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Scientific Notebook # 261: Structural Deformation and Seismicity (SDS); Structural geology investigation of deformation associated with faulted rocks at Yucca Mountain (04/17/1998 through 05/13/2005)

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**Scientific Notebook 261** **April 16, 1998**
**Initial Entry: John Stamatakos**
**Project: 20-1604-471 Structural Deformation and Seismicity (SDS)**

**Title of Experiment:** Structural geology investigation of deformation associated with faulted rocks at Yucca Mountain.

The aim of the research is to examine the evolution of fault zones as it pertains to two SDS sub issue: (1) potential adverse consequences from direct fault rupture of waste packages and (2) structural control of groundwater flow in the saturated and unsaturated zones. Current working group on this project are:

Dr. John Stamatakos, Ph.D. - CNWRA Senior Research Scientist (Principle Investigator)
Dr. David Ferrill, Ph.D. - CNWRA Senior Research Scientist

Dr. Mary Beth Gray, Ph.D. - Consultant, Professor of Geology, Bucknell University, Lewisberg, Pennsylvania.
Dr. William Dunne, Ph.D. - Consultant, Professor of Geology, University of Tennessee, Knoxville, Tennessee.

Scientific Notebook 261 April 17, 1998

Entry: John Stamatakos
Project: 20-1604-471 Structural Deformation and Seismicity (SDS)
Experiment: Structural geology investigation of deformation associated with faulted rocks at Yucca Mountain.

Purpose: Description of first subtask of this experiment.

The first subtask of this project experiment is to analyze deformation associated with faulted rocks at Yucca Mountain (YM) and in the surrounding region. The aim of this first subtask is to resolve uncertainties associated with the conceptualization and modeling of fault zones in ongoing SDS total system performance (TPA) sensitivity analyses. Initial sensitivity studies of faulting performed in the fall of 1997 using TPA code, version 3.1.1 showed that repository performance may be sensitive to fault zone width. Fault zones in that version of the code were modeled after surficial mapping data, primarily from Scott and Bonk (1984), see Ghosh et al. (1998) for the details of the sensitivity analyses. Recent observations of faults in the Exploratory Studies Facility (ESF) suggest that fault zones at the level of the repository horizon are smaller than those mapped at the surface. This subtask will examine differences in fault zones at the surface and subsurface. Results from the study will form a component of the technical bases for SDS issue resolution on faulting. Results from this subtask will also be used as the bases for recommended modifications of the TPA code and methodologies in future performance assessments of faulting.

For these analyses, oriented samples will be collected from faults exposed at the surface and in the ESF. The work will include both field observations and detailed examination of thin sections. Field observations will be initially documented in standard geological field notebooks. Pertinent observations from those notes will be copied into this scientific notebook, conforming to CNWRA QA guidance QAP-001. Sample collection, thin section preparation, and thin section analysis will follow standard geological practices and procedures under the supervision of Dr. Mary Beth Gray. On the Test site and in the ESF, sample collection and DOE sample regulations in accordance with YAP-S11.4Q – *The Collection, Submission, and Documentation of Non-Core and Non-Cuttings Samples to the Sample Management Facility for Site Characterization.* Observations from those analyses will also be entered in this notebook in accordance with CNWRA QA guidance QAP-001.

References:

Ghosh, A., J.A. Stamatakos, S. Hsiung, R. Chen, A.H. Chowdhury, and H.L. McKague, 1998, *Key technical Issue Sensitivity Analysis with the SEISMO and FAULTO Modules within the TPA (Version 3.1.1) Code*, Center for Nuclear Waste Regulatory Analyses, San Antonio, Texas.

Scott, R.B., and J. Bonk. 1984. *Preliminary geologic map of Yucca Mountain, Nye County, Nevada with geologic sections.* USGS Open-File Report 84-494. Denver, CO: U.S. Geological Survey: Scale 1:12000.



May 2, 1998

I decided to photograph each specimen collected from the Exploratory Studies Facility at Yucca Mountain, NV, and nearby. These photographs will serve as a visual record of the state of each specimen prior to further analysis. The specimens are in generally poor condition. Tuffaceous fault rocks such as those being studied are friable and porous. Each specimen was carefully sampled ~~s~~packed & then shipped in bubble wrap. After unpacking them, I tested one loose piece of a sample to see if they would withstand a gentle washing in water before I photographed them. The sample disintegrated immediately. I have therefore opted to photograph the samples in their present, dirty condition. Further, some samples JSSC-A,B,C,D are so friable that as I began to unwrap the tissue surrounding them, they began to crumble. I decided to take pictures of them in their present wrapping and resolved to photograph them on the day that I unwrap them for impregnation with epoxy.

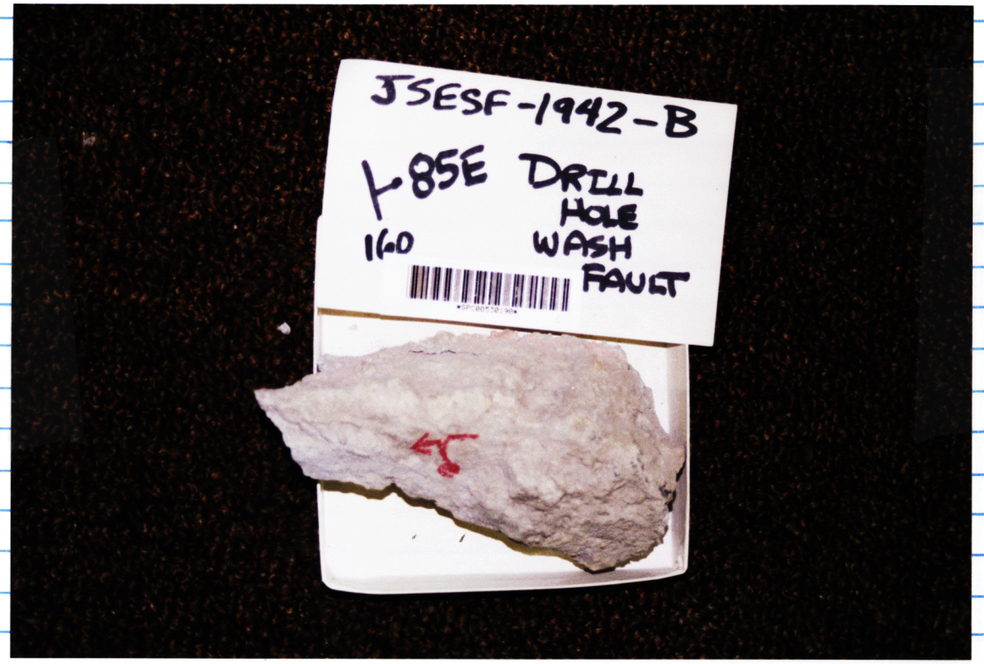
Mary Beth Gray

MBG

May 25, 1998

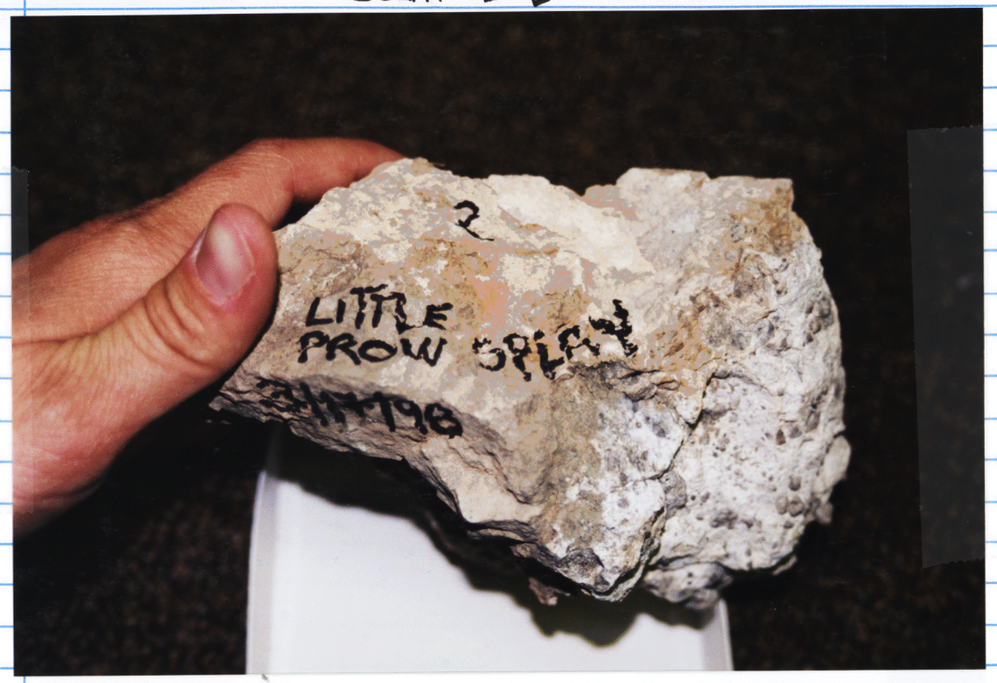
Photographs of the Yucca Mountain samples are included in the following pages:

SPC00530190 7



JSLPPF-B-2

JSLPPF-B



JSLPPF-A

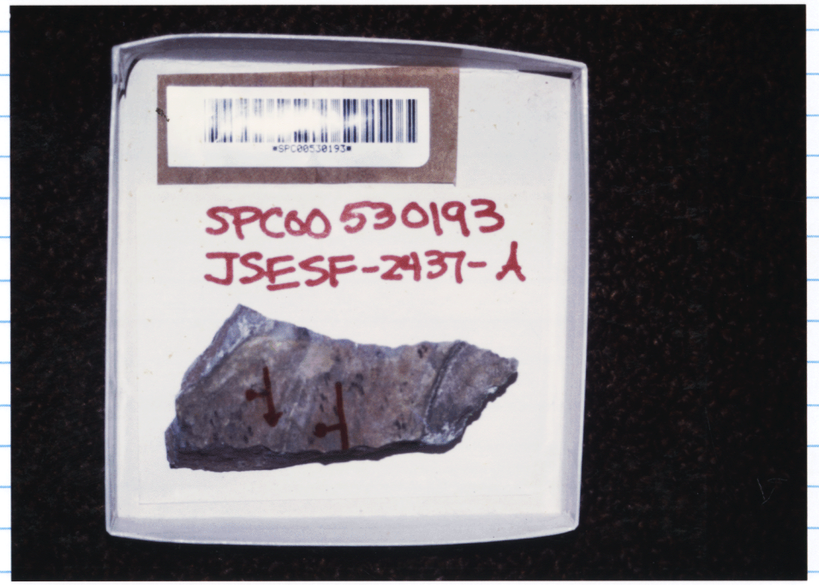


JSSC A,B,C & D – FAULT GOUGE WRAPPED IN TISSUE AWAITING EPOXY.

