

Factors Influencing the Development of Diagenetic Shrinkage Fracture of Shale (DSFS)*

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Abstract

As an important type of (non-structural) fracture, diagenetic shrinkage fracture of shale (DSFS) plays an important role in the reservoir, seepage, and especially fractured production of shale oil and gas. However, study on it is relatively rare. According to the similarity of desiccation crack of argillaceous sediment and DSFS in the cause of formation, morphology and development, 4 groups and 19 experiments on the desiccation crack of shale core powder in the marine-continental transitional facies were designed. Combined qualitative analysis with quantitative research, five factors, including shale thickness, water salinity, clay mineral content, heating temperature and sand content, were conducted, an analogy study, on the DSFS.

The study showed that the greater the thickness, the later the time of fracture initiation (TFI), and the higher the critical water ratio (CWR) of fracture initiation; also, that the greater the average fracture length, width and fracture ratio, the smaller the area density of fractures. Influenced by the strong diagenesis and low content of montmorillonite in shale, the water salinity has smaller relation with the DSFS. Samples with different water salinities have similar TFI and CWR. As water salinity increases, the width, length, and fracture ratio of DSFS tend to decrease, and area density (the number of fractures) increases, but their degree of decrease or increase is minor. The high content of clay mineral in transitional-facies shale exerts a tremendous influence on DSFS. In addition, higher clay mineral content causes later TFI and greater CWR of shale; the fracture length and fracture ratio increase, and the width increases sharply, but the area density decreases. With higher the temperature, there is a decreased tendency of the TFI, length, width and fracture ratio, but the CWR and area density are increased. On the whole, the influence of clay mineral content on the DSFS is largest, followed by thickness and temperature, and water salinity impacts the least. The DSFS under different influence factors all have four development stages: formation of main-fracture, formation of sub-fracture, stabilization stage, and fixed stage. Other influence factors of DSFS need to be further studied.

Selected References

Kidder, D.L., 1990, Facies-Controlled Shrinkage-Crack Assemblages in Middle Proterozoic Mudstones from Montana, USA: *Sedimentology*, v. 37, p. 943-951.

Nelson, R.A., 2001, *Geologic Analysis of Naturally Fractured Reservoirs*, 2nd edition: Gulf Professional Publishing, 332 p.

Nelson, R.A., 1979, Natural Fracture Systems, Description and Classification: *American Association of Petroleum Geology Bulletin*, v. 63/12, p. 2214-2221.



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May 22, 2018

Outline

1. Study setting

2. Experiments and image processing

3. Influence factors of DSFS

4. Conclusions

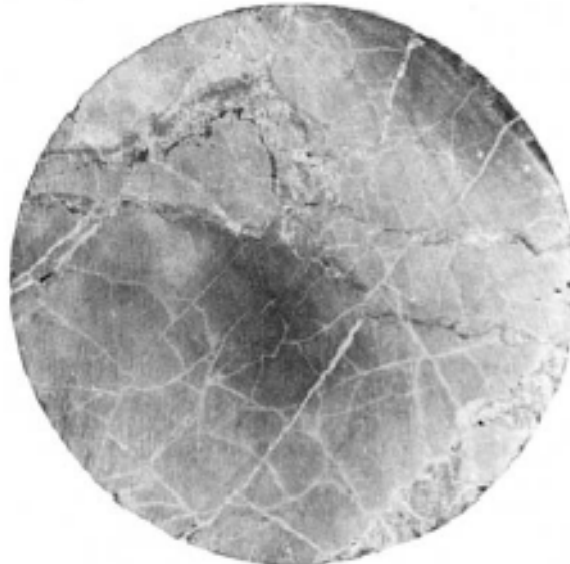
1. Study setting

Shrinkage Fracture: A tension or extension fracture owing to the **volume reduction** of sediment/rock by **water loss**.

Genesis	Cause explanation	Location	Process feature	Fracture shape	Fracture size	Fracture pattern
Desiccation	Water evaporation in dry climate	Subaerial	Physical	polygon, branch; V- or U-shape	Macro	Non-Diagenetic
Syneresis	Salinity change/increase	Subaqueous	Main chemical	polygon, branch; V- or U-shape	Macro	Non-Diagenetic
Compaction	Overlying load	Shallow layer	Physical	polygon, branch, Spindle; V- or U-shape, sinuous	Macro	Diagenetic
Thermal gradient	Hot rock cools	Shallow-deep layer	Physical/Chemical	polygon, branch; U- or V-shape	Macro	Diagenetic
Mineral phase change	From montmorillonite to illite, from calcite to dolomite	Deep layer	Chemical	Main irregular, or certain regular, partially branch, individual polygon	Micro	Diagenetic

(Thirrumalai, 1970; Glaessner, 1969; Plummer and Gostin, 1981; Nelson, 1979, 2001; Kidder, 1990; Astin and Rogers, 1991; Pratt, 1998; Tanner, 1998; Kargel, 2004; Zhao et al, 2008; Ding et al, 2011, 2013; Zhao et al, 2013; Anderson, 2015; Huo et al, 2018)

DSFS



(Nelson, 1979)

Desiccation crack



(Jstuby, 2009; from Wikimedia)



(Kidder, 1990)



1. Study setting

Study method

Simulation experiments of desiccation cracks of shale to conduct analogy study

Study significance

- (1) Simple qualitative description of characteristics and causes; very few study their influence factor;
- (2) Playing an important meaning on production of shale oil and gas;

2. Experiments and image processing

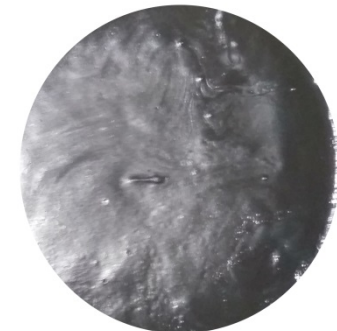
2.1 Experiment materials

5 cores: from the Permian,
Southern North China Basin

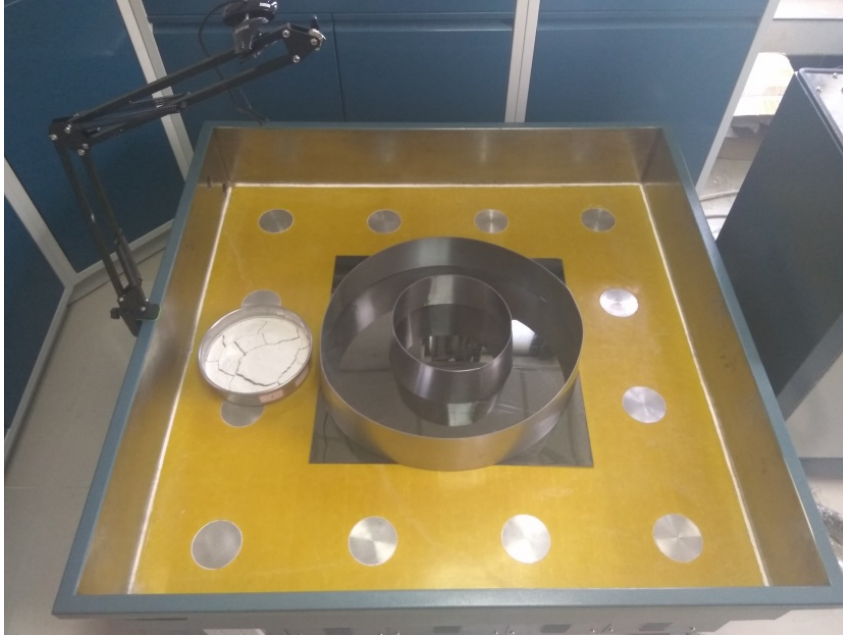
NO	Well	Depth (m)	Whole rock mineral							Clay mineral			
			Clay mine ral	Quartz	Feldspar	Calcite	Dolomite	Siderite	Pyrite	Illite	Kaolinite	Chlorite	Illite- montmo rillonite
			(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
S1	ZXY-1	3330.7	1	8	0	91	0	0	0	31	0	3	66
S2	MY-1	2920.5	20	52	7	0	19	0	2	80	4	0	16
S3	MY-1	2950.09	41	40	3	0	8	3	5	42	21	11	26
S4	MY-1	2848.62	60	29	6	0	2	2	1	47	23	13	17
S5	MY-1	2807.74	75	24	0	0	0	0	0	8	51	17	24



