Authigenic Illite in the Sandstone Reservoirs of Taiyuan Formation, Northeast Ordos Basin*

Keke Huang[1]

Search and Discovery Article #50706 (2012)**
Posted August 31, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

[1]State Key Laboratory of Oil/Gas Reservoir Geology and Exploitation, Institute of Sedimentary Geology, Chengdu University of Technology, Chengdu, China (h-k-k@yeah.net)

Abstract

The Upper Palaeozoic sandstones are important hydrocarbon reservoirs in the Northeast Ordos Basin. More extensive illitization is observed in the Upper Carboniferous Taiyuan Formation than those in other reservoir units. In this research, the nature and porosity effects of illite in the Taiyuan Formation of Northeast Ordos Basin have been investigated by means of thin-section observations, scanning electron microscope (SEM), and X-ray diffraction techniques. We have shown different types of illite in the sandstones based on their textural features. Detrital illite, the least abundant component, frequently occurs as tangentially arranged, grain-lining, ragged plates. A detrital origin can be distinguished by its poorly-crystalline morphology with wrinkled surface and blurred boundary, suggesting it was suffering from sedimentary transport. Diagenetic illite, recognized by their delicate, fibrous or lathy morphology, occurs commonly as pore-filling phases formed by feldspar alteration and radially-oriented, grain-rimming cements. It is also observed replacing kaolinite, as laths are extending from pseudohexagonal plates.

It is only in the sandstone of Taiyuan Formation that kaolinite concentration does not increase at the expense of feldspar. This intense illitization, and relative scarcity of kaolinite, may be due to the prolonged exposure to saline depositional pore-waters during Miaogou transgression in the early Taiyuan period. The growth of authigenic K-feldspar, occurring as intergrowths with grain-lining illite, implies that a high concentration of potassium ions were present in the original ground waters. K-feldspar dissolution, inhibited or slowed down by early penetration of K-rich fluids, may provide other potential sources of potassium for illite formation at the expense of kaolinite during burial diagenesis. This process has a greater temperature dependency and burial histories indicate that the Taiyuan Formation entered the illitization window (130° C and 140° C) at 108-135 Ma.

There is a positive correlation (R^2= 0.55) between the abundance of authigenic illite and variations in thin-section porosity for Taiyuan sandstone reservoirs. This is interpreted to indicate that the majority of the total sandstone volume is secondary porosity, produced primarily by illitization at the expense of kaolinite and K-feldspar.

References

Liu, D., P. Peng, C. Pan, and L,K. Wang, 2008, Influence of different experiment conditions in the procedure of (^{40}) Ar- (^{39}) Ar dating of authigenic illite: Bulletin of Mineralogy Petrology and Geochemistry, v. 27/2, p. 169-174.

Yang, Y., W. Li, and L. Ma, 2005, Tectonic and stratigraphic controls of hydrocarbon systems in the Ordos Basin: a multicycle cratonic basin in Central China: AAPG Bulletin, v. 89/2, p. 255-269.

Authigenic illite in the sandstone reservoirs of Taiyuan Formation, Northeast Ordos Basin

Huang Keke
Institute of Sedimentary Geology,
State Key Laboratory of Oil/Gas
Reservoir Geology and Exploitation,
Chengdu University of Technology,
China

E-mail: h-k-k@yeah.net

Outline

Background information:

- Basin location, Study area, Stratigraphy, and Sedimentary facies

What does the petrography of the investigated sandstones tell us?

- Investigated by thin section observations, SEM analysis, XRD measurements
- Rock composition, types of porosity, as well as diagenetic clay minerals associated with feldspar alteration

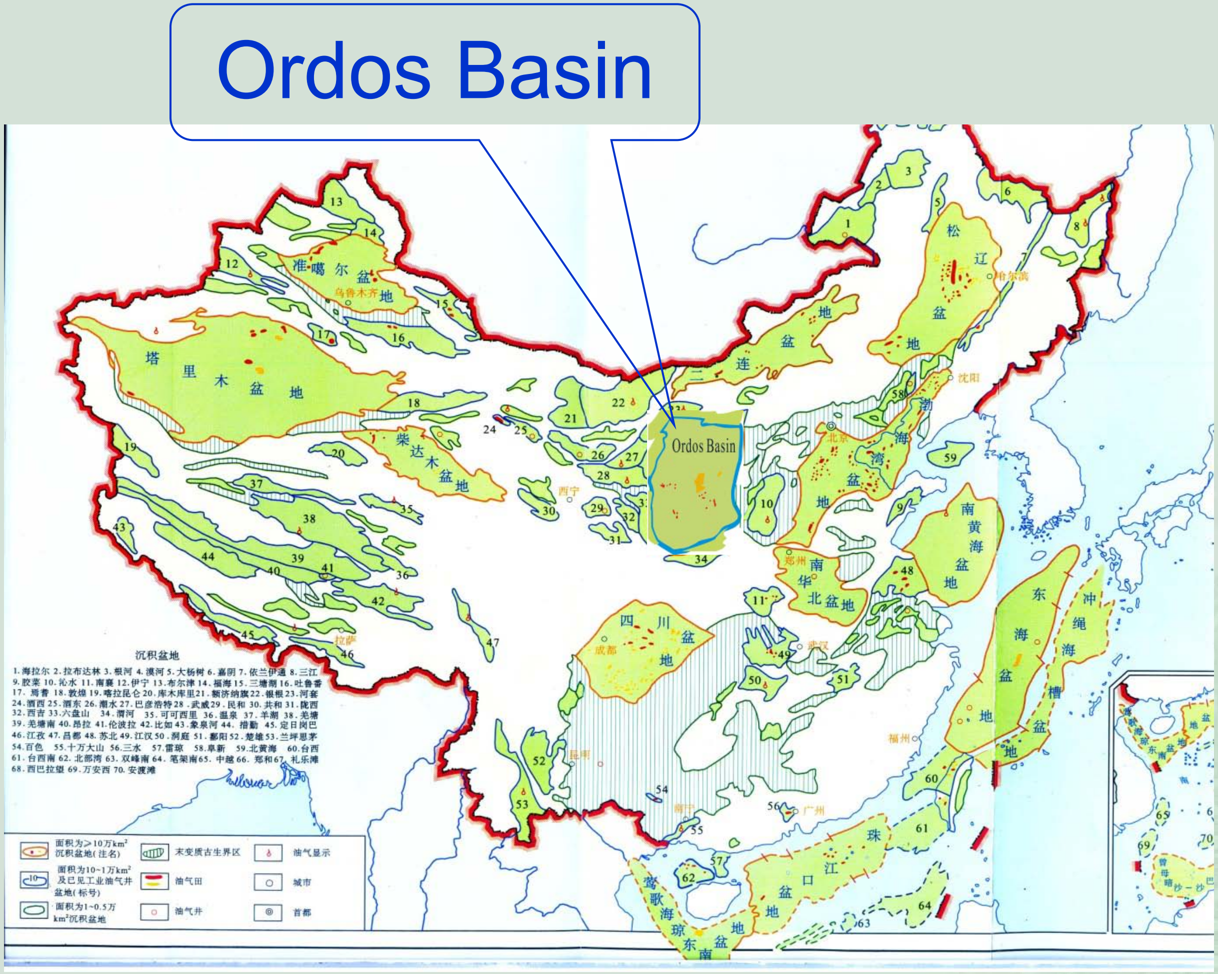
Authigenic illite in the sandstone reservoirs of Taiyuan Formation

- Abundance, Occurance, Morphology

Origin of authigenic illite in the Taiyuan Formation

- Implications for pore fluid chemistry
- Source of potassium for illite precipitation

Basin Location



Map of Basins in China

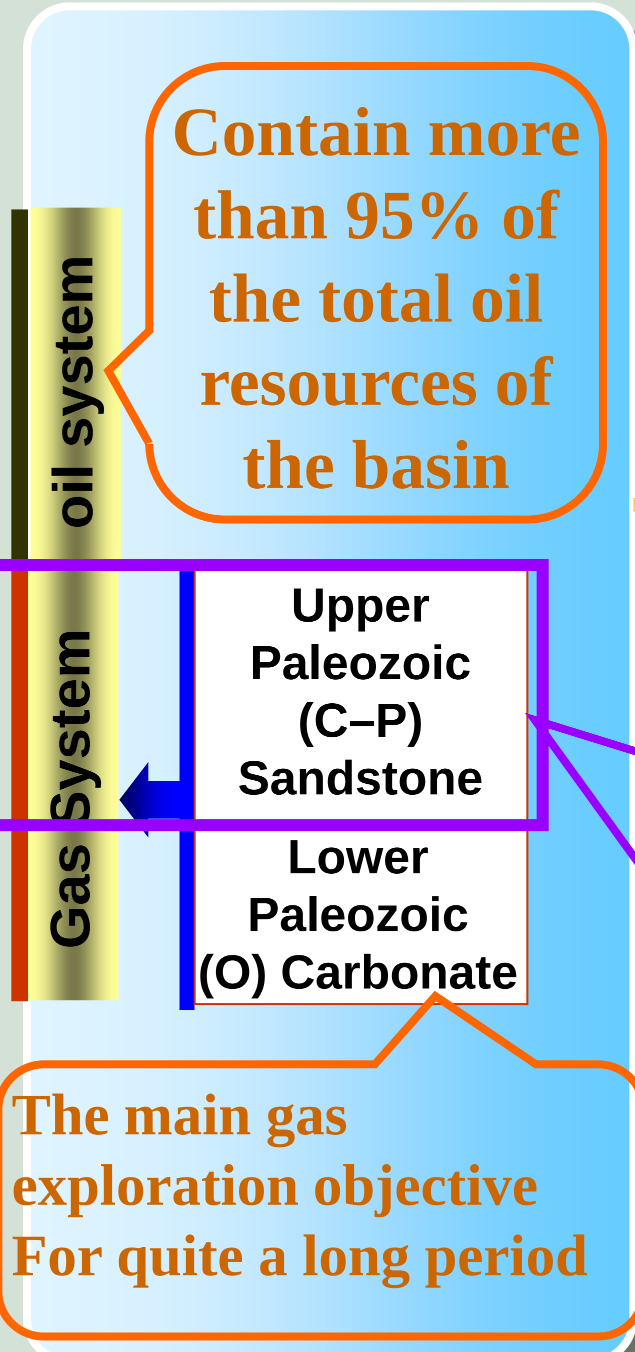
One of the largest, the oldest, and still an important hydrocarbon Province in China

Contains sediments with a total thickness of 4000–6000m

Covers an area of 320,000km^2

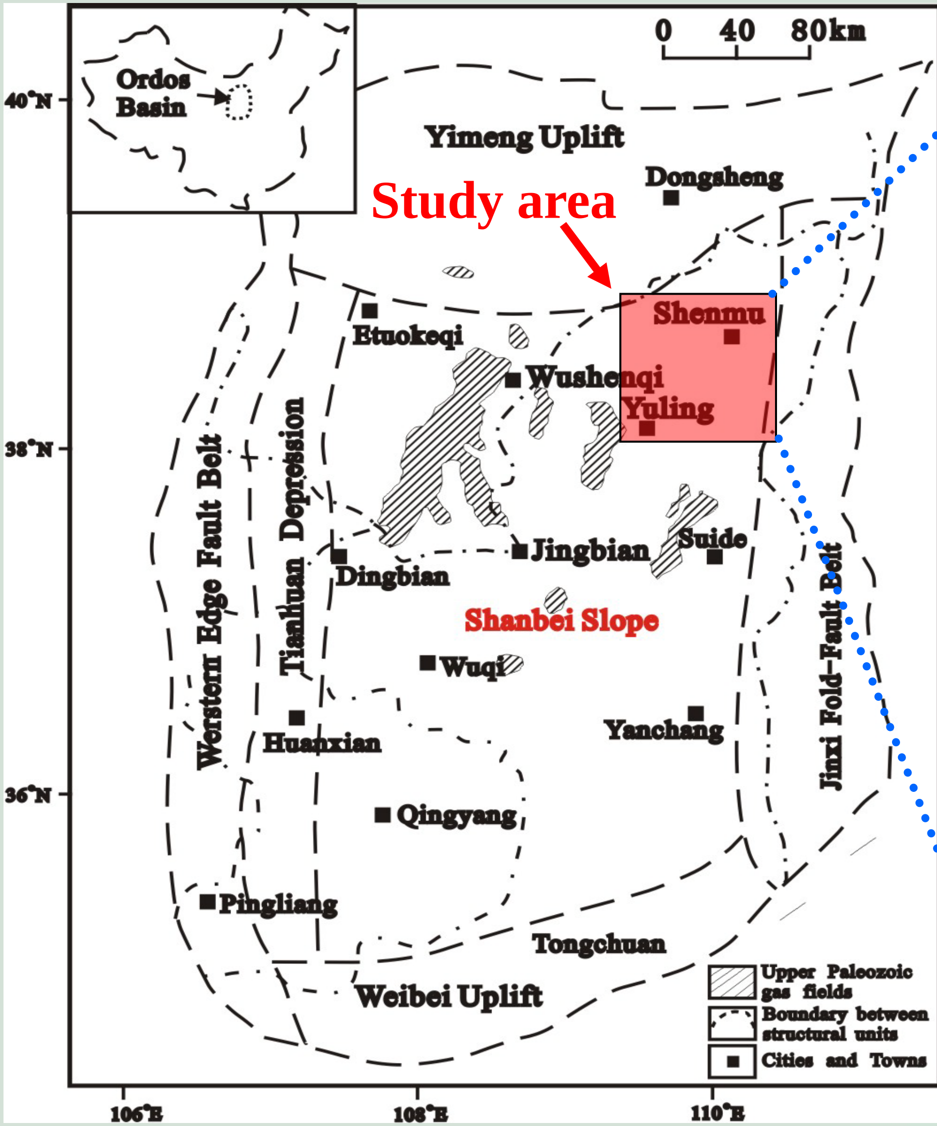
Hydrocarbon systems in the Ordos Basin

Stratigraphic System			Group/ Formation	Thickness (m)
Cenozoic	Neogene			
	Paleogene			
Mesozoic	Cretaceous	K_1	Zhidan	100-1200
	Jurassic	J_3	Fenfanghe	100-1200
		J_2	Anding	150
			Zhiluo	200-600
		J_1	Yanan	250-300
	Triassic	T_3	Fuxian	0-156
			Yanchang	200-1400
		T_2	Zhifang	1100
		T_1	Liujiagou	260-280
Paleozoic	Permian	P_3	Shiqianfeng	250-280
		P_2	Shangshihezhi	140-200
			Xiashihezhi	100-200
		P_1	Shanxi	37-125
	Carboniferous	C_2	Taiyuan	22-276
			Benxi	0-40
	Ordovician	O_3	Beiguoshan	270-800
			Jiangjiawan	230
		O_2	Pingliang	130-215
		O_1	Majiagou	100-900
	Cambrian	ϵ_3	Changshan	90
			Gushan	270
		ϵ_2	Zhangxia	170
			Xuzhuang	120
		ϵ_1	Mantou	70
			Houjiashan	100
Proterozoic				
Archean				

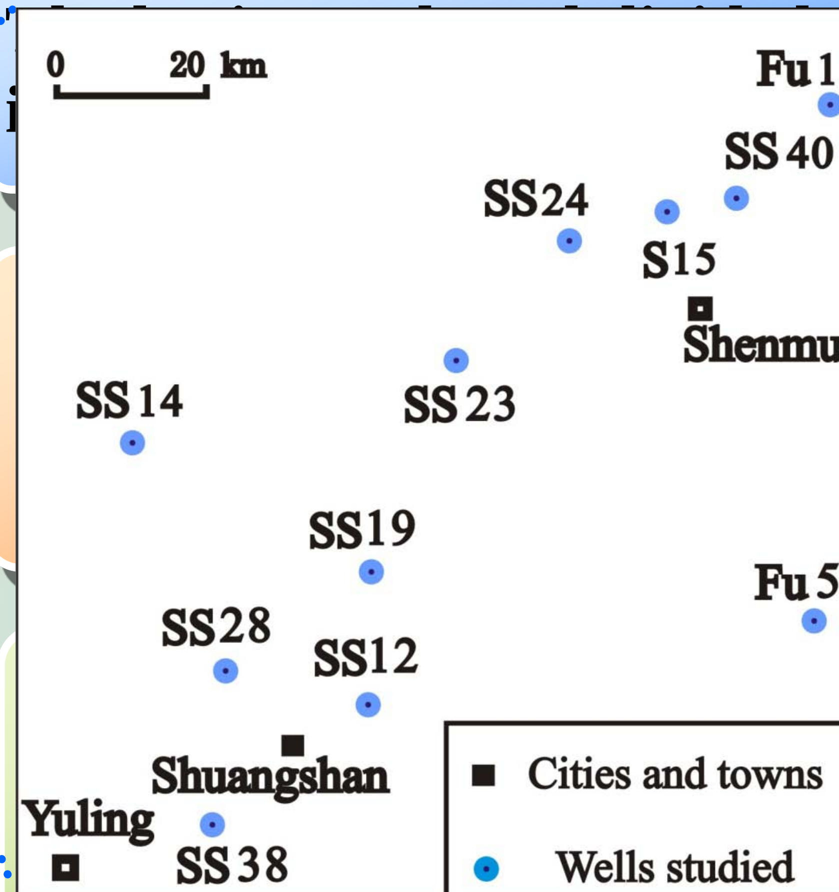


Successions involved in our project "Role of diagenesis on reservoir quality in Upper Paleozoic sandstones, Ordos basin"

Study Area



Index map of the Ordos basin structural units. Upper Paleozoic gas fields shaded.



