filled features that crosscut bedding, commonly at a high angle, with no visible offset *(Arthur et al., 1980; Carson et al., 1982)*

- Veins are Synsedimentary fractures and are faults (veins offset bedding)

- They are planar, curviplanar, irregular or anastomosing; darker in coloration and finer grained than the host sediment *(Lindsley-Griffin et al., 1990)*

- Disaggregation and grain boundary sliding is an important processes in vein development *(Knipe, 1986)*

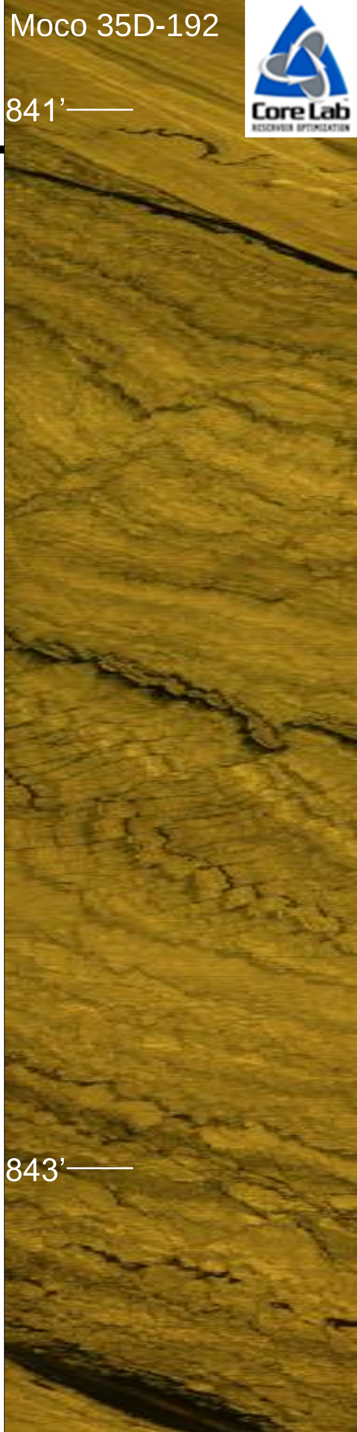
- Oligocene to Pleistocene diatomaceous mudrock cores from DSDP and ODP legs in active margins during the 1980s-1990s *(Ogawa and Miyata, 1985; Knipe, 1986; Lundberg and Moore, 1986)*
  - deformation and tectonics in active margins
  - how natural fracture systems control hydraulically induced fracture stimulation treatments

- "**IMZs** are a hybrid fault/vein structure that are stratally bounded by undeformed sediments" *(Grimm and Orange, 1997)*

- Opal-A, opal-CT and chert reservoirs of the Monterey Fm. contain natural fractures

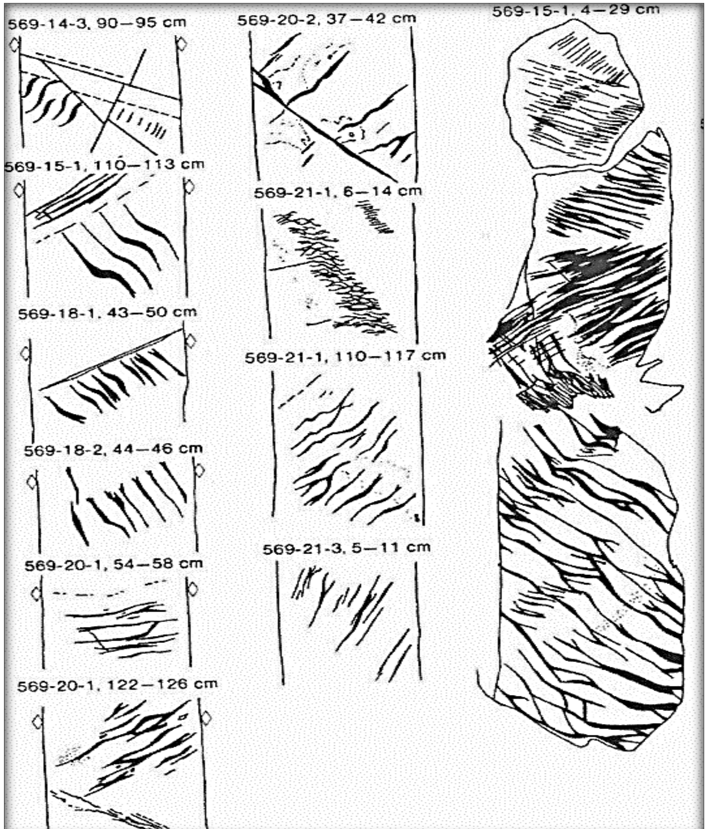
- Hydraulic fracture stimulation treatments induce fractures

- What is the relationship between natural and induced fractures?
- How might this understanding provide insights into thermal pilot programs, full field development and in helping to solve engineering concerns of steam breakthrough, sweep efficiency, steam conformance, well failures and other reservoir and production engineering concerns?

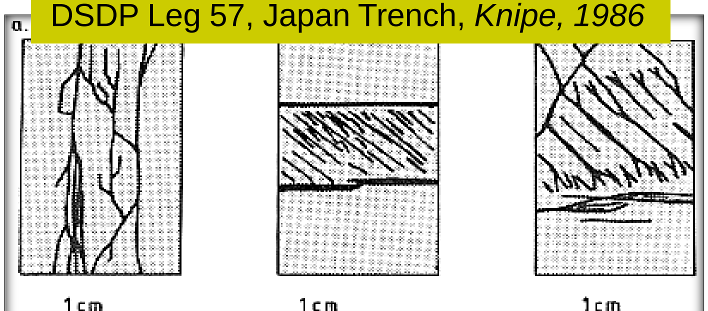


DSDP Legs in active margins
Vein descriptions and formation

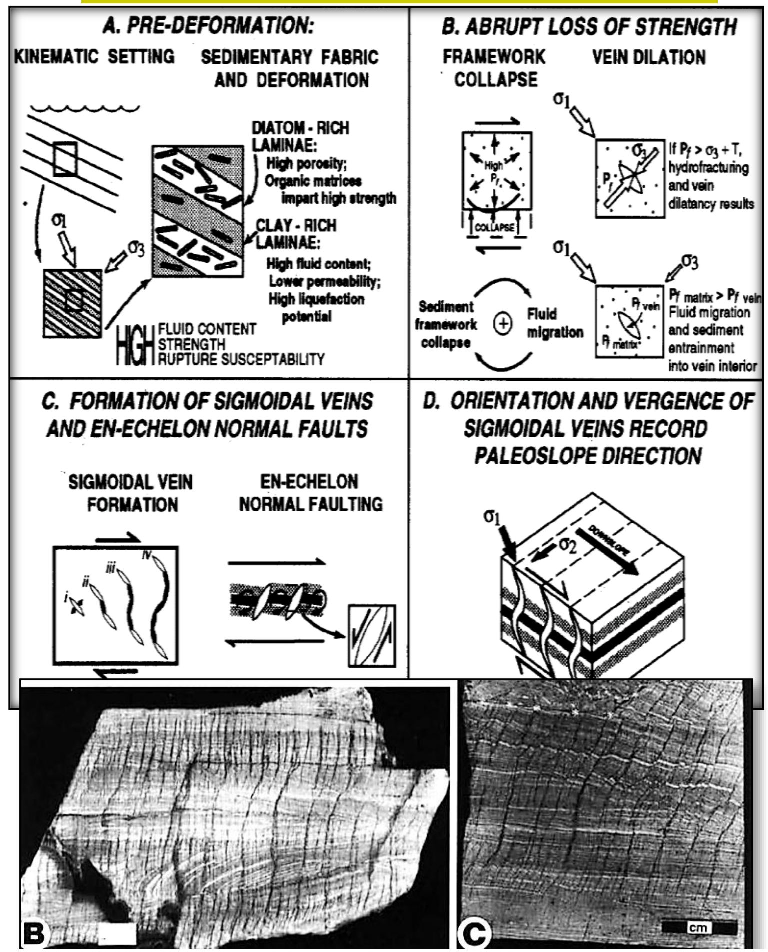
DSDP Leg 84, Middle America Trench, Guatemala., *Ogawa and Miyata, 1985*



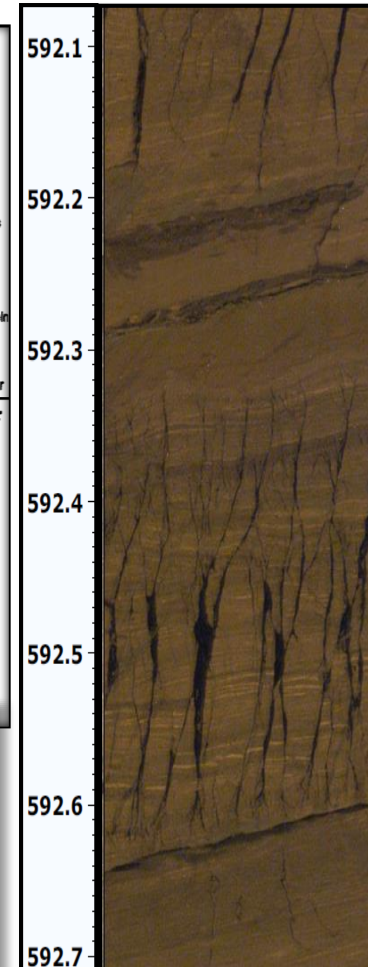
DSDP Leg 57, Japan Trench, *Knipe, 1986*



Intrastratal Microfractured zones (IMZ), Monterey Fm.,*Grimm and Orange, 1997*



This study

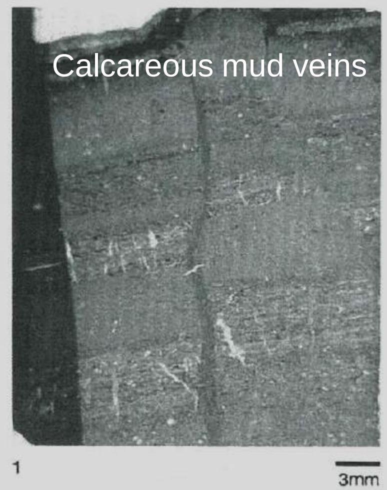


Parallel sets of planar to curviplanar, en-echelon seams that bifurcate into distributary networks. Various terms include: tension gash arrays, veins, stratal disruption, spaced foliation, kink bands, crenulation folds, web structures, cataclastic fabrics, scaly foliation, web structure and microstructural domains

Vein structures of the Peru Margin, Leg 112,

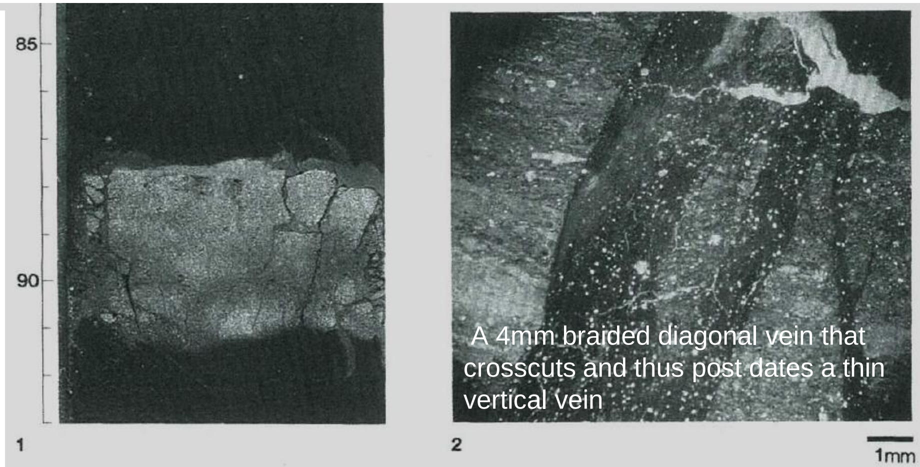
Sites 679-688, mid-upper slope to inner shelf, Late Miocene - Quaternary

Lindsley-Griffin et al., 1990



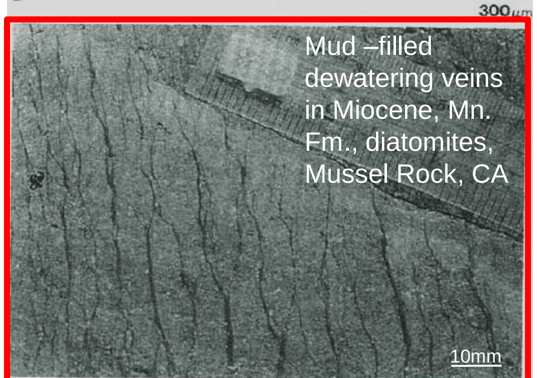
Calcareous mud veins

Veins form during sediment dewatering, initiated by diatom frustule collapse during compaction and by overloading during downslope slumping

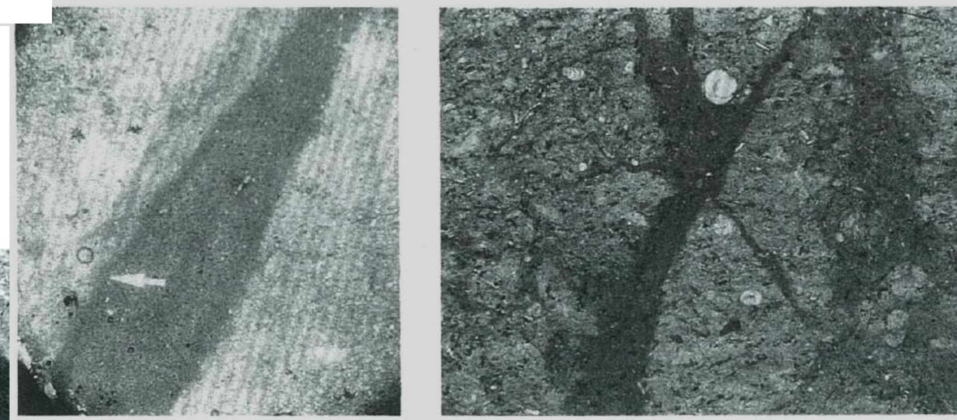


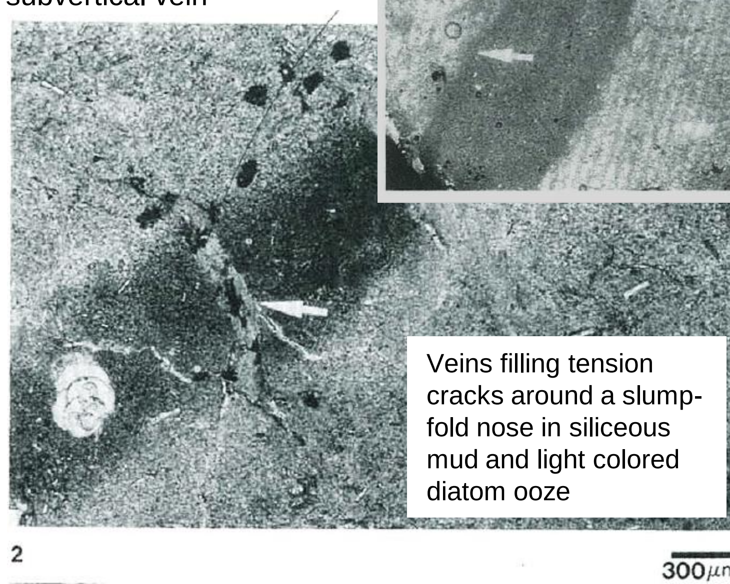
A 4mm braided diagonal vein that crosscuts and thus post dates a thin vertical vein

