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Scientific Notebook No. 181: Assessment of Joints from Natural Examples at Yucca Mountain (07/26/1996 through 11/25/2003)

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The contents of this ~~[illegible]~~ W.D. notebook ~~is the~~ records the work of William (Bill) Dunne for CNWRA-SwRI Project number 20-5708-471 Bill Dunne W.D.

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Consultant to CNWRA (July to Sept. 1996)

Project – assessment of joints from natural examples at Yucca Mt. as input parameters to mechanical & hydrogeological models

Contents

Questions of concern derived from readings

July 26th, 1996

(1) What % of N to NW striking joints are reactivated as faults at Yucca Mt? How do their "aperatures" compare to joints or faults that formed without exploiting pre-existing surfaces? (Sweetkind et al. 1996 EOS v.77, p.S266, abstract) → see (9)

(2) Do cooling joints have regionally consistent orientations? Why orthogonal rather than polygonal? (Sweetkind et al. 1995, EOS v.76 p. F597, abstract).

(3) What are the likely load conditions (external tension, stretching, internal elastic adjustment, or ?)? (Sweetkind et al, 1995, Eos v.76 p.597, abstract).

(4) Does width of a fault zone, number of subordinate faults, and degree of reactivation of joints depend on host lithology (e.g. crystal-poor vs. crystal-rich)? (Potter et al, 1996, EOS v.77, p.S265)

(5) Source of anomalously trending (WNW - 290° to 315°) fractures encountered in ESF tunnel? Are they one zone of +800m width or 2 zones of about 300m width? What is meant by cooling joints cross-cutting them (I.D. of origin for cooling joints? Cross cut as joints or faults?)? What does intense mean for spacing as compared to surface studies? Did surface studies find similar fracture zones in other orientations (perhaps, fault-related?)? (Brocoum, May 22 1996, Forwards Reportable Geologic Condition US DOE Study plan 8.3.1.4.2.2. "Characterization of Structural Features within Site Area") If not fault-related, likelyhood of not being stratigraphically controlled?

(6) In ESF, what type of fractures does the drilling process produce? How are they distinguished & segregated from population of pre-existing cooling & tectonic fractures (while examining Fig. 4, Sweetkind et al, 1996, RMAG guidebook)

(7) In ESF, Abundance of subhorizontal cooling joints? (same citation as (6), except bottom of pg. 6)

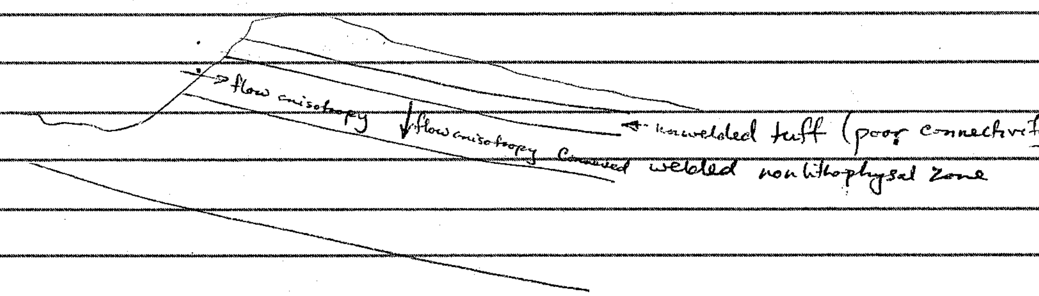
O.K. Table 1 uses several measures, including length/area

✓ (8) Why are ESF (or Sweetkind et al) using fracture/m² rather than trace length/m²? Second is more exact and comparable to D value of fractal studies. (Same citation as (6), middle of page 7)

(9) In contrast to (1), Sweetkind et a (1996) reporting on photogrammetry work in ESF state that joints reactivated as faults strike NE (not NW to N), which is stated as typical of → joint reactivation at surface. ? inconsistent? overgeneralized? site dependent?

(10) Why do the photogrammetric & pavement mapping yield such different results at UZ-7a? (Fig 5 in reference of (6)) Or, between DLS & photogrammetry on DLS survey line (Fig. 6, p.11)?

(11) What about "down-dip" infiltration along subhorizontal fractures rather than vertically along near-vertical fractures? Direct vertical connectivity through less fractured units becomes less of an issue (thought based on other consideration on p. 13 of citation from (6)) Cartoon:



Would create lithostratigraphically constrained channel flow. Examining Fig. 5 in Scott (1990 DNAG), the Bedded Tuff between Tiva Canyon Member and Topopah Spring Member is low enough with respect to the topography to block this more convolute fluid pathway. (see p. 13. Sweetkind et al 1996 RMAG for similar comment for simple vertical pathways). Still, faults might be the vertical connecters for strata-bound flow (similar comment p. 13 Sweetkind et al. 1996, RMAG)

(12) Does the prominence of more E-W trending (than say N-S or NW-SE) washes at Yucca Mt. site act as an indicator of more E-W trending fracture (fault) zones? Any evidence of stratigraphic offset between N & S sides of the washes? (Examining Fig. 1 Sweetkind et al. 1996 RMAG while considering the ESF info from the trouble zone (4.2 to 5.0 km))

(13) What damage does Poisson point process do (no fracture center affects the location of another fracture center (= origin in mechanical model & not center of the final fracture. Although both are essentially the same for this assumption))? (Anna & Wallman 1996 RMAG, Pt II to Sweetkind et al. 1996)

July 27th 1996 (14) What about the possibility of the intense fracture zone being related to a strike-slip (relay?) fault that pre-dates the Ghost Dance fault? Look for horizontal or gently inclined fault-slip indicators. Negative to this idea; should still see stratigraphic offset of tuffs across split wash from horizontal offset of tilted beds.

(15) ~~Orient~~ Orientation of basaltic dikes in N. Yucca Mt? (p. 254, Scott 1990 GSA Mem. 176)

(16) Would the orientations of the two cooling joint sets have been controlled by a horizontal stress field where σ_h (σ_3?) was NE-SW trending? A possibility as Paintbrush Tuff was deposited during 13.5 to 11.5 my - period when early extension (NE-SW directed) was occurring (Using Sweetkind et al. 1996 RMAG, Wernicke 1992 DNAG, + Scott 1990 DNAG)

(17) Anna & Wallman (1996 RMAG) are using a discrete fracture model (DFM), but for
* a small area. Is that ~~too~~ impractical (number of calculations?) for modelling a volume that includes ESF & rocks above (vertical profile)?
→ Why do Anna & Wallman not show their mesh? **Problem** →
Anna & Wallman use a Poisson distribution (fracture centers are positionally independent of each other) to create a simulated fracture network with the calculated characteristics of the paper. While the calculated parameters do reasonably represent the natural fracture system, the use of "Poisson" negates an important characteristic of the natural example → positional dependence of fractures and the very limited number of truly conductive fracture pathways. As a result, the simulation only finds a directional difference in permeability of a factor of two (hence treated as isotropic), WHEREAS, the natural example has only one conductive pathway in one direction (clearly, strongly anisotropic). Use of a spatial variogram or a rules-based approach to define fracture centers would be more useful and accurate, if possible.
→ **Problem** → The other weakness of Anna & Wallman is the definition of their sets (statistical, ignoring field assessments). These should be defined qualitative with a low filter (minimum trace length of about 1 to 2 m) which would keep orientation dispersion down. For a model, applying Sweetkind et al, the 5 sets would provide "3 sets" as they only have 3 unique orientations within them. Of course, in the ESF, one than one DFM would have to used because of the dominant E-W trending in the trouble zone at 4200 to 5600 m.
* Could the modellers use "sample areas" to employ DFM, but keep the number of calculations ~~number~~ reasonable?

(18) How do Carr (1992, SAND91-7037 report)'s conclusions/interpretations about the source of the calcite in fractures in the upper 1000' (including the Paintbrush) as derived by infiltration from surface calcite, fit concerns about rates of meteor water flux into ESF? What does it say about possible pathways.

July 28th, 1996 (19) How much has been eroded off the top here (allowing for differential sedimentation as a function of distribution of fault-controlled basins)? Has erosion been sufficient enough to produce unloading joints at the surface? Is it fair to say that this should not be an issue at +300 m depth in ESF due to amount of present overburden? (Throckmorton & Verbeek USGS open file report 95-2).

(20) Hydro models have surface roughness parameter for modelling flow through joints? If so, cooling joints would be quite different to the tectonic joints which are much rougher. Anna & Wallman did not have an aperature/roughness parameter. Barton's aperature data at surface is quite suspect in subsurface → erosion, weathering & loading conditions.

(21) Barton etc. & Sweetkind etc. showed triangular plots where most joints had intersecting or abutting relationships. Yet Throckmorton & Verbeek (1995 ~~95-2~~) comment on cooling joints (oldest joints after all) ending at blind terminations (p. 10). This result as T+V (1995) comment is intuitively expected as the oldest joints have nothing to abut against. Examining Barton's pavements, many cooling joints "run off" the pavements with minimum (exposed) lengths of 10 to 30 m. The same is true at P2001 (Sweetkind et al 1996), ~~So~~, do we really know how long the cooling joints are? → They are most likely to create pathways ~~as they~~ are the biggest (despite being the smoothest.

(22) **Problem** → Anna & Wallman (1996) → Fracture characteristics have not been correlated to sets. Specifically, trace length + intensity. ~~Figure 5 provides~~ Table 1 does attempt some correlation of length to set, but sets are poorly defined in A+W (1996) → see (17) → all fractures (faults, joints, drilling fractures(?)) are being mixed. Also, as seen in Barton etc., Sweetkind etc. & Throckmorton & Verbeek different genetic (cooling vs tectonic) sets ~~have~~ share orientations but have very different characteristic lengths, smoothness, etc.

This means that an "average" characteristic for a set choosen by orientation has little meaning because it is calculated from a composite of least two sets with quite different characteristics (e.g. trace length of cooling joints vs. parallel tectonic joints). **Remember that population statistics are not set statistics.**

Example
→ Anna & Wallman length averages ≈ 1.5m
T_1 lengths > 3m Throckmorton & Verbeek

(23) Would it be possible to "see" a Barton pavement prior to clearing? The amount of surface regolith plus the details of the fractures in the pavement would allow an investigation of meteoric infiltration that combined fracture & regolith effects. Seems a better idea than the vertical one dimensional models that can not incorporate fractures for assessment of near surface meteoric infiltration.

(24) Could some of the fractures encountered in the ESF between 4200m & 5600m be cooling joints? 6 of 8 Tonopah stations at Fran Ridge and 7 of 22 stations in the Tiva Canyon member at Yucca Mt. have fractures of the orientation (N85W to N45W) encountered in ESF, (Throckmorton & Verbeek 1995). Also T4 set is a possibility, but poorest development.

(25) Who did the field stations and pavements on the W side of Yucca Mt above Solitario Canyon (as shown in Fig. 1, Sweetkind et al 1996 RMR?)? Is it Sweetkind et al 1995 USGS Admin Report to DOE (1995)? If so, I might need that as well.

(26) Do the existence of subhorizontal cooling joints (e.g. Throckmorton & Verbeek 1995) mean that thermoelastic contraction overcame body forces which would be small anyway (ρ of thickness (h) flows above spot × g ?)?

(27) **Problem** → Throckmorton & Verbeek found abundance of T_1 + T_2 to be inversely related to abundance of older sets (e.g. P37) [For T_1 → C_1, C_2 ; For T_2 → T_1, C_1, C_2] [Also T_1 not subparallel C_1 or C_2, unlike T_2 which is subparallel NW-striking cooling joints]. Abundance as a function of abundance of older joint sets is not factored into the DFM for Anna & Wallman (1996). Except T4 which is opposite!

July 29th 1996 (28) Why are the cooling joints so much longer than typical columnar cooling joints? Fracture toughness of welded tuffs? Fracturing mechanism (Gas driven? unlike in basalts → remember that mostly thermally driven). Columnar joints are incremental in vertical growth as a function of inward cooling; what about these joints (look for fractographic features → smooth.... could be a problem)?

July 30th 1996 (29) W.D.

(29) W.D.

August 6th 1996 (30) In the ESF, are the breccias in the faults cemented?

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Yucca Mt - SWRI
August 5th, 1996

11:15 am Since 8:00 am → had breakfast, Bought food + liquid + got a little explanation of today's travel plans. We are now setting out to swing through Death Valley to enable Dave Ferrill to collect 3 to 5 Apatite + Zircon fission track samples for unloading histories to time extension events + rates.

So, we are leaving Las Vegas on State road 85 (Charleston Blvd.) to Red Rocks National Recreation Area to look at Jurassic Aztec Sst. in footwall of keystone thrust from there going over Spring Mts via State Roads 159 + 160 to Pahrump, NV. From Pahrump go SW to Shoshone, CA on state roads 372/178 in Chicago Valley between Nopah Range on East side + Resting Springs Range on W. At Shoshone turn and go north into ~~to Death~~ Valley Furnace Creek Valley (SE end of Furnace Creek FZ + enter Death Valley National Park).

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Go NW into Furnace Creek Valley to turnoff to W to Dante's Overlook in the Black Mountains, and then return to the valley + continue NW to Furnace Creek (Dinner). Go onto Beatty, NV (NE) to settle into motel.

(1) Stopped past entrance to Recreation area + took photos. (about 2 miles before right into Bottom Spring Rd)
NV1-1 → 3000' subvertical face through the Aztec Sst in the footwall of Keystone thrust
NV1-2 → Prominent joint sets in rocks to left (SW or S) of Photo 1.

(2) Rt. 160 in Aztec Sst within 500 m of keystone thrust in gully (wash) off of left (north side) of road to collect Aztec sample for NSF proposal. Also, to take pictures for class.

NV1-3 → Scenery
NV1-4 → details of faulting in Aztec with orange layers as markers for offset.
I might be able to do work on this

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Aztec
A1 - Sandstone sample. Orientation marked on top bedding.
145/83 NE BEDDING.

NV1-5 → } PHOTOGRAPHS of oriented sample
NV1-6 → } in situ.

(3) 5:45 pm → exiting Chicago Valley + within 2 miles of Shoshone → David is showing me a geologic wonder → a welded tuff that looks like a coal! Also, a nifty fault

7, 8 → fault
9, 10 → welded tuff on top of a rhyolitic tuff.

(4) Dante's View into Death Valley above the Badwater Basin
11-17
→ view into Basin
→ Ravens
→ Hilight sign
→ Alluvial fan.

8-6-96

12-?.. Photos of Ron H. from "porch" outside the room

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August 6th, 1996

Overall purpose of day is to visit fracture localities at Fran Ridge and Yucca Mt. to familiarize myself and David Ferrill with the fracture population that has been reported by the site investigators. A related issue is to determine whether the illustrations and text of the site investigations clearly describe the fracture population.

First stop → Rock Pavement 2001 on the SE side of Fran Ridge. This pavement was exhumed as part of the Large Block Heater Test ~~Experiment~~. ~~It~~ W.D. The pavement contains 3 cooling joint sets and 3 tectonic joint sets as described by the site investigators. The fractures were viewed in the pavement and two adjacent pits, which highlighted penetration depths of fractures into the ground.

The pavement is not parallel to the compaction banding, but rather topographic slope except where it was notched along subhorizontal cooling joints. The small

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version of the site map (Figure 3, Sweetkind et.al. 1996 RMAG) is a clear illustration of fractures in the pavement, for fractures longer than 5 feet. The only significant limitation was ~~not~~ W.D. that fractures reactivated as faults were not marked with indicators such as a shear arrow. Also offset sense + magnitudes were not shown for these faults as a result.

All fractures contain caliche making viewing of surface relief and features very difficult. Two characteristics that are not obscured are the planarity/smoothness of cooling joints and the brecciated clasts in joints reactivated as faults.

As commented on by the site investigators, 3 subhorizontal (subparallel to compaction banding) cooling joints are amongst the 5 most extensive fractures in the exposure. Some cooling joints were observed to change continuous from subhorizontal to moderately inclined. These fractures would provide fluid pathways from subhorizontal to subvertical fractures.

A nother set of parallel fractures are subhorizontal joints with cm's of

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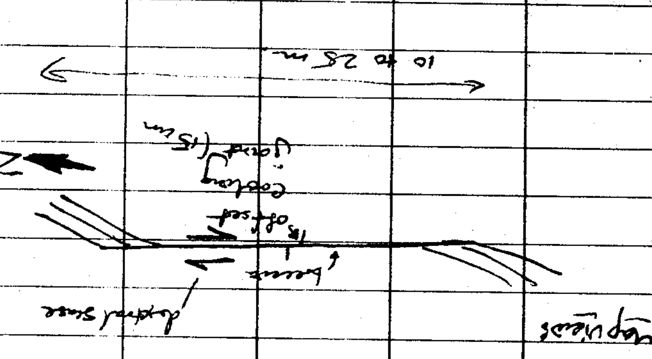
relief, irregular surfaces, and traces that zigzag through lithophysae. These joints are amongst the youngest fractures in the outcrop from termination relationships (Throckmorton & Verbeek 95, USGS open file report). They were only encountered in one of the pits and hence, would not show on the pavement map. In contrast, the subhorizontal cooling joints do have surface topography but it is on a wavelength of about 35 m and not cm's, and amplitudes of 50 to 100 cm and not cms.

2 ~~2~~ W.D. NW-trending cooling joints and 3 T_1 joints show brecciation and the development of secondary "tail" faults with measurable

Map views



offsets on 3 that are all consistent with dextral offset that would be consistent with the present stress field + not the

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Miocene/Pliocene stress field. Offsets are 5 to 15 cm and the faults all contain calcite. In one case, only a portion (about 10 m) of a large T_1 joint is reactivated as a fault. No reactivation of T_2 or T_3.

A final point here is that fracture intensity decreases abruptly upsection (and up pavement) as lithophysae become very abundant and tend to baseball and softball size.

In summary, this pavement illustrated the differences in fracture smoothness, the geometry of subhorizontal cooling joints, the trace lengths of fractures and the morphology of joints reactivated as faults.

Chat Vision Film: Pictures

23,24 (1) Cooling joints (subhorizontal) relief
(film 2) 4,10 (2) Surface morphology of young subhorizontal joint
3,4 (3) Small tubercles ~~off~~ W.D. on gently inclined cooling joints
1,2 (4) Breccia in reactivated joints
5,6 (5) Offsets of cooling joints + other joints
7,8 (6) "Tail" geometry off of faults.

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11,12 (7) Extent of T_1 and subhorizontal cooling joints
13,14
15,16 (8) Lack of joints in zone with large
17,18 lithophysae

Second stop – UZ-7a drill pad – Profile across the Ghost Dance fault. This stop contrasts with P2001 because of the presence of a normal fault with 60 to 70' of W.D. dip-slip displacement (down to the west). Hanging wall is much more intensely fractured than the footwall. No cooling joints were identified. In the footwall, again see transition upwards to lithophysae-rich zone (baseball + softball size) with loss of fractures (as at P2001).

The two most different things here as compared to P2001, besides a fault and much fault-related jointing are very long, subhorizontal collapsed large lithophysae and radial splays (see Fig. 5 in Sweetkind et al. 1996 RMAG). The collapsed lithophysae are shown in the profile from this exposure & would plot in the same place on a stereonet as the subhorizontal cooling joints of P2001.

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However, fracture characteristics would be quite different between the two types of subhorizontal fractures:

	Cooling Joints	Collapsed Lithophysae
Trace length	+ 10m	> 1m
Dilation	minimal	up to 3cm
vein fill	none	partial vuggy fill

So, cooling joints much more extensive but much smaller apertures.

The radial splays are interpreted as crack-tip effects off of terminations of lithophysae (Ferrill pers. comm. from Williams-Stroud). They are rare and centered on crack tips in all cases. I need more explanation of geometry and origin to buy into this concept.

Another interesting point is the caliche deposit in the main fault zone ⇒ a major infiltration conduit of fault origin that could transect units that otherwise lack fracture permeability.

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Photos

Photos (Chad Glenn camera)

Vapor phase planes (VPP)

1. Flattened Lithophysae
2. Radial Splay (Steve Batson, pers. comm.) (manmade) } 22,23
3. Caliche in fault zone 20,21
4. Stratigraphic transition into lithophysae-rich zone upwards. 18,19

August 7th, 1996

Part 1 – Visit ESF at Yucca mountain to see fracture population recorded by subsurface investigators at the site of the potential HLW disposal site. Also, to compare these data to data collected by surface workers.

Questions:

1. Ease of recognition of cooling joints
2. Timing relationships between cooling joint sets
3. Evidence of reactivated joints as faults
4. ✓ Large collapsed lithophysae present?
5. Fracture communication through different lithologies?
6. Fracture population in W.D. vs the units above repository level.
7. Between 2800m + 5600m is about a 25° swing in polar cluster of W.D. fracture orientation. Is that represented

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by appearance of a different type of fracture or ?

8. In "Reportable Geologic Condition... 960524009," Intense zone of fractures have "uniform spacing" and are cut by cooling joints. What do these statements mean?
9. In the same document as (8) the statement is "orientation not anticipated from surface data" but one of cooling joints sets meets this orientation. – Query?
10. ✓ Filter for recording of trace length? → 1m.

Answers

1. Chief characteristics for recognizing cooling joints in ESF are planarity, but more importantly bleaching zones in rocks adjacent to fractures due to vapor passage. In the range of 5200 to 4200m the frequent parallel planar fractures are not all bleached. Only about 1 in 4 or 1 in 5. So only 20 to 25% are syn cooling. Others could be significantly younger + could have propagated off of parallel flaws created during cooling
2. The ESF contains no better data than the surface pavement about the relative or simultaneous age of the two subvertical sets of cooling joints.

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Beth Deanne
4-15-97

(3) ESF does contain evidence for joints reactivated as faults but surface pavements show this better.

(4) They are, but more impressive & in fact

W.D. (8) what is really at UZ-7a are subhorizontal (compaction parallel) vapor phase planes (VPP) that show strong bleaching, some mineral precipitate & not as smooth as subhorizontal joints. In places, these planes reach lengths of 5 to 20m. (particularly in the Tiva Creek). They would constitute a mechanical parting. Also, they were a propagation barrier to some veins (subvertical) that stopped, but which crack-tip stresses triggered fracture propagation of a new crack on the other side of the VPP.

(5) Fracture communication –

Fractures are abundant in the welded tuff without without lithophysae. In lithophysal-rich zones, discrete planar fractures are rare, but thinner more discontinuous fractures with rougher traces are present. These are not measured by the DLS in the ESF because they are commonly less than

a meter in length. But they must be significant because chlorine 36 was found in non-lithophysal units of Topopah below these units. Tuff units between (above) Tiva Creek and Topopah Tuffs have a bulk permeability rather than a fracture permeability. See Moyer et al 1996 USGS OFR 95-397

(6) See (5)

(7) Change of orientation mostly occurs between 4500 & 4800m in a zone where fractures are much less abundant. The change in orientation is not accompanied by a change in morphology for roughness, intersects or trace length. In the fracture intense zones, the single abundant set dominates and represents 80 to 90% of fracture population by orientation.

(8) "Cut by cooling joints" means little. Uniform spacing means they are very frequent at about 5 to 15cm spacing.

(9) Not relevant.

(10) 1 m.

Steve Beason stated than in 15,000 fractures, only about 1 or 2% had demonstrable offsets. They have only one piece of unusual nomenclature → offset > 10cm = fault; offset < 10cm = shear } Shear not a commonly used term.

ESF work is clearly characterizing the fracture population by orientation and 11 other attributes, so they can easily avoid the pitfall of letting orientation become too important.

In ESF from 9:20am to 3:00pm.

Part 2 Went back to UZ-7a & P2001 with Chad Glenn to take pictures that were listed in yesterday's notes. Frame numbers for this listed beside #'ed photo list in yesterday's notes.

Final observation of day → In the ESF, the four major faults (Ghost Dance, Sun Dance, Drill Wash, Bow Spring) do not create major wide fracture zones. They are all characterized by polished planes that record slickenlines (possibly only last motions) with brecciated zones that extend out no more than 15cm to either side of the fault surface. Thus, in models these faults should be no wider than 30cm at repository depth if sealed appropriately. Also, excluding the Drill Wash fault, they have dip separations of less than 2m, so lack major displacements within the repos. [illegible]

August 8th, 1996

Today, David Ferrill and I will return to Yucca Mt to visit surface sites for fracture characterization. We are particularly interested in examining pavements that given areal presentation of the fractures (CARP-1, Barton's pavement 100, pavements reported in Sweetkind et al. 1996 RMAG). Main issues to be examined are type and abundance of joint reactivation as faults, abutting relationships and trace lengths of tectonic joints vs cooling joints where fault reactivation has not occurred, and abutting relationships between cooling joints where fault reactivation has not occurred.

Stop 1 – Rock Pavement on Tonsil Ridge in CR1 (although lithophysae are present)

Only pre/syn lythophysae set trends about 040. They have tubercles & are very planar. Some have trace length in excess of 10m. A few other irregular cooling joints are present but 040's are only systematic set.

Beth Deanne
4-15-97

Bill Dunne 4-15-97

with much rougher surface amplitudes

The post-lithophysae joint sets! (000, 110-130, but no 040) (tectonic of previous workers) cut the 040 cooling joints, so that several have tracelengths in excess of 10m. However, tectonic joints (110°) abut at other tectonic joints (000-010 → T1) with consistent age relationships. The fact that the tectonic joints cut the cooling joints indicates they were closed or filled (perhaps by vapor phase (excluding tubercles)) when tectonic joints propagated. If generally true, tectonic joints could be long where cooling joints already exist.

No signs of joints be reactivated as faults.

Summary: (1) One set cooling joints
(2) Tectonic joints cut cooling joints
(3) Tectonic joints abut at tectonic joints
(4) V. little faulting/reactivation
(5) At 10 joints with 10m trace lengths.

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Stop 2 Barton Pavement 100 (upper lithophysal, Tiva Canyon) between Coyote Wash (N) and Split Wash (S).

The swarm of 040 cooling joints in the map really standout on the crop. Being in a lithophysal unit, the tubercles are clearly developed. Swarm consists of 8 to 10 parallel fractures in about a 4m spacing.

Joints reactivated as faults are not clearly seen anywhere in the pavement. The less developed cooling joint does terminate at 040 set, but only two such terminations observed. Large tectonic joints cut the cooling joints for 3 or 4 fractures. Away from the swarm, the pavement is poorly fractured. Two cooling joint morphologies of interest. One segment a 1.00m in length of a cooling joint is in the middle of a post-lythophysal fracture with a +6m trace length. Did the ~~stcto~~ W.D. cooling joint act as a flaw for the formation of the tectonic joint. Second example, a cusp

formed by two curviplanar smooth joints (they cut lythophysae but are very smooth). Total length about 2.5m with about 20cm relief and 30-40° strike changes in both cases. They are "parallel" to the poorly developed cooling joints.

Stop 3 - Arp 1 in Antler Wash. The pavement crosses the Ghost Dance Fault in a region with less displacement than UZ-7a. Stratigraphically, in the lower and middle lithophysal units of the Tiva Canyon Tuff.

The right end of the pavement (E) is in the footwall of the Ghost Dance fault and like at UZ-7a has subhorizontal late fractures with noticeable short-wavelength relief.

The Ghost Dance fault is about 20m from the right end of the crop. ~~and~~ In the remaining 150m of the crop to the W the pavement is intensely fractured by surface trending 360 to 330°. Transition to 330° is sharp (within about 10m). Many surfaces are brecciated. Allowing for complications

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from caliche, brecciation in narrow zones of secondary faults is common. If all the faults moved simultaneously, they have subvertical intersections, which would necessitate strike-slip and not dip-slip.

If the 5 pavements visited so far & the ESF are considered, a picture evolves:

Barton 100 + Tonsil Ridge → Cooling joints & tectonic joints cut rock with moderate to large spacings. Moderate to weak anisotropy.

P2001 → (approaching a fault?) → approaching a major fault zone, so some joints reactivated as faults and additional fractures are introduced during faulting

UZ-7a, Arp-1 → One spectrum of subvertical fractures dominates with ~~some~~ spacings of 2 to 10cm and some brecciation. The ~~major~~ pre-faulting fractures are essentially obscured by the intensity of the fault-related fractures. This rock should have a very strong fracture anisotropy.

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ESF → (in 4200m to 5800m range) prominent closely spaced fractures, somewhat like at ARP1. two differences:

(1) Brecciation missing

(2) 110 to 140 in ESF vs 080 to 150 at ARP1.

Certainly ESF is not a product of simple situation that formed Barton 100 or Tonsil Ridge Pavement.

Stop 4 – CCR2 (Throckmorton & Verbeek) at BM 1959-1 on Yucca Crest in crystal transition subzone of the Crystal-rich member of Tiva Canyon Tuff (cr1).

They identified 3 cooling sets including subhorizontal set, 050 subvertical, 140 subvertical & subhorizontal). Many surfaces do have tubercles but some of the subhorizontal partings have the white bleaching of VPP's (vapour phase partings).

The description is appropriate. Station lacks reactivated joints and intensely developed planar joints, so similar to Tonsil Ridge pavement & Barton 100 pavement.

Subvertical joints have trace lengths of [illegible]

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Stops 5, 6, & 7 → Attempts to locate pavements of Sweetkind et al. on Crest of Yucca Mt. in CR1 & CR2 of Tiva Canyon Tuff. If these pavements exist, they are natural and uncleaned. After examining much of the CR2 / CR1 crop along Yucca Crest, David Ferrill & I found the situation to be much like at stop 4, today with planar joints in 020-050 orientation, 110-140 orientation, and subparallel to compaction banding. Most of these fractures lacked tubercles because lithophysae are absent in CR2 where pumice & lithic fragments dominate. Some subhorizontal surfaces could be vapor-phase partings though. The two subvertical sets are infrequent as at Stop 4, so block sizes are m's by m's on the existing rock crops. Individual fractures have trace lengths of at least a few meters but actual lengths can not be determined because rocks crops were are insufficient ~~size~~ w.D. size to encapsulate the fractures. Still, they are long and smooth (cutting pumice & lithic fragments).

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Stop 8 – Pavement 1000 on SW side of Fran Ridge in of the Topapah Spring Tuff. This pavement was described by Barton before it was mostly removed by a pit. The essential elements of Barton's Illustration are preserved, which is a dominant continuity of N-S & NNE-SSW trending ~~long~~ w.D. joints. The fracture intensity is comparable to ARP1 to W of the Ghost Dance Fault. The ~~pit~~ w.D pavement is in the footwall of two Normal faults that bound Fran Ridge. The western one runs quite close to this site (immediately to W & trending N-S), so much of this fracturing may be fault related and similarly the joints at P2001 (Tuesday) across Fran Ridge that were reactivated as ~~joints~~ w.D. faults.

In summary, intense fracture populations at the surface with spacings similar to the ESF between 4200 & 5800 are only encountered in proximity of faults. These populations of intense fractures may develop

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at over 100m from the faults as shown at ARP1. Otherwise, surface fracture populations are weakly developed, although most of the individuals tend to have trace lengths easy in excess of 8m.

Bill Dunne 4-15-97

Assessment of Administrative Report (Sweetkind et al. 1996, USGS to DOE)

1. This document is timid until possibly the last few pages. It mostly deals with the data in large populations without resolving many fracture characteristics by set and structural domain. Maybe this style is a necessity of the regulatory situation, where initiative is not rewarded in favor of careful safe statements? Or, perhaps, they are keeping the "good stuff" for themselves, or later? Also, although nine important outsides citations are made, the vast majority of the reference list and citations are site specific. They need to tackle the problem and stop worrying about piling the data? Look at Michael Gross's body of work? Search for the limited amount of research on jointing in welded tuffs? In fairness to the document, a contribution is made as a function of lithology (p. 60+), which is important to constructing two-dimensional vertical models at the site. A nice job is done with stress history of the tectonic joints (although they "use you" incorrectly on p. 73).

