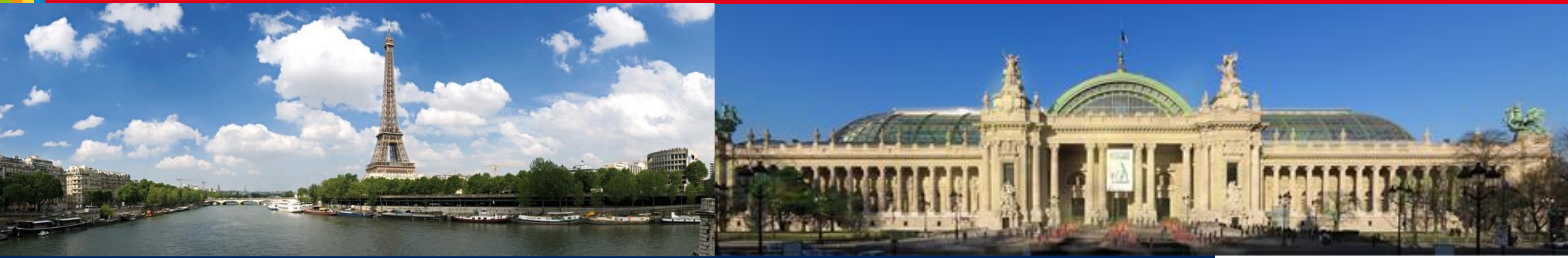
26th World Gas Conference

1 – 5 June 2015 – Paris, France



TS.WOC 1 1

A Study on Hydraulic Fracture Geometry using Macro-Scale Physical Simulation in Marine Shale

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China National Petroleum Corporation

WGCPARIS2015
WORLD GAS CONFERENCE

OUTLINE

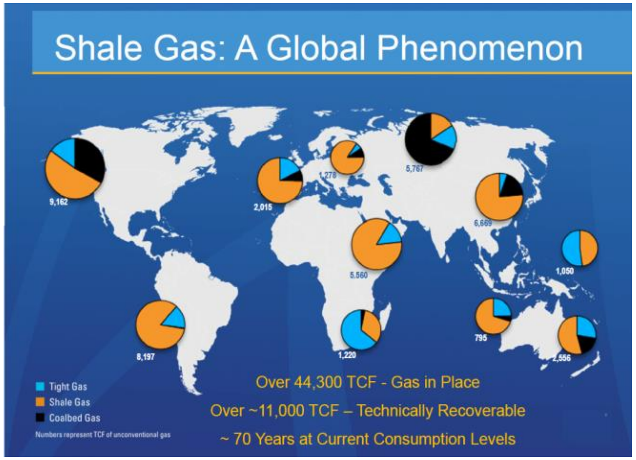
1 Background——Why?

2 Technology——How?

3 Results——what?

1.Background——

- **Opportunities in Shale Gas Industry**
  - ☐ **seismic technology**
  - ☐ **horizontal well drilling**
  - ☐ **multi-stage hydraulic fracturing**



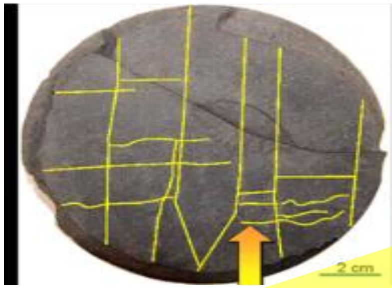
*EIA AEO 2011

- **Challenge in China Shale Gas Stimulation**
  - ☐ **More complex geological conditions**
  - ☐ **Fracturing mechanism unclear.**
  - ☐ **Fracturing design method immature.**

1.Background——

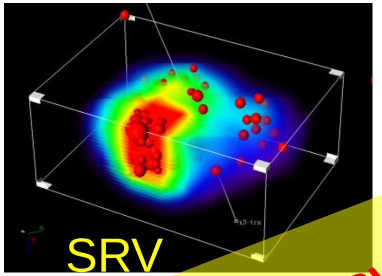
- **The Purpose of Physical Simulation**
  - ☐ **The effect of geological & pumping conditions on SRV**
  - ☐ **Trying to solve three key questions**