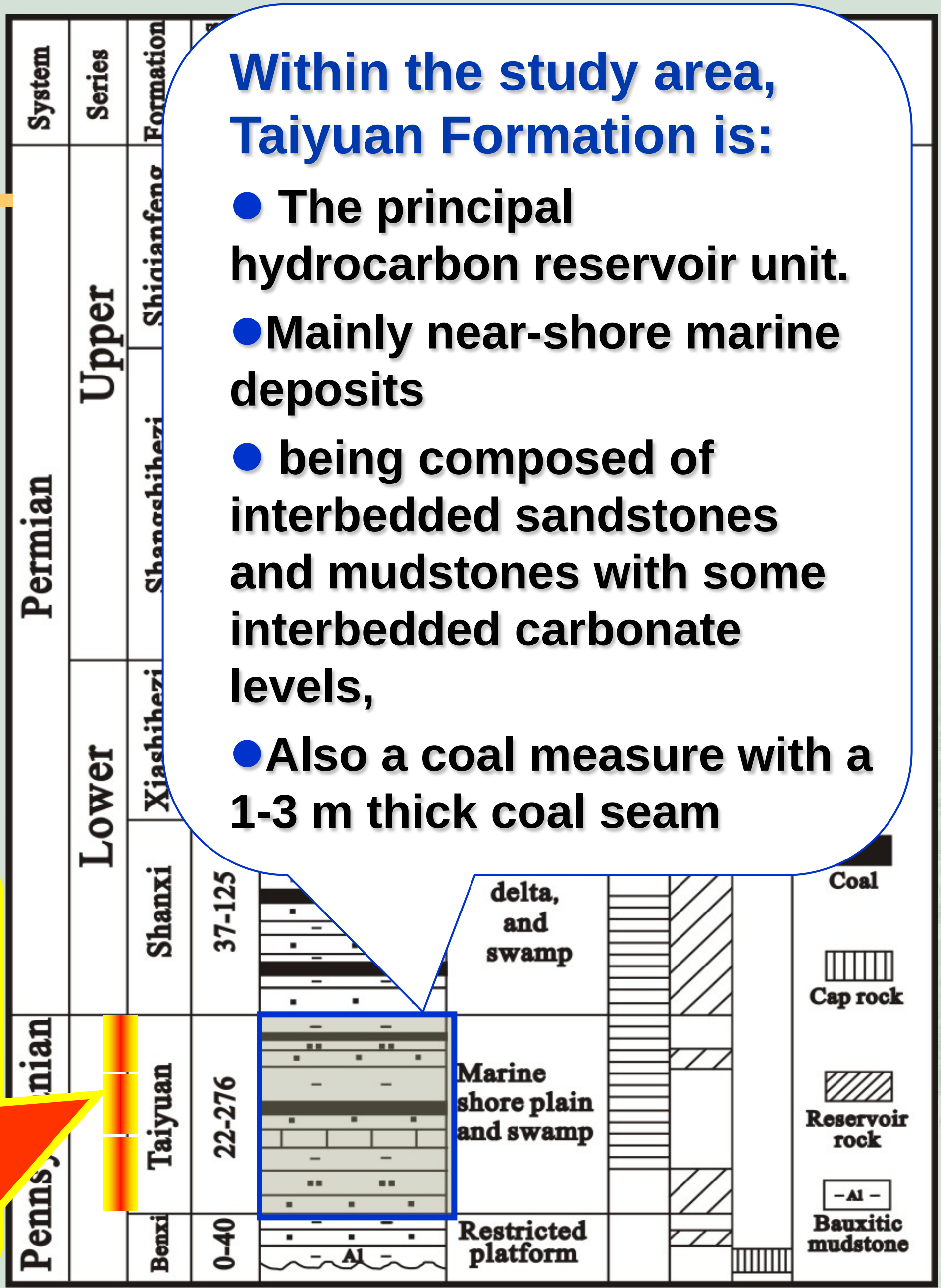
northeast part of the basin

Geologic Properties

The gas system is characterized by widely distributed coal measure source rocks and tight sandstone reservoirs

- *Source Rocks*
  - *—Coals and associated dark mudstones occurring in the Carboniferous–lower Permian coal measures*
- *Cap Rocks*
  - *—Thick mudstone in the upper Permian strata*
- *Reservoirs*
  - *—Mainly Pennsylvanian–early Permian tight sandstones*

the focus of this study



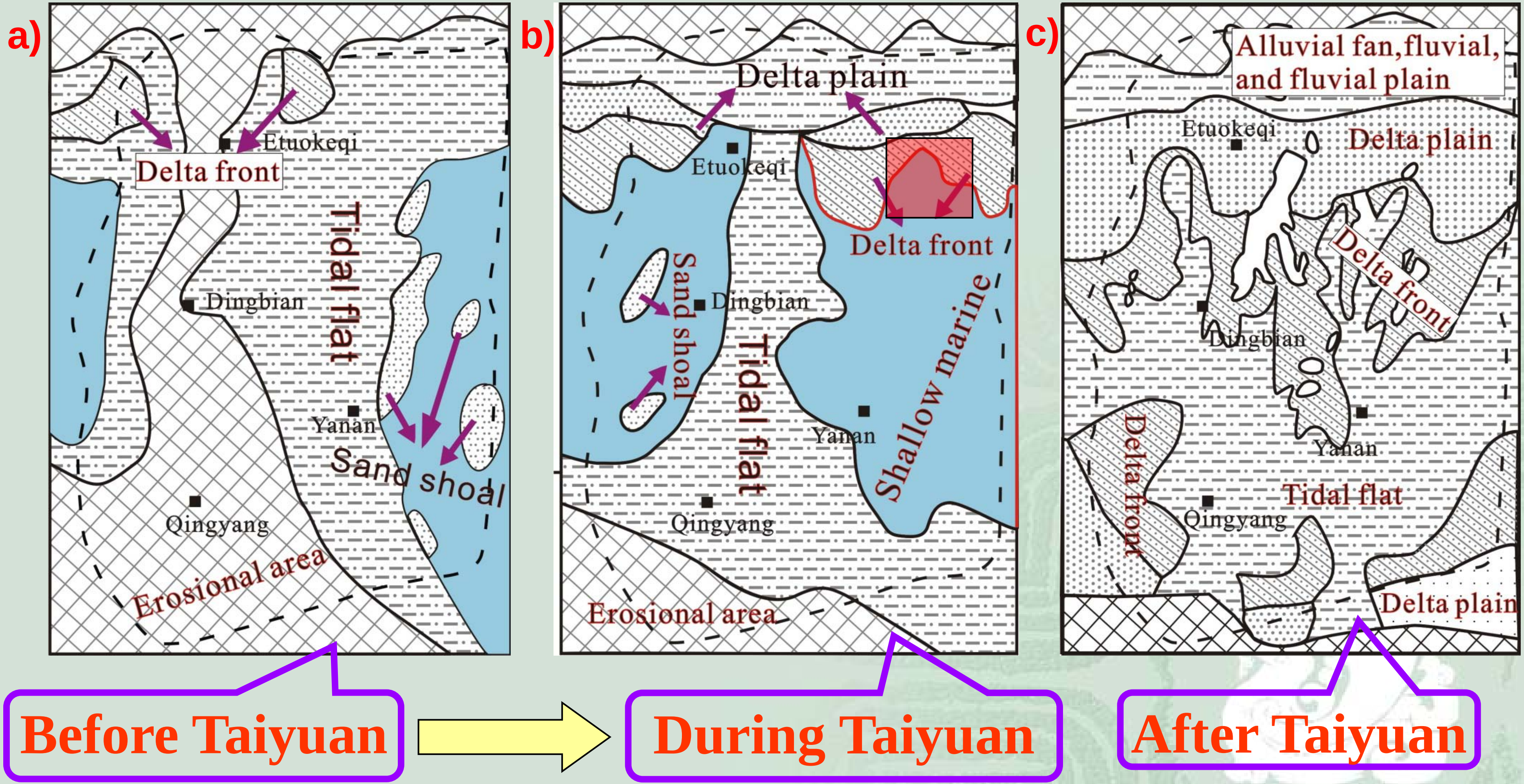
Within the study area, Taiyuan Formation is:

- The principal hydrocarbon reservoir unit.
- Mainly near-shore marine deposits
- being composed of interbedded sandstones and mudstones with some interbedded carbonate levels,
- Also a coal measure with a 1-3 m thick coal seam

Stratigraphic columns, depositional environments, and source-reservoir-seal associations in the Ordos basin for the Upper Paleozoic. after Yang et al., 2005

Sedimentary facies

Maps of sedimentary facies in the Ordos basin during the deposition of
a) Benxi Formation; b)Taiyuan Formation and c) Shanxi&Xiashihezi Formations

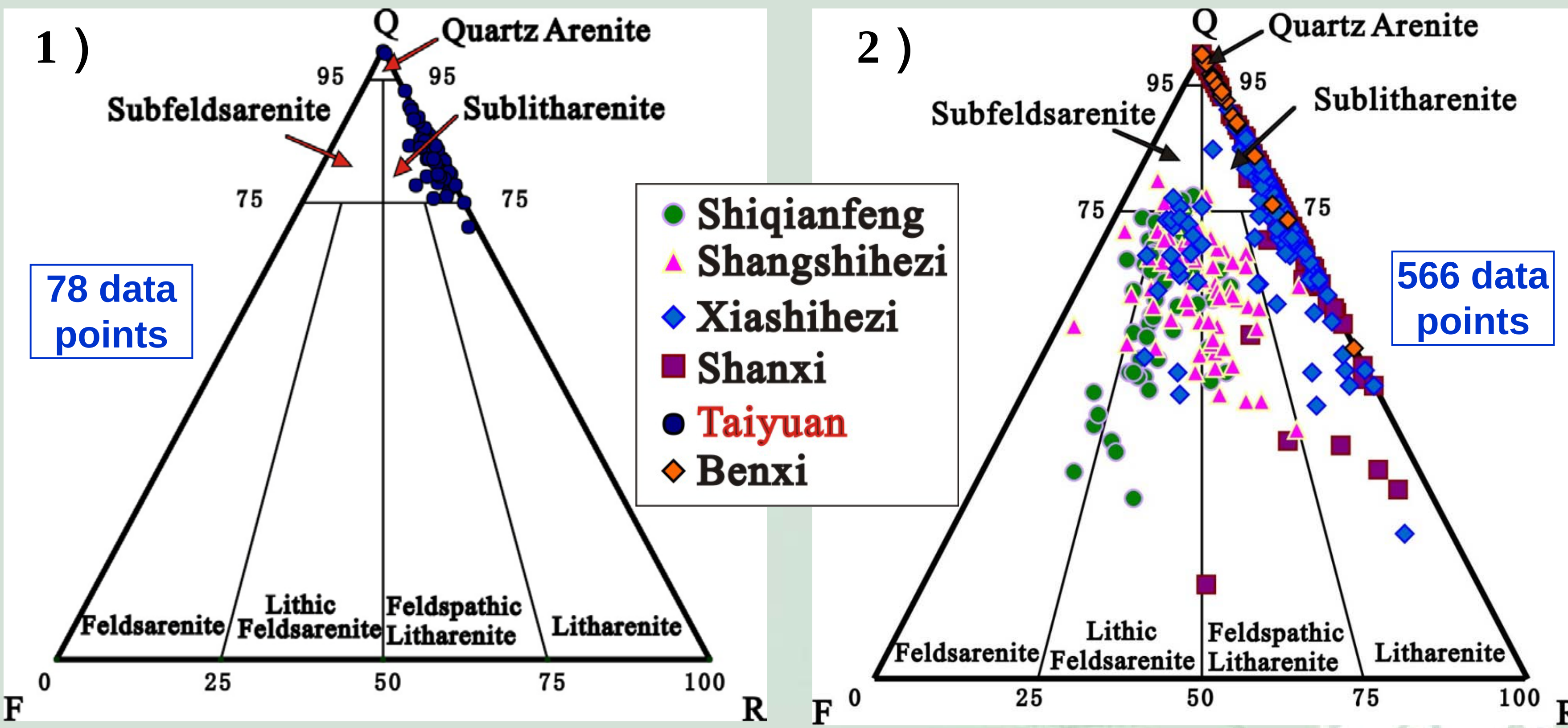


Miaogou transgression

Modified after Yang et al., 2005

Petrologic data

——Framework grain composition of sandstones



Classification of sandstone samples collected from :

1) Taiyuan Formation 2) Other Formations of Upper paleozoic strata

Questions

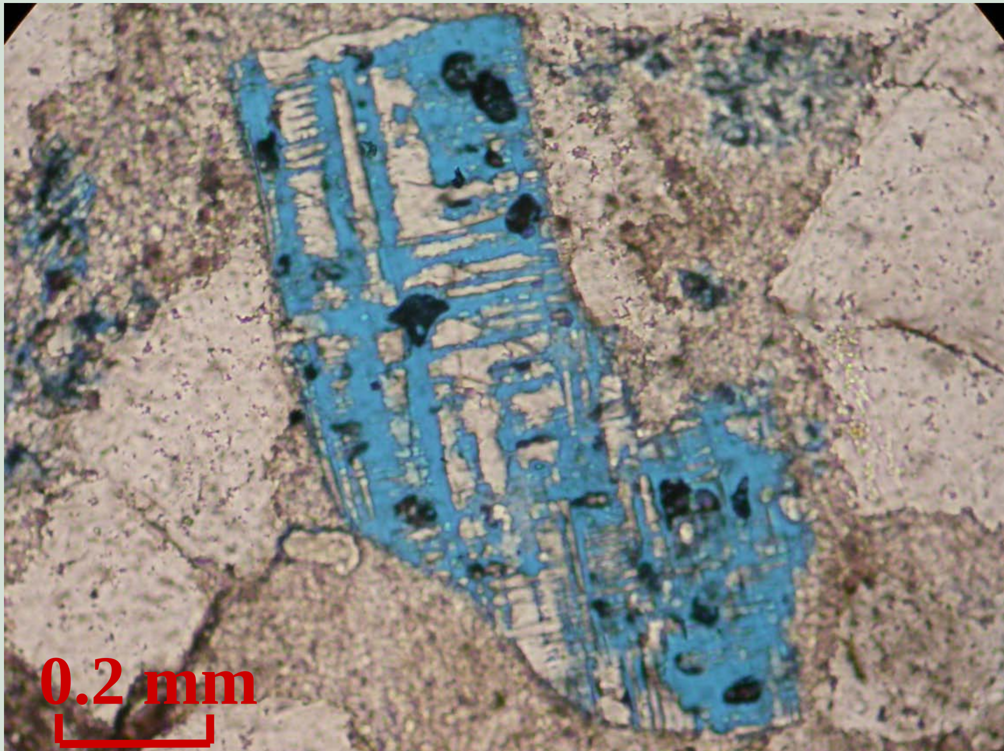
What created this nearly absence of feldspar in the Taiyuan Formation samples?