Solitario Canyon 2 –

SPC00530192 — JSESF-2437-B

SPC00530193 - JSESF-2437-A

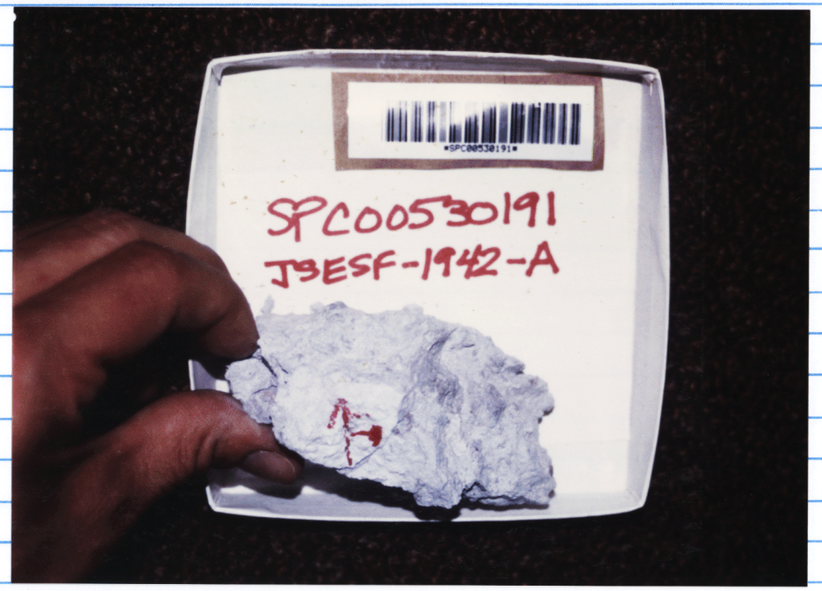




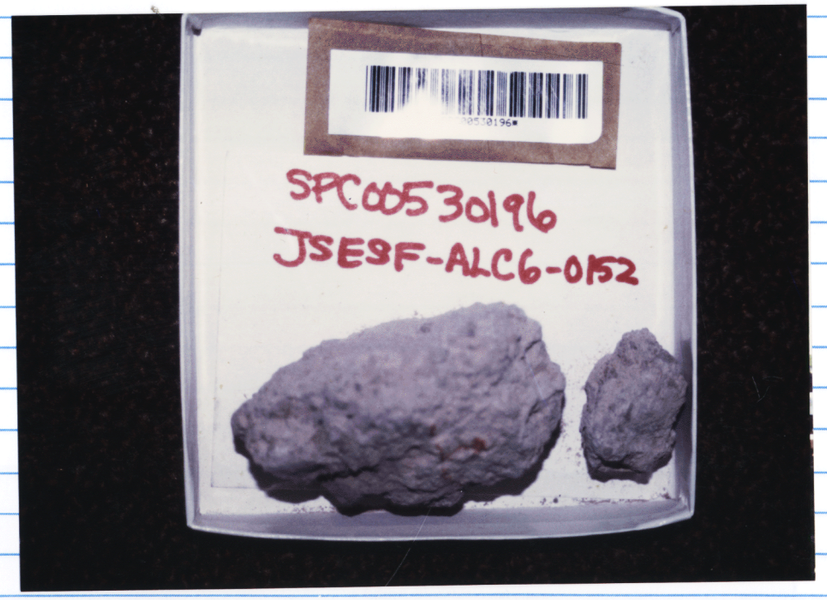

Solitario Canyon 1

Little Prow SPLAY 3

SPC00530191 – JSESF-1942-A

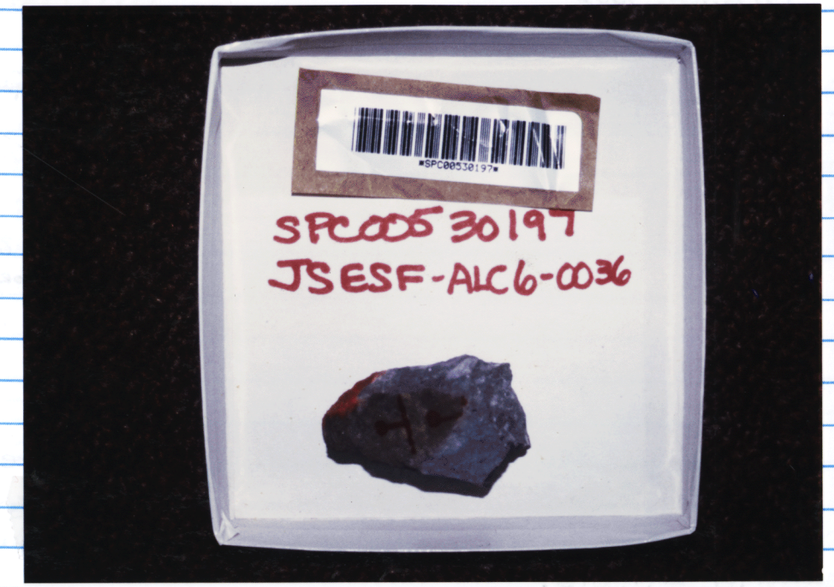



SPC00530196 – JSESF-ALC6-0152






SPC00530197 – JSESF – ALC6 – 0036




Mary Beth Gray

MBG

May 26, 1998

Today, I cut some of my rock samples into chips to be made into thin sections.

Samples cut into chips:

JSLPPF-A : 1 chip
JSLPPF-B 0 chips – decided 6 was enough for now.
JSLPPF-C : 5 chips
JSSC-2 : 3 chips

I used Hillquist A/B Epoxy to coat the surface of the chips. I placed them on a hot plate and let them cure at a temperature of 75°C for 1 hour then let them cool. I plan to return to them after 24 hours.

Mary Beth Gray

MBG



May 27, 1998

I polished the 9 chips I made yesterday using first a 45 micron lap and then a 30 micron lap. I heated the chips, applied epoxy (Hillquist A-B epoxy) and glass slides were affixed to the polished faces of the chips. The chips attached to the glass slides were left at room temperature to cure overnight.

Mary Beth Gray

MBG

May 28, 1998

I cut chips off ~~off~~ MBG the glass slides and finished making the thin sections using a Hillquist thin sectioning machine. I used 1000 μ grit to remove saw marks as appropriate.

Mary Beth Gray

MBG

June 16, 1998

The vacuum desiccator arrived in the mail yesterday. It is a Nalgene product (Cat No. 5310-0250). The geology department purchased vacuum tubing to accompany the desiccator. We also purchased Dow Corning High vacuum grease. Today, I prepared approximately 200 ml of Petropoxy 154 for the purpose of vacuum impregnating some of the rock samples. Petropoxy 154 is made by Palouse Petro Products (Ph. 509-878-1848) and is known for its low viscosity (ideal for impregnation) and strength (v. high). I placed each of the selected samples in the container ~~and~~ MBG holding the epoxy and then placed the container in the desiccator. The desiccator was then evacuated using a standard vacuum pump. When the vacuum pressure reached ≥65 cm of Hg the epoxy began to boil and I discontinued using the vacuum pump. I then removed each sample and

June 16, 1998 – continued

placed them in an oven at 135°C to cure. The samples were held at 135°C for 1½ hours and then removed. I then made additional marks on the samples to make sure they were clearly labelled. In some cases the samples were sufficiently small to warrent abreviating the sample code # used/supplied by the Sample management facility at Yucca Mtn. This abbreviated code consists of the last four digits in the code consisting of 11 digits. This necessary abbreviation of the code for each sample is temporary and the full code will appear on the finished thin sections and sample remnants.

I began by impegnating the following samples in a vacuum:

SPC00530190 Photo page 5 – before epoxy
SPC00530191 Photo page 10 – before epoxy
SPC00530196 photo page 10 – before epoxy

I photographed and then:
I then vacuum impregnated the following samples:

JSSC-A
JSSC-B
JSSC-C
JSSC-D
} Photo page 7 (of these wrapped in tissue.)

The photographs of the unwrapped JSSC samples will appear in this book when I get them developed.

Meanwhile I thought it best to carefully describe the surface features of the fault rocks before I cut chips: I used an Olympus Binocular Microscope and oblique illumination to pick out surface features. The microscope is capable of 40x magnification. The following is a description of those rocks that I examined.

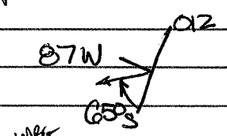


June 16, 1998 – continued

SPC00530197 – (JSESF-ALC6-0036)

This sample was taken at STA 0+35.7 in the ESF Alcove 6. My field notes from this ~~sight~~ site indicated "subsidiary fractures (en echelon) and horizontal slickenlines indicate strike-slip motion", "RL movement". ~~the~~ Inspection of the sample under magnification reveals slickenlines that rake 65°S. These may be slickenfibers as they are stepped indicating down to the west sense of shear. What are the fiber minerals? I can't tell without a thin section. The apparent slickenfibers might just be cataclasite or gouge in "fiber form"

Sample orientation w/ "fiber" (slickenline) orientation




SPC00530192 – ~~24~~ (JSESF-2437-B)

This sample has a generally polished surface. It was taken at STA 24+37.5. My field notes reflect seeing slickenlines that rake 62°N at this sample site. The sample shows multiple slickenlines. Again, the slickenlines are not merely scratches or grooves but are made up of some light colored material (of suspect fault rock) that has the form of a mineral fiber in a fault zone ("slickenfiber").
One set of slickenlines rakes 45°S.
Another set rakes 50°N
A third set rakes 90°
Some of the patches that appear to be well polished have coincident Fe-Mn coatings which add to the sheen but this is not the cause of the overall appearance of polish/sheen on this ~~fau~~ surface

June 16, 1998 – continued

It should be noted that this particular sample is described at a cooling joint in a lithophysal zone. It caught my eye because of the obvious shear polish, apparently inconsistent with the reported joint origin of these structures.