Large Shale Block



Which rock is suitable for volume stimulaton

Which fracturing process can create network



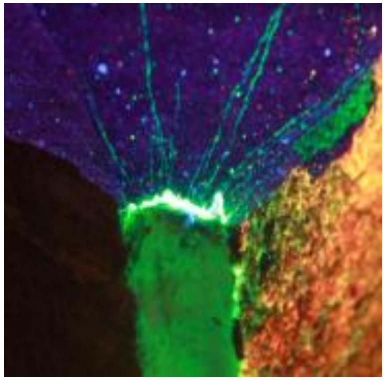
How to estimate SRV

1.Background——

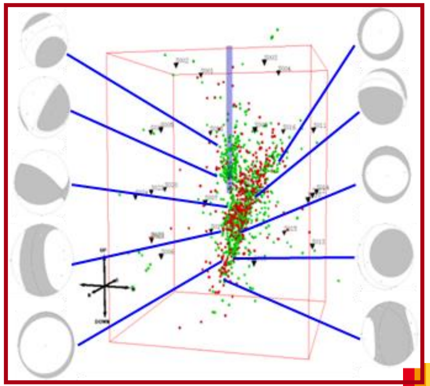
- **Physical simulation is an effective way**
- **Observe HF geometry**
  - ☐ **Single/Multiple/ fracture**
- **Test new fracturing process**
  - ☐ **Massive fracturing**
  - ☐ **Hybrid fracturing**
- **Modify acoustic location**
  - ☐ **Tensile/shear events**

sandstone

Linestone



Fibre fracturing



Acoustic monitoring

1.Background——

- **Large-scale test for hydraulic fracturing is useful.**

Research Institute	Sample Dimension	Injection Pressure	Post-evaluation Method
China University of Petroleumn	300mm	20MPa	Manual Splitting
Delft University of Technology	350mm	35MPa	Active Accoustic Monitoring
University of California,Berkely	450mm	60MPa	Manual Splitting
TerraTek Company	914mm	69MPa	Manual Splitting
CNPC	914mm	69MPa	Passive Acoustic Monitoring Real-time

DELFT

Terratek

OUTLINE

1 Background——Why?

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2.Technology——

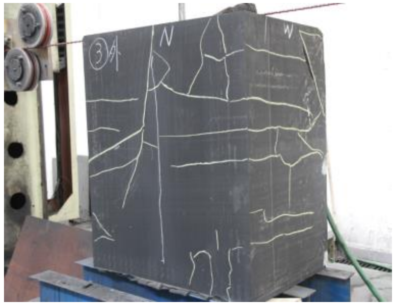
Technology of Natural Block Preparation.

Diamond Line-saw Cutting

- Sample standard dimension:

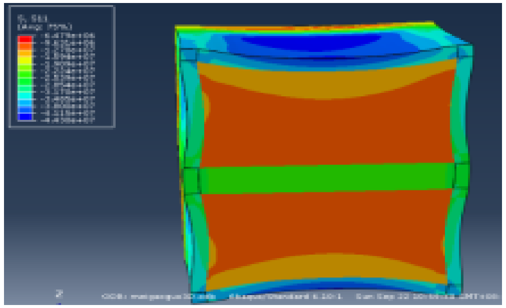
762(length)×762(width)×914mm(height)

- Larger block should be cut
- Shale is easy to crush due to brittleness



Cementing and Numerical Simulation

- Smaller block should be cemented
- Difference of mechanical property
- Numerical simulation of stress distribution

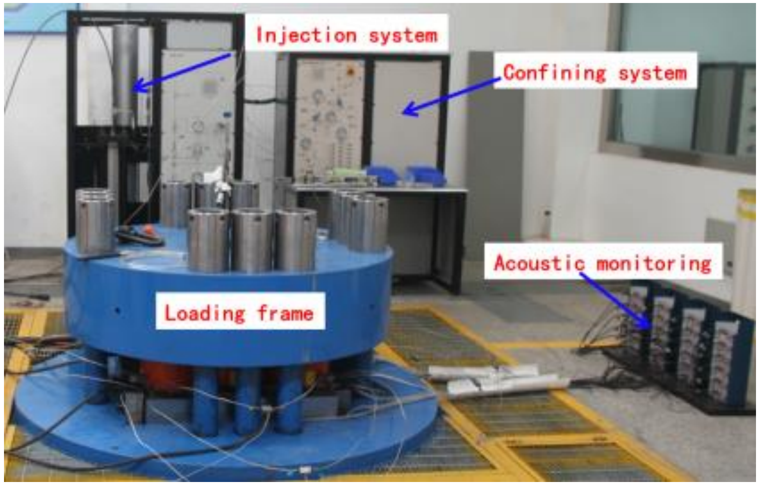


2.Technology——

Technology of Hydraulic Fracturing Experiment.