**Cores → powder + water
= slurry (100% water
content, saturation)**



2.2 Experiment facilities



Desiccation fracture simulator

Taking photos **by camera**

Weighing sample **by scale**



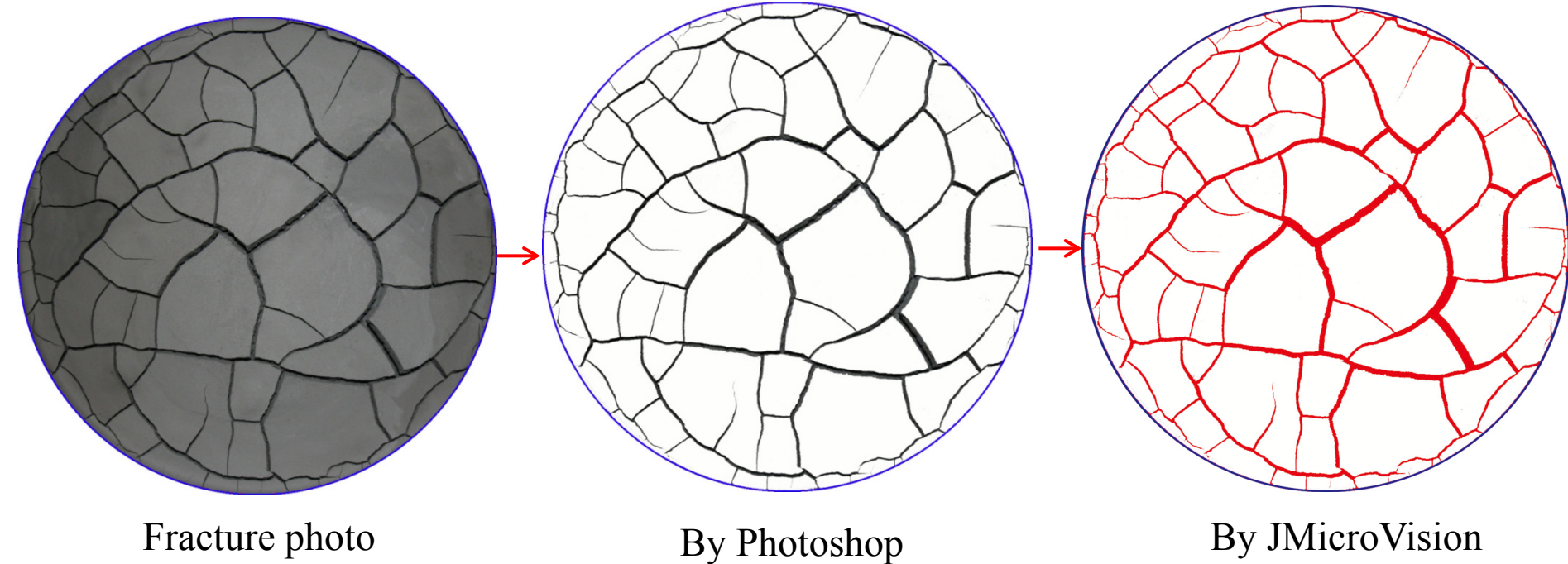
Control device



Mechanical device

2.3 Image processing

Binarization processing



Many fracture parameters (number, length, width and area) can be rapidly and accurately extracted by JMicroVision

3. Influence factors of the DSFS

5 possible influence factors studied

**(1) Clay mineral content and composition; (2) Thickness
(3) Water salinity; (4) Temperature; (5) Sand content**

Fracture parameters:

Time of fracture initiation (TFI);

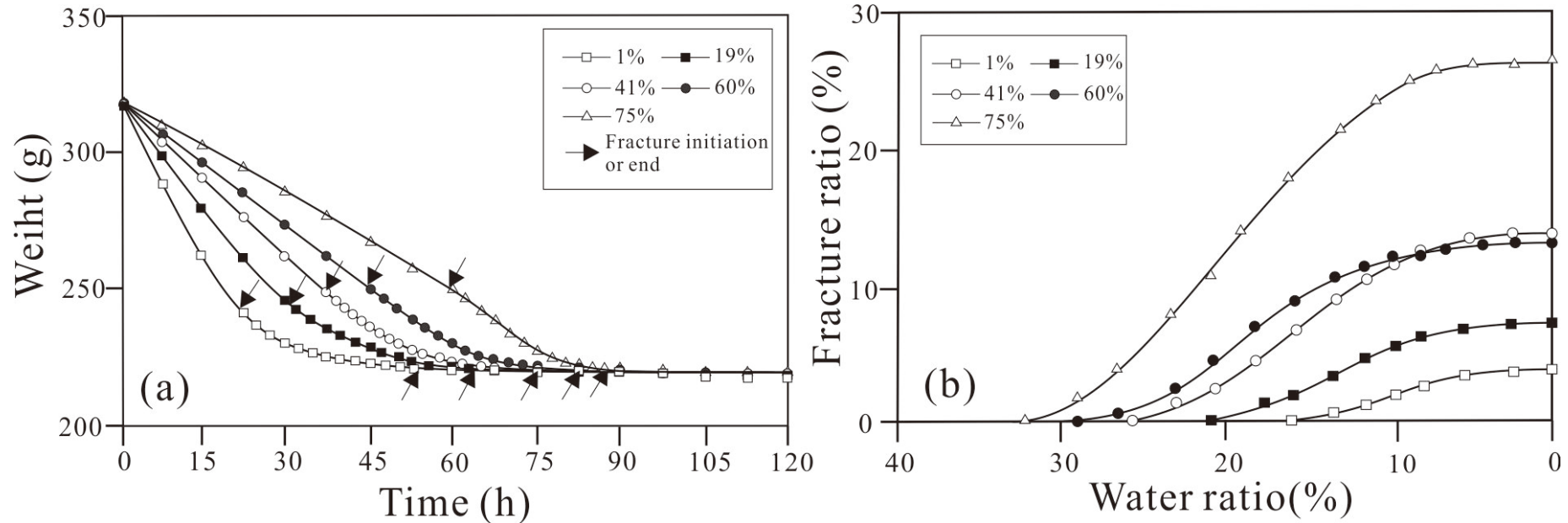
Boundary water content (BWC) of fracture initiation;

Fracture length and width;

