### Reservoir-Scale Controls on Fracture Orientation: Structural Position vs. Mechanical Variation\*

### Caroline M. Burberry<sup>1</sup>

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### **Abstract**

Characterizing fracture networks across a single field has been a consideration within the petroleum industry for decades but has become increasingly more important with the exploitation of unconventional plays such as tight sandstone and carbonate fields. Recent work has considered the importance of the mechanical stratigraphy in fracture network formation, and whether the present-day mechanical stratigraphy is an accurate predictor of the fracture stratigraphy or fracture network. A third question concerns the scale over which mechanical stratigraphy can influence the generation of fractures. This study considers fracture orientations in several positions across a single anticline, together with the mechanical and diagenetic history of the stratigraphic sequence. Measurements were taken on the crest of the anticline and on both the gently dipping backlimb and the more steeply dipping forelimb. At each location, bedding and fracture orientations, and lithology were recorded and unit hardness was measured with a rebound hammer. Samples were collected for thin section analysis of the diagenetic history. Results for the anticline limbs indicate that there are two characteristic patterns, one for each limb, which are not influenced by variation in hardness between individual beds. On the crest of the anticline, a third characteristic fracture pattern can be identified, with some variation between the patterns developed in dolomitic mudstone and the overlying tight sandstone. Again, individual beds within each lithology show variations in hardness with no change in fracture pattern. Thin-section analysis indicates late-stage (i.e. post fracturing) diagenetic changes to the units, which are expected to influence the present-day hardness. This data suggests that in a highly deformed area such as a fold-thrust belt, the structural position is the strongest control on the developing fracture pattern, followed by large-scale variations in lithology and diagenesis rather than bed-scale variations in hardness. In less deformed areas, smaller-scale mechanical variation may have a greater influence. In addition, those diagenetic processes occurring after major fracture development will also affect which fracture orientations can be used as fluidflow pathways.

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<sup>&</sup>lt;sup>1</sup>Department of Earth and Atmospheric Sciences, University of Nebraska-Lincoln, Lincoln, Nebraska, USA (cburberry2@unl.edu)

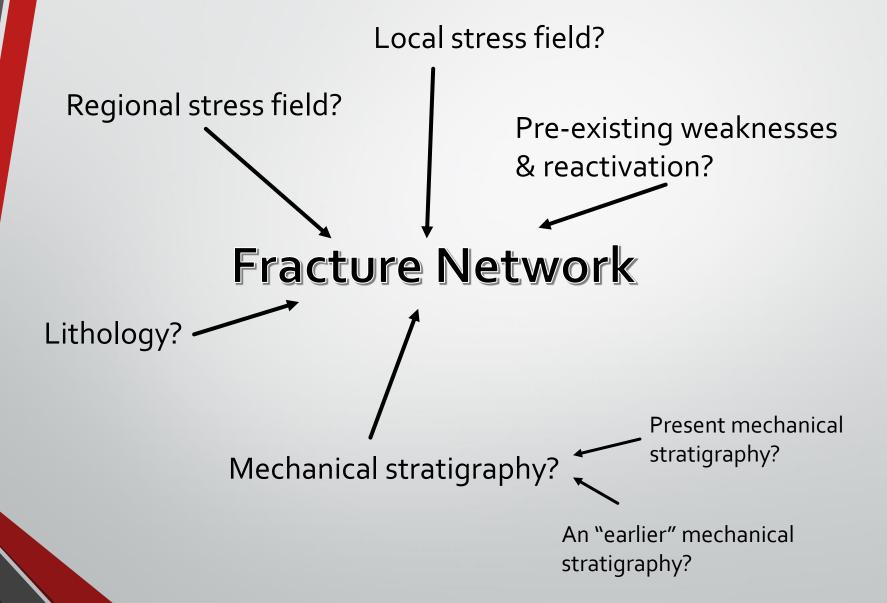


# Reservoir-scale controls on fracture orientation: structural position vs. mechanical variation

Caroline M. Burberry

University of Nebraska-Lincoln

### **RATIONALE**



# **RATIONALE**

Or, of course, some combination of all of the above,

... but with what relative importance?

... but on what scale? ... but in which situations?



This study sets out to investigate the relative importance of some of the influencing factors, in a field area where the Hmax history is known.

