Sandstone Injectites of the Colorado Front Range: Age, regional extent, emplacement mechanism, and significance as a fluid migration pathway

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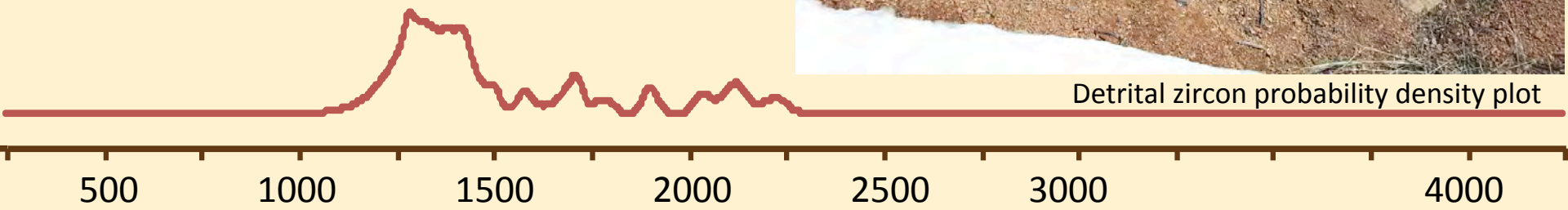
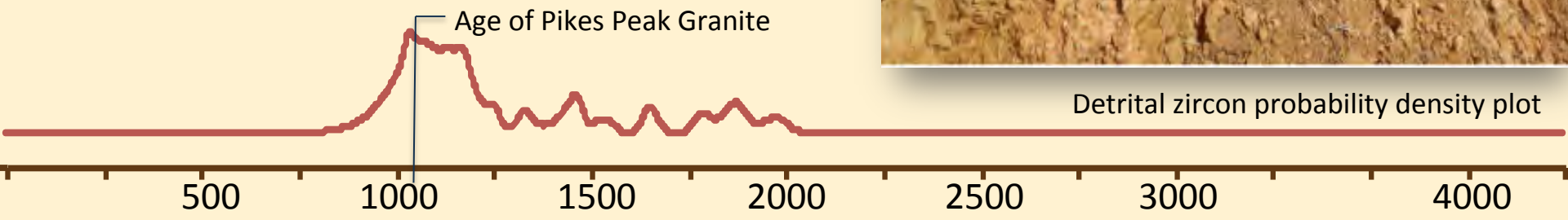
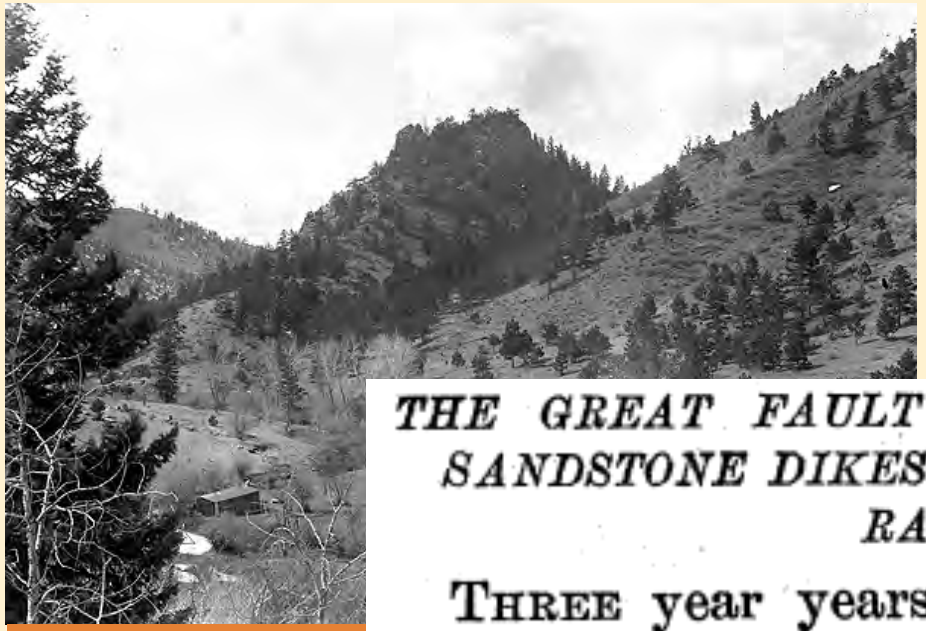


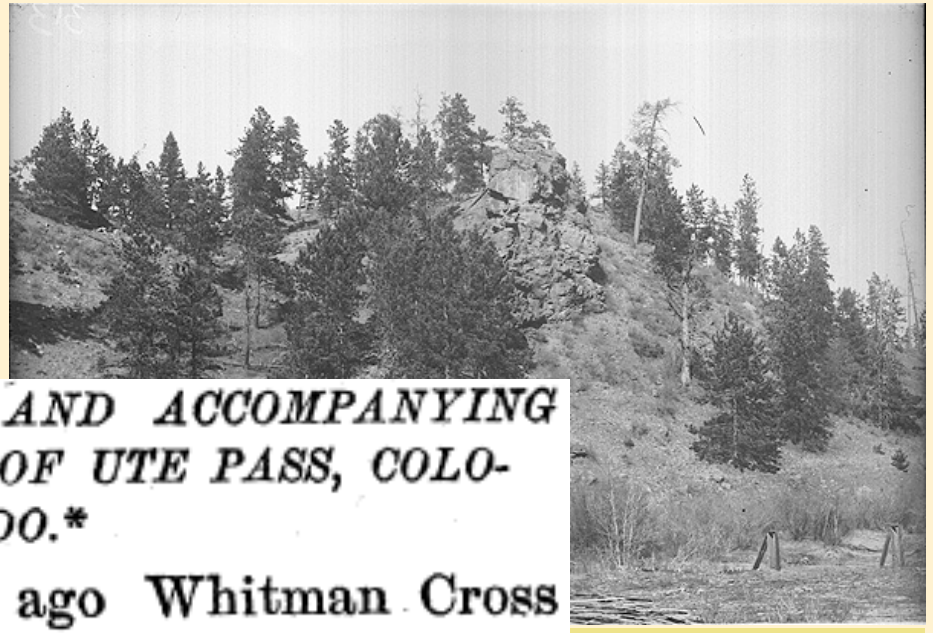
1/ Injectites: When and how did these form?

Crosscutting sandstone dikes, hosted by 1.08 Ga Pikes Peak Granite ; at least two injection events, separated in time.



Detrital zircon probability density plot





Chrystola, CO: Tab
ridge, 1 x 0.25 km
granite surrounds

Granite (very near the

t, so the vertical

THE GREAT FAULT AND ACCOMPANYING SANDSTONE DIKES OF UTE PASS, COLORADO.*

THREE year years ago Whitman Cross first directed the attention of geologists to the fact that dike-like masses of sandstone occur in the granite of the Pike's Peak massif, forming a belt about one mile wide extending north-northwest from the vicinity of Green Mountain Falls, in Ute Pass,

*Abstract of a paper read before the Boston Society of Na al History, January 20, 1897.

Images from George H. Stone Glass Plate Negatives, c. 1904
Special Collections, Tutt Library, Colorado College