Surface density of fracture; Fracture ratio

3.1 Influence of clay mineral

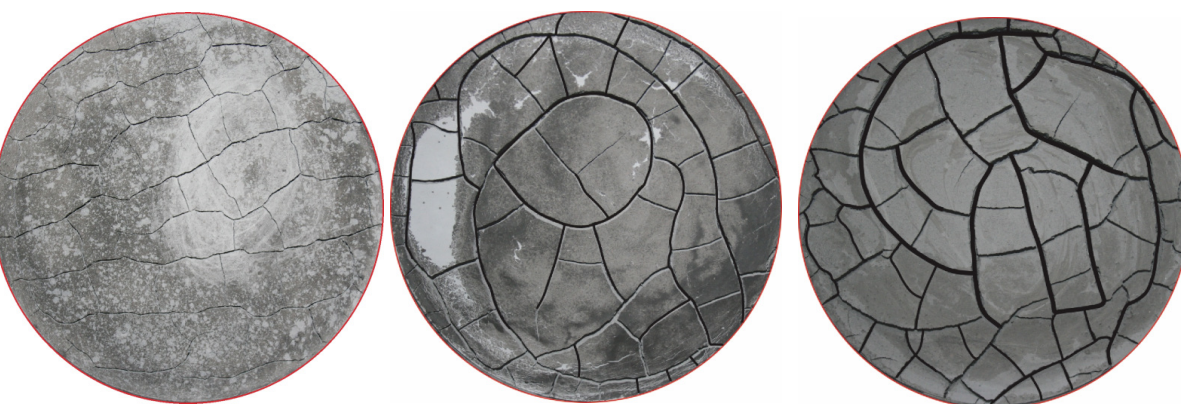
Clay mineral content: 1%, 19%, 41%, 60%, 75%



Content increases ↑ : TFI and BWC increase ↑

Why? With higher ability to absorb water, slower water loss velocity; at TFI, less water loss to fracture

3.1 Influence of clay mineral



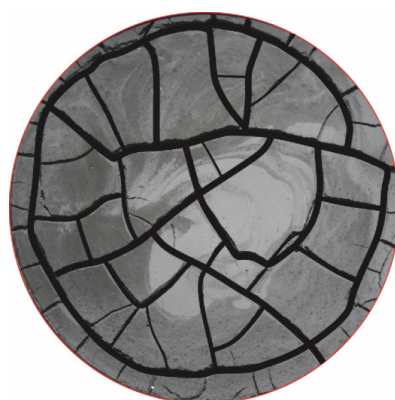
1%

19%

41%



60%

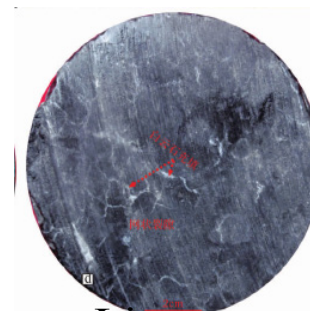
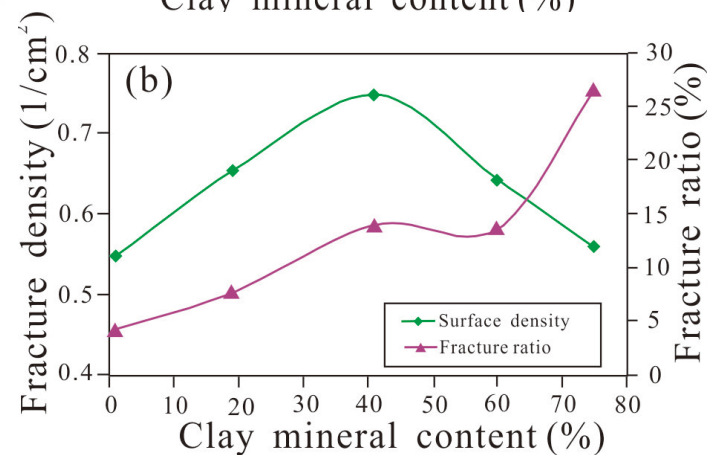
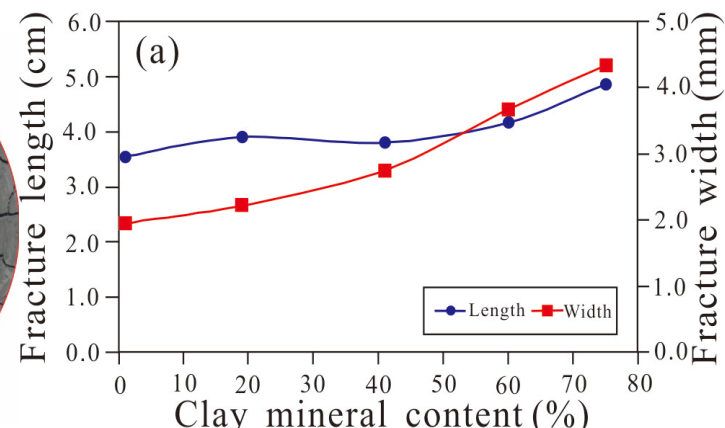


75%

Content ↑ :