2. Domainal thinking is in order here. Lumping all of the data together that was collected the same way serves little purpose. The "user" of the data must have in mind what structural/tectonic situation they want to deal with. Just consider the pavements:
   a. ARP-1 and UZ-7A are in proximity to the hanging wall of a "large" normal (possibly sinistral too) fault. High intensity fracture patterns in hangingwall.
   b. 400 and 1000 are down the southeast corner of the area between faults with normal and strike-slip components. "Polygonal patterns".
   c. P2001 is also between the faults of pavements 400 and 1000, but shows a non-polygonal pattern. Function of lithology? Function of dextral reactivation of joints at P2001 which may reflect this "block" responding more readily to "present day stresses (if our interpretation of timing of causative stresses is correct at P2001)? What about the number or abundance of smaller faults around 400, 1000 (p. 76, yes!) and P2001, and how this affects or generates the fracture pattern (particularly the polygonal).
   d. FS-1 to FS-3 are in footwall and near Solitaro Canyon normal fault, which trends N-S. They show a preponderance of N-S trending joints, consistent with E-W extension of fault.
   e. 600 has as it nearest faults NW-trending a sinistral strike-slip fault, which is part of a "package". The 110's could be antithetic fractures to the faults in this domain, the 000 related to E-W extension where N-S normal faults were not abundant, or? But, still another setting from the previous ones.
   f. 100, 200, & 300 in HW of Ghost Dance, but not particularly affected except for "noise" of 300, which is nearest the fault?
   g. 12 pavements and at least 5 structural settings. Mixing data from these different settings could be and is a futile pastime. In some cases, sets could reasonably be expected to change orientation as a function of the presence/absence/activity of faults in the domain that contains a particular station or pavement. Fig. 29 (with pages 66 through 69) is the ***beginning*** of a first cut at this with a nice factoring in of lithology/stratigraphic level, but very little is made of the product. What about doing the same thing and factoring out components in the stereonet by sets (they comment on cooling joint orientations being a problem, so "eliminating these" might provide some clarity or what about a "form line map of cooling joint traces with field data is closely spaced like at the crest?). This situation of many potential structural domains with stratigraphic variations also makes the point that it might be naive to expect one geometric distribution of fractures to be representative. Maybe a better idea is look at constructing a set of "typical" geometries?

3. The fracture trace length data are functionally useless as presented because it lumps all of the sets together (although, it at least considers stratigraphic data). Cooling joints are separated from tectonic joints, but that is not a breakout by sets. If constructing a synthetic, a breakout by sets is needed.
4. The fracture intensity data are functionally useless as presented because it lumps all of the sets together. No attempt is made to split the data out by set. If you are constructing a synthetic, you need information by set!
5. Problem of using the roughness coefficient as a discriminator of cooling from tectonic joints after our jaunt into the ESF. Steve Beason showed us many closely spaced parallel fractures with similar surface roughness, yet only about 1 in 5 displayed vapor-phase-paths. I have a hard time believing that they are all cooling-related given the thermoelastic requirements, so many parallel smooth joints could be tectonic and cooling, and more tectonic than smoothness might indicate (like in Figure 28 for the 1:240 mapping along the Ghost Dance where the fracture population comes closest to having similar spacing and smoothness characteristics (I know that the orientations are different as compared to the ESF 'tho'!)).
6. Kamb contouring of stereonets if they want to be "statistical".
7. The underlying problem with the utility of the document is that the composers may not have been put into a position of having to try to use their product. If they were made to do this, I lay you money that domains, sets by domains, orientation dispersion by position, fracture trace lengths by sets, and fracture intensities by sets would appear. However, this would involve some "seat of the pants" work perhaps to the final product and the work rules and Q & A rules that they operate under might not allow this.

<u>Inputs from field data, using the NE-striking set of cooling joints after reading document:</u>

I. Length (sq) of side of sample square where $0 \le \theta \le 180^\circ$, and θ has been defined above, already: Either $sq = \frac{2\ddot{L}}{|\cos\theta|}$, when $45^\circ \ge \theta$ or $\theta \ge 135^\circ$; or $sq = \frac{2\ddot{L}}{\sin\theta}$, when $45^\circ \le \theta \le 135^\circ$. - about 20 meters

II. Length (g) of side of generation square where $0 \leq \theta \leq 180^{\circ}$, and θ has been defined above, already: Either $g = \frac{6\ddot{L}}{|\cos\theta|}$, when $45^{\circ} \geq \theta$ or $\theta \geq 135^{\circ}$; or $g = \frac{6\ddot{L}}{\sin\theta}$, when $45^{\circ} \leq \theta \leq 135^{\circ}$. - about 60 meters

III. Scale of resolution (SR) - 20 cm.? 1 m.?

IV. Mean trace length of fracture set - not available

V. Population description for variation in trace lengths of fracture set - log-normal or exponential

VI. Mean orientation of fracture set - 035°, but could be positional dependent

VII. Population description for variation in orientation of fracture set - not available

VIII. Determination of whether fracture set has a clustered or anticlustered spacing distribution

A. If anticlustered: -

1. mean fracture spacing - not available
2. Population description for variation in mean fracture spacing - not available

B. If clustered: - they seem to think so with clusters/zones at +30 m spacing

1. Probability of an individual fracture being inside or outside a fracture zone - not addressed in this manner
2. Mean number (integer) of joints in a joint zone as counted in a traverse normal to the zone. - not addressed in this manner
3. Population description for variation in number of joints in a joint zone - not addressed
4. Mean number (integer) of joints between adjacent joint zones as counted in a traverse normal to the zone. - not addressed
5. Population description for variation in number of joints between adjacent joint zones. - not addressed
6. Mean spacing between joints in a joint zone. - not addressed
7. Population description for variation in mean spacing inside a joint zone. - not addressed
8. Mean spacing between joints outside a joint zone. - not addressed
9. Population description for variation in mean spacing outside a joint zone. - not addressed

IX. Fracture intensity for the joint set using parameter P_{22}. - available on a site specific basis that could be useful but not divided into components by sets

X. Population description for variation in fracture intensity. - not available

<u>Comments from Verbeek & Throckmorton (1995)</u>
USGS open-file report

1. Page 21 bottom and 23 top, Fig. 9 - Cooling joints can display curvature of strike of 60° over distances of only 30 m. So, if common, in a generation area of 60 m edge length, one could expect a set of cooling joints to show a large orientation dispersion but in a spatially dependent manner. They site only one specific example, but feel that this phenomenon is common in a qualitative sense.
2. Page 37 bottom - They felt that many cooling joints were cemented by vapor phase crystallization, so T1 joints could be abundant (and in fact, either cut the cooling joints if not parallel, or grow without stress-shadowing inhibition from the cooling joints as they were sealed and could not generate a stress shadow).
3. Page 38 top - Upper lithophysal units - dominantly contain cooling joints (not surprising as they did not have to propagate through the lithophysae like subsequent tectonic joints).
4. Page 38 middle - One cooling joint set clusters in orientation with strikes around 050° and only show about a 20° dispersion about this median in the northern half of Yucca Mt in upper lithophysal unit of the Tiva Creek Tuff. NW-striking set is commonly orthogonal.
5. page 41 to 42 - Paleostress interpretation for cooling joints - Three possiblities (first two discussed by V & T): (a) Barton's suggestion that Tiva Creek Tuff was deposited on a slope that imposed gravitational stresses and oriented fractures parallel and perpendicular to slope; (b) At Fran Ridge in Tonopah Spring Tuff have a N-S trending cooling joint set that could be age equivalent to E-W regional tectonic extension (implies different regional stress conditions during deposition of two Tuffs (my comment - but T1's which do show E-W extension postdate cooling joints in both units, which would require another flip-flop of stress field - likely?); and (c) my comment - strike of cooling joints could be normal to "steepest" thermal gradient in tuffs in go with the assumption that Tuffs did not have blanket-like isotherms parallel to top surface of falls (Beason and Moyer believed in nonblanket-like isotherms). This type of control could certainly cause gentle curvature of 1. above, which would not be expected if a regional depositional slope controlled stress geometry like with 5(a).

Comments about Larry Anna Report (USGS report to DOE, 1996): *[signature] 4-15-97*

Page 6 lines 10-12: He states that fracture orientations do NOT change spatially, which ignores two things: (1) cooling joints are the result of thermoelastic processes centered on the geometry of isotherms in the ash-fall tuffs during their cooling and the resultant thermal gradients were not directionally constant across the region; and (2) The Sweetkind & Williams-Stroud Admin. Report does state that .variation occurs in the orientations and abundance of tectonic joints as a function of position in the region and the locally dominant type of fault.

Page 6 lines 14-15: He states that a controversy exists about whether the joints formed under tension or as conjugate fractures. This "controversy" does not exist in the fracture Admin. Report.

Page 7 lines 1-6: He states that cooling joints are not treated as separate sets from the tectonic joints because they are less abundant, hard to distinguish, and parallel to tectonic joints. Yet, the Admin. Report identifies cooling joints as being the longer fractures because they are older and they have zonal distributions with increased fracture intensity that should be important as fluid pathways. Anna even says on the previous page that abundance is not a sufficient criterion for determining the importance of a fracture set. Failure to separate the cooling joints may obscure a key component of the fracture network in statistical data for sets poorly defined by broad orientation criteria (Anna does the same as in the last report on this front).

Report: Essentially, the entire modelling effort is done from the fracture data in the first 400 m of the ESF and does not include the surface data for the Tiva Canyon Tuff. This makes the study of surface fractures superfluous for purposes of constructing discrete fracture networks. Following this logic, all consideration of surface data should cease immediately. Do these two components of the USGS investigation team not interact closely?

Report: A Enhanced Baecher or BART generation technique is used, so no effort is made to consider spatially dependent variations in the characteristics of the fracture pattern during generation of the synthetic fracture network. Still, as Anna says, the data and analyses for these dependencies do not exist.

Building One Synthetic Fracture Set *[signature] 4-15-97*

Purpose:

A quantitatively reasonable synthetic representation of the fracture population in the tuffs of the repository horizon and vertically adjacent layers improves the quality of models for geomechanical reactivation or movement of pre-existing fractures by seismic events, and for the meteoric infiltration of groundwater to and through the repository horizon along fractures. The first step and purpose of this document is to construct a rules-based synthetic representation for one fracture set at Yucca Mt. The chosen set is the older cooling joints (NE-striking in the reports of fractures, e.g. Sweetkind & Williams-Stroud, 1996, Administrative Report, USGS), which are the oldest systematic joints in the rocks. These joints consistently predate other fracture sets, eliminating the need to conceptualize interaction with other fractures, which would be a complicating factor. Interaction with other fractures is a parameter to be included in the second step toward a reasonable synthetic representation: **building a synthetic two-dimensional fracture network.** The third step is: **conversion of network to a vertical profile plane with variation in lithology.** The fourth step is: **building a three-dimensional network.**

Initial Configuration:

I. Two-dimensional square view that is subhorizontal and parallel to rock layering. This view is subsequently referred to as the "sample area".
   A. reason - majority of geomechanical and hydrological models that I was shown during my SWRI visit consider fractures in vertical two-dimensional geometries.
   B. disadvantages -
      1. a layer-parallel plane is at right angles to the vertical-plane models run at SWRI.
      2. ESF data will not be initially used, and these data are pseudo-three-dimensional because fracture traces may be partially inferred across the diameter of the tunnel. However, the ESF has an extensive region (4210 m to +5000 m with a waning between 4506 to 4580m) of anomalous intense fractures (as compared to other sampled fracture populations) that are also presently of unknown origin. Thus, using the data for these fractures could be inappropriate and limits the level of concern about this disadvantage.
      3. The representation is not three-dimensional, which is what is actually happening in the rock, but the models are only two-dimensional and it is virtually never practical to sample a fracture population in three dimensions. These two restrictions limit the level of concern about this disadvantage.
   C. advantages (counterbalance the disadvantage (i)) -

1. Much of the fracture data (excluding the ESF, some trenching data and the limited number of logged boreholes) has been gathered on rock pavements that are sub-parallel to rock layering. These sample sites are superior because they are areal rather than linear, yielding a much higher quality of data about the geometry of the fracture pattern (e.g. Wu & Pollard, 1995, Journal of Structural Geology).
2. These data are similar to those used in previous attempts to characterize fracture geometries synthetically.

II. No initial fractures or flaws exist in sample area. All fractures will be placed in the area by a sequence of rules based on observations of the NE-striking joint set.

III. Orientation of sample square - Orientation of the sample area is not an important variable and so can be arbitrarily defined. The square will be placed in the upper right quadrant of a Cartesian coordinate system with E-W directions parallel to x axis (E is positive) and N-S directions parallel to the y axis (N is positive). Sides of the square are parallel to the axes.

IV. Size of the sample square - This parameter has a critical influence on the perception of the development of the fracture set. For example, a small size with large sparse fractures might indicate that fractures are absent. Alternately, a large size for small frequent fractures might mask the geometric characteristics of the fracture set. One ideal case that will be attempted here would be to have the side dimension of the square exceed the trace length of the synthetic fractures, so that some fractures have a single termination or are completely contained within the sample area. In the case at hand, this parameter may be difficult to establish because the NE-striking joints are persistent with trace lengths that commonly exceed the size of the field measurement sites. Some sites had linear dimensions in excess of 10 m.

V. Size of generation area (a square region concentrically centered on the square sample area) - The primary purpose of the generation area is to eliminate "edge effects" in the sample area. For example, during the construction of the synthetic fracture set, some fractures will have traces that terminate in the sample area, but have centers located outside the sample area (just as with examining fracture populations in rock exposures). Thus, an area is needed outside the sample area to allow the synthesizing of this fracture geometry. This size choice for the generation area should mean that any fracture that could terminate in the sample area will be formed in the generation area.

Sequence of Rules (General Case where fracture traces are straight)

I. The first fracture - Placing the first fracture consists of four steps:
   A. Locate the fracture center in the generation area (length units = meters) (see sample illustration)
      1. select x ordinate randomly from the range -a<x<2a
      2. select y ordinate randomly from the range -a<y<2a
      3. Issue - resolution of selection range (possibilities - equal to smallest "cutoff filter" used by fieldworkers to select the minimum fracture size considered, equal to minimum resolution used in the model where the synthetic will be applied, an arbitrary resolution of 10 cm's as most fractures in a single set have spacing that exceeds this value, or ?). ***This issue may have little importance for locating the first fracture, but could matter later in synthesizing the single set.***
      4. Result is a fracture center location (r,s)
   B. Define the trace length of the fracture -
      1. apply the mean trace length of the natural fracture set
      2. deviate from the mean trace length as a function of a "population distribution of lengths" for the natural set.
      3. Issue - be sure to apply the same length scale of resolution as used for locating the center.
      4. Result is a fracture trace length, L.
   C. Define the orientation of the fracture -
      1. apply the mean orientation of the natural fracture set. Orientation is defined as the azimuthal trend measured clockwise as an angle from North (000^o) in the range of $0 \leq \theta \leq 180$.
      2. deviate from the mean orientation of the fracture set as a function of a "population distribution of orientations" for the natural set.
      3. Issue - resolution of angles. Probably the best choice is to round to nearest integer as measuring devices for determining angles do not resolve below the accuracy of a single degree.
      4. Result is a fracture trend, θ.
   D. Generate the fracture - The final result is a fracture centered at (k,l) with terminations at $(k+\frac{L}{2}\sin\theta, l+\frac{L}{2}\cos\theta)$ and $(k-\frac{L}{2}\sin\theta, l-\frac{L}{2}\cos\theta)$ where $0 \leq \theta \leq 180$. Terminate the fracture trace if it extends beyond the generation area, -a<x<2a and -a<y<2a.

II. Placing additional fractures using a "generation line" - placing the second fracture in a manner dependent on the location of the first fracture consists of six steps - arbitrary choice of side to generate next fracture, spacing, locate center, set trend, define length, draw)
   A. Select a point along the fracture trace length. All points should have equal probability of selection. Number of points is a function of the chosen resolution and hence, the number of segments that the line would be divided into by the scale of resolution. The point should be located in the middle of a segment.
   B. Construct a "generation line" at right angles *to the mean fracture orientation* that passes through the selected point and terminates against the boundaries of the generation area. The line should be defined by an equation, so that terminations can be determined for the boundary conditions of -a<x<2a and -a<y<2a.
   C. Decide whether dealing with an anticlustered or clustered fracture population, in terms the geographic distribution of spacings. Anticlustered means that the

probability of a particular fracture being a certain spacing from another fracture is uniform for all fractures. Clustered means that the natural pattern consists of "zones" or "swarms" of closely spaced joints, which are separated by a few fractures with much larger spacings. Thus, the fracture population has two characteristic spacings (although they will not show as "modes" in the statistical sense because the smaller spacings of the zones will generally be much more common than the larger spacings of joints not in the zones).

D. If clustered go to II.E., but if anticlustered,
   1. divide the range of the spacing population into segments (segment size equals previously chosen scale of resolution).
   2. Assign each segment a probability.
   3. Select a direction to traverse line from first fracture as a 50/50 probability
   4. Use a "dice-rolling function" to determine the spacing from the spacing distribution.
   5. Precede along line a distance equal to the spacing and locate a point.
   6. Repeat process until generate the first point beyond the termination of the "generation line". Do not create this point.
   7. Return to selected point on first fracture and repeat steps 4. to 6. while going in the opposite direction from the first fracture until a point is generated beyond the other end of the "generation line". Do not create that point.

E. If clustered
   1. Consider the distribution of fracture spacings as two separate populations: the population of smaller spacings that defines fracture distribution in a joint zone and the population of larger spacings that defines fracture distribution outside a zone.
   2. Define the range of the number of joints that may compose a zone and assign each number a probability of occurrence based on observation of naturally occurring fracture zones.
   3. Define the range of the number of joints that may occur between zones and assign each number a probability of occurrence based on observation of naturally occurring fractures between zones.
   4. Define a probability for a joint being in a fracture zone based on the total number of fractures inside and outside of zones in the natural examples.
   5. Apply the probability of step 4. to determine if the first-formed fracture is within a zone or outside a zone. Also, select a direction to traverse line from first fracture as a 50/50 probability.
   6. If inside continue, if outside go to E.11.
   7. Use a "dice-rolling function" to determine the spacing from the spacing distribution for joints in a fracture zone.
   8. Precede along "generation line" a distance equal to the spacing and locate a point.

   9. Test this point for being within a joint zone where the number of joints in the zone equals two. If outside go to E.11. If inside continue.
   10. Continue to repeat steps 7. through 9., where the probability of step ix is adjusted for the number of joints that are now present in the generated zone, until step ix. is failed, meaning that the joint zone is "exited". Go to E.11.
   11. Use a "dice-rolling function" to determine the spacing from the spacing distribution for joints outside a fracture zone.
   12. Precede along generation line a distance equal to the spacing and locate a point.
   13. Test this point for being outside a joint zone where the number of joints outside equals two. If inside go to E.7. If outside continue.
   14. Continue to repeat steps 11. through 13., where the probability of step 13. is adjusted for the number of joints that are now present outside a zone, until step 13. is failed, meaning that a joint zone is "entered". Go to E.7.
   15. Stop process of steps 7. through 14. when a point is generated beyond the end of the "generation line". Do not create that point.
   16. Return to selected point on first fracture and repeat steps 5. to 15. while going in the opposite direction from the first fracture with one initial modification. The first fracture is already defined as being within or outside a zone. Also, during steps 5. to 15., the number of points created before changing state from inside to outside, or outside to inside from the first fracture should be noted and retained. This number is used to determine the probability of the first point in the new traverse direction being inside or outside a zone. Once this state is determined apply the appropriate spacing distribution and repeat steps 5. to 15. until a point is generated beyond the other end of the "generation line". Do not create that point.
   17. *******During generation of points that are determined to be in fracture zones, the exterior points for each zone and the line segment in between should be noted and retained for later usage.

F. The "generation line" should now be "ornamented" by a set of points. For each point perform the set of steps G to J:

G. Define the trace length of the fracture -
   1. apply the mean trace length of the natural fracture set
   2. deviate from the mean trace length as a function of a "population distribution of lengths" for the natural set.
   3. Result is a fracture trace length, L.

H. Define the orientation of the fracture -
   1. apply the mean orientation of the natural fracture set. Orientation is defined as the azimuthal trend measured clockwise as an angle from North (000°) in the range of $0 \leq \theta \leq 180$.

2. deviate from the mean orientation of the fracture set as a function of a "population distribution of orientations" for the natural set.
3. Result is a fracture trend, θ.

I. Determine the position of the point along the trace length by dividing the line into a number of segments by the scale of resolution. The point should have an equal probability of being the midpoint of each segment. Use a "dice-rolling function" to determine which segment contains the point.

J. Generate the new fracture trace about the point with the trend from H. Terminate the trace where it extends beyond the generation area, $-a<x<2a$ and $-a<y<2a$.

III. Placing more fractures second generation line -

A. Select a side of the first generation line using a 50/50 probability.

B. Proceed a distance of *twice the mean trace length* of the fracture population from the generation line along a trend normal to the line.

C. Construct a new generation line that is parallel to the first line and terminates at the boundaries of the generation area.

D. If none of the line lies within the generation area, delete the line, return to the first generation line, repeat steps III.B. and III.C. for the opposite side of the first generation line. Otherwise, proceed to step III.F.

E. If none of this second attempt at a generation line lies within the generation area, delete the line and stop the fracture generation process. Otherwise, proceed to step III.F.

F. Locate the first point on the generation line.
1. divide the new generation line into segments by the scale of resolution
2. If the fracture population is anticlustered, each segment should have an equal chance of having the first point. Use a "dice-rolling function" to determine which segment midpoint is the first point. Create point. For subsequent points:
3. If the fracture population is clustered and the clusters are persistent parallel to zone orientation for distances of greater than twice the mean fracture trace length, identify those segments that are along trend from the zones of the first generation line (information retained in II. E. 17) and assign only them to have an equal nonzero chance of containing the first point. Use a "dice-rolling function" to determine which segment midpoint is the first point. Create point. Note that this point will be arbitrarily defined as being in a fracture zone for purposes of calculating the distance to the next generation point, as the underlying assumption of placing this first point is that it is along trend from a fracture zone on the first generation line.

G. Placing additional fractures (points) along new generation line:
1. If the fractures are anticlustered (F2 above):
   a. divide the range of the spacing population into segments (segment size equals previously chosen scale of resolution).
   b. Assign each segment a probability.

   c. Select a direction to traverse line from first fracture as a 50/50 probability
   d. Use a "dice-rolling function" to determine the spacing from the spacing distribution.
   e. Precede along line a distance equal to the spacing and locate a point.
   f. Repeat process until generate the first point beyond the termination of the "generation line". Do not create this point.
   g. Return to first point (fracture) on this generation line and repeat steps d. to f. while going in the opposite direction from the first fracture until a point is generated beyond the other end of the "generation line". Do not create that point.
2. If the fractures are clustered (F3 above):
   a. Consider the distribution of fracture spacings as two separate populations: the population of smaller spacings that defines fracture distribution in a joint zone and the population of larger spacings that defines fracture distribution outside a zone.
   b. Define the range of the number of joints that may compose a zone and assign each number a probability of occurrence based on observation of naturally occurring fracture zones.
   c. Define the range of the number of joints that may occur between zones and assign each number a probability of occurrence based on observation of naturally occurring fractures between zones.
   d. Assume that the first-formed fracture (point) is within a fracture zone, following from F.3. above. Also, select a direction to traverse the line from first fracture as a 50/50 probability.
   e. As inside a zone, continue,
   f. Use a "dice-rolling function" to determine the spacing from the spacing distribution for joints in a fracture zone.
   g. Precede along "generation line" a distance equal to the spacing and locate a point.
   h. Test this point for being within a joint zone where the number of joints in the zone equals two. If outside go to 2.j. If inside continue.
   i. Continue to repeat steps f. through h., where the probability of step h. is adjusted for the number of joints that are now present in the generated zone, until step h. is failed, meaning that the joint zone is "exited". Go to 2.j.
   j. Use a "dice-rolling function" to determine the spacing from the spacing distribution for joints outside a fracture zone.
   k. Precede along generation line a distance equal to the spacing and locate a point.

l. Test this point for being outside a joint zone where the number of joints outside equals two. If inside go to 2.e. If outside continue.

m. Continue to repeat steps j. through l., where the probability of step l. is adjusted for the number of joints that are now present outside a zone, until step l. is failed, meaning that a joint zone is "entered". Go to 2.e.

n. Stop process of steps e. through m. when a point is generated beyond the end of the "generation line". Do not create that point.

o. Return to first fracture (point) on this generation line and repeat steps e. to n. while going in the opposite direction from the first point with one initial modification. The first fracture is already defined as being within a fracture zone. Also, during steps e. to n., the number of points created before changing state from inside to outside from the first fracture should be noted and retained. This number is used to determine the probability of the first point in the new traverse direction being inside or outside a zone. Once this state is determined apply the appropriate spacing distribution and repeat steps e. to m. until a point is generated beyond the other end of the "generation line". Do not create that point.

H. The "generation line" should now be "ornamented" by a set of points. For each point perform the set of steps G to J:

I. Define the trace length of the fracture -
   1. apply the mean trace length of the natural fracture set
   2. deviate from the mean trace length as a function of a "population distribution of lengths" for the natural set.
   3. Result is a fracture trace length, L.

J. Define the orientation of the fracture -
   1. apply the mean orientation of the natural fracture set. Orientation is defined as the azimuthal trend measured clockwise as an angle from North (000°) in the range of $0 \leq \theta \leq 180$.
   2. deviate from the mean orientation of the fracture set as a function of a "population distribution of orientations" for the natural set.
   3. Result is a fracture trend, θ.

K. Determine the position of the point along the trace length by dividing the line into a number of segments by the scale of resolution. The point should have an equal probability of being the midpoint of each segment. Use a "dice-rolling function" to determine which segment contains the point.

L. Generate the new fracture trace about the point with the trend from J. Terminate the trace where it extends beyond the generation area, $-a<x<2a$ and $-a<y<2a$.

IV. Placing more fractures using additional generation lines -

A. If the last generation line was placed by continuing in the first direction from the first generation line (steps III. B. to D.), then continue in that direction a distance of *twice the mean trace length* of the fracture population from the last generation line along a trend normal to the line.

B. Construct a new generation line that is parallel to the first line and terminates at the boundaries of the generation area.

C. If none of the line lies within the generation area, delete the line, return to the first generation line, repeat steps IV.B. and IV.C. for the opposite side of the first generation line. Otherwise, proceed to step IV.H.

D. If none of this second attempt at a generation line lies within the generation area, delete the line and stop the fracture generation process. Otherwise, proceed to step IV.H.

E. If the last generation line was placed by continuing in the second direction from the first generation line (steps III. D. to E.), then continue in that direction a distance of *twice the mean trace length* of the fracture population from the last generation line along a trend normal to the line.

F. Construct a new generation line that is parallel to the first line and terminates at the boundaries of the generation area.

G. If none of the line lies within the generation area, delete the line, and stop fracture generation. Otherwise, proceed to step IV.H.

H. Starting from III.F. using the procedures in III. to generate the first fracture (point), all subsequent points and then, fracture traces on the new generation line.

I. Return to IV. A. to create the next generation line

V. Step III. E. or IV.G. will terminate generation of the synthetic fracture pattern. One possible check to determine whether the synthetic population in the **sample area** (not the generation area) is representative is to calculate the fracture intensity in the sample area. The measure of intensity would be P_{22}, the total fracture trace length in the area divided by the area (Dershowitz & Herda, 1992, Interpretation of fracture spacing and intensity, in, Rock Mechanics, ed., Tillerson & Wawersik, Balkema Press, Rotterdam). The check would be conducted by calculating the total fracture trace length for all fractures that have segments in the sample area, dividing by the area, then comparing the result to the population of P_{22} values from natural outcrops for that fracture set. Other checks may be designed, but are not a primary concern, until synthetics sets are being generated for examination.

Inputs from field data, using the NE-striking set of cooling joints

I. Length (sq) of side of sample square where $0 \leq \theta \leq 180°$, and θ has been defined above, already: Either $sq = \frac{2\ddot{L}}{|\cos\theta|}$, when $45° \geq \theta$ or $\theta \geq 135°$; or $sq = \frac{2\ddot{L}}{\sin\theta}$, when $45° \leq \theta \leq 135°$.

II. Length (g) of side of sample square where $0 \le \theta \le 180^\circ$, and θ has been defined above, already: Either $g = \frac{6\ddot{L}}{|\cos\theta|}$, when $45^\circ \ge \theta$ or $\theta \ge 135^\circ$; or $g = \frac{6\ddot{L}}{\sin\theta}$, when $45^\circ \le \theta \le 135^\circ$.

III. Scale of resolution (SR) -

IV. Mean trace length of fracture set

V. Population description for variation in trace lengths of fracture set

VI. Mean orientation of fracture set

VII. Population description for variation in orientation of fracture set

VIII. Determination of whether fracture set has a clustered or anticlustered spacing distribution

A. If anticlustered:

1. mean fracture spacing
2. Population description for variation in mean fracture spacing

B. If clustered:

1. Probability of an individual fracture being inside or outside a fracture zone
2. Mean number (integer) of joints in a joint zone as counted in a traverse normal to the zone.
3. Population description for variation in number of joints in a joint zone
4. Mean number (integer) of joints between adjacent joint zones as counted in a traverse normal to the zone.
5. Population description for variation in number of joints between adjacent joint zones.
6. Mean spacing between joints in a joint zone.
7. Population description for variation in mean spacing inside a joint zone.
8. Mean spacing between joints outside a joint zone.
9. Population description for variation in mean spacing outside a joint zone.

IX. Fracture intensity for the joint set using parameter P_{22}.

X. Population description for variation in fracture intensity.

XI. The above determination of these variables proceeds in a manner that assumes that they are independent. What if they are not?

A. For example, the dispersion of orientations for individual sets of fractures could be ***dependent*** on variables such as:

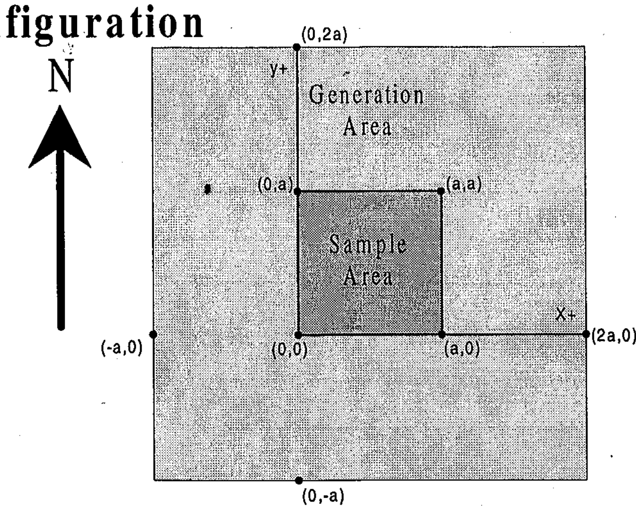
1. fracture trace length - longer fractures may show less variation of orientation;
2. geographic position - in an individual rock pavement (10's of meters by 10's of meters) a set may not show much orientation variation as compared to on a regional scale. If one or both of these dependencies exist, then the probability function for orientation variation should incorporate them and trace lengths should be determined before orientation in the synthesis process.

3. anticlustering and whether the fracture is inside or outside of a joint zone - The orientation dispersion may be noticeably less inside a joint swarm than outside of a joint swarm.

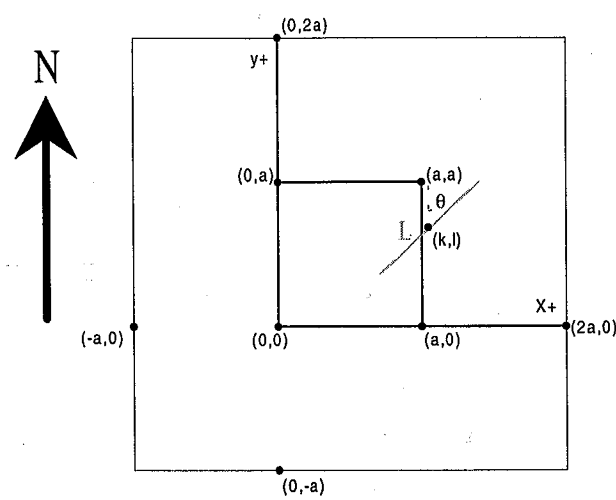
B. Alternately, the fracture trace length may be a function of being within or outside a joint zone in an anticlustered distribution of fractures. A general case for either greater average length or lesser average length could be made, so the parameters of the specific case should definitely be gathered, if possible.

