

# **Fractures Types of Volcanic Reservoir and its Significance to Reservoir in the Dixi Area of the Kelameili Gas Field, Junggar Basin, Northwestern China\***

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## **Abstract**

Volcanic rock reservoirs have been reported in many locations around the world. The lithologies range from basalt to andesite or rhyolite formed in various geological ages. As a relatively new area in oil and gas exploration, volcanic reservoirs are attracting the attention and interest of scholars in the oil industry. In particular, the discovery of volcanic hydrocarbon reservoirs in China presents a huge opportunity for the development of igneous rock hydrocarbon reservoirs. Recent years have seen a breakthrough in Carboniferous volcanic rocks exploration in the Junggar Basin: the Kelameili Gas Field was discovered, offering good prospects for exploration in the Kelameili area and even the whole of northern Xinjiang province

## **Selected Reference**

Zhao, D., Y. Tian, J. Lei, L. Liu, and S. Zheng, 2009, Seismic image and origin of the Changbai intraplate volcano in East Asia: Role of big mantle wedge above the stagnant Pacific slab: *Phys. Earthy Planet Inter.*, v. 173, p. 197-206.

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# **Fractures Types of Volcanic Reservoir and its significance to reservoir in the Dixi Area of the Kelameili Gas Field, Junggar Basin, Northwestern China**

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- Volcanic reservoirs in global
- Geological Background of the Study Area
- Types and Characteristics of Fractures
- Samples and Analytical Methods
- Discussions
- Significance to Reservoir
- Conclusions

# Volcanic Hydrocarbon Reservoirs

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## The previous opinions:

- It is difficult to form an effective reservoir space, have no economic value.
- There is almost no organic matter, volcanic rock can not generate oil and gas.

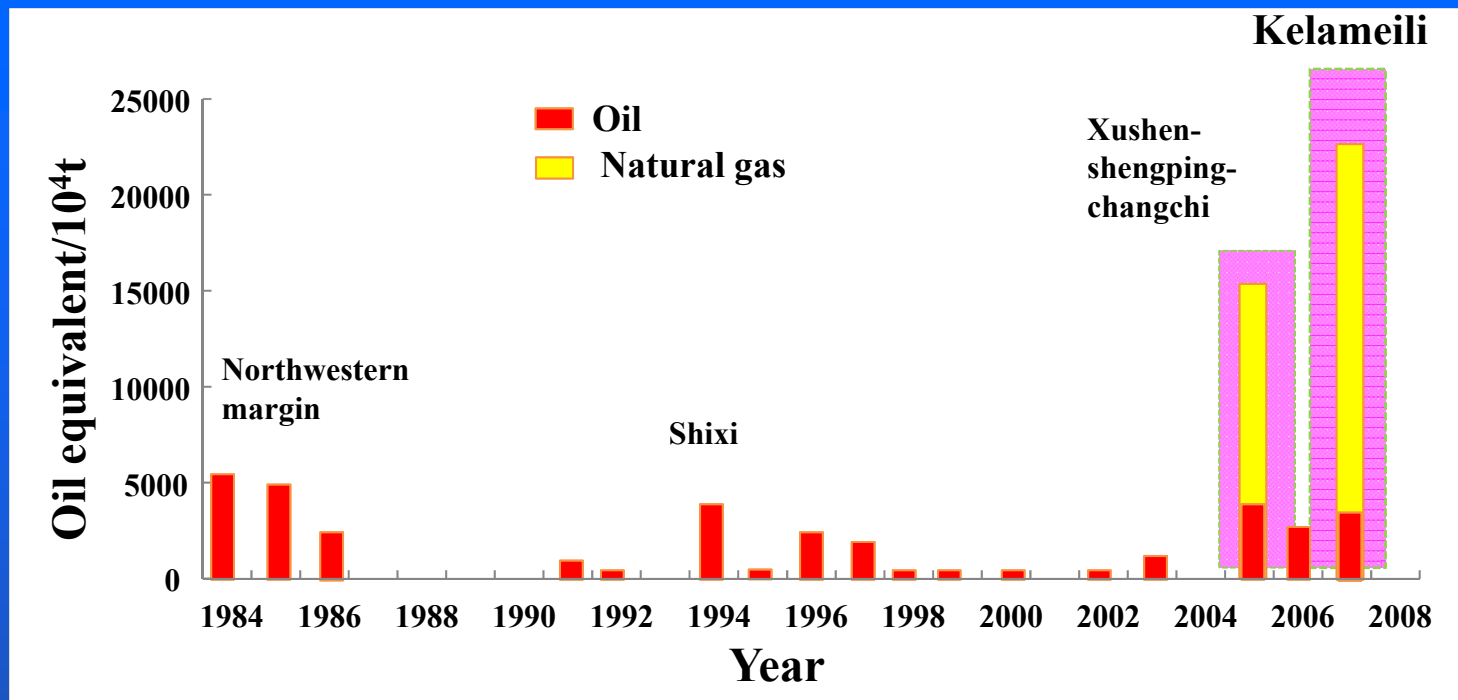
## Nowadays:

- A growing number of volcanic oil and gas reservoirs have been discovered.
- With the discovery of volcanic oil-gas pools, igneous rock hydrocarbon reservoirs, a special oil-gas reservoir type, are paid more and more attention in these days.