Large Block Test System for Hydraulic Fracturing

Structure Diagram



Technical Parameters

- Maximum Loading pressure： **10000psi**
- Maximum stress difference： 2000psi
- Maximum borehole diameter： 4.9in
- **Maximum injection pressure 12000psi**
- Maximum injection rate： 12L/min
- **Acoustic monitoring ： 24 channels**

2.Technology——

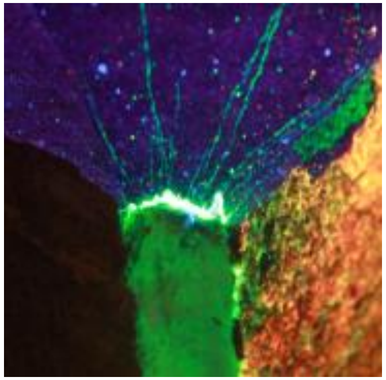
Large Block Test System for Hydraulic Fracturing

Areas of Investigation

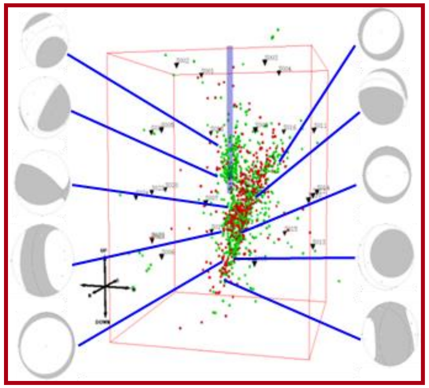
- Fracture Initiation
- Fracture Containment
- Fracture Complexity
- Acoustic monitoring
- Perforation
- Shale Completion

sandstone

Linestone



Fibre fracturing



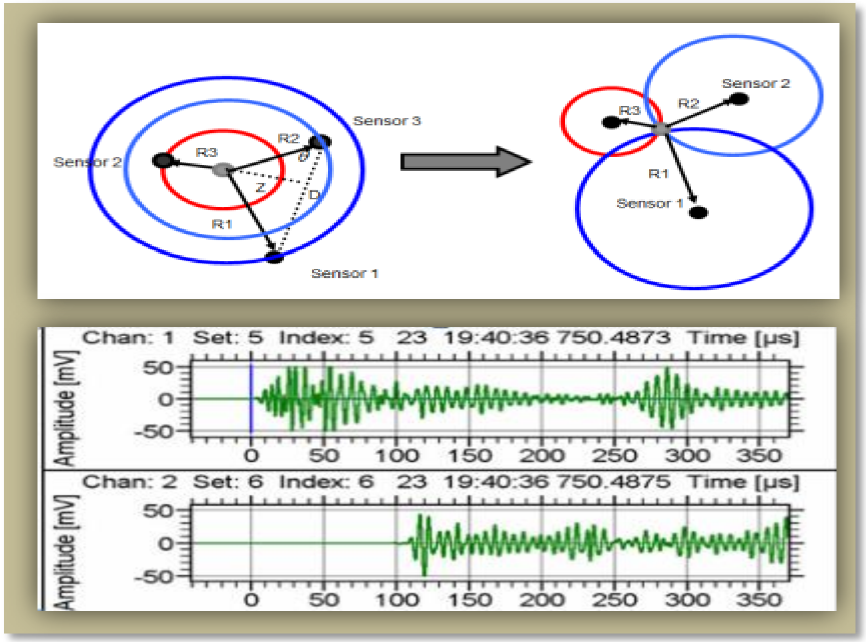
Acoustic monitoring

2.Technology——

Technology of Passive Acoustic Monitoring.

To describe fracture propagation in real-time

- Sensors at different sites.
- Signals emitted by fracturing are located.
- Signals at the same time can reflect fracture geometry.



OUTLINE

1 Background——Why?

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3.Results——what?

1. Basic data

Ⅰ type shale

- Higher clay content;
- Weathering;
- Easy to be crushed;

Ⅱ type shale

- Lower clay content;
- Tight ;
- Cut without damage;

Total rock x-ray diffraction analysis and Clay mineral

Rock type	Clay mineral relative content (%)					Total rock quantitative (%)						
	K	C	I	I/S	%S	Clay	Quartz	Potassium feldspar	Plagioclase	Calcite	Dolomite	Chromite
Ⅰ	5	20	36	39	10	44	28	1	7	9	9	2
Ⅱ		8	85	7	5	12	52		1	20	14	1
Tips	K: kaolinite, C:chlorite, I:illite, S:smectite, I/S: illite/smectite interlayer, %S: interlayer ratio											

3.Results——what?