Mary Beth Gray

June 17, 1998

Continued description/documentation of surface features on the fault rock samples using a binocular microscope @ 40x magnification.

SPC00530193 – (JSESF-2437-A)

~~The~~ MBG This specimen was collected in the ESF at STA 24+37.5 – same locality as sample SPC00530192. Reported to be a "joint" among a host of others that have similar appearance/morphology. I was struck by the polish and slickenlines on these surfaces – in the field and in the tunnel. Under the microscope, slickenlines are evident. Again, mineralization (slickenfibers) and/or linear streaks of fault rock give a stepped appearance on this polished surface. Multiple orientations of slickenlines are present.

The surface is oriented 220/80E

Slickenlines: Rake
15°N – 0°N
48°N
90° APPEAR HW↑ sense of shear



June 17, 1998 ~~cont'd~~ MB – continued

The slickenlines (slickenfibers?) that rake 48°N appear to be younger than the set at rake = 90°. This observation is based upon the fact that the mineralization associated with the set of slickenlines that rake 90° is well developed and appears to have fine slickenlines on it that belong to the 48°N-raking set.

It occurs to me that the apparent lack of correspondence between field observations on lineations and those lineations that I observe may be due to several things:

(1) field data are incorrect → I doubt this since I have confidence in my observation skills using a 10x hand lens.

(2) Natural variability of lineations on a single fault surface. ⇒ Most slickenlines are naturally variable due to (A) repeated episodes of fault displacement with temporal changes in slip vectors, (B) irregular fault surfaces will naturally produce lineations in different areas of the surface as rocks variably accommodate slip.

(3) Scale dependance of lineations? Is it possible that some lineations are ~~resist~~ MB restricted to a particular scale of expression? Certainly some slickenlines can be very coarse, but is it possible that during that same episode no very fine slickenlines were formed? If so then, my binocular microscope observations simply may add to the lineation sets observed mesoscopically.

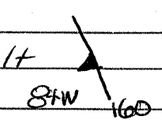
June 17, 1998 – continued

Since three of the three specimens that I have examined carefully using the binocular microscope have had more than one fault lineation, I am troubled about having to choose a cut plane in which to study the fault zones. Shear sense indicators will be need to be used with extreme caution in thin section!

The mere presence of multiple fault lineations on these surfaces (many multiply lineated faults were observed in the FSF) suggests that the fault zone development did not involve sufficient hardening mechanisms to prevent reactivation of single surfaces.

SPC00530198 – (JSESF 4339)

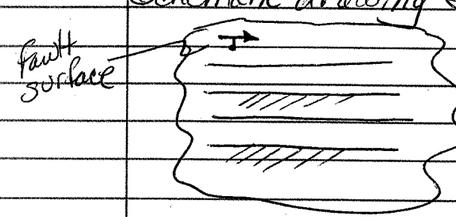
JTA 43 & 39 a nearly vertical fault




In binocular microscope 20x and 40x two distinct slickenlines are evident:

Rake ~0° strike slip slickenlines are coarse and appear to predate slickenlines that rake 60S.

Schematic drawing shows relationships:




each line is a "ridge". the 0° rake slickenlines localize the occurance of apparently later 60°S slickenlines.



The 60°S slickenlines indicate an oblique slip event with reverse dip slip and right lateral strike slip components

Following description in the microscope, I vacuum impregnated the sample (SPC00530198) and put the sample in the oven to cure.

Mary Beth Gray 6/17/98

June 18, 1998

I spent some time today cutting rock chips from the samples that I have impregnated with epoxy and those that did not require epoxy. Each oriented sample was carefully marked with indelible marking pen such that each chip cut from it would bear orientation markings on it. I have had some difficulty with the friable nature of the rocks despite having vacuum impregnated them with epoxy. The chips have been abraded by the saw and clasts have been plucked from the cut face. Nonetheless, I have managed to prepare ~19 chips. Those that seem to require further epoxy will be treated by coating the surface with more epoxy and/or vacuum impregnation for a second time. About 9 chips are coherent enough to be directly glued to the glass slides w/o further treatment (after saw marks are removed, of course).

I have cut chips in two planes relative to the fault planes,

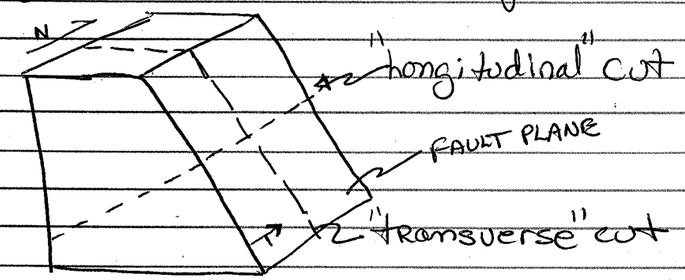
"Transverse" = Normal to the fault plane and parallel to the dip direction of the fault.

"Longitudinal" = Normal to the fault plane and parallel to the strike of the fault.

June 18, 1998 continued.

A block diagram of the footwall of a fault is below:

figure 1

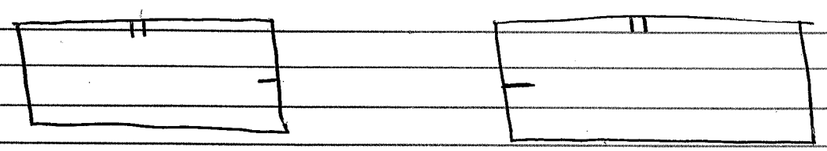



Note that the fault surface contains a strike and dip symbol similar to those on my samples. The strike and dip symbol has an arrow on the northern end of the strike line, thereby distinguishing whether the surface is the top (underhang) of a fault surface or whether the surface is the bottom (overhang) of a fault surface.

MARKINGS:

TRANSVERSE CUTS: LONGITUDINAL CUTS

figure 2a,b



In the transverse plane, each oriented sample shall contain two identifying saw marks (1-2 mm long nicks in the sides of the chip). Two closely spaced saw marks indicate the side of the chip that is, or is closest to, the discrete fault plane. A single saw mark will indicate the down dip direction of the fault plane and down dip end of the oriented chip.



June 18, 1998 continued

In longitudinal cuts: two sawblade marks (nicks) will be used to indicate that side of the chip that is, or is closest to, the fault plane surface. One saw mark (nick) will indicate the North end of the longitudinal cut.

In the case of the figures 2a & b, these chips would indicate a surface looking to the north once transverse cut, and a longitudinal cut looking down on the cut face.

CHIPS PREPARED TODAY:

note: 6/19/98 MBG - All glass slides attached to these chips are standard 2.6 x 4.6 cm size.

SPC 00530193 A
SPC 00530193 B } longitudinal
SPC 00530193 C
SPC 00530193 D } transverse
~~SPC 00530193~~ MBG 6/18/98
SPC 00530192 A
SPC 00530192 B } longitudinal
SPC 00530192 C
SPC 00530192 D
SPC 00530192 E } transverse
SPC 00530197 A
SPC 00530197 B } transverse

Mary Beth Gray 6/18/98

MBG

June 19, 1998

I further coated cut surfaces of selected samples with more Petropoxy 154 AND placed the chips in an oven at 135°C to cure for 2 hours. I then sized AND made identifying marks on all chips, washed and polished the cut faces on the chips. The chips were placed on a hot plate at 70°C to dry out for 2 hours.

Chips made:

| | | GLASS SLIDE SIZE (cm) |
|---|---|---|
| SPC00530190 A | Transverse | 5.0 x 7.5 |
| SPC00530190 B | Transverse | 5.0 x 7.5 |
| SPC00530190 C | LONGITUDINAL | 5.0 x 7.5 |
| SPC00530191 A | Transverse | 5.0 x 7.5 |
| SPC00530191 B | Transverse | 5.0 x 7.5 |
| SPC00530196 | Transverse | 5.0 x 7.5 |
| SPC00530198 A | Transverse | 5.0 x 7.5 |
| SPC00530198 B | Transverse | 5.0 x 7.5 |
| SPC00530198 C | Transverse | 5.0 x 7.5 |
| SPC00530198 D | Longitudinal | 2.6 x 4.6 |
| SPC00530198 E | Transverse | 5.0 x 7.5 |

Standard thin section size is 2.6 x 4.6 cm ← area of glass slide
Some thin sections were made at a larger size, so as to give optimum areal coverage of the fault zone textures. This larger size is 5.0 x 7.5 cm ← area of glass slide.

I have noted the size of the glass slide attached to the chips on this page and on page 21.

Due to the fussy nature of Petropoxy 154, I decided to attach the chips to the slides with a different epoxy – Hillquist AB epoxy. Instructions for using



June 19, 1998 continued –

Petropoxy 154 state that rocks with a significant % of epoxy in the pores sometimes cause cracking of the glass slides when the chips are attached to the glass slides to cure. Hillquist AB epoxy is not known to cause this problem, although it is not clear that there will be no reaction between the two different epoxies.

I left the chips & slides to cure on a hot plate at 80°C for several hours.

SAMPLES JSSC A,B,C,D

I am very disappointed with the results of my attempts to vacuum impregnate the Solitario Canyon fault zone samples. The samples are still very friable and will certainly not survive the vibration while attempting to hand cut chips from them. I have left them for now.

Mary Beth Gray 6/19/98

June 22, 1998

I vacuum impregnated the Solitario Canyon Fault zone samples (JSSC A,B,C,D) again with Petropoxy 154. I was careful not to allow the Petropoxy to boil as I evacuated the chamber. I cured the impregnated samples at the prescribed ~~T and~~ MBG temperature and for the correct length of time. ~~I continued~~ MBG ~~to cut~~ I cut rock chips from the thin section glass slides and began the process of thinning the thin sections from about 10-15 thin sections. ~~that~~ thin sections that I have thinned are now about 10μ thick. I will remove saw marks and continue polishing the thin sections as I manually thin them ← 10μ on the dial on the Hillquist.