Length and width ↑ ; Fracture ratio ↑

Density: first ↑ , then ↓



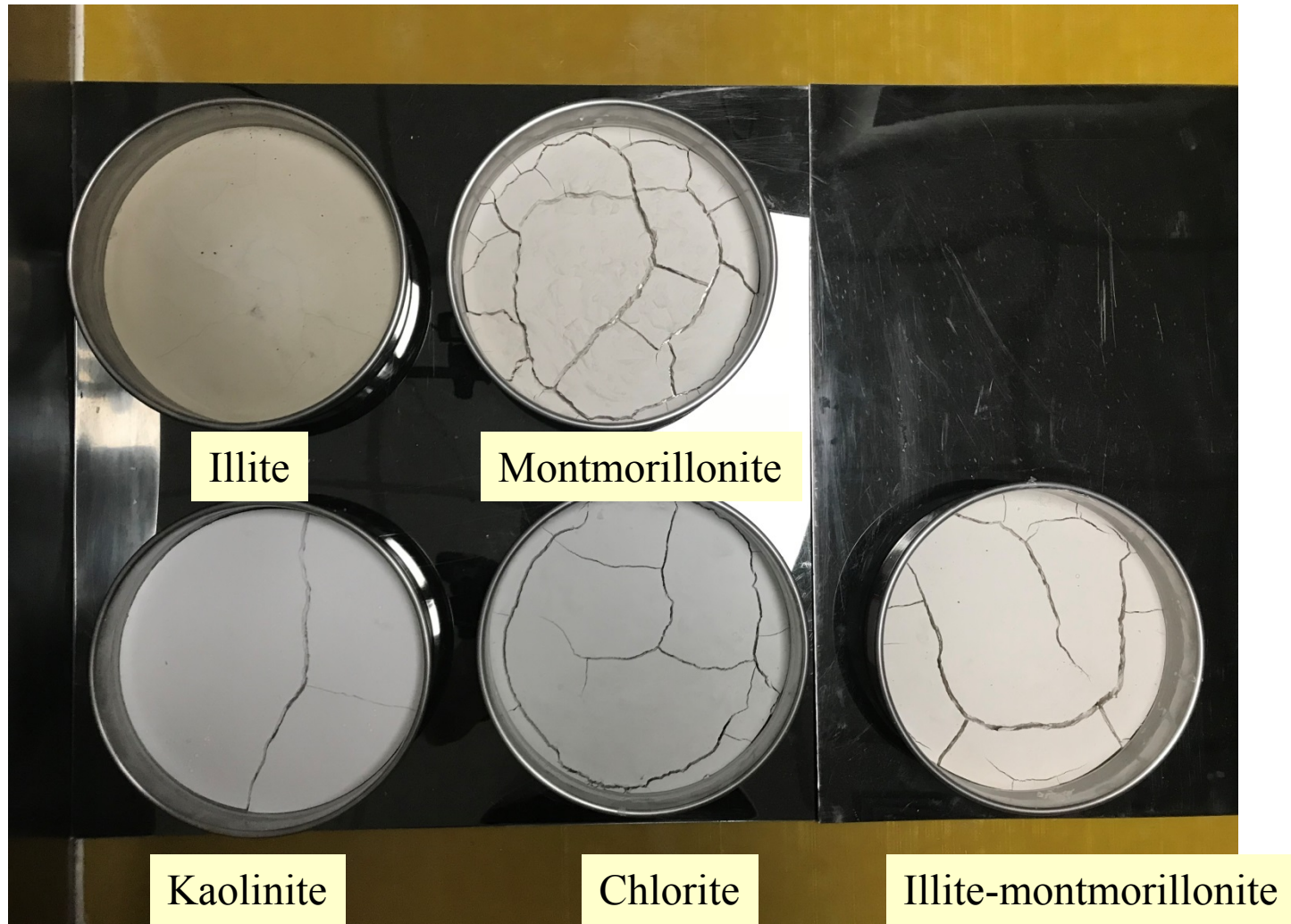
Limestone

(Zhao et al, 2013)



Shale

3.1 Influence of clay mineral

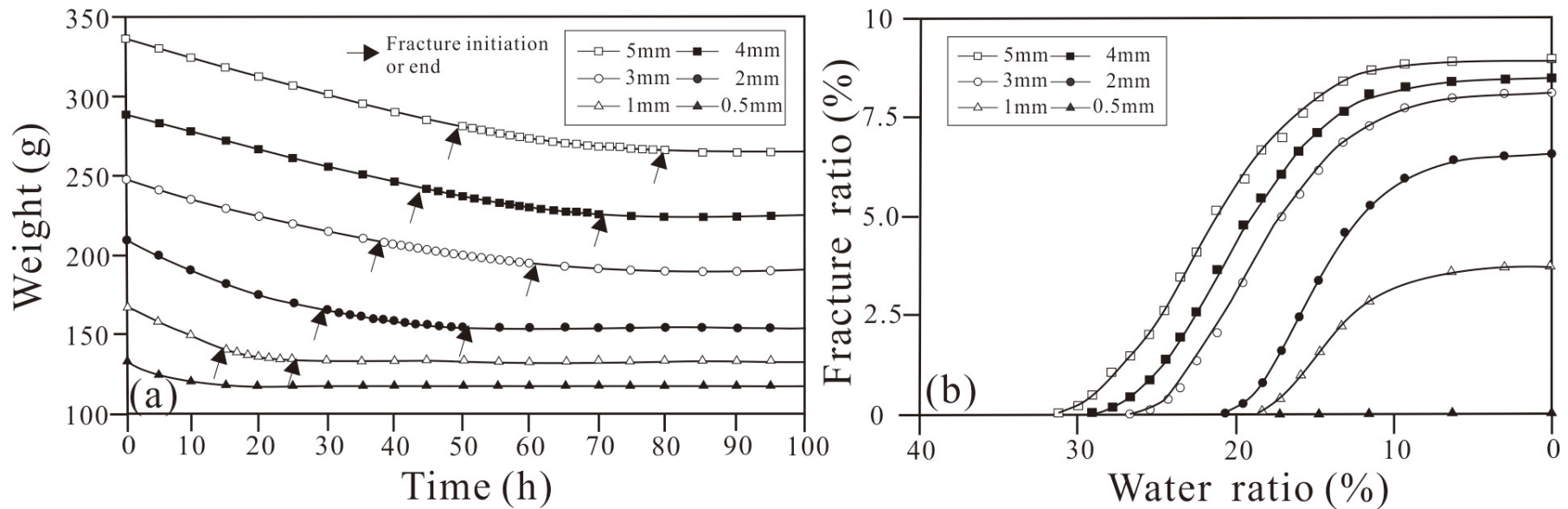


Shrinkage volume ratio

Montmorillonite>Illite-montmorillonite>Chlorite>Kaolinite>Illite

3.2 Influence of thickness

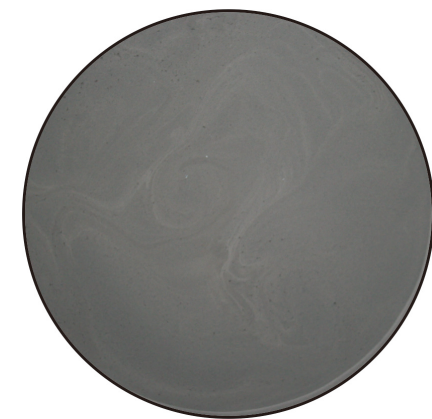
**Thickness: 0.5mm, 1mm, 2mm, 3mm, 4mm, 5mm
(>10mm)**



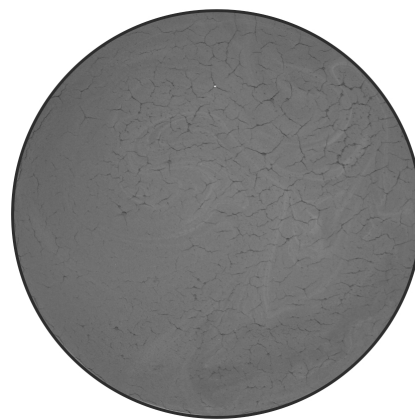
Thickness ↑, TFI and BWC ↑

Why? Thicker, lower section has higher water content

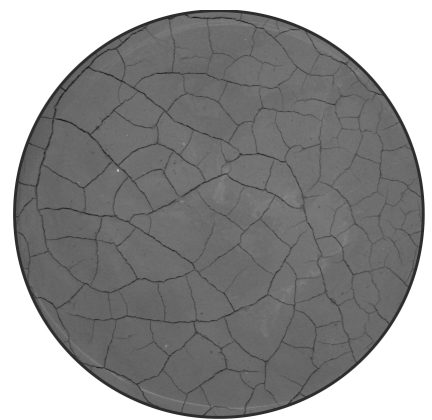
Causing the water move to upper section, so TFI and CWC ↑