Subhorizontal vein set crosscut by later subvertical vein



Mud –filled dewatering veins in Miocene, Mn. Fm., diatomites, Mussel Rock, CA



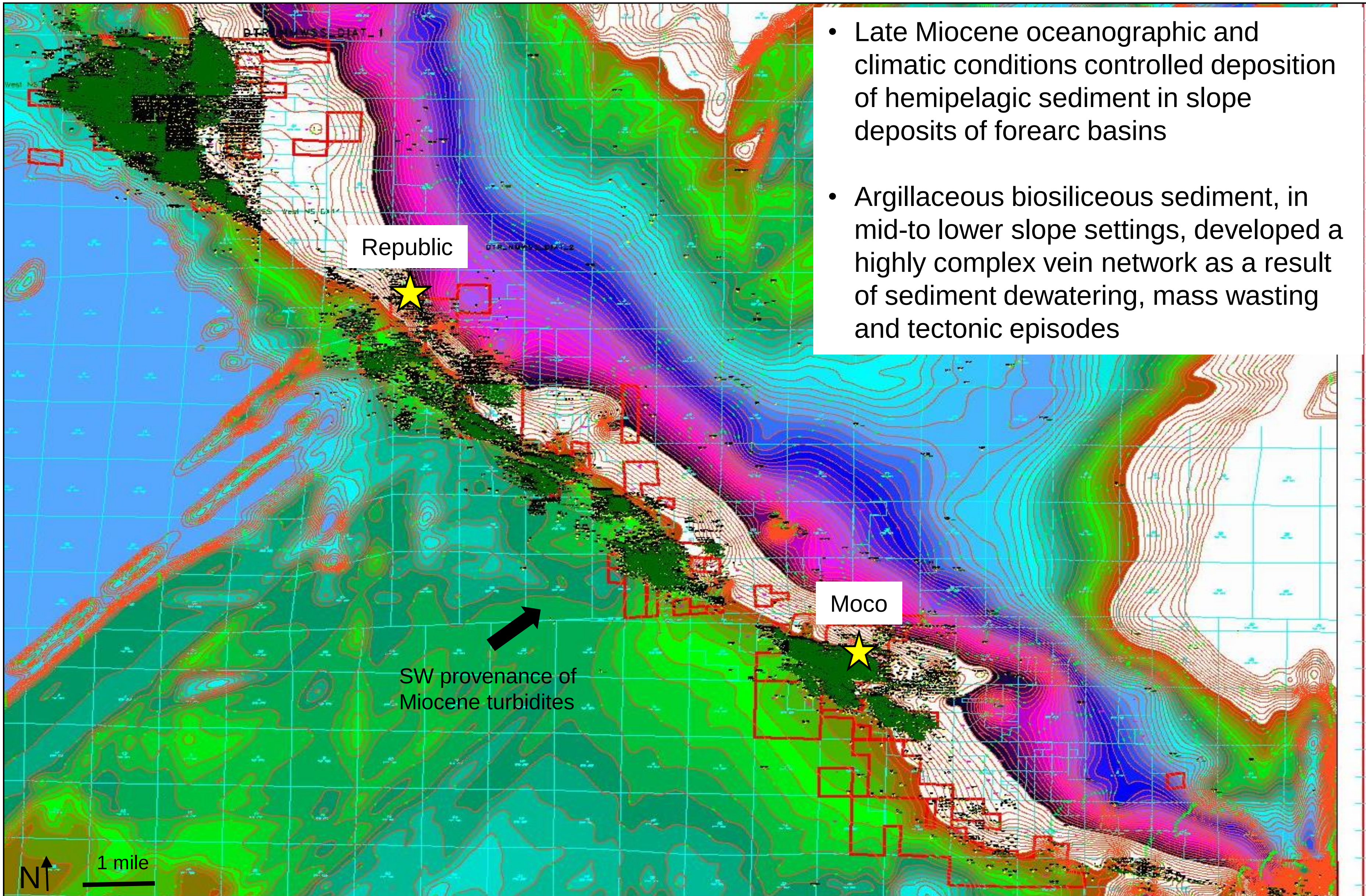


Veins filling tension cracks around a slump-fold nose in siliceous mud and light colored diatom ooze

Vein sets and arrays

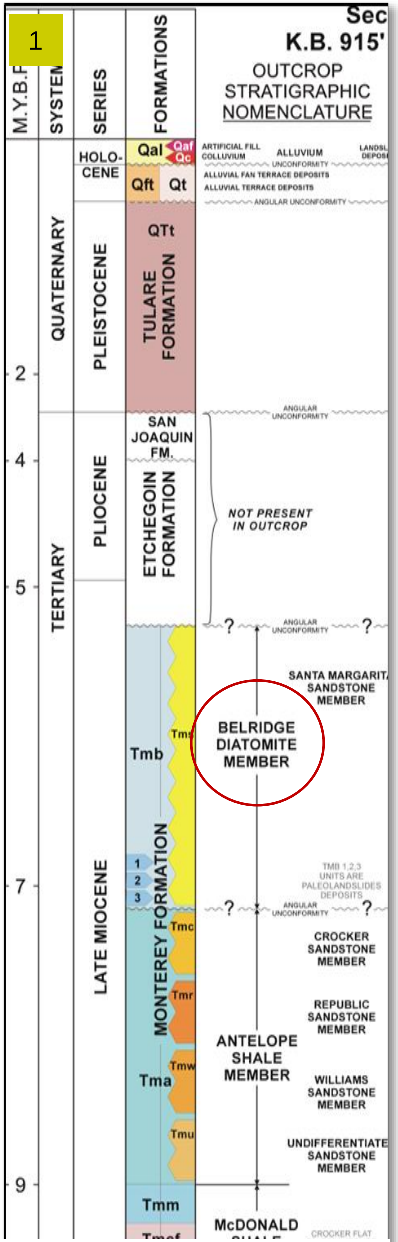
- Preferred orientation of particles parallel to vein walls
- Trains of particles (silt and diatom fragments) are subparallel to sharply defined walls

Where is this fracture study?
Midway-Sunset Field, San Joaquin Basin, CA.

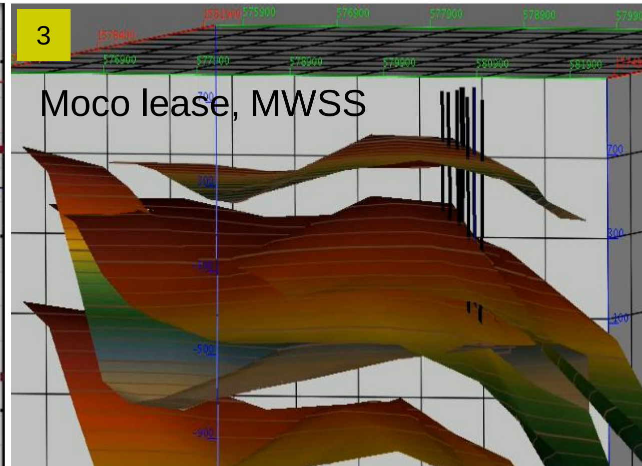


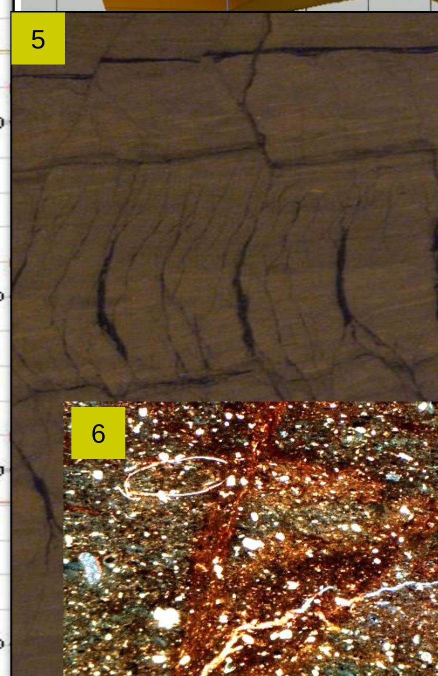
- Late Miocene oceanographic and climatic conditions controlled deposition of hemipelagic sediment in slope deposits of forearc basins
- Argillaceous biosiliceous sediment, in mid-to lower slope settings, developed a highly complex vein network as a result of sediment dewatering, mass wasting and tectonic episodes

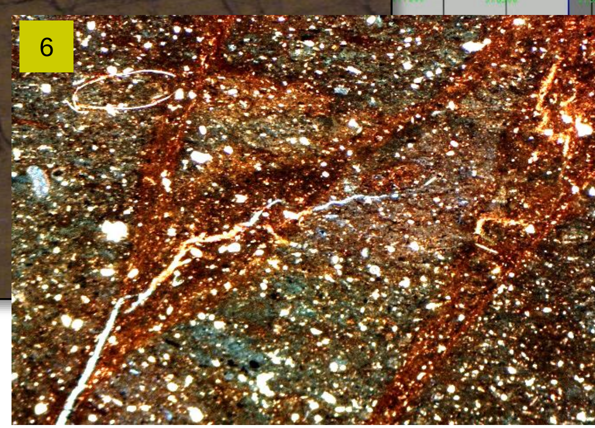
Opal-A diatomite vein studies, south MWSS



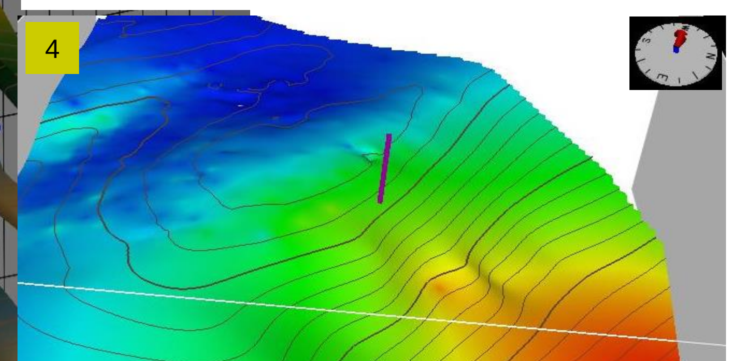
(Gregory, G.J., *in* Nilsen et al., 1996)

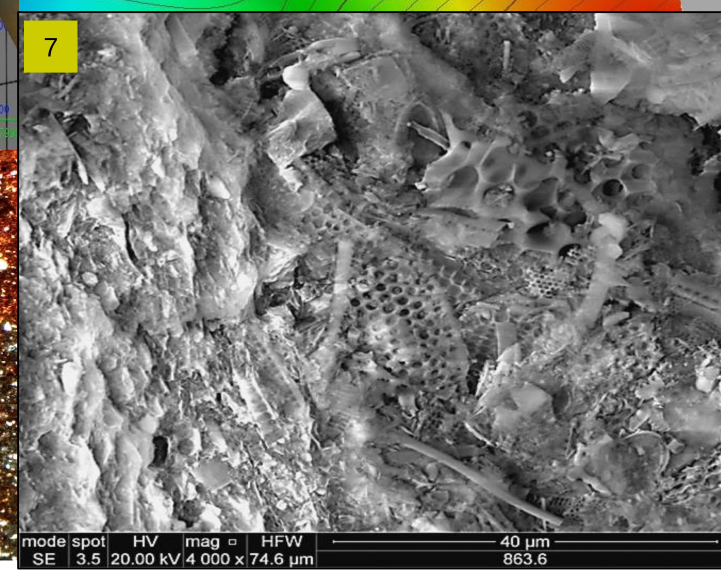


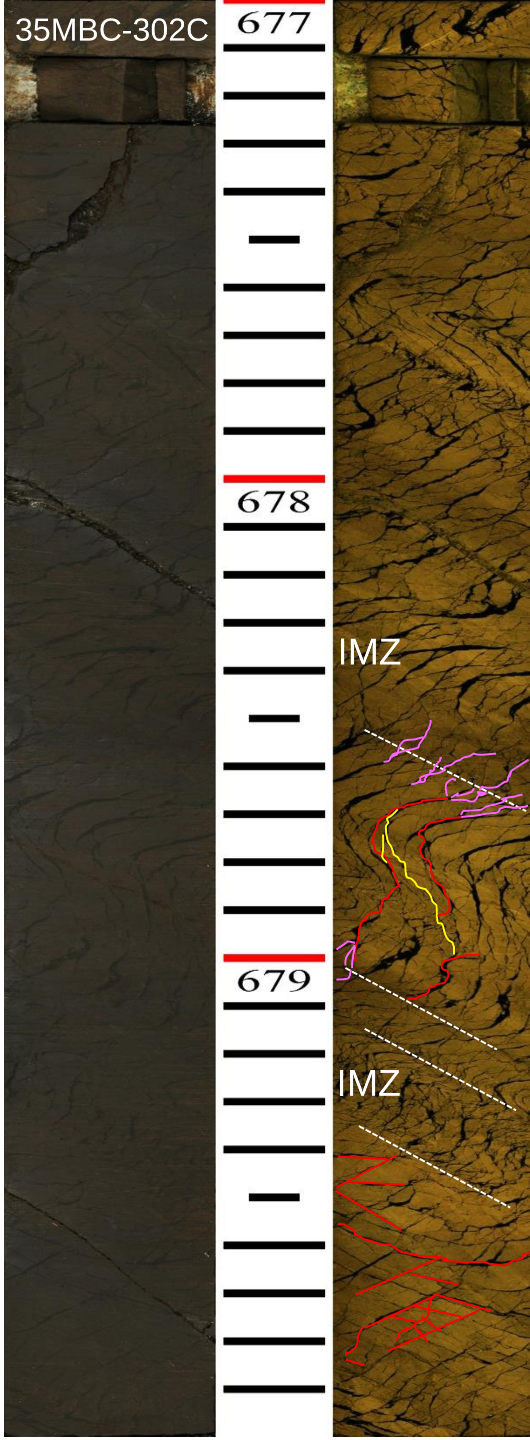




- Opal-A diatomite is a mechanically and lithologically varied highly fractured biosiliceous mudrock
- Natural fracture systems are weak planes that reactivate during induced treatments
- Exchange of ideas and understandings of fracture properties between engineering, geological and petrophysical staff is critical to insure that a synergy of knowledge exists