Mary Beth Gray 6/22/98

June 23, 1998

I have now cut all of the chips from the glass slides listed on pages 21 & 22. The thin sections were properly labelled using a diamond scribing tool on the glass slide. I have properly stored and labelled the sample remnants using the assigned Sample Management Facility Identifiers. I plan to further thin the thin sections as necessary as I begin to perform the microscopic analyses of the thin sections.

Mary Beth Gray 6/23/98

June 24, 1998

Today I begin to analyze the structures in thin section. I have struggled with thinning the thin sections to ~30μ (using optical methods) because as the thin section become thin, plucking of the thin section began to occur. I have decided to work without cover slips on the thin sections because I believe many of the sections would show interesting features in a cathodoluminoscope. Cathodoluminescence requires thin sections without cover slips. Note: it also damages the thin sections. I must ask CNWRA if this is acceptable.

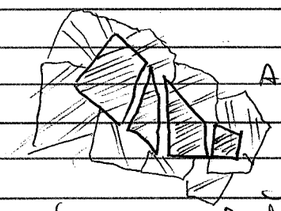
SPC053019 8C — this thin section is from Station 43+39 in the ESF. The fault is a NW trending fault with multiple slickenlines (see p. 18-19). I have coated the surface of the thin section with glycerine. I will do this to all subsequent thin sections ~~p~~ that do not have cover slips prior to



June 24, 1998 continued.

any microstructural analyses. Without having digitized the fault rock on this thin section, I would estimate that at least 50% of this fault rock is mineralized. Most of these crystals are calcite with sizable diameters. Some are as large as 5mm (viewed with a 2x objective) and most are 0.5mm – 1.0mm diameter. Some are smaller than 0.5mm. Abundant growth and deformation twins are obvious. Other minerals are present. I will need to identify them optically.

The textures are very interiguing. Wall rock (tuff) clasts are angular and commonly contain intragranular fractures – fractures that completely or partially transect individual clasts without passing into the matrix of crystals surrounding the clasts. The mineralization in the fractures appears to be more inclusion free than the calcite in the matrix surrounding the clasts. This appearance is suggestive of multiple episodes of mineralization and also suggests that the clasts fractured readily with respect to the crystal matrix of the fault rock.



A sketch of a single clast of wall rock surrounded by a crystalline matrix of calcite

note that I have not depicted the different character of the calcite crystals in the matrix and in and near the filled fractures of the clast.

Fractures in the clast do not necessarily follow the compaction foliation in the tuff. Many tuff clasts do not appear to have been significantly displaced along the fractures that cut across them. Mainly pure dilation – but small enough to easily tell all the original, matching pieces of the fractured clasts.

Mary Beth Gray 6/24/98

7/27/98

I have been examining the suite of thin sections using an Olympus BX50 research polarizing microscope. I have used 2x – 40x objectives to look at different scales of textures & structures. I have taken photo-micrographs of textures using 200 ASA slide film.

Mary Beth Gray

8/6/98

After reading about the green fluorescence of opal in Paces et al, 1996, I shone a short wave UV light on all of the Yucca Mountain Samples and was able to identify 3 distinct fluorescent minerals in the collection:

Flourescent colors:

green → non effervescent in dilute HCL
this mineral is likely opal as described in Paces et al 1996.

orange → I'm not sure about this mineral yet but it does appear to be most prevalent on weathered, rather than fresh surfaces.

light blue – sparse, small, isolated crystals fluoresce this color. Note that this mineral phosphoresces for 3 seconds after turning off the UV lamp. The green & orange minerals appear to cease illumination as UV lamp is turned off (no discernable delay).



MBG 8/6/98

8/6/98

I shone a UV lamp on the thin section collection and found that the thin sections fluoresced slightly (less dramatic than hand samples). It may be advantageous to use a research microscope with a UV light to pick out textures & occurrences of the fluorescent minerals.

Mary Beth Gray

8/10/98

I have used HILLQUIST AB EPOXY TO ATTACH THE FOLLOWING CHIPS TO 5.0 x 7.5 cm glass slides.

| | |
|---|---|
| SPC00534002A | UNORIENTED |
| SPC00534002B | UNORIENTED |
| SPC00534003 | LONGITUDINAL |
| SPC00534005 | TRANSVERSE |
| SPC00534007A | TRANSVERSE |
| SPC00534007B | TRANSVERSE |
| SPC00534007C | TRANSVERSE |
| SPC00534007D | TRANSVERSE |
| SPC00534008 | LONGITUDINAL |
| SPC00534009A | TRANSVERSE |
| SPC00534009B | TRANSVERSE |
| SPC00534009C | TRANSVERSE |
| SPC00534011 | UNORIENTED |
| SPC00534014A | TRANSVERSE |
| SPC00534015 | UNORIENTED |
| SPC00534016 | UNORIENTED |
| ~~SPC00534017A~~ | ~~TRANSVERSE~~ MBG |
| SPC00534017B | UNORIENTED |
| SPC00534017C | UNORIENTED |
| SPC00534023 | TRANSVERSE |
| SPC00534014B | TRANSVERSE |

Mary Beth Gray

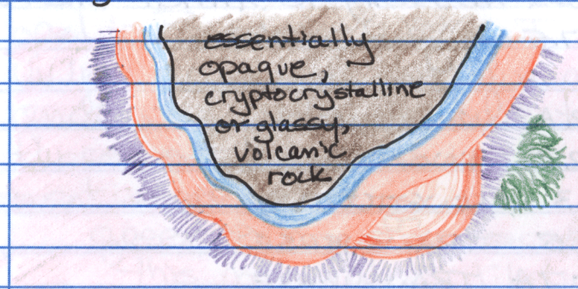
8/11/98

Microstructural analysis:

SPC00534005: Bow Ridge Fault Zone exposed in surface trench.

Several generations of mineralization are obvious in this rock. Mineralization progressed from the rims of void spaces in the fault rock and eventually sealed up void spaces with a sparry calcite cement.

Sketch of ~~s~~ textures in this sample: Phases identified herein by the colors on the sketch below:




Blue: forms a rim of relatively uniform thickness on the perimeter of voids. Ribbon like appearance. few inclusions in it. Too thin to resolve figure. Opal? Chalcedony?

Orange: this stage of mineralization is distinct from the first by its appearance in plain light. This phase has a lot of inclusions within it, giving it a "dirty appearance". Same relief and texture as the first phase of mineralization (blue). It's probably the same mineral.

Purple: this phase of mineralization has a different crystal habit. It is bladed and the blades/fibers lie perpendicular to the undulating surface of the mineral precipitated during the second phase.



8/11/98 continued

Purple mineral phase: continued – the mineral fibers have the relief and birefringence of quartz. It might be microcrystalline quartz.

Green: this may be another layer of the mineral phase identified in purple on p. 28. It's appearance is slightly different. The crystal habit is less uniform and forms a somewhat radial array of curving fibers. I'm not capable of speculating on its possible mineralogy given its size.

Pink: Calcite. It has v. large crystal size and is void-filling. It is the last stage of mineralization.

Mary Beth Gray

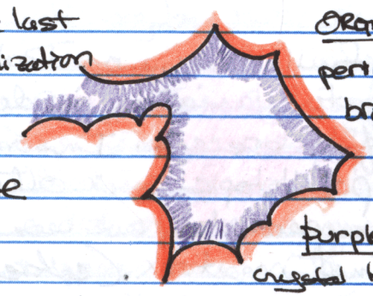
8/12/98

Microstructural/microtextural Analyses.

SPC00534014B –

This sample is from the surface of Yucca Mountain. The sample was taken in the gully east of Dune Wash at a spot on the map where fault breccias were identified. It's not possible to independently establish whether this breccia is a fault breccia or a breccia that formed by cementing surficial deposits. Below, I describe the textures in this rock.

Pink: the last phase of mineralization is calcite(?) This calcite is cryptocrystalline (micritic?).



Orange: this mineral is enclosing the perimeter of a void space in this breccia. It has a ribbon-like, botryoidal appearance.

Purple: this mineral has a bladed, fibrous crystal habit. It lies perpendicular to the face on which it grew. It is length slow, and has parallel extinction. I think it might be chalcedony.

8/12/98 - continued.
microtexture / microstructure analysis.

SPC00534014B - description continued.
This sample would be an excellent candidate for cathodoluminescence study.
I consulted AAPG Memoir #27, "Carbonate Rock constituents, Cements, and Porosities" for information on cement mineralogy & textures.

SPC00534016 — This sample was taken for the purposes of comparison with fault rock breccias. This sample was convincing as a cemented surficial deposit in Split Wash on the north side of the wash where the dirt road bifurcates. There are no fault breccias indicated on the map at this spot.

This sample looks distinctively different from all others I took. The matrix/cement in this breccia is milky white with varying degrees (patchy) of translucence. Rock fragments float within and are supported by a micro-crystalline matrix/cement, perhaps (probably) calcite. Many odd inclusions in the matrix. These have a tabular appearance and are filled with other minerals. Are these moot casts? Bladed crystals fringe wall rock clasts. These crystals are uniaxial(+) and have the same relief as quartz. Note that most of the fibers in this thin section are sub parallel. This alignment is found on both sides of the clasts in contrast to pendent cements.

SPC00534007D - Thrust fault breccia on Diabolous Ridge
This rock has a spatial variation in degree of mineralization of the breccia. In some places the matrix is poikilotopic & in others the wall rock clasts appear to have been crushed to form a fine grained matrix (cataclasite).



8/12/98 - continued

SPC00534009A & C
Poikilotopic texture is very impressive in this specimen collected from the Diabolous Ridge thrust fault. The cement is cryptocrystalline & full of tiny inclusions. Large patches of this (probably calcite) cement go extinct at once.

SPC00534008 -
This sample contains abundant opal. It fluoresces green under short wave UV light. The opal has a ribbon like texture and coats the wall rock clasts.

SPC 00534011 - This rock was collected on a walking traverse from Dune Wash to the South Portal from West to East. When we sampled it, we suspected that this was cemented surficial materials, rather than a fault breccia, as indicated by the ▲ on the map at this spot. The rock fluoresces under UV light. It fluoresces green. The mineral is probably opal. It has a botryoidal, ribbony texture and coats the perimeter of wall rock clasts. This stage of mineralization is the first in a series of distinctive mineralization episodes/species. It has a very clean, translucent appearance in plain light (v. few impurities/inclusions). This stage of mineralization is followed by infilling by two substages of fibrous mineralization. These crystal fibers grew perpendicular to the perimeter of the first stage of growth (opal?). The first increment of fibrous crystal growth is distinct from the later stage because it has a lot of inclusions/impurities giving it a "dirty" appearance. The second stage of fibrous mineral growth is very "clean", relatively free of inclusions and impurities. The fibers are probably chalcedony in both cases.