Outline for this talk

1/ Tava sandstone – location and characteristics

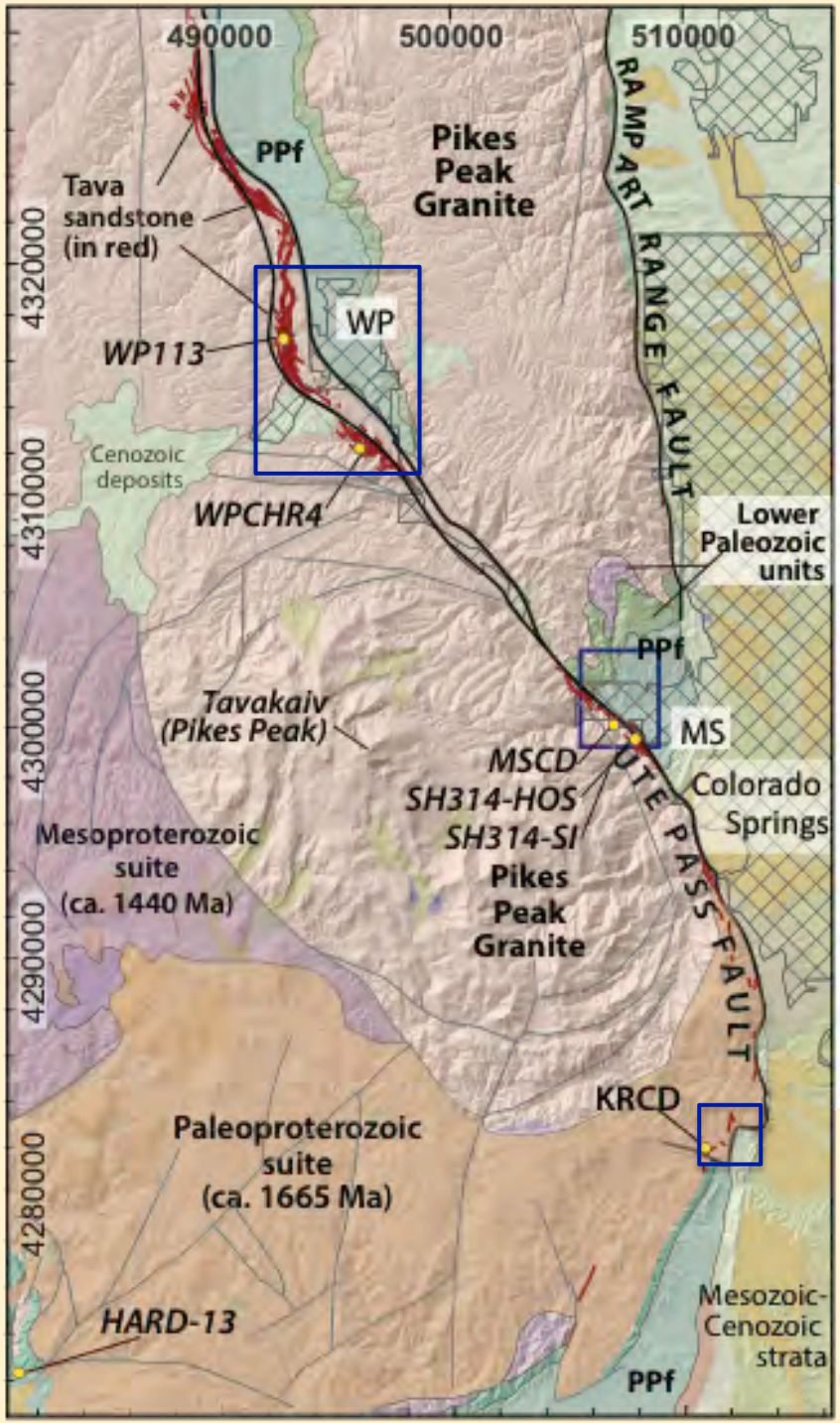
2/ Colorado injectites – *once an oddity, now a beacon from the Proterozoic:* Age determined from detrital zircon reference spectra

3/ Parameters for emplacement, with bearing on emplacement mechanisms and triggers

association with hydrocarbon reserves

4/ Regional extent

5/ Paleoenvironments of Rodinia supercontinent



LOCATION

Distribution of Tava sandstone along the southern Ute Pass fault

- *multiple types of host rock*
- *sample sites at intervals along the fault … and further afield…*

Informal name: ***Tava sandstone***

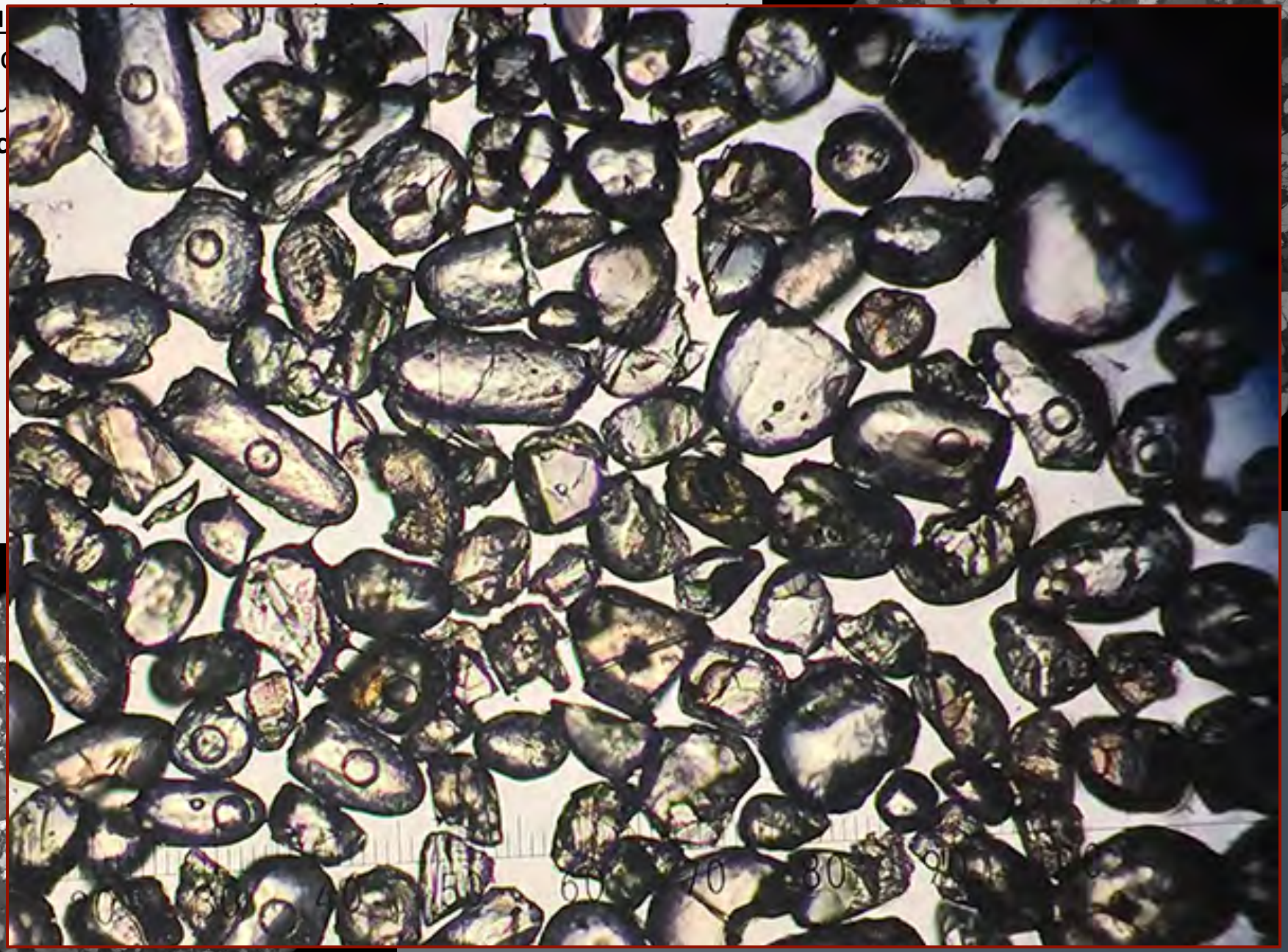
Distribution: along base of the Pikes Peak massif. ***Tavakaiv*** the indigenous name for the Peak, translates ~ as *Mountain-first-touched-by-the-Sun* (*Tabeguache Ute*).

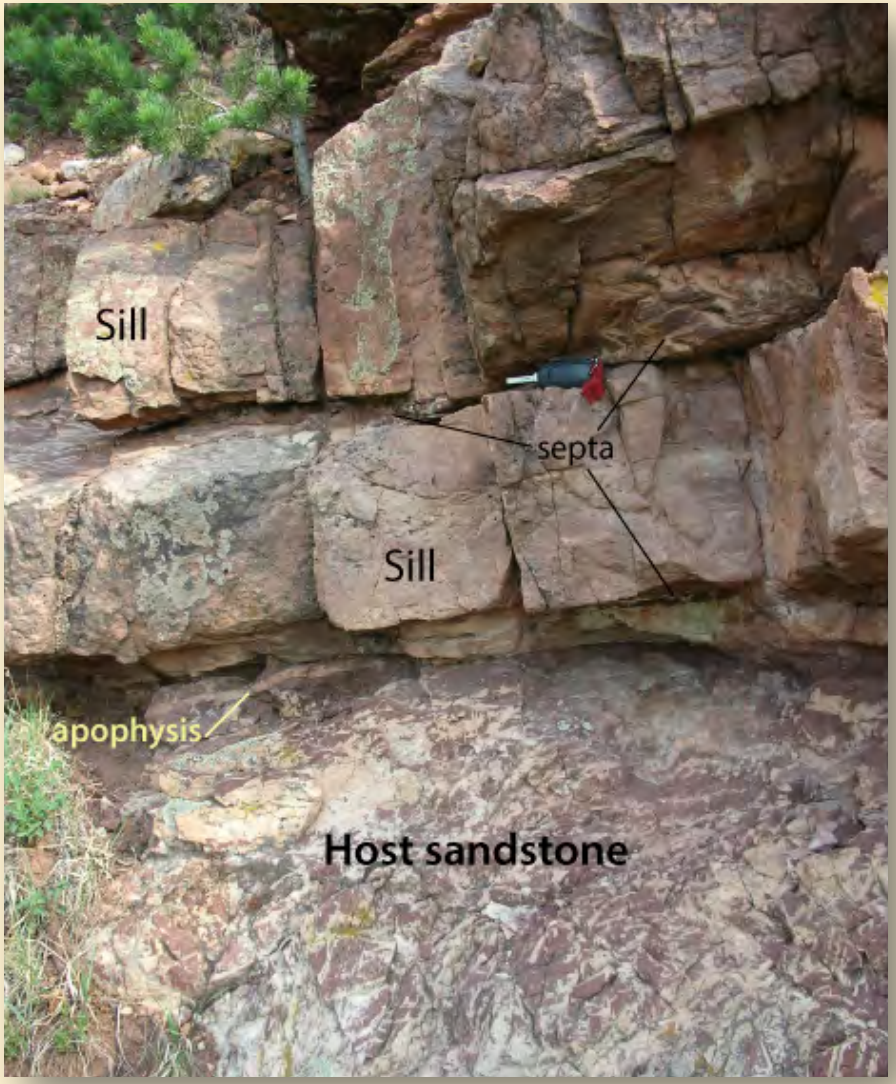
Red line pattern = Tava sandstone
Bold lines = faults
PPf = Pennsylv. Fountain Formation
upon simplified geological map