Veins are fractures and faults
Variable vein dip and azimuth

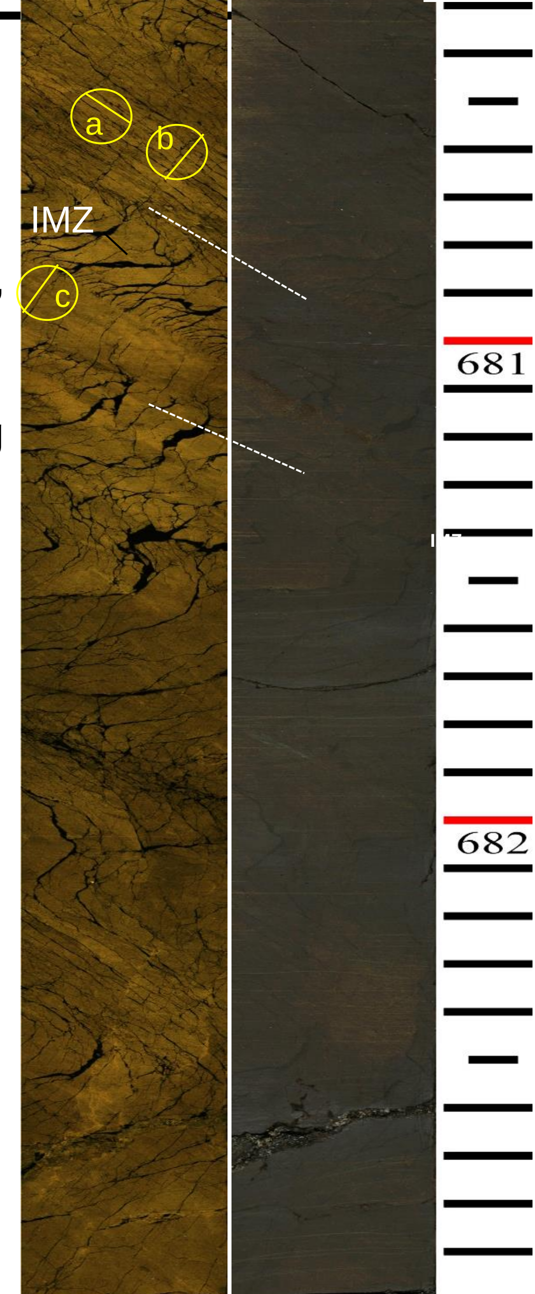
- Veins develop in response to sediment dewatering and slope instability
- Veins exhibit shear and extensional features
- Veins are sealed with finer grained matrix, darker in color, reduced porosity

- Veins are normal to subnormal to bedding
  - ➢ Bedding dip N 45.59°E; azimuth 26.29°
  - ➢ Fracture dip N 50.16°; azimuth 186.16° (vector mean from FMI log)

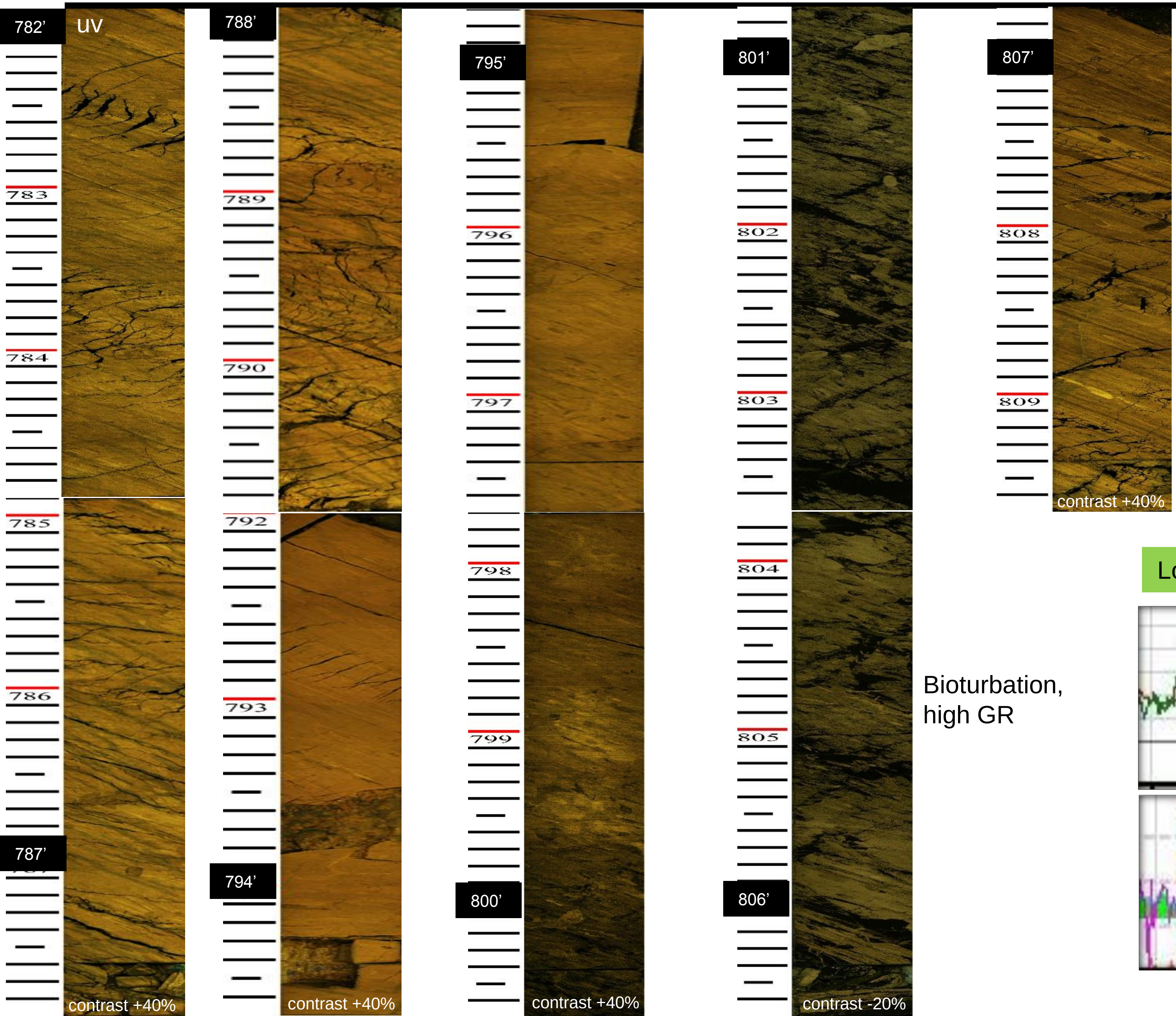
- Vein styles:
  - Tension gash arrays (TGAs)
  - Single discrete and wide
  - As extensional microfaults
  - As larger scale fold complexes in jointed matrix

- Vein fill is not hydrocarbon charged

- Intra-vein and vein parallel open fractures are zones of weakness

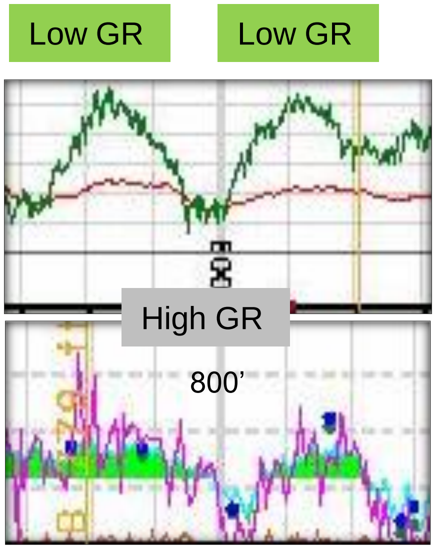


Core and corresponding log gamma ray (GR) curves - Matrix mineralogy influences the development of natural fractures



Vein fracture and fault geometry, occurrence and frequency is a function of lithofacies

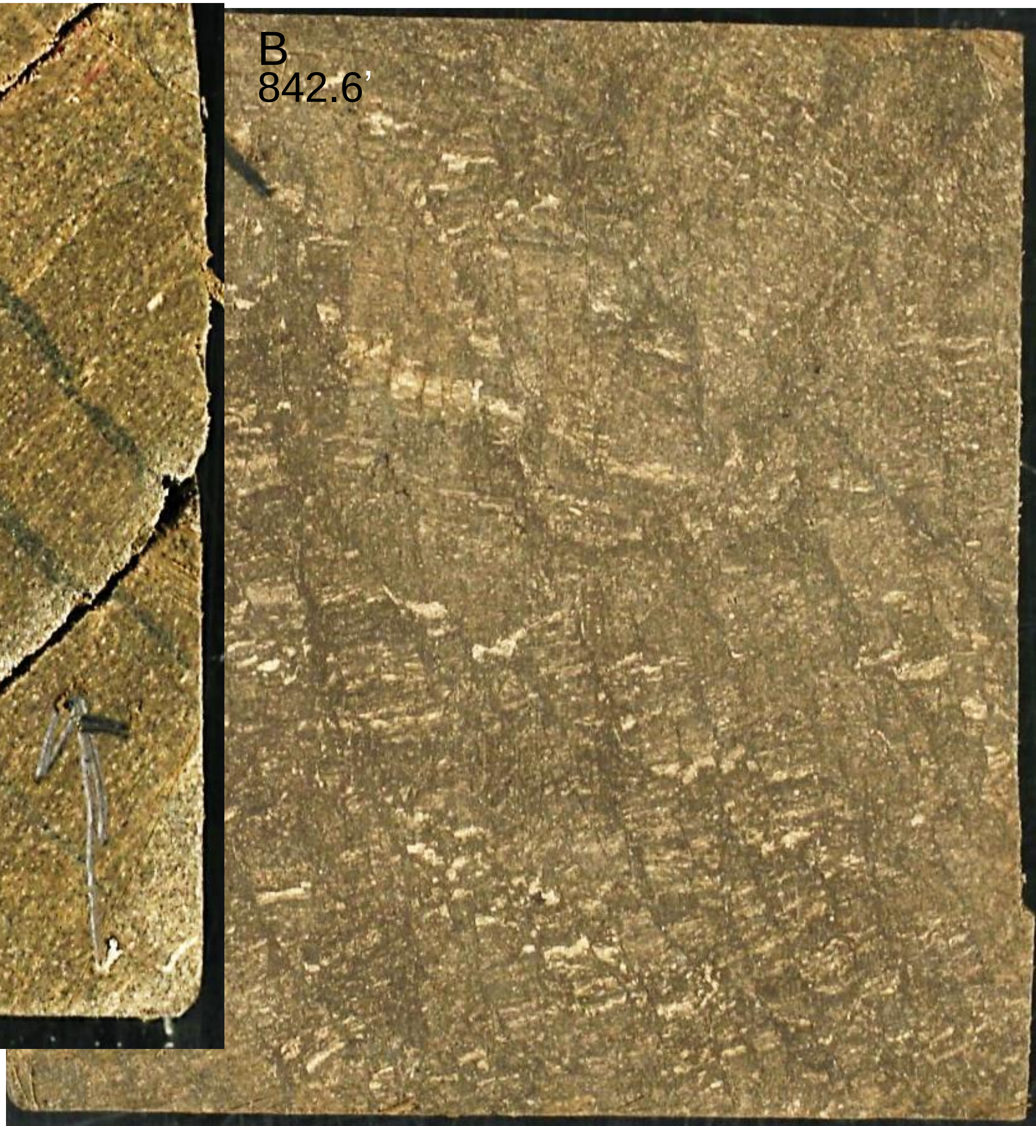
Low GR = less clay
High GR = more clay



RP8-2-3A

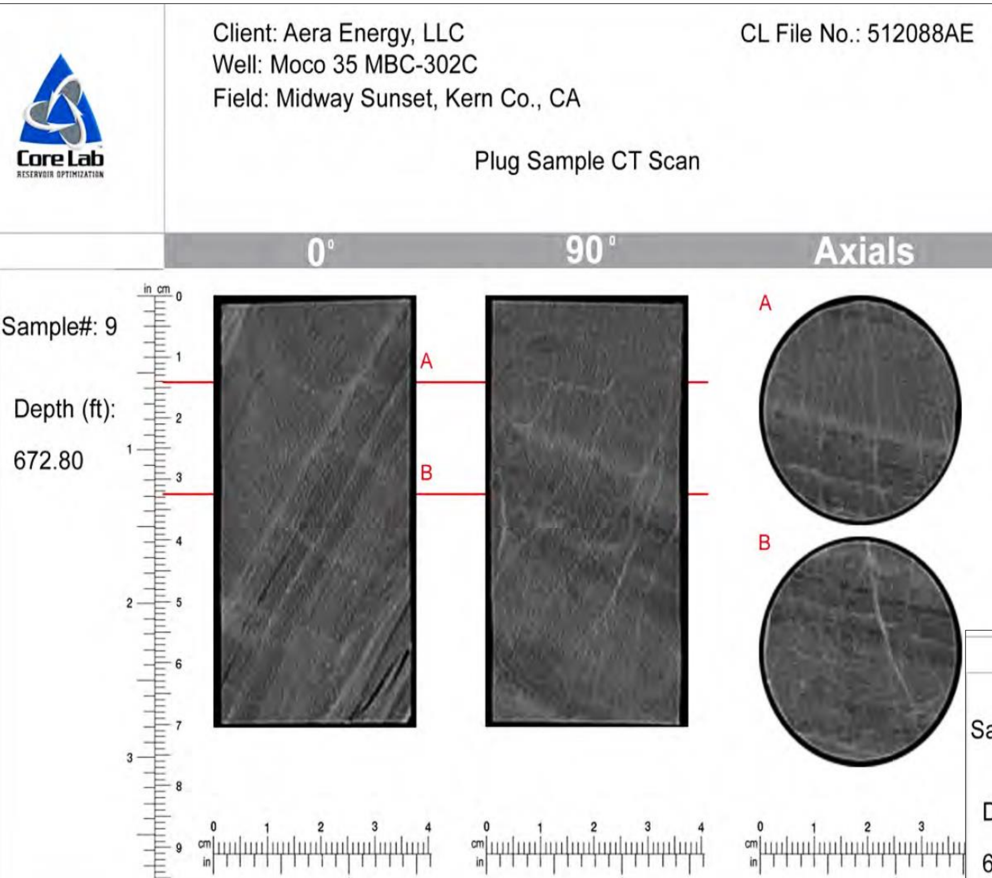
Tension gash arrays and microfaults

TGAs, discrete veins, stacked IMZs (A), normal to subnormal to bedding. Vein microfaults, offsets are along closely spaced veins (B)