### **METHODS**

### Data/Analysis:

- lithological descriptions at outcrop
- hand samples for thin section microscopy (PPL/XPL & CL)
- fracture orientations, abutting relationships and fill characteristics
- photographs for fracture intensity analysis
- hardness values (as Proceq Q values) using a Schmidt hammer

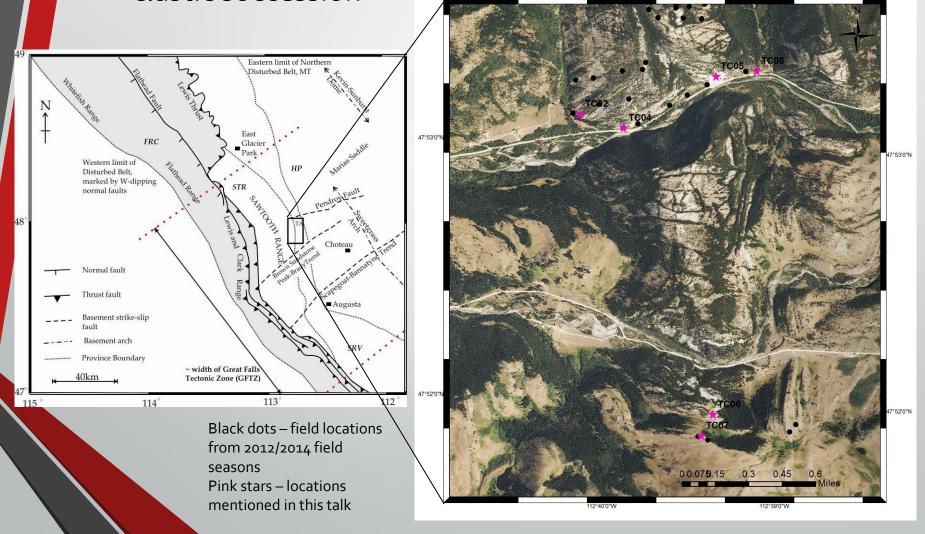


### **STUDY AREA - LOCATION**

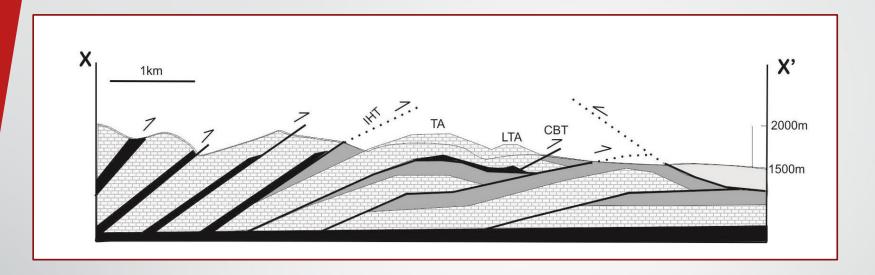
Sawtooth Range, MT, thin-skinned (Sevier) FTB

Teton Canyon area – Anticline in the Miss. carbonate/Jr

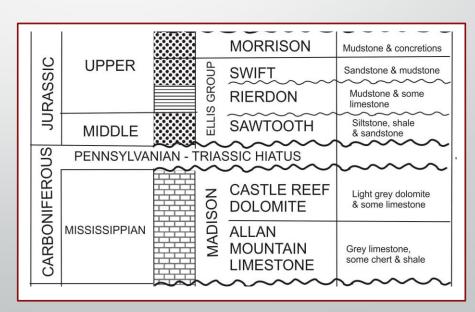
clastic succession



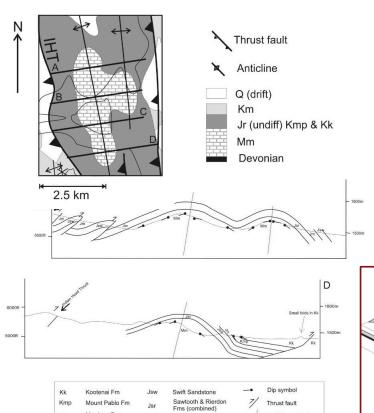
### STUDY AREA – BACKGROUND



- Regional deformation related to advancing thrust front from W
- Anticline forms close to the deformation front
- Miss. carbonates and Jr clastic units exposed in the study area