—— Depositional or diagenetic?

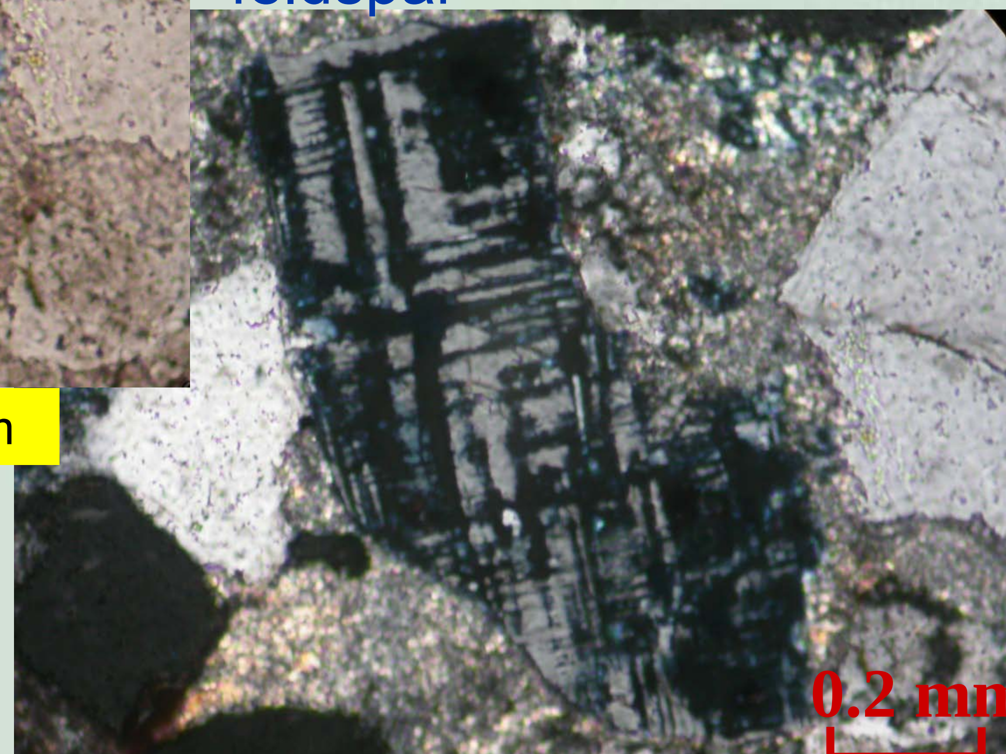
How does it compared to the samples from other Formations?

Petrographic evidence of feldspar dissolution

A feldspar crystal has been partially removed by dissolution, leaving molded pores and remnant portions of feldspar

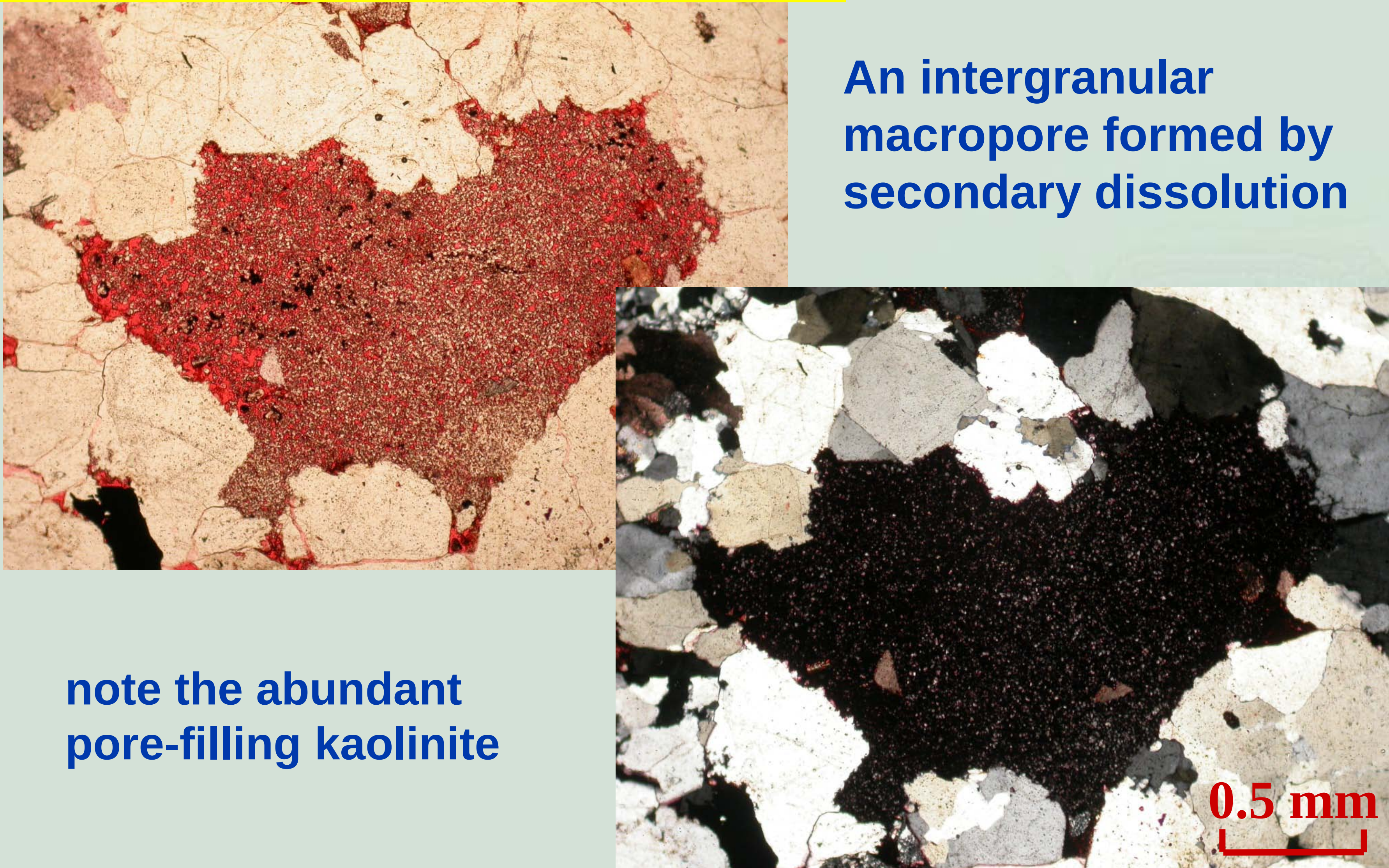


Well S19,Taiyuan Formation, 2439.5m



Petrographic evidence of feldspar dissolution

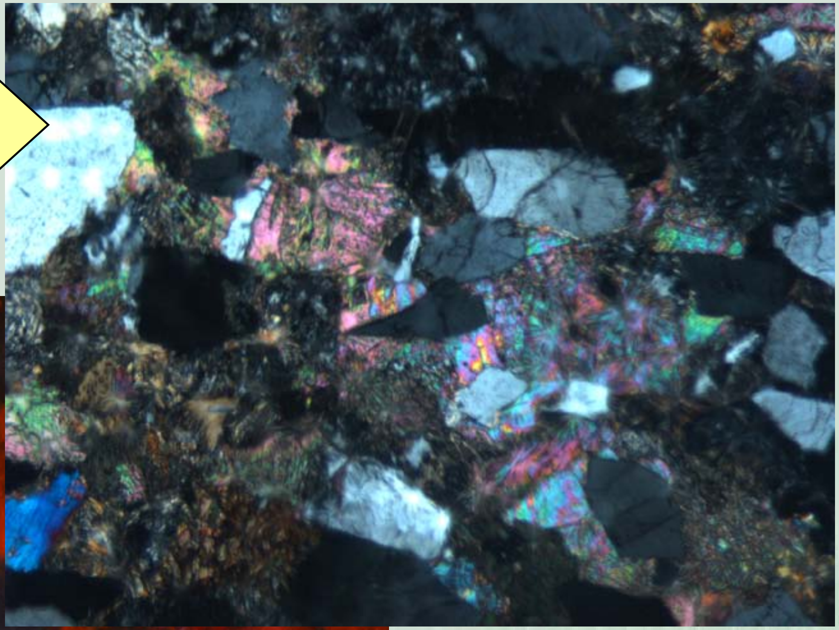
Well F1, Member 2 of **Shanxi** Formation, 2081.82m

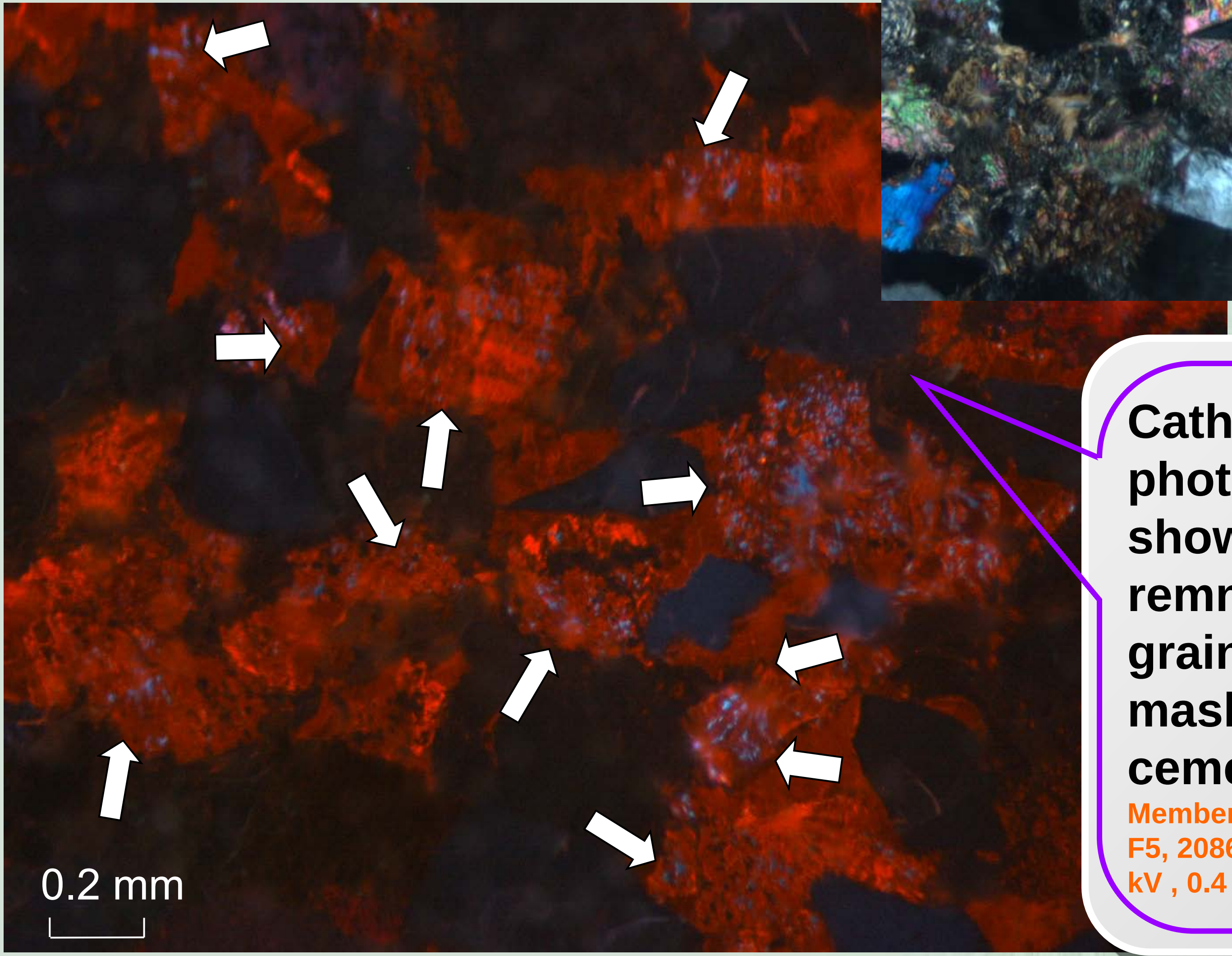


An intergranular macropore formed by secondary dissolution

note the abundant pore-filling kaolinite

A feldspar-absent sample with extensive calcite cementation



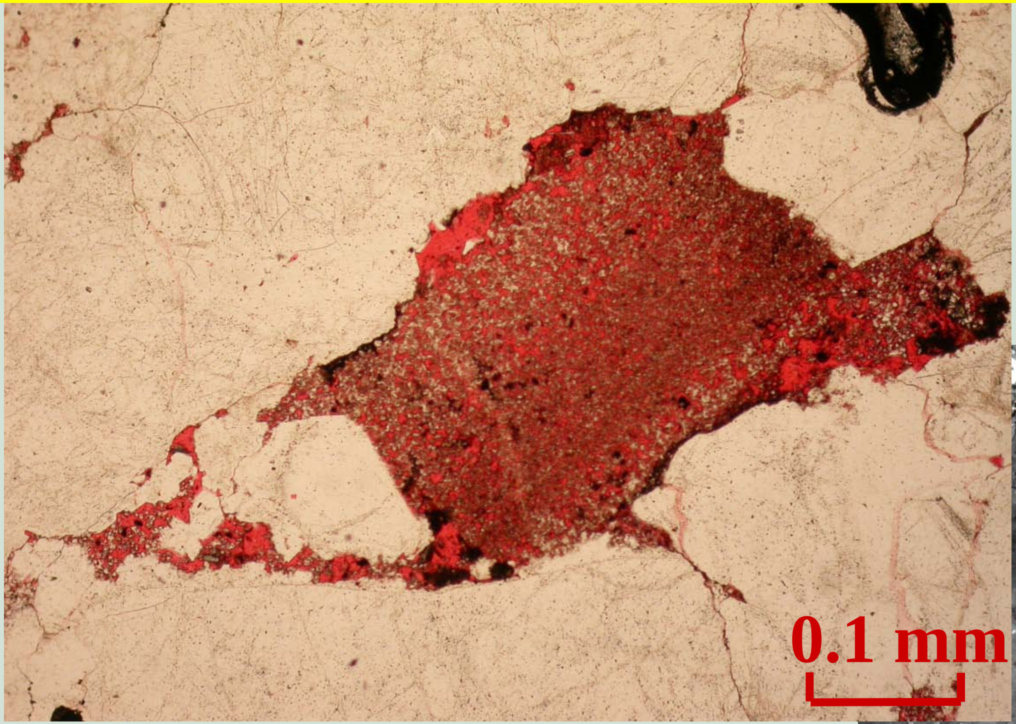


Cathodoluminescence photomicrograph showing the dissolved remnant feldspar grains, which were masked by calcite cements.

Member 2 of Shanxi Formation, Well F5, 2086.9m. Operating condition: 10 kV , 0.4 mA.