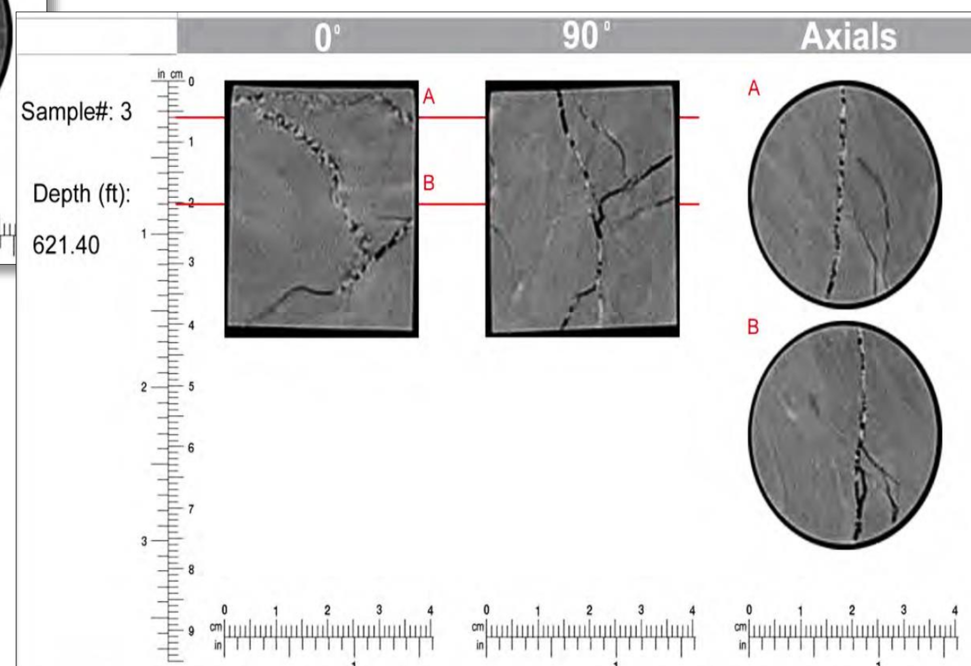
Computerized Tomography (CT) core plug scans

Doll Research, Cambridge, MA

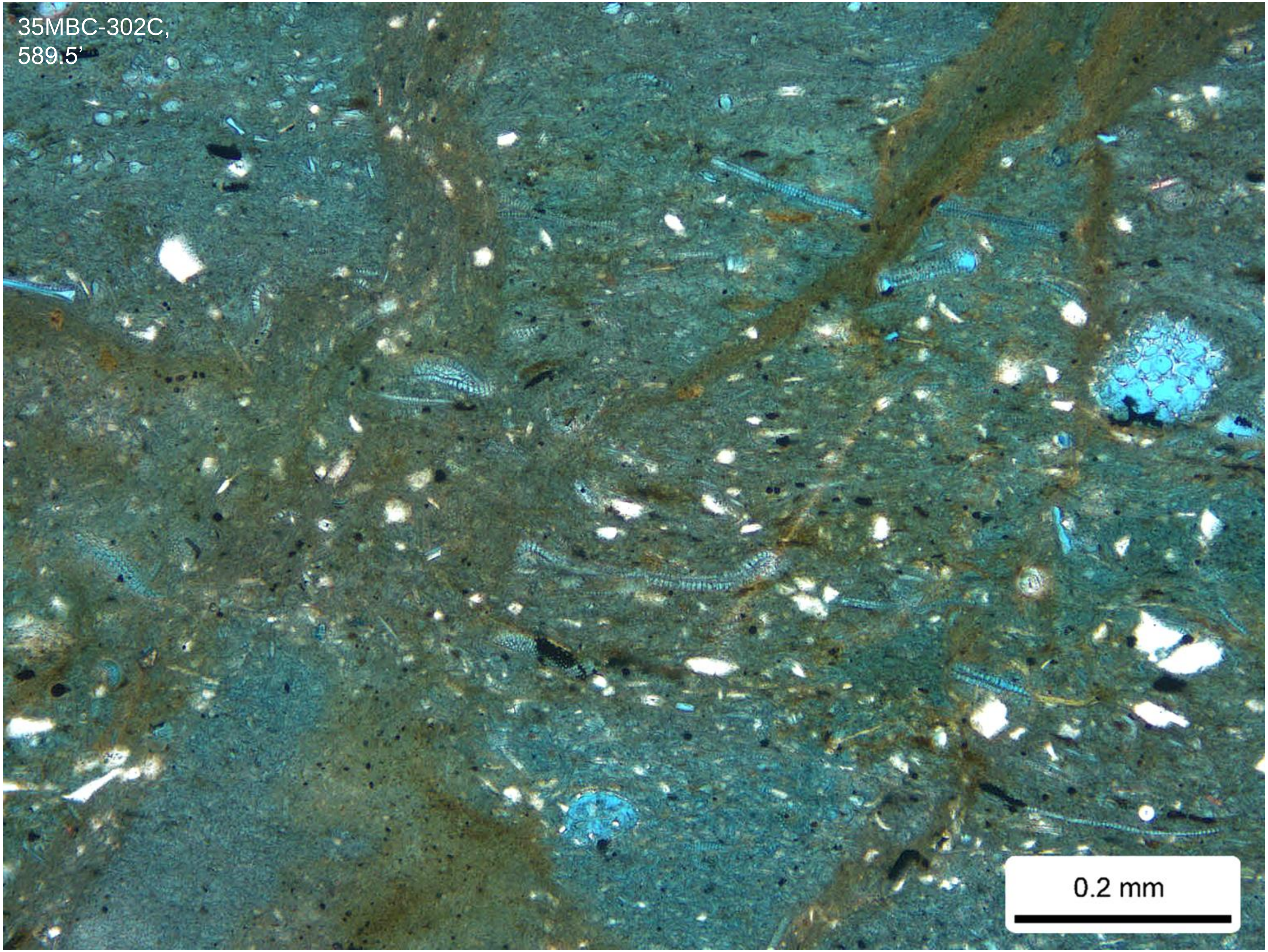


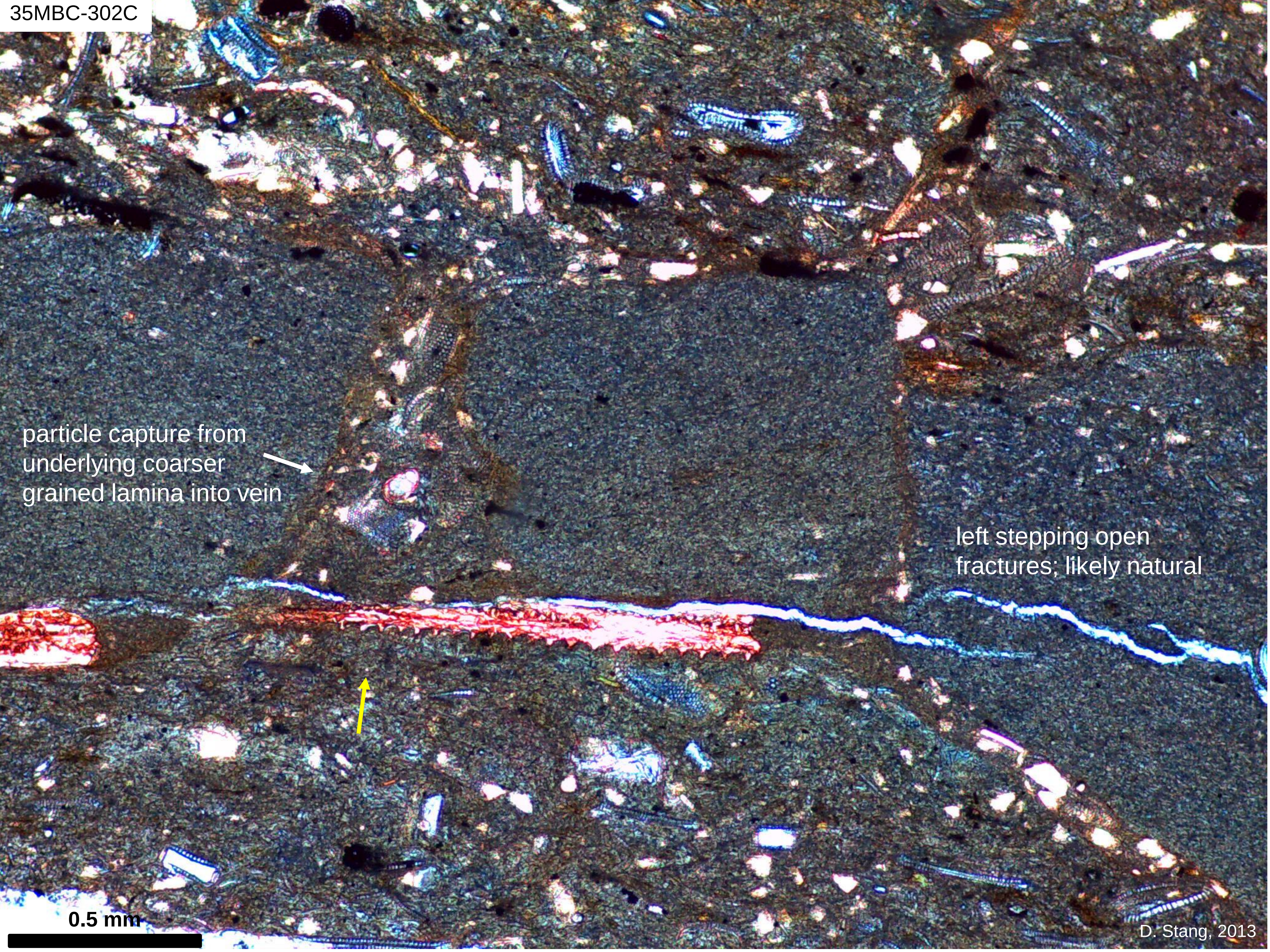
CT scans combine a series of X-ray views taken from many different angles to create cross-sectional images