10 km


IN GOD WE TRUST
LIBERTY 1972

Qu
poo
tou
Acc



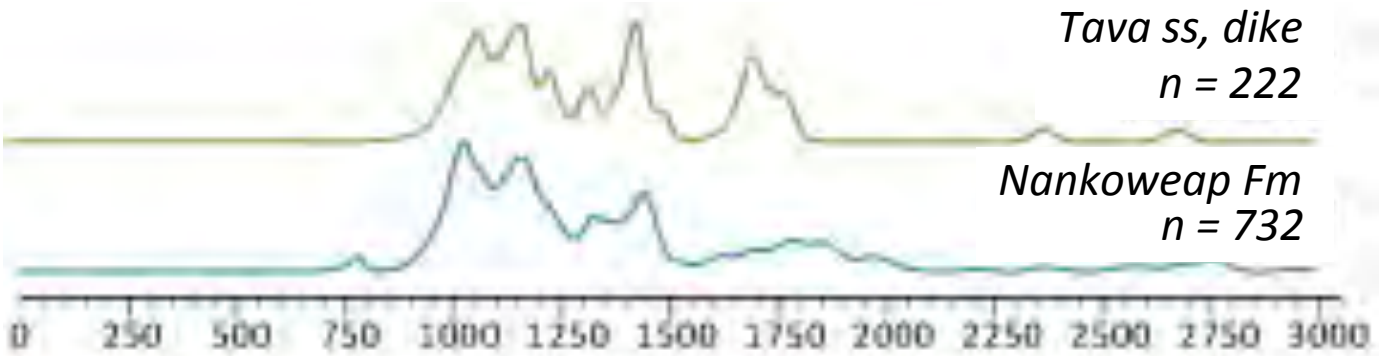


Kms-scale fault-bounded sandstones also are cut by injectites. Shared characteristics :

Isolated ("floating") quartz granules to pebbles, 2mm to 6 cm in length
Matrix-supported – uniform fine quartz sand, well rounded.
Absence or paucity of clay

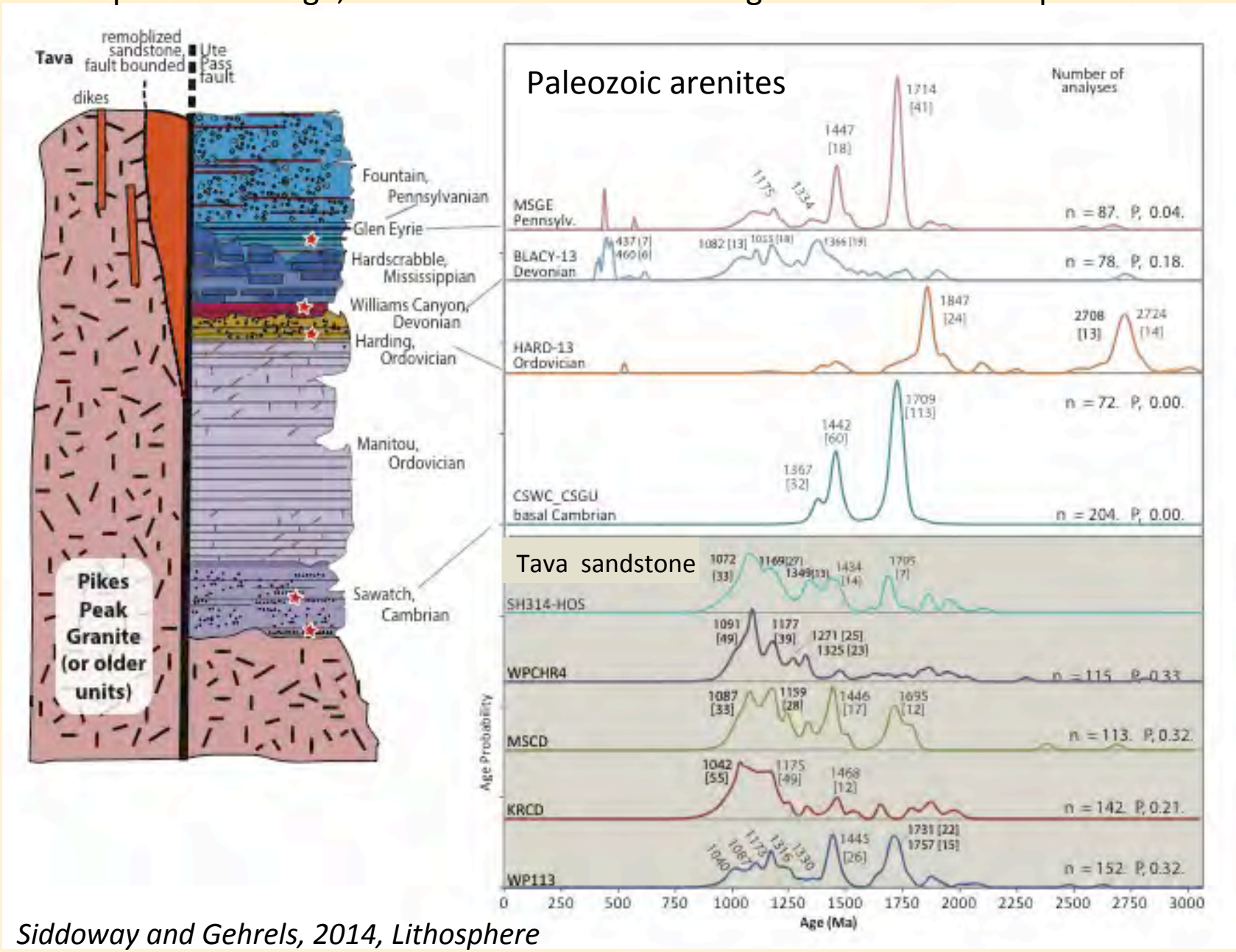
These point to a **common age and origin** in a dynamic tectonic setting that experienced rapid sedimentation, high pore fluid pressure, and liquefaction/ injection events.

Neoproterozoic age (circa 750 Ma) established on this basis: **contemporaneous rock units incorporate detrital zircon from regional reservoirs** that contain **diagnostic zircon age populations.**



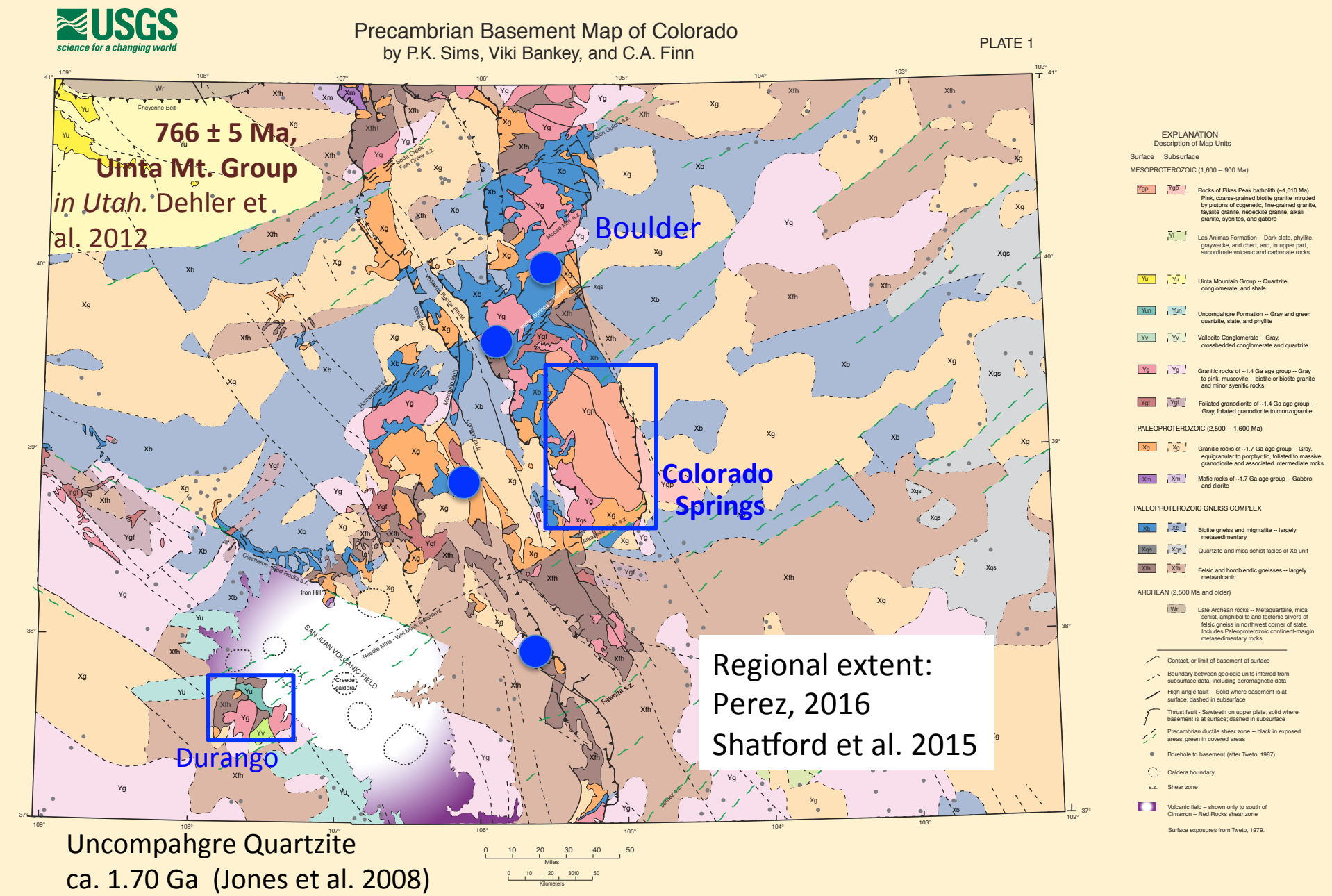
Visual and statistical comparison of normalized probability density plots, such that the area beneath the plot is the same for all samples, irrespective of number of analyses.