Petrographic evidence of feldspar dissolution

Well SS12, Xiashihezi Formation, 2328.52m

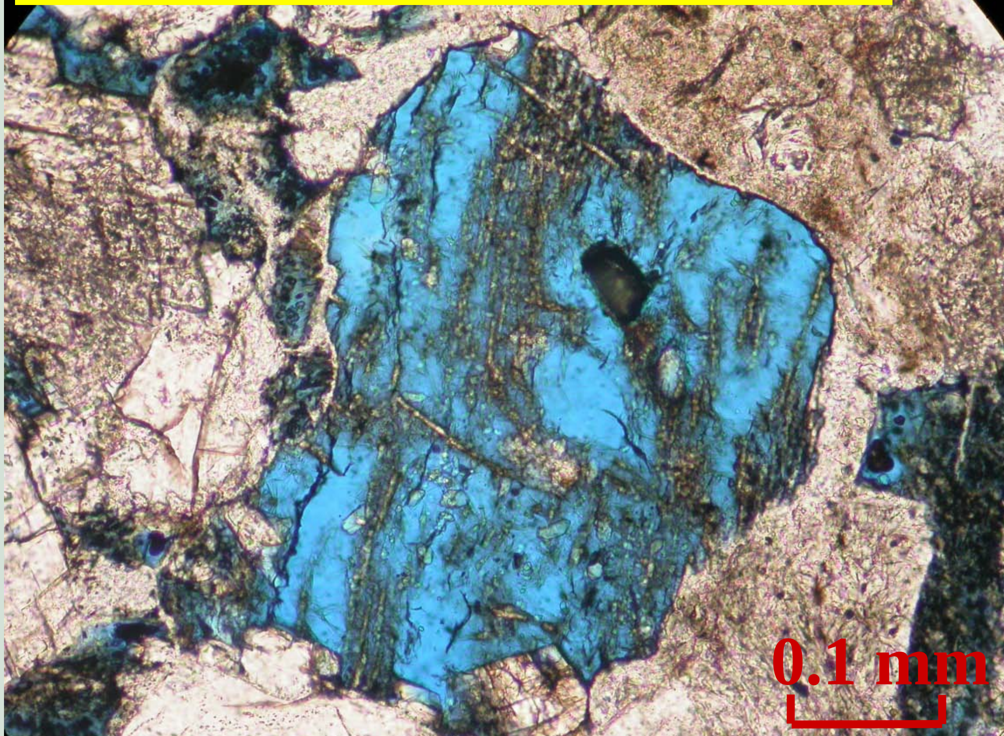


Feldspar grain has been almost completely dissolved, leaving molded pores and secondary clay mineral

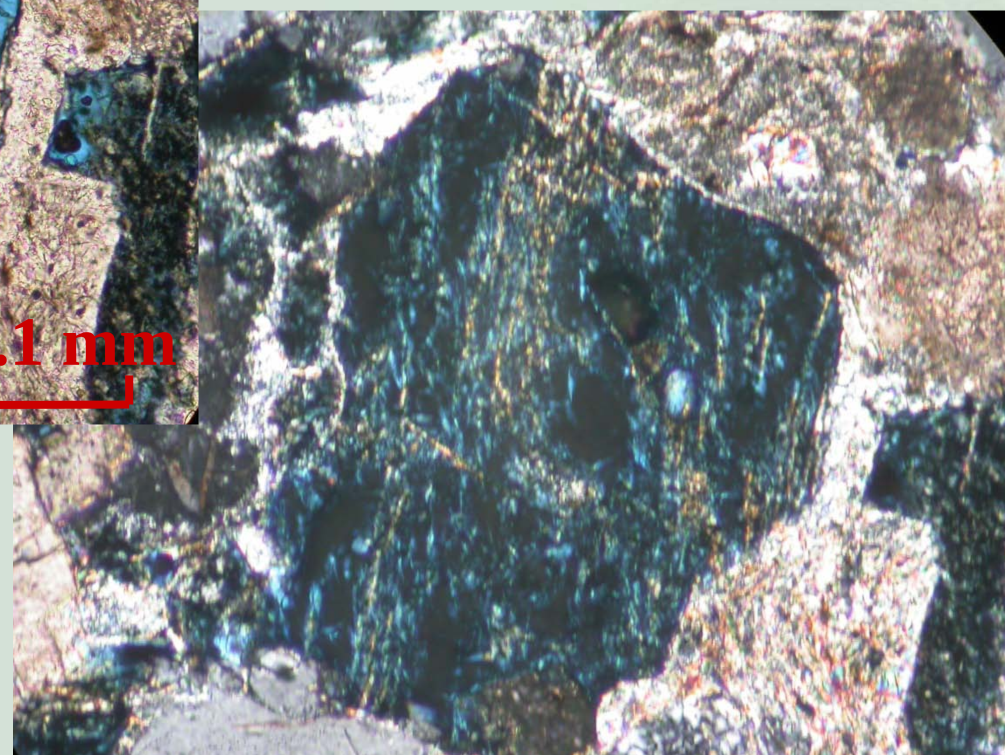
Note: dissolution of feldspar was accompanied by precipitation of authigenic kaolinite

Petrographic evidence of feldspar dissolution

Well S19,Taiyuan Formation, 2439.5m



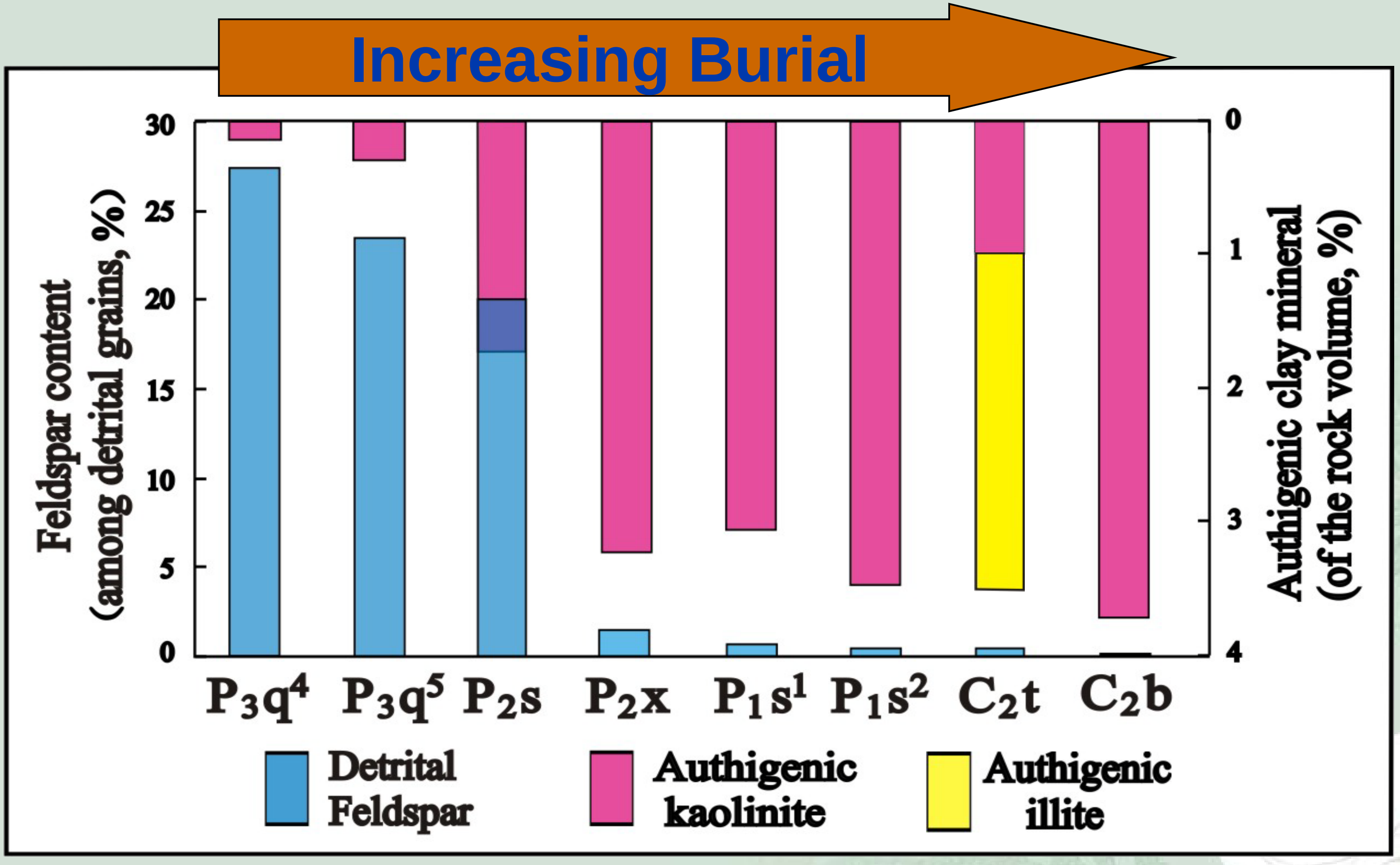
Feldspars have been completely dissolved, leaving molded pores and secondary clay minerals



Note: dissolution of feldspar was accompanied by precipitation of authigenic illite

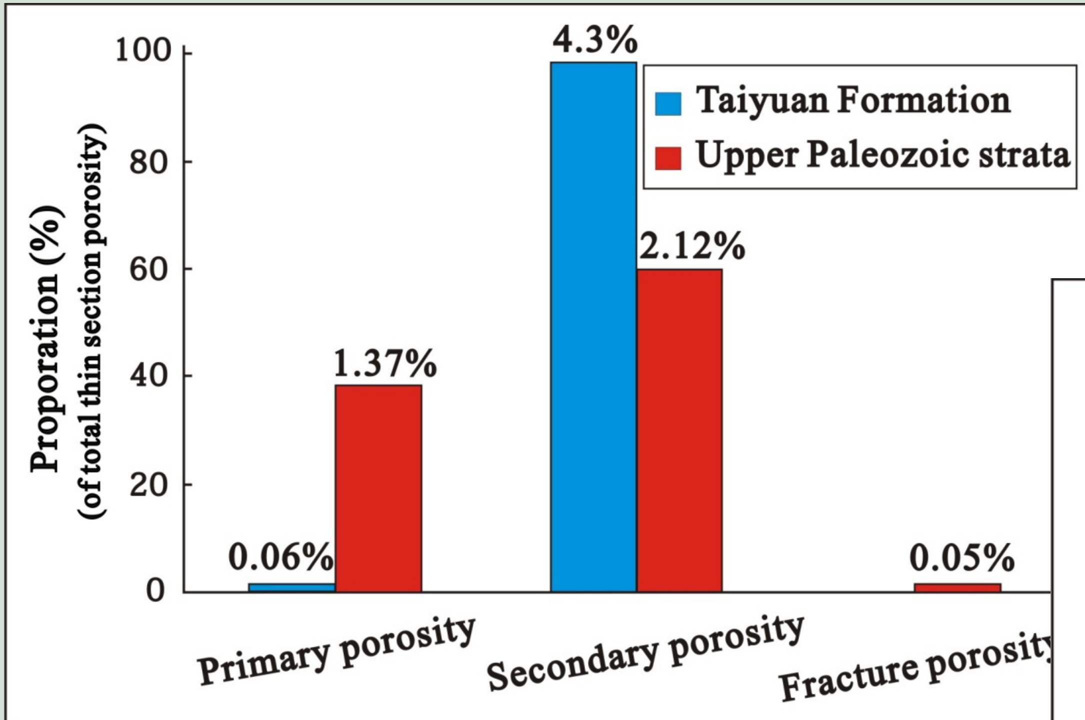
Petrologic data

—— Covariance of feldspar content with secondary clays

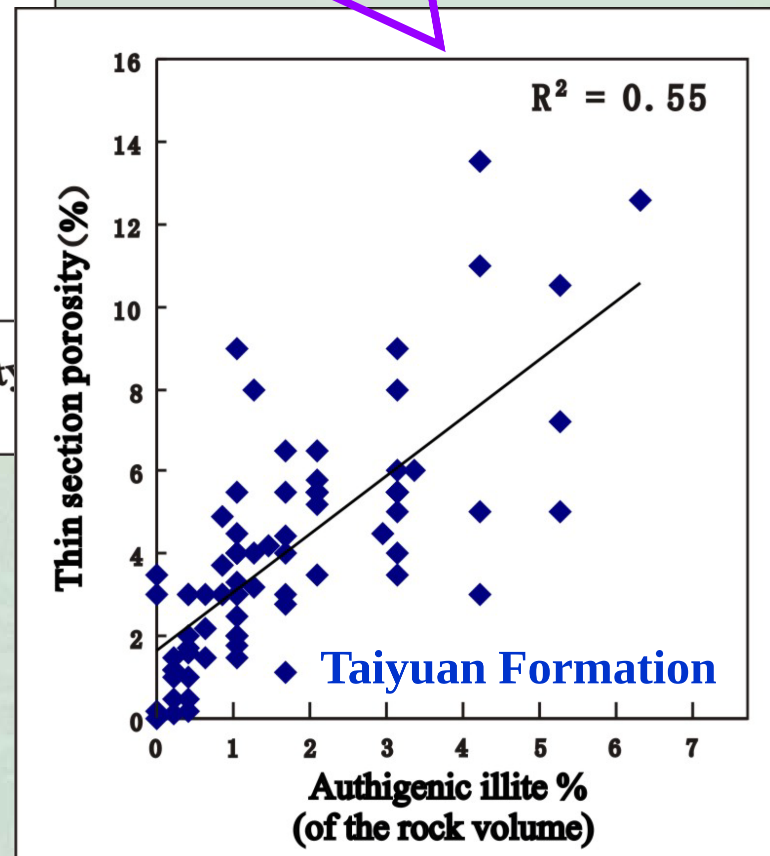


Taiyuan Formation dose not match general feldspar-kaolinite content covariance trend represented in other Upper Paleozoic sandstones