C. This examples do not cover all of the possibilities, but indicate what an operator should be considering when constructing the list of input parameters. Dependency relationships would affect the construction of computer code for the simulation.

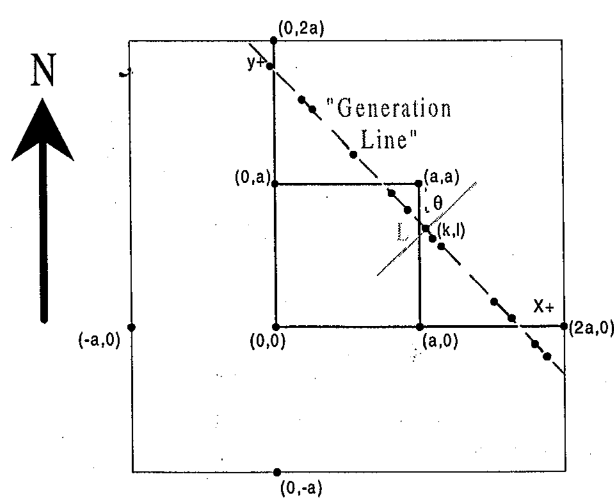
Initial Configuration



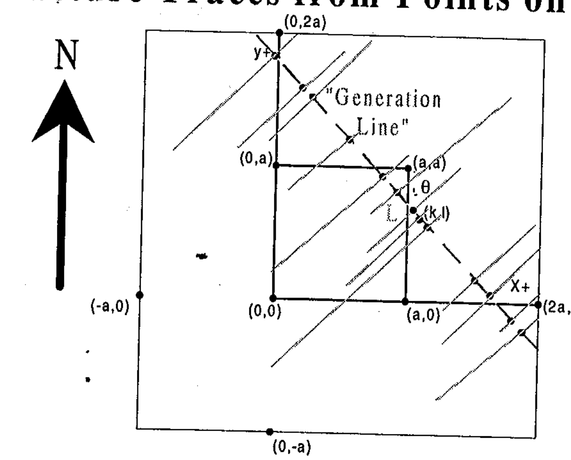
Generation of First Fracture



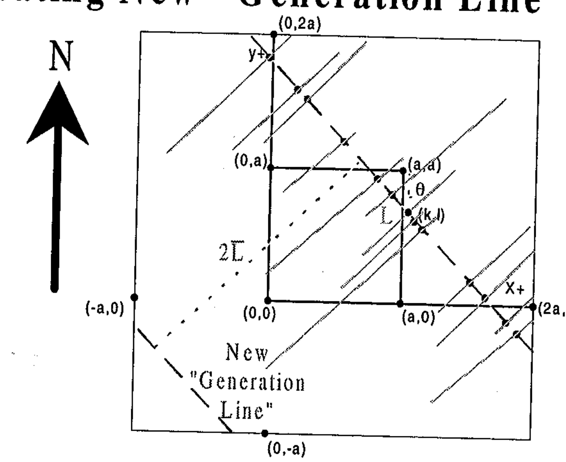
Creating Point Distribution on "Generation Line"



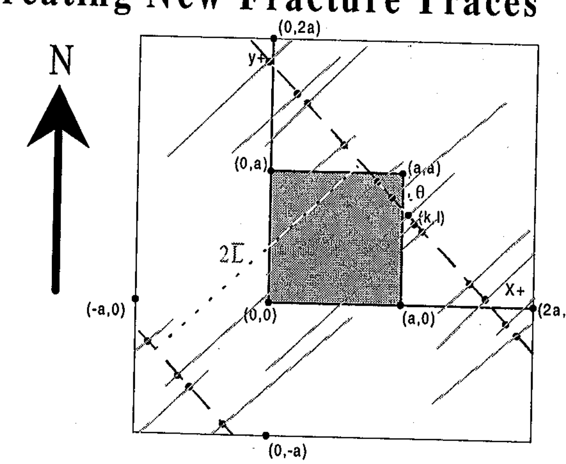
Creating Fracture Traces from Points on "Line"



Creating New "Generation Line"



Creating New Fracture Traces



Remember that this illustration isonly one example of number, orientation, size and distribution of both generation lines and synthetic fracture traces!!!

Comments on my Synthesizing Routine Considering some of the Options available in Fracman, Using content of LaPointe (1993)

(LaPointe, 1993, Pattern analysis and simulation of joints in rock engineering: Comprehensive Rock Engineering, ed., Hudson, v. 3, Rock Testing and Site Characterization, Pergamon)

I. **Spatially uncorrelated analysis** - The approach that I designed, is partially spatially uncorrelated (which is the simplest of the Stochastic-Geometric approaches) for the following reasons:
   A. Trace lengths of adjacent or nearby fractures are not dependent.
   B. Orientations of adjacent or nearby fractures are not dependent.
   C. The position of fractures created on adjacent generation lines is not dependent.
   D. The only exceptions to this situation are twofold:
      1. The positions of points on the fractures along the generation zones are dependent as a function of a scanline-like spacing relationship.
      2. The consideration of clustering vs. Anticlustering eliminates one of the greatest weaknesses of the patterns generated by a spatially uncorrelated approach (such as Poissonian), which is the inability to generate joint zones. An extension of this approach to include changes in orientation and trace length as a function of whether joints inside or outside of zones are being described, would limit the weaknesses of I.A. and I.B. above. The existing synthesizing routine does include a means of limiting the weakness of I.C. above by allowing the presence of joint zones to dictate where fracture intersects appear on adjacent generation lines.
   E. Still, the approach would not be able to select a point in a generating area and apply a description of changes in orientation and trace length as a function of distance and direction from that position, which is a better way to avoid the weaknesses of a spatially uncorrelated effect.

II. **Geostatistical methods** - The approach that I designed, can be improved by incorporating the use of variograms that describe changes if parameters of fractures as a function of distance from the fracture of interest. The variogram takes the form of:

$$\gamma(h) = \tfrac{1}{2}n(h)\sum_{i=1}^{n(h)}(X(z_i) - X(z_i + h))^2$$

where γ(h) is the variation as a function of distance, n(h) is the number of pairs separated by the relative distance h in the sample population (which is a vector quantity as the property being analyzed may vary both as a function of both direction and distance from the fracture of interest), $X(z_i)$ is the value of the property at the first fracture, and $X(z_i+h)$ is the value of the property at a distance h (vector!) from the first fracture.

This approach could be used to correct for the problems of I.A., I.B. above, where for I.A. and I.B., h would be parallel to the generation line and normal to the median orientation of the fracture set. I.C. is trickier and would ideally result in an infinite (or a small number as a function of the "class size" for the angular change between lines) number of radial generation lines from a center point that would describe the population in an area. Such an approach for I.C. would run into the problem of setting off to describe fractures in a direction where some fractures already existed from previous generation in other directions. This is a variant of the same problem that exists with my approach: How to interface ("make dependent") fractures on different but nearby generation lines.

Apparently (p. 224-225) to solve this problem, modellers distribute points for fracture centers using a Poissonian Function (like with spatially independent approach), selecting one point to be the start position, assigning mean characteristics to that fracture and then using the variograms as a function of direction (sectors of a joint rosette for the directional, as well as, distance variation in properties (p. 14, La Pointe & Hudson, 1985 GSA Spec. Pap. 199)) to assign fracture characteristics at the other centers as they are encountered. This really does not solve the problem of spatially dependent location of fracture centers (although centers may not be the fracture initiation sites as a function of the interaction of growing fractures during fracture propagation (Pollard & Segall, 1987, in Fracture Mechanics, ed., Atkinson, Academic Press). So, the implementation of variograms does not address the issue of interaction of a newly synthesized fracture with respect to existing synthetic fractures, in terms of the spatial dependence of the center locations.

III. **Fractal analysis** - Simply, the fractal dimension of a characteristic of a phenomenon is the complexity of its occurrence as a function of the number of spatial dimensions being considered. For example, for the fractal occurrence of the number of points on line, the dimension, D, can vary between 0 (zero points) and 1 (points occur in every segment length of the line at that scale of observation):

$$D = \log(N) / \log(1/R) \text{ or } D = \log(N) / \log(R)$$

where N is the number of occurrences and R is the scale of observation. N's are calculated for a range of R's and plotted on log/log paper as cumulative frequency of N vs. scale of observation. When plotted this way, observation of a strong linear correlation (power law relationship) is interpreted to mean that the population characteristic is fractal and that the slope of the line is D. A major advantage of this approach is the simpler data sets that are required as compared to the geostatistical methods above (for example, a map of fractures, fracture centers or fracture intersections is all that is needed to calculate D). Another advantage is that unlike the Poissonian generation of fracture centers, a fractal generation of centers would not be purely random, but would be a function of scale and distance (where the smallest scale used would be the cutoff dimension as used in the fracture studies at Yucca Mt. that varied between 0.2 m and 1.5 m as a function of investigators and approach). Thus, a center could be established in a fractal synthesizing simulation, the generation area divided into directional sectors (like with variograms in La Pointe & Hudson 1985), and a function describing fractal abundance of centers as a function of direction and distance could be used to position other centers. Then, spatial variograms (fractal or nonfractal) for other characteristics could be used to construct fractures at these centers. In theory, this approach might have a better chance of generating joint zones (p. 227, Fig. 7), if spatial clustering is present in the fracture population. It also establishes spatial dependency between centers.

Problems exist with this approach:

A. No verification exists to demonstrate that the fractal approach is actually any better than other approaches with synthetic fracture populations at producing realistic results (p. 229). This conclusion is supported by the observation that while many investigators of joint patterns, such as Barton and his coworkers at Yucca Mt., have calculated fractal dimensions for joint patterns, they have not demonstrated that this geometric characterization is a superior or more accurate approach. Also, Barton et al. (1993, USGS Open File Report 93-269, p. 42) could not identify a generator, which is the replicating key stone to populations of phenomenon with fractal behavior. The inability to demonstrate that fractals describe more accurately the fracture patterns, and the inability to identify generator calls into question the utility of describing joint patterns at Yucca Mt. as fractal.

B. The Yucca Mt. fracture investigations have the distinction of making the ground-breaking assertion that joint *patterns* are fractal (Barton and coworkers, various publications). With several refinements to eliminate sampling errors (see Barton et al. 1993, p. 40), the basic approach was to divide a rock pavement into square areas of edge size R and determine whether the box sides intersected a fracture. The total number (N) boxes that intersected a fracture for an edge size R could be plotted on a log-log graph of N vs. R or N vs. 1/R as a point. By changing the size of R, new points were generated in the plot and the points were fit with a straight line, which Barton and coworkers interpreted to mean that the joint pattern is fractal (e.g. Barton et al., 1993, p. 40, Fig. 18). However, as stated by Barton et al. (1993, P. 40), the data points lay along smooth curves even though they were fit with straight lines. Walsh & Watterson (1993, Journal of Structural Geology, v. 15, p. 1509-1512) and Gillespie et al. (1993, Tectonophysics, v. 226, p. 113-141) demonstrated that these types of data sets with true fits by curved lines are not fractal because they are not straight, even when the correlation coefficient for the regression fit of the straight line exceeds 0.993. The high correlation coefficient is an artifact the ranking of the box numbers (N) and a better measure of fit is found when plotting line slope vs. box size (R or 1/R). For this type of a plot, the results are strongly nonlinear (e.g. Walsh & Watterson, 1993, Fig. 4b) and hence, non fractal. As Walsh and Watterson (1993) perform their analyses on accurate versions of the fracture maps for pavements 100 and 1000, the joint patterns at Yucca Mt. have not been successfully demonstrated to be fractal.

C. Another problem is that the joint characteristics could be scale invariant or fractal for portions of the scales at which the fractures are observed (La Pointe, 1993, p. 229, e.g. Wojtal, 1994, Journal of Structural Geology, v. 16, p. 603 - 614, Aydin, 1996, Fig. 2.43 in NRC report), rather than simply fractal over the entire range of observation. If so, it is necessary to identify this situation rather than assuming that the characteristics of the joints are invariant for all scales. If the data sets at Yucca Mt. are "multifractal (consist of populations at different ranges of scales that each have their own fractal dimension)", the data (Fig. 7, Barton et al. 1993) would be fit with several straight line segments (e.g. Wojtal 1994). The test was not conducted, so multifractal behavior over the range of observation is unproven.

D. Establishing a fractal dimension for the one characteristic of the joint pattern (occurrence or absence of a fracture in a box of side dimension R) may not usefully characterize the individual characteristics of a joint pattern, even if these characteristics are fractal (Gillespie et al. 1993). 2D box-counting techniques, such as used by Barton and coworkers for occurrence, clump together many interdependent characteristics of the joints such as size distribution, orientation, linkage, and spacing, which may scale independently. Thus, the approach of measuring one parameter (presence or absence of a joint in a box of side dimension R) is insensitive to the individual and interrelated effects of these characteristics, and does not describe them even if they are individually fractal or "multifractal". Hence, the fractal dimensions determined by Barton and coworkers have little utility when trying to synthesize fracture populations in terms of characteristics such as size distribution, orientation, linkage, and spacing. This problem is exacerbated by observations about the population distribution of characteristics such as fracture spacing. This characteristic has been shown by many workers to be nonfractal because it lacks in a power-law distribution, but instead, may have a log normal, exponential, gamma, normal (periodic), or multimodal distribution (Rives et al., 1992, Journal of Structural Geology, v. 14, p. 925-937; Gillespie et al. 1993; Becker & Gross, 1996, Tectonophysics, v. 257, p. 223-237)(distributions are illustrated in Fig. A4 on p. A12 in the Fracman User Documentation of Dershowitz et al., 1996).

E. In summary, it is the opinion of this investigator that the fracture networks at Yucca Mt. have not been shown to be fractal, are not fractal, and even if they were fractal in the manner described by Barton and coworkers, the "bulk" characteristic would have little use in constructing realistic synthetic fracture patterns that addressed directly characteristics such as size distribution, orientation, linkage, and spacing.

IV. **Rule-based Methods** - As presently employed (Stone, 1984, Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr., v. 21, p. 183-194; La Pointe 1993) this method cannot be used to generate synthetic joint populations for a rock volume. Presently, the method uses one-dimensionally measured data (e.g. scanline or borehole) to predict local fracture geometry in the immediate rock volume. One of the simplifications of this approach is to assume that fracture centers lie along the linear traverse, which would be incredibly fortuitous in nature. However, the crux of the approach, melding empirical rules with statistical observations, may have some use. The rules are used to define the dependencies and hence, the order in which characteristics (statistical properties) are consider/applied. This general approach could be used to meld geostatistical observations about fracture size, spacing and orientation, in terms of their interdependencies (e.g. consider different suites of statistics if considering clustered or anticlustered fracture populations).

V. **Stochastic-mechanistic Methods** - Constraints on the statistical analyses of characteristics of a fracture population could be bounded by mechanical parameters that affect the ability of rock to fracture. Three examples are bed thickness, curvature and lithology. At Yucca Mt., only lithology has been identified as a controlling mechanical parameter from this set of three possibilities (Sweetkind & Williams-Stroud, 1996, USGS Admin. Report to DOE). The welded-tuff lack the thin layering, except in the PTn portion of the stratigraphy (Sweetkind et al., 1995, USGS Admin. Report to DOE), for fracture spacing control by layer-thickness. Dips and dip changes at Yucca Mt. are too small for fracturing induced by curvature to have occurred.

Sidebar to Synthesizing One Fracture Set

1. This approach differs from the dominant approach of FRACMAN, which is to define population statistics and generate the entire fracture population in one calculation. This approach is chosen because the distribution of fractures in a synthetic population is not dependent on other fractures (possible exception is the warzone simulation). A mechanism exists in FRACMAN to create a population, one fracture at a time. That might be the means for applying this approach to FRACMAN, but the code is not really configured to do this effectively.
2. How many synthetics have to be used in the geomechanical or hydrological modelling runs to get a representative range (or convergence?) of results? Remember that all synthetic populations meet the generation parameters and hence, should be "legitimate" examples. One possible "independent" check of the utility of a synthetic might be to calculate the trace length per unit area (P_{22} of Dershowitz & Herda, 1992) and compare that to the range of P_{22} calculated from the appropriate rock pavements for individual sets, or total populations, or?
3. The resolution of parameters such as joint length, spacing or angles could usefully be a function of the model where they will be applied. However, the models that have dimensions of several hundred meters to kilometers will not have useful resolutions for applying these synthetics. Hence, the creation of the synthetics may directly alter the scale of the system being simulated in the geomechanical or hydrological models.
4. P_{22} is a better measure of fracture intensity than the spacing between fractures, particularly when more than one fracture set is present. Unfortunately, it is a scalar quantity that is a function of both trace length and spacing, and I believe cannot be used to help generate the synthetic populations (although it may constitute a useful check after generation).
5. A problem with this generation technique of essentially using "spaced scan lines" is that while it includes spatial dependency between fractures along single generation lines, it does not do this between lines. The use of the double the mean trace length to space generation lines damps "interference" of synthetic fractures between generation lines, but really does not positively address a dependency relation between fractures as a function of their termination geometries. I need to think about this some more. The up side is that incorporation of clustering effects, if they exist, does build dependence of fracture location between generation lines, which may partially alleviate this concern. Still, this type of problem is to be expected when trying to geometrically characterize a structural phenomena that is the result of mechanical controls, but which controls are not well understood or reproducible as unique discriminants for geometric characterization.
6. Dependent variable problems -
   a. For example, the dispersion of orientations for individual sets of fractures may be ***dependent*** on three other variables in some cases (such as the early cooling joints?):

i. fracture trace length - longer fractures may show less variation of orientation;

ii. geographic position - in an individual rock pavement (10's of meters by 10's of meters) a set may not show much orientation variation as compared to on a regional scale. If one or both of these dependencies exist, then the probability function for orientation variation should incorporate them and trace lengths should be determined before orientation in the synthesis process.

iii. anticlustering and whether the fracture is inside or outside of a joint zone - The orientation dispersion may be noticeably less inside a joint swarm than outside of a joint swarm.

b. Alternately, the fracture trace length may be a function of being within or outside a joint zone in an anticlustered distribution of fractures. A general case for either greater average length or lesser average length could be made, so the parameters of the specific case should definitely be gathered, if possible.

7. Later, when assessing causes for the "excess" fracturing in the ESF beyond 4200m, the two applicable load states (Engelder & Fischer, 1996, Tectonophysics) should be considered: thermoelastic loading (cooling of tuff) and "axial extension" (not fixed grips). For the thermoelastic case, the multiplier of the relative amount of energy (and hence the Δtemp?) to cause this much fracturing as compared to a "normal", less abundant population of cooling joints could be calculated. For the strain case, the Ghost Dance Fault *hangingwall* with intense fracturing is the analog, if assume that fractures are forming in a "release quadrant" for the fault (if all along fault in HW, then normal motion, if only along ½, then strike-slip). For this hypothesis, the joints would result from strain partitioning to absorb horizontal extension (very small amount despite number of joints!), but only in release quadrant (HW, not FW if near top of normal fault, for example). Amusingly, if this geometry/hypothesis is correct, then a similar "package" of fractures should exist at depth in the footwall of the fault in the other release quadrant. By analogy, if the ESF is in or above the HW of a normal fault, the joints could be from this type of cause. Also, the fault need not be major, if one considers the intense joint pattern at surface within HW of Ghost Dance for displacement of Ghost Dance. Problems with this idea - (a) if related to a NS trending normal fault, would expect NS trending joints; (b) very large zone of intense fractures along ESF for fracture trends of 290° to 315° unless ESF is parallel/above a NS trending sinistral strike-slip fault, which would generate such joint trends in its release quadrant (implies fault length that runs well to south of ESF, so that stay in release quadrant)(note that Potter et al. 1996 GSA abs. Denver spent a lot of time talking about sinistral movement events on faults in and around repository site); and © fractures trending 290° to 315° are NOT going to simply be a strain partition from the EW extension event that formed the normal faults in the area.

Some Interesting Calculations when considering that the Frequent Fractures in ESF in the Tonopah Springs Tuff are of Cooling (thermoelastic) Origin

One approach is to consider the temperature change necessary to cause sufficient thermoelastic stress that will trigger a initial flaw to fracture (crack tip stresses exceed fracture toughness of rock)

Have these start parameters for Tuff:

$K_I c$ (fracture toughness) = 1 MPa (1,000,000 Pa)
c (initial flaw size) ranges from 0.1 mm (0.0001m) to 1 cm (0.01m)
E (Young's modulus) = 5×10^{10} Pa
α (coefficient of thermal expansivity) = 2×10^{-5} °K^{-1}
Y (shape factor for crack) ≈ 1

for case where calculate Temperatures necessary to cause fracturing for different size initial flaws in the rock, by using the equation:

$$K_I c = \sigma Y \sqrt{\pi c},$$
$$\Rightarrow \sigma = {K_I c}/{Y\sqrt{\pi c}}$$

to determine σ and then substitute it into:

$$\sigma = E\alpha\Delta T,$$
$$\Rightarrow \Delta T = \sigma/{E\alpha}$$

to determine ΔT, the change in temperature required to generate the necessary σ that will cause flaw failure.

Flaw size - c (m)	σ (MPa)	ΔT (°K)
0.0001	56	56
0.001	18	18
0.01	5.6	5.6

Calculated stresses of 5.6 to 56 MPa for the magnitude of remote tension by thermoelastic contraction are reasonable (e.g. as compared to 1 to 40 MPa from Segall & Pollard 1987)

****

Another approach is to temperature change required to cause the strain from joint formation.

Consider two situations: (1) fractures every 5 cm (21 joints in 1 m) - frequent in ESF; and (2) fractures every 1m (2 joints in a 1 m) - interpreted (mine) "background" joint spacing in Tonopah Spring Tuff from stations TV1 through TC4 in Verbeek & Throckmorton (1995, USGS Open File Report). An additional parameter is necessary to determine the extension (elongation normal to the plane of jointing for mode I fracturing) - dilation for each fracture. A range is of possible dilations is offered here of 1 µm (0.000001 m) to 100 µm or 0.1 mm (.0001 m) per fracture. In this case, the equation of choice is:

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$$\varepsilon = \alpha \Delta T,$$

$$\Rightarrow \Delta T = \varepsilon / \alpha$$

where ε is the magnitude for the extension by the number of joints in a meter.

Number of Joints	Dilation (m)	Extension	α (10^{-5} °K^{-1})	ΔT (°K)
21	.000001	.000021	2	1
21	.0001	.0021	2	105
2	.000001	.000002	2	0.1
2	.0001	.0002	2	10

This second approach yields a larger range of temperature change, but a temperature change of 0.1°K seems very unlikely. Otherwise, any fluctuation in temperature in rocks behaving elastically would cause fracturing! If this type of calculation is appropriate then the "background" amount of joint formation by cooling joints is releasing almost negligible thermoelastic stress. Hence, thermoelastic contraction for the "background" case is either small or being accommodated by some unspecified mechanism that behaves continuously (no fracturing). Another thing to note is that for the fractures in the ESF to be strictly the result of thermoelastic contraction during cooling, the temperature decrease would have to be an order of magnitude greater than at other locations with just the "background" population. Even allowing for thermal plumes in the welded tuff during cooling, the high intensity zones in the ESF have one oblique dimension (tunnel parallel) of 100's of meters. Would plume scale and organization be this large scale?

So, the two approaches yield ranges of about 5 to 50 (one order of magnitude) °K and 1 to 100 (two orders of magnitude) °K for the temperature change.

****

This type of analysis leads to several questions:

1) What was the temperature of the tuff immediately after welding ?
2) How long did it take the tuff to cool down to the ambient thermal conditions for rocks buried at a couple 100 m's?
3) Are the elastic properties of the tuff different at elevated temperatures (specifically E, α, $K_{I}c$)?

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4) Does anyone have useful aperature values for joints and what are those values?
5) Would size and organization of thermal plumes in the welded tuff during cooling be on the order of 100's of meters?

Comments Dave (or from your sources at SWRI)?
****

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WZ1

Parameter	Value	Comments
1FM = (meters)	50	center region edge length = 33.3 m
Scale (% viewed)	0.5	Looking at region 17 m bigger than center
Fracture set	yes	
Model	War zone	
Generation mode	centers	
truncation mode	by region	
Orientations	pole	
Fracture intensity	P32	
# of sides (range:1-16)	10	
Shape	box	
Region	inside	
Region Dim (L,W,H)	(100, 100, 100)	
Center Xo (x,y,z)	(0, 0, 0)	
Pole (tr,pl)	130/05 (040/85NW)	Cooling joints at 040,layer normal
Orientation spread	Bivariate normal	
Spread parameters	k1,k2,k12 = 1,1,1	attempting tight orientation spread
Size (eq. radius)(m)	5	5 m is bigger than total pop. mean (but cooling)
Size distribution	Trun. Exp. (0,20)	Exponential one of state possibilities
Dir. of elongation	N/A	
Elongation distribution	N/A	
Aspect ratio	1 (circular)	
Aspect distribution	N/A	
WZ intensity	5	5 times more intense inside War Zone
WZ Parallelism	1.2	allow the effect to occur for parallelism of <6 deg.
WZ Largeness	2	range (1 to 5),kinda large relative to norm.
WZ Closeness	2	range (1 to 5), kinda distant relative to norm
termination %	0	do not terminate!
Intensity P32	1.00E-01	.1 is kinda low compared to .3 to 2.0 for P21, P10
Intensity distribution	gamma	not a report choice, but they are probably wrong.
gamma coeff.	3.00E-04	should be 5e-2?? not well defined in manual
Fracture radius lower	1	m?
Fracture radius upper	20	m?
TRANSMISSIVITY		
correlates to	size	
exponent	2	where 1 = linear correlation
factor	1.00E-04	
deviation factor	1	
STORATIVITY	1.00E-06	
correlates to	none	
exponent	N/a	
factor	N/A	
deviation factor	N/A	
FRAC THICKNESS		
correlates to	size	
exponent	2	

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factor	1.00E-04	
deviation factor	1	

error? = singular covariance in (ransph)setup_bivnormal - all fracs are parallel

WZ2

In generate menu, used single fracture with war zone option to form three "derminate" war zones
They are bounded by surfaces at 040/85NW, eq. rad. of 50 or 75m, 16-sided polygons,
& separated by 4m. - wz2naked.fdt
Then I attempted a single set generation with war zone turned on.

Parameter	Value	Comments
1FM = (meters)	50	center region edge length = 33.3 m
Scale (% viewed)	1	Looking at region 17 m bigger than center
Fracture set	yes	
Model	War zone	
Generation mode	centers	
truncation mode	by region	
Orientations	pole	
Fracture intensity	P32	
# of sides (range:1-16)	16	
Shape	box	
Region	inside	
Region Dim (L,W,H)	(100, 100, 100)	
Center Xo (x,y,z)	(0, 0, 0)	
Pole (tr,pl)	130/05 (040/85NW)	Cooling joints at 040,layer normal
Orientation spread	Bivariate normal	
Spread parameters	k1,k2,k12 = 2,2,.9	attempting tight orientation spread
Size (eq. radius)(m)	4	4 m is bigger than total pop. mean (but cooling)
Size distribution	Trun. Exp. (1 to 10)	Exponential one of state possibilities
Dir. of elongation	N/A	
Elongation distribution	N/A	
Aspect ratio	1 (circular)	
Aspect distribution	N/A	
WZ intensity	10	5 times more intense inside War Zone
WZ Parallelism	1.2	allow the effect to occur for parallelism of <6 deg.
WZ Largeness	2	range (1 to 5),kinda large relative to norm.
WZ Closeness	2	range (1 to 5), kinda distant relative to norm
termination %	0	do not terminate!
Intensity P32	1.00E-01	.1 is kinda low compared to .3 to 2.0 for P21, P10
Intensity distribution	gamma	not a report choice, but they are probably wrong.
gamma coeff.	3.00E-04	should be 5e-2?? not well defined in manual
Fracture radius lower	1	m?
Fracture radius upper	10	m?
TRANSMISSIVITY		
correlates to	size	
exponent	2	where 1 = linear correlation
factor	1.00E-04	
deviation factor	1	
STORATIVITY	1.00E-06	

[signature] 4-15-97

correlates to	none	
exponent	N/a	
factor	N/A	
deviation factor	N/A	
FRAC THICKNESS		
correlates to	size	
exponent	2	
factor	1.00E-04	
deviation factor	1	

ran without the binormal variance error, but warzones betweent "warzones"?

WZ3

Parameter	Value	Comments
Began with wz2naked.fdt		
Changing parameters so that warzones do not occur between "warzones"		
Then I attempted a single set generation with war zone turned on.		
1FM = (meters)	50	center region edge length = 33.3 m
Scale (% viewed)	0.5	Looking at region 17 m bigger than center
Fracture set	yes	
Model	War zone	
Generation mode	centers	
truncation mode	by region	
Orientations	pole	
Fracture intensity	P32	
# of sides (range:1-16)	16	
Shape	box	
Region	inside	
Region Dim (L,W,H)	(100, 100, 100)	
Center Xo (x,y,z)	(0, 0, 0)	
Pole (tr,pl)	130/05 (040/85NW)	Cooling joints at 040,layer normal
Orientation spread	Bivariate normal	
Spread parameters	k1,k2,k12 = 2,2,.9	attempting tight orientation spread
Size (eq. radius)(m)	4	4 m is bigger than total pop. mean (but cooling)
Size distribution	Trun. Exp. (1 to 10)	Exponential one of state possibilities
Dir. of elongation	N/A	
Elongation distribution	N/A	
Aspect ratio	1 (circular)	
Aspect distribution	N/A	
WZ intensity	10	5 times more intense inside War Zone
WZ Parallelism	1.2	allow the effect to occur for parallelism of <6 deg.
WZ Largeness	2	range (1 to 5),kinda large relative to norm.
WZ Closeness	5	range (1 to 5), kinda distant relative to norm
termination %	0	do not terminate!
Intensity P32	1.00E-01	.1 is kinda low compared to .3 to 2.0 for P21, P10
Intensity distribution	gamma	not a report choice, but they are probably wrong.
gamma coeff.	3.00E-04	should be 5e-2?? not well defined in manual
Fracture radius lower	1 m?	

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Fracture radius upper	10 m?	
TRANSMISSIVITY		
correlates to	size	
exponent	2	where 1 = linear correlation
factor	1.00E-04	
deviation factor	1	
	1.00E-06	
STORATIVITY		
correlates to	none	
exponent	N/a	
factor	N/A	
deviation factor	N/A	
FRAC THICKNESS		
correlates to	size	
exponent	2	
factor	1.00E-04	
deviation factor	1	

ran without the binormal variance error, but warzones betweent "warzones"?

WZ4

Parameter	Value	Comments
Began with 3 single fracture warzones with thicknesses of 40, so that bounding fractures of adjacent warzones are close together and far from other half		
Then I attempted a single set generation with war zone turned on.		
1FM = (meters)	50	center region edge length = 33.3 m
Scale (% viewed)	0.5	Looking at region 17 m bigger than center
Fracture set	yes	
Model	War zone	
Generation mode	centers	
truncation mode	by region	
Orientations	pole	
Fracture intensity	P32	
# of sides (range:1-16)	16	
Shape	box	
Region	inside	
Region Dim (L,W,H)	(100, 100, 100)	
Center Xo (x,y,z)	(0, 0, 0)	
Pole (tr,pl)	130/05 (040/85NW)	Cooling joints at 040,layer normal
Orientation spread	Bivariate normal	
Spread parameters	k1,k2,k12 = 2,2,.9	attempting tight orientation spread
Size (eq. radius)(m)	4	4 m is bigger than total pop. mean (but cooling)
Size distribution	Trun. Exp. (1 to 10)	Exponential one of state possibilities
Dir. of elongation	N/A	
Elongation distribution	N/A	
Aspect ratio	1 (circular)	
Aspect distribution	N/A	
WZ intensity	10	5 times more intense inside War Zone
WZ Parallelism	1.2	allow the effect to occur for parallelism of <6 deg.