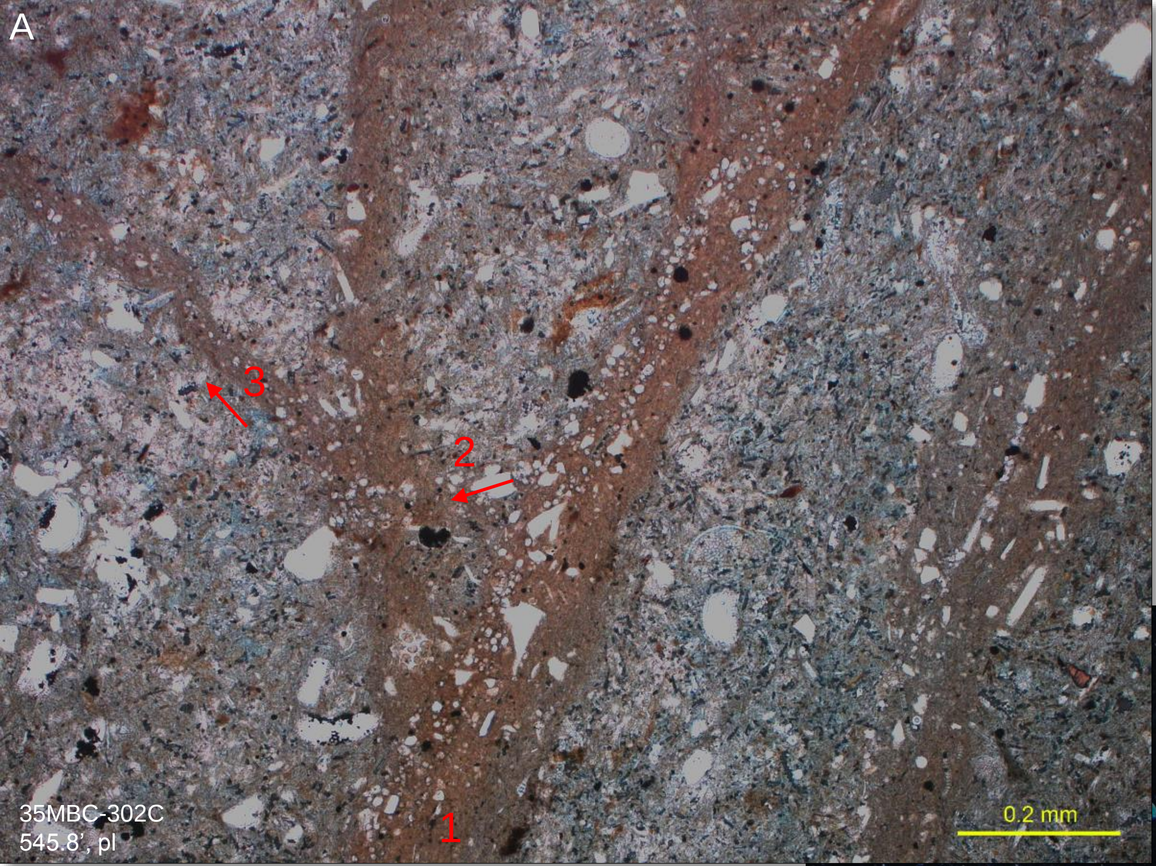
3-D images are used in vein mapping



Branched and anastomosing vein structure

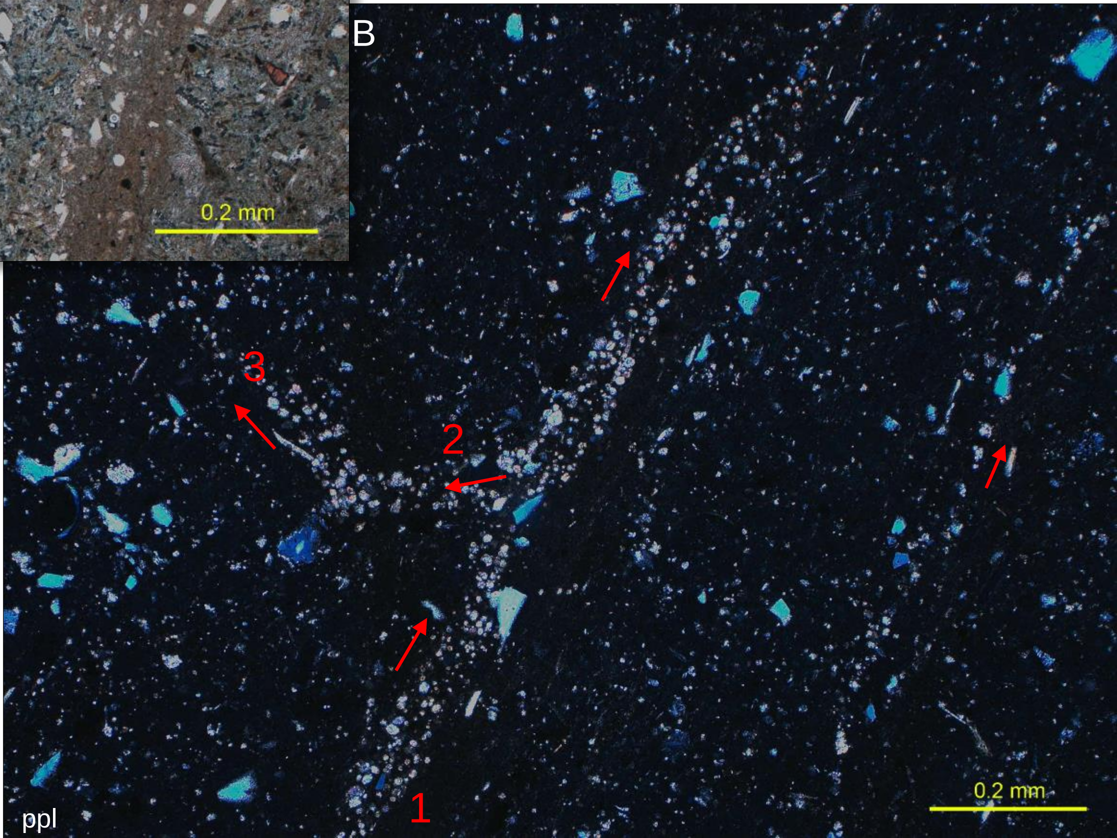



35MBC-302C
particle capture from underlying coarser grained lamina into vein
left stepping open fractures; likely natural
0.5 mm
D. Stang, 2013



Branched vein habit –
veins influence sedimentary microfabrics

- Sediment flushing and upward particulate mass transport of particles during sediment dewatering
- Subvertical particle realignment within veins
- Rounded to subrounded shape of diatom and silt particles within veins



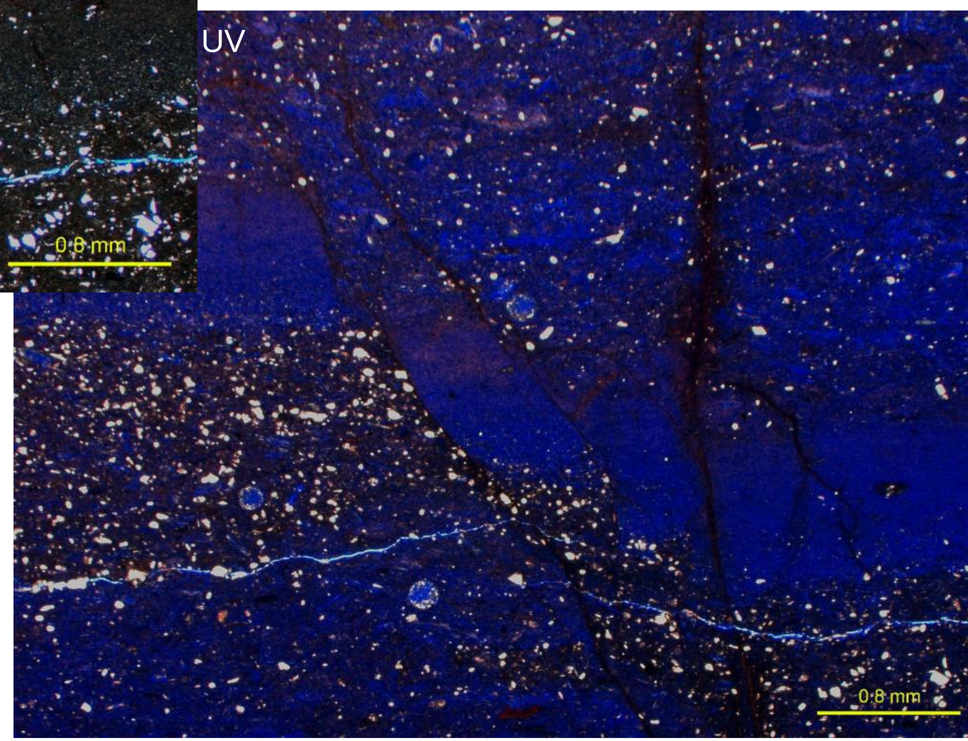
- “Streaming” of particles into vein from underlying lamina (B) and from side branches

- Plane polarized light distinguishes diatom frustules and silt from the matrix clay fraction

35MBC-302C
543’

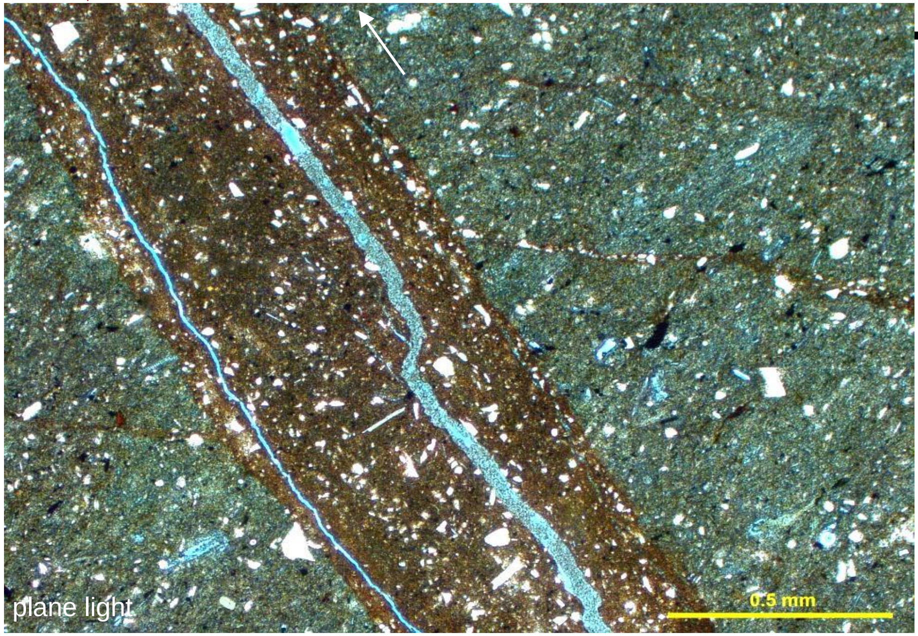
Branched veins

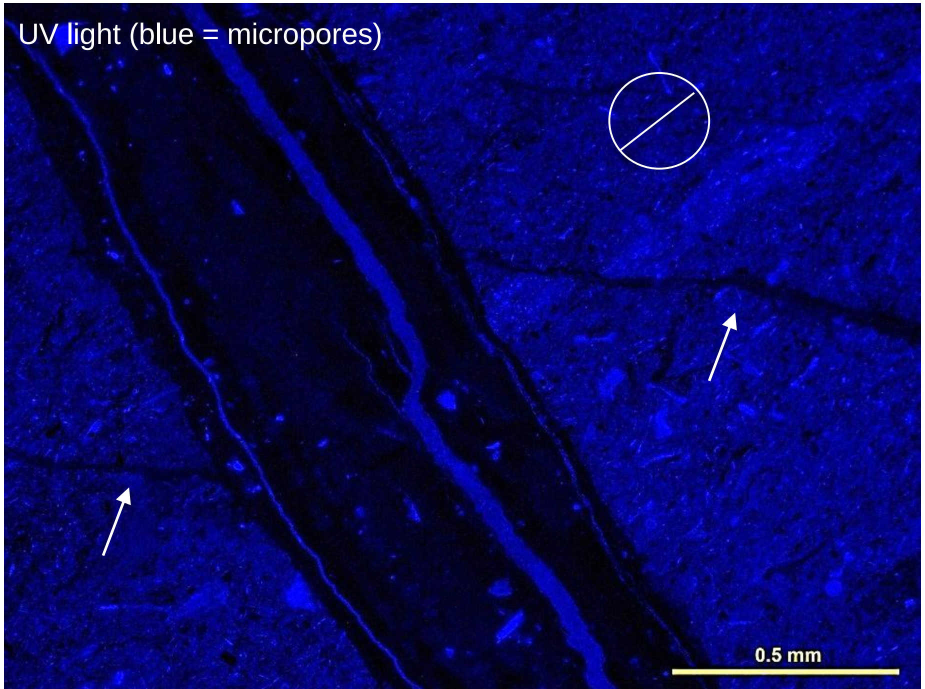
- Veins are faults, note offset
- Vein boundaries are often sharp
- Open fractures at bed boundaries
- Fining upward sequences



Moco 35D-192

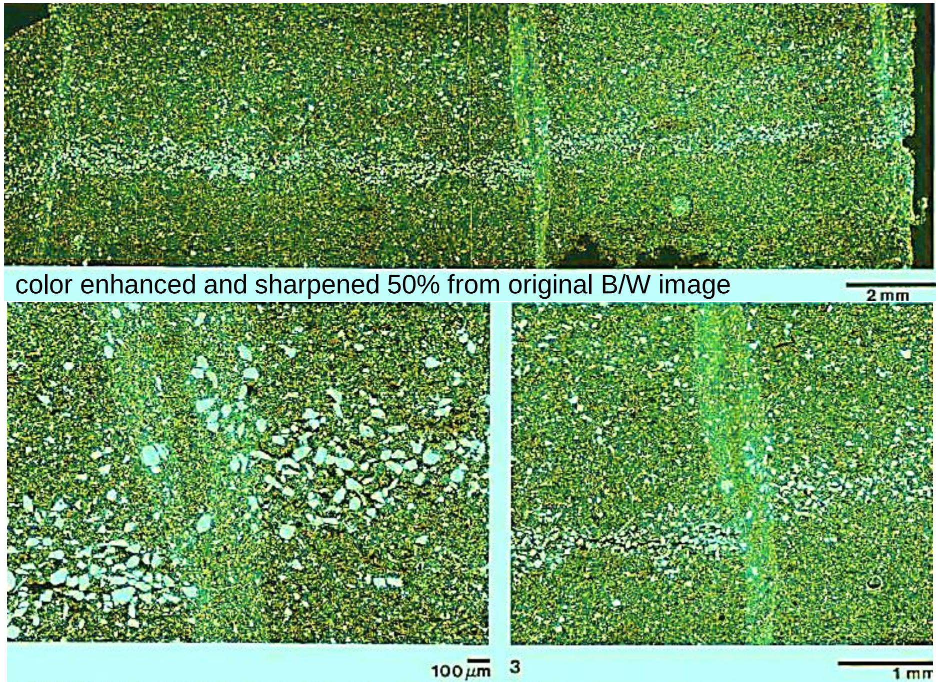
Intra-vein open fractures and adjacent vein offsets





- Wide vein is younger than adjacent thin vein oriented sub vertical; offset noted by arrows
- Thin vein is a fault that cuts bedding
- “Train” of single particle grains in thinner vein
- Particle reorientation subparallel to vein wall in large vein

“Impregnated silty diatomaceous mud shows evidence for upward mass transport related to upward of fluid migration in vein structures.” (*Kemp, 1990)*