Amounts of main pore types

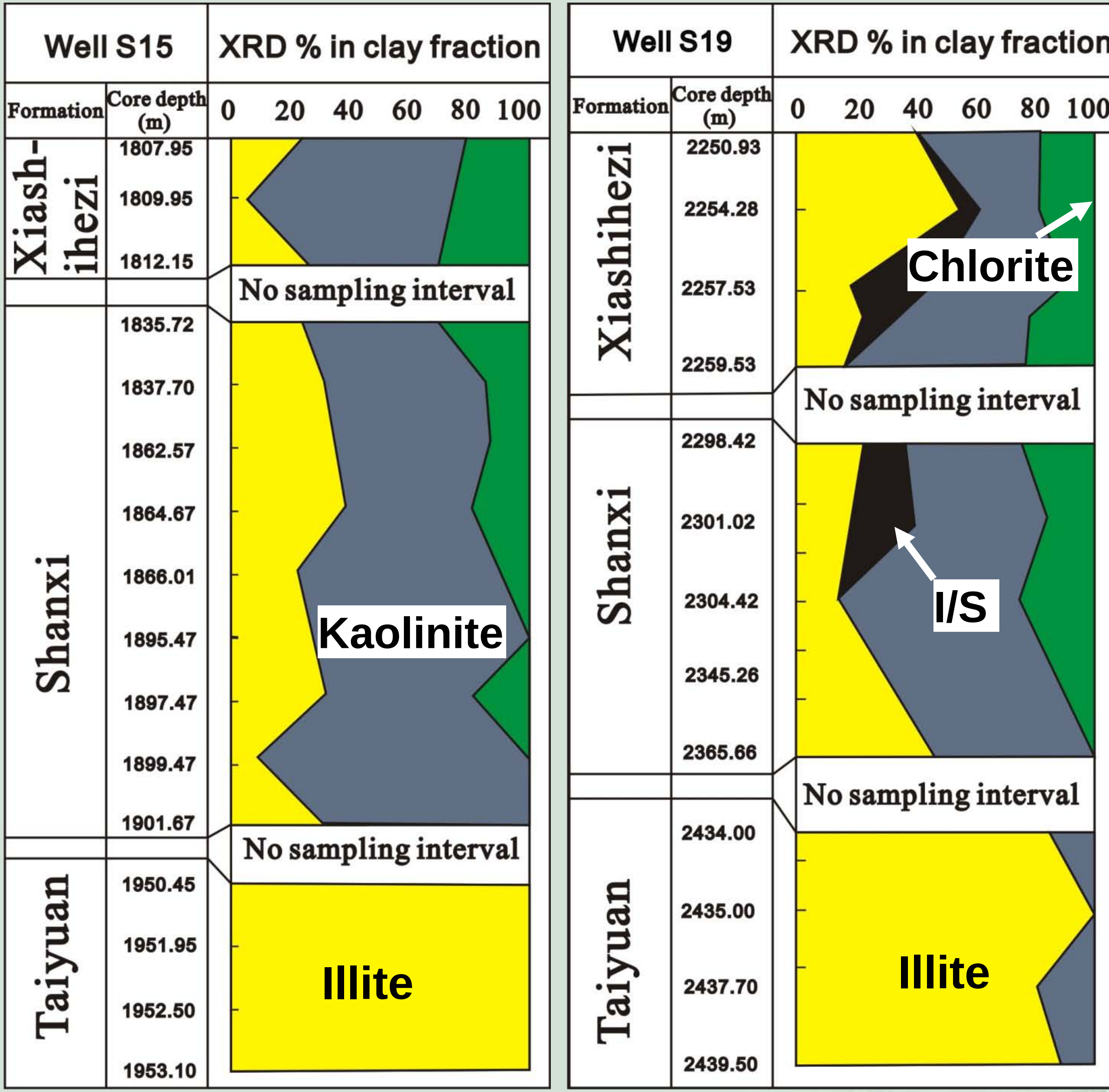


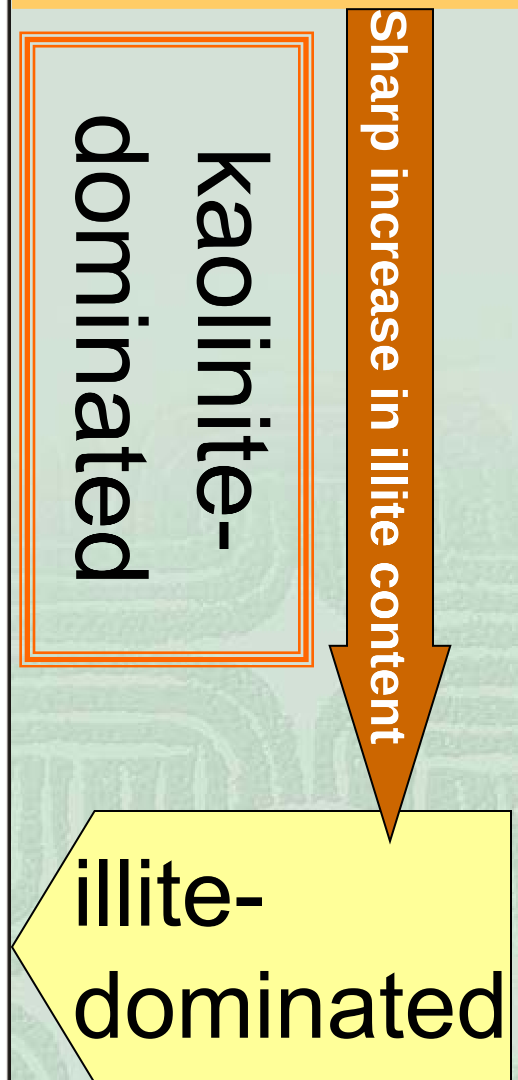
Increased porosity towards the greater degree of illitization



- The pores of upper Paleozoic sandstone reservoirs are mainly secondary in origin
- Secondary porosity (predominantly provided by dissolution of feldspar grains) is nearly the only type of porosity observed in Taiyuan Formation

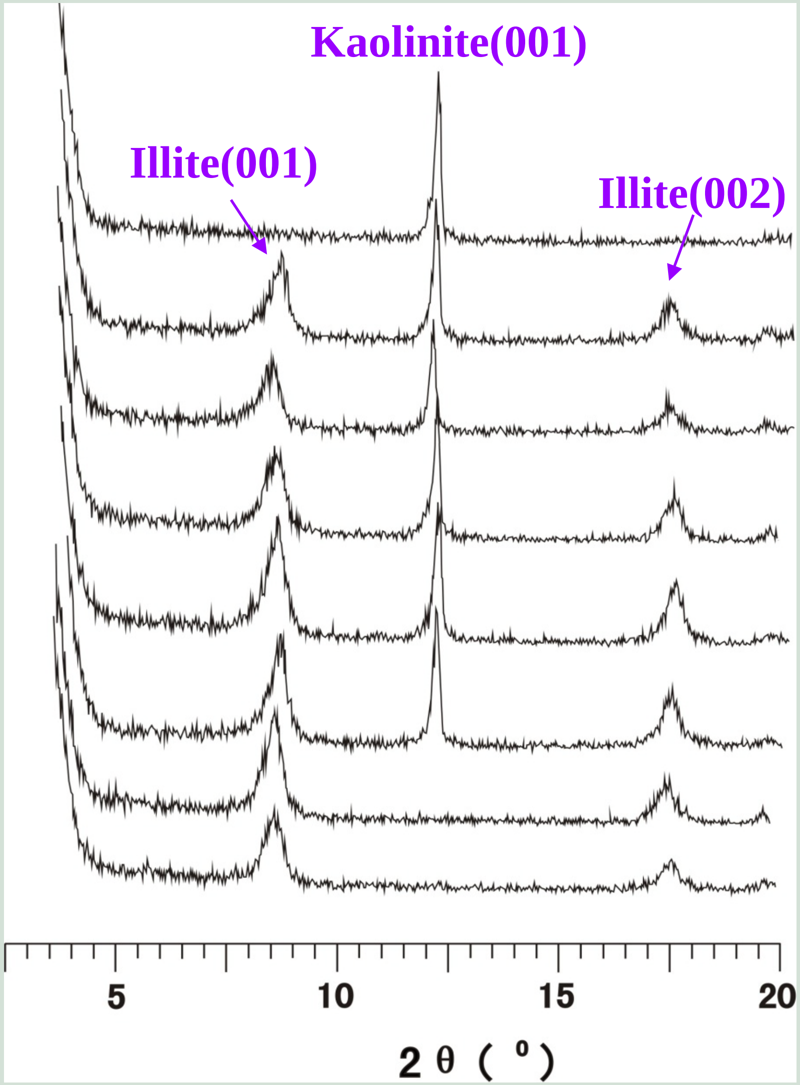
Clay XRD Results



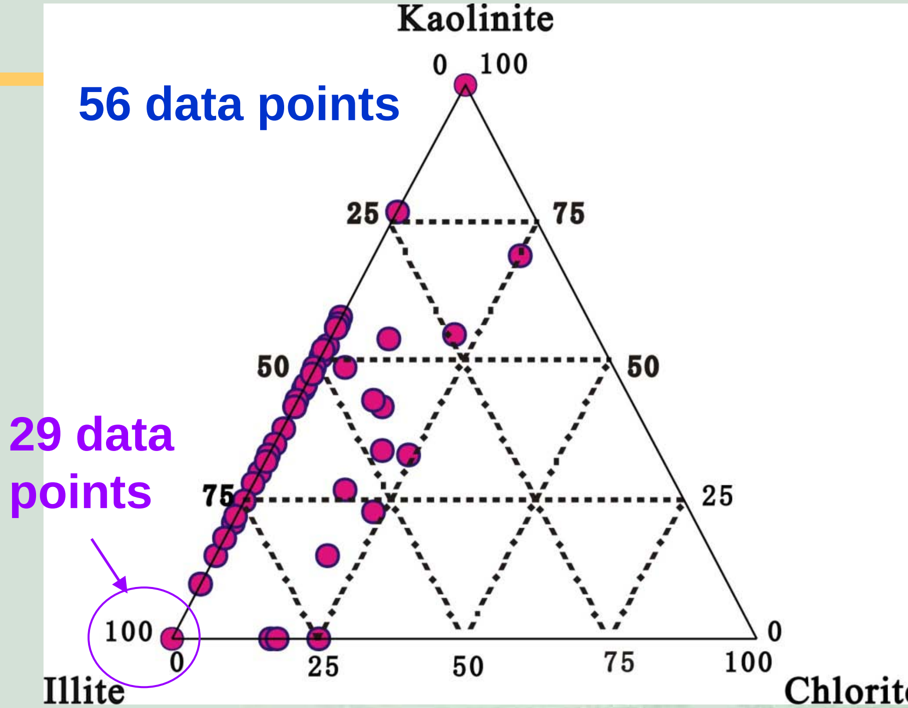


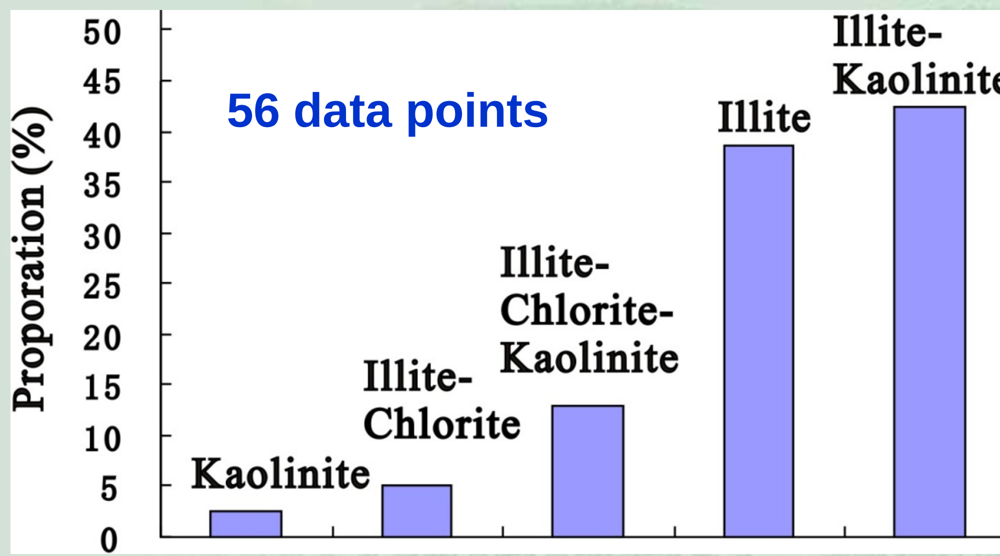
Vertical distribution of clay minerals(<2μm) in two of the wells studied

Clay XRD Results



Representative XRD patterns of the <2μm fraction of 8 samples

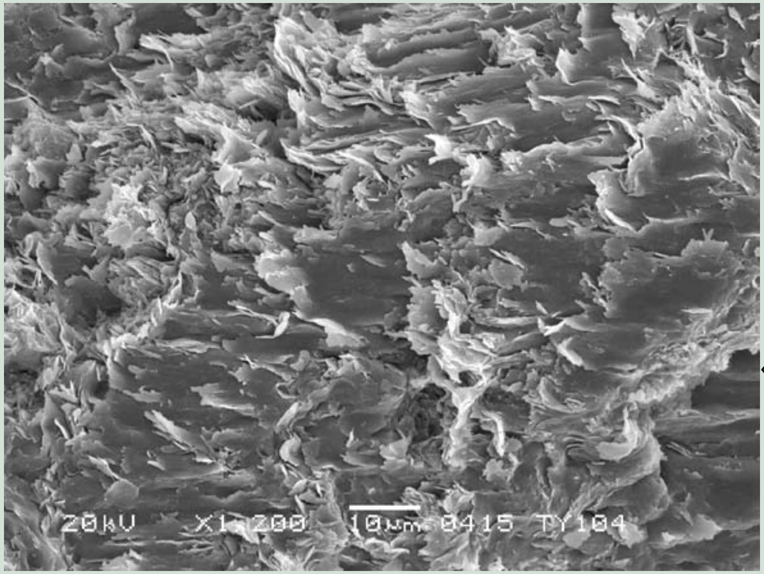




Types of illite

Detrital illite

- ***Abundance:*** volumetrically minor
- ***Morphology:*** poorly-crystallized with wrinkled surface and blurred boundary
- ***Occurrence*:** as tangentially arranged, grain-lining, ragged plates

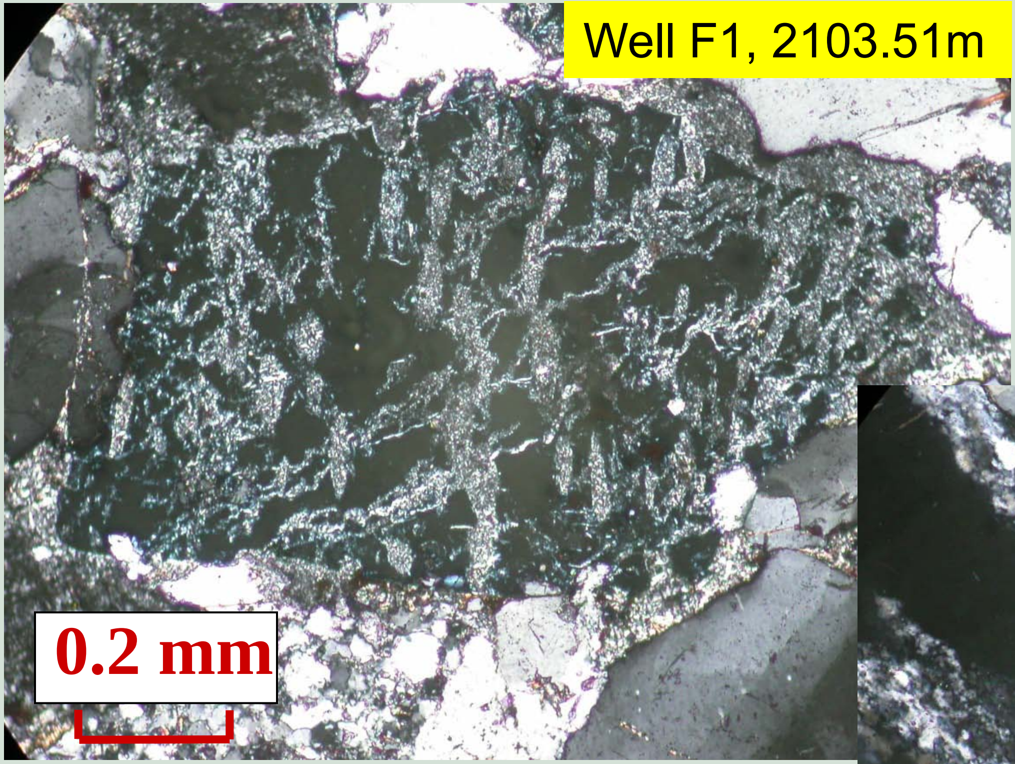


Authigenic illite

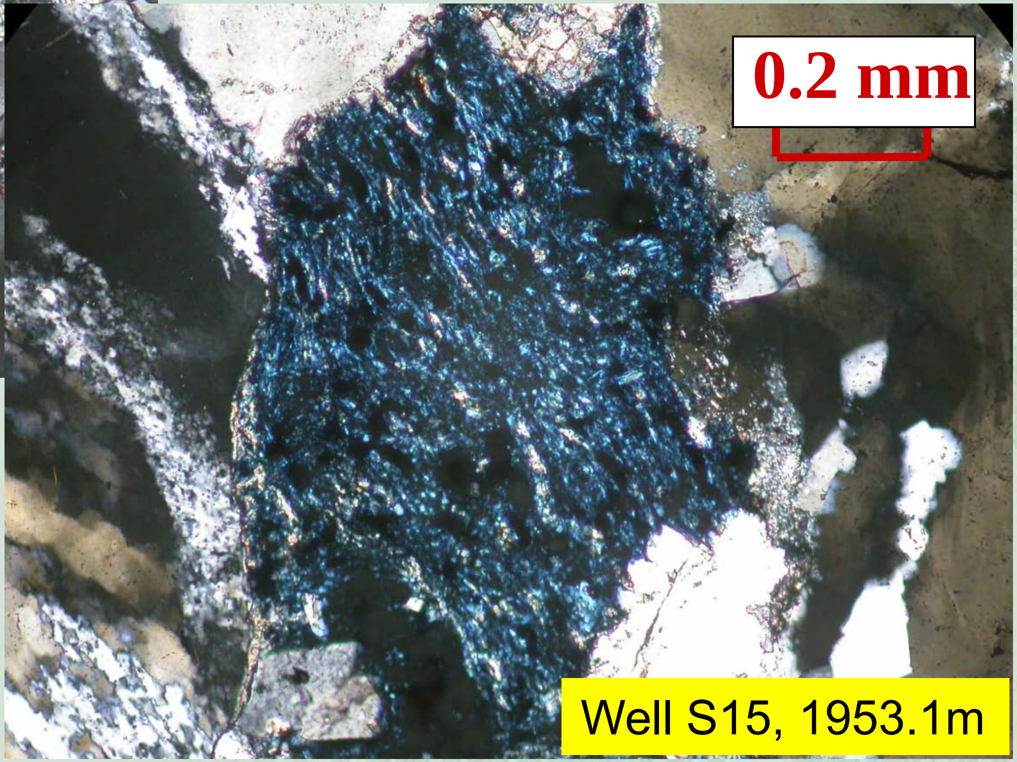
- ***Abundance:*** widespread
- ***Morphology:*** delicate, fibrous or lathy crystals
- ***Occurrence*:**
  - Pore-filling/bridging
  - Feldspar-replacing
  - Kaolinite-transitional
  - Grain-coating