Neoproterozoic age, on basis of Detrital Zircon age distributions and provenance



Siddoway and Gehrels, 2014, Lithosphere

Sandstone hosted by Proterozioc crystalline rock, not restricted to Ute Pass fault system

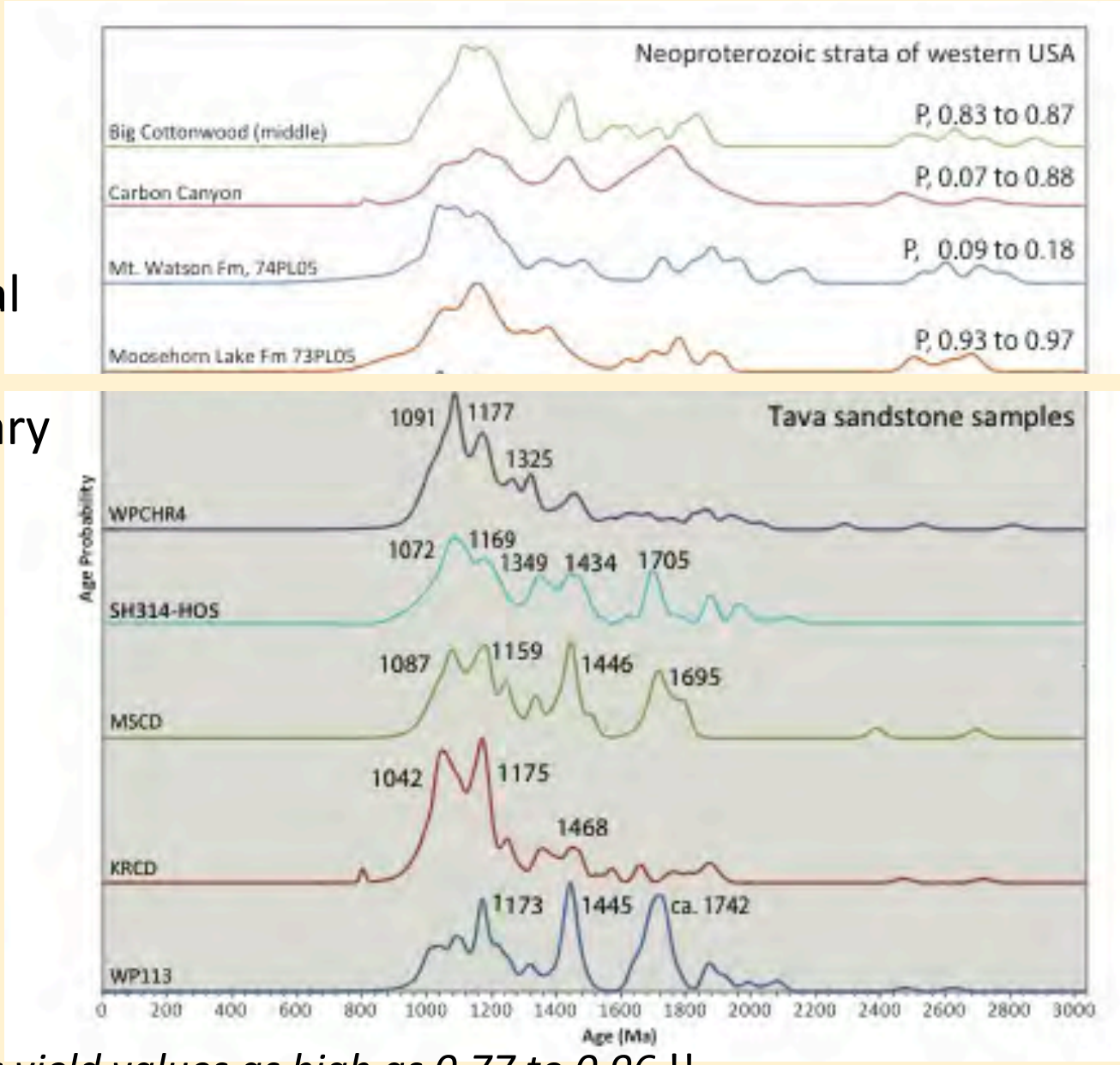


Uncompahgre Quartzite
ca. 1.70 Ga (Jones et al. 2008)

Regional Comparison

(*pmag pole position rules out Mz and Cz*)

Comparison to detrital zircon age reference spectra for sedimentary units in western USA, of known Neoproterozoic age



*For datasets having K-S probability of correlation > 0.40

Several comparison-pairs yield values as high as 0.77 to 0.96 !!

Paleogeographic reconstruction

1- Uintah Mountain group
2- Chuar-GC
3- Pahrump Group
4- Tava (this study)

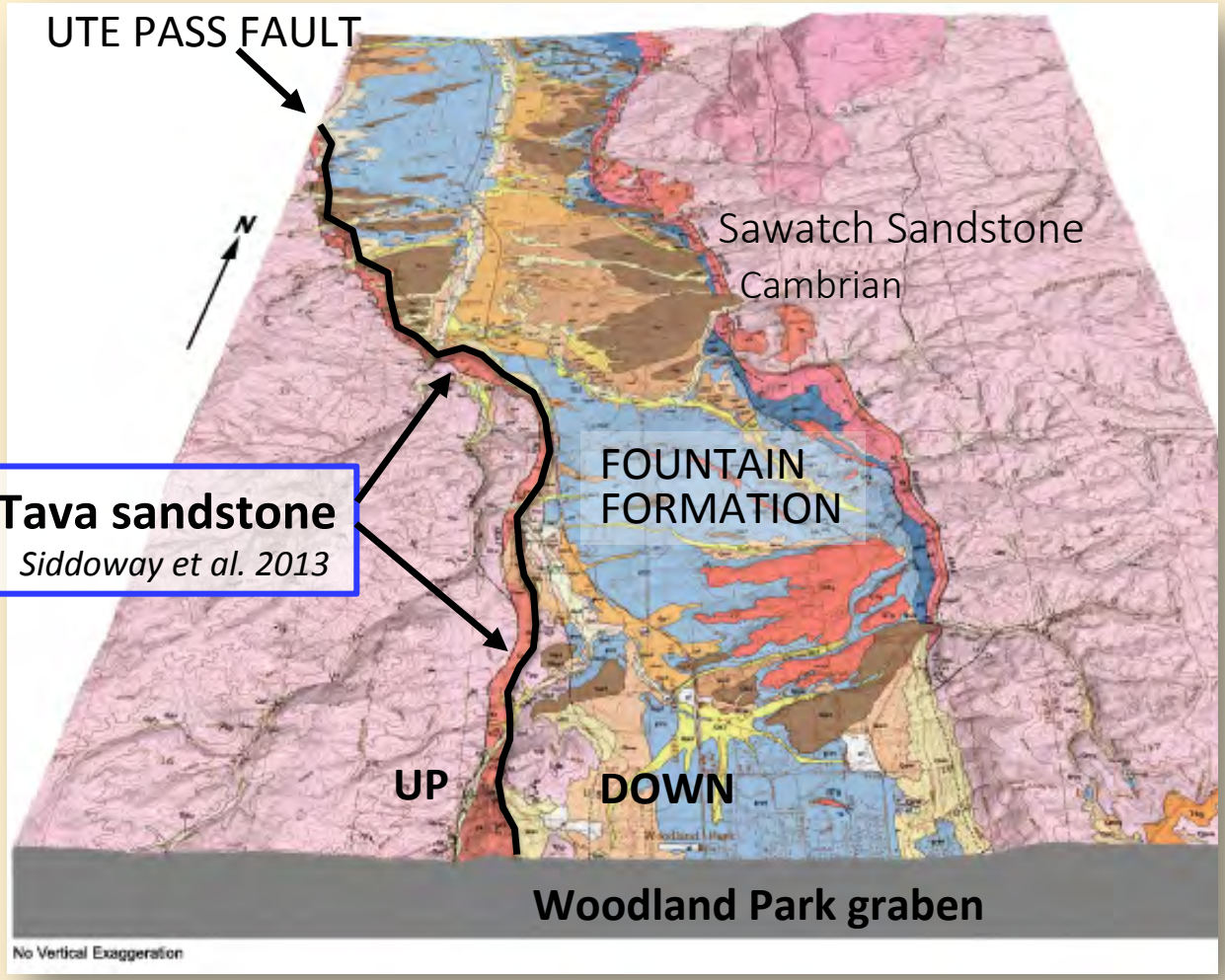
Sediments transported across Laurentia, quartz component concentrated, and 'fines' winnowed out, prior to incorporation in Tava sandstone.