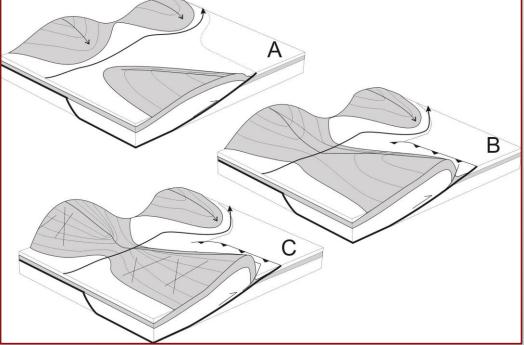


### STUDY AREA – BACKGROUND



 Associated changes in thrust sheet geometry

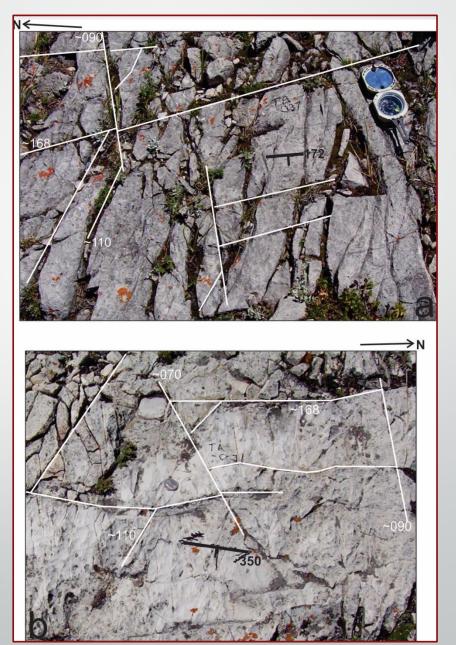
- Anticline geometry varies along strike
- Formation by along-strike linkage of two different structures, followed by tightening in the linkage zone



Work from Burberry et al., in prep.

### STUDY AREA – BACKGROUND

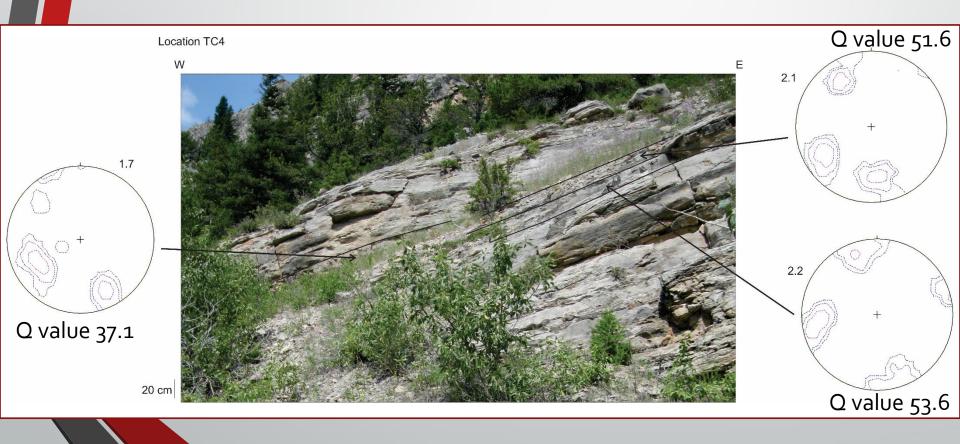
- Fracture sets
  - J1, orientation 090, earliest regional stress
  - J2, orientation 070, regional stress prior to anticline development
  - J<sub>3</sub>, orientation 168, parallels anticline hinge line
  - J<sub>4</sub>, orientation 110, "cross-fold" joints
  - Late wrench faults, reactivating earlier joint sets



Work from Burberry et al., in prep.