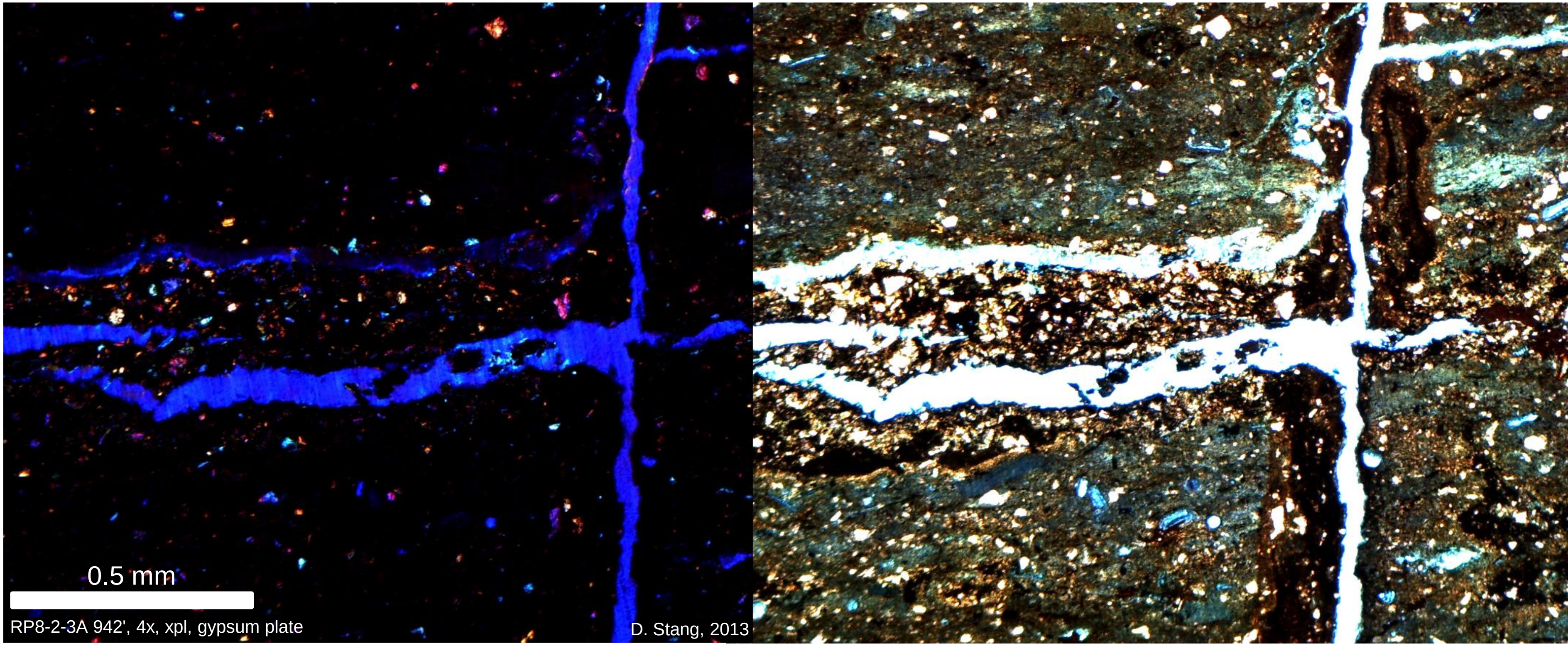


RP8-2-3A

AERA

Vein fill and intra-vein open fractures in a branched vein system

Core Lab

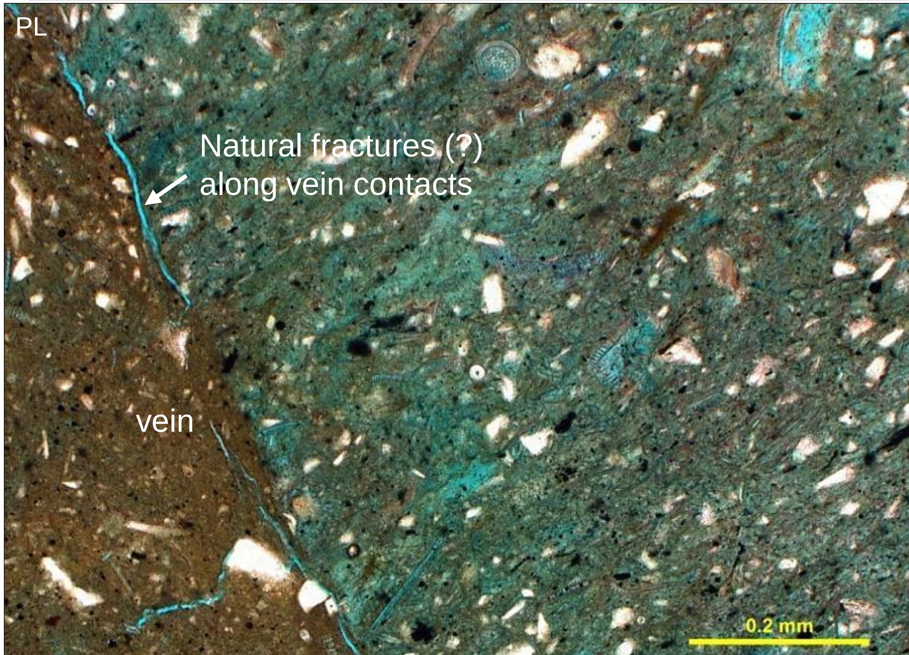


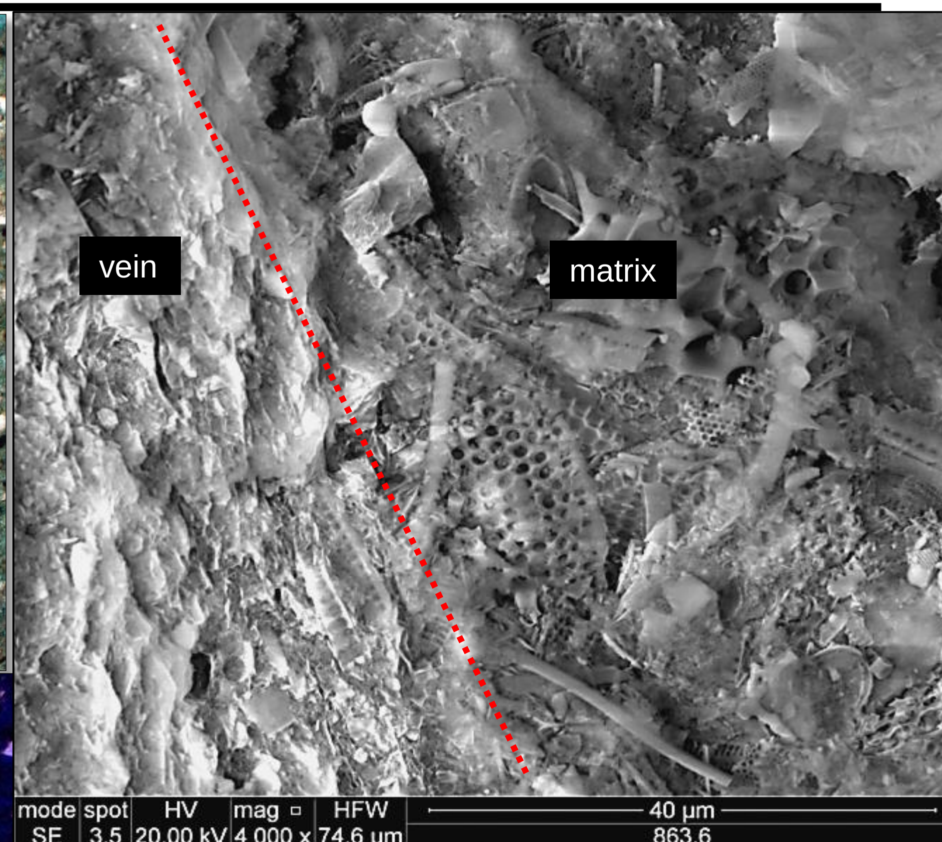
Vein fill and matrix mineralogy

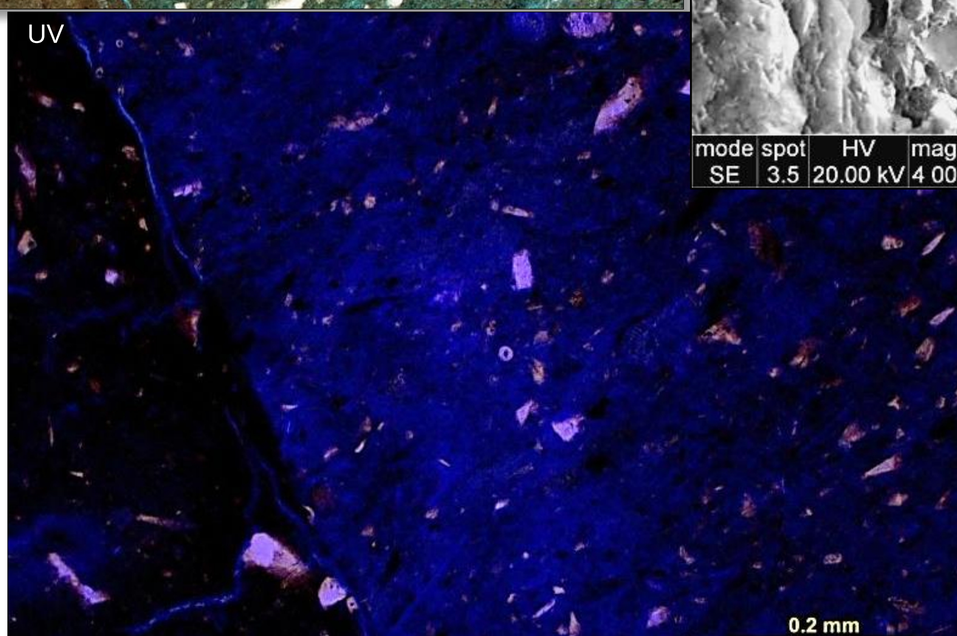
Sample	Sample	CLAYS				CARBONATES			OTHER MINERALS								TOTALS		
Identity	Depth (ft)	Chlorite	Kaolinite	Illite/Mica	Mx I/S*	Calcite	Dolomite(Fe/Ca^{+})[1]	Siderite	Quartz	K-spar	Plag.	Pyrite	Gypsum	Opal CT	Amorphous[2]	Barite	Clays	Carb.	Other
Vein Fill	833.75	1	Tr	4	5	Tr	1	Tr	13	10	26	2	1	1	36	0	10	1	89
Microfault Fill	833.75	1	Tr	3	4	Tr	1	Tr	12	7	19	2	1	Tr	50	0	8	1	91
Matrix	833.75	1	Tr	2	4	Tr	1	Tr	12	6	20	1	1	1	51	0	7	1	92

RP8-2-3A, 863.6’

Vein and matrix

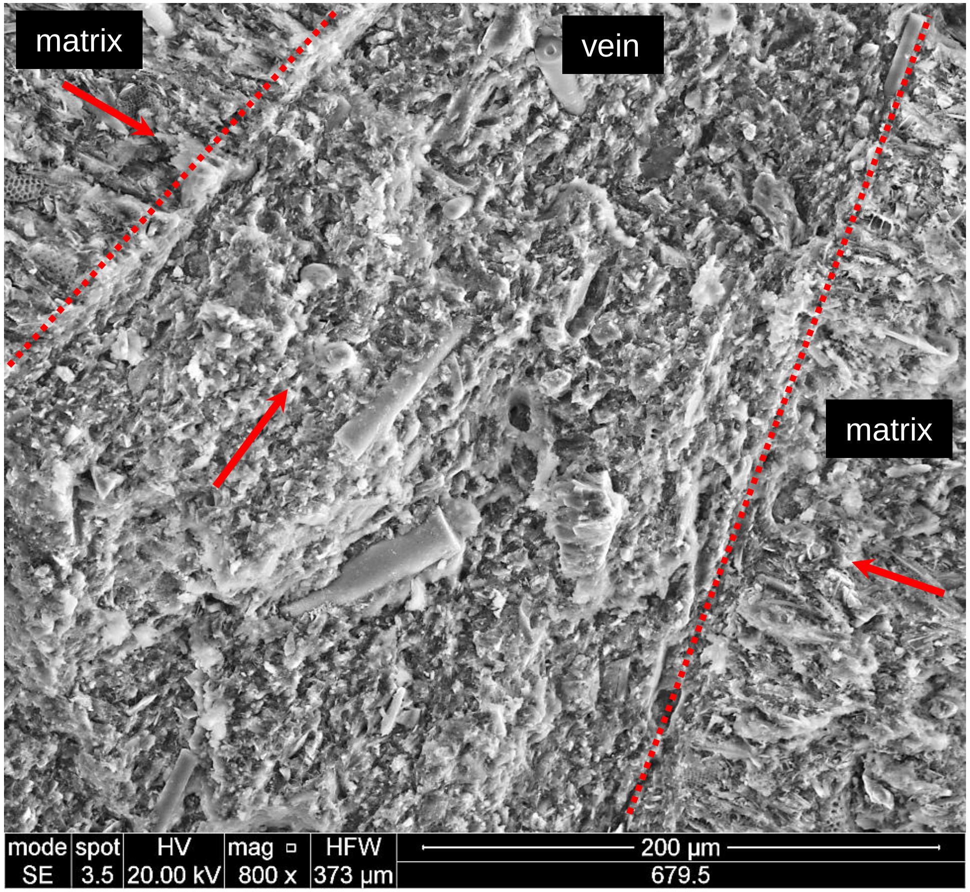


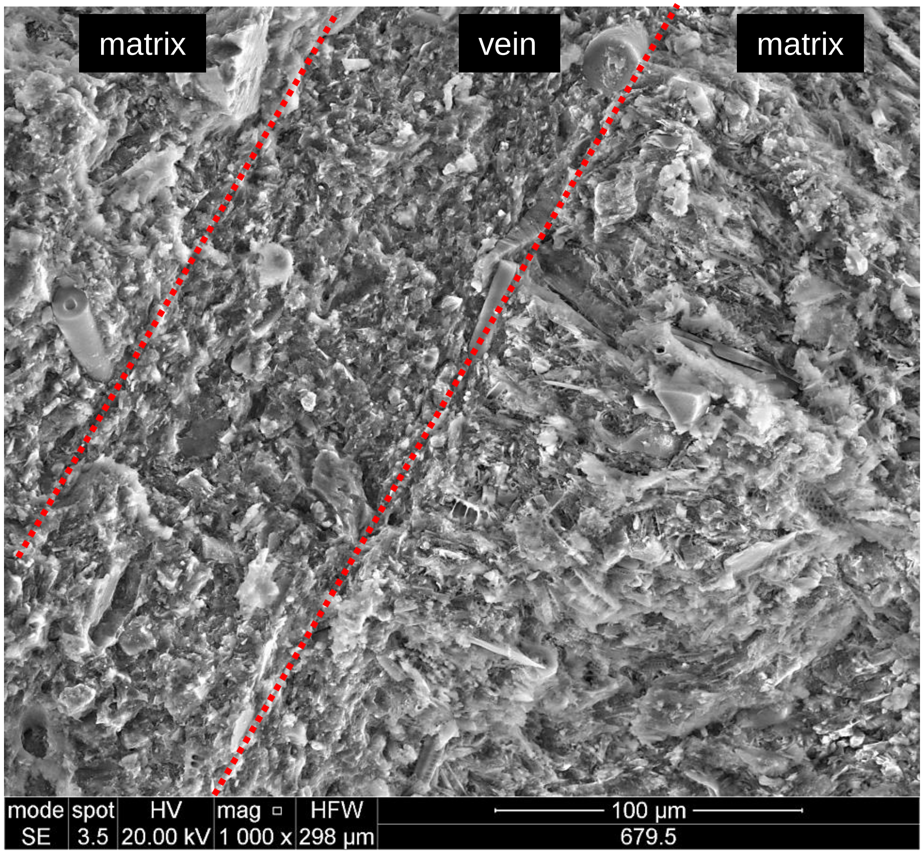




- Similar mineralogy
- Reduced porosity in vein
- Iron oxide red-brown coloration in veins
- Reorientation of particles in vein
- Open fractures develop along vein boundaries