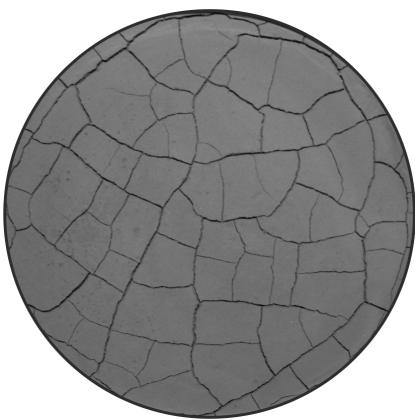
0.5mm



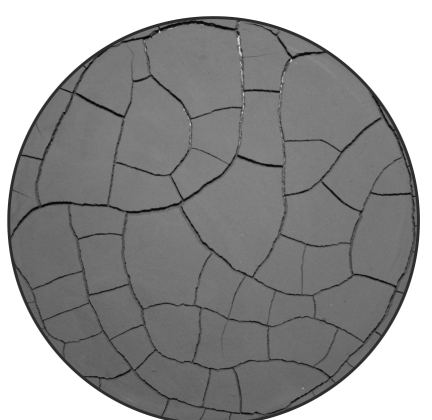
1mm



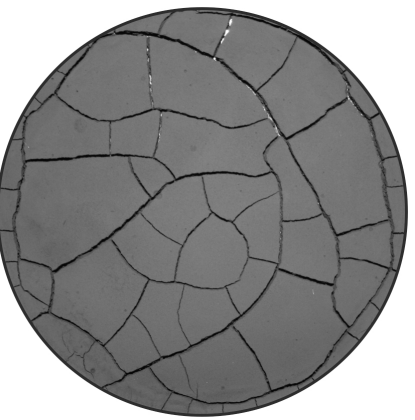
2mm



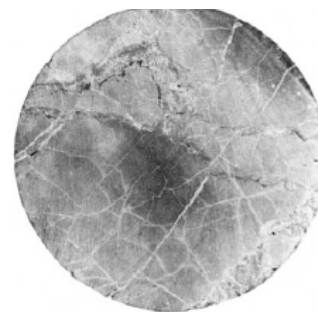
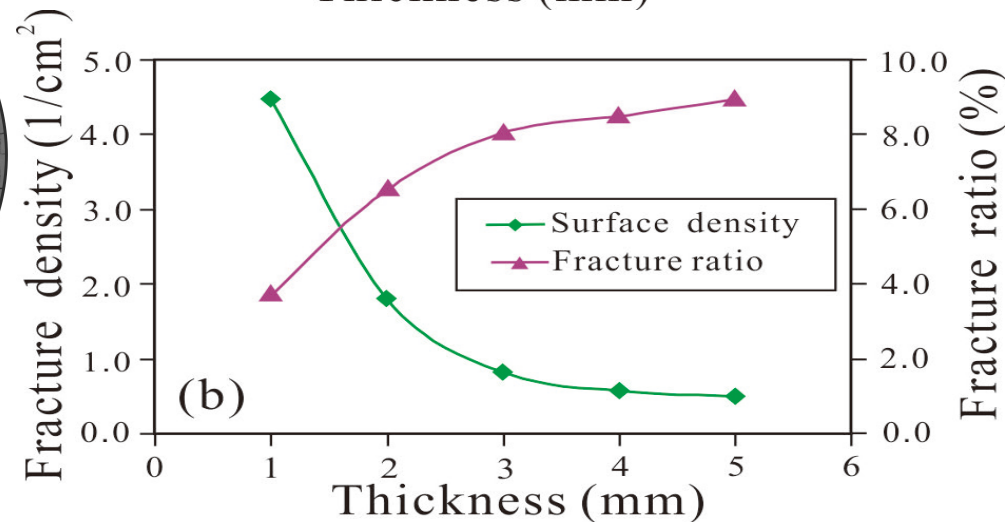
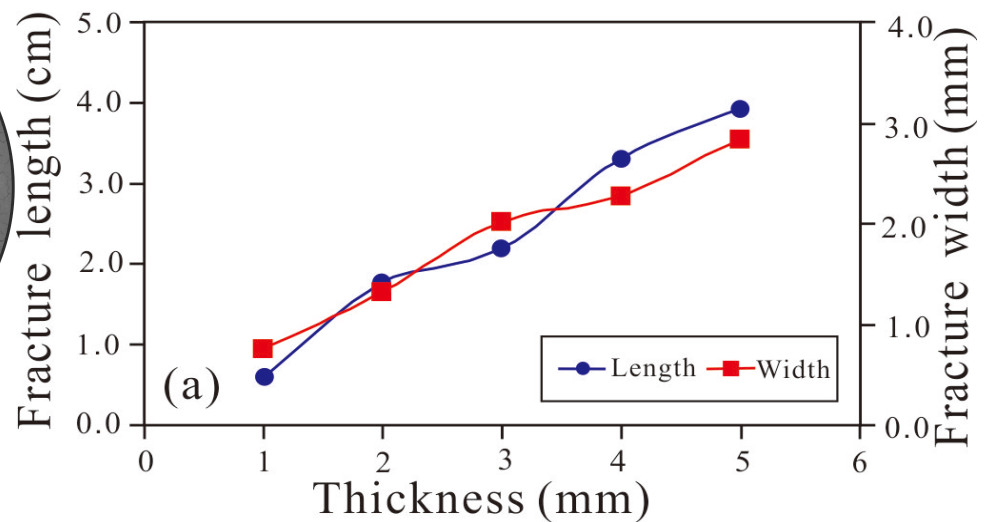
3mm



4mm



5mm



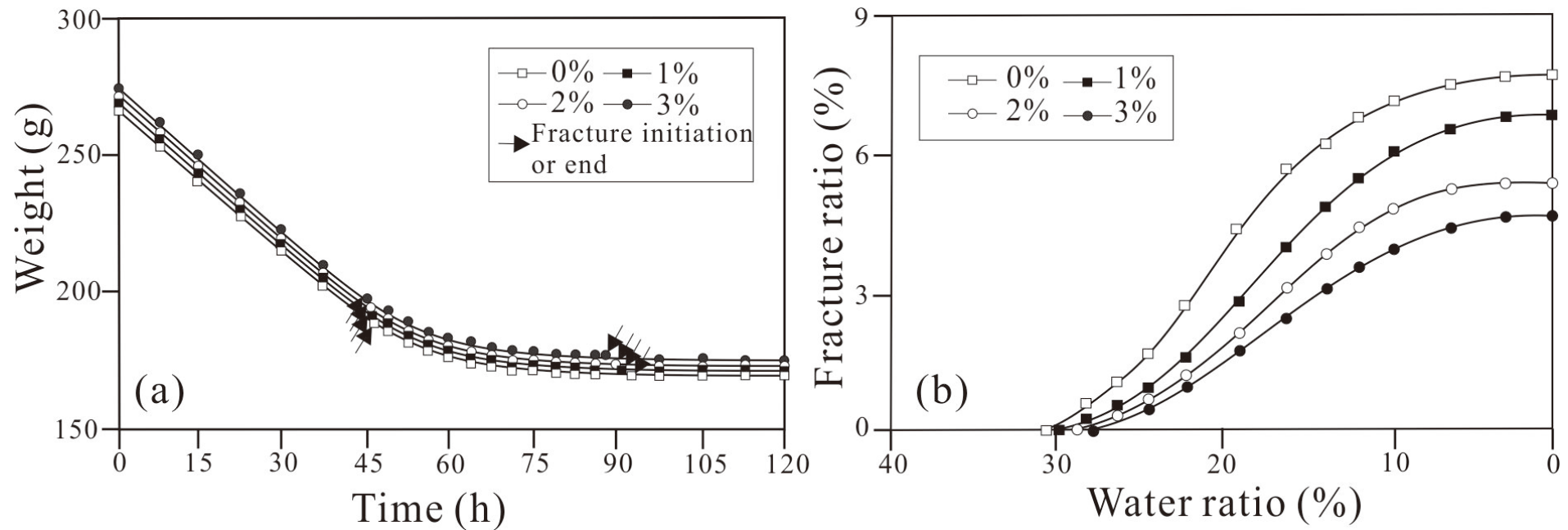
(Nelson, 1979)