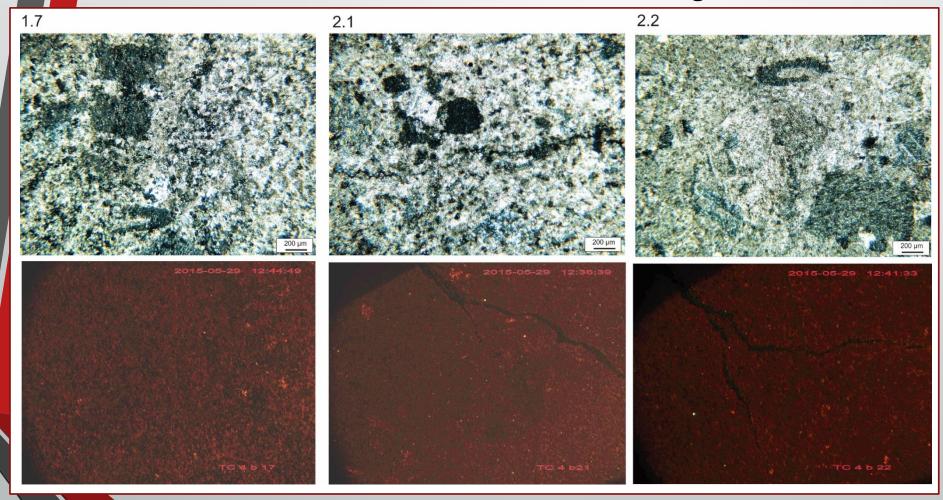
### **RESULTS – WEST-DIPPING LIMB**

- Location TC<sub>4</sub>, lithology Castle Reef Dolomite
- S<sub>o</sub> 165/19 W (average)
- Representative fracture sets & Q-values from 3 beds but is the apparent variation real?



### **RESULTS – WEST-DIPPING LIMB**

- All beds are pervasively dolomitized bioclastic wackestones
- CL indicates no marked differences in hi-Mg Calcite content

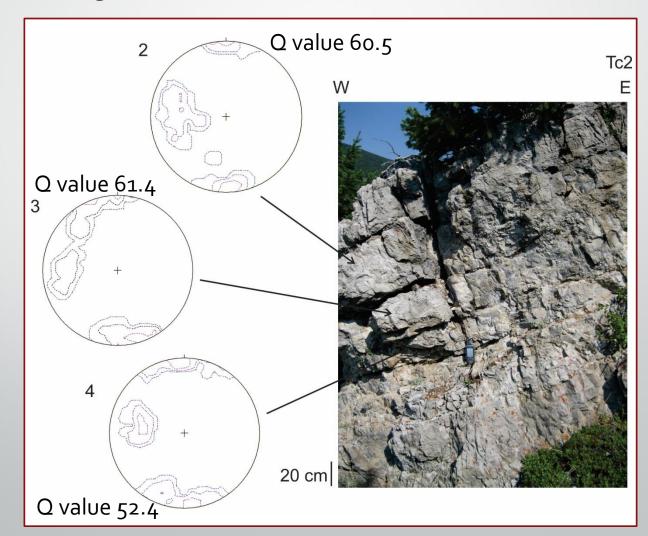


 Any variation in fracture orientation doesn't appear to be a result of lithologic change

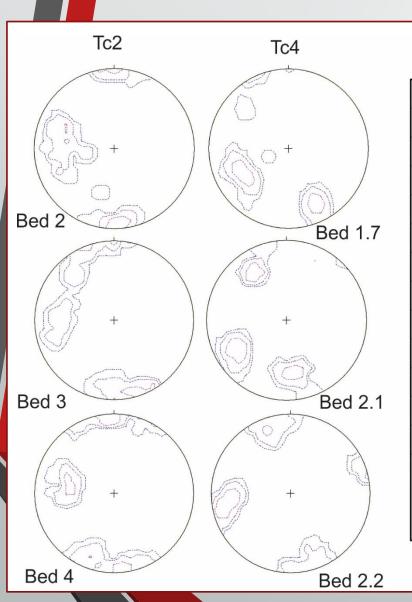
### **RESULTS – WEST-DIPPING LIMB**

- Comparing to Location TC2, lithology Castle Reef Dolomite,
   Sun River Member (a dolomicrite)
- S<sub>o</sub> 170/26 W (average) at TC2

Fracture
 intensity
 different, Q
 values a little
 higher, but
 fracture
 orientations
 similar



### **SUMMARY – WEST-DIPPING LIMB**



<b>WEST LIMB</b>						
Site	bed	Lith	Q	s	Mech	Frax
UNL14TC02	2	SRD	60.5	6.6		
	3	SRD	61.4	4.7	Α	
	4	SRD	52.4	4.6	В	Χ
UNL14TC04	1.7	CRD	37.1	13	С	
	2.1	CRD	51.6	6.9		
	2.2	CRD	53.6	5.2	В	Χ

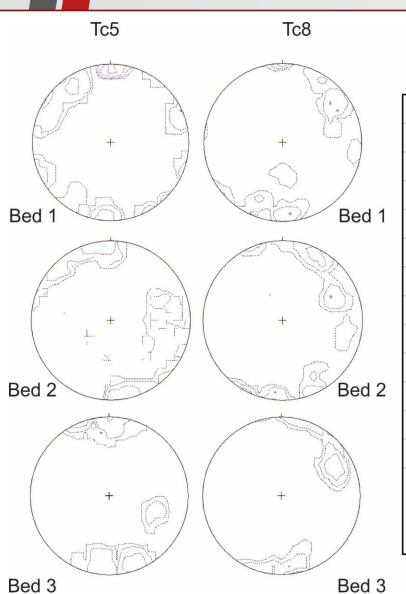
dataset contains 3 distinct units based on Q values, two different lithologies and essentially the same fracture pattern in all beds