Detrital illite: skins of tangentially arranged illite visible on grain surface.
Well:Shuang 28, Depth: 2787.28m

Pore-filling illite

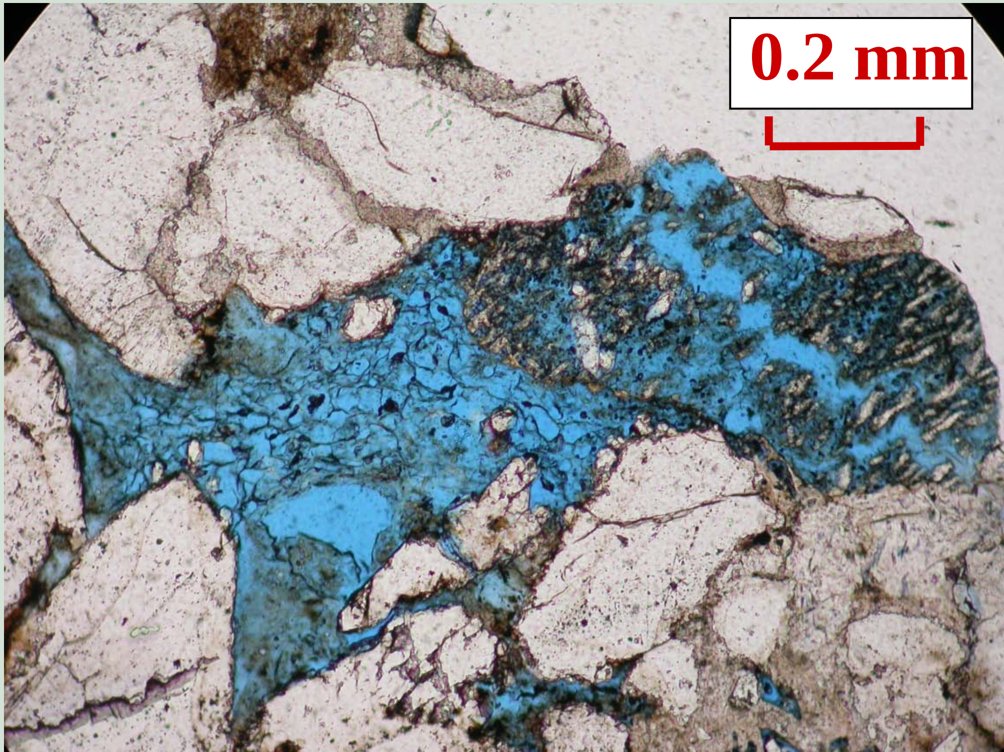


Thin section results: cross-polarized views showing the occurrence of authigenic illite within secondary grain dissolution pores

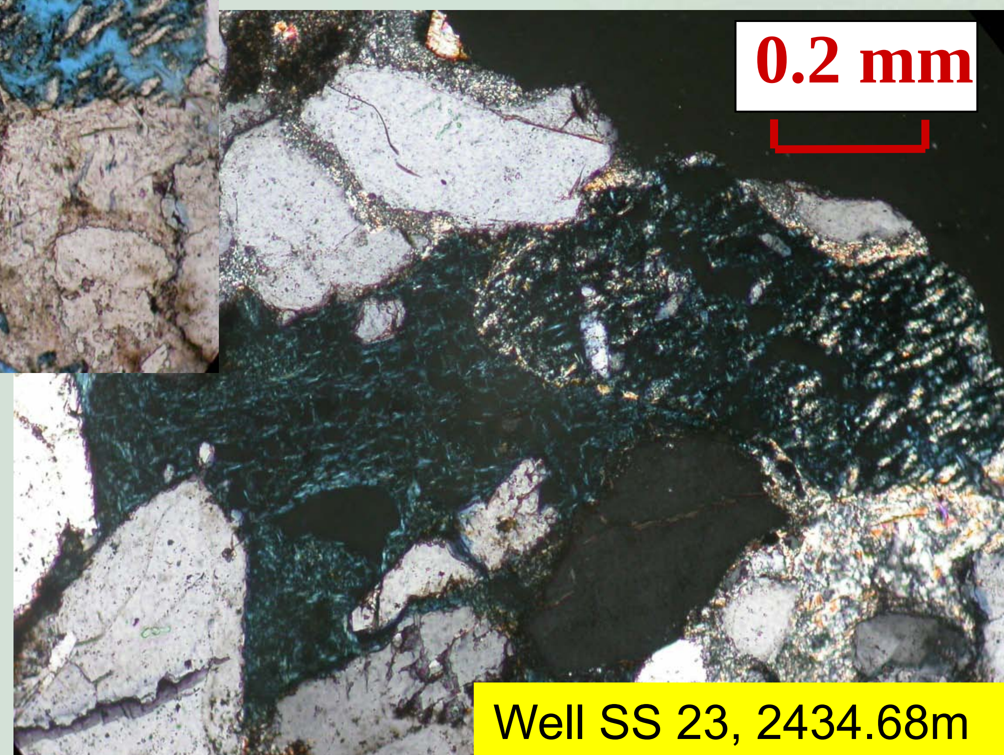


Note: the outlines of the original detrital feldspar shape are preserved

Pore-filling illite

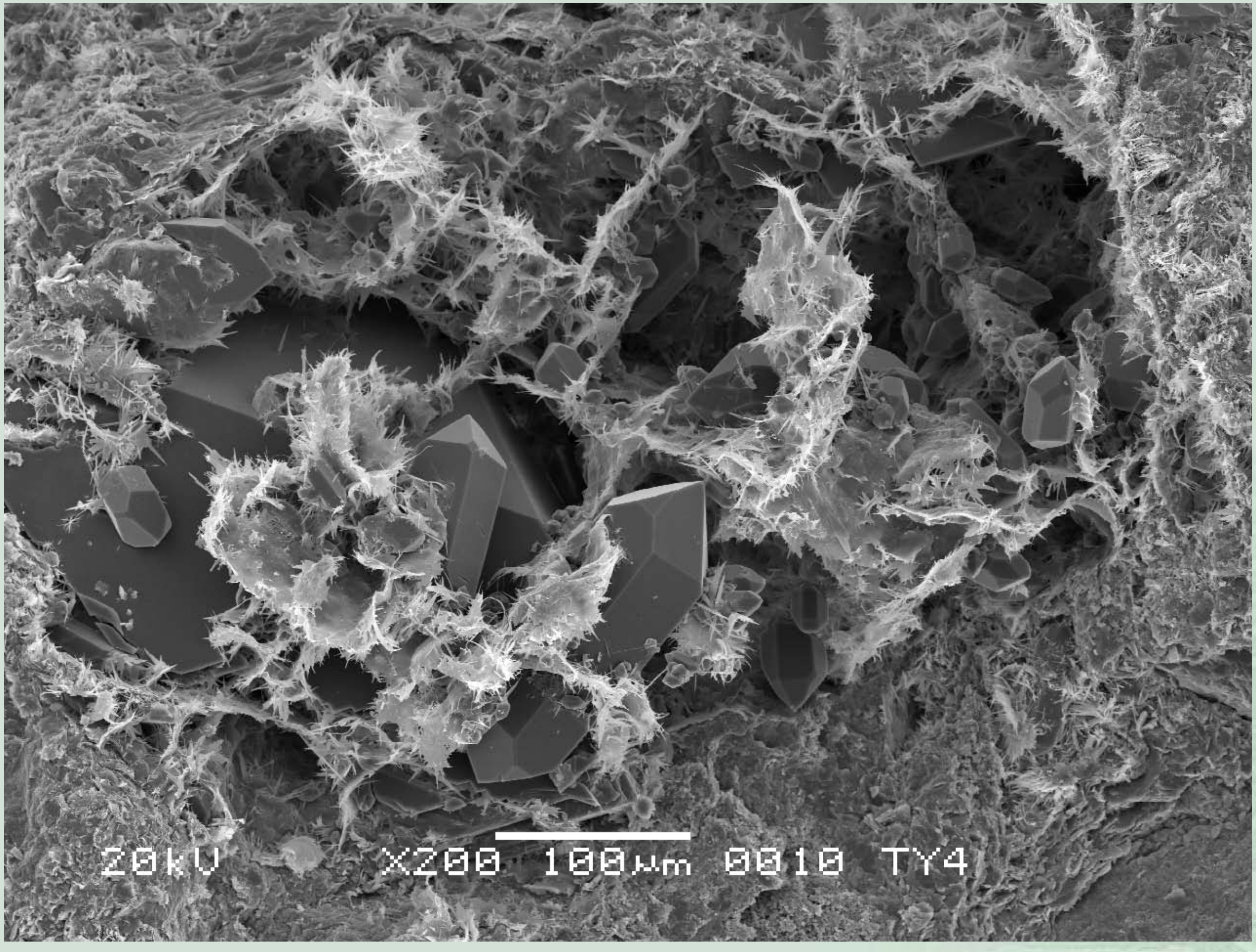


Thin section results: plane-polarized light and cross-polarized views showing the occurrence of authigenic illite within secondary grain dissolution pores



Note: Both the secondary dissolution porosity and secondary pore-filling illite cements are uncompacted

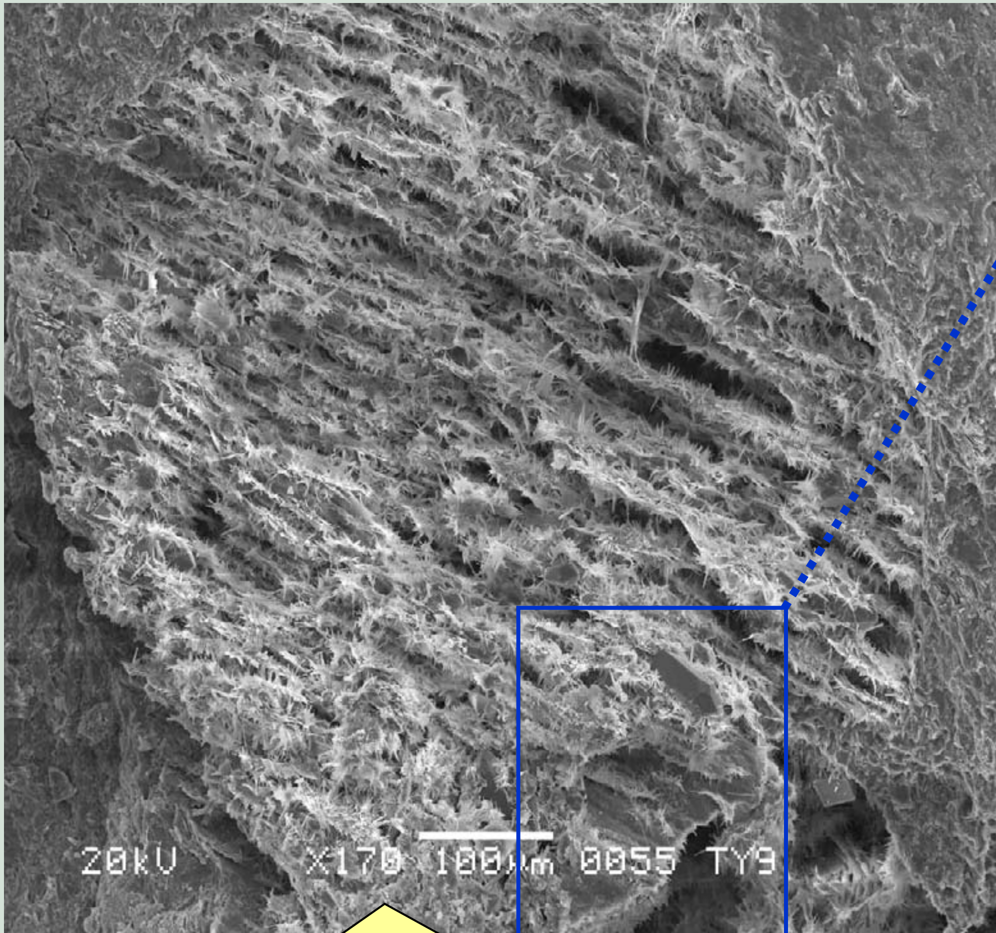
Pore-bridging illite



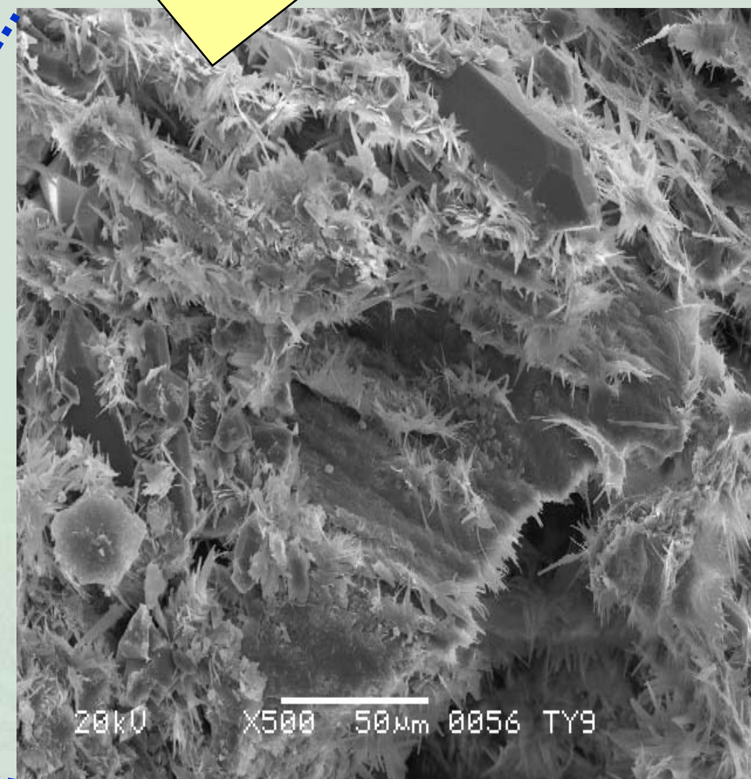
- **Growing along the general orthogonal orientation, possibly indicating feldspar cracks**
- **Apparent simultaneous growth of illite and quartz**
- **Note the conversion of the dissolution pore scale from macro to micro by this illite**