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WZ Largeness		4	range (1 to 5),kinda large relative to norm.
WZ Closeness		5	range (1 to 5), kinda distant relative to norm
termination %		0	do not terminate!
Intensity P32		1.00E-01	.1 is kinda low compared to .3 to 2.0 for P21, P10
Intensity distribution	gamma		not a report choice, but they are probably wrong.
gamma coeff.		3.00E-04	should be 5e-2?? not well defined in manual
Fracture radius lower		1	m?
Fracture radius upper		10	m?
TRANSMISSIVITY			
correlates to	size		
exponent		2	where 1 = linear correlation
factor		1.00E-04	
deviation factor		1	
STORATIVITY		1.00E-06	
correlates to	none		
exponent	N/a		
factor	N/A		
deviation factor	N/A		
FRAC THICKNESS			
correlates to	size		
exponent		2	
factor		1.00E-04	
deviation factor		1	

ran without the binormal variance error, but warzones betweent "warzones"?

WZ5

Parameter	Value		Comments
Used wz2naked.fdt for deterministic warzones			
Then, in set generation, set the warzone parameters all to 1, so WZ=3, => no warzone			
1FM = (meters)		50	center region edge length = 33.3 m
Scale (% viewed)		1	Looking at region 17 m bigger than center
Fracture set	yes		
Model	War zone		
Generation mode	centers		
truncation mode	by region		
Orientations	pole		
Fracture intensity	P32		
# of sides (range:1-16)		16	
Shape	box		
Region	inside		
Region Dim (L,W,H)	(100, 100, 100)		
Center Xo (x,y,z)	(0, 0, 0)		
Pole (tr,pl)	130/05 (040/85NW)		Cooling joints at 040,layer normal
Orientation spread	Bivariate normal		
Spread parameters	k1,k2,k12 = 2,2,.9		attempting tight orientation spread
Size (eq. radius)(m)		4	4 m is bigger than total pop. mean (but cooling)

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Size distribution	Trun. Exp. (1 to 10)		Exponential one of state possibilities
Dir. of elongation	N/A		
Elongation distribution	N/A		
Aspect ratio	1 (circular)		
Aspect distribution	N/A		
WZ intensity		10	5 times more intense inside War Zone
WZ Parallelism		1	allow the effect to occur for parallelism of <6 deg.
WZ Largeness		1	range (1 to 5),kinda large relative to norm.
WZ Closeness		1	range (1 to 5), kinda distant relative to norm
termination %		0	do not terminate!
Intensity P32		1.00E-01	.1 is kinda low compared to .3 to 2.0 for P21, P10
Intensity distribution	gamma		not a report choice, but they are probably wrong.
gamma coeff.		3.00E-04	should be 5e-2?? not well defined in manual
Fracture radius lower		1	m?
Fracture radius upper		10	m?
TRANSMISSIVITY			
correlates to	size		
exponent		2	where 1 = linear correlation
factor		1.00E-04	
deviation factor		1	
STORATIVITY		1.00E-06	
correlates to	none		
exponent	N/a		
factor	N/A		
deviation factor	N/A		
FRAC THICKNESS			
correlates to	size		
exponent		2	
factor		1.00E-04	
deviation factor		1	

again, the deterministic warzones are not controlling the fracture intensity

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II. DESCRIPTIONS OF FRACTURE PATTERNS FROM SURFACE DATA

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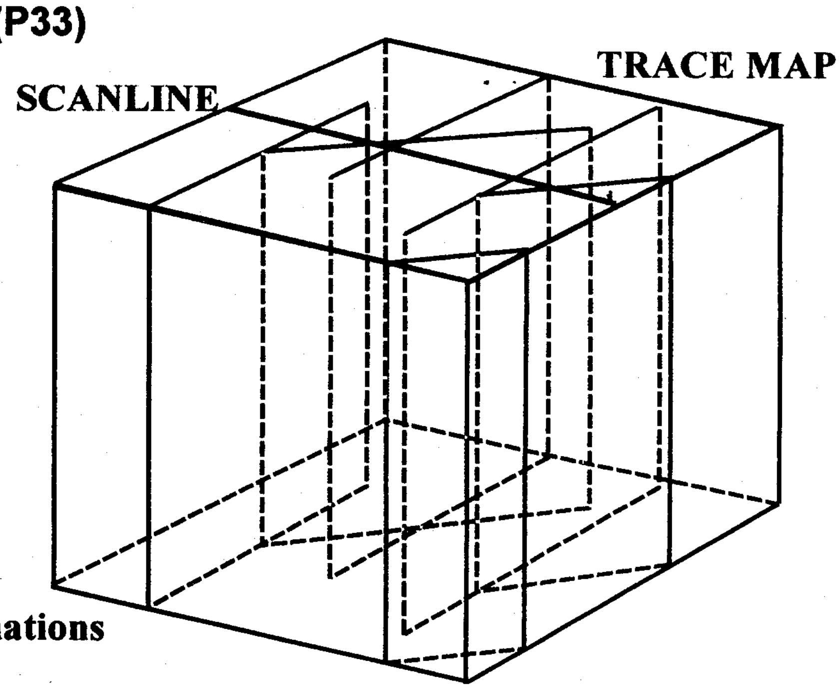
IDEAL FRACTURE DATA (volumetric)

- Exact Locations of Fracture Centers and Dimensions
- All Fracture Orientations and Variations
- Fracture Aperatures and Variations
- Volumetric Fracture Intensity (P33)
- Connectivity



REALITY

- Areal Data (Tracemap)
  - Trace Centers and Lengths
  - Fracture Orientations
  - Areal Fracture intensity (P22)
  - Some Connectivity and Terminations
- Linear Data (Scanline)
  - Fracture Orientations
  - Fracture Spacing (P11)

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FRACTURE DATA TYPES FOR CONSTRUCTING DISCRETE FRACTURE NETWORKS

- Identification of Fracture Sets
- Positions of Fracture "Centers"
- Orientations and Population Characteristics
- Trace Lengths and Population Characteristics
- Spatial Intensities and Population Characteristics
- Termination, Age, and Connectivity Relationships

- Variations as a Function of Lithology
- Variations as a Function of Geographic or Structural Position
- Variations as a Function of Other Fracture Characteristics

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Information potentially subject to copyright protection was redacted from pages 57 through 65 of this scientific notebook.. The redacted material (listed below) is from the following reference:

Sweetkind and Williams-Stroud. 1996. No additional information is known.

Figures: Fracture sets at pavement 2001 at Fran Ridge; Grouped fracture data from TIVA canyon tuff..., orientations of joints in TIVA canyon and Topopah spring tuffs...Fracture trace length data, (table) Fracture intensity and network geometry..., Fracture intensity and fracture frequency data, Termination relationships, Generalized stratigraphy of the Paintbrush group..., Fracture strike distributions.

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LITHOLOGICAL CHANGES TO FRACTURE CHARACTERISTICS

- **Increased Welding of Tuffs Increases Fracture Intensity, Connectivity and Fracture Size**
- **Fractures Tend to Terminate at Limits of Welded Zones, Limiting Vertical Connectivity**
- **Where Welding is Less, Increased Pumice Content and Clast Size Decrease Fracture Intensity**
- **Lithophysae-rich Zones Decrease Fracture Size, Decrease Fracture Intensity, and Increase Fracture Roughness**
- **In Lithophysae-rich Zones, Cooling Joints may be Abundant, and They are Unaffected Because They Predate the Lithophysae**

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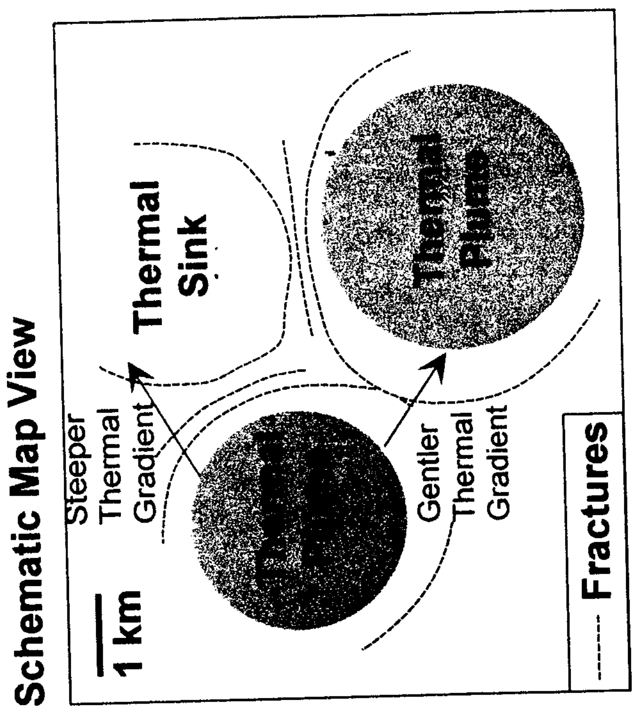
Variations to Fracture Pattern During Cooling of Tuffs

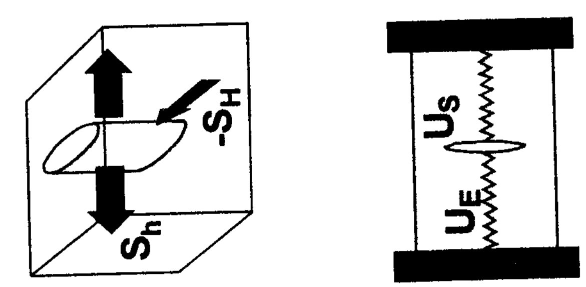
Variations

Schematic Map View



- Changing Fracture Orientations
- Changing Fracture Spacing

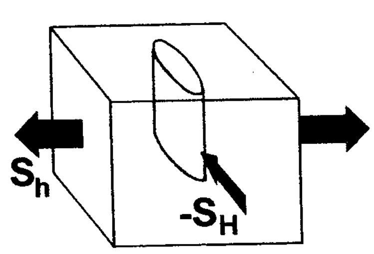
Thermoelastic Loading

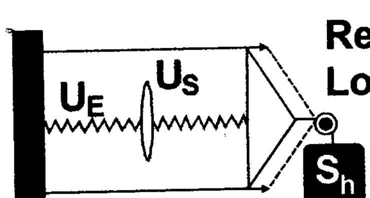


$dU_E = dU_S \quad dU_W = 0$

Variations to Fracture Pattern During Normal Faulting

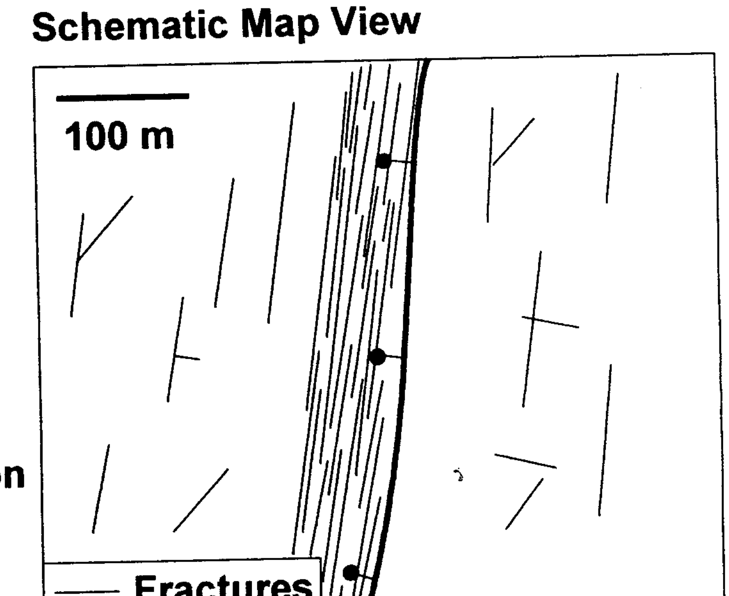
Joint Normal Loading





Variations

Schematic Map View



- Changing Fracture Spacing
- Changing Relative Abundance of Fracture Orientations
- Changing Size Distribution of Tectonic Joints

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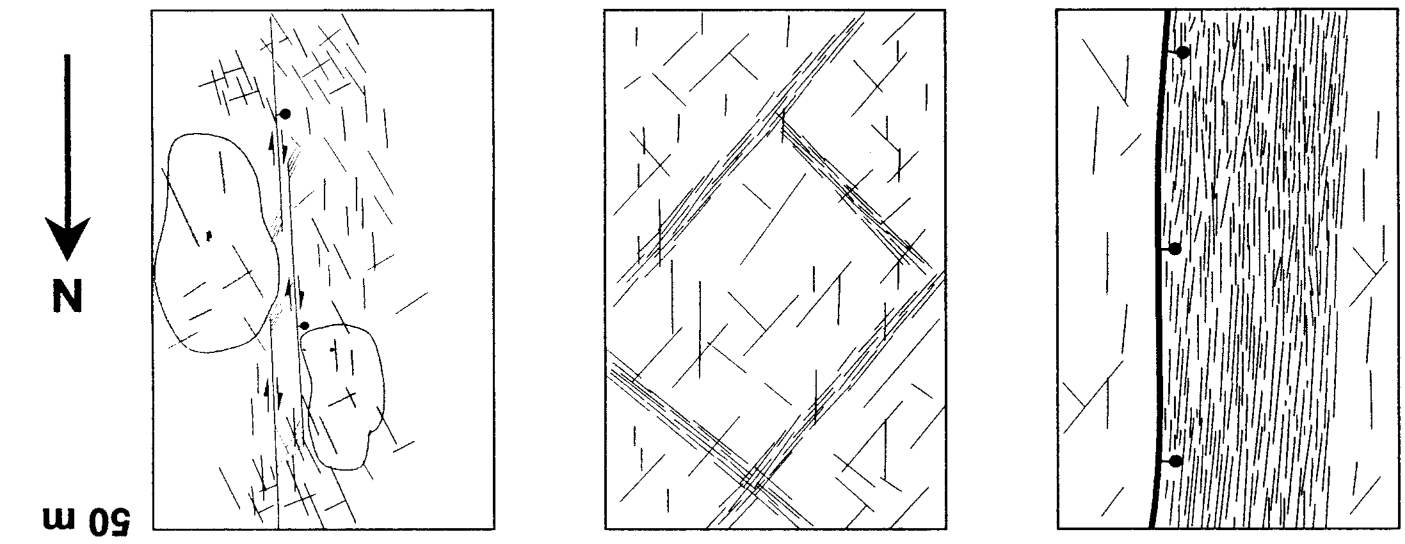
SCHEMATIC VARIATION OF JOINT PATTERNS AT YUCCA MOUNTAIN AS A FUNCTION OF GEOGRAPHIC AND STRUCTURAL POSITION

4-15-97



Fran Ridge
Multiple Cooling and Tectonic Joint Sets with Reactivation of Some Joints as Faults

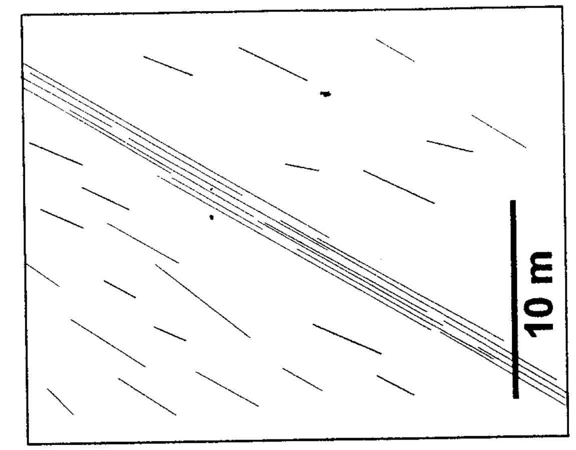
Yucca Ridge
Two Sets of Cooling Joints Distributed in a Zonal Pattern with Less Abundant Tectonic Joints

Ghost Dance Fault
Single Dominant Joint Set in Hanging Wall of Fault

INHOMOGENEITIES AND DEPENDENCIES OF FRACTURE CHARACTERISTICS

- Investigators of Surface Fractures Indicate that the Cooling Joints may Show Spatial Clustering
- Tectonic Joints do Show Spatial Clustering near Faults
- Where Joints are Spatially Clustered, They Form Zones or Swarms where Fracture Sizes and Abundance are Greater while the Variation in Fracture Orientation Decreases

EFFECTS OF CLUSTERING ON CHARACTERISTICS OF A JOINT SET



- Increase in Joint Size
- Increase in Fracture Intensity
  - Increase in Joint Size
  - Decrease in Joint Spacing
- Decrease in Variation of Orientation
- Increase in Aperature?
- Creation of "Penetrative" Fracture Pathways through Rock Volumes

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III. BUILDING A DISCRETE FRACTURE SET

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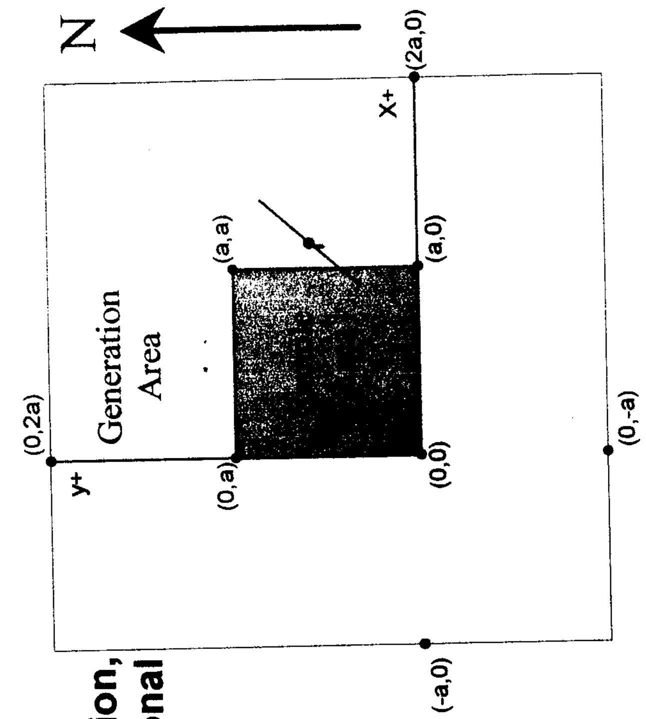
STEP 1: ESTABLISH SAMPLE AREA

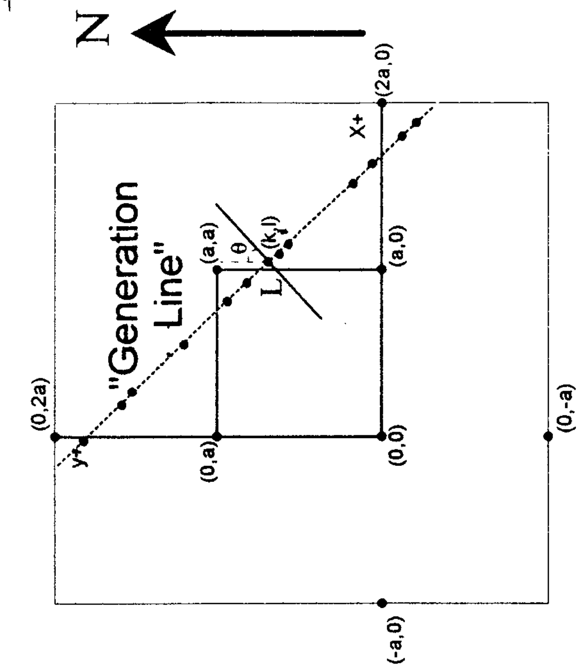
Initial Configuration



- **For Simplicity, in this Conceptualization, Illustrations will be Two Dimensional**
- **Sample Area within Generation Area to Eliminate "Edge Effects"**
- **Example "Edge Effect" is a Fracture that Terminates in the Sample Area, but which has a Center Outside the Sample Area**

WHY CONSIDER MODELLING GROUNDWATER FLOW WITH DISCRETE FRACTURE NETWORKS AT YUCCA MOUNTAIN?

- Fractures are the Dominant Form of Rock Permeability, Particularly in Welded Tuffs
- Fracture Populations are not Uniform across the Repository Site and Change Dramatically on the Scale of 100 to 200 m as a Function of Lithology, Cooling History, Structural Position, and Interdependencies between Fracture Characteristics
- At a Given Location, the Large Interconnected Fractures have only a Few Orientations
- Fractures Display Zonal (Clustered) Distributions
- Colloid Tracer Experiments for Fractures in Tuffs Show Large C/Co Values for Breakthrough Curves and Measured Aperatures of 0.05 to 0.6 mm.

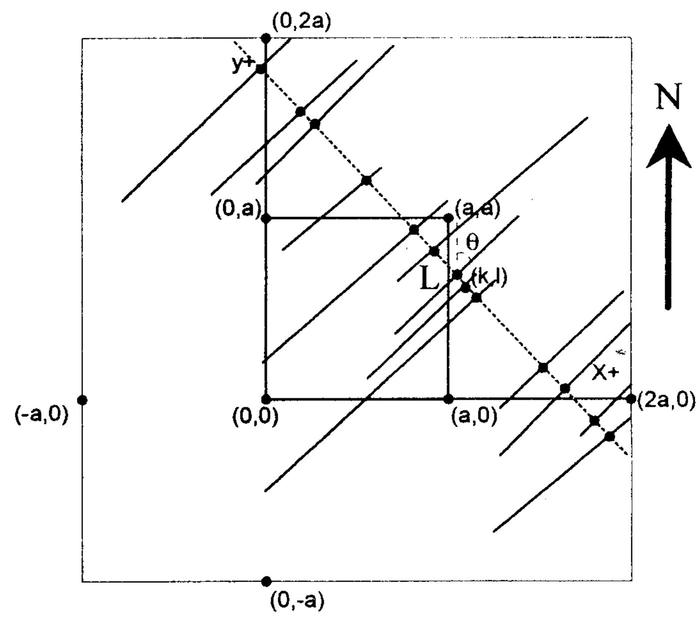


STEP 2: LOCATING FRACTURE CENTERS

- Perhaps, the Most Problematic Step as Little Data about Fracture Center (or Initial Flaw) Distributions
- No Simple Observational Rules Exist
- Common Approaches are:
  - Poissonian (Uniform Random)
  - Fractal (Scale and Fractal Dimension)
- Future Technique to use Geostatistical Variograms
- Here a less Sophisticated Approach is Applied, Using a Generation Line that is Oriented Normal to Mean Orientation of Set and Fracture Spacing Data

STEP 3: GENERATING FRACTURE TRACES

- **Spatially Independent Approach:**
  - **Locate a Fracture Center**
  - **Use the Population Distribution to Determine the Trace Length about a Mean Length**
  - **Use the Population Distribution to Determine the Orientation about a Mean Orientation**
- **Spatially Dependent Approach:**
  - **Use an Approach such as a Variogram or Fractal Scaling to Determine Changes in Size and Orientation as a Function of Position**
- **Also, Consider Whether Clustering is Present, and if so, Modify Population Distributions for Fracture Characteristics within the Clusters**

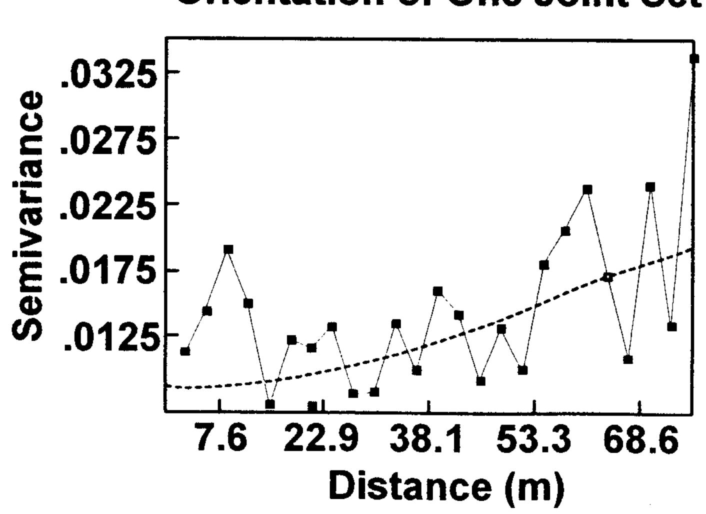


EXAMPLES OF SEMIVARIOGRAMS FOR SPATIAL DEPENDENCE

$$\gamma(h) = \tfrac{1}{2}n(h)\sum_{i=1}^{n(h)}(X(z_i) - X(z_i + h))^2$$

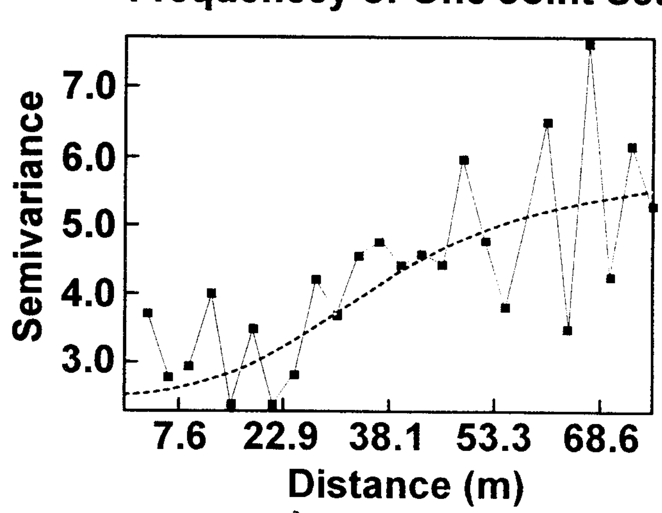
where γ(h) is variation as function of distance, n(h) is number of pairs separated by relative distance h (a vector quantity!), X(zi) is value at first fracture, and X(zi + h) is the value at a distance h from first fracture

Example Variogram For Fracture Orientation of One Joint Set



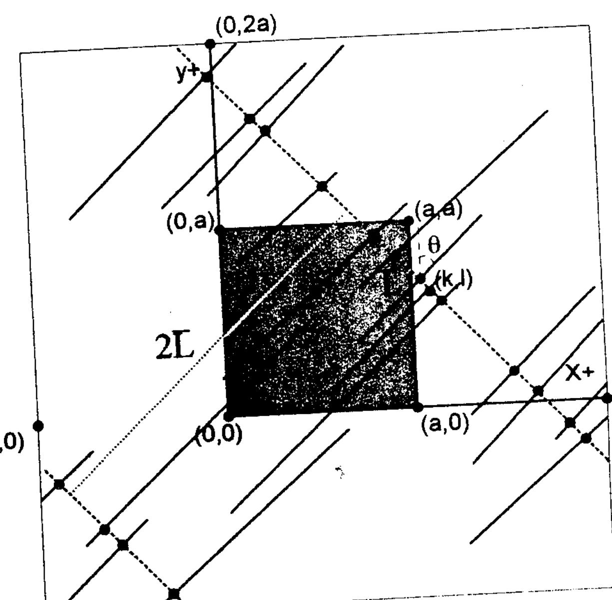
**Modified from La Pointe & Hudson (1985)*

Example Variogram For Fracture Frequencey of One Joint Set

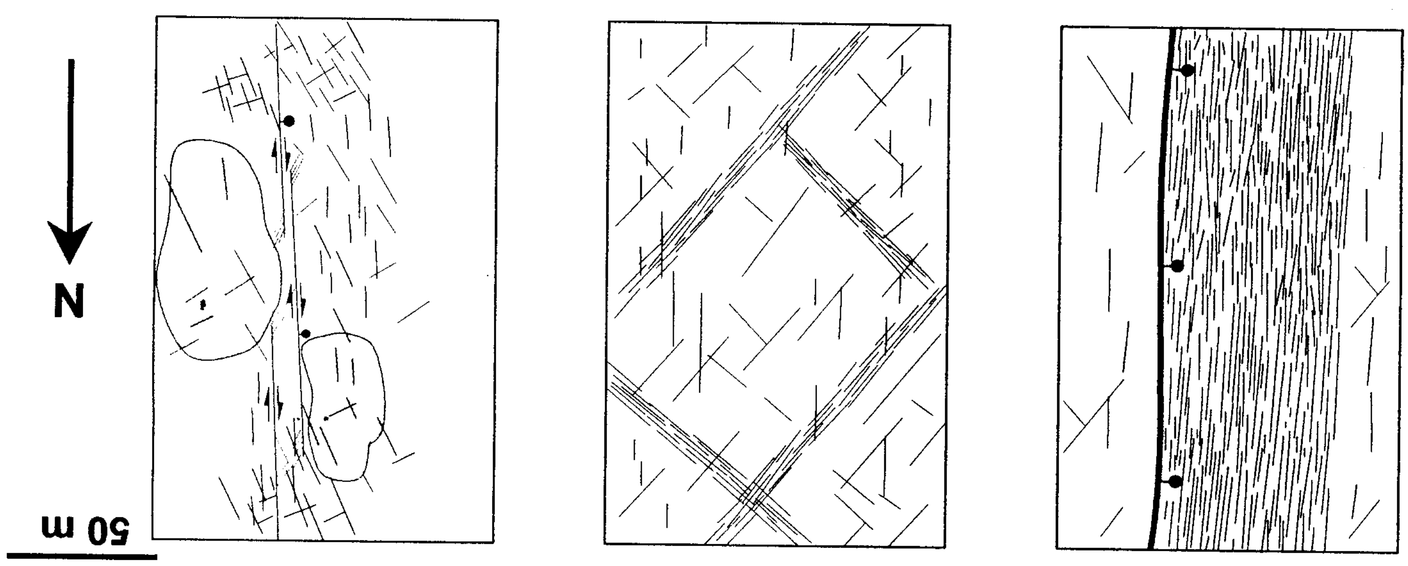


GENERATION OF ADDITIONAL FRACTURE TRACES

- In this Case, Additional Fractures are formed by Creating New Generation Lines, and Replicating the Process
- With other Approaches to Defining the Initial Distribution of Fracture Centers, this Step is Unnecessary



SCHEMATIC VARIATION OF JOINT PATTERNS AT YUCCA MOUNTAIN AS A FUNCTION OF GEOGRAPHIC AND STRUCTURAL POSITION



Fran Ridge
Multiple Cooling and Tectonic Joint Sets with Reactivation of Some Joints as Faults

Yucca Ridge
Two Sets of Cooling Joints Distributed in a Zonal Pattern with Less Abundant Tectonic Joints

Ghost Dance Fault
Single Dominant Joint Set in Hanging Wall of Fault

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V. FRACMAN PROGRAM FOR CONSTRUCTING AND TESTING FLOW IN DISCRETE FRACTURE NETWORKS

Information potentially subject to copyright protection was redacted from pages 81 through 84 of this scientific notebook.. The redacted material (listed below) is from the following reference:

Dershowitz, et al., 1995. No additional information is known.

Figures: Fracman modeling package, Fracman graphical user interface, Geometrical conceptual models for constructing hypothetical fracture networks, Sampling a discrete fracture network...