(Jstuby, 2009)

3.3 Influence of water salinity

Water salinity: 0%, 1%, 2%, 3%

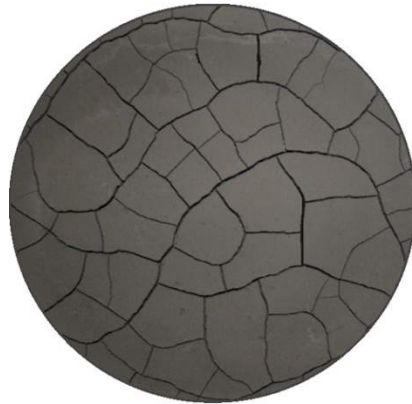


Water salinity \uparrow , TFI and BWC \downarrow , but similar

3.3 Influence of water salinity



0%



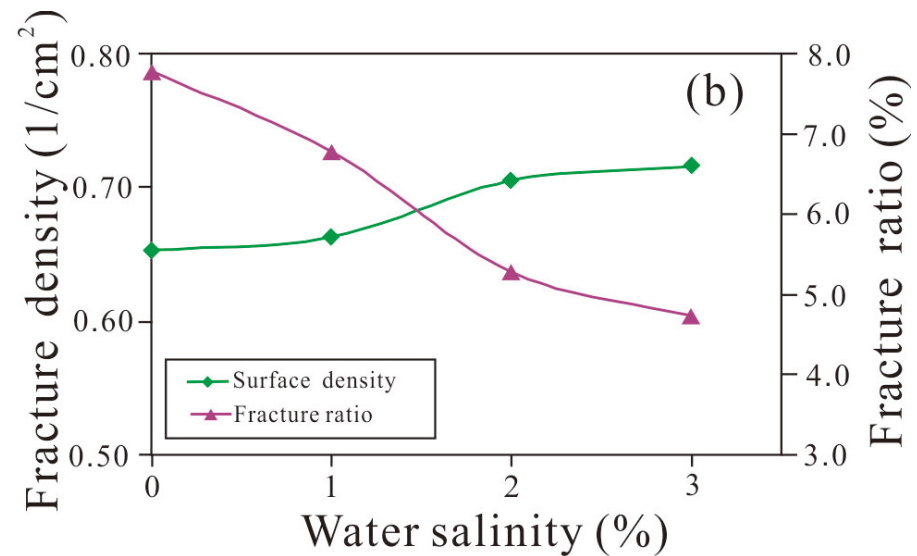
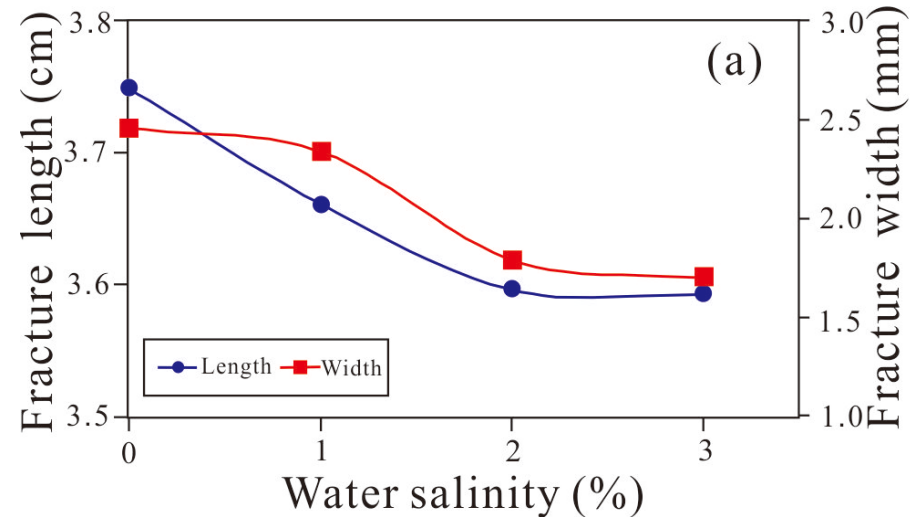
1%



2%

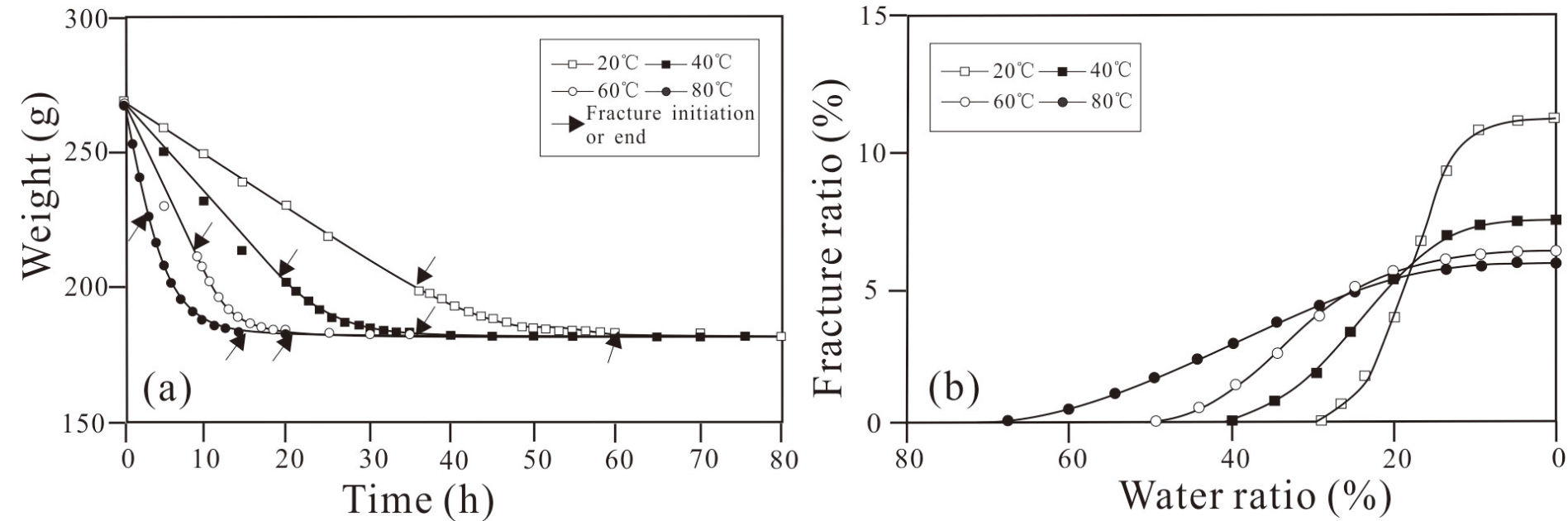


3%



3.4 Influence of heating temperature

Temperature: 20°C, 40°C, 60°C, 80°C



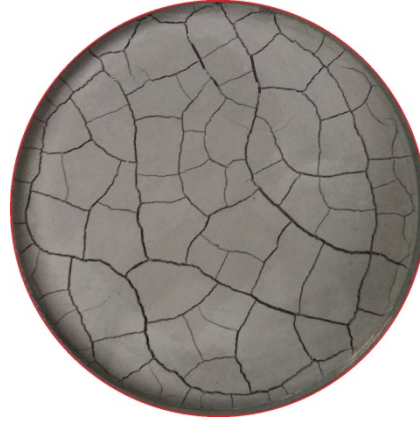
Temperature ↑, TFI ↓ but BWC ↑

Why? With faster water loss velocity, earlier fracture;
lower section has higher water content, CWC ↑