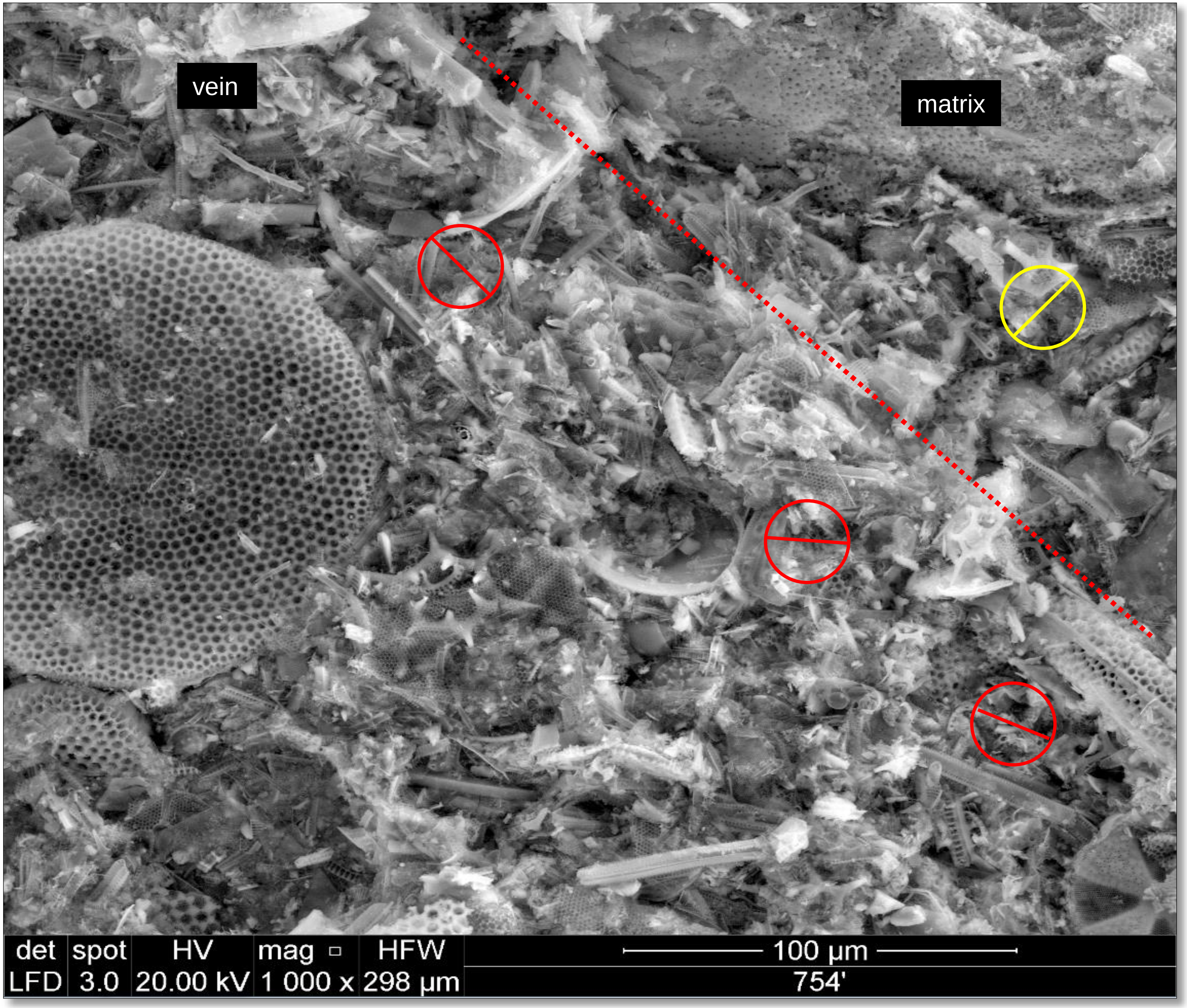
Vein and matrix





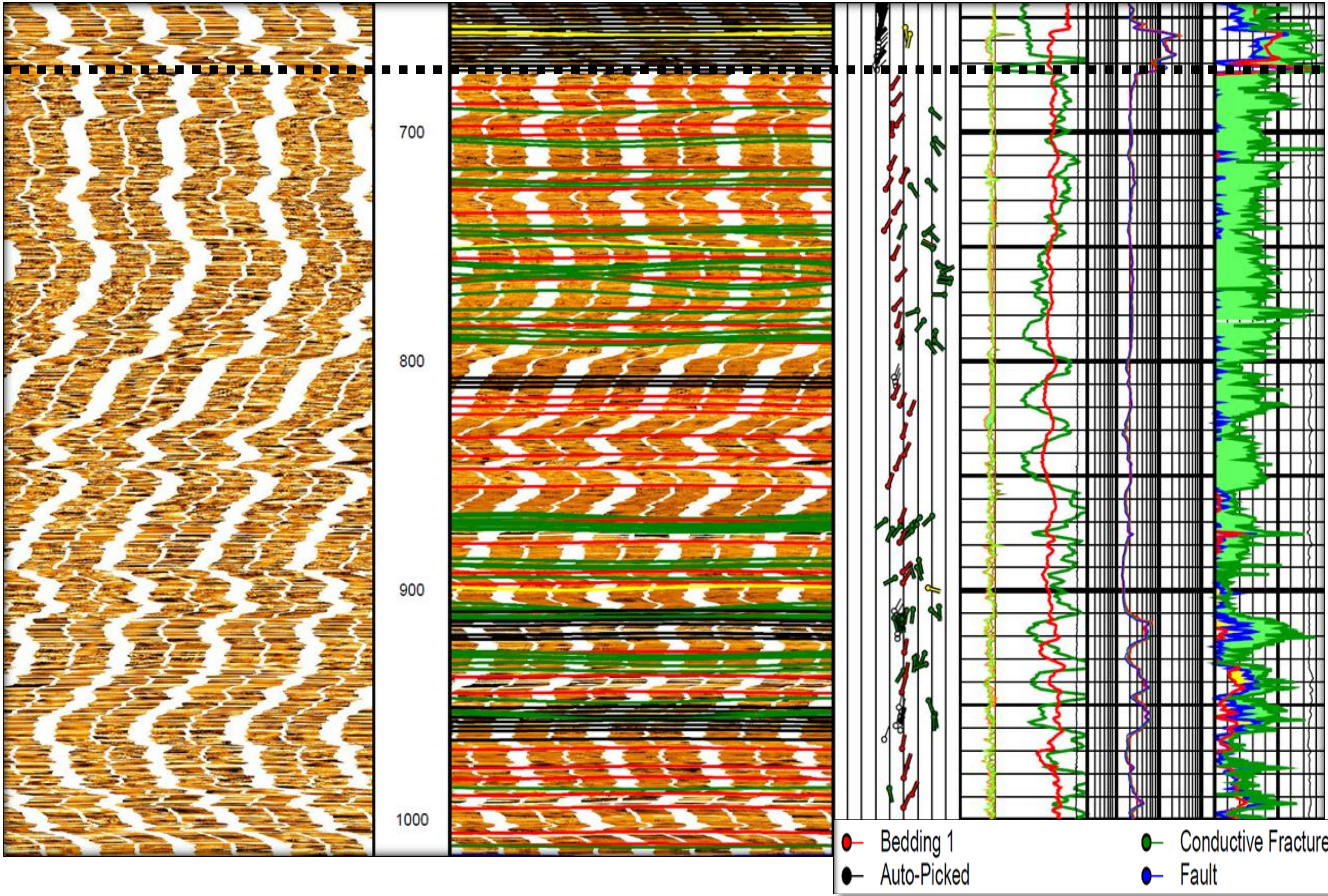
Particle realignment in vein, fluid flow streaming

Moco 35D-303A, 754', SEM



Conductive fractures are subnormal to bedding and intersect at high angles

Fracture dip vector mean 50.16°, azimuth vector mean 186.16°



Bedding dip stereonet

674'-1036' – diatomite interval

Fisher statistics
Vector Mean

Bedding

Dip	**Azimuth**
45.59	26.29

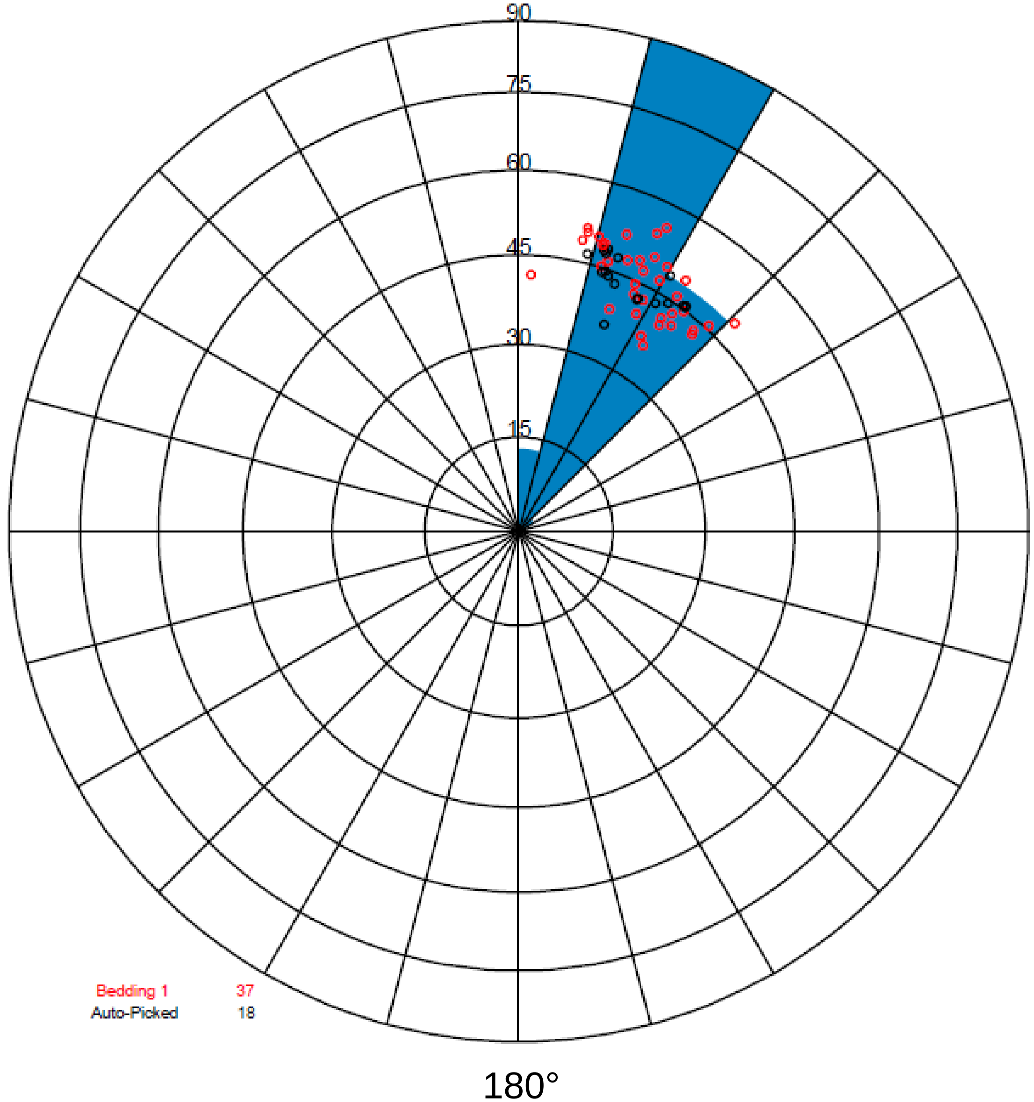
Fracture

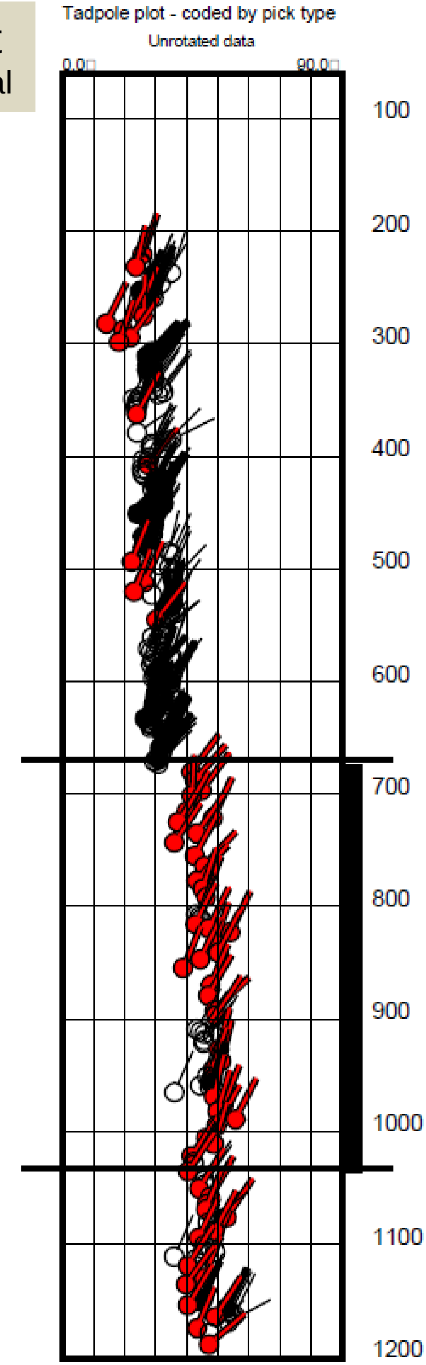
Dip	**Azimuth**
50.16	186.16

Fault

Dip	**Azimuth**
36.30	183.73

Well Name: MOCO 35 D-192
Rose bin size: 15.0
Rose rim value: Auto
Azimuth Plot
N = 55