Well SS 14, 2792.2m

Feldspar-replacing



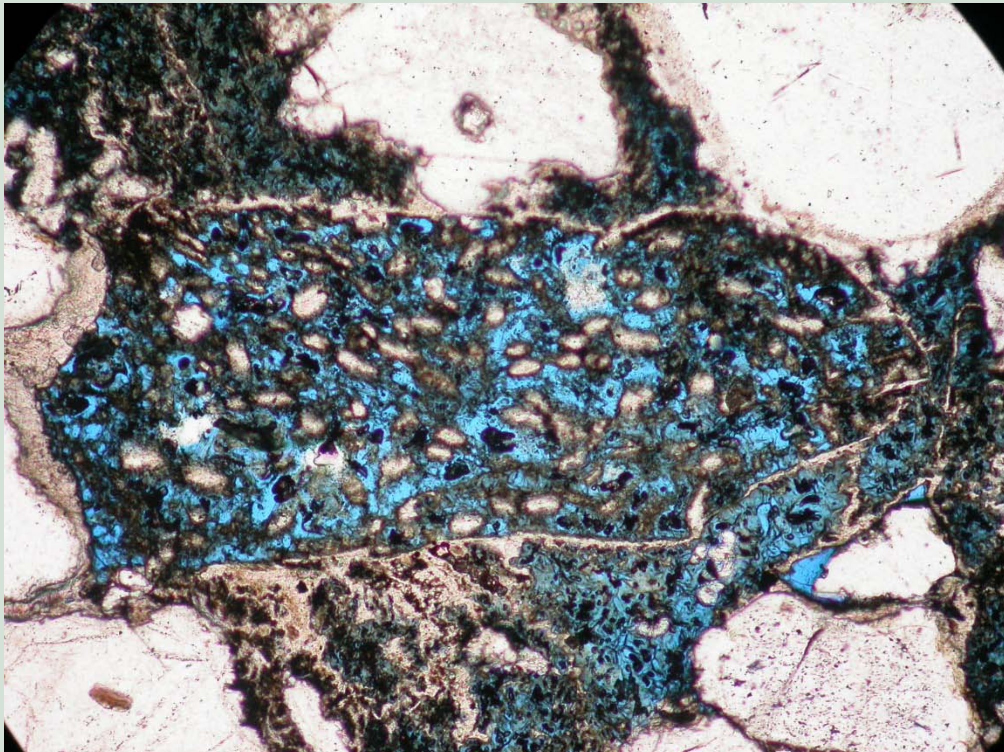
Remnant portions of feldspar and authigenic quartz



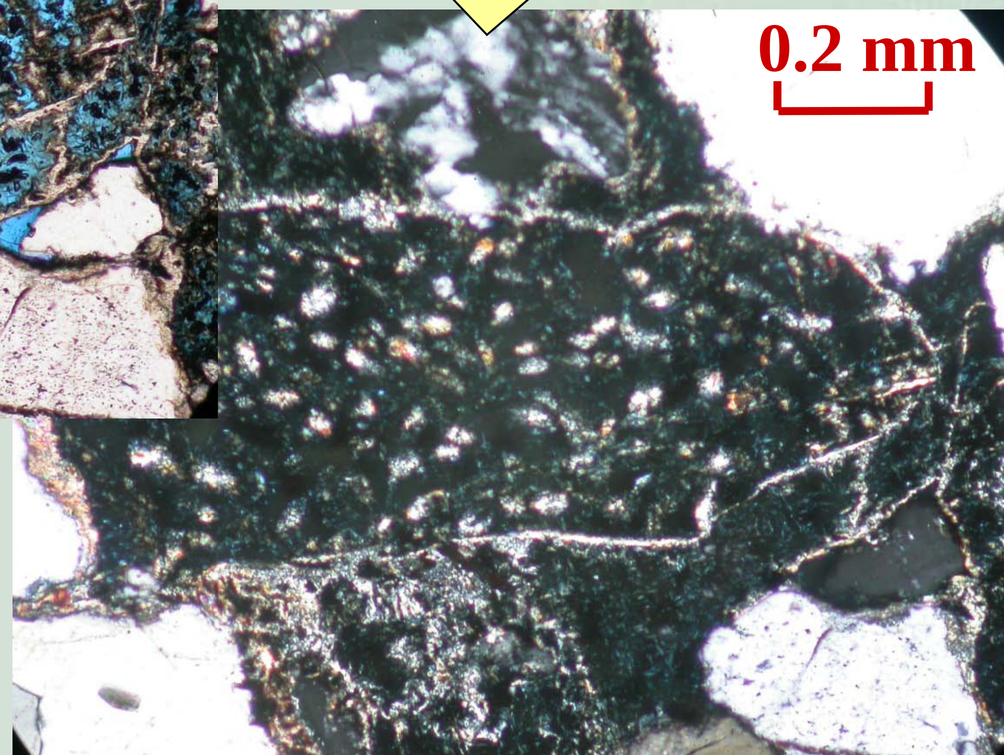
SEM photomicrographs showing the replacement of feldspar by illite occurs preferentially along cleavage traces

Well F1, 2120.07m

Grain-coating



Illite occurring as a grain-coating mineral, forming continuous clay-coating on a pre-existing feldspar.

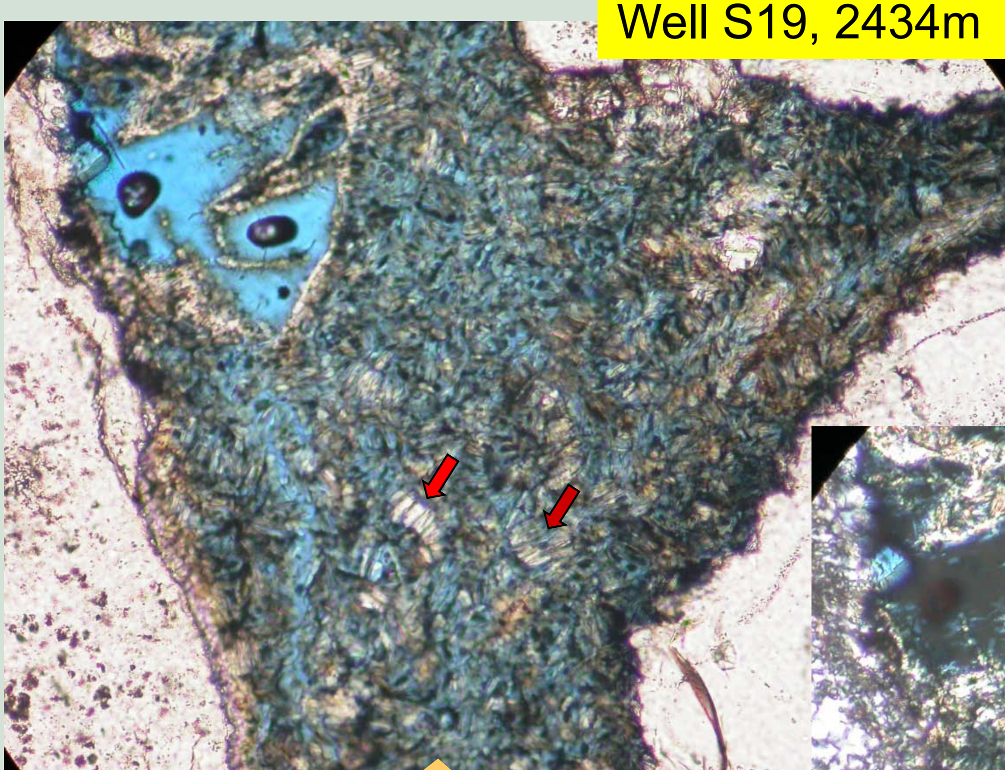


Note: Primary depositional grain shape preserved with illitic clay coating.

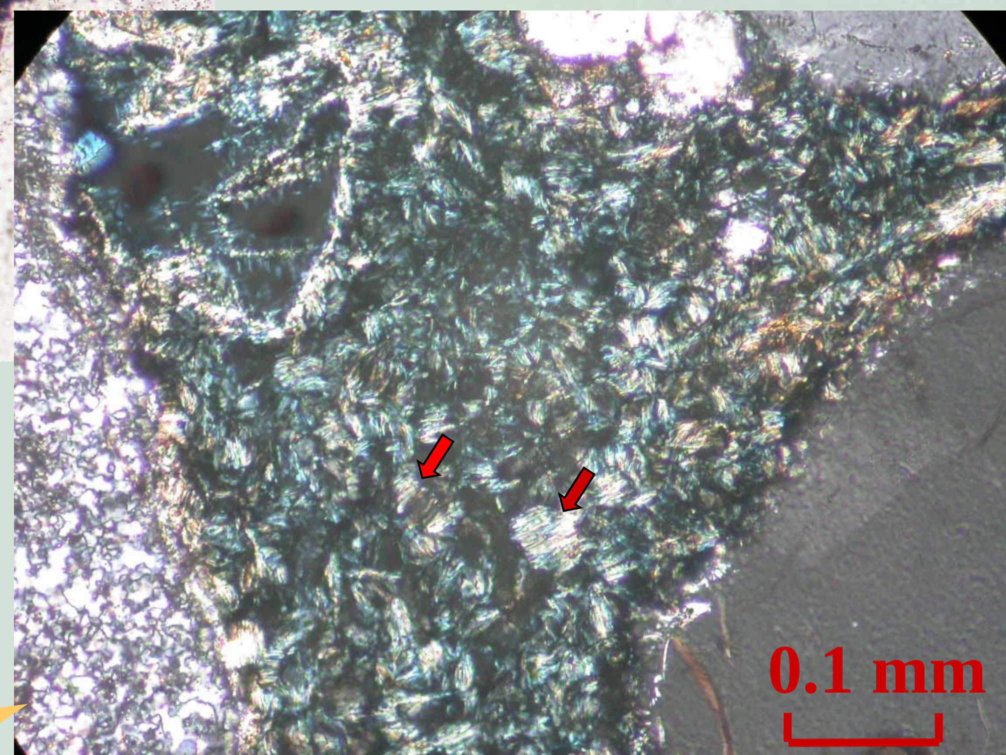
Well SS 12, 2498.05m

Kaolinite-to-illite transition

Well S19, 2434m



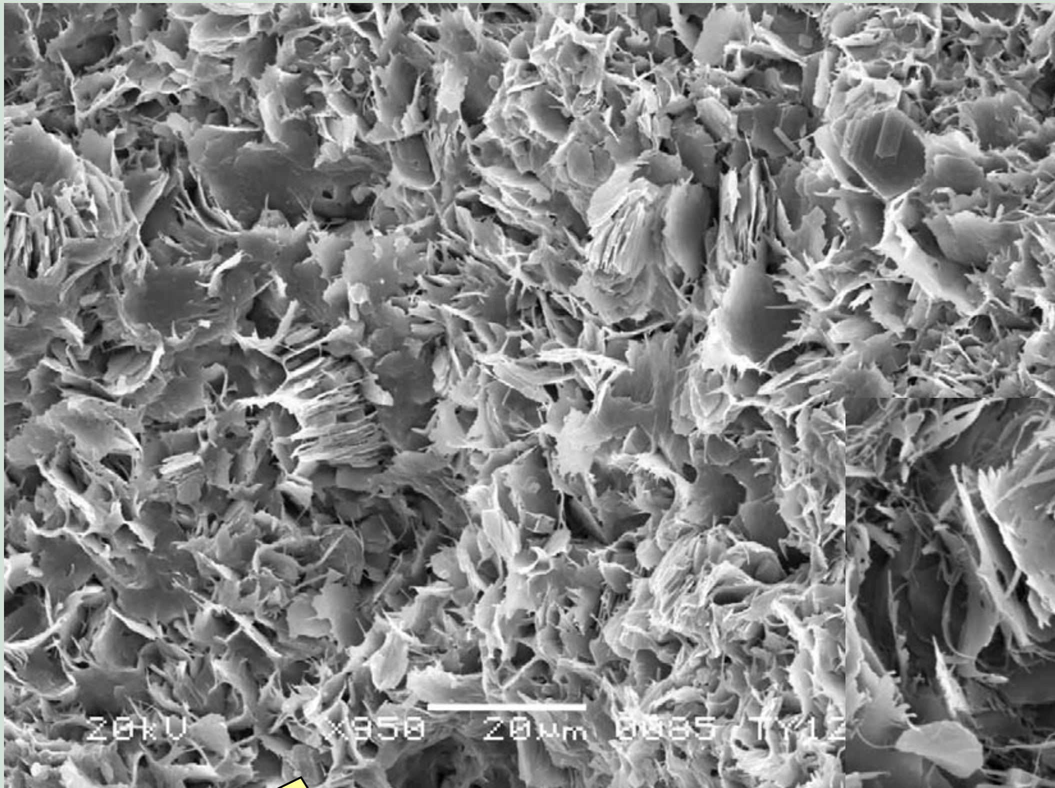
Some of platy illitic clays (red arrows) are arranged into books, probably pseudomorphing earlier formed kaolinite.