2. Results.

Summary of test conditions and results

Test number	Rock type	$\sigma_{V,H,h}$ (MPa)	K_h	Viscosity (cP)	Pump rate(cm^3/s)	$P_{net,D}$	Fracture geometry
1	I	24,24,10	1.4	5	8.33	0.21	Complex, many nature fractures dilated
2	I	13,13,10	0.3	5	166.67	0	Simple, one fracture connected one discontinuity
3	II	13,13,10	0.3	5	...67	3.02	Complex, three nature fractures dilated
4	II	13,13,10	0.				...lex, one fracture connected ...re fractures
5	II	24,24,1... 0	... 4				...e fracture connected ... nature fractures
6	II	24,24,10	1.4	150	8.33	0.39	Simple, only one hydraulic fracture

all the conditions are the same as that in field

Note: **Horizontal stress difference**

$$K_h = (\sigma_H - \sigma_h) / \sigma_h$$

Dimensionless net pressure

$$p_{net,D} = \frac{p_{net}}{\sigma_H - \sigma_h}$$

3.Results——what?

◆ **Case 1**

Tight Sandstone without natural fracture : Penny Shape fracture

Coal with horizontal natural fracture : T shape fracture

Shale with complex natural fracture system : hydraulic fracture network

3.Results——what?

◆ Case 1

The existing and pattern of natural fractures determine hydraulic fracture geometry.

- More natural fractures, More complicated
- Higher injection pressure, More tortuosity

(a) Ⅰ type

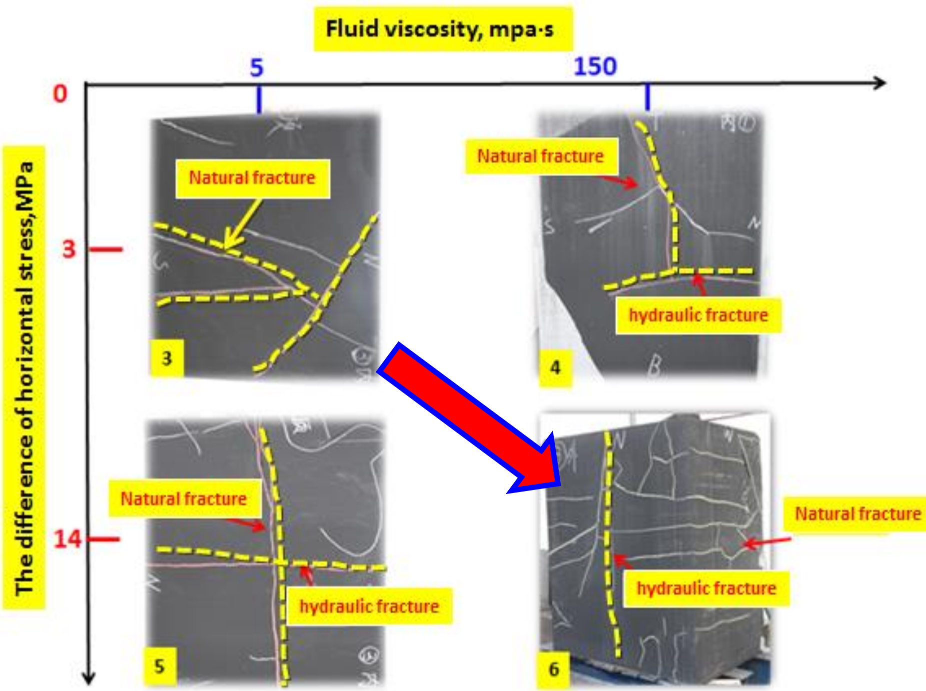
(b) Ⅱ type

Test number	Rock type	$\sigma_{V,H,h}$ (MPa)	K_h	Viscosity (cP)	Pump rate(cm^3/s)	$P_{net,D}$
1	Ⅰ	24,24,10	1.4	5	8.33	0.21
5	Ⅱ	24,24,10	1.4	5	8.33	0.12

3.Results——what?

◆ Case 2

Lower horizontal stress difference and fluid viscosity, More complex geometry, as test 3 and test 6 showed.