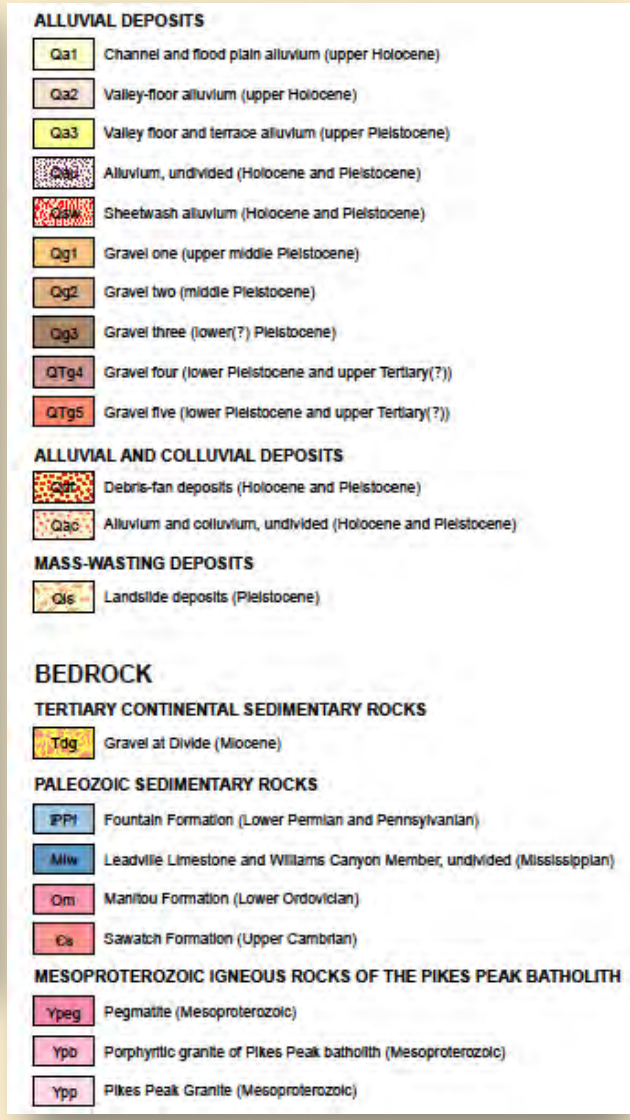
ca. 750 Ma reconstruction: Blakey, cpgeosystems.org

Descriptive characteristics

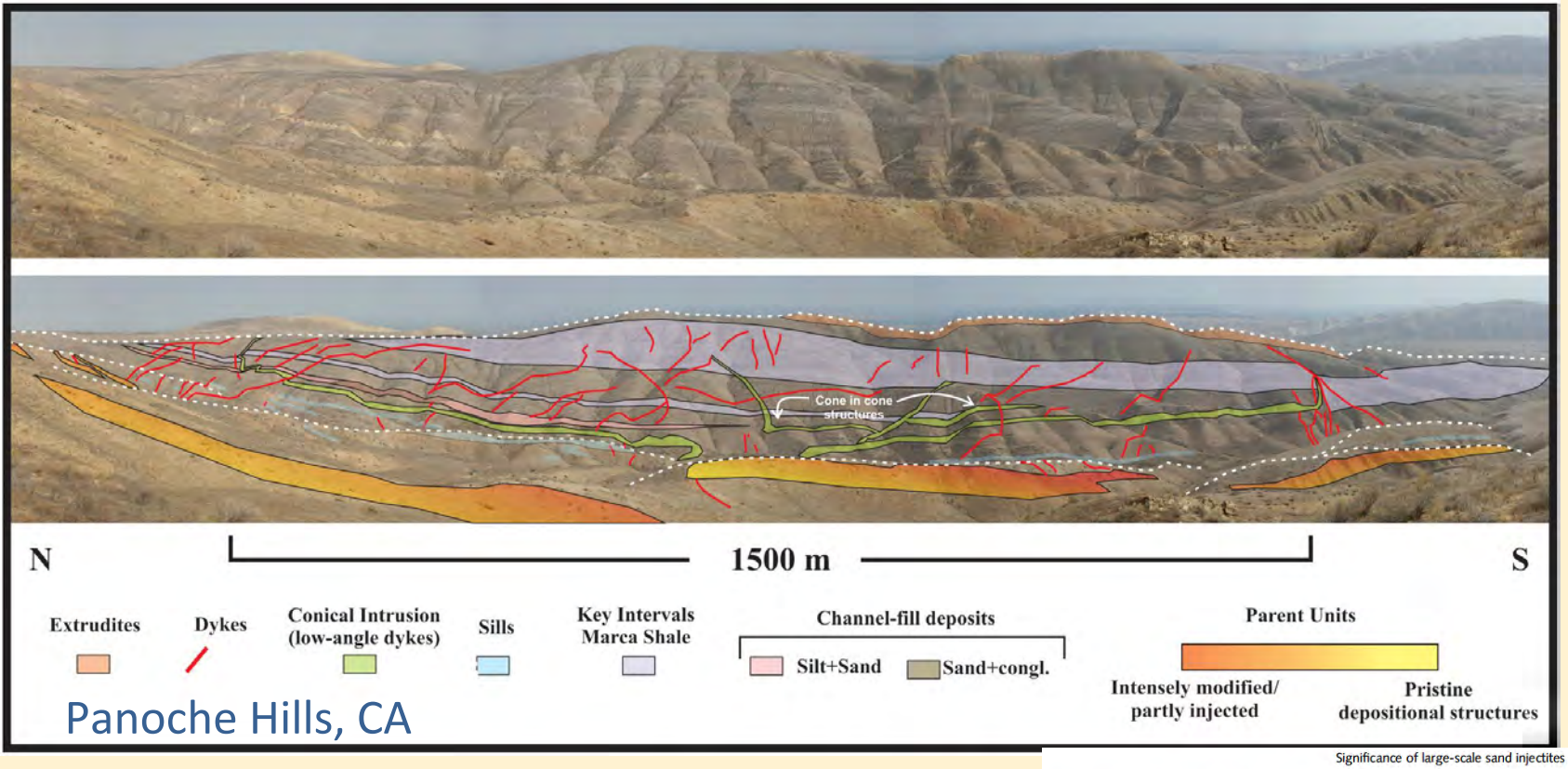
- Poorly sorted, very fine to medium grained sand with dispersed rounded pebbles and quartz grains
- Massive structureless to weakly graded matrix-supported granules to pebbles (3mm to 5 cm)
- 95 to 98% quartz
- Tabular bodies within granite host
- Sandstone dikes and sills within Tava sandstone host
- At least two generations – unequivocal crosscutting
- *Pronounced brittle structural overprint*

Scale of the system?