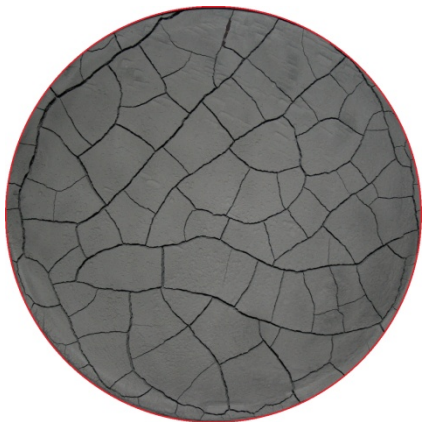
3.4 Influence of heating temperature



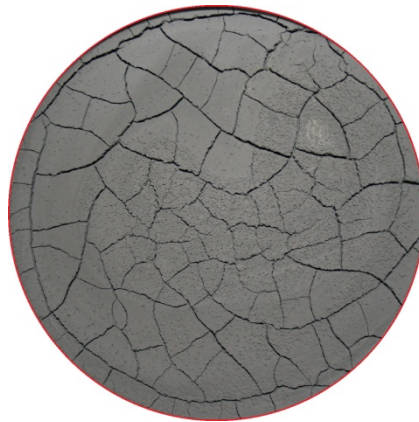
20°C



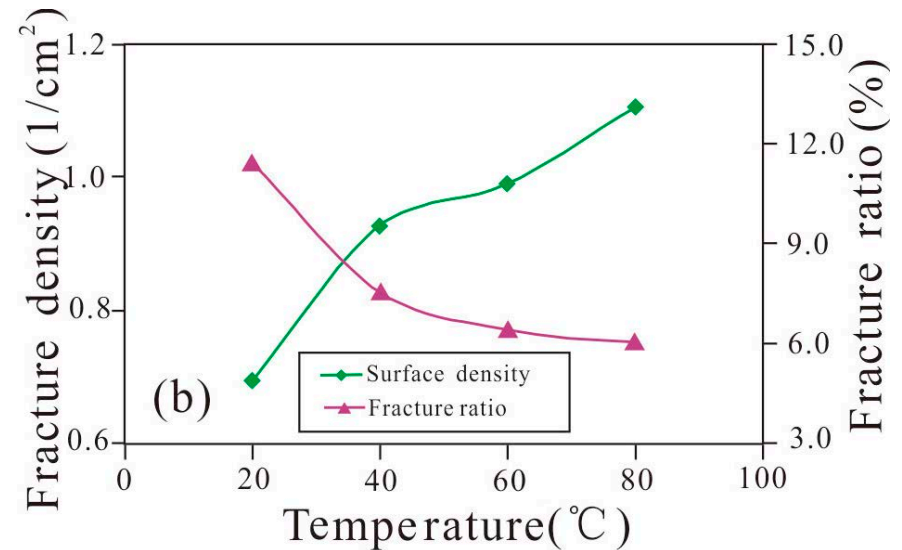
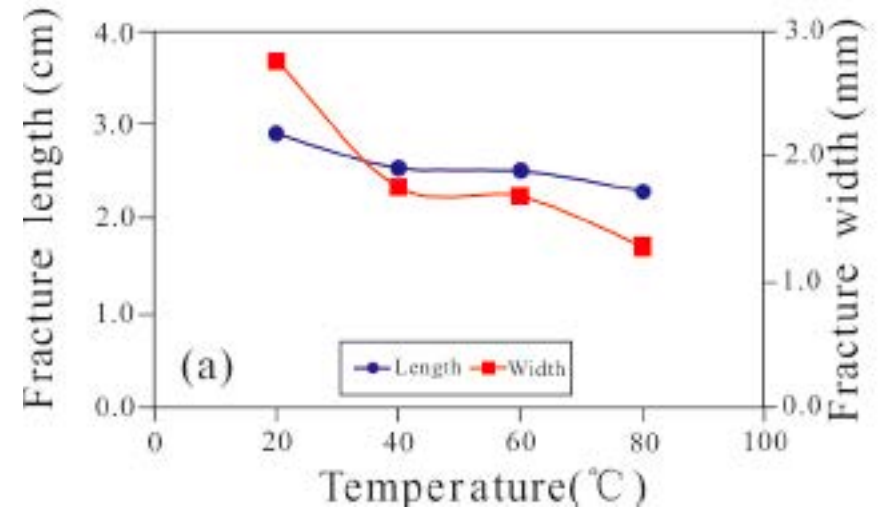
40°C