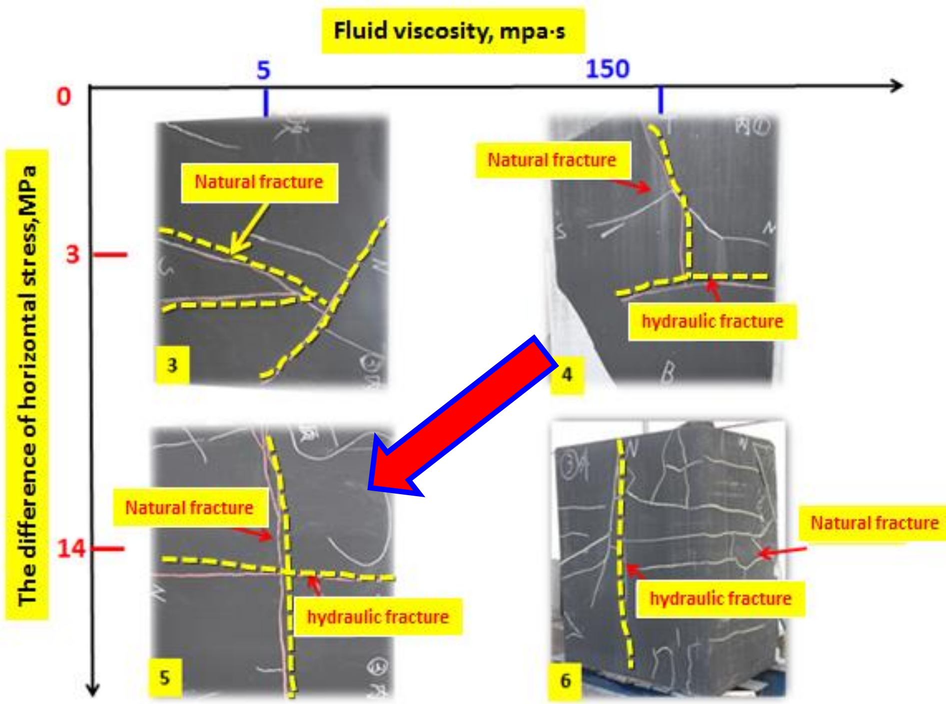


Test number	□$\sigma_{V,H,h}$ (MPa)	Viscosity (cP)	Pump rate(cm^3/s)	$P_{net,D}$
3	13,13,10	**5**	166.67	**3.02**
6	24,24,10	**150**	8.33	**0.39**

3.Results——what?

◆ Case 2

- Test4 and test5 show less complex fracture geometry can exist in some cases.
- It is difficult to produce complex fracture geometry with higher viscous fluid.



Test number	□σV,H,h (MPa)	Viscosity (cP)	Pump rate(cm3/s)	Pnet,D
4	13,13,10	150	1	3.6
5	24,24,10	5	8.33	0.12

3.Results——what?

◆ Case 2

Higher injection pressure indicated more complicated fracture geometry using the same frac fluid.

Net pressure and fluid should be paid more attention to evaluate reservoir stimulation.

Test number	**Pump rate(cm³/s)**	**Viscosity (cp)**	**$P_{net,D}$**
3	166.67	5	**3.02**
5	8.33	5	0.12
4	1	150	**3.6**
6	8.33	**150**	**0.39**

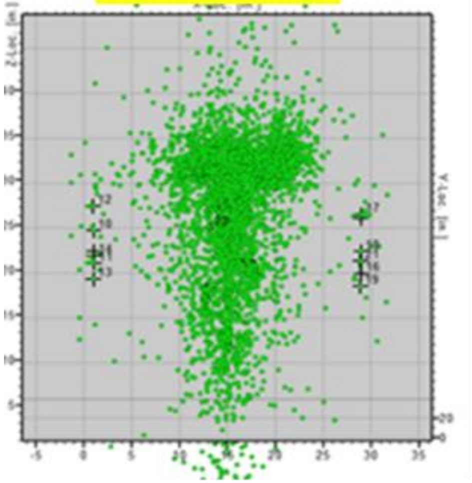
$$p_{net,D} = \frac{p_{net}}{\sigma_H - \sigma_h}$$

3.Results——what?