8/12/98 continued

SPC00534023 – this oriented sample was collected at Station ~~67+85.20~~ in the ESF at Yucca Mtn. This section does not contain obvious large quantities of calcite or silicate minerals. The fault rock has a cataclastic texture. Coherent tuff fragments are angular to sub angular and are rotated such that the eutaxitic structure within is aligned differently in each clast. The clasts are supported by a fine-grained glassy matrix. Some primary void spaces have some vapor phase minerals w/in.

STA 62+08.5
MBG 11/30/00

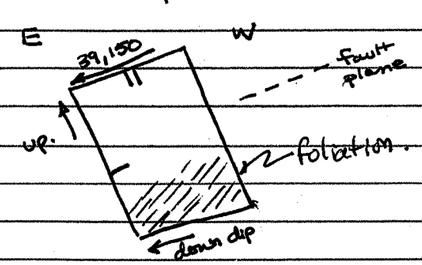
MBG

Mary Beth Gray

8/13/98 Microstructural/microtextural ANALYSES.

SPC00534007C – Thrust fault breccia at Diabolous Ridge
Opal is most abundant on the face of the chip farthest from the top of the fault breccia, perhaps indicating that the opal is a pendant cement. This breccia has a micritic (cryptocrystalline calcite?) matrix/cement which is most prominent on the underside of this fault breccia. Isolated bladed minerals with a quartz-like set of optical properties (probably chalcedony).

SPC00534007B – This specimen has a poorly developed foliation that lies at a low angle to the fault plane (~20°). Given the orientation of this specimen, the foliation should dip about 60° to the east. Note that this foliation is best developed on the lower half of the chip.






8/13/98 – continued

SPC00534009B – Diabolous Ridge thrust fault plane breccia sample. This specimen has a poikilotopic cement. The crystal size in the cement is too small to resolve optically but it has the character of calcite. This micritic cement is fractured and was subsequently recemented with coarse, sparry calcite.

Mary Beth Gray

2/19/99
On 2/12/99 and 2/13/99 I cut and vacuum impregnated several samples in preparation for making chips for thin section analysis. Today I continue this process by cutting chips from impregnated samples. The samples were impregnated with Petropoxy 154 manufactured by Palouse Petropoxy Products. Samples were cured at 135°C for several hours to make sure they were properly cured.

AFTER CUTTING THE CHIPS, THE CHIPS WERE DRIED IN AN OVEN FOR SEVERAL HOURS @ 140°C. Some of the chips were poorly impregnated, especially the Solitario Canyon fault chips. I believe they didn't impregnate easily because of their fine grained texture.

Mary Beth Gray

2/22/99
I fully labeled the dried chips and found that many of them had such poor, rough surfaces, that another round of epoxying was called for. I slathered the cut surface of the chips with more petropoxy and placed them in an oven to cure

2/22/99 continued

| chips | ORIENTATION | SIZE |
|---|---|---|
| SPC00534020A | TRANSVERSE | LARGE |
| SPC00534020B | TRANSVERSE | LARGE |
| SPC00534020C | LONGITUDINAL | LARGE |
| SPC00530195A | unoriented | LARGE |
| SPC00530195B | unoriented | large |
| SPC00534025A (MBG 2/22) | Longitudinal | small |
| SPC00534025B | TRANSVERSE | large |
| SPC00543708A | TRANSVERSE | LARGE |
| SPC00534018A | UNORIENTED | SMALL |
| SPC00534018B | UNORIENTED | SMALL |
| SPC00543706A | TRANSVERSE | LARGE |
| SPC00543706B | TRANSVERSE | LARGE |
| SPC00543707A | TRANSVERSE | LARGE |
| SPC00543707B | TRANSVERSE | LARGE |
| SPC00543707C | TRANSVERSE | SMALL |
| SPC00534024A | transverse | small |
| SPC00534024B | TRANSVERSE | small |
| SPC00534024C | LONGITUDINAL | large |
| SPC00534019A | TRANSVERSE | SMALL |
| SPC00534019B | TRANSVERSE | SMALL |
| SPC00534019C | LONGITUDINAL | SMALL |
| SPC00534007E | TRANSVERSE | SMALL |
| SPC00534007F | LONGITUDINAL | SMALL |
| SPC00534001A | TRANSVERSE | SMALL |
| SPC00534000A | TRANSVERSE | SMALL |
| SPC00534000B | LONGITUDINAL | SMALL |
| SPC00534000C | LONGITUDINAL | SMALL |
| SPC00530198F | LONGITUDINAL | SMALL |
| SPC00530198G | TRANSVERSE | SMALL |
| SPC00530194A | LONGITUDINAL | SMALL |
| SPC00530194B | LONGITUDINAL | SMALL |
| SPC00530194C | TRANSVERSE | SMALL |
| SPC00530194D | TRANSVERSE | SMALL |

Mary Beth Gray



Scientific Notebook 261 April 1, 1999

Entry: Mary Beth Gray
Project: 20-1604-471 Structural Deformation and Seismicity (SDS)
Experiment: X-ray Diffraction analyses of Solitario Canyon Fault Gouge
Purpose: Determination of clay mineralogy in Solitairo Canyon Fault gouge

Mary Beth Gray

This entry constitutes documentation of a clay mineralogy investigation on Solitario Canyon Fault gouge specimen SPC00543707 collected at ECRB Station 25+85.1. Brad Jordan and Mary Beth Gray, Bucknell University performed analyses on Feb 26, 1999.

**Instrument and Maintenance Specifics:**

Sample analyses were performed on a Philips Automated Powder Diffractometer, housed in a climate and humidity controlled room and maintained by the Department of Geology at Bucknell University. The diffractometer is supported by an XRG - 3000 generator, an APD - 3720 computer control cabinet, a PW 1710 diffractometer control unit and a copper long fine focus tube. An IBM Pentium PC is interfaced with the diffractometer and has two Philips software support packages: PC APD, ver. 3.6 (control software) and PC identify, ver. 1.0f (search-match software). The diffractometer undergoes semiannual maintenance inspections performed by Philips technicians under a service contract with the Department of Geology at Bucknell University. The calibration of the X-ray diffractometer is checked frequently by the Director of Laboratories in the Geology Department, Brad Jordan. A 400-mesh quartz standard sample mounted on a low-background holder is used as a control. If the standard produces a diffraction pattern that deviates from the expected pattern, the machine is recalibrated. The calibration of the machine was checked in this way immediately before the Solitario Canyon Fault samples were analyzed. The x-ray diffractometer required no adjustment.

Mary Beth Gray

APRIL 1, 1999 continued.

**Analytical Procedures**

Three different analyses were performed on sample remnants. X-ray diffraction patterns were generated from one random powder mount and two oriented powder mounts. Both oriented powder mounts were air-dried and one was further vapor glycolated.

Procedure for sample preparation of **random powder mount**:

1. Sample fragment was crushed and dry sieved.

2. The fraction that passed thought the 400 mesh sieve was placed inside a back holding loader and inserted into the x-ray diffractometer to be analyzed. Results are shown on x-ray diffraction pattern 543707B.RD. Vertical line on x-ray diffraction pattern marks the 14.42 angstrom peak indicative of some clays.

Procedure for sample preparation of **oriented powder mounts**:

1. The fraction that did not pass through the 400 mesh sieve was crushed and dry sieved.

2. Approximately 0.25 of the fraction that passed through the 400 mesh was then extracted and placed in a clean beaker with 200 ml. of distilled water.

3. Approximately 0.25 g. of sodium hexametaphosphate was added to the suspension.

4. The beaker containing the mixture was then placed in an ultrasonic bath at room temperature for approximately 10 minutes.

5. The mixture was poured into a 1000 ml graduated cylinder.

6. Distilled water was added to the mixture until the total volume of the mixture was raised to 1000ml.

7. The mixture was then stirred.

8. The mixture was then left undisturbed for 3 hours and 50 minutes.

MBG



APRIL 1, 1999 continued

9. A pipette was used to draw off the uppermost 5 cm of the mixture. The extracted suspension should have contained suspended particles of 2 micron diameter or less.

10. 3 oriented powder mounts were prepared using the Millipore® Filter Transfer Method detailed in Moore and Reynolds (1989).

Procedure for **air-drying** of two oriented powder mounts:

1. The oriented powder mounts were allowed to air dry at room temperature. As this occurred, the mount was observed to curl at the edges. The result is x-ray diffraction pattern 5437070.DI.
A broad peak (probably the result of curling) corresponds to a 14.42 angstrom peak.

Procedure for **glycolating** oriented powder mount:

1. One oriented powder mount was exposed to ethylene glycol vapors at 60°C for 4 hrs. in a closed container.

2. The powder mount was extracted and immediately placed in the x-ray diffractometer and analyzed. The mount did not curl. The resulting x-ray diffraction pattern was labeled 543707G.DI. A peak at 16.6 angstroms indicates a shift characteristic of smectites (Starkey and others, 1985).[4] MBG

REFERENCES:

MOORE, D.M., AND REYNOLDS, R.C., 1989, X-ray diffraction and the identification and analysis of clay minerals, ~~USGS~~ MBG ~~Bulletin~~ MBG Oxford University Press, Oxford 332p.

STARKEY, H.C., BLACKMON, P.D., Hauff, P.L., 1984, The routine mineralogical analysis of clay-bearing samples. USGS Bulletin B 1563, 32 p.

MBG

Scientific Notebook 261 June 29, 1999

Entry: Mary Beth Gray
Project: 20-1604-471 Structural Deformation and Seismicity (SDS)
Experiment: Documentation of samples and sample markings shipped to Mark Evans, University of Pittsburgh
Purpose: U-stage analyses of mechanical twins

Mary Beth Gray

Four thin sections and four oriented rock chips from which they were produced were shipped to Mark Evans on June 29, 1999. These oriented thin sections and chips are from two different fault localities at Yucca Mountain. Details are found below:

**SPC00530198**: This sample was gathered from within the Exploratory Studies Facility (ESF) main drift STA 43+39. The fault strikes AZ 160 and dips 84 to the southwest. This fault had sub-horizontal slickenlines and associated fracture arrays that appeared to suggest right lateral strike-slip.