Fisher statistics
Vector Mean

Bedding

Dip	Azimuth
45.59	26.29

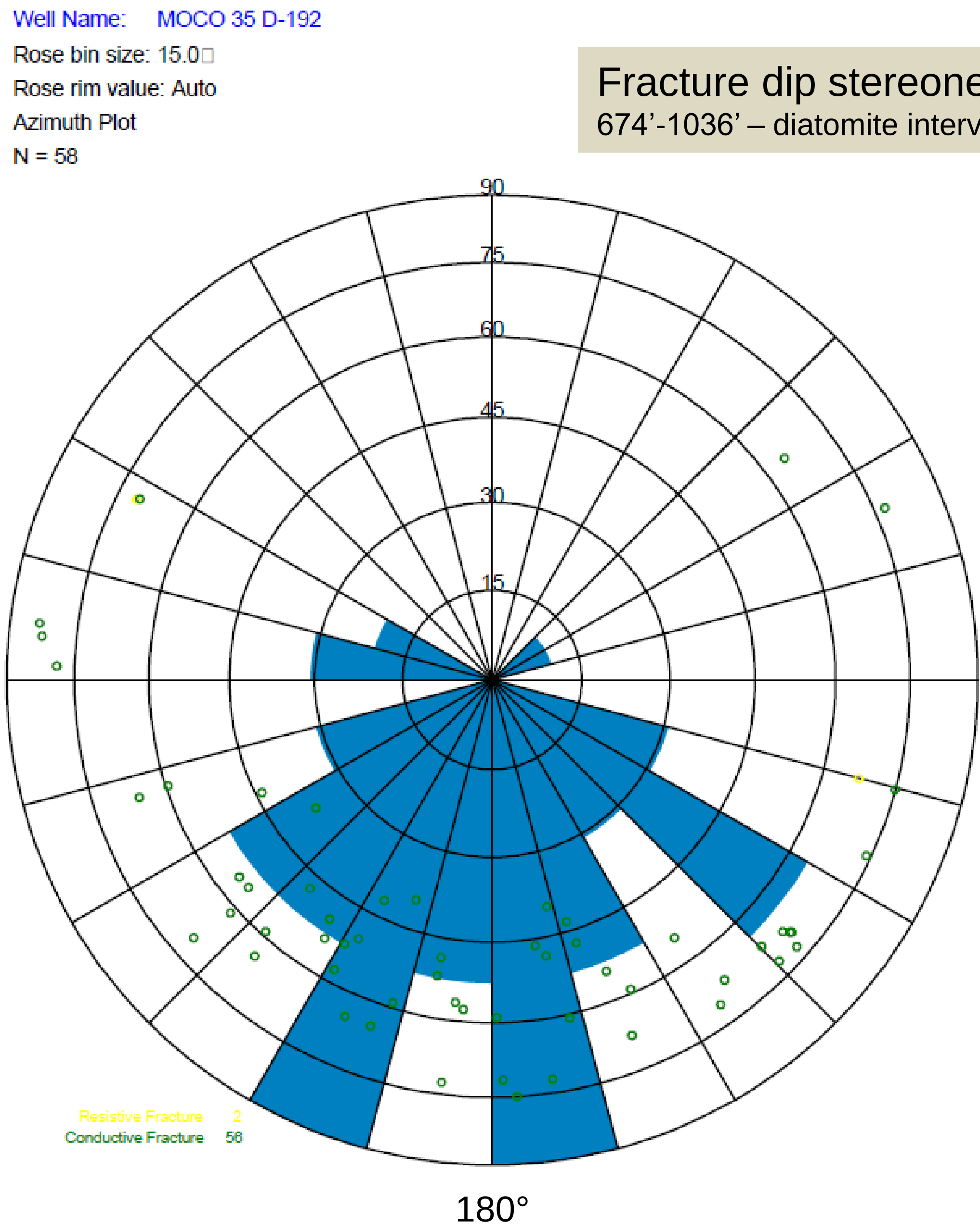
Fracture

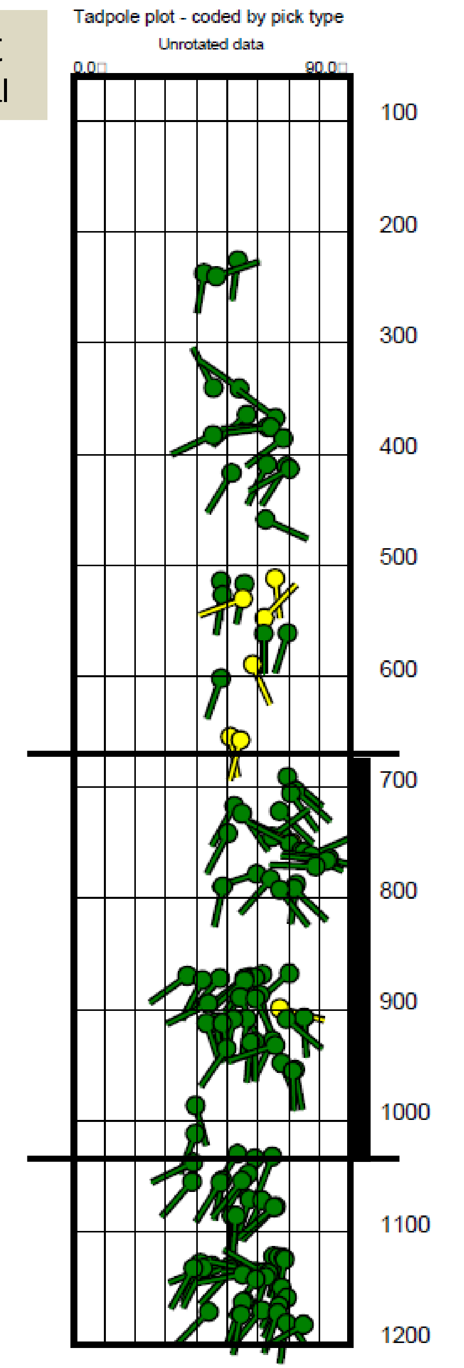
Dip	Azimuth
50.16	186.16

Fault

Dip	Azimuth
36.30	183.73

Fracture dip stereonet
674'-1036' – diatomite interval





Fisher statistics
Vector Mean

Bedding

Dip	Azimuth
45.59	26.29

Fracture

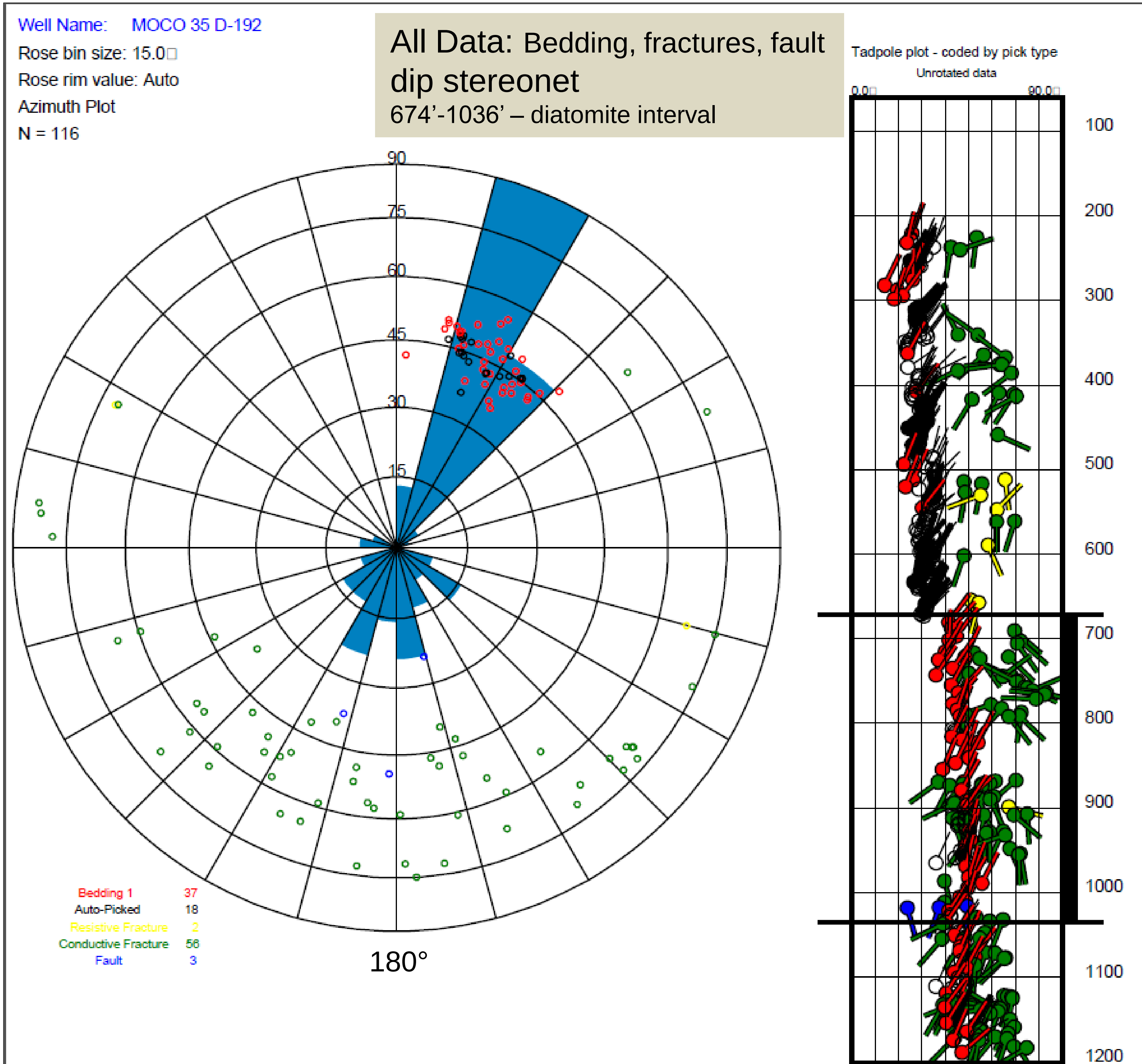
Dip	Azimuth
50.16	186.16

Fault

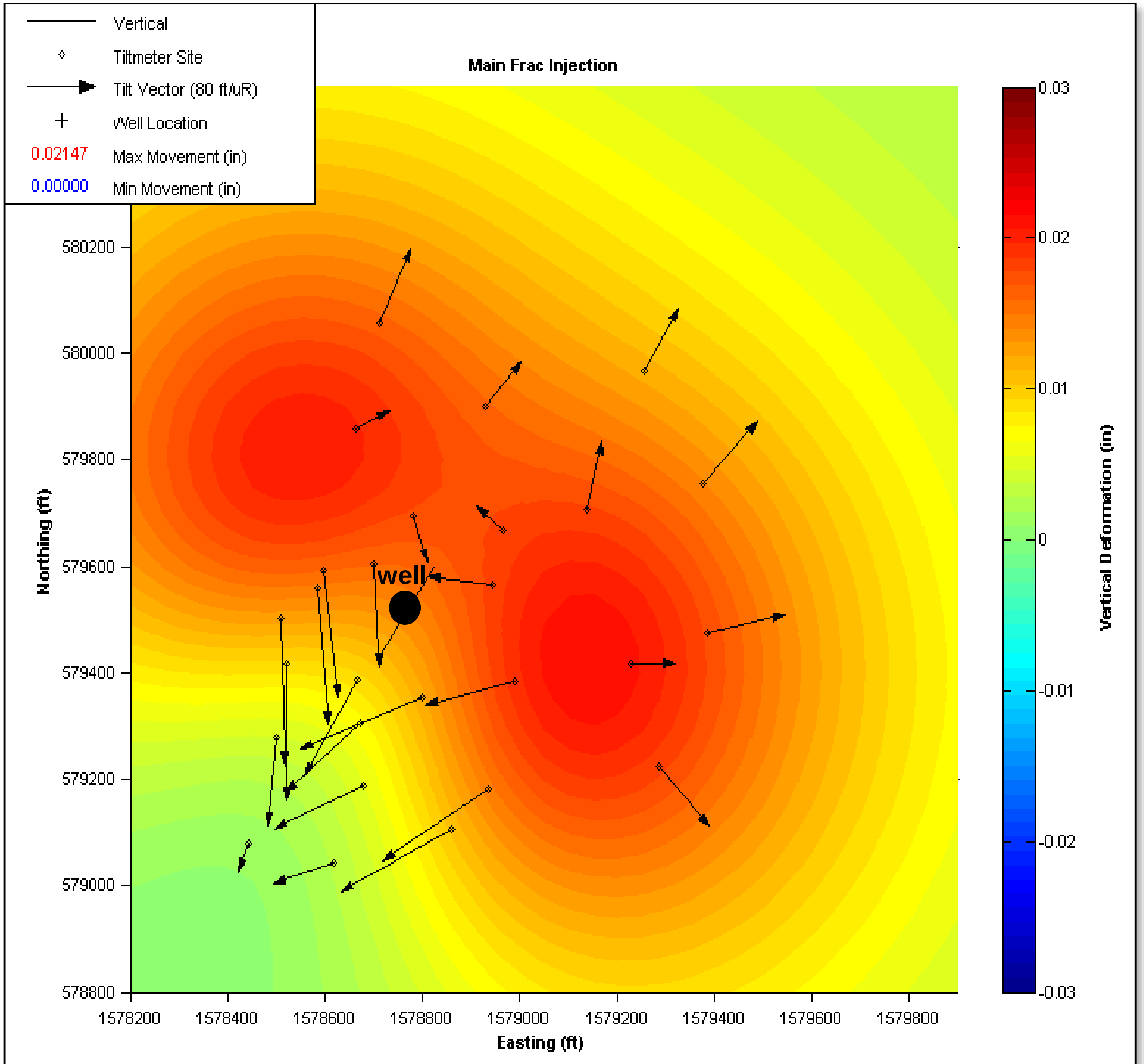
Dip	Azimuth
36.30	183.73

All Data: Bedding, fractures, fault dip stereonet

674'-1036' – diatomite interval



Surface Deformation Image
Well Moco 35D-192: Main Frac



Surface tiltmeter mapping measures the fracture induced tilt at points above a hydraulic fracture and then solves the geophysical inverse problem to determine the fracture parameters that produced the observed deformation field.

Direct measurement of critical fracture parameters:

- Hydraulic fracture azimuth and dip
- Fracture volume and location of fracture center
- Fracture complexity (multi-planar growth, fracture twisting, etc.)

Stage A (Main Frac)

- Vertical fracture azimuth is N34ºE
- Dipping 90º (vertical)
- 36% horizontal fracture component

Fracture top 660 ft

Fracture Orientation Results
Moco 35D-192

Stage	Treatment Data/Time	Perf Interval (ft)	Azimuth	Dip	Vertical Component	Horizontal Component
Stage A Injection Test	4/12/2013 (9:19 – 9:28)	740 - 890	N 34º E ±2º	87º ±2º down SE	60%	40%
Stage A Main Frac	4/12/2013 (10:32 – 10:39) End of Pad	740 - 890	N 33º E	87º ± down SE	62%	38%
Stage A Main Frac	4/12/2013 (10:32 – 10:46) End 2 ppg	740 - 890	N 35º E	89º ± down SE	60%	40%
Stage A Main Frac	4/12/2013 (10:32 – 11:08) End 6 ppg	740 - 890	N 34º E	89º ± down SE	59%	41%
Stage A Main Frac	4/12/2013 (10:32 – 11:22) End of Job	740 - 890	N 34º E ±2º	90º ±2º (vertical)	66%	34%

Induced fractures propagate at a higher dip angle (70-80°) compared to FMI log derived dip; induced fractures are more closely aligned to the upper natural fracture sets

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