60°C



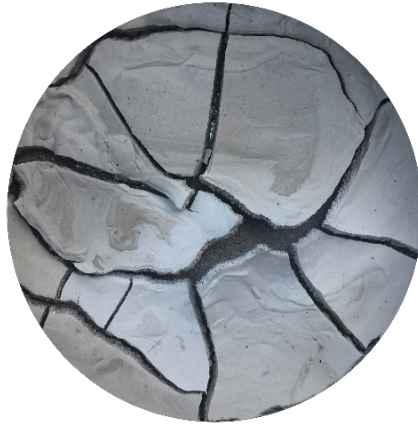
80°C



3.5 Influence of sand content



0%



25%

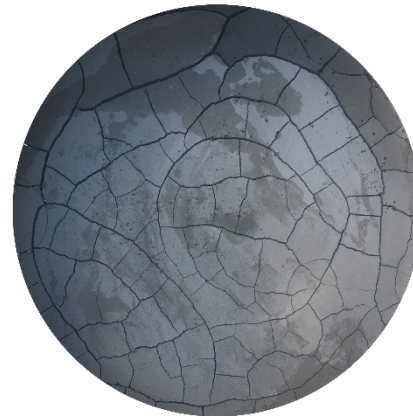


50%

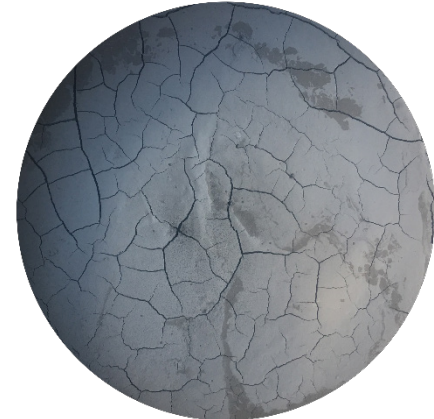


75%

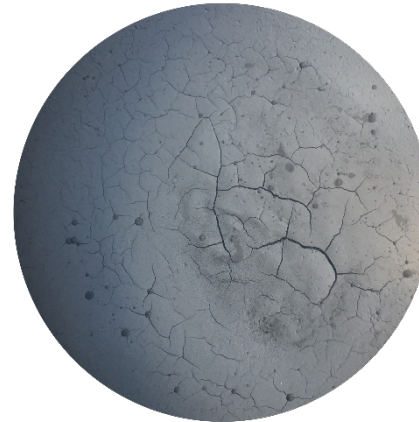
Mineral powder + sand



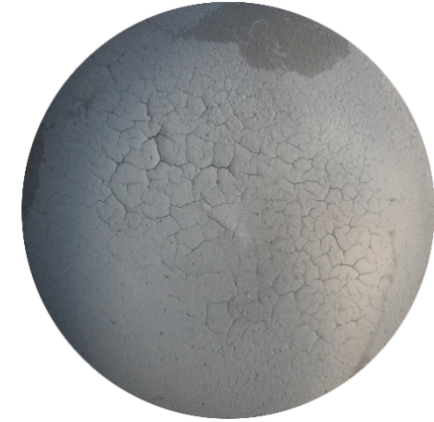
0%



25%



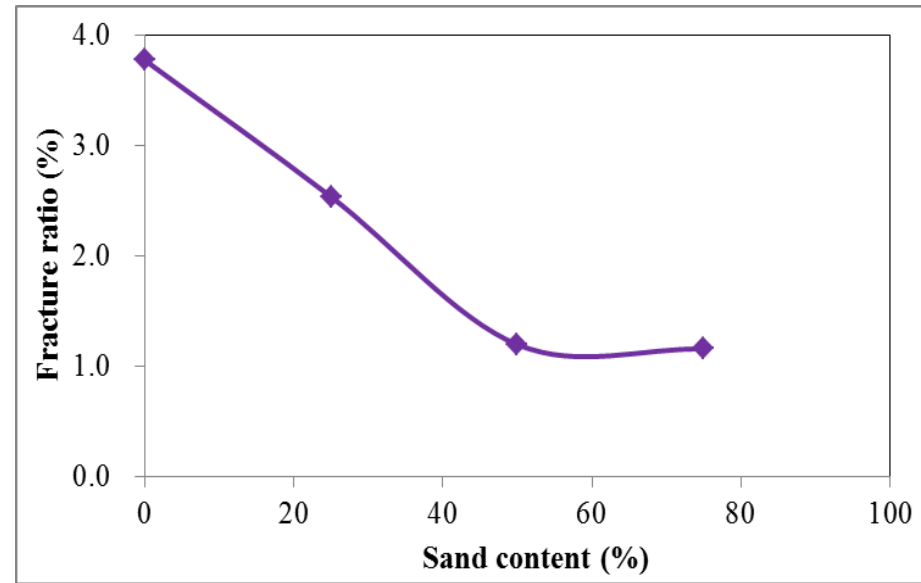
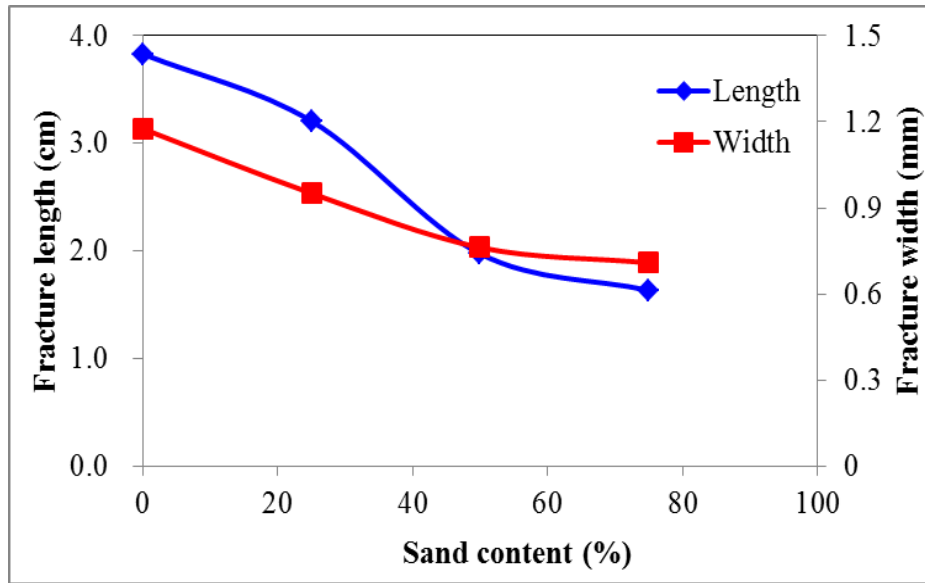
50%



75%

core powder of black shale + sand

3.5 Influence of sand content



Why? Like clay mineral



Shale (Kidder 1990)



**Muddy siltstone
(from Uinta Basin)**

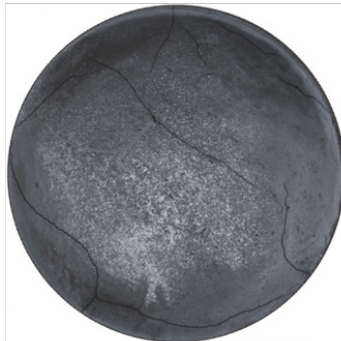
3.6 Development stage of the DSFS



(a) 0 hour



(b) 1 hour



(c) 2 hour



(d) 3 hour



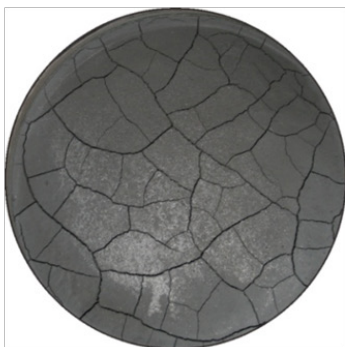
(e) 4 hour



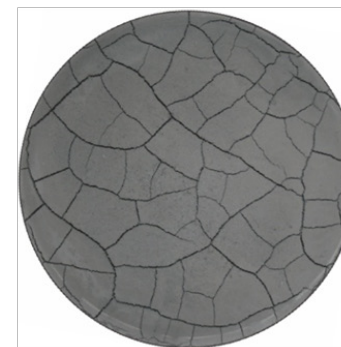
(f) 5 hour



(g) 10hour



(h) 20 hour



(i) 30 hour

Four development stages

(1) **Main-fracture** formation
(a-c)

(2) **Sub-fracture** formation
(d-g)

(3) Fracture **stabilization**
(g-h)

(4) Fracture **fixation** (i)

4. Conclusions

Factor	Change trend for the DSFS						
	Factor	TFI	BWC	Length	Width	Surface density	Fracture ratio
Clay mineral	↑	↑	↑	↑	↑	↑ ↓	↑
Thickness	↑	↑	↑	↑	↑	↓	↑
Water salinity	↑	↓ Similar	↓	↓	↓	↑	↓
Temperature	↑	↓	↑	↓	↓	↑	↓
Sand content	↑	↑	↓	↓	↓	↑ ↓ 0	↓

Clay mineral > sand content > thickness > temperature > water salinity

4. Conclusions

Some important contents need be studied

- (1) Further certify the similarity between the DSFS and ground desiccation cracks
- (2) Study other influence factors (more similarity with underground shale)

Factors completed study	Factors in study
Clay mineral content and composition	Sandstone-shale combination
Sand content	Pore pressure
Thickness	In situ stress
Water salinity	Overlying load Compaction/diagenesis degree (Ro)
Temperature	Heterogeneity
	Uneven, dip angle of layer
	Former pores, fractures, or coarse particle

- (3) Larger scale experiments (> 0.5 m)
- (4) The characteristics and influence factors of clay-mineral-shrinkage fracture

The end!

Thank you so much!



(From Uinta Basin)