### **RESULTS – EAST-DIPPING LIMB**

- Comparing to Location TC<sub>5</sub>, lithology Allan Mountain Limestone, a wackestone that has not been dolomitized
- S<sub>o</sub> 357/30 E (average)



### **SUMMARY – EAST-DIPPING LIMB**

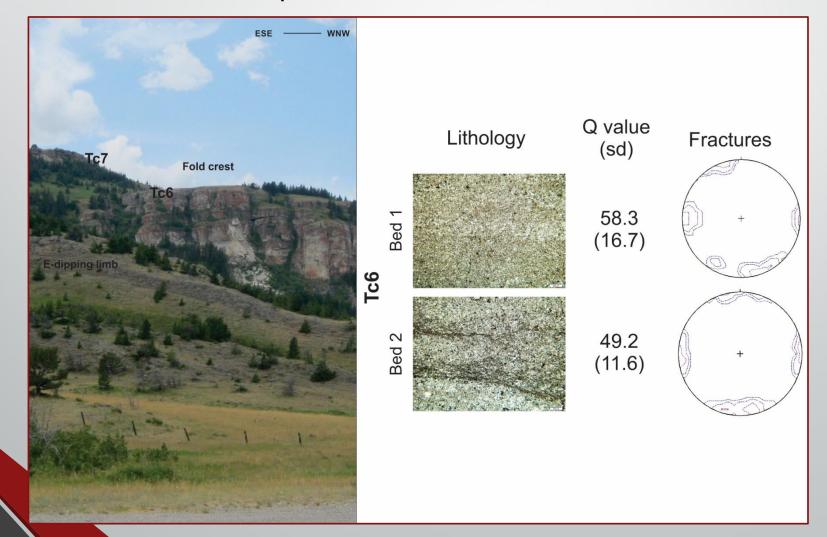


EAST LIMB						
Site	bed	Lith	Q	s	Mech	Frax
UNL14TC08	1	CRD	50.1	11.6		
	2	CRD	48.4	11.4	В	
	3	CRD	59.3	7.1	Α	Za
UNL14TC05	1	AML	68.8	2.7	D	
	2	AML	54.7	10.2		
	3	AML	49.3	10.9	В	Zb

dataset contains three distinct units based on Q values, two different carbonate lithologies and a very similar fracture pattern between the two sites

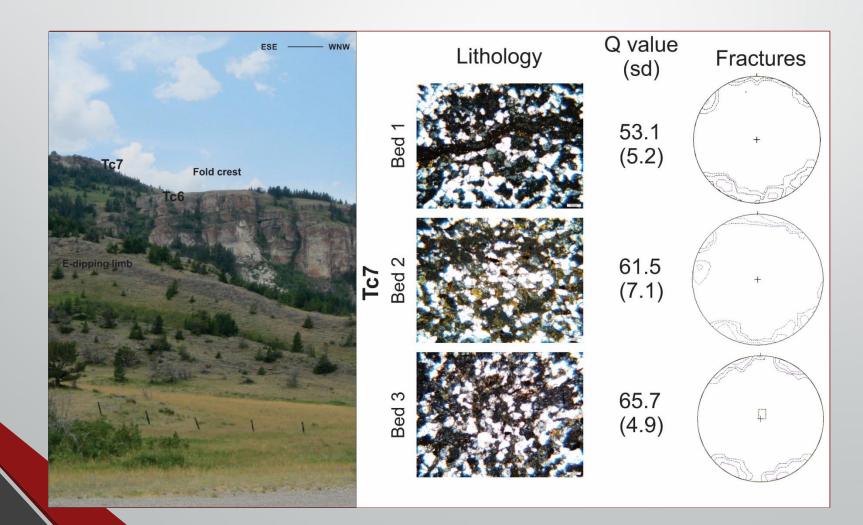
## **RESULTS – FOLD CREST**

- Comparing to Location TC6, lithology SRD, a dolomicrite with algal mats, beds approx. horizontal
- Different fracture pattern from limbs