**SPC00534007**: This sample was collected from the surface of Yucca Mountain at an exposure of the Diabolous Ridge thrust fault, a rare minor contractional feature at Yucca Mountain. The thrust fault where I sampled it, dips toward AZ 150 at a dip angle of 39 degrees. The fault rock has fine grained calcite within which it may be possible to see mechanical twins. I don't see much at the moment but perhaps after more polishing and a cover slip is added, he may be able to see some and work with this sample. Please note that since this is a sample from the surface, there may be features within this sample that reflect surface weathering processes.

**Sample markings**:

Each chip is marked with at least one strike and dip symbol indicating the orientation of the fault plane. Note that each strike and dip symbol has an arrow at only one end of the strike line. The arrow denotes the northern end of the strike line. This is the method I use to uniquely orient hand samples and thin section chips. Each sample was cut in two perpendicular directions. One cut (which I call "longitudinal") is perpendicular to the fault plane and parallel to the strike of the fault. The other (which I call "transverse"), is cut perpendicular to the fault plane and parallel to the dip direction of the fault. Thin sections SPC00530198F

MBG



June 29, 1999 continued

and SPC00534007F are from longitudinal cuts. SPC00530198G and SPC00534007E are from transverse cuts.

I denote the upper surface (structural top, in this case the upper surface of the fault rock) of the thin section with two, approximately 1 mm length nicks (created by a saw blade). On thin sections cut longitudinally, one nick is cut into the northern end of the chip (on the northern end of the strike line). On thin sections that are cut transversely, one nick is cut into the down dip direction of the fault rock (on the down dip end of the dip symbol).

I think that thin sections from SPC00530198 will be ideal for twin strain analysis. I'm not sure that the other specimen will be usable. I enclosed the oriented chips in case Mark needed to make additional thin sections.

Mary Beth Gray

July 30, 1999

I cut some chips from some samples. These chips are listed below. Orientations of cut planes and sizes of thin sections are noted. These thin sections were mounted using Hillquist A/B Epoxy cured at 100°C for 12 hours.

| BOREHOLE | SMF SPECIMEN ID | CUT PLANE | THIN SECTION SIZE |
|---|---|---|---|
| USW G-2 | #02016214 | cut parallel to core axis | 5.0 x 7.5 cm |
| USW VH-2 | #02016211A | CUT PARALLEL TO CORE AXIS | 5.0 x 7.5 cm |
| USW VH-2 | #02016211B | CUT PARALLEL TO CORE AXIS | 5.0 x 7.5 cm |
| USW VH-2 | #02016210 | CUT NORMAL TO CORE AXIS | 5.0 x 7.5 cm |
| USW G-1 | #02016202 | CUT NORMAL TO CORE AXIS | 5.0 x 7.5 cm |
| ESF | SPC00543701A | cut normal to fault, normal to B | 2.6 x 4.6 cm |
| ESF | SPC00543701B | cut normal to fault, NORMAL to A | 2.6 x 4.6 cm |
| ESF | SPC00543701C | cut normal to fault | 5.0 x 7.5 cm |
| ESF | SPC00543701D | | |
| CRATER FLAT | TLS4-9A | cut in a vertical plane in azimuth of plunge of core | 5.0 x 7.5 cm |
| CRATER FLAT | TLS4-9B | cut in a vertical plane in azimuth of plunge of core | 5.0 x 7.5 cm |

MBG

sent to Mark Evans on 7/31/99 MBG

JULY 30, 1999

CRATER FLAT TLS5-16A1 CUT IN A VERTICAL PLANE, PARALLEL TO PLUNGE DIR. 2.6x4.6
CRATER FLAT TLS5-16A2 CUT IN A VERTICAL PLANE, PARALLEL TO PLUNGE DIR. 2.6x4.6
CRATER FLAT TLS5-15A CUT IN A VERTICAL PLANE PARALLEL TO PLUNGE DIR 5.0x7.5
CRATER FLAT TLS5-15B CUT IN A VERTICAL PLANE PARALLEL TO PLUNGE DIR 5.0x7.5

MBG

JULY 31, 1999

Some samples required vacuum impregnation before cutting was possible. I used STRUERS "EPOFIX" Epoxy for the following samples*. THIS epoxy cures at room temperature and is low viscosity, suitable for vacuum impregnation. I allowed one week for the epoxy to cure

| Borehole | SMF SPECIMEN ID | CUT PLANE | THIN SECTION SIZE |
|---|---|---|---|
| USW VH-2 | #02016206* | cut ∥ the core axis | Large |
| USW VH-2 | #02016205* | Cut ∥ the core axis | Large |
| USW G-1 | #02016198 | Cut ∥ the core axis | Large |
| USW G-1 | #02016200A | cut ∥ the core axis | Small |
| USW G-1 | #02016200B | cut ∥ the core axis, ⊥ #02016200A | Small |
| USW G-1 | #02016201A | cut ∥ the core axis, directly below #02016201B | large |
| USW G-1 | #02016201B | cut ∥ the core axis | ~~Large~~ MBG SMALL |
| USW VH-2 | #02016204 | cut ∥ the core axis | large |
| USW VH-2 | #02016212A | cut ∥ the core axis, ⊥ #02016212B | large |
| USW VH-2 | #02016212B | cut ∥ the core axis | large |
| USW G-2 | #02016217 | CUT ∥ the core axis | Small |
| USW VH-2 | #02016209 | CUT ∥ the core axis | large |
| USW VH-2 | #02016208 | CUT ∥ the core axis | large |
| USW G-2 | #02016213A | CUT ∥ the core axis, ⊥ to #02016213B | SMALL |
| USW G-2 | #02016213B | CUT ∥ the core axis, ⊥ to #02016213A | SMALL |
| USW G-2 | #02016213C | CUT ∥ the core axis, ∥ to #02016213B | large |
| USW G-2 | #02016215 | CUT ∥ the core axis | large |

MBG



August 9, 1999

More trimming, cutting and polishing of ESF & Borehole samples.

| SMF SPECIMEN ID | CUT PLANE | SIZE OF THIN SECTION |
|---|---|---|
| SPC00552501A* | TRANSVERSE | SMALL |
| SPC00552501B* | TRANSVERSE | SMALL |
| SPC00552501C* | LONGITUDINAL | SMALL |
| SPC00552501D* | TRANSVERSE | SMALL |
| SPC00543704A* | ⊥ to SPC00543704B | LARGE |
| SPC00543704B* | | SMALL |
| SPC00552500A* | ⊥ fault, TRANSVERSE | LARGE |
| MBG ~~SPC00552500B*~~ | ~~⊥ fault, TRANSVERSE~~ | ~~LARGE~~ |
| SPC00543709A* | 78S 312 | SMALL |
| SPC00543709B* | 23N 072 | SMALL |
| SPC00543709C* | 78S 312 | SMALL |
| SPC00543709D* | 78S 312 | LARGE |
| SPC00552502AS* | TRANSVERSE, CONTAINS GOUGE | LARGE |
| SPC00552502BS* | TRANSVERSE, E of AS | LARGE |
| SPC00552502CS* | TRANSVERSE, E of BS | LARGE |
| SPC00552502E* | LONGITUDINAL, CONTAINS GOUGE | LARGE |
| SPC00552502F* | LONGITUDINAL, E of E | LARGE |
| ~~SPC00552502~~ MBG 8/9/99 | | |
| SPC00552502G* | LONGITUDINAL, E of F | LARGE |
| SPC00552502H* | LONGITUDINAL, E of G | LARGE |
| SPC00552503A* | ⊥ fault plane | LARGE |
| SPC00552503B* | ⊥ fault plane | LARGE |

MBG

August 10, 1999

I vacuum impregnated the following samples using EPOFIX EPOXY:

#02016203
#02016216
#02016207
SPC00552506
SPC00552507

I continued to work with the chips recorded under entries dated 7/31/99 (p. 40) and 8/9/99 (p. 41). Chips were washed and oven dried after polishing. Oven temperatures did not exceed 40°C. Chips were mounted to glass slides using Hillquist AB epoxy. The epoxy was cured for 24 hours at temperatures that did not exceed 40°C.

MBB



August 12, 1999

I cut the following chips to be mounted on glass slides:

| | |
|---|---|
| large | SMF # 02016203 A cut ∥ core axis, ⊥ #02016203B |
| small | SMF # 02016203 B cut ⊥ core axis |
| large | SMF # 02016207 A cut ∥ core axis, ∥ #02016207B,C |
| large | SMF # 02016207 B cut ∥ core axis, cut sub ∥ dip dir. of foliation |
| large | SMF # 02016207 C cut ∥ core axis |
| LARGE | SMF # 02016216 cut ∥ core axis |
| | ~~SMF~~ MAG |
| LARGE | SPC00552506A, cut ⊥ SPC00552506B, TRANSVERSE |
| LARGE | SPC00552506B LONGITUDINAL |

Samples were not exposed to temperatures in excess of 40°C during drying in an oven.

MBB

August 13, 1999

Chips #02016203A and B and #02016216 were mounted to glass slides ~~an~~ MBG using Hillquist A/B epoxy and cured at 40°C. Other chips prepared on August 12 (#02016207A,B,C and SPC00552506A,B) required further epoxy before mounting. I used Hillquist A/B epoxy and cured them in an oven at 40°C.