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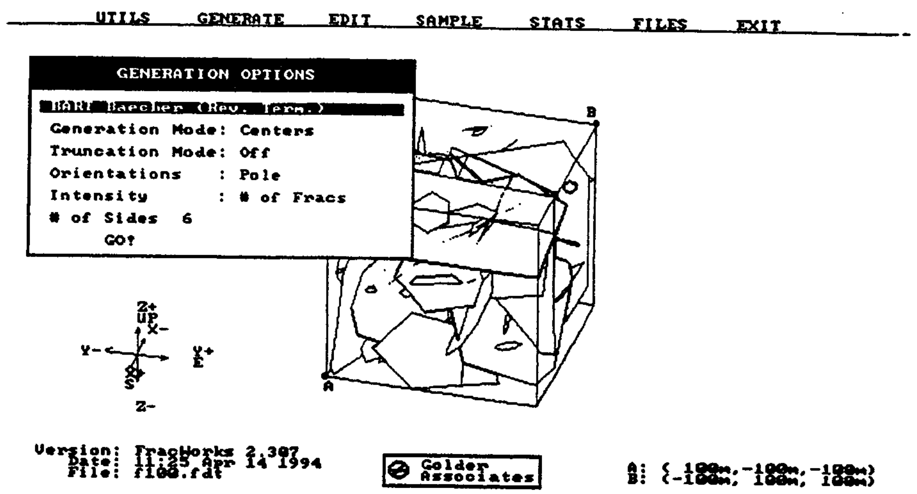
FRACMAN GRAPHICAL USER INTERFACE



(from Dershowitz et al. 1995)

GEOMETRICAL CONCEPTUAL MODELS FOR CONSTRUCTING HYPOTHETICAL FRACTURE NETWORKS

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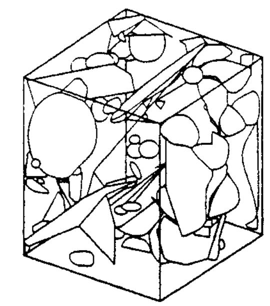
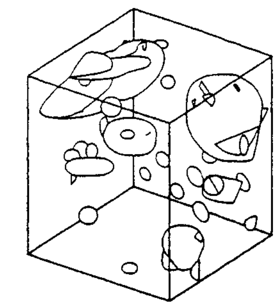
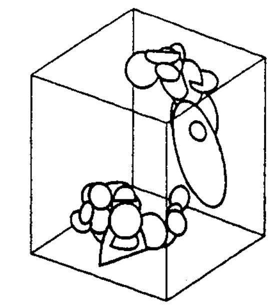


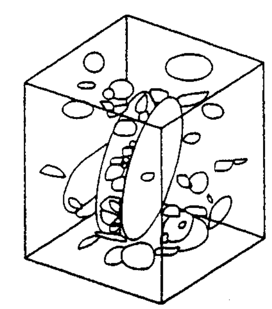
a) Enhanced Baecher Model, BART (Stationary Poisson Point Process)



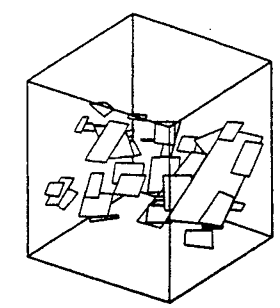
b) Nearest Neighbor (Non-Stationary Poisson Point Process)



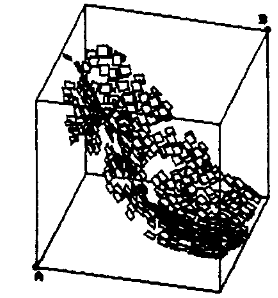
c) Levy-Lee Fractal Model



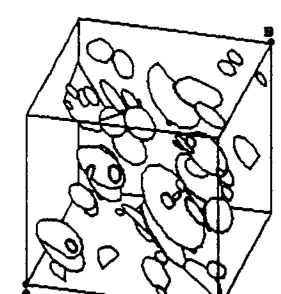
d) War Zone Model



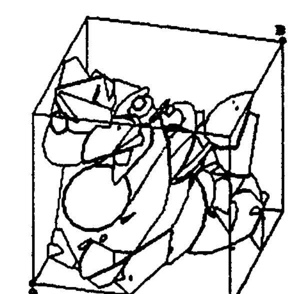
e) Poisson Rectangle Model



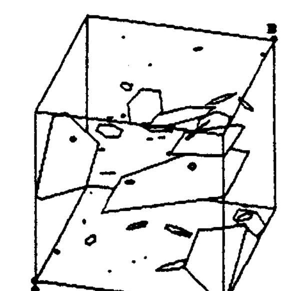
f) Non-Planar Zone Model



g) Fractal POCS Model



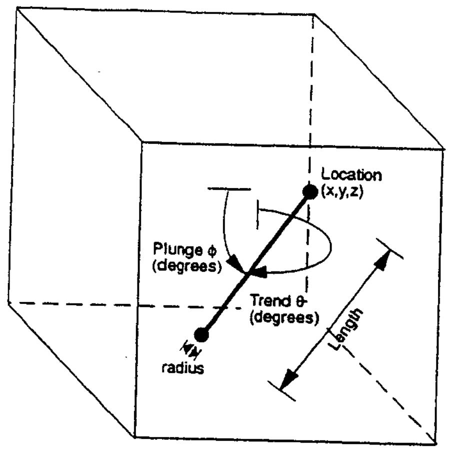
h) Fractal Box Model



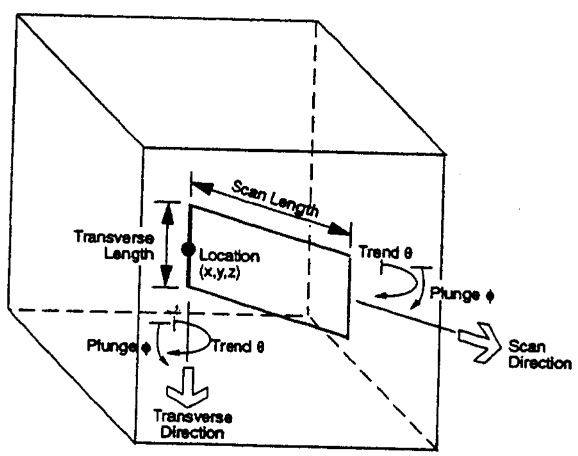
i) Geostatistical Model

(from Dershowitz et al. 1995)

SAMPLING A DISCRETE FRACTURE NETWORK USING BOREHOLE OR TRACEPLANE GEOMETRIES



a) Borehole



b) Traceplane

(from Dershowitz et al. 1995)

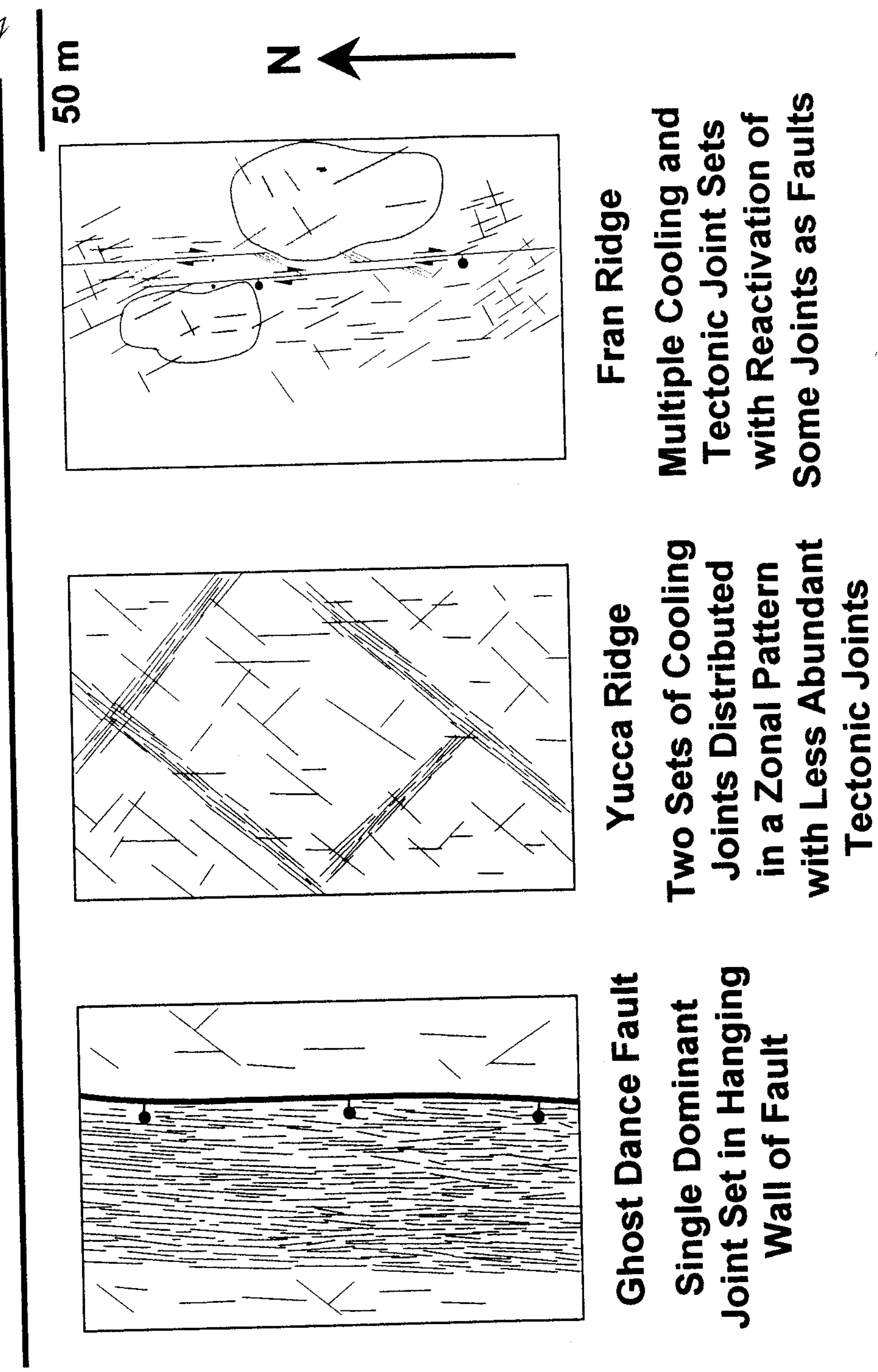
CONCERNS ABOUT APPLICATION OF FRACMAN TO CONSTRUCTION OF DISCRETE FRACTURE NETWORKS FOR YUCCA MOUNTAIN

- Distribution of Fracture Centers by Poissonian or Fractal Approaches
- Potential Inability to Handle Interdependent Fracture Characteristics ("Work Arounds" may exist)
- Program output of Parameters Sets and Images of Discrete Fracture Networks are "Cludgy"

- Alternatives to FRACMAN may exist, but the Program has not yet been used Effectively to Simulate Fracture Patterns at Yucca Mountain (e.g. Compare Sweetkind & Williams-Stroud (1996) to Anna (1996)), so it is not yet Clear that an Alternative is Needed

VI. REVIEW OF ADEQUACY OF YUCCA MOUNTAIN SURFACE FRACTURE DATA FOR CONSTRUCTION OF REPRESENTATIVE DISCRETE FRACTURE NETWORKS

SCHEMATIC VARIATION OF JOINT PATTERNS AT YUCCA MOUNTAIN AS A FUNCTION OF GEOGRAPHIC AND STRUCTURAL POSITION



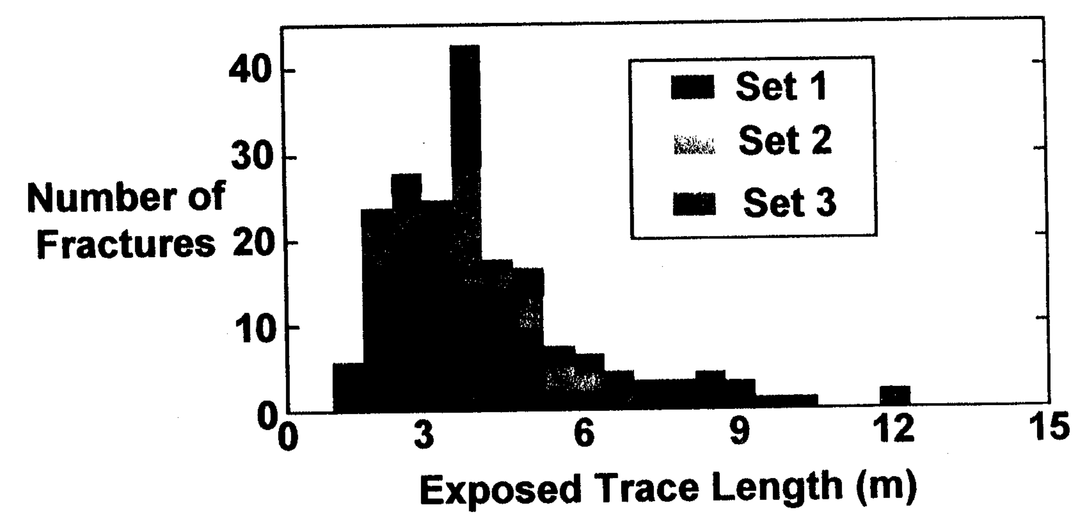
Bill Dunne 8-15-97

ADDITIONS/CHANGES OF SURFACE DATA ABOUT JOINT PATTERNS TO MORE EFFECTIVELY CONTRIBUTE TO CONSTRUCTION OF DISCRETE FRACTURE NETWORKS FOR MODELLING

- **Division of Repository into Structural Domains that Contain Consistent Fracture Geometries**
- **Within Domains, Separation of Characteristics such as Fracture Intensity, Connectivity and Size by Sets**
- **Within Sets, Identify if Homogeneous or Clustered Fracture Distributions Exist. If Clustered, Determine if and how Fracture Characteristics Vary Between Inside and Outside of Clusters (Joint Zones)**

SCHEMATIC EXAMPLE OF DIVIDING A FRACTURE CHARACTERISTIC IN A DOMAIN BY SETS TO DETERMINE IF VARIATION EXISTS BETWEEN SETS

Bill Dunne 8-15-97



I HAVE REVIEWED THIS SCIENTIFIC NOTEBOOK AND FIND IT IN GENERAL COMPLIANCE WITH QAP-001 AND THERE IS SUFFICIENT TECHNICAL INFORMATION SO THAT ANOTHER QUALIFIED INDIVIDUAL COULD REPEAT THE ACTIVITY

H. Lawrence McKague
4/16/97

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Yucca Mt. - SwRI
July 24th, 1997

This work is second visit to Yucca Mt. to examine fractures (particularly joints). Field partner and supervisor is David Ferrill. This visit is a five day campaign with 3 components → (1) Examine fracture patterns around identified faults and corollary faults that might provide fast-path infiltration routes to repository level; (2) aid David Ferrill and John Stamatakos in their work at south end of ~~Bare~~ Mountain, and (3) meet with Chad Glenn to show him some of our observations and have him take pictures for us.

For the fracture work, the basic plan is:

① Review four stations from the work of Throckmorton & Verbeek. These stations are nonpavement exposures of the kind that we will be dealing with this trip, so they can act as [illegible] for us. They are directly above ~~our~~ or w.o. quite close to the repository. They feature multiple tectonic joints, so that surface smoothness

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and termination relationships and be examined in particular.

② Examine the regions around the Diabolous Ridge thrust and Sundance fault to see:

(a) local surface fracture pattern
(b) local presence/absence of alluvium
(c) changes as a function of presence/absence of fault.

③ Examine Abandoned Wash fault around Highway Ridge to compare fracture patterns and alluvial occurrence to faults of ②. Faults of ② are identified in Cl_{36} report as likely pathways through Ptn strat. unit to repository level. The Abandoned Wash fault from surface and core work is a similar fault and its presence could impact the southern 20% of the western segment for the proposed repository.

Other issues to consider during this 3-stage plan:

1) Evidence for joint swarming and intersecting of swarms
2) Role of ccr1 ~~strat.~~ unit of the Tiva Canyon Tuff in fracture pattern development

Biff Dunne
3/13/99

Bill Dunne 3/13/99

3) Fracture set development

Stop 1 - Station CH2 of Throckmorton & Verbeek (1995) in "Hackly" unit of Tiva Canyon Tuff (lower non-lithophysal unit of more modern lithostratigraphic descriptions). [NW end of Drill Hole Wash]
The T&V (Throckmorton and Verbeek) story is of 4 joint sets → T1 (006°), T3 (028°), T4 (284°) and SH (subhorizontal partings). T1 is portrayed as dominant. Also, no cooling joints are here).

The exposure is a rib that sticks out of the hillside for several hundred meters. Excellent side views of the fracture pattern exist and a limited amount of map view is present walking along the edge of the exposure on top.

Much of T&V's description resonated with curvilinear fractures weaving through the rock mass. Surprises were that T1 did not dominate as much as expected, and that the

unit often had a subpolygonal appearance with a block size of 40 to 80 cm. Also, T4's were, in several places, more abundant and larger than a late-forming set ought to be (as described by T&V).

The subpolygonal geometry would suit hydrologic modelling where an isotropic parameter describing ability to allow flow was made larger. No need for anisotropic or spatially dependent descriptions.

Actually result of T&V examining unit immediately above columnar unit w.o. unlike Dave and I who did both.

I am not entirely comfortable with assigning most of the subvertical fractures to three sets. The result is a classification with a large masked dispersion, particularly when reporting only median orientations. The medians of 006°, 028° & 04° should produce a very rectilinear pattern rather than the subpolygonal pattern that is seen. This discrepancy in geometric appearance arises from the use of large unreported dispersions.

The prominence of SH set is obvious in the exposures, but reinforced when looking at the weathered/eroded blocks. Do not have columns lying on the ground. Instead, have stubby polyhedrons.

Dave Ferrill went further up hillside to NW to examine vertical consistency of pattern. We are going to do that again by leaving CH2, crossing wash and going up SW side of wash to look at fractures as a function of lithology.

~~Dale~~ Crossed the wash to the same unit that we saw at CH2 and Dave again discussed the possible stratigraphically controlled distribution of the subpolygonal joints. I just remembered that under the lower lithophysal unit is a columnar unit, so Dave's observation is consistent with the stratigraphy.

Went to hill top through crystal-poor Tiva Canyon and reached crystal-rich (specifically Cr1 and Cr2) at hill top. Saw float of lithophysal units with tubercles but none in place. On hilltop have much exposed bedrock but sediment is in all possible fracture sites. How does water infiltrate through sediment in fractures?

O.K. through with CH2. Now going to CUL 7 on top of Live Yucca Ridge.

Stop 2 - CUL7 → out on main road and will go SW cross country to hillcrest where this station is located.
[upper lithophysal of Tiva Canyon Tuff]
This T&V locality had 26 joints in two cooling joint sets (055°, 315° median strikes) and miscellaneous unspecified tectonic joints. Two cooling sets were not uniformly spaced across site and they all had tubercles.
We found the 055° tough to find. Only really found one occurrence and it is w.d. a swarm. The 315° occurred but not together. Also, further upslope found a swarm of N-S trending, post-lithophysae joints (T1) that ran at least 15 m and had at least 6 m vertical penetration.

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Saw no intersection of different swarms from different sets. So, as reported previously by others w.D. Cul is locally vertically connected by syn and postcooling joint swarms. Now onto CH6.

Stop 3 - CH6 A Locality in the footwall of the Ghost Dance fault at a distance of about 8m from the fault. Small crop adjacent to wash by ~~UZN-47~~ w.D. USW-UZ48.

Saw very few tubercle-ladden joint faces, but the cooling joints are incredibly smooth unlike the proposed tectonic joints (smoothness is a key criteria for most workers).

Most of the joints are large (exceed extent of the exposure) and not connect. No swarming.

Day 2 - July 25th

Continuing today with completion of examination of T & V work (specifically CKS 1) and then moving onto examine the key faults from the CC36 study

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(Diabolous Ridge thrust and Sundance fault)

Stop 4 - CKS 1 (trench at UZN 66, which is not on the 1:6000 map of Day et al.). w.D. ~~Two~~ Three sets of comments for this site: (1) site specific, (2) assessment of cataloguing approach of T&V (1995); and (3) brief discussion of $T_1 \rightarrow T_4$ nomenclature with implications for fracture development.

(1) The site description emphasizes the importance of T3 and T1 sets while noting unusual problems with occurrence of arrest lines and ambiguous abutting relationships. The site is unusual because it is a manmade trench, which means that the rocks absorbed some work from manmade sources. Some fractures without calcrete mineralization have twisthackles and arrest lines, which I interprete to mean that they were induced by manmade efforts.

The site had no swarming fractures except for S_p's. T_3 not as well developed as T_1's despite site description. Also, the site had wide dispersion of orientations which was not clearly described in T&V 1995. This site had many

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"nonsystematic" effects with the large dispersions, various abutting relationships, and the effects of additions to the fracture pattern from manmade efforts. The site description creates too simple of an "image" of the fracture population as a result.

(2) Binning of the joints at the various Stations in T&V (1995) into 3 cooling sets, 4 tectonic sets and 1 late unloading set seems to be arbitrary after visiting 4 localities from the work of T&V (1995). T1 (N-S trending) seems consistent in orientation and style characteristics. However, the other tectonic sets, particularly T2 and T4 do not show consistent style elements, which I interprete to mean that the "binning" by orientation is grouping fractures of different age and origin together. That would be a mistake. Possibly some sets, particularly T2, may not result from a single cause, so the variation in style and abutting relationships for T_2 could indicate this. Also, as

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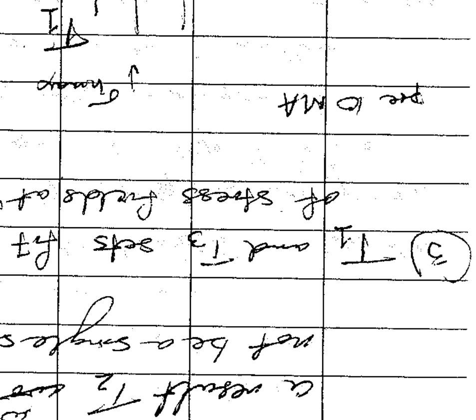
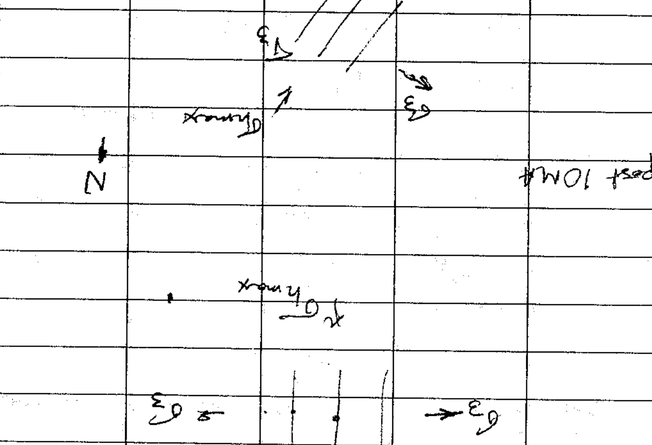
a result T_2 w.D. ~~are~~ fractures would not be a single set.

(3) T_1 and T_3 sets fit the basic history of stress fields at Yucca Mountain.

pre 10 MA



post 10 MA



Yet, T_2 and T_4 do not. Sweetkind & Williams-Stroud (1996) face this problem by making T_2 time equivalent to T_1 and then having T_2 secondary to some fault movement (specifically sinistral). Yet the sinistral movement would require stress field

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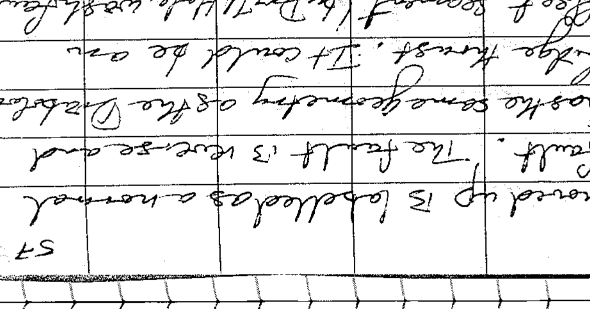
reorganization that would make T_2 younger than T1. Also, T_2 and T_3 only occur together at 4 stations with uncertainty about abutting relationships. Consequently, T_2 could be younger than T_1 and any age with respect to T_3. As a result, other causes for T_2 (and T4) for that matter would include stress field perturbation ~~from~~ W.D. between two or more faults:



Other possibilities exist. So, T_2 and T4 may not constitute single sets of fractures responding to a single regional stress field. But rather, fractures accrued over time at several sites in response to the interaction of different faults. Instead of being single regional sets, they

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would be local sets of different ages and causes.

Having completed the look at 4 T & V stations, we are now going on to look at the surface traces of the two feature faults of the Cl_{36} study: Diabolous Ridge thrust and Sundance fault.

Stop ~~4~~ 5 W.D. - On Yucca Mt. at upslope end of Diabolous Ridge ~~[illegible]~~ W.D. Parked and preceded down ridge to the thrust with two objectives: (1) look for unusual fracture patterns, and examine area to verify map pattern of the fault.

(1) Fracture patterns in HW + FW were typical of cr1 and cr2: Moderately spaced (0.5 to 3 m) large (+2m trace lengths) fractures of several orientations (T_1, T_2, T_3). No intensification or addition of sets occurred for ~~[illegible]~~ joints ~~[illegible]~~ was the fault was approached W.D.

(2) Map pattern. Several differences were found from the geology as mapped on the 1:6000 map (Dayetal)

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(a) fault breccia were found on the S side of Diabolous Ridge along the mapped trace of the fault, however, dips of the zone are 52° to 60° and not the 25° and 32° of the map. Besides 25° and 32° are insufficient values to produce the steep "V" of the fault trace

(b) cplrc is missing from the base of the hill on the south side of Wren Wash on the map. It is there in reality and improves the resolution on the displacement magnitude of the fault

(c) the repetition of Cr2 on the N side of Diabolous Ridge is uncertain for several reasons: (i) no clear Cr1 exists on hillside between two "proposed" different exposures of cr2 (ii) the gap is only 2.5 m on a 15° slope for the fault to pass, and (iii) the change in fault geometry between the two sides of the hill would be amazing. An alternative is for the fault to go down a gap in exposure much like the trace on the S side of the hill.

(d) On Azreal ridge, a steeply dipping fault (to the SE) with its hanging wall (SE block)

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moved up is labelled as a normal fault. The fault is reverse and has the same geometry as the Diabolous Ridge thrust. It could be an offset segment (by Drill Hole wash fault) displaced right laterally from the trace of the Diabolous Ridge thrust.

So, the thrust is steeper (≈60°) and W.D. longer than mapped. In the Cl_{36} report [Fig. 6] if the key figure was revised, I would be steeper and closer to the ESF, which would further encourage infiltration into the ESF.

Stop 6 - Parked at HS platform off of Yucca Crest road: Preceded along west of Purgatory Ridge to location of Sundance fault. Unable to "proof" the fault but USGS were careful with this one so it is real. In HW on east side of fault (NNW-SSE trending) within 20m of fault trace have an abundance of T1's (30 to 80 cm spacing, +2m trace lengths, ++50 cm penetration depths) in cr2. Also, the abundant joints occur in bedrock "pinnacles

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with 6-10m width and 1-4m height that lack soil. So, on the top of the hill is a good setting for infiltration → abundant fracture pathways ~~and~~ w.D. in exposed bedrock. Should be interesting to compare to the Abandoned Wash fault where it cuts the cr2.

Day 3 - July 26th

One more comment from yesterday comparing the infiltration potential around the Diabolous Ridge thrust and the Sundance fault. As noted at Stop 6 (Sundance), the hanging wall has perched emergent bedrock with abundant trans-ridge joints. This geometry would favor infiltration. By contrast, Diabolous Ridge does have Cr 2 at the surface in both footwall and hangingwall, but it is pavement with soil rather than emergent bedrock. Also, joint intensification approaching the thrust does not occur ~~approaching the~~ w.D. unlike with the Sundance fault.

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By contrast, Diabolous Ridge has a noticeably larger area of cr 2 in map view than the Cr 2 ~~[illegible]~~ w.D. at Purgatory Ridge where the Sundance fault is located.

Today we are going to work on the Abandoned Wash fault across Highway Ridge and Broken Limb Ridge. Also, we will look at the complex of normal faults to the east of the Abandoned Wash fault on Broken Limb Ridge. Issues will be (1) presence of faults; (2) geometry and intensity of fracture (joint) pattern; and (3) degree of emergence of bed rock cap above soil "baselevel".

Stop 7 - North side of Highway Ridge along the trace of the Abandoned Wash fault. Downhill from here the fault makes or is coincident with a gully that contains little sediment (good for infiltration)

Stratigraphically in the Cpmn on both sides of fault. Coming downslope, encountered prominent breccia in the

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top end of the gully. Breccia zone is 25 to 35 cm wide with clast size up to ±5cm. Proceeded back up slope to here where have a good Cpmn exposures trending from the fault in the HW to the west.

~~250~~ ← ≈18.8m — ≈4.7m — fault 070 →

38 fractures — continuous exposure — poor exposure & hypothesis → intensity even higher so easier to erode.

400cm

38 fractures in ~~[illegible]~~ 14.6 (wD) m ≈ 2.6 fractures a meter.

~~055/~~

∤	324/76 SW	∤ 020/78 NW
∤	014/81 W	∤ 011/70 W
∤	340/77 E	∤ 016/81 E
∤	028/86 SE	∤ 037/80 NW
∤	012/88 W	∤ 347/90
∤	334/90	∤ 017/88 E
∤	349/77 W	∤ 341/89 W

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DEPTHS ≈ 0.3 to >2m

- SEVERAL OF THE JOINTS ARE FAIRLY PLANAR.
- NONE EXTREMELY SMOOTH AND NO TWIST/WEAR STRUCTURES OBSERVED → SUGGESTING THAT JOINTS IN THIS OUTCROP ARE TECTONIC

Preceded ~~[illegible]~~ w.D. 5m up slope to rocks in FW where encountered 8 fractures in 7.5m starting 2m from fault with scanline on a bearing of 250. So, fractures are abundant ≤1 per 1m (but less abundant than hangingwall) within 10m of fault.

∤ 339/88 W	Shorter exposure with
∤ 338/84 E	penetration depths not
∤ 355/87 W	exceeding 0.5m due to
∤ 347/73 W	exposure height.

Stop 8 - At high point on Broken Limb Ridge in FW of Abandoned Wash fault. The N side of Highway Ridge and the ground to the saddle in Broken Limb Ridge are both soil rich. A little breccia shows up in the "road" that was run onto

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Bill Dunne
3-13-99

Cap on ridge here:

Did scanline for fractures across

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the area, but otherwise exposure is very sparse. Turning east and coming to here, exposure is very abundant from the first occurrence of cr1 to here in cr2. Did not find direct evidence for the normal faults that cuts the ridge through cr 1. Also, did not see any joint set appearances or intensification across that part of the ridge either.

Went off N side of rib looking for 5 small faults that support uphill beneath Cr2. There was some "breccia" in "lines", but could have been calcrete effects in Cpmn.

Returned to ridge top in Cr2 and examined joints. Not particularly abundant. Although this bedrock cap is a good generic infiltration site, faults and joint intensification are absent, so fracture permeability does not unusually enhance the infiltration conduits here.

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113° line bearing.

23 fractures in 24m. Persistent trace lengths in map view of 1 to >8m. More smaller fractures may be present in ground between joint bounded pavements, but had +70% exposure along the scanline.

FROM 293° END ↓	ORIENTATION	TRACE LENGTH
∮	023/90	+1.8 m
∮	350/74W	+1.4 m
∮	023/86W	+0.9M
∮	028/89W	+3.2M
∮	015/89E	+1.7M
∮	028/63W	+0.7M
∮	026/64E	+4.9M
∮	027/84W	+5.7M
∮	026/72W	+5.3M
∮	027/89E	+3.7M

- THERE ARE SOME ORTHOGONAL JOINTS THAT ABUT AGAINST 026 SET WHICH WOULD GIVE SOME CONNECTIVITY BETWEEN 026 SET. THESE CROSSING JOINTS HAVE 2+ M SPACING.

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Stop 9 - Continuing east on ridge toward Ghost Dance fault. Reached wide saddle where that normal fault complex is located. On a pavement of subhorizontal CR2.

Did another scanline along 113° and found 6 joints in 16.5 meters. Much bigger block size than Stop 8 and not long in one direction (i.e. ∥ ≈25°) like at stop 8.

Scanline has 85% exposure and all six are not parallel.

	ORIENTATION	l	
∮	081/82S	+7.9M	
∮	355/70W	+19.5M	curved
∮	021/73E		

Stop 10 is FW of Ghost Dance fault on Broken Limb Ridge. Cr2 present all the way from Stop 9 to here and beyond to east. Did another mini-scanline along 113° into FW. Had 5 fractures in 16m But only had 50% exposure.

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	ORIENT	l
∮	011/63W	+3.7 M
∮	025/69W	+5.7 M
∮	015/84E	+3.2 M
∮	019/87E	+3.1 M

Returning to Stop 9 across Ghost Dance complex, we examined pavement quality of cr2 pavement to see if we could locate faults or joint intensification. Interestingly, the pavement only broke up twice and not three times. Also, unlike at Stop 9, a joint set trending 015-025 occurs with spacings of 1.5 to 2.0m. Also, these joints have long trace lengths as we have found all afternoon. The more easterly break in pavement in hangingwall of most easterly fault is coincident with 'uz' - Tn pavement and could reflect more abundant fractures making the pavement more susceptible to weathering.