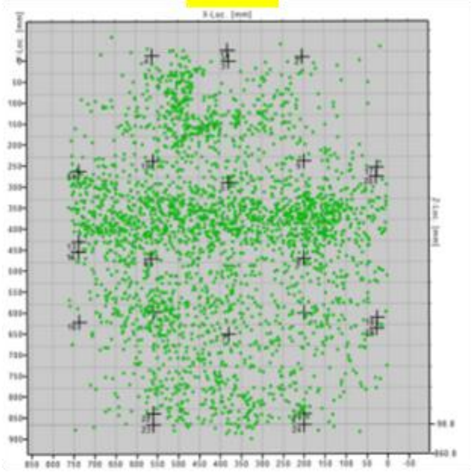
◆ **Case 3**

Application of Acoustic Monitoring in Lab

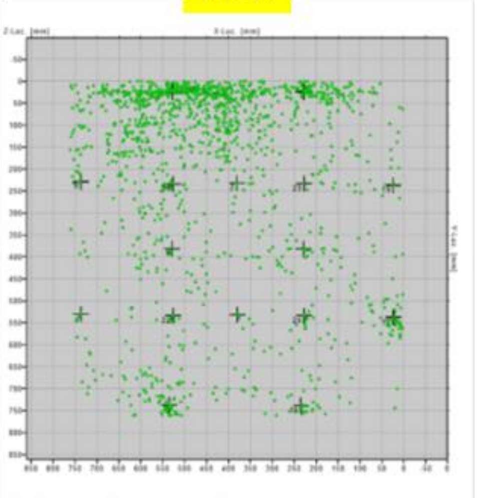
tight sandstone



coal



shale

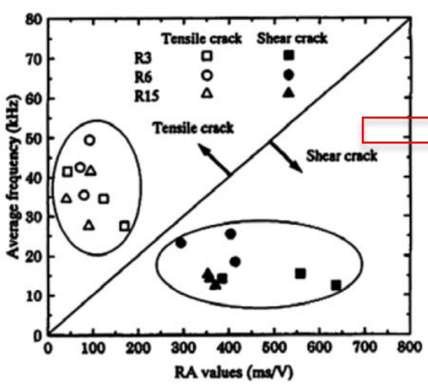


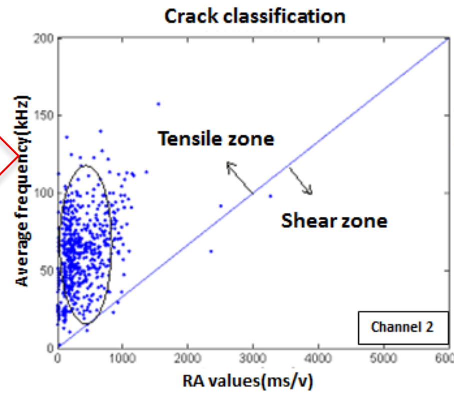
- Attenuation and anisotropy lead to locate acoustic event badly.
- Advanced locating needs to be improved in future.

3.Results——what?

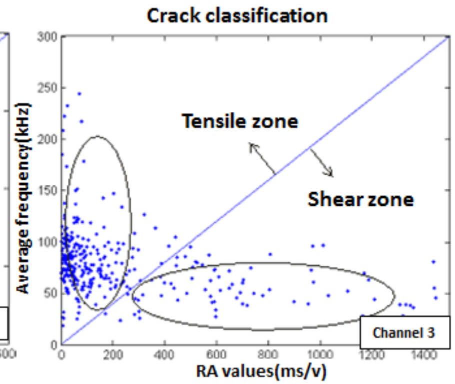
◆ Case 3

Rock failure mechanism analysis

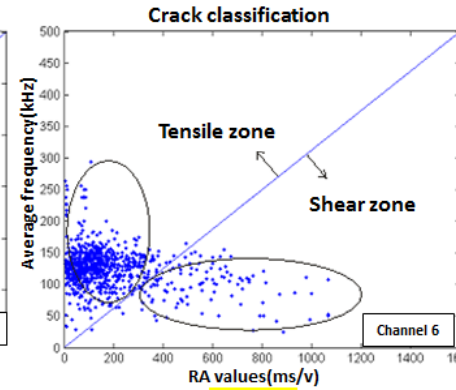




CQ tight sandstone



SX coal



Shale

- the tensile rupture is dominated in tight sandstone.
- the proportion of shear events is the largest in coal.
- Shear event or slippage is also usual in shale.

Conclusion

- Large-scale physical simulation is an effective way to research.
- More complex fracture with natural fractures、high net pressure 、low stress difference and fluid viscosity.
- Acoustic events corresponding to complex fracture will be investigated.

Acknowledgement

- Thanks to our company CNPC for supporting us on this paper.
- Thanks to my working team for their great job.

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