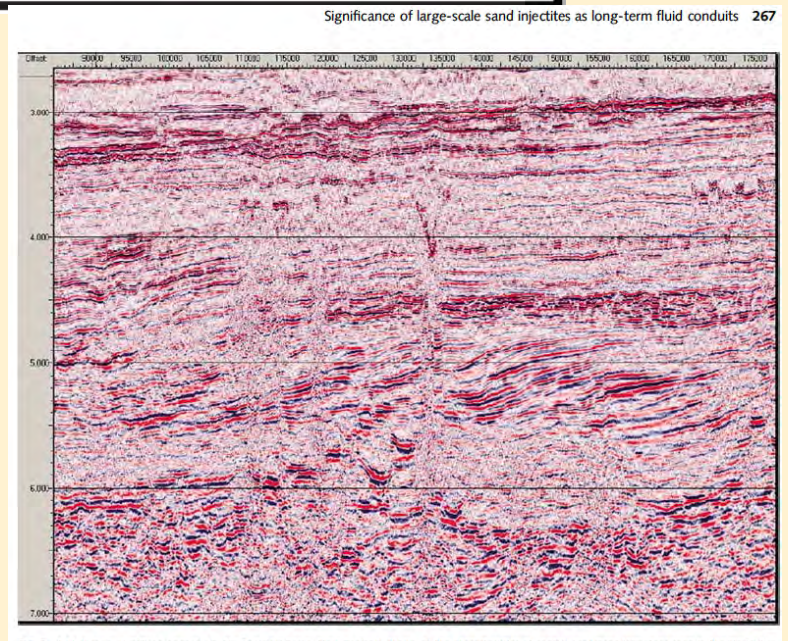


Mount Deception quadrangle
Colorado Geological Survey
Temple et al. 2007



Panoche Hills, CA

Great Valley Sequence, California (Jurassic-Cretaceous)



Deep-water sediment of the North Sea: remobilization structures imaged seismically

Hurst et al. 2003, *Geofluids*

hydroFRACKING ON A GRAND SCALE

Table 1

Estimates of sand and fluid volumes during sand injection and fluid volumes liberated by liquefaction and consolidation of parent sand units. V_{T1} = gross volume of injected sand at the time of injection (using Ø = 60–80%). V_{T2} = present day volume of injected sand. V_g = grain (mineral) volume of injected sand body. V_{finj} = fluid volume at the time of injection. V_{fcon} = fluid volume at the present day. Volumes in m^3. Data for the small and large injectites are values taken from Injected Sands database (Universities of Aberdeen and Cardiff). Data for the consolidated parent unit is a maximum figure based on the large composite consolidation complex in Fig. 2, Hurst and Cronin (2001). Table compiled and modified after Hurst et al. (2003a).

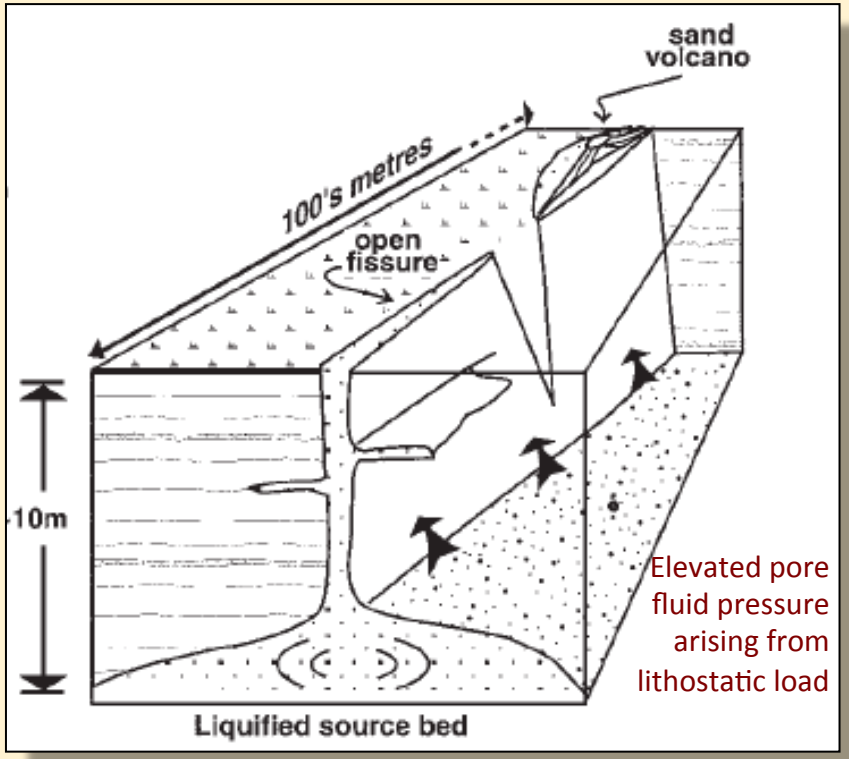
Units: m^3	V_{T1}	V_{T2}	V_g	V_{finj}	V_{fcon}
Small injectite	$6.5–7.5\times10^4$	5×10^4	3.5×10^4	$3.0–4.0\times10^4$	1.5×10^4
Large injectite	$5.2–6.0\times10^7$	4×10^7	2.8×10^7	$2.4–3.2\times10^7$	1.2×10^7
Consolidated unit	–	4×10^2	3.5×10^2	1.5×10^2	1.5×10^2

A “large injectite” involves
24,000,000 to 32,000,000 cubic meters of water and
52,000,000 to 60,000,000 cubic meters of sand !!!!

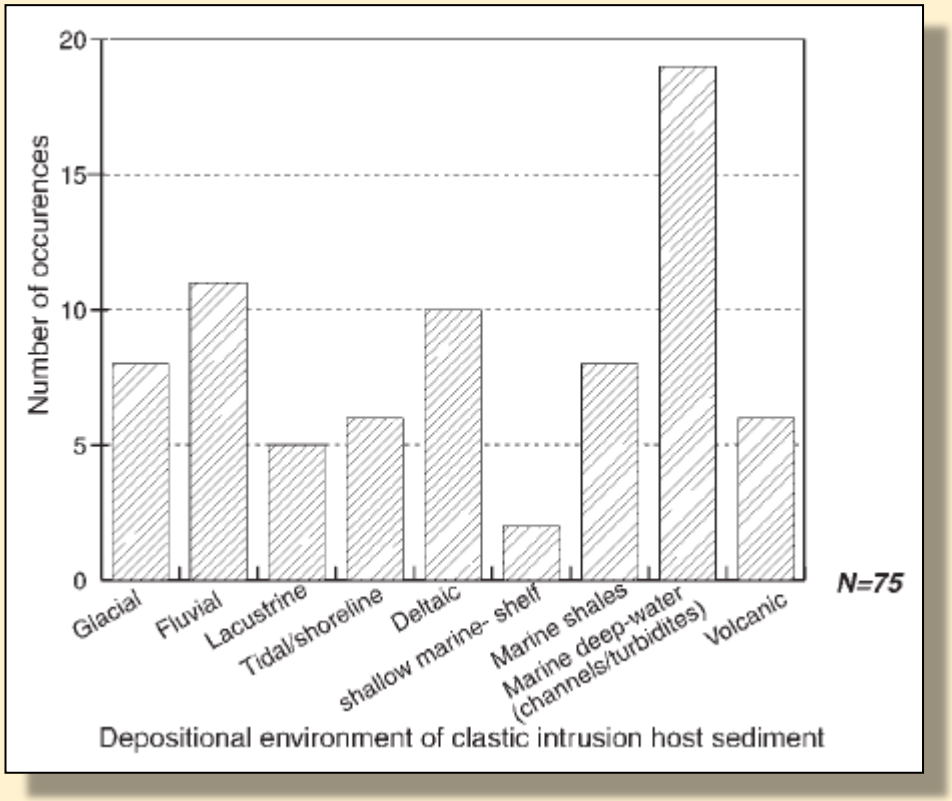
Sandstone injectites

manifestation of high-velocity fluid flow of sand-rich layers interbedded with clay-rich successions within the shallow subsurface, typically < 500m of burial.

Conceptual scheme for formation



Summary of world examples



PROCESSES: liquefaction, remobilization, injection

Jolly & Lonergan 2002

* From survey of literature, **one** of this number is hosted by crystalline rocks, and is of comparable scale & extent.

modern analogs?

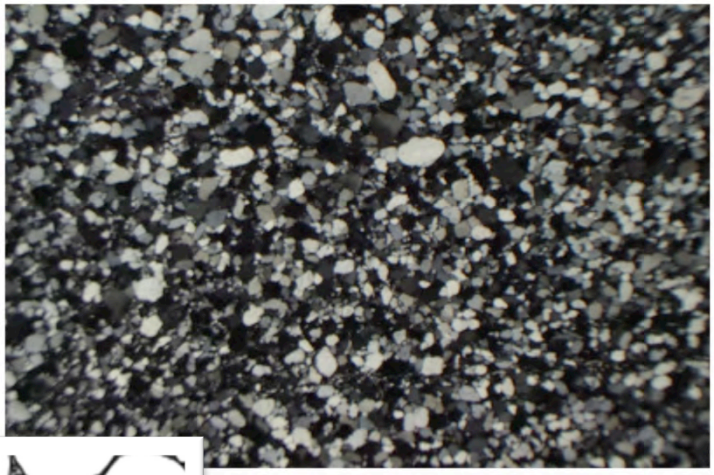
- Christchurch, New Zealand
- 2010 2011
- M4 to 7

Christchurch, New Zealand, http://www.kuriositas.com/2012/07/


Once emplaced, the sandstone provides a fluid migration pathway
Host sandstone, “redox” patterns
Mottling, indicative of
Migration of reducing fluids
sufficient cohesion to fracture ; permeability low enough that a fluid flow gradient arises (overpressure)