Reviewing scanlines of afternoon Stop 9 is an end member with few fractures that are not parallel and huge block sizes, so water will have great

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difficulty infiltrating.
Stop 8 is the other endmember (although Stop 6 yesterday is even moreso!) with an abundant set (≈1m spacing) of joints with cross joints in bedrock that has relief and is bounded by steep N and S dipping slopes.
Stop 10 is in between with a set of parallel fractures and a few cross joints, but bigger spacing than Stop 8. This stop is representative of much of the preserved pavement in Ghost Dance fault complex as it crosses Broken Limb Ridge.

Another observation is that the smaller normal faults to the N and W of today's activity do not cut much bedrock, so they may not be significant sources of infiltration.

July 27th, 1997

Change of pace today, acting as a field assistant to Dave Ferrill and John Stamatakos as the do a run across

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the southern "tail" of Bare Mountain at the south end of Crater Flats. They want a better feel of the ground including orientation measurements because they have to construct a cross section through the area.

The hills are capped by megabreccia, which slide off of Bare Mountain. These deposits overly the Tertiary tuffs, including Rainier Mesa, Tiva Canyon and Tonopah Springs, so there is a chance to see repository rocks outside of the repository if a different setting. Also, a Tertiary basalt caps the tuff but underlies the breccia, and some normal faults cut the entire sequence including the breccias.
The basalt is about 9 m.y. old. So mass wasting and normal faults are younger than 9 m.y.

See David Ferrill's notebook for results of day's work

July 28th, 1997 (Monday)

It rained today and continues to rain down at Eagle Rock and vicinity.

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Today we are at Fran Ridge pavement #2001. Purpose is to tie down evidence for fracture formation sequence, and both reactivation as faults and types of fault movement. Much of data may be on pavement map from report.
See David Ferrill's copy of this map which has all of the annotations for timing relationships.

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Yucca Mt. - SWRI
June 26th, 1998

Commencing a new campaign of fieldwork at Yucca Mt. to examine the joint patterns. Today was a group work day because a team of investigators (David Ferrill, Randy Marrett, John Stamatakos, Mary Beth Gray, James Hogan and Peter) had related purposes today.
The different agendas are:
(1) John Stamatakos and Mary Beth Gray - characterizing fault rocks as a function of fault size and displacement.
(2) Randy Marrett & David Ferrill - establishing the existence or absence of scaling relationships for faults over a displacement range of 10 cm to 100+ m (10,000 cm) or 4 orders of magnitude
(3) Bill Dunne (me), David Ferrill, James Hogan, & Peter - attempting to expand the understanding of joint networks above the scale of pavement studies for the purposes of identifying anisotropies, connectivity architecture, and testing the applicability of James Hogan's remote sensing work.

These agendas were all initially served by visiting the Southern Portal of the ESF

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this morning. The visit was from about 9:00am (after training & equipping) to noon. The entire party with escort examined fractures from 78+77 (portal exit) to 70+00 during this time period. I learned the following things:

1) A refresher on the stratigraphic/lithological differences between the nonwelded tuffs (PTn) and the weld tuffs of the Topopah Springs Tuff (lithophysal and nonlithophysal).

2) Clear representation of the significant decrease in fracture abundance, but the dominance of normal faults in this smaller population for the PTn vs. the welded units of the Topopah Spring Tuff.

3) Realization from discussion that if the cooling joints are coeval with the lithophysae and ~~the~~ that if the lithophysae are degassing phenomena for each pyroclast flow unit in ~~the~~ single larger cooling unit, then at least some of the

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cooling joints must form after each fall event but before the entire cooling unit acts as a single package. This timing means that ~~some~~ of the cooling joints in the lower lithophysal unit of the Topopah Springs Tuff are older than in the upper lithophysal unit. Thus, no timing requirement exists for the geometry and magnitudes of horizontal stresses being the same ~~but~~ for cooling joints in both of these lithophysal units. They could be experiencing different remote stresses, stresses due to slope of deposition surface, stresses ~~due~~ due to the geometry of the flow unit and/or stresses related to the temperature distribution and heat flux in the fall unit. This situation adds another "degree of freedom" to the variation in the orientation of cooling joints across the repository site as a function of stratigraphic subunits with the "cooling units" of the Tiva Canyon and the Topopah Spring. This situation is hence another reason ~~with~~ W.D. for why cooling joints will change orientation with position across the repository.

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4) Given Mary Beth's concerns, what parameter was measured for "offset" of a fault along the DSL in the ESF. Inspection indicated that the offsets were measured only in the confines of the DSL and that essentially vertical separations were measured. In at least one case, the offset recorded on the face ~~in~~ along the DSL did not match the observed offset. Cause not clear. But this ~~case~~ was an exception.

Lunch Stop at Yucca Crest - the location provided an opportunity for David and John to describe the regional situation directly to the new investigators by direct observation. This process was greatly aided by a new "facility" at the crest: a large steel box containing poster size illustrations of the geological map, geological cross sections, topography, fluid flux in the subsurface, etc. An excellent tool for accelerated education. The afternoon was used to examine two pavements, Barton's Pavement 100 and pavement 2001 at Fran Ridge.

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Fran Ridge P2001 - David and I showed the others the reported sequence of events with the related field evidence. Plus, we showed them the evidence for the younger fracture reactivation with dextral strike-slip, including rhombochasms, secondary feather fractures, and localized occurrence of breccia zones on tectonic joints. Dave then showed them the 1:24,000 map of Day et al. to show them the correlation between map sequence scale of faulting and the sequence at P2001.

Barton's Pavement 100 W.D. - The cooling joint "swarm" with its subhorizontal tubercles at this site on Dead Yucca Ridge was the feature of central interest. The fractures in the pavement were compared to the photolinears that James Hogan had found in his remote sensing investigation.

June 27th, 1998

Today's main objective is to commence the attempt to characterize the joint pattern above the scale of a single pavement study. The target will be pavement 100

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of Barton on Live Yucca Ridge.
The first pavement "artifact" that will be examined beyond the limits of the pavement is the swarm of NE-trending cooling joints located on the east side of the pavement. Peter and James Hogan will be operating the GPS gear that will be used to build a data set for download into a GIS program. David Ferrill and I will be tracing and marking features related to joint trace length and intersections that can then be located with the GPS gear.

A secondary objective may be to spend part of the afternoon with Randy Marrett doing a transect along section CC' (1:6000 geological map of Day et al) looking for evidence of intermediate-scale faults. Such faults are defined as having displacements of 50cm to 20m.

Preliminary thought concerning the persistance of joint swarms inside pavement 100 to outside: Pavement 100 is in the Tcpul (Tiva Canyon upper lithophysal), but it is at a location with lithophysae size is typically only 1 to 3 cm.

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Thus, while we will be examining fractures in the lithophysae layer that have a better chance of going into the w.D. nonlithophysae unit underneath (Tcpmn) rather than visa versa, the joints may not make it through a lithophysae zone in the Tcpul with lithophysae reach +10cm in diameter with spacings of <50cm. Should we encounter such a zone we may just need to work out laterally in the Tcpul and see if we can characterize pattern variation within the lithological subunit of the Paintbrush Group.

Two changes occurred during the course of the day. First the GPS equipment failed to operate, and second as a result, David Ferrill and I remained at Pavement 100 all day. We focused on preliminary marking of persistant joints particularly cooling joint swarms using pink flag tape. Key results:

① Established that the cooling joint swarm of pavement 100 was

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persistant through the Tcpul for a total distance of 3.25x width of pavement where swarm crosses the pavement.

② Demonstrated that lack of exposure in the underlying Tcpmn (middle nonlithophysal) precluded tracing swarms through this unit.

③ w.D. Found joints in Tcpll (lower lithophysal) at the base of the Southern slope of Live Yucca Ridge, but no tubercles, so not sure if cooling related

④ Found joints crossing the swarm, so joints in the swarm are connected

⑤ Located to the west of the pavement 100, two swarms that are parallel to the one in the pavement, plus one swarm on an orthogonal trend.

Tomorrow, we will fill in some of the unmarked fractures (joints), using a 5 m truncation limit.

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6·28·98

At Pavement 100 on Live Yucca Ridge to continue locating joints for the GPS survey. First stage is that David Ferrill has gone to Spit Wash to climb up the ridge to the South of Live Yucca Ridge. He will direct me to position flagging tape on linears as defined by vegetation via radio. These linears will be located on the south side of Live Yucca Ridge.

Using Dave's directions, w.D. I flagged a series of joints to the south and southwest of Pavement 100. Most vegetation linears could be flagged as they contained segments of a joint trace. A few were not flagged because soil abundance obscured the ground, so that no joint traces was found. While we believe that the linear is joint related, the lack of direct evidence for the joint meant that we would not define the linear as a joint trace.

Our division of joint types in the Tcpul is simple. We have defined cooling joints as having to have tubes. These joints are common enough and they consist of swarms. These characteristics make us comfortable with using this arbitrary but

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previously defined basis for picking cooling joints. All other joints are defined as tectonic, but we have not seen much of the problematic morphology, which is planar, very smooth joints with no tubes. The "tectonic" joints have not had the planar smoothness. So, in the field, we flag cooling joints as pink and tectonic joints as orange.

Because Dave was parked in Split wash, we had the opportunity to examine natural mass wasting paths to the west of pavement 100 on the south side of Live Yucca Ridge. The youngest of these paths ~~common~~ WD come in two pairs that start about 75% to 80% of the way up the slope in the Tcpul and are continuous to the slope base in the Tcpll. Hence, the paths expose the Tcpmn and provide us with a look at the fracture pattern in the Tcpmn (an issue from observation ② of 6.27.98). Casual inspection indicates fracture trace continuity in the Tcpmn between parallel paths. If true fracture traces are long in the Tcpmn. Fractures are abundant

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in the Tcpmn (spacings < 15cm in many instances), which lead Dave to hypothesize that the lack of exposure in the Tcpmn may reflect ease of erosion due to abundance of joints. So, the existence of these paths provides sites for scan lines across the Tcpmn. The scan lines have the advantage of also allowing sampling of joint patterns at both the lower boundary (Tcpmn/Tcpll) and upper boundary (Tcpmn/Tcpll) of the Tcpmn for continuity of fracture pathways vertically.

Remaining field objectives:

① complete flagging of fracture pattern in Tcpul on Live Yucca Ridge, particularly to:

(a) connect area of flagged joints on the south side of Live Yucca Ridge to cooling joint swarms near cairn on west side of saddle.

(b) carry area to east to see if fracture pathways can be found from the cap rock (Tccr1, Tccr2) into the Tcpul

② Construct parallel scanlines up mass wasting paths for fracture abundance in the Tcpmn and for fracture connectivity across boundaries

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of the Tcpmn

③ Conduct scanline down Split Wash to provide center hydrogeologists with fracture info for them to include in their assessment of infiltration pathways.

6.29.98

Today, David Ferrill, Britt, and I completed the preliminary survey of Live Yucca Mt. from pavement 100 west to the cairn on the opposite side of the saddle. We stuck to flagging fracture segments of 5m or greater. Color code was:

pink – joints with tubercles (cooling origin)

orange – joints without tubercles (cooling or tectonic origin)

Caution yellow – vegetation alignments with no visible fracture trace though

pink + orange + caution yellow – horizontal parting (perhaps cooling, tectonic, or unloading)

South side of ~~[illegible]~~ Live Yucca Ridge WD continued to have good pavement exposures for tracing joints, but the north side had quite poor exposure. Data on that side

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will consist mostly of blank areas with a few persistent prominent joints cutting through.

Britt offered David and ~~[illegible]~~ his ideas about tubercle origin, which is that gases are present on the cooling joints and exploit flattened lapilli to chemically corrode the fracture walls. This process would not be dilatant, so these subhorizontal tubes are not evidence for inferring principal strain or stress directions.

Tubercles were observed to deflect continuously around joint corners and to meet exactly where two separate joint surfaces intersect. Consequently, the tubercles and two sets of sub orthogonal cooling joints were coeval.

We finished flagging joint segments about 3.00pm. Based on the time taken to complete the ground between pavement 100 and the western cairn, marking the joints toward the cap rock (Tccr1) to the east was shelved; particularly given the time consuming progress of the GPS team.

We examined briefly Barton's pavement 200 + 300 on Dead Yucca Ridge.

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82 Geef

6-30-98

Primary task - scan line along northern tributary of Split Wash (previously named as Spit Wash in this field book). We will start at the top and go downhill. We will flag the beginning, end and bend points in the scanline. We will gather joint orientation and spacing data, and correlate with lithological data that we will gather. A cutoff length of 1 m will be attempted, but poor exposure quality may eliminate this possibility.

Left and right is respect to travel direction + downstream
t = truncated by cover, T = tipline ; Order is left to right , a = abuts, i = intersection

~~S.W. # orientation spacing position length~~ Comment

Given the variable exposure, we will use a 2m wide "observation port" centered on the tape, where if bed rock is absent under the tape, we will go laterally to the first occurrence of bedrock to look for joints. If none appears in the port, we will record no exposure. "SW #" will be joints but "SW Letter" will be bend positions in the scan line.

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Coworker: David Kerrill

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SW #	Orientation	Spacing (cm)	length (cm)	Comment
SWA → B	086/04° (BEARING/PLUNGE) CAPROCK			
1	132/59°	375	101 tt	190 - 350 COVERED; PLANAR, SMOOTH
2	159/52	10	95 ta	CURVED; 2 TERMINATES AT 1
3	178/78	612	83 tt	111 - 205 COVERED
4	181/79	196	190 tt	CURVIPLANAR (UNDULATING) 7cm PSEUDOAMPLITUDE
5	159/58	276	74 tt	CURVED
6 (B)	167/83	337	24 tt	48 - 310 COVERED
B → C	100/08 (BEARING/PLUNGE) CAPROCK.			
7	356/86	13	9 tt	
8	176/79	18	23 tt	
9	183/89	15	26 tt	
10	154/82	159	59 tt	0 - 132 COVERED
11	202/63	30	72 t[illegible]	UNDULATING, 5cm
12	028/68	191	31 tt	NOTE: SHORT NONSYSTEMATIC FRACTURES WITH SPACING INTERVAL NOT MEASURED.
C		998		74 - 998 COVERED
C → D	085/11 (BEARING/PLUNGE) CAPROCK			
C → 13	146/75	363	52 tt	0 - 363 COVERED
14	348/86	96	111 tt	
15	168/82	134	92 tt	0 - 96 COVERED
16	015/34	0	82 tt ← 1 scan; 36 at ← 2 scan	SCAN LINE CURVED; TUBULAR STRUCTURES
17	154/87	573	233 tt	UNDULATING 2cm; 0 - 521 COVERED
18	332/84	263	40 at	PART OF COMPOUND FRACTURE w/ > 1m TRACE LENGTH
19	144/67	148	130 tt	
20	153/77	73	137 tt	

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SW #	ORIENTATION	SPACING (cm)	LENGTH (cm)	COMMENTS
21, D	154/74	56	307 tt	
D → E	087/29 (BEARING/PLUNGE)			
22	138/78	118	120 tt	
23	158/87	88	155 at	IRREGULAR
24	153/87	117	70 tt	
25	149/82	286	42 tt	
caprock 26	248/72	239	211 tt	
cpal 27	332/75	120	80 tt	1ST OCCURRENCE OF LITHOPHYSAE
28	224/79	[illegible]	258 tt	0 - 206 COVERED 685 - 895 cov.
E → F	082/~~34~~ (BEARING/PLUNGE)			UPPER LITHOPHYSAL, TIVA C.
29	215/76	345	91 tt	SUBPLANAR; 78 - ~~282~~ COVERED
30	212/87	360	167 ta	SUBPLANAR
31	186/81	113	132 tt	SUBPLANAR
32	178/84	77	120 tt	SUBPLANAR
33	154/86	72	82 tt	SUBPLANAR
34	219/88	30	374 tt	SUBPLANAR
35	243/71	916	122 ta	35 - 903 COVERED
36	243/87	47	120 aa	← abutting on 37
37	052/90	66	130 tt	
F		396		130 - 360 COVERED
F → G	107/23 (BEARING/PLUNGE)			UPPER LITHOPHYSAL TIVA C.
38	200/42	143	172 tt	18 - 93 COVERED
39	058/76	217	390 DAF [illegible] at	} JOIN TO FORM FRACTURE THAT TERMINATES TO THE NORTH
40	054/72	20	75 at	ABUTS AGAINST 39
41	048/73	22	[illegible] Tt	ABUTS AGAINST 39

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SW #	ORIENTATION	SPACING	LENGTH	COMMENTS
42	346/86	118	253 tt	
43	240/72	221	88 it	
44	155/57	0	370 tt	
45	131/63	623	92 tt	BRANCHING; 0 - 623 COVERED
46	194/68	152	55 tt	
47	200/83	51	48 tt	
48	022/84	193	130 tt	
49 (G)	006/87	157	169 tt	} INTERSECT WITH 52
G → H	108/23 (BEARING/PLUNGE)			
50	019/87	57	103 tt	
51	354/76	54	81 tt	
52	087/88	18	286 tt	
53	319/89	0	+800 it	
54	131/72	65	200 tt	CURVED
55	140/86	62	75 tt	
56	184/74	244	77 tt	
57	315/87	502	280 it	TUBULAR STRUCTURES; 0 - 383 COVERED
58	058 (~~053~~)/88	~~77~~	60 ta	abuts against 57
59	266/87	239	300 tt	BRECCIA PRESENT ALONG FRAC. SEVERAL FRACTURES BRANCH OFF
60	220/77	173	124 tt	
61	318/83	262 DAF (~~269~~)	135 tt	TUBES
62	209/84	127	102 ta	← 0 - 795.
63	090/90	795	410 tt	INTERLOCKING NETWORK OF NONSYSTEMATIC FRACTURES

IN A VARIETY ORIENTATIONS WITH AVERAGE SPACINGS ≈ 25cm AND CLOSELY FITTING WALLS

BEJ 3-13-99

B. [illegible] 3-13-99

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SW #	ORIENTATION	SPACING (cm)	LENGTH (cm)	COMMENTS
H			147	
H→I	126/16	(BEARING / PLUNGE)		
64	183/88	25 (from H)	135 ~~[illegible]~~	Ta
65	210/83	48	238 tt	
66	143/87	422	437 tt	TUBES
67	218/81	76	120 tT	CURVED
68	018/86	785	270 tt	127-687 COVERED
69	267/87	1071	77 tt	
70	191/82	83-125	120 tt	ZONE OF 7 (8) PARALLEL FRACTURES
71	206/73	72-101	45 tt	ZONE OF 5 (5) // FRACTURES
72	133/90	61	423 TT	TUBES
73 (open, cpl)	156/75	641	220 tt	
I (cpl)		191		
I→J	106/12	(BEARING / PLUNGE)		
74	324/86	761	102	424-761 COVERED; 0-424 EXPOSURE
	CONTAINS NUMEROUS SMALL FRACTURES ON ~50 cm SPACING IN VARIETY OF ORIENTATIONS - CLOSELY FITTING WALLS			
75	015/85	166	74 tt	
76	197/75	31	80 tt	
77	195/89	30	192 tt	
78	031/87	33	120 Tt	CURVED
79	195/82	33-51	191 tt	ZONE OF 7 FRACTURES
80	200/76	27	175 tt	
81	197/77	21	161 tt	CURVED
82	195/79	31	175 tt	

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SW #	ORIENTATION	SPACING (cm)	LENGTH (cm)	COMMENTS	
83	217/68	444	66 tt	110-354 COVERED	
84	209/88	37	69 tt		
85	211/73	32	62 tt		
86	325/74	108	247		
J		1347		0-1347 = COVERED	
J-K	092/15	BEARING / PLUNGE 2890 to K		0-2890 = COVERED	
K→L	100/11	(BEARING / PLUNGE) PAVEMENT ALL THE WAY.			
87	351/83	51	168 tT	PLANAR	LOWER LITHOPHY-
88	349/86	97	108 tt	PLANAR	SAL ZONE OF AUA
89	351/86	34	160 Tt	PLANAR	CANYON. TUFF
90	007/86	66	216 tt	PLANAR	
91	030/86	94	133 tt	PLANAR	
92	~~[illegible]~~ 142/60	32	92 i?t	PLANAR	
93	177/85	130	96 tt	PLANAR	
94	175/82	102	170 tt	PLANAR	
95	174/68	28	65 tt	PLANAR	
96	159/68	186	192 tt	"	
97	213/74	72	155 tt	"	
98	145/68	116	114 tt	"	
99	156/72	35	103 tt	"	
100	144/83	79	137 tt	CURVED BUT SMOOTH	
101	134/85	81	205 tt	~~CURVED~~ PLANAR (two sp lays), SMOOTH	
102	159/90	118	289 tt		
103	166/89	43	270 tt	ZONE OF 10 SUBPARALLEL	
104	156/82	150-332	+600 tt	CURVIPLANAR FRACTURES	

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SW #	ORIENTATION	SPACING (cm)	LENGTH (cm)	COMMENT
105	186/82	72	234 tt	
106	168/78	202	305 tt	
107	172/88	44	273 ta	ABUTS AGAINST 110
108	177/73	45	230 tt	
109	181/85	69	248 tt	
110	249/89	91	270 tt	
111	346/81	122	310 tt	
112	177/82	77-151	310 tT	ZONE OF 7 SUBPARALLEL FRACTURES
113	358/88	410	214 tt	
~~114~~	356/72	63	180 tt	
L		~~72~~ 12		
L→M	108/09	(BEARING / PLUNGE)		
115	342/86	16	140 tt	
			158-1033 COVERED	
	FOR 431-1033 → WE ARE STEPPING 240 cm NORTH INTO STREAM CHANNEL.			
		431-809		ZONE OF NONSYSTEMATIC FRACTURES IN VARIETY OF ORIENTATIONS SPACED <30 cm
116	159/77	809	431 tt	SAME FRACTURE AS AT 1038 ON PRIMARY SCANLINE
117	338/82	178	299 tt	
118	347/87	98	305 tt	
	NOTE: THERE IS A CROSSING FRACTURE THAT STRIKES/DIPS 067/87, CROSSES 117, AND ABUTS AGAINST 116 & 118.			
119	175/82	147	430 tt	LOOKS LIKE SITE OF INFILTRATION EXPERIMENT SILICONE AQUARIUM SEALANT MARKS OUTLINE OF BOX ON BEDROCK SURFACE - NORTH FRACTURE.

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SW #	ORIENTATION	SPACING	LENGTH	COMMENTS
120	353/88	311	410 tt	VERY IRREGULAR
121	342/87	190	455 tt	VERY IRREGULAR
*	166/87	168	147 tT	SECOND EXPERIMENT SITE
122	340/87	158	283 tt	WITH SILICONE SEALANT DEFINING BOX ON FRACTURE
123	340/85	117	160 Tt	
124	156/76	99	235 tt	
125	154/82	56	94 tt	
M		487		UNFRACTURED PAVEMENT
M→N	123/14 (BEARING / PLUNGE)			
	NOTE: WE HAVE CROSSED ~~SEVERAL~~ TWO (2) METER-HIGH LEDGES CONTROLLED BY LAYER-PARALLEL IRREGULAR JOINTS. (BEST SEEN FROM DOWN SLOPE) BETWEEN L & M.			
126	175/87	171	198 tt	
~~(127~~		~~57~~	~~93 Ta)~~	~~TOO SMALL BUT~~
127	010/87	182	125 tt	~~ABUTS A FRACTURE THAT ABUTS 127.~~
128	160/81	323	320 tt	NOTE: ONE LAYER-
129	167/78	132	185 tt	PARALLEL JOINT VISIBLE
130	162/83	65	267 tt	ON NORTH SIDE OF
131	156/81	86	327 Tt	GULLY - TIPS TO WEST.
		(933)	OUTCROP WITH A FEW NONCONNECTED JOINTS - IN A VARIETY OF ORIENTATIONS ALL TOO SHORT TO MAKE OUR CUTOFF.	
		(677)	COVERED INTERVAL.	
		↑ TOTALING THESE PLUS ADD'L OUTCROP (137)		
132	342/82	1737	172 Tt	

B. [illegible] 3-13-99

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Sw#	ORIENTATION	SPACING	LENGTH	COMMENTS
133	350/84	84	165tt	
N		143	POSITION IS AT THE FORK	
	IN THE NORTH BRANCH of SPLIT WASH.			

7.1.98

Returning to Split Wash to do parallel Scanlines up mass wasting tracks (west pair), which expose the units on the southside of ~~Split~~ w.o. Live Yucca Ridge excellently. Scanline pairs will be David Ferrill and Mary Beth ~~Gray~~, and ~~Bill~~ John Stamatakos and Bill Dunne

(1) Truncation length - 1 m
(2) Using left to right convention as yesterday
(3) Using t, T, a, i convention as yesterday
(4) Probably will not need an "observation port" approach given the quality of the exposure.
(5) Going uphill so left is west & right is east.
(6) As masswasting path is straight and slope is essentially constant, we will only mark the Beginning and end points, A & B respectively.
(7) SPACING BETWEEN ~~LINES~~ = 9 M 23 CM, 923 CM

Scan w.D.

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LYE #	orientation	(cm) spacing	(cm) length	Comments

(8) START IN BOTTOM of SPLIT WASH, IN TIVA CANYON - LOWER LITH (TCPll)

(9) TRAVERSE DIRECTION = 031°, PLUNGE of LINE = 211°/25°

* MEASURED ON ROUGH SURFACE (±2CM RELEIF)

LYE #	orientation	(cm) spacing	(cm) length	Comments
1	170/88	0	430tt	
2	155/89	52	195ti(?)	CURVED
~~3~~		~~37~~	~~230tT~~	
3	340/17*	0	i(?) i(?)	SUB HORIZONTAL THAT SPANS DISTANCE BETWEEN 3 AND 4
4	350/84	37	280tT	
4a	—	0-21	—	ZONE of 4 joints Subparallel to #4 - INTER ANASTAMOSING
5	280/08	0	204tt	
6	184/87	114	499 ~~304~~tt(?)	
7	164/06*	0	120tt	
8	336/19	39	102tt	
9	360/05*	69	225tt	
10	131/87	16	255tt	
11	027/08 *	19	370at	VERY ROUGH
12	337/69	27	288 tt	
13	349/79	18	221 tt	
14	346/78	40	271at	UNDULATORY 16 cm AMPLITUDE # 14 ABUTS INTO #13
15	177/03	0	280tt	

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LYE #		S/D Orientation	(cm) SPACING	(cm) LENGTH	Comment
16		070/75	57	390 ta	ABUTTED BY # 20
17		163/82	25	190 tt	
18		356/04	0	205tt	
19		160/81	99	317 tt	UNDULATORY CURVING
20		028/06	0	206 tt	ROUGH
21	(ZONE)/6	347/86	70-113	170tt	ZONE of 6 joints
22		006/04 *	0	160 tt	4cm RELEIF VERY Rough
23		335/06	79	315tt	
24	(ZONE/7(?))	336/86	15-45	303 tt	ZONE of About 6 joints
25		170/75	36	420 tt	
26		314/09	0	385tt	
27		136/84	98	295 tt	
28		038/04	0	360 tt	
29		166/82	43	353tt	
30		162/89	62	172aT	30 & 31 INTERSECT AT SCAN LINE
31		246/86	0	204ta	
32		344/05	0	210 tt	
33	242/89	~~275~~(?)	190	275 ~~TT~~	(2 Big Ts)
34		146/73	36	270Tt	34 INTERSECTS WITH #33
35		158/88	72	376 tt	
36		155/73	31	308TT	
37	ZONE/11	175/84	64-130	345tT	ZONES of 11 joints
38		153/64	192	195tt	
39		063/84	24	381Ta	
40		151/81	36	270 tt	

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LYE #	S/D ORIENTATION	(Cm) Spacing	(Cm) Length	Comments
41	353/07	44	280tt	
42 (ZONE)	158/86	87-194	360 tt	ZONE of 11 joints - All HAVE TRACE LENGTH = to ZONE TRACE LENGTH, ALL ARE PLANAR - CANNOT BE TRACE TO WESTERN SCAN LINE
~~43~~				
43	148/82	117	275 tt	
44	330/80	42	190 tt	-
45	260/04	37	320 tt	
46	154/87	94	248 tt	THERE ARE 3 ANASTAMOSING AND UNDULATORY fractures BETWEEN 46 AND 47
47	331/88	76	302 tt	
48	139/80	59	268 tt	9 (?)
49	038/88	55	249 TT	UNDULATORY w/ ~~4~~cm of RELIEF
50	111/76	42	190 tt	CURVES
51 (ZONE) (a) (b)	(a) 158/89 (b) 146/89	193 407-521	403 tt	ZONE of 7 FRACTURES - ZONE HAS 2 PROMINANT BOUNDING joints - PLANAR w/ SMALLER ONES BETWEEN
~~52~~				CONNECTS w/ ENECHELON LEFT STEPPING UPHILL to WEST LINE
(ZONE) 52 (a) (b)	(a) 150/84 (b) 156/79	73-204	440 tt 433tt	2 major joints Bounds 6 additional fractures
53	150/75	68	307 tt	
54	142/81	74	244 Tt	CURVED
55	164/86	78	198 Tt	
56	155/87	53	493 tt	PROMINANT
57	156/86	76	257Tt	
58	158/80	30	170 tt	

Note! WE NOTE SEVERAL NE-SW FRACTURES THAT DON'T QUITE MAKE THE SCAN LINE. ONE NEAR # 52 HAS small Bit of Breccia with orientation 046/87

Bill Dunne 3.13.99

S.J. Pezzopane 3-13-99

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LYE #	S/D ORIENTATION	(cm) SPACING	(cm) Length	Comments
59	157/80	28	197 TE ~~2597 tt~~	
60	158/85	29	443 tt ~~110 tt~~	PLANAR / PROMINANT
61	354/85	66	233 aT	CURVED
ZONE (62) a / b Tcpmn	168/88 / 167/81	43 – 194	358 tt / 342 tt	ZONE of 8 fractures w/ persistant Bounding fractures – some in center are also long and persistant. Appears to connect with zone on west scan line
COVERED ZONE (63)		449		COVERED By SOIL, CALICHE – Fractures ABUDENT FROM CALCIFI-CATION – NO FRACTURES MEASURED.
~~(63)~~ WILD ASS ZONE (64)		510		NETWORK of NON-systematic joints CENTERED ON TREND of 350° w/ 60-80° DISPERSION About TREND. Fracture traces ARE CURVED ~~AND DIP STEEPLY~~ Both EAST and WEST, SPACINGS < 25 CM.
ZONE (65) a / b	154/82 / 156/83	0 – 160	385 tt / 334 tt	ZONE of 7 joints 1st ONE IS PLANAR AND PERSISTANT – NEXT 5 ARE CURVED-PLANAR / ANASTAMOSING OTHER BOUNDING ZONE IS CURVED-PLANAR AND ANASTAMOSING

S.J.P.

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PLAY CALLED ON EAST LINE BECAUSE of POOR EXPOSURE AND CALICHE. PINK TAPED END of Line

End position named LYEB

The two scanlines at LY (Live Yucca South side mass wasting tracks) sampled from near the base of the lower lithophysal unit of the Tiva Canyon (Tcpll) to the base of the upper lithophysal unit (Tcpul). Thus, they like the split wash scanline sample the rock units under the Tcpul, which is the unit for which the fracture network map is being constructed on the top of Live Yucca Ridge. These scanlines with the network map should provide a "picture" of the fracture pathways due to joints through the Tiva Canyon Formation for meteoric water infiltration. The split wash scanline with the two Live Yucca scanlines sample the sub Tcpul units at almost right angles, which should eliminate/minimize the orientation bias (Terzaghi correction) of scanlines. That scanlines are also biased to sample longer joints is not an issue here because longer systematic joints

S.J. Pezzopane 3-13-99

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are the central concern. Users of these data should also remember that they represent and underestimate of the joint population density because sub-100cm (1m) joints were not sampled, and short but interlocking curviplanar joints were not sampled. The latter joints may well be only surficial features (compare to data set in ESF) with little vertical persistance. Hence, they propably do not constitute vertical pathways for meteoric water infiltration.