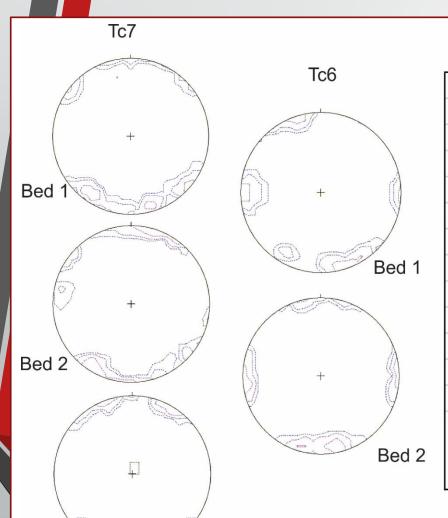


### **RESULTS – FOLD CREST**

- Comparing to Location TC7, lithology Swift Sst, part of the Jr succession, quartz sst with glauconite
- Different fracture pattern from TC6 and higher Q-values



# **SUMMARY – FOLD CREST**



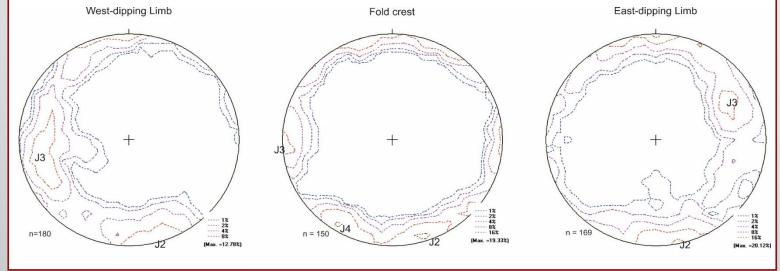
Bed 3

FOLD CREST						
Site	bed	Lith	Q	S	Mech	Frax
UNL14TC07	1	Sst	53.1	5.2	В	
	2	Sst	61.5	7.1	Α	
	3	Sst	65.7	4.9	D?	Ya
UNL14TC06	1	SRD	58.3	16.7	Α	
	2	SRD	49.2	11.6	В	Yb

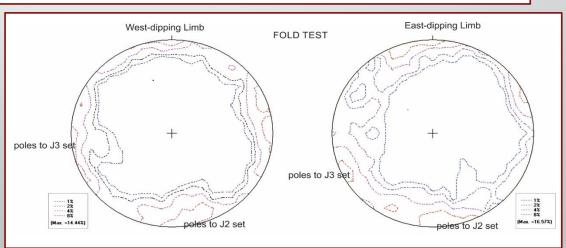
dataset contains two or three distinct units based on Q values, two very different lithologies and a fracture pattern that shows some variation with lithology

### **SUMMARY – FRACTURE ORIENTATIONS**

- 3 different fracture orientation patterns, controlled by structural position
- J2 is regional stress; J3 and J4 are fold-related



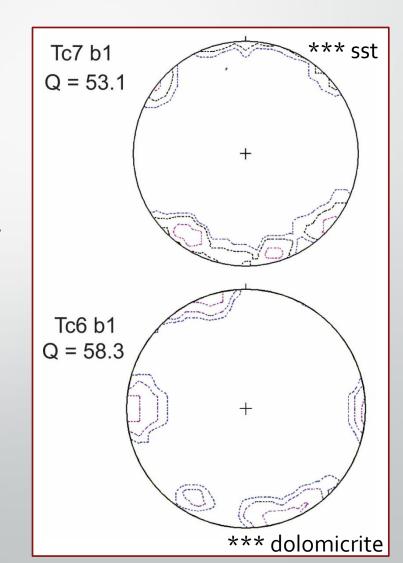
"fold test"
 confirms that
 fracture
 development
 post-dates
 folding



### **SUMMARY – MECHANICAL VARIATION?**

So what about the mechanical variation? Does this have an effect on fracture orientation or other characteristics?

- Mechanical variation (i.e. Q value variation) seems to be tied to lithological changes
- Some mechanical/lithologic variation is large enough to alter the fracture orientations – rotation of fracture set at the fold crest
- Also seems to affect fracture intensity, SRD more intensely fractured than CRD, for example.



## **CONCLUSIONS**

- Fracture orientations are primarily controlled by structural position, particularly in deformed zones such as the present study area
- 2. Subtle mechanical variations between different carbonate units affect fracture intensity, but not overall orientation