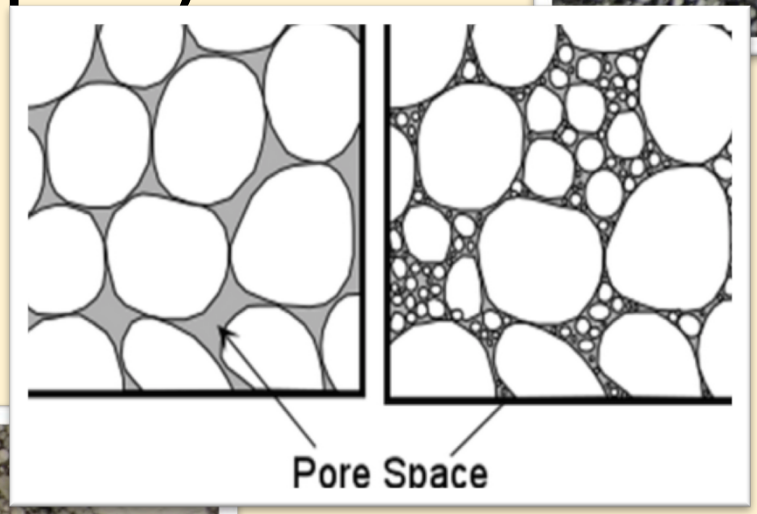
Tava Petrology

- **Mature, quartz sandstone (>90% quartz)**
- **Poorly sorted**

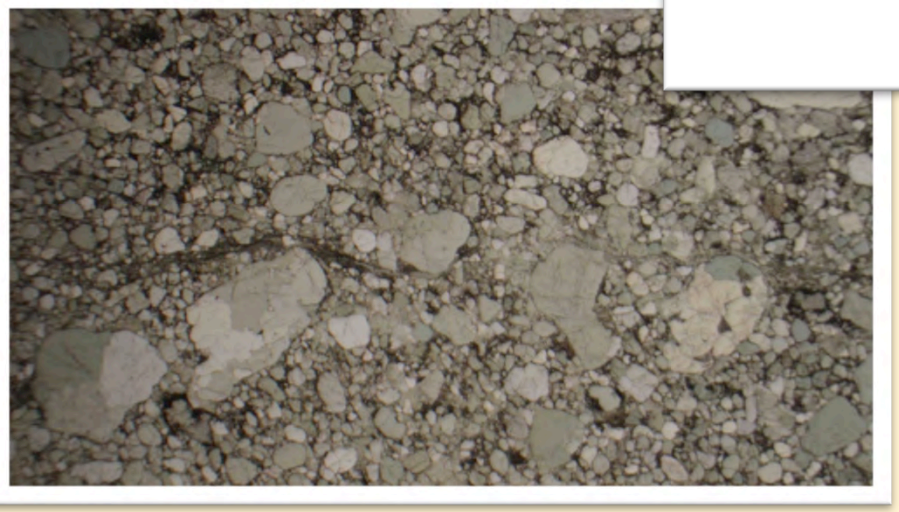


Cross polarized light, 40X magnification

Well sorted = high porosity



Poorly sorted = Low porosity



Plane polarized light, 40X magnification

- Matrix = fine to medium grained sandstone(0.20-0.33 mm)
- Suspended pebbles (1-4 mm)

Grain sorting

Strand-like interpenetrating swirls formed during fluidized injection of Tava sandstone into Pikes Peak Granite; evident from grain size variations and degree of cementation

Transmitted light and surface illumination, 10X magnification

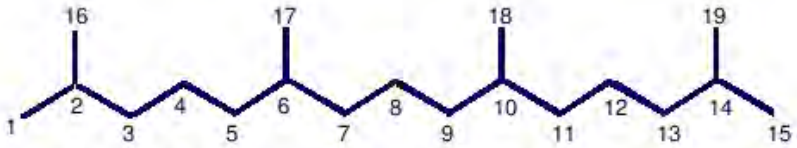
Undergrad thesis of Alec Lee, 2015

Phanerozoic Hydrocarbons

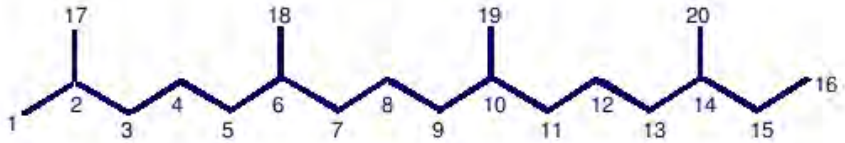
With further work and funding (!), may be able to determine sources

- Reducing Fluids: Hydrocarbons and petroleum reservoir brines?
  - (Boron in SLT-6/DUPLX)

- Phanerozoic: HC from Denver Basin/Florence Oil Field?
  - n-alkane chains (n-C27,29,31) easily migrate/biodegrade
  - Gas/liquid hydrocarbons



pristane C_{19}

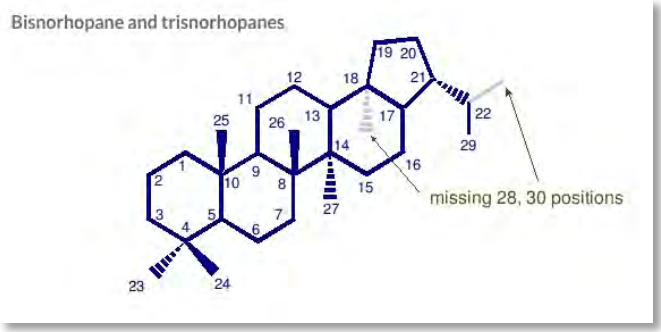


phytane C_{20}

http://summons.mit.edu/biomarkers/biomarker-classification/lipids/isoprenoids/acyclic-and-cyclic-isoprenoids/

Neoproterozoic Hydrocarbons

- Neoproterozoic: Remnant crystalline hydrocarbons?
  - Solid diamondoids (steranes, hopanes, carotenoids)
    - » long lasting and hard to migrate
  - Trisnorhopane = euxinic conditions in Neoproterozoic (sulfur metabolizing organisms?)



http://summons.mit.edu/biomarkers/biomarker-classification/lipids/isoprenoids/polycyclic-isoprenoids-with-concatenated-ring-system/hopanoids/