On a side issue, I asked Mary Beth Gray and John Stamatakos to look for the distribution of joints with tubercles in the Topopah Springs Formation during their data collection efforts in the entire ESF on June 29th, 1998. They reported back that they only found the tubercles in the upper lithophysal unit (see Mary Beth Gray's notebook for the data on which this report is based). Thus, when combined with my observation of joints at the surface

S.J.P.

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in the Tiva Canyon Formation, tubercles for vertical joints only occur in the upper lithophysal units of these two welded tuff sequences. Thus, the best indicator that a vertical joint has a cooling origin is only present in one subunit of each welded tuff sequence. So, in the other subunits, determining a cooling joint age is much more difficult! This issue becomes particularly tricky when you consider that vapor plane fillings & joint surface smoothness indicate more than one age for cooling joints (with + without tubercles) in the upper lithophysal units.

Bill Dunne 3-13-99

Morphological Observations about Joints from Scanlines in Split Wash

Split Wash "North Fork"

1) **General** - (comments for 165 joints where 134 are measured and an additional 31 are in closely spaced joint zones or "swarms" (5 zones – 2 in Tcpmn, 3 in Tcpll) for which single orientation measurements were taken as part of the 133 orientation measurements.)
   - **Abutting fractures** – Only 10 joints had abutting relations and 4 of those abutted joints with tracelengths of less than 1 meter (hence, they were not recorded in the scanline data). Of the remaining 6, 4 abutted with subparallel joints (azimuth differences of less than 10°) and a 5th one only had an azimuthal difference of 27°. **Thus, abutting relationships along the scanlines do not indicate age differences between sets as defined by azimuthal modes.**
   - **Joint tracelengths and Terminating joints** – Only 8 joints had single fracture tips in the "window" along the scanline. No joint was doubly tipped along the scanline. So, between abutments and terminations, only 17 of 165 fractures have one termination in the scanline "window" (one joint is fully contained in the "window" as it has one abutting end and one terminating end). Thus, 164 joints cannot have their tracelengths determined. Instead, "tracelengths" as recorded along the scanline is a function of "window" width, which commonly was greater than 1 meter wide (centered on the scanline) and locally exceeded 3 meters. These censored tracelengths cannot be used to reasonably estimate the tracelength distribution as a function of length or joint orientation.
   - **Apertures** – This parameter was not measured as many joints consisted of single faces, others involved outer joint walls that may have "loosened", and the effect of weathering could not be isolated. These problems are typical with the measurement of aperature from surface exposures of joints.
   - **Tubercles** – 5 joints possessed tubercles (1 in Tccr, 1 in Tcpul, 3 in Tcpmn), so only 5 joints could be categorically identified as cooling joints. Azimuths for these 5 joints are 015 (Tccr), 135 (Tcpul), and 138, 143, 133 (Tcpmn). Thus, the most prominent azimuthal mode (135°) in the Tcpul and Tcpmn stratigraphic intervals includes cooling joints.

2) Cap rock (Tccr)
- **Azimuthal mode may not equal joint set** - 5 joints in the 155 azimuthal mode are curviplanar, curved, undulatory or irregular, so this azimuth (set?) is not defined by planar smooth joints. This azimuth may represent an "accumulation" of joints from different causes: cooling, tectonic, unloading, given the morphological variability.

3) Tcpul
4) Tcpmn
- 1 fracture in the 085 azimuthal contains breccia and has several short joints terminating at it with acute angles, so it may be a fault or a joint reactivated as a fault.
- **Stratigraphically restricted joint zones** - 2 joint zones are in "basal" 9 meters of scanline (51.75 m of scanline in this unit)
- 1 eight-meter-wide joint zone containing a network of nonsystematic interlocking joints with trace lengths of less than one meter.

5) Tcpll
- **Infiltration experiment sites** - Encountered "infiltration experiment sites" at joint 119 (175 azimuthal mode) and joint * (165 azimuthal mode) between 121 and 122. These two fractures did not display atypical characteristics as compared to other joints in their azimuthal modes.

Bill Dunne 3.13.99

- **Subhorizontal joints** - Encountered 3 subhorizontal joints with irregular traces adjacent to scanlines, so subhorizontal joints are present in this unit, although recorded in scanline data set, as the fractures did not cross the scanline.
- **Spatially variable intensity** - In lower 33 meters of the scanline for this unit (stations M to N, joints 126 to 133), we encountered 4.87 meter of unfractured pavement, a 9.33 meter interval with short (< 1m) isolated joints in a variety of orientations, no joint swarms, and an intensity of only 0.28 m^{-1}, so this part of the unit is less intensely fractured than the unit as a whole.

Live Yucca East and West

1) General
- **Abutting fractures** – Only 6 joints had abutting relations and 4 of these abutted joints with trace lengths of less than 1 meter (hence, they were not recorded in the scanline data). Of the remaining 2, 1 abutted a subparallel joint (azimuth difference less than 10°).
- **Joint tracelengths and Terminating joints** – 11 joints displayed fracture tips in the scanline "windows" and 3 of these showed double tips. Thus, visible terminations are more common in the Live Yucca scanline as compared to the Split Wash North Fork scanline, but then, the "window size" for the Live Yucca lines consistently exceeded two meters and commonly exceeded three meters. Thus, the "windows" for the Live Yucca lines are wider and hence, more likely to sample joint terminations for the same population of joint sizes. The tracelengths of the doubly terminated joints are 2.75 m, 3.08 m, and 2.49 m, and they are all in the Tcpll.

  While the wider "window" at Live Yucca provides a better sample than Split Wash North Fork for tracelengths, the sample is still severely censored, and cannot be used to estimate tracelength distribution or joint orientation.
- **Apertures** – as with the Split Wash North Fork scanline
- **Tubercles** – none encountered. Are these features only found in the upper stratigraphic units of the Tiva Canyon and Topopah Spring Formations (they were separate cooling units)?

2) Tcpmn
- **Calculated Fracture Intensity** – The fracture intensities calculated for the Tcpmn are less than for the Tcpll along the same scanlines. However, two problems arose with measuring joints in the Tcpmn. First, caliche was noticeably more abundant in the Tcpmn, terminating the eastern scanline well below the western scanline, and obscuring joint traces along both scanlines. Second, both scanlines contained at least one occurrence of a zone about 5 meters wide with joint spacings of less than 25 cm, and the joints are quite curviplanar and anastomosing. Thus, the calculated intensities for this unit should be viewed as a minimum.

3) Tcpll
- **Subhorizontal Joints** – 20 subhorizontal joints (from a total of 119) were encountered in this unit along the two scanlines, so this attitude of joint is prevalent in the unit.
- **Joint zones** – 2 joint zones connecting between the scanlines and an additional 8 zones on single scanlines were observed. Their trends (the joints are subvertical) are 155 (5), 165 (3), 175 (2), in terms of azimuthal "bins". So, they are mostly parallel to most abundant joint trends in this unit. They added 73 joints to the existing total of 119 for a combined total of 192.

Comparisons Bill Dunne 3-13-99

1) **Similarity of results for two Live Yucca scanlines** – The two scanlines are only 9.23 m apart at the lower ends. They yield similarity of orientation data (comparison of combined plots versus the plot for only Live Yucca East), and at least two joint zones or swarms could be traced between the two scanlines. Thus, at the scale of about 10 m without the close proximity of a fault (<10 m), the two samples yield comparable results.

2) **Similarity of results for Live Yucca scanlines vs. Split Wash North Fork scanline** – In terms of orientation data, the Tcpmn results are quite different between these locations, but the Tcpll results are similar. In terms of intensities, the intensities are a factor to 3 or 4 greater along the Live Yucca scanlines than along the Split Wash North Fork scanline. The Live Yucca scanlines are within 20 meters of the Ghost Dance fault and do display joint trends that are subparallel to the fault. Perhaps, they record the intensification of north-south trending joints in proximity to the fault, unlike with the Split Wash North Fork scanline.

3) **Similarity of results for Live Yucca scanlines vs. P100 pavement** – Stratigraphically, the P100 pavement is in the Tcpul, unlike the two scanlines, which are in the underlying Tcpmn and Tcpll. Thus, this comparison is made on the basis of geographic proximity and not stratigraphic equivalency. The two locations appear to record entirely different elements of the joint pattern at Yucca Mt. The pavement contains at least 40 joints with tubercles, whereas none were observed along either scanline. The prominent trends on the pavement center on 30° and 140°, whereas they cluster around 165° along the scanlines. The pavement has a smaller fracture intensity despite using the smaller truncation limit (0.2 m vs. 1.0 m for the scanlines). While tracelengths cannot be compared directly, the tracelength distribution for the pavement indicates that fracture intensity is dominantly a function of the cooling joints, trending about 30°. As this element of the joint pattern is absent along the scanlines, their enhanced fracture intensity is a function of noncooling (tectonic?) joints. Thus, the Live Yucca scanlines and the P100 pavement share little similarity in their joint patterns.

4) **Similarity of results to 3 nearby "selective inventory" stations (Throckmorton & Verbeek, 1995, USGS OFR 95-2)** – Of the 41 stations in their investigation, three are located in Split Wash (CH4 and CH5, which are in the Tcpln, the unit under the Tcpll of the scanlines; and CUL7, which is in the Tcpul). Joint spacings are not rigorously recorded by selective inventory, so only orientations may be compared between these stations and the scanlines. CH4 and CH5 (approximately 120 m to E in FW of Ghost Dance Fault) contain no cooling joints and have prominent tectonic joint orientations at 008°, 158°, and 035°. The, 158° joints are so poorly developed that spacing could not be estimated. Thus, these trends do not correspond the results of the nearby Live Yucca scanlines. Nor do they match orientations seen in the Tcpll or Tcpmn for the Split Wash North Fork scanline. CUL7 contains only cooling joints, which trend 055° and 135°. Thus, this station contains the two cooling joint orientations sampled by Barton at Pavement 100 and Pavement 300, and the 135° trend was observed in Split Wash North Fork.

5) **Similarity of results for all scanlines and fracture characteristics used for LBNL UZ Hydro model** (Sweetkind et al., 1997) – The purpose of the USGS 1997 fracture report was to formally provide the investigators using the LBNL three-dimensional unsaturated zone groundwater flow model with the parameters that they requested for purposes of including fractures in their model. They specifically needed fracture spacing (the inverse of intensity) and dip spectra for their model. Sweetkind et al. (1997) reported these parameters for each of the stratigraphic model layers, plus provided full orientation data for the most prominent sets. The two model layers that are comparable to the results from the scanlines are: tcw11 (Tccr and Tcpul), and the twc12 (Tcpmn, Tcpll, and Tcpln (not sampled by scanlines)).

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It should be noted that the scanlines sample 318 m of exposed rock in the 4 stratigraphic units (two model layers) as compared to about 550 m of detailed survey line (DSL – same approach as our scanline methodology) in the ESF (not including South Portal) and 33 "selective inventory" sample sites, which are distributed over about 60 km^2. So, sample sizes are comparable.

Orientation comparison (caveat – do the global descriptors developed for LBNL by Sweetkind et al. Usefully handle horizontal or vertical flow anisotropy or spatial heterogeneity in conduit frequentcy?) –

(a) tcw11 (Tccr, Tcpul) - surface data only - Cooling joint sets strike of 050, 092 and 132. Tectonic joint sets strike 007 and 155. Cumulative intensity for all sets is 0.5 to 2 m^{-1}. In Split Wash North Fork, the approximate equivalents of 132 and 155 were seen, and perhaps 050, although cooling joint age was not proven. Intensities of 0.8 and 1.25 fall in the range of 0.5 to 2.

(b) Tcw12 (Tcpmn, Tcpul, Tcpln (not seen)) – surface data only – Cooling joint sets strike 131, 014 and 085, whereas tectonic joints strike 004 and 155. Cumulative intensity for all sets is 0.33 to 2 m^{-1}. The 131 trend is recorded in Split Wash North Fork, and the 155 trend is observed on all scanlines. Intensities of 0.98, 1.11, 2.81 and 3.98 fall partially outside the range of 0.5 to 2.

Bill Dunne 3-13-99

Intensity Calculations for Split Wash Scanlines

Scanline	Strat Unit	Scanline Length (m)	Covered Length (m)	"Uncovered Length"	Number of Fractures (n)	Terzaghi-corrected n*	Intensity (n/L)~	"Uncovered" Intensity (n/L)**	Intensity Comparisons
SW	caprock	57.84	17.77	40.07	26	32	0.55	0.80	(0.5 to 2, 1, 5.8)^^
SW	Tcpul	67.9	27.89	40.01	31	50	0.74	1.25	(2.13)^, (0.5 to 2, 1, 5.8)^^
SW	Tcpmn	51.75	5.6	46.15	16	34	0.66	0.74	(.33 to 2, 0.69, 7.3)^^^
	Tcpmn				26	45	0.87	0.98	
SW	Tcpll	150.6	62.33	88.27	61	75	0.50	0.85	(.33 to 2, 0.69, 7.3)^^^
	Tcpll				82	98	0.65	1.11	
LY	Tcpmn	27.52	5.49	22.03	28	50	1.82	2.27	(.33 to 2, 0.69, 7.3)^^^
	Tcpmn				37	62	2.25	2.81	
LY	Tcpll	81.81	0	81.81	119	226	2.76	2.76	(.33 to 2, 0.69, 7.3)^^^
	Tcpll				192	324	3.96	3.96	

*this number comes from summing n's in Terzaghi corrected rose diagrams, which are rounded values - so this value is an "estimate", but this value is still the one used for the intensity calculations

~ units for intensity are meter -1 independent of whether using scanline (number of joints/scanline length) or trace map data (total joint tracelength/area of map) data

**"Uncovered Intensity" uses (Scanline length - Covered Scanline length) as line length for the denominator in the calculation

!!!These "intensity values" are spots on lines, so they offer no direct insight into tracelength distributions for these joints

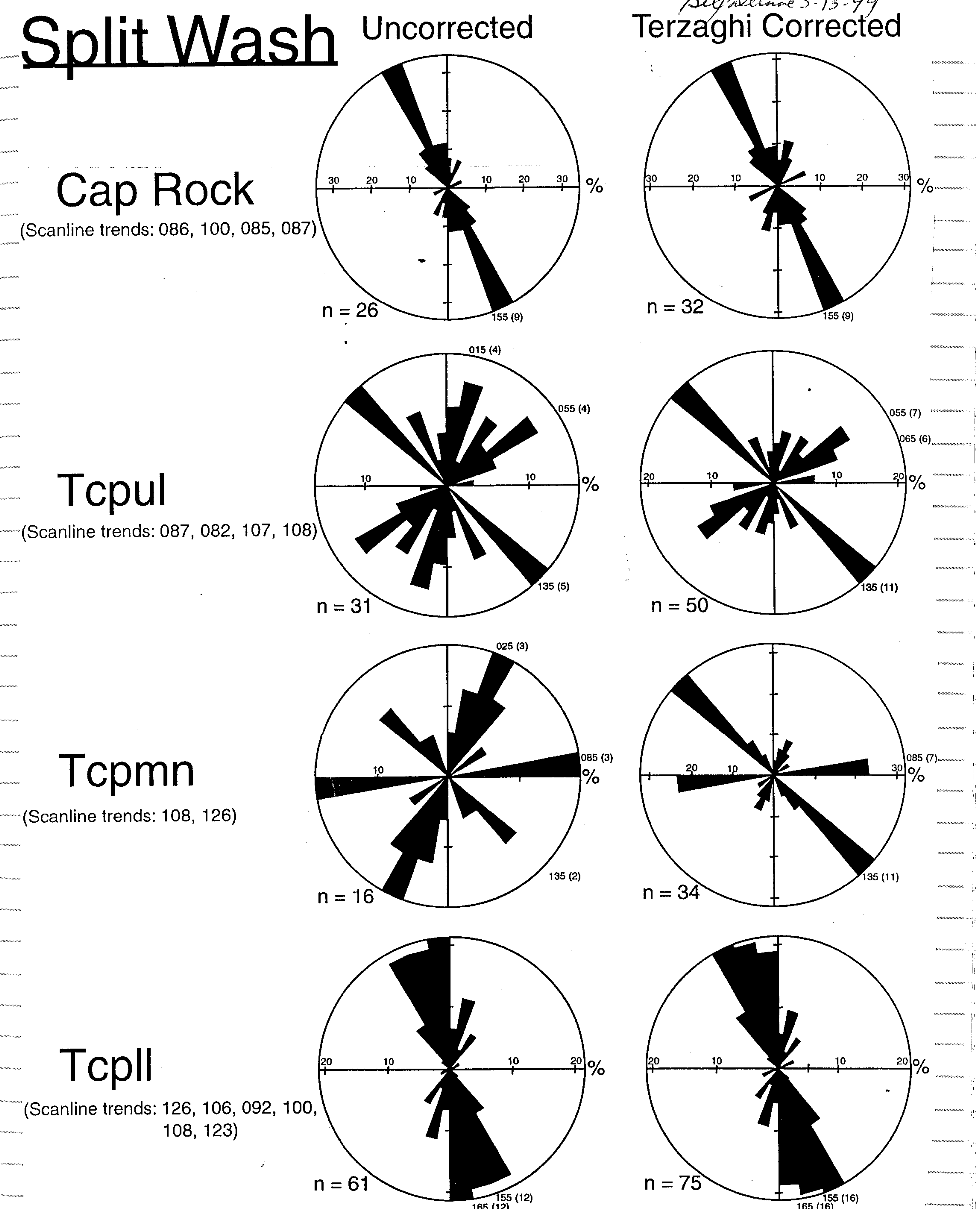
The shaded cells include additional fractures from joint zones or swarms that were encountered, but did not have their orientations measured. Including these joints does mean that all joints with tracelengths of over 1 meter are included in the intensity calculation, but the calculation increases the magnitude of this "average" value for the whole unit with locally concentrated contributions to the sample. A spatial homogeneity problem!

^Barton's pavements 100 with a correction to a cutoff length of 1m (pavement was done with cutoff of 0.2m), 2.35 - 0.22 (46.6m of tracelength for 214 sq. m.) = 2.13. Enhanced intensity with respect to Split Wash scanline could be artifact of the pavement sampling the NE-trending cooling joints, which are not observed along the scanline in the Tcpul.

^^Sweetkind et al., 1997, intensities inverted from spacings for tcw11 layer (Tccr and Tcpul in combination) of LBNL model, for respectively, surface data, ESF and boreholes (table 2, page 24)

^^^Sweetkind et al, 1997, intensities inverted from spacings for tcw12 layer (Tcpmn, Tcpll, Tcpln (not seen in this study)) of LBNL model, for respectively, surface data, ESF and boreholes (table 3, page 27)

Bill Dunne 3-13-99



Live Yucca West and East

(Scanline trends: west - 205, east - 211)

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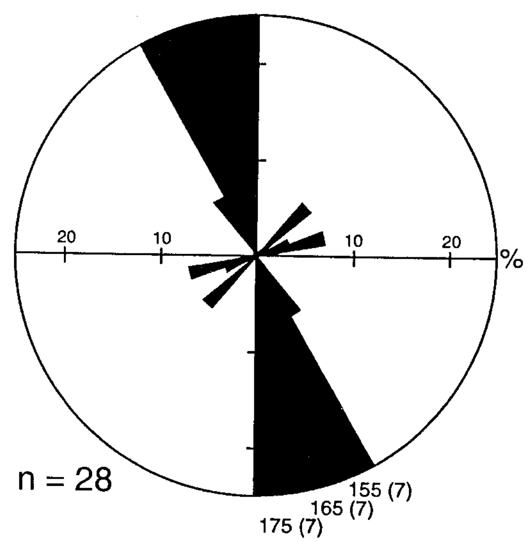
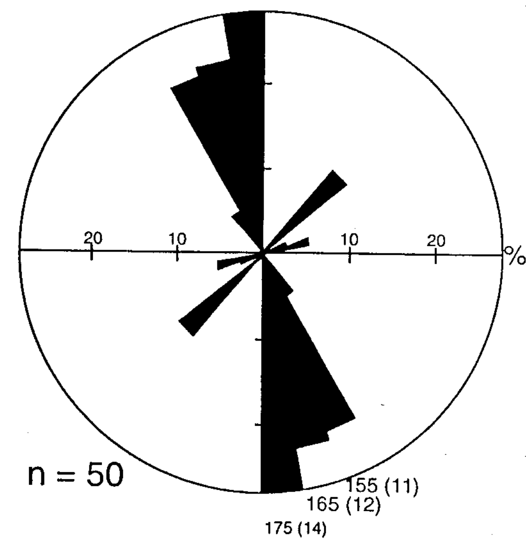
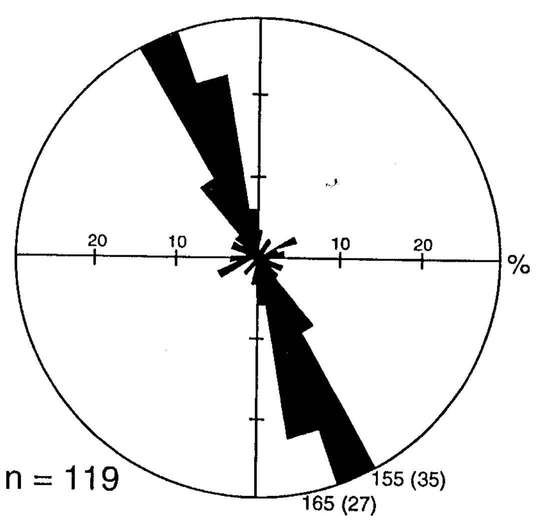
Uncorrected | Terzaghi Corrected

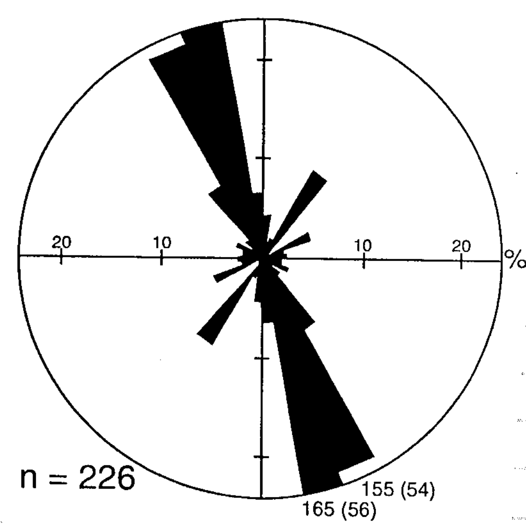
Tcpmn





Tcpll



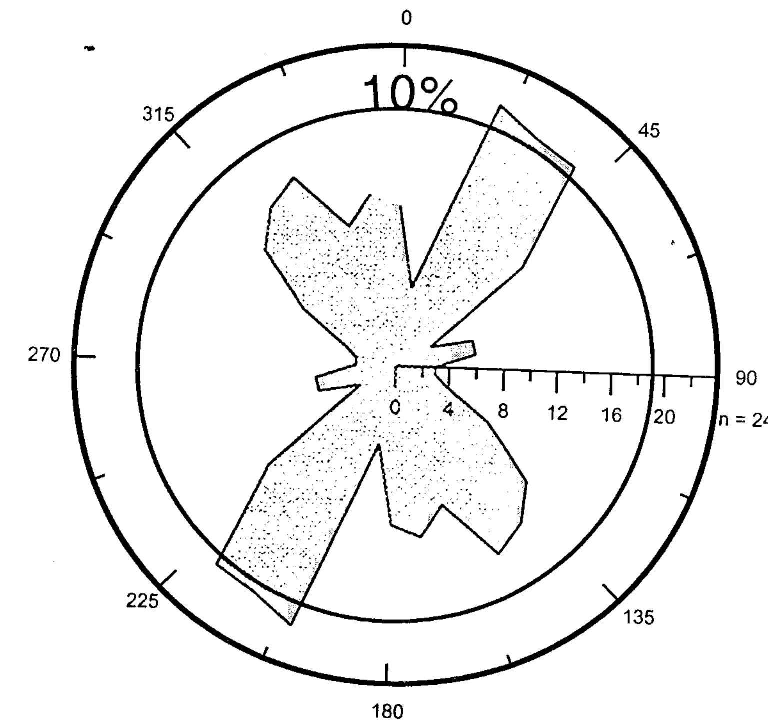


Pavement 100 Rose Diagrams

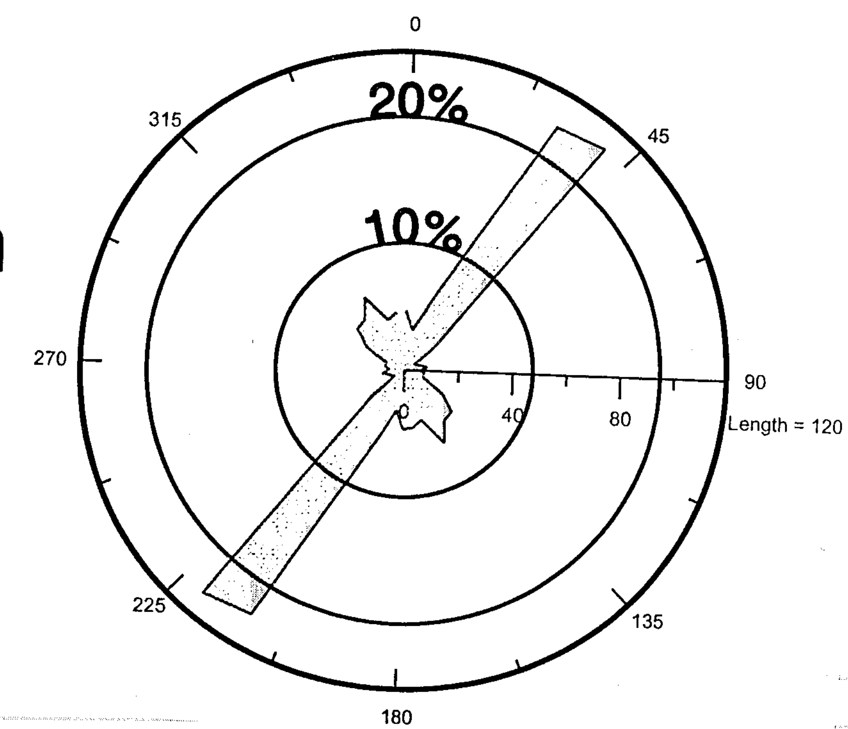
Orientation vs. Trace Length

Bill Dunne
3.13.99

Orientation
n = 192



Trace Length
L = 476.5 m
$I = 2.23m^{-1}$



Data for Orientation Rose Diagram at P100

3-13-99

Degree	# of Joints	
0	12	6.3%
10	6	3.1%
20	21	10.9%
30	20	10.4%
40	20	10.4%
50	12	6.3%
60	3	1.6%
70	6	3.1%
80	6	3.1%
90	3	1.6%
100	3	1.6%
110	4	2.1%
120	8	4.2%
130	13	6.8%
140	15	7.8%
150	16	8.3%
160	11	5.7%
170	13	6.8%
180	12	6.3%
190	6	3.1%
200	21	10.9%
210	20	10.4%
220	20	10.4%
230	12	6.3%
240	3	1.6%
250	6	3.1%
260	6	3.1%
270	3	1.6%
280	3	1.6%
290	4	2.1%
300	8	4.2%
310	13	6.8%
320	15	7.8%
330	16	8.3%
340	11	5.7%
350	13	6.8%