Mary Beth Gray

MBG



Scientific Notebook 261 August 17, 1999

Entry: Mary Beth Gray
Project: 20-1604-471 Structural Deformation and Seismicity (SDS)
Experiment: Documentation of samples and sample markings shipped to Mark Evans, University of Pittsburgh
Purpose: U-stage analyses of mechanical twins

Mary Beth Gray

Six thin sections and seven oriented rock chips from which they were produced were sent to Mark A. Evans of University of Pittsburgh on August 17, 1999. I enclosed seven additional chips from five additional localities. All of the sections and chips were collected from Yucca Mountain, Nevada. One set of oriented thin sections and chips is from the Exploratory Studies Facility at Yucca Mountain and the other 2 sets are from the G-1 and G-2 drill cores. Note that core samples have a different code designation than ESF samples. ESF samples always use a code that begins with "SPC....." The core samples enclosed use a code that always begin with "#020....". Note that none of the chips or thin sections in this package were ever permitted to be exposed to temperatures in excess of 40° C <u>during sample preparation</u>. I cannot vouch for their conditions of retrieval or storage prior to my custody. The enclosed thin sections are relatively thick and will need to be thinned by Mark as needed. I have found that as I attempt to thin them the coarse calcite crystals begin to pluck off of the slide. Rather than risk more plucking, I sent them as is. Details are found below:

**Thin sections and rock chips:**

**SPC00552501**: This sample was gathered from within the Exploratory Studies Facility (ESF) cross drift (ECRB) at STA 25+85.5. It was collected from the hanging wall of the Solitario Canyon Fault, the fault that forms the western

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escarpment of Yucca Mountain. The fault zone is tens of meters wide, has a large dip separation and dip and strike slip slickenlines. This sample was gathered in a brecciated zone 0.4 m west of the foliated gouge in the fault core. The fault zone has a dip direction of AZ 291 and dips 65° at the location where I collected the sample. Although the sample is obviously indurated with secondary minerals, it was necessary to vacuum impregnate the sample before attempting to prepare thin section from it. I used Struer's Epofix epoxy for this purpose (refractive index $N_D$ = 1.571). I mounted the chips using Hillquist A/B epoxy. I enclosed two thin sections: SPC00552501A and SPC00552501C. SPC00552501A is a transverse thin section, cut sub-parallel to the dip direction of the fault and in a vertical plane. SPC00552501A is scribed with two parallel tick marks on the structural top and one tick mark on the down-dip end of the thin section. SPC00552501C is a longitudinal thin section, cut parallel to the strike of the fault and normal to the fault plane. SPC00552501C is scribed with two marks on the structural top of the section and one tick mark on the north end of the section. I sent the chips that correspond to the thin sections I mention above. Since they are very small, I also enclosed an additional chip, SPCOO552501D, which should be useful if mark needs to make additional sections in any orientation. FYI: I am in possession of two other oriented, small, thin sections SPC00552501B and SPC00552501D.

**#02016200:** This sample was gathered from core collected from a drill hole, USW G-1, located in Drill Hole Wash at the northern terminus of Yucca Mountain. This sample was derived from the interval at 3586-3587 ft. in an unnamed flow breccia below the Crater Flat Fm. Both #02016200A and B were cut in a plane that lies parallel to the core axis. I calculated that USW G-1 deviated 6° based on data in Spengler et al (1981). This implies that the planes of the sections are sub-vertical. The plane of A is normal to the cut plane of B. Both glass slides have arrows scribed on them. The arrows point in the direction of shallowing in the core.

**#02016213**: The sample was collected from core from the USW G-2 borehole at Mile High Mesa about 2 km north of USW G-1. The sample interval is 1248.5-1248.7, within an unnamed-bedded tuff directly below the Tram Unit in the Crater Flat Tuff. This bedded tuff has brecciated (autoclastic) horizons. Without the benefit of larger context, it is difficult to tell whether the breccia I sampled is





"primary" or fault related. Thin section examination should resolve this issue. Both #02016213A and B were cut in a plane that lies parallel to the core axis. USW G-2 had a maximum drift of 5° (Maldonado and Koether, 1983), therefore the cut planes should be subvertical. The plane of A is normal to the cut plane of B. Both glass slides have arrows scribed on them. The arrows point in the direction of shallowing in the core.

**Other rock chips:**

I enclosed several rock chips from cores that yielded potentially suitable calcite. I made large (5.0 X 7.5 cm) thin sections from these chips which are apparently not possible to use with universal stage apparatus. If any or all of these chips are suitable, mark is encouraged to make thin sections from them for U-stage analyses. Information on these chips is found below. Mark was encouraged to try to avoid duplicating thin section labels I've already used.

**#02016201A&B**: These chips are from USW G-1 at interval 3587.9-3588.2. B directly overlies A in the core. Red arrows point in the direction on shallowing of the core. Note that I have one thin section from both chips A and B in my collection (labeled "#02016201A and #02016201B").

**#02016210:** This chip is from USW VH-2 at 1854.5 – 1854.7. The black arrow points in the direction of shallowing. I have one thin section cut normal to the core axis in my collection ("#02016210A").

**#02016204**: This chip is from USW VH-2 at 1024.5-1024.8. The red arrow points in the direction of shallowing in the core. I have one thin section from this chip in my collection ("#02016204A").

**#02016211 A&B**: These chips are from USW VH-2 at 1912.0-1911.8. Black arrows point in direction of shallowing. I have one thin section from each chip in my collection (they are labeled "#02016211A and #02016211B").

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**#02016205**: This chip is from USW VH-2 at 1168.3-1168.6. It has been vacuum impregnated with Struer's Epofix epoxy. Direction of shallowing is unknown. Cut plane is parallel to core axis. I have one thin section from this chip in my collection ("02016205A").

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**References:**


Maldonado , F., and Koether, S.L., 1983, Stratigraphy, structure,and some petrographic features of Tertiary volcanics rocks at the USW G-2 drill hole, Yucca Mountain, Nye County, Nevada. USGS OFR-83-732.

Spengler, R.W., Byers, F.M., Warner, J.B., 1981, Stratigraphy and structure of volcanic rocks in Drill Hole USW G-1, Yucca Mountain, Nye County, Nevada. USGS OFR-81-1349.


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Sample Management Facility samples I have used to make thin sections and polished chips.

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CSITS v.1

## SMF Specimen Custody Receipt

Requestor:
John Stamatakos
Southwest Research Institute
6220 Culebra Rd
San Antonio , TX 78238-0000

Ship To:
John Stamatakos
Southwest Research Institute
6220 Culebra Rd.
San Antonio, TX 78238-0000

Date Received: _____
Shipment ID: 01000302 Shipping Date: 09-jun-1999
SMF Geotechnician [signature] Date 6/18/99

Container ID: 01002444

Specimens in this container: 18

| Specimen ID | Type | Top | Bottom | Parent Borehole: |
|---|---|---|---|---|
| 02016198 | WCSpec | 942.8 | 942.9 | USW G-1 |
| 02016199 | Frag | 3557.8 | 3558.0 | USW G-1 |
| 02016202 | Frag | 3620.2 | 3620.5 | USW G-1 |
| 02016203 | Frag | 5338.7 | 5338.9 | USW G-1 |
| 02016213 | Frag | 1248.5 | 1248.7 | USW G-2 |
| 02016214 | Frag | 2805.3 | 2805.8 | USW G-2 |
| 02016215 | Frag | 2818.6 | 2818.8 | USW G-2 |
| 02016216 | Frag | 4890.0 | 4890.2 | USW G-2 |
| 02016217 | Frag | 4896.4 | 4896.6 | USW G-2 |
| 02016204 | WCSpec | 1024.5 | 1024.8 | USW VH-2 |
| 02016205 | WCSpec | 1168.3 | 1168.6 | USW VH-2 |
| 02016206 | WCSpec | 1179.3 | 1179.6 | USW VH-2 |
| 02016207 | WCSpec | 1180.6 | 1180.7 | USW VH-2 |
| 02016208 | WCSpec | 1182.1 | 1182.3 | USW VH-2 |
| 02016209 | WCSpec | 1192.0 | 1192.1 | USW VH-2 |
| 02016210 | WCSpec | 1854.5 | 1854.7 | USW VH-2 |
| 02016211 | WCSpec | 1911.8 | 1912.0 | USW VH-2 |
| 02016212 | WCSpec | 1951.5 | 1951.5 | USW VH-2 |

I hereby acknowledge the receipt of the Specimens listed above. I will return this form to the SMF within 10 business days of receipt.

Recipient _____ Date _____

Please Sign this form and return to:
Sample Management Facility
Yucca Mountain Site Characterization Project
P.O. Box 617
Mercury, NV 89023-0617

Page 1 of 2: 2 Containers shipped.

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CSITS v.1

## SMF Specimen Custody Receipt

Date Received: _____

Shipment ID: 01000302 Shipping Date: 09-jun-1999

SMF Geotechnician [signature] Date 6/9/99

| Requestor: | Ship To: |
|---|---|
| John Stamatakos<br>Southwest Research Institute<br>6220 Culebra Rd<br>San Antonio , TX 78238-0000 | John Stamatakos<br>Southwest Research Institute<br>6220 Culebra Rd.<br>San Antonio, TX 78238-0000 |

Container ID: 01002445

Specimens in this container: 2

| Specimen ID | Type | Top | Bottom | Parent Borehole: |
|---|---|---|---|---|
| 02016200 | Frag | 3586.3 | 3587.5 | USW G-1 |
| 02016201 | Frag | 3587.9 | 3588.2 | USW G-1 |

I hereby acknowledge the receipt of the Specimens listed above.
I will return this form to the SMF within 10 business days of receipt.

Recipient _____ Date _____

Please Sign this form and return to:
Sample Management Facility
Yucca Mountain Site Characterization Project
P.O. Box 617
Mercury, NV 89023-0617

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Thin section description:

~~SPC00530198:~~ MBG 8/20/99

SPC00530196: This sample was gathered from the Ghost Dance fault breccia in Alcove 6. This specimen exhibits a cataclastic texture with little to no evidence of secondary mineralization. Eutaxitic foliation is prominent and well preserved in some clasts. Clast shapes are widely variable. Some are fairly equant and rounded (well preserved eutaxitic foliation with the clast). Others are elongate and highly angular. The direction of elongation of the clast does not correspond with the direction of the eutaxitic foliation. In fact, there appears to be a sub-perpendicular relationship between the long dimension of the elongate clasts and the eutaxitic foliation. This angular relationship may be suggestive of the initial fracture orientation in intact rock. Some clasts appear to be composed of cataclasite. This suggests that this fault breccia has undergone at least two cycles of brecciation followed by hardening / healing. Eutaxitic foliation is randomly distributed through the breccia — no preferred orientation is apparent. This implies significant rigid body grain rotations of clasts. Boundaries between clasts vary in morphology. Some are straight and very discrete, others are more irregular / sinuous but nonetheless, discrete. This thin section is best viewed in plane-polarized light due to the lack of secondary minerals and abundance of glass shards in this lithology. Since the clast boundaries are discontinuities across which abrupt changes in lithology and/or foliation orientation occur, I interpret these boundaries to be predominantly sliding surfaces or microfaults.