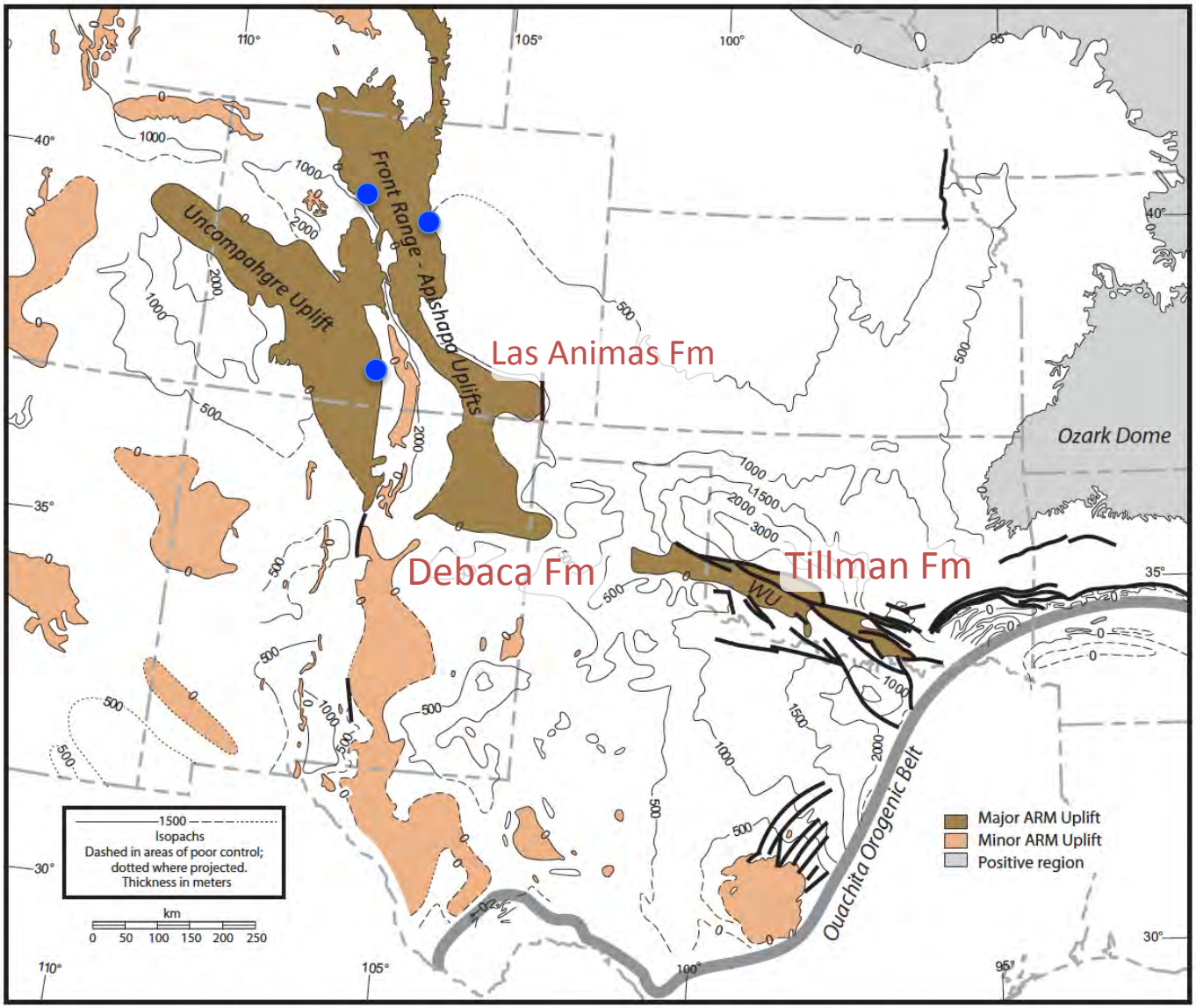


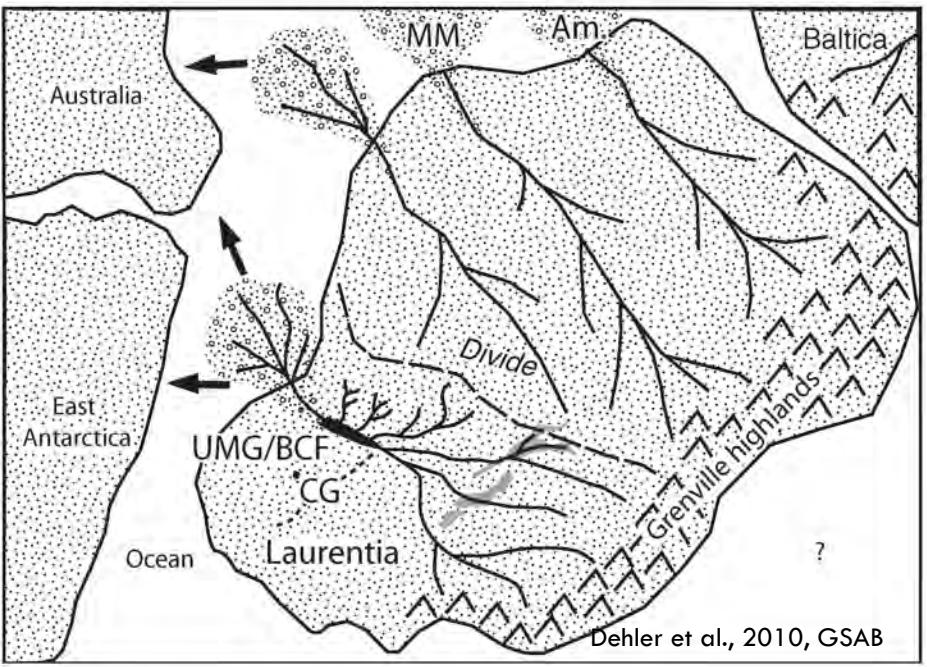
Figure 2. Isopach map showing preserved Pennsylvanian strata of the region shown in Figure 1. ARM—Ancestral Rocky Mountains. Note the large (>1000 m) thicknesses of Pennsylvanian strata adjacent to the Uncompahgre, Front Range–Apishapa, and Wichita uplifts (WU; see Fig. 1). Bold black lines are faults. Modified from McKee and Crosby (1975).

Regional context, vestigial basins of Proterozoic

Las Animas Fm in subsurface; Tillman in Wichita Uplift (Tweto, 1976)

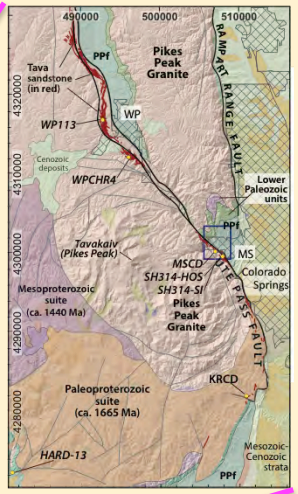
DeBaca Fm: Amarante et al. 2005, circa 1.26 Ga

Figure from Soreghan et 2012 Geosphere: Ancestral Rocky Mtns



Dehler et al., 2010, GSAB

Karlstrom, K.E. et al., 1999



Transport from south, from Llano?

Intracontinental deformation, associated with Rodinia breakup?

Tava, εHf -13 to -18, with *few* -20 to -23
(A. Hantsche, Feb. 2015)

εHf for PPG, -20 to -27 (Howard 2013)
εHf for Llano and Franklins, -21 to -27
(A. Hantsche, Feb. 2015)

trigger mechanisms for injection

- seismic shaking
- instantaneous loading
- Wet-based glaciation with glacial surges
  ice confined within bedrock channel

Neoprot.
snowball earth
glaciations

- rapid migration of pore water as a result of mineralogical phase changes (opal A to CT (Davies et al., 2006), or rapid migration of hydrocarbon gas (Brooke et al., 1995).
- decomposition of gas hydrates / instantaneous pore pressure excess

<u>For sand remobilization by fluidization</u>: stresses at grain-grain contacts must be low enough to be overcome by drag forces exerted by moving fluids

burial depths < 500 m, ordinarily, and certainly < 1km.

High strain-rate processes required, with development of overpressure (Jolly & Lonergan, 2002)

THANKS TO:

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Jay Temple

CGS - Vince Matthews

Pearl & Bessie
(intrepid Labradors)

David Freedman

NMHU rock mag gang

Monty Swan

Charlotte Cadow

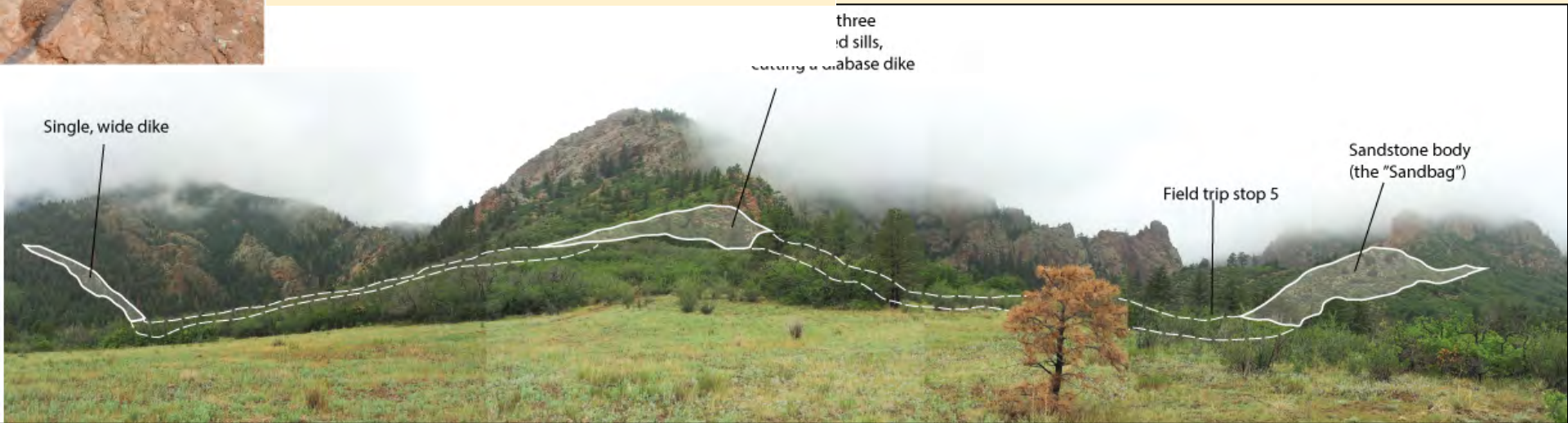
George Gehrels

Mark Pecha

U Arizona Laserchron

Anderson Cole

Chuar and UMG authors



Opportunities for deeper insights - paleoenvironment

- Mature quartz sandstone / near-absence of other detritus
  - Circumstances of weathering on Proterozoic vegetation-free landscape? (Dott, 2003)
  - Elutriation of clay and silt component; "sanding in" of narrow fissures
- Source of fluid overpressure and cause of remobilization/injection* of inconceivable volume of sand and water
  - Rodinia breakup / Fault controlled depocenter / rapid sedimentation (of supermature sandstone)
  - Sturtian glaciation : warm-based glaciers to generate fluid and sediment (quartz sand possibly eroded from preexisting strata, e.g. Grand Canyon Supergroup-type)
- Variability in degree and type of interstitial cement --- variations in porosity
  - Primary cement in dike array on Cheyenne Mountain: specularite
  - Alteration, elsewhere: red/white mottling with friable texture: evidence of migration of reducing fluids ? Relationship to late Paleozoic remagnetization event ? (Geissman and Harlan 2002 - attribute to regional scale fluids migration)
- Potential for atmosphere or groundwater record: Fe or sulfur isotopes