Total # of Joints - **192.0**

Data for Rose Diagram about Trace Length at P100

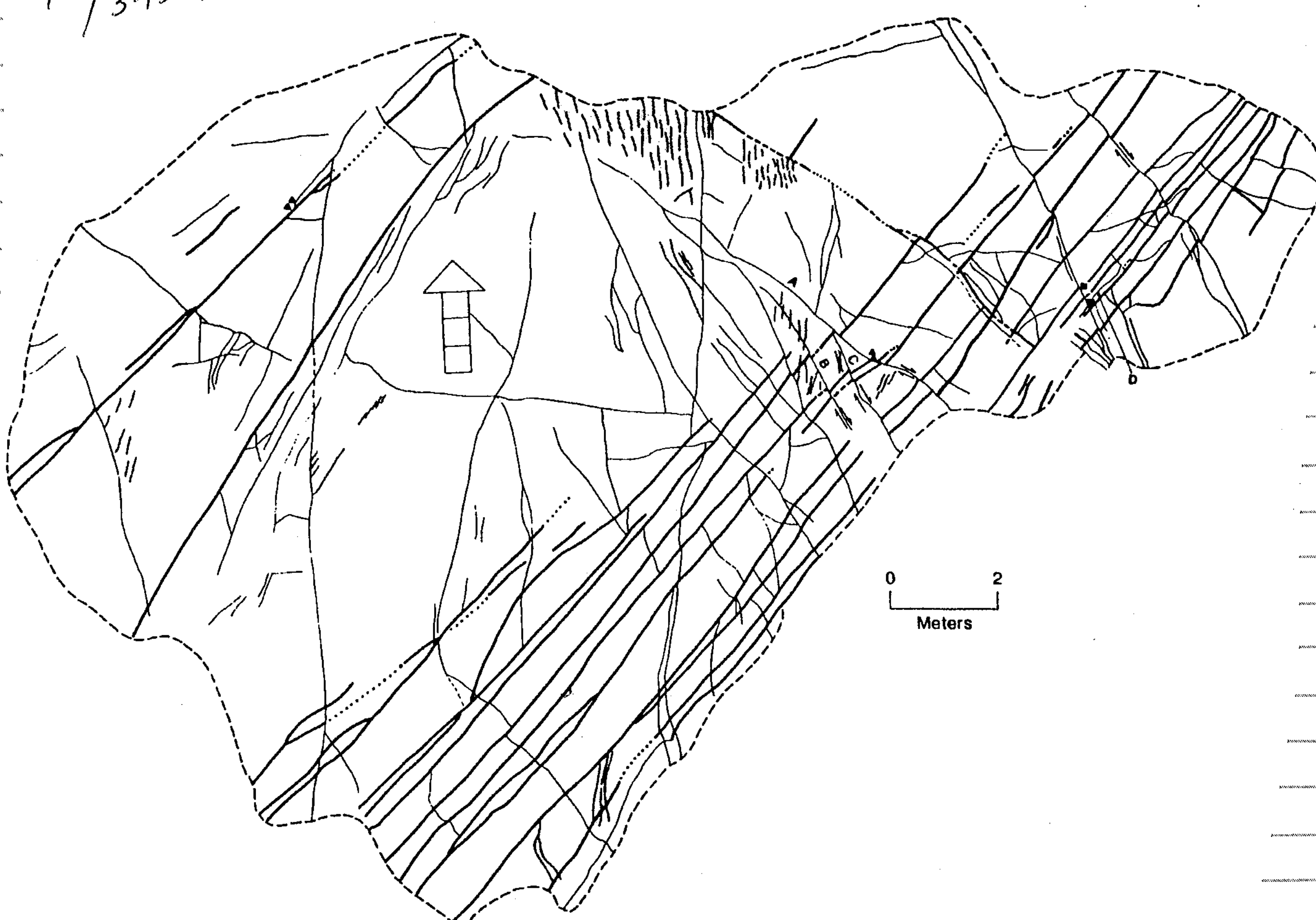
3-13-99

Degree	Tracelength (meters)	
0	22.2	4.7%
10	15.3	3.2%
20	28.9	6.1%
30	107.7	22.6%
40	111.7	23.4%
50	15.1	3.2%
60	4.4	0.9%
70	5.8	1.2%
80	8.4	1.8%
90	6.1	1.3%
100	7.5	1.6%
110	7.5	1.6%
120	16.4	3.4%
130	23.4	4.9%
140	23.8	5.0%
150	30.9	6.5%
160	19.7	4.1%
170	21.8	4.6%
180	22.2	4.7%
190	15.3	3.2%
200	28.9	6.1%
210	107.7	22.6%
220	111.7	23.4%
230	15.1	3.2%
240	4.4	0.9%
250	5.8	1.2%
260	8.4	1.8%
270	6.1	1.3%
280	7.5	1.6%
290	7.5	1.6%
300	16.4	3.4%
310	23.4	4.9%
320	23.8	5.0%
330	30.9	6.5%
340	19.7	4.1%
350	21.8	4.6%

total tracelength= **476.5**

Pavement 100 - Tpcpul - Barton

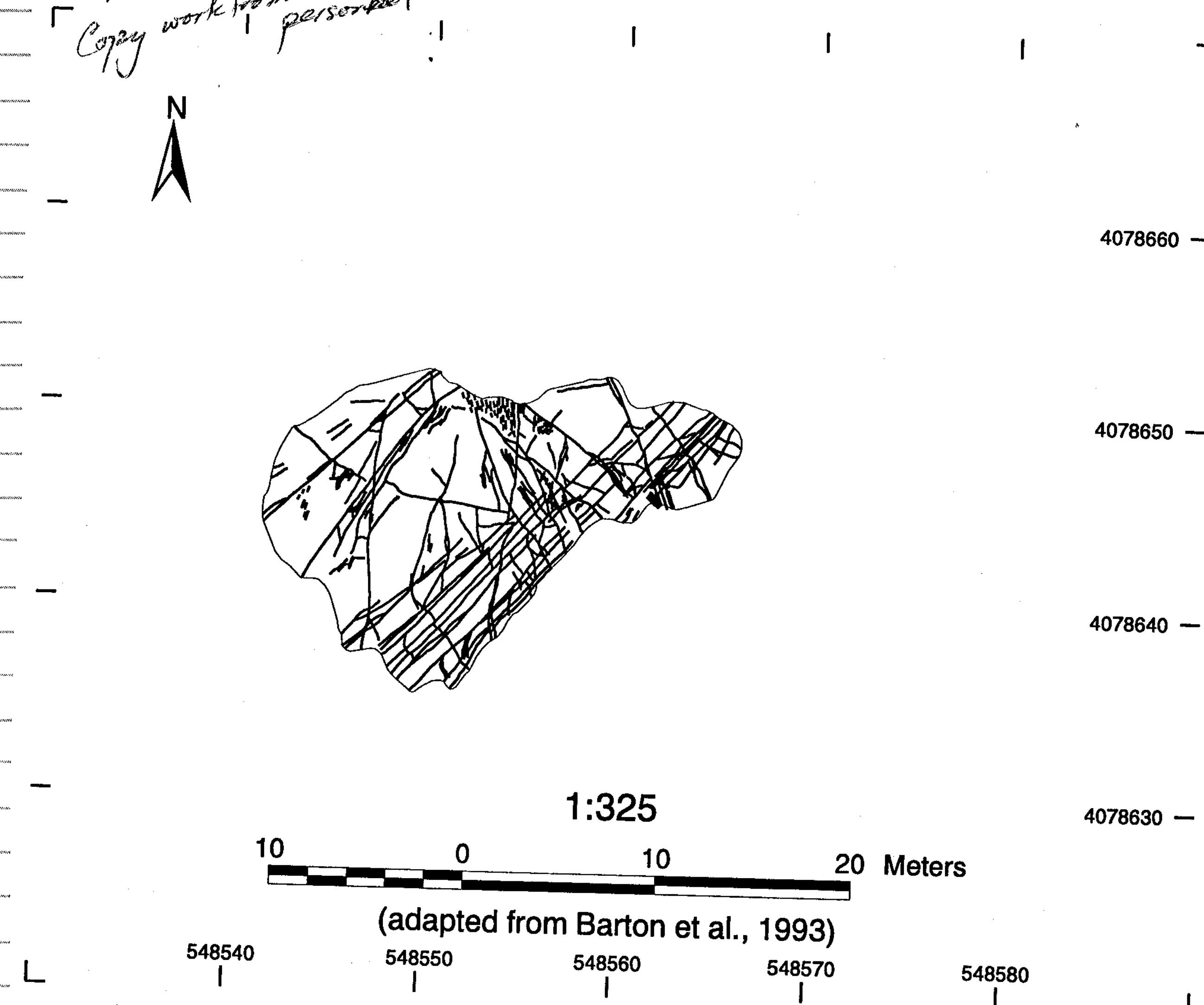
Seth Dunne
3-13-99



Seth Dunne
3-13-99
Copy work from SwRI personnel

bigbend

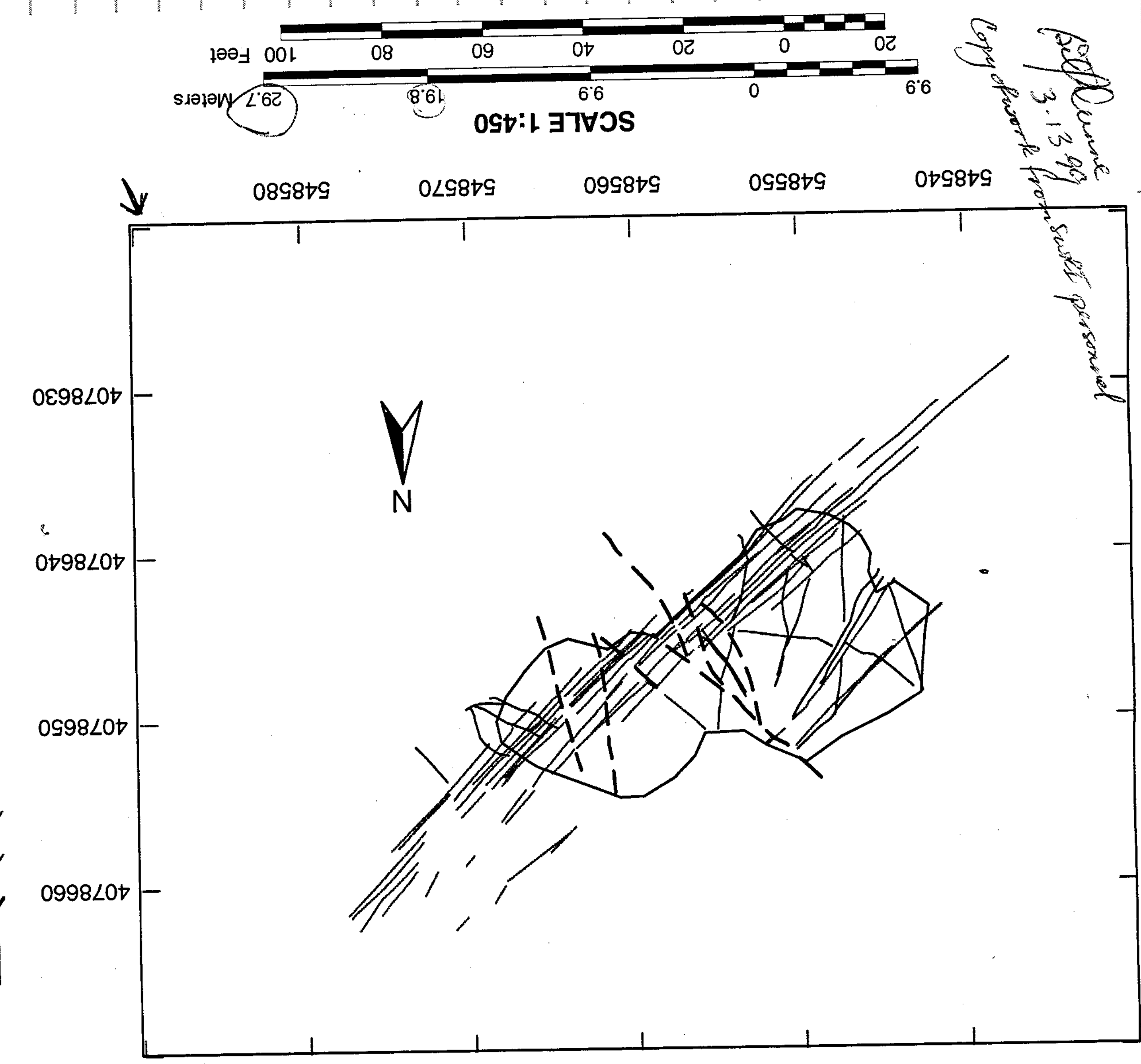
BARTON P100.ps



Bill Dunne 3-13-99
Copy of work from SwRI personnel

Pavement 100, Live Yucca Ridge, Yucca Mountain, Nevada

by, James P. Hogan, SwRI



SYMBOL LEGEND

- P100 Perimeter
- Faults
- Tectonic Joints
- Cooling Joints

Projection: UTM, zone 11
Magnetic North Declination: 14.5 deg E
Datum: NAD83
Units: Meters
Created: 16-Jul-98
J. Hogan, Southwest Research Institute

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98 Yucca 1999 - ...

March 15, 1999 (Monday)

Working with David Ferrill, Peter La Femina and Debbie Waiting on Live Yucca Ridge today is Monday and we are here to Friday at the "Ridge". Purpose is to complete the work from last summer (June 26th - July 1st 1998) specifically, to build the map of the joint pattern beyond the P100 exposure of Barton. Procedure is to flag the joints:
a) pink - cooling joint with tubercles
b) orange - tectonic joint with "rough surfaces
c) blue - subhorizontal joint
d) Caution - vegetation line without exposure of joints.

(2) Step 2 - use GPS gear to map in flagged traces. Intent is to use a 5m cut off on trace length of joints, but this decision may be revisited. While gathering GPS data, structural data about orientation and morphology of joints will be gathered.
*change → Cutoff length of 2m will be used.

(3) Step 3 - map in limits of rock exposure in map area, so as to get % exposure and to be able to calculate trace length / area = intensity.

Immediate goals of map construction are:

(1) Characterize joint (fracture) pattern at scale between "Barton pavements" (10x20 m) and 1:6000 geologic maps

(2) Assess impact of mapped pattern on infiltration magnitudes in 30 x 30 m blocks of infiltration numerical models in terms of whether fracture intensity (trace length per 30 x 30 m box) varies noticeably

(3) Consider horizontal components for permeability (2x2 matrix in the 3x3 permeability matrix). If pattern is strongly orthogonal, argue that select initial coordinate system parallel to two joint directions, have two non zero terms parallel to two joint directions and set two "shear terms" to zero. If wish to consider other horizontal w.r.t. coordinate systems, should transform from this system.

Bill Dunne 6-12-2000

100

Now, involved in Step 1 with David Ferrill calling the shots from Antler Ridge. I spot fractures on ground and he identifies lines of vegetation where I should check ~~here~~ W.D. for joints.

Change of plan. We had familiarity with the hillside, so we basically knew where fractures are. As a result, David returned to the S side of Live Yucca Ridge. We (including Debbie) flagged for the day. GPS gear went on the fritz, so no useful GPS work was done

3.16.99 (Tuesday)

Today's plan hinges on the stableness of the GPS gear. We have almost completed flagging the S side and need to flag the N side (which as we learned last summer has much more soil and therefore is "flagged" more quickly). After that, ideally, we would commence GPS work, but that depends on the gear. If it is down we will mark out exposure boundaries.

1:40 pm - finished flagging south side
- GPS in mas area (yellow tape)
-> Lunch

101

Now going to use GPS to start mapping fractures. See notes of Debbie Waiting and digital GPS data of Peter La Femina for results of day's effort

3.17.99

Completed 2/3's of South side doing GPS mapping of fractures (see notes of Debbie Waiting and digital GPS data of Peter La Femina)

3.18.99

Fracture mapping with GPS, he completed flagging of the North side of Live Yucca Ridge. Complete GPS map of joints (2m cutoff) on S side. See notes of Debbie and Peter.

3.19.99

(1) Completed joint GPS map on N side
(2) Did a "prototype" perimeter map of a rock pavement to separate it from colluvium
(3) Photos by David Ferrill
22, 23 - unfractured rock pavement near base station on South side of ridge,
24, 25 - Pete at base station

Bill Dunne 6-12-2000

102

South W.D.

26, 27, 28	P 100 on ~~side~~ side near east edge showing cooling joint swarm of Barton.
29 to 36	Looking at same cooling joint swarm, but downhill to South, so as to show the good quality of exposure (pink flags are on cooling joints, but not all cooling joints have pink flags, so as to conserve flagging tape). David took a series of shots going downhill.
New roll (includes two of Bill) 1-4	More pictures of cooling joints in this major NE-SW trending swarm
5	View to south to show colluvium cover "breaking up" exposure pattern of cooling joints
6	Bill "talking"
7	Bill walking
8	Large colluvium covered area on S side
9, 10, 11	NW-SE trending cooling joints (around C53) to show them and the patchiness of exposure for this joint swarm.
12, 13	The "Three Cacti" at C57
14	Close up of C56
15, 16, 17	"Veg line" polygon in rock pavement with few joints. Includes one line marked by two "caution" flags.
18, 19	Rock pavement to NW of T88 with no flagged fractures (none longer than 2m)
20	Rock pavement to NW of T16 without joints (none > 2m) again.
21→25	Joint C84 with branching tips at SW end.
26	Looking up C84
27	Tectonic joint cutting lithophysae (T104)
28	T112 → foliation parallel parting

Bill Dunne 6-12-2000

104

29,30	NE-SW trending joint swarm looking NE from southend of C100
31,32	Showing intense cooling joint development around C98 - C105
33,34,35' 36	T129 cutting across cooling joint swarm, providing connectivity

Questions and Observations from GPS mapping of joint pattern

(1) W.D. Cooling joints (for purpose of the survey, joints with tubes) occur heterogeneously in swarms that are 1 to 5m across and over 100m long.

a) What causes the spatial heterogeneity?

b) What causes the orthogonal pattern?

c) Why are neither set N-S trending, if E-W extension was the direction for σ_3 during 10-12 m.y.b.p.?

d) How long do the cooling joints have to form in the cooling ash fall tuff sequence. Possible bounds:

i) when do the falls become welded (let time Ø = completion of weld tuff deposition)? Assumption: cannot fracture until welded.

ii) when do the falls develop lithophysae? Assumption (documented by others): that cooling joints formed before lithophysae and that tubes are age equivalent to the lithophysae.

e) (6" continued) If the joints form from thermoelastic contraction (driving tension) during cooling, why is the joint network not polygonal? What stress component is causing an orthogonal ($\sigma_2 \neq \sigma_3$, and σ_2 and σ_3 alternate directions) rather than polygonal ($\sigma_2 \simeq \sigma_3$) network? As

i) the pattern is not E-W and N-S trending, remote tectonic "tension", σ_3, which is

ii) E-W, seems unlikely cause. Barton has hypothesized regional topographic slope and anecdotally mentioned rectilinear patterns in mudcracks on slopes as evidence (no documentation). Is this a possibility? What was the orientation of the Caldera slope in the Yucca Mt. area at the time that the Tiva Canyon Tuff was deposited?

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iii) What about the possibility of rotated stress directions in a "tensional" domain caused by the "interaction" of ~~the~~ two N-S trending normal faults.

→ Solitario Canyon?
→ Bow Ridge?
→ Ghost Dance? too small?

(2) The cooling joints in the tcpul and higher units contain ~~tubes~~ tubes, which are interpreted by volcanologists as exsolution features that postdate fracture formation. ~~[illegible]~~ W.D. Also, previous workers have interpreted planar ~~smooth~~ large oldest joints in units where tubes are absent as cooling joints (and even in units with tubes ⇒ more than one generation of cooling joints or that not all joints from single event experience exsolution). So, if tube-bearing joints occur in swarms in tcpul, you would expect them to continue as swarms of non tube-bearing cooling joints in lower unit, if conditions are equal. What if they don't (we have not seen an exposure of this contact with a swarm of cooling joints in the tcpul to investigate this issue)? Shouldn't the tcpmn and tcpul have approximately the same material properties during the formation of the cooling joints if both welded? Or, do properties differ because one is "colder" (tcpul, for example), or because one bears more gas (tcpul, for example)? We need to find an exposed contact with a swarm in tcpul at it. Resolving this issue would bear on the role of fluid pressure (due to volcanic gases) during cooling joint formation.

(3) Infiltration study still requires one more key data component ⇒ the location of rock pavements. Reasons for need:

a) demonstrate existence of significant pieces of pavement without joints greater than 2m

b) Provide area for calculating fracture intensities (needed to consider intensities in 30m X 30m model grid)

c) Provide true sample size in box

d) Provide stronger documentation for orthogonal pattern.

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④ What else is needed to make a strong infiltration case?

a) soil depths?

b) vegetation types?

Note that email to David Ferrill on 3/21/99 contains more complete rendition or comments on pages 104 to 108

June 21, 1999 (Monday)

This fieldwork will be a two-part enterprise from the point of view of team composition. Fieldwork overall objectives will remain the same through the two team configurations. Likely team configurations:

Monday - David Ferrill, Randy Fedors, Debbie Waiting, Bill Dunne

Tues - Fri - David Ferrill, Randy Fedors, Peter La Femina, Bill Dunne

(team composition is subject to change.)

Objectives

1) Most important! Continue fieldwork from June 26th - July 1st, 1998, and March 15th - 19th 1999 by completing Step 3 as specified in notes for March work (see page 98) - specifically map the pavements, so as to know the % exposure, the correlation of swarms to pavements or lack thereof, and to be able to calculate fracture intensity.

2) Determine lateral persistence of pattern mapped on Live Yucca Ridge by examining [illegible] two east-west ridges to the N and S.

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Approach could be to locate swarms on these ridges, measure orientation of individual fractures, see if swarm trends line up between mapped area and location on adjacent ridge. If that approach fails, then another approach might be to locate swarms on adjacent ridges and see if they have the same orientations, trace lengths and spacings. Exposure quality may impede either approach. GPS may be used to facilitate locating and determination of trend alignment.

3) Determine upward vertical connectivity of fracture pattern from swarms to fractures in caprock of Tiva Canyon. The best approach here is probably to attempt to identify cooling swarms in Tpcpul of ridge to N with caprock is present (Purgatory Ridge). If find swarms, try to trace them vertically upward and trace fractures in caprock (See Stop 6, Page 57-58, July 25th, 1997) downward to see how and if they connect. The "joker in the deck" with this approach may be that on Purgatory Ridge is the Sundance Fault,

which may create anomalous vertical connectivity through enhanced presence of tectonic joints caused as secondary fractures to fault.

In field on June 21st, 1999 at Live Yucca Ridge

Randy Fedors not present as work kept him at CNWRA. He will be here on Tuesday.

We used green tape to outline first pavement/exposure that includes Barton's pavement 100. Flags are numbered sequentially from A1 to A150. Commencing on Tuesday, we will use a table format to record pavements etc.

June 22nd, 1999

Team - David Ferrill, Peter La Femina, Randy Fedors, Bill Dunne

Mapped pavements should be large enough to measure 2m fractures independent of orientation was our pavement size criterion.

(Notes continue on p. 116)

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NAME	Description	East central west / top middle bottom	Last number	Day
A	Outline of a pavement		150	6-21-99
B	Window in pavement A		13	6-22-99
C	Window in pavement A W.D.		7	
D	Pavement - south slope, east		10	
E	Pavement - south slope, east		4	
F	Pavement - South slope, east		7	
G	Pavement - south slope, east, bottom		5	
H	Pavement - south slope, east, bottom		11	
I	Pavement - South slope, east, bottom complex polygon		26	
J	Pavement - "hill top", to east of Pioo		7	
K	Pavement	south slope, east, middle	9	
L	Pavement	south slope, east, top	9	
M	Pavement	south slope, east, middle	12	111a-1b M7a-7f
N	Pavement	south slope, east, middle	11	
O	Pavement	south slope, east, middle	7	
P	Pavement	south slope, east, bottom	11	
Q	Pavement	south slope, ~~east, central~~ central, bottom W.D.	6	
R	Pavement	south slope, ~~east central~~ central, bottom W.D.	8	
S	Pavement	south slope, ~~east, central~~ central, bottom W.D.	11	
T	Pavement	south slope, ~~central~~ central, bottom	5	
U	Pavement	south slope, central, bottom	5	
V	Pavement	south slope, central, middle	6	
(In U pavement, 1 cooling joint (318/90))				
W	Pavement	south slope, central, middle	5	
X	Pavement	south slope, central, middle	10	

NAME	Description		Last number	Date
Y	Pavement	south slope, ~~top~~, middle central, top W.D.	6	
Z	Pavement	south slope, ~~top~~, middle central top W.D.	6	
AA	Pavement	south slope, central, bottom	5	
AB	Pavement	south slope, central, middle	6	
AC	Pavement	south, central, top	5	
AD	Pavement	south, central, top	13	
AE	Pavement	south, central, bottom	7	
AF	Pavement	south, central, bottom	5	
AG	Pavement	south, central, bottom (large)	43	36a-d
AH	Window in AG		7	
AI	Pavement	south, central, top	7	
AJ	Pavement	south, central, top	5	
AK	Pavement	south, central, top	12	
AL	Pavement	south, central, top	7	
AM	Pavement	south, central, top	7	(38 pavements) (358 stations today)
AN	Pavement	south, west, bottom	13	6-23-99
AO	Pavement	south, west, top	10	
AP	Pavement	South, west, top	9	
AQ	Pavement	South, west, middle	34	
AR	Pavement	South, west, top	12	
AS	Pavement	south, west, top	8	
AT	Pavement	south, west, bottom	21	
AU	Pavement	south, west, bottom	9	
AW	Pavement	south, west, bottom	15	
AV	Pavement	south, west, bottom	16	

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Name	Description	Last number	Date
AX	south, west, middle	10	
AY	south, west, top	11	
AZ	south, west, top	4	
BA	South, west, bottom	5	
BB	south, west, bottom	15	
BC	South, west, bottom	15	
BD	south, west, middle	6	
BE	South, west, top	6	
BF	South, west, middle	7	
BG	south, west, top	8	2a-2b
BH	South, west, top	7	
BI	south, west, middle	5	
BJ	south, west, top	5	Last of the green flagging tape
BK	south, west, top	16	blue flagging tape
BL	south, west, top	6	
BM	south, west, top	6	
BN	South, west, middle	12	
BO	south, west, bottom	8	
BP	South, west, bottom	9	
BQ	South, west, bottom	5	
BR	south, west, middle	14	
BS	South, west, middle	8	
BT	south, west, top	14	
BU	South, west, top	7	
BV	south, west, middle	5	
BW	south, west, middle	9	"Sawteeth" on South side are short joints

Name	Description	Last Number	Date
BX	south, west, bottom	7	
BY	south, west, bottom	9	
BZ	South, west, bottom	28	
CA	south, west, middle	9	
CB	South, west, middle	7	blue → red tape change
CC	South, west, middle	24	
CD	south, west, middle	7	
CE	south, west, middle	13	
CF	South, west, bottom	6	
CG	south, west, middle	5	
CH	south, west, middle	30	
CI	south, west, bottom corner	11	
CJ	South, west, middle	9	
CK	South, west, middle	6	
CL	south, west, top	6	
CM	South, west, top	7	
CN	South, west, top	6	
CO	south, west, top	11	
CP	South, west, top	13	
CQ	South, west, top	9	
CR	south, west, top	5	
CS	south, west, top	7	
CT	south, west, top	7	
CU	south, west, top	12	→ yellow tape start
CV	south, west, top	11	(61 pavements, 635 stations today) end of day 6-23-99

(Continued on. P. 119)

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Some pavements at the boundaries of the study area are "truncated" because their sampled area is stopped at the boundary rather than continued to their actual limit. They are still much smaller than the study area, so the truncation effect to the population size distribution is probably not large.

June 23rd, 1999

Commencing second full day of pavement mapping. Had breakfast at 5:00 am to get out earlier and beat the heat some (4:30 am - Mercury - 70°F, forecast 10 to 15 mph SW wind). In terms of mapping, we will pick up on the south slope (referred to as "south" from pavement AC onward). Same team of four: David Ferrill, Pete La Femina, Randy Fedors, Bill Dunne.

We completed pavement mapping on the south side of Live Yucca Ridge in the study area, but we went through several different colors of flagging (green, blue, red, yellow) for the pavements because of limited tape supply vs. the large number of stations. Back in Beatty, we purchased 6 light green rolls of tape and we have 6 blue rolls that we will take for tomorrow for doing the north side of the ridge.

During pavement mapping this afternoon we encountered the "prototype" pavement (cutting W.D.) that we constructed on March 19th, 1999 (see page 101, bottom 1/3). The prototype used a less restrictive definition for defining a pavement outline, by allowing larger gaps (+50 cm) between smaller rock pavements. The result was a larger pavement segment that defined an area dominated (+75%) by exposed pavement, but not essentially 100% pavement, which is the criteria being used in constructing pavement outlines for the present survey.

June 24th, 1999

Interesting side thought - is Barton fractal measurement (fractal dimension - D) a poor (insensitive) or equivalent proxy for fracture intensity.

Today, we are going to attempt to complete the south side ~~[illegible]~~ W.D. flagging of pavement and then return to poorly exposed areas

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to see if swarms can be tracked through those areas - First item will be redoing Pavement Q because of poor GPS data (loss of telemetry during surveying of this one pavement.

We completed the pavements on the north side with David Ferrill taking over entering notes in book (hence change in handwriting at station FN). We then reexamined some of the cooling joint arrays to determine if they ~~were~~ are (W.D.) swarms (See detailed notes on pages 123 and 124). Bottom line is that three possible NE-SW trending groups are not swarms. The most westerly and most easterly groups are swarms and the group adjacent to the westerly swarm consistently has two side-by-side joints, but never three, so not really a swarm. However, the other two groups of NE-SW trending joints are not swarms. They each contain one large cooling joint but these fractures are isolated. Three NW-SE trending swarms do exist and are more closely spaced than those trending NE-SW, although they do not contain as many fractures. (p. 123 & p. 124 contain site specific notes ~~[illegible]~~ for these interpretations (observations).

Name	Description	Last Number	Date
CW	Window in Pavement A (north side)	6	6-24-99
CX	Pavement north, east, bottom	9	
CY	Pavement north, east, bottom	7	
CZ	Pavement north, east, middle	5	
DA	Pavement north, east, middle	8	
DB	Pavement north, east, top	4	
DC	Pavement north, east, top	13	
DD	Pavement north, east, ~~middle~~ top W.D.	10	
DE	Pavement north, east, middle	8	
DF	Pavement north, east, top	5	
DG	Pavement north, east, top	7	
DH	Pavement north, east, top	5	
DI	Pavement north, east, top	9	
DJ	Pavement north, east, top	9	
DK	Pavement north, east, top	6	
DL	Pavement north, east, top	7	
DM	Pavement north, east, top	8	
DN	Pavement north, east, top	7	
DO	Pavement north, east, top	9	
DP	Pavement north, east, top	6	
DQ	Pavement north, east, middle	14	
DR	Pavement north, east, bottom	9	
DS	Pavement north, east, bottom	7	
DT	Pavement north, east, bottom	10	
DU	Pavement north, east, middle	12	
DV	Pavement north, east, middle	9	

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Name	Description			Last Number	Date
DW	Pavement	north, east, bottom		11	
DX	Pavement	north, east, bottom		9	
DY	Pavement	north, east, bottom		16	
DZ	Pavement	north, east, ~~bottom~~ middle w.p.		8	
EA	Pavement	north, east, middle		6	
EB	Pavement	north, east, top		6	
EC	Pavement	north, east, top		10	
ED	Pavement	north, east, top		5	
EE	Pavement	north, east, top		6	
EF	Pavement	north, east, top		8	
EG	Pavement	South, east, top		5	
EH	Pavement	south, east, top		10	
EI	Pavement	south, east, top		7	
EJ	Pavement	south, east, top		7	
EK	Pavement	South, east, top		5	
EL	Pavement	South north, east, top		6	
EM	Pavement	~~[illegible]~~ north, east, middle		7	
EN	Pavement	north, east, top		6	
EO	Pavement	north, east, middle		4	
EP	Pavement	north, ~~middle~~ ~~[illegible]~~ central w.p., top		5	
EQ	Pavement	north, ~~middle~~ central w.p., top		1	
ER	Pavement	north, ~~middle~~ central w.p., top		6	
ES	Pavement	north, ~~middle~~ central w.p., top		5	
ET	Pavement	north, ~~middle~~ central w.p., top		4	
EU	Pavement	north, ~~middle~~ central w.p., ~~top~~ middle		6	
EV	Pavement	north, ~~middle~~ central w.p., top		4	

Name	Description			Last Number	Date
EW	Pavement	north, central, top		5	
EX	Pavement	north, central, top		7	
EY	Pavement	north, central, top		6	
EZ	Pavement	north, central, top		6	
FA	Pavement	north, central, middle		11	
FB	Pavement	north, central, middle		7	
FC	Pavement	north, central, top		8	
FD	Pavement	north, central, top		6	
FE	Pavement	north, central, top		7	
FF	Pavement	north, central, top		7	
FG	Pavement	north, central, top		11	
FH	Pavement	north, central, top		10	
FI	Pavement	north, west, top		8	
FJ	Pavement	north, west, top		9	
FK	Pavement	top, west, top		6	
FL	Pavement	north, west, top		6	
FM	Pavement	north, west, top		11	
FN	Pavement	north, west, bottom		4	
FO	Pavement	north, west, bottom		7	
FP	Pavement	north, west, bottom		5	
FQ	Pavement	north, west, top		12	
FR	Pavement	north, west, top		5	
FS	Pavement	north, west, top		10	
FT	Pavement	north, west/crest		7	
FU	Pavement	north, west, crest		10	

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Name	Description			Last Number	Date
FV	Pavement	South, west, crest		8	swapped to blue tape
FW	Pavement	South, west, crest		5	
FX	Pavement	north, west, crest		16	+16a
FY	Pavement	South, west, crest		~~8~~ 11	
FZ	Pavement	~~South~~ north, west, crest		7	
GA	Pavement	South, west, crest		12	
GB	Pavement	north, west, crest		7	
GC	Pavement	north, west, top		7	
GD	Pavement	north, west, top		6	
GE	Pavement	north, west, top		6	
GF	pavement	north, west, top		7	
GG	pavement	north, west, top		6	
GH	Pavement	north, west, top		10	
GI	pavement,	north, west, top		6	
GJ	pavement,	north, west, top		5	
GK	pavement,	north, west, top		6	
GL	pavement,	north, west, middle		5	
GM	pavement,	north, west, middle		9	
GN	pavement,	north, west, bottom.		7	last pavement 96 pavements 728 stations
			Totals		196 pavements 1879 stations

Notes for examining cooling joints to see if they are swarms:

cjpt 1 - COOLING JOINT POINT — UNMAPPED (too short) cooling joints

231/84
Peter LaFemina has the location in file "cool624a" (548390E, 4078676 N) UTM NAD 83.

Looking at group of NE-trending cooling joints to the east of the well-developed western swarm to determine if the group is a 'swarm.' Have found no more than cooling joints in NW traverses across group, but have now located an adjacent pair (see notes above). Also the most southwesterly fracture of this group terminates to SW inside the study area and inside their pavement.

Traced group to N side of ridge. Found no new occurrence of cooling joints and present NE "terminations" are censored ends due to NO exposure to NE. Group never has more than two cooling jts across group.

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Next SW trending group to the east is not a swarm. The long cooling joint on the south side of the ridge is definitely on its own.

Continuing east to the single SW trending long cooling joint on the N side of the ridge, it too is an isolated fracture, and not an element in a swarm.

June 25th, 1999

Working with Randy Fedors and David Ferrill in the south fork tributary in the Split Wash watershed study area. Purpose is to measure channel profiles, identify channel segments and determine sediment depth in the lower 1/2 of this fork. Key data are in Randy Fedors' notebook.

Bill Dunne
6-12-2000

I have reviewed this scientific notebook and find it in compliance with QAP-001. There is sufficient information regarding procedures used for conducting tests, acquiring, and analyzing data so that another qualified individual could repeat the activity.

[signature] for 06/15/00

H. L. McKague **Date**

GLGP Element Manager

MDM 06/15/00

Scientific Notebook # 181 has been used exclusively for NRC tasks. There have been no work on NRC tasks related to field work over the last 41 months or the tasks are such that documentation in a scientific notebook is not required (non technical activities). Thus there are no entries in this notebook for the last six month period.. There are currently no field activities anticipated that would be recorded in this notebook. This notebook should be archived.

H. Lawrence McKague

11/25/03

Date 11/25/03