booklet: typical crystallite morphology of kaolinite

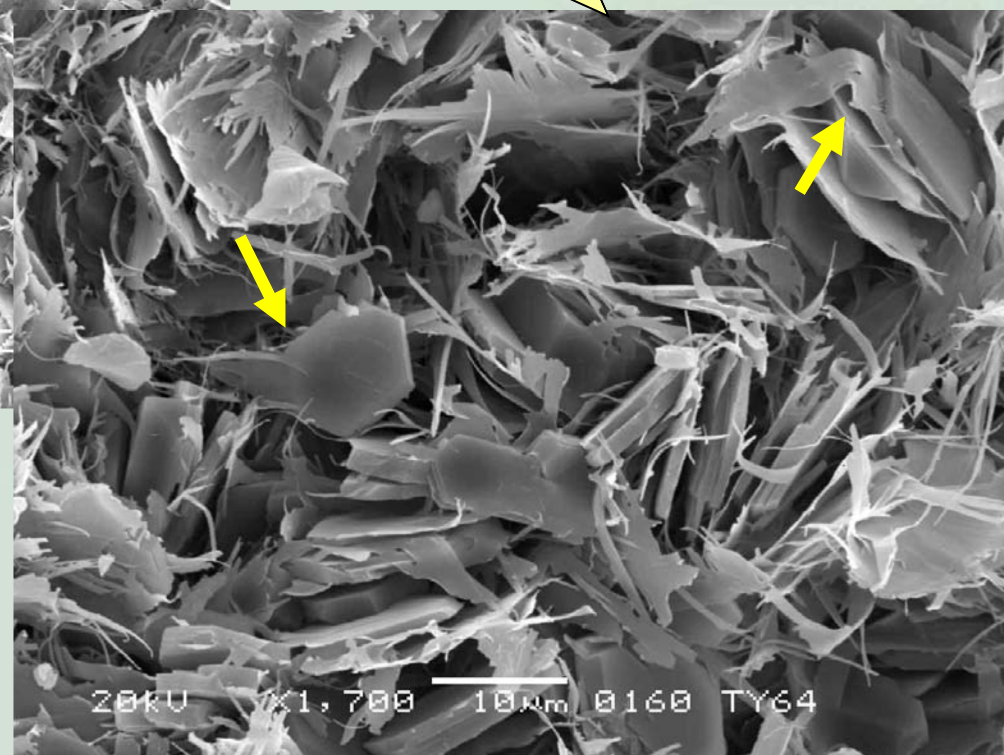
High-order interference colors

Kaolinite-to-illite transition

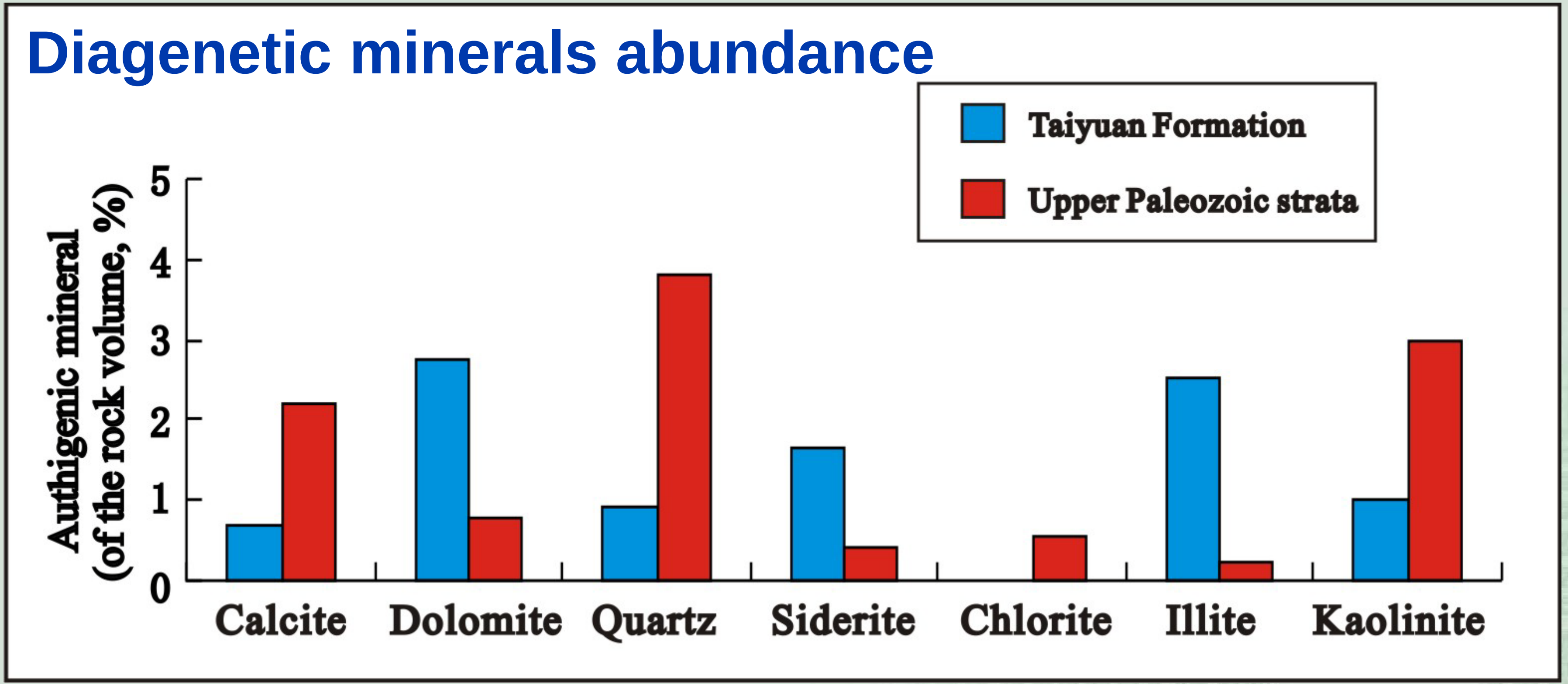


Illite crystals exhibit cornflake morphology with ragged edge, implying a kaolin mineral precursor. Well F1, 2158.89 m

SEM photomicrographs showing incipient illitization of kaolinite. Well S19，2434m



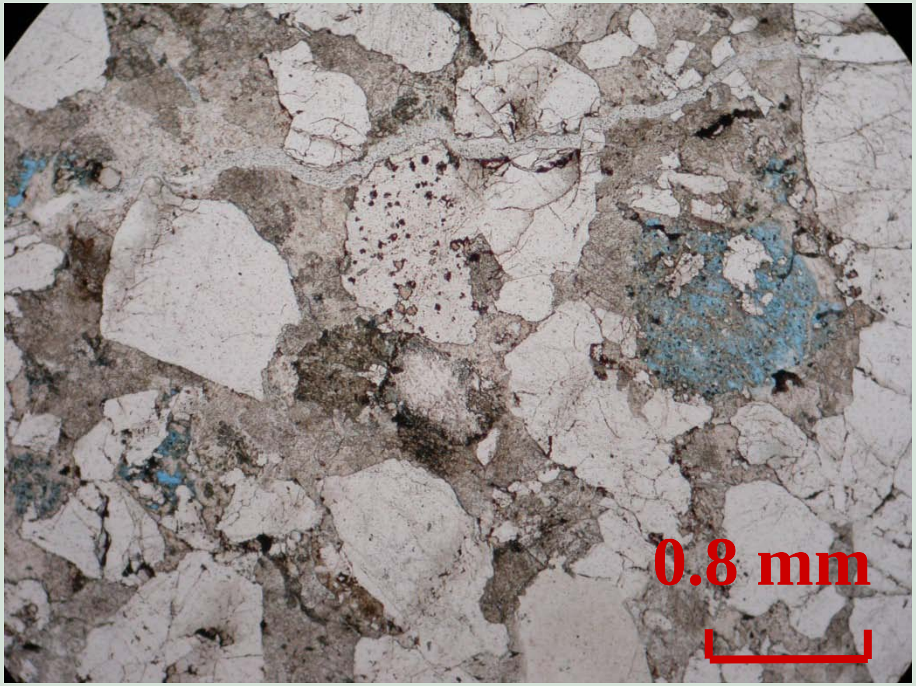
Origin of authigenic illite

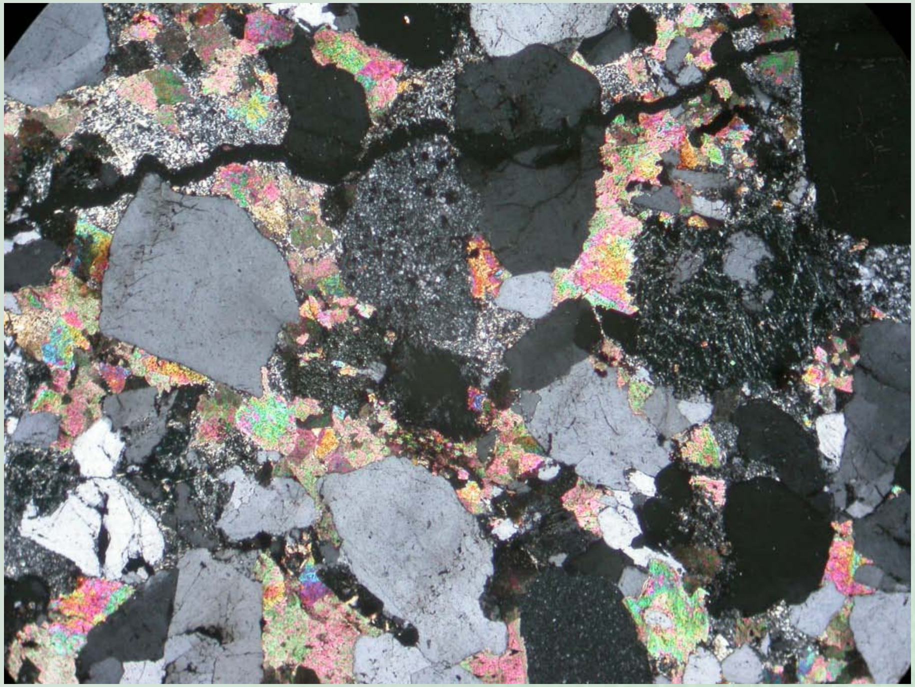


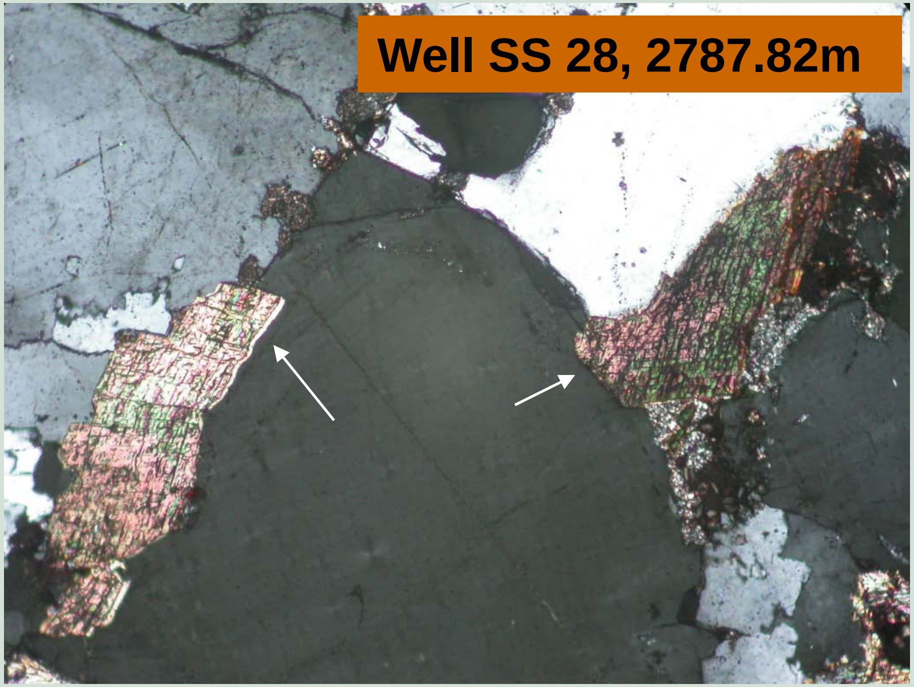
The striking diagenetic feature for Taiyuan Formation is:

- relative scarcity of acid-prefer minerals
- relatively rich in alkali-prefer minerals

——Taiyuan Formation has Pore-water with relatively high alkalinity level







In many sandstones, dolomite cementation pre-dates burial diagenetic features

—— dolomite was an early cement

—— large amounts of alkalinity fluids moving through the Taiyuan Formation rocks at shallow depth

Origin of authigenic illite

Two stages of feldspar dissolution are inferred:

- **Early-stage, Open system: Feldspar-Kaolinite**

$$2KAlSi_3O_8 + 2H^+ + H_2O = Al_2Si_2O_5(OH)_4 + 4SiO_2 + 2K^+$$

—— Possibly in response to organic acid-rich fluids derived from the coal measures

——Slowed down due to large amounts of alkalinity fluids moving through the Taiyuan Formation rocks.

- **Late-stage, Closed system:**

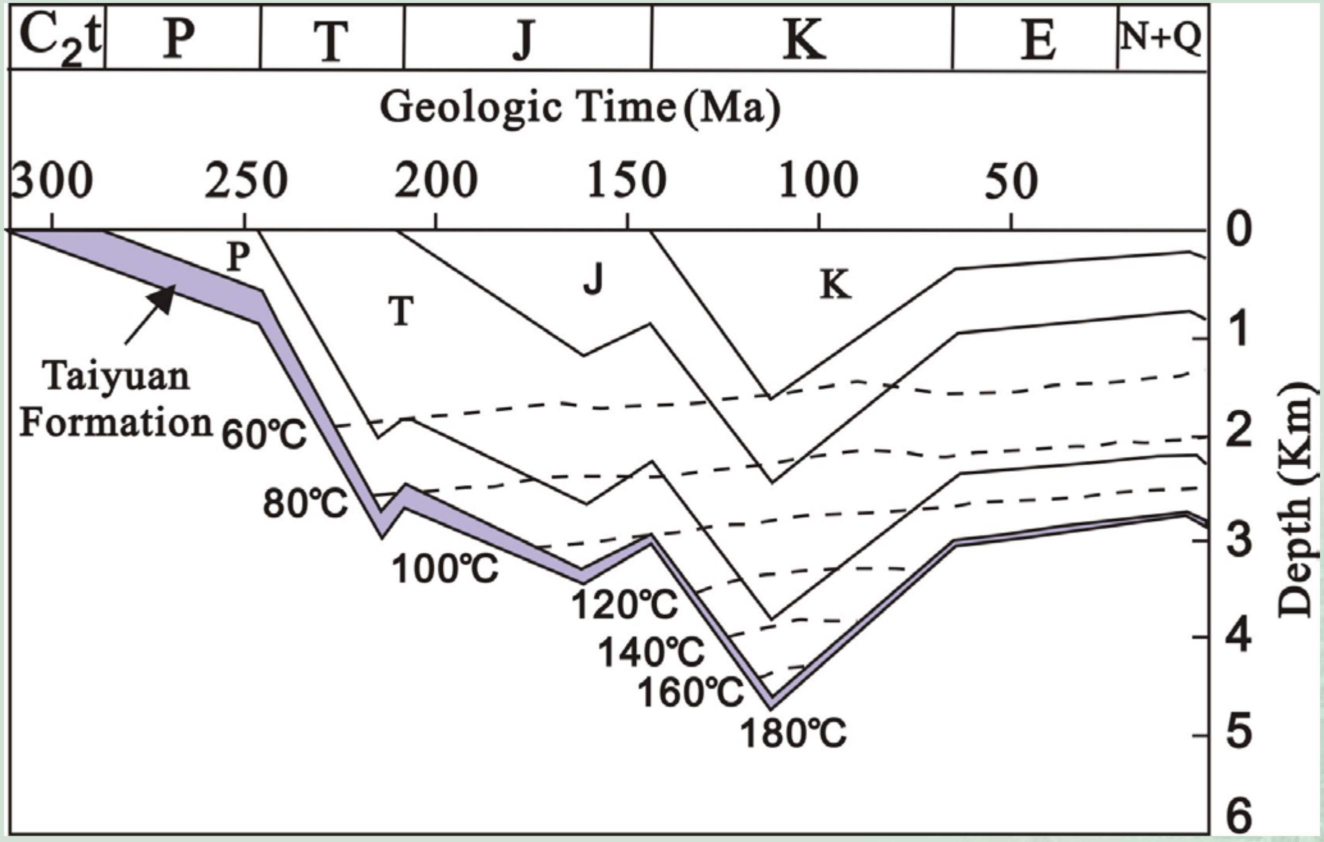
main mechanism responsible for illite formation

$$KAlSi_3O_8 + Al_2Si_2O5(OH)_4 = 2SiO_2 + KAl_3Si_3O_{10}(OH)_2 + H_2O$$

—— Possibly in response to increased temperature

—— Much of the K-feldspar reaction occurred during burial diagenesis, which is suggested by the presence of uncompacted secondary dissolution porosity and secondary pore-filling authigenic illites

Origin of authigenic illite



Burial and thermal history model for northeast Ordos basin depicting incremental burial history for the Late Carboniferous through to the present (after Liu, 2008)

The reaction of K-feldspar + kaolinite to form illite

- has a greater temperature dependency

- require minimum temperature of ~120℃, which corresponds to thermodynamical destabilization of kaolinite + K-feldspar assemblage

- Taiyuan Formation had reached this temperature threshold

Acknowledgements

- ***Invitation from AAPG 2012 ACE Technical Program***
- ***Assistance from CDUT for this presentation***
- ***Support for our research:***

State Key Laboratory of Oil/Gas Reservoir Geology and Exploitation

The State Key Program of NNSF of China, No. 40839908

Research Institute of Exploration and Development, Changqing Oil field Company of CNPC

Thank you!

Ordos