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SPC00530198E – This fault breccia contains abundant, large crystals of calcite. These crystals are well twinned, some twins are mechanical and appear to be "thick". Clasts are suspended within large crystals (diameter >2mm) of calcite. Clasts contain cataxitic foliation in some cases. The foliation is randomly oriented. The calcite matrix is poikilotopic (several crystals go extinct together in discrete patches that envelope several wall rock clasts). This specimen exhibits evidence of multiple generations of calcite precipitation. The earliest stage is most voluminous, well twinned, contains small inclusions which give the crystals a "dirty" appearance. This generation of breccia & matrix is clearly cut by younger, less twinned calcite with few inclusions. The younger calcite occurs in partially filled veins. The calcite of both generations is poikilotopic. Poikilotopic cements are often associated with recrystallized cements. Wall rock clasts have irregular, angular shapes which in some cases can be matched precisely with the adjacent wall rock clast. This texture is a jig-saw or puzzle-peise texture.

SPC00530198F – The photomicrograph taped to page 53 of this notebook was taken in plane-polarized light with a 2x objective. Field of view is 11mm in the long dimension. I digitized the percentage calcite in the field of view. It is 64.5% calcite. Note that this particular field of view shows only one generation of calcite, the early one.

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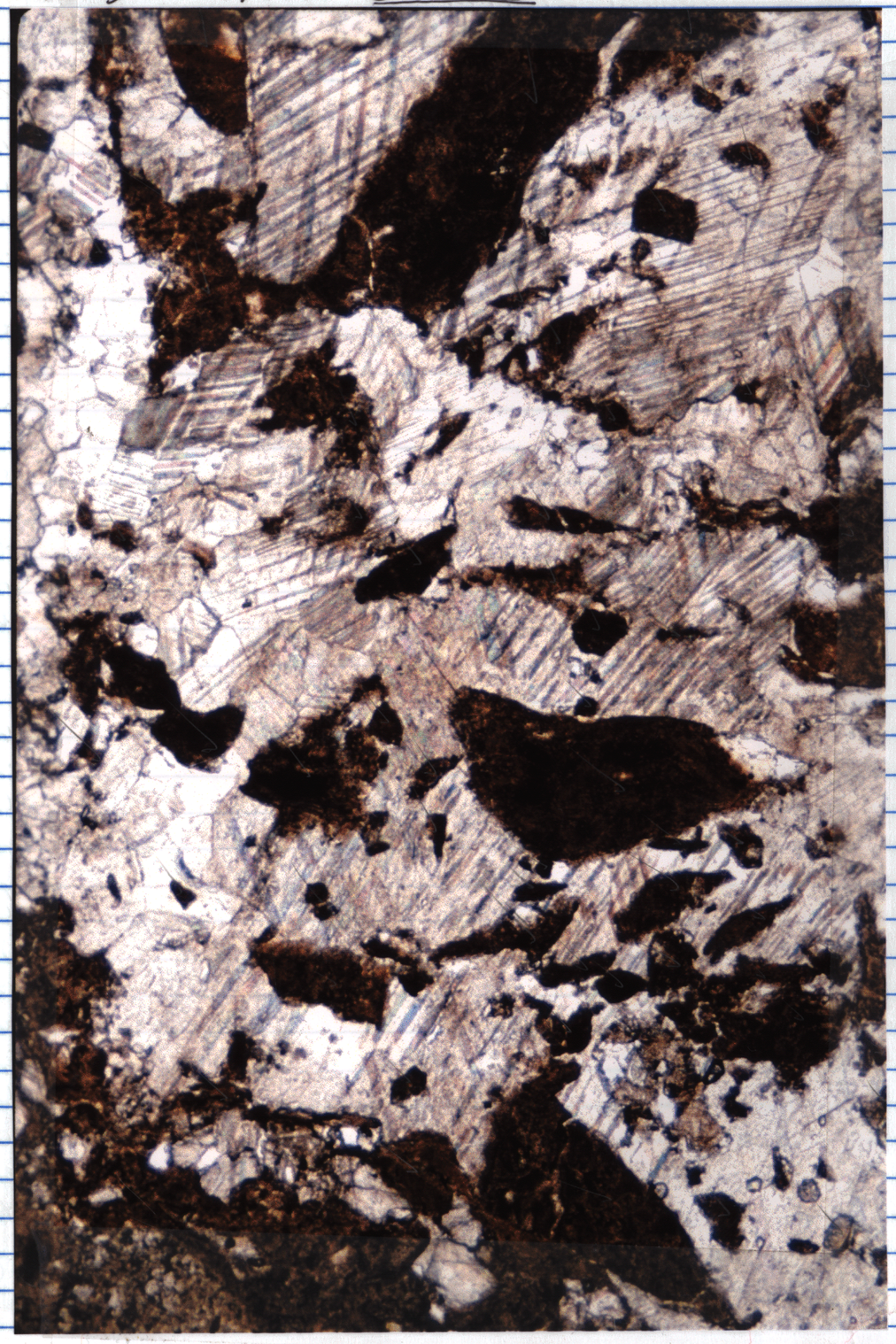

August 21, 1999

Thin section description –

SPC 00534017C – This specimen was collected from the south drift of the exploratory studies facility. It consists of a fault breccia with abundant calcite. The photomicrograph taped to page 55 of this book illustrates the general character of this fault breccia. The photo was taken with crossed polars, using a 2x objective and has an 11 mm field of view in the long dimension. I digitized the image to determine the % calcite. This image shows 65.4% calcite relative to wall rock clasts. This specimen clearly has a smaller average crystal diameter than SPC00530198F featured on page 53 of this book. Crystal sizes are fairly uniform and equant.

SPC 00543706A – This specimen was collected from the cross drift (ECRB) of the exploratory studies facility. It is gouge from the core of the Solitario Canyon Fault. It is an oriented thin section. The thin section clearly shows a composite foliation similar to S-C structure in mylonites. The foliation flows (wraps) around rare wall rock clasts. The gouge is predominately clay size particles, identified earlier as smectite (see page 35 of this book). The geometry of the composite foliation suggests a hanging wall down sense of shear for the Solitario Canyon Fault, consistent with the mapped normal stratigraphic separation of the fault.

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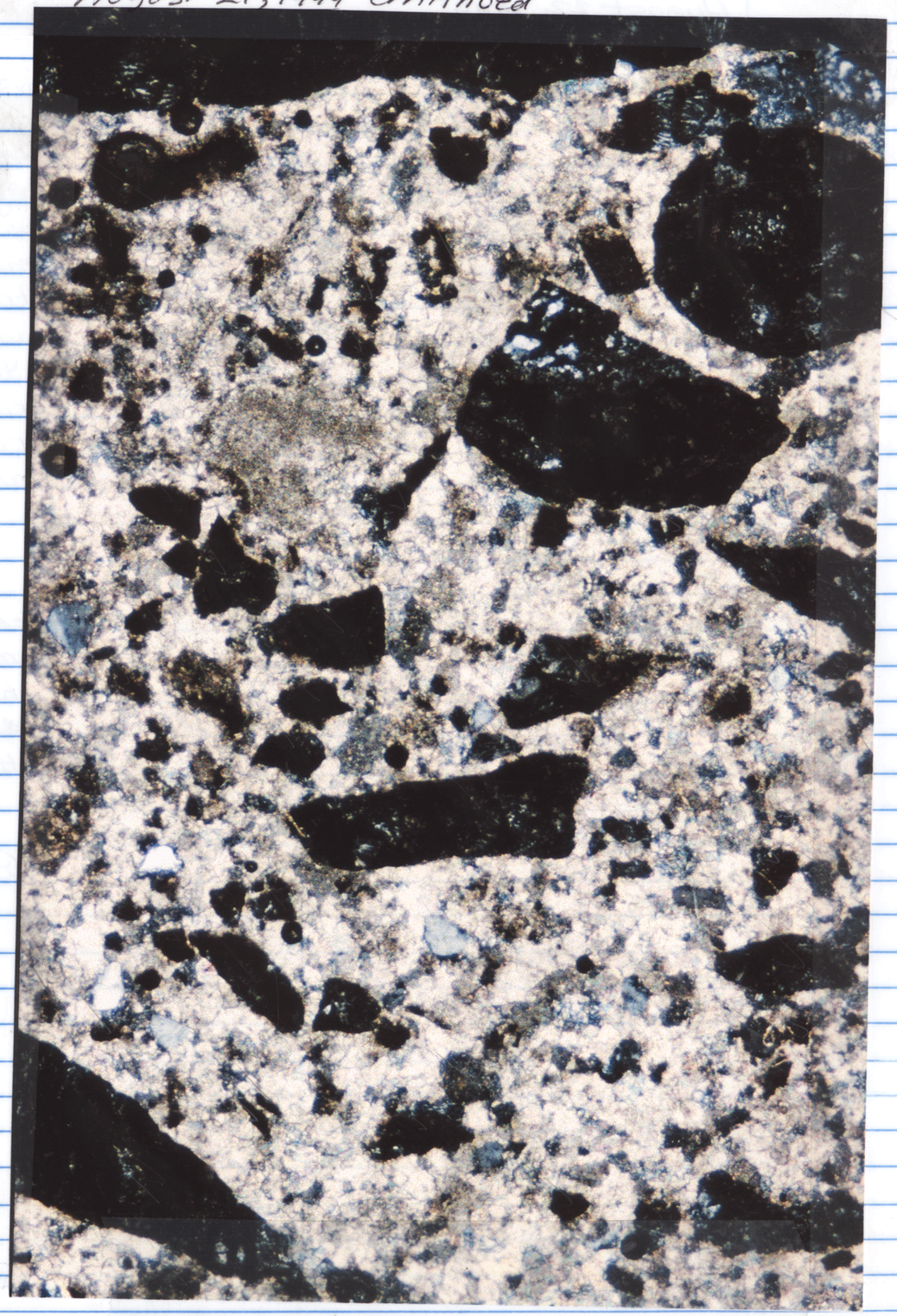
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