## Global production statistics for volcanic reservoirs

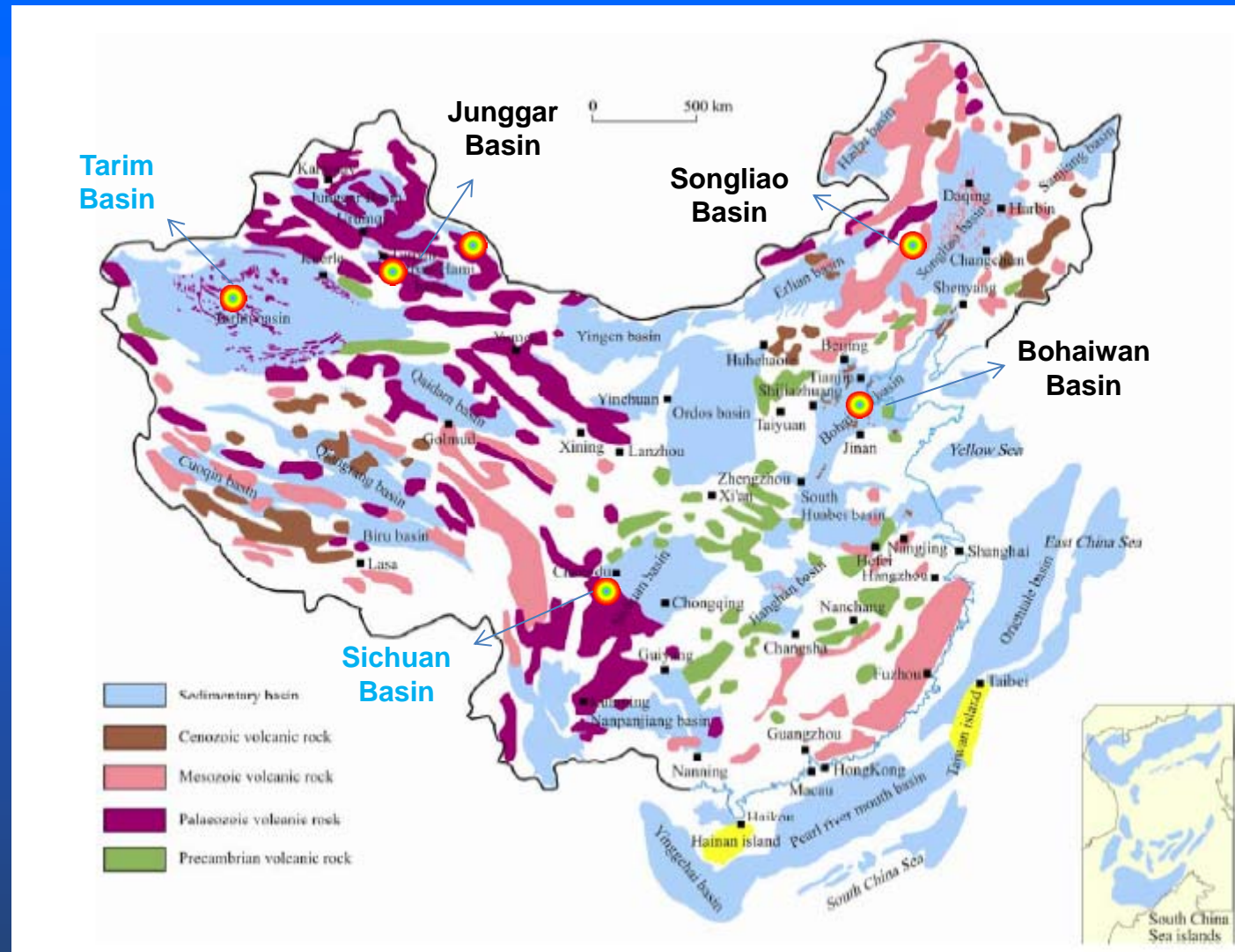
Country	Field	Basin	Fluid property	Reserve		Lithology
				Oil /(t·d <sup>-1</sup> )	Gas /(10 <sup>4</sup> m <sup>3</sup> ·d <sup>-1</sup> )	
Cuba	Cristales	North Cuba	Oil	3425		Basaltic tuff
Brazil	Igarape Cuia	Amazonas	Oil	68–3425		Diabase
Vietnam	15-2-RD 1X	Cuu Long	Oil	1370		Altered granite
Argentina	YPF Palmar Largo	Noroeste	Oil, gas	550	3.4	Vesicle basalt
Georgia	Samgori		Oil	411		Tuff
America	West Rozel	North Basin	Oil	296		Basalt, agglomerate
Venezuela	Totumo	Maracaibo	Oil	288		Volcanic rock
Argentina	Vega Grande	Neuquen	Oil,gas	224	1.1	Fractured andesite
New Zealand	Kora	Taranaki	Oil	160		Andesitic tuff
Japan	Yoshii-Kashiwazaki	Niigata	Gas		49.5	Rhyolite
Brazil	Barra Bonita	Parana	Gas		19.98	Plateau basalt, diabase
Australia	Scotia	Bowen-Surat	Gas		17.8	Crack andesite

- The first successful exploration of volcanic reservoirs was in Lapasi Oilfield of Venezuela in 1953, the highest production for a single well was up to 1828 m<sup>3</sup>/d.
- The exploration of volcanic rock reservoirs have been carried out worldwide since the 1970s, and the output increases rapidly.
- The lithologies range from basalt to rhyolite formed in various geological ages .



## History of reserve increasing and exploration for onshore volcanic rock in China

- In China, it is first discovered in the northwest margin of the Junggar basin in 1957, and the exploration in this region have been witnessed for over 50 years.
- The discovering of Kelameili Gas Field in Junggar Basin offering good prospects for exploration natural gas in Carboniferous volcanic rock.
- The reservoir forming conditions are different from the Xushen-shengping-changchi Gas Field of Songliao Basin which is located in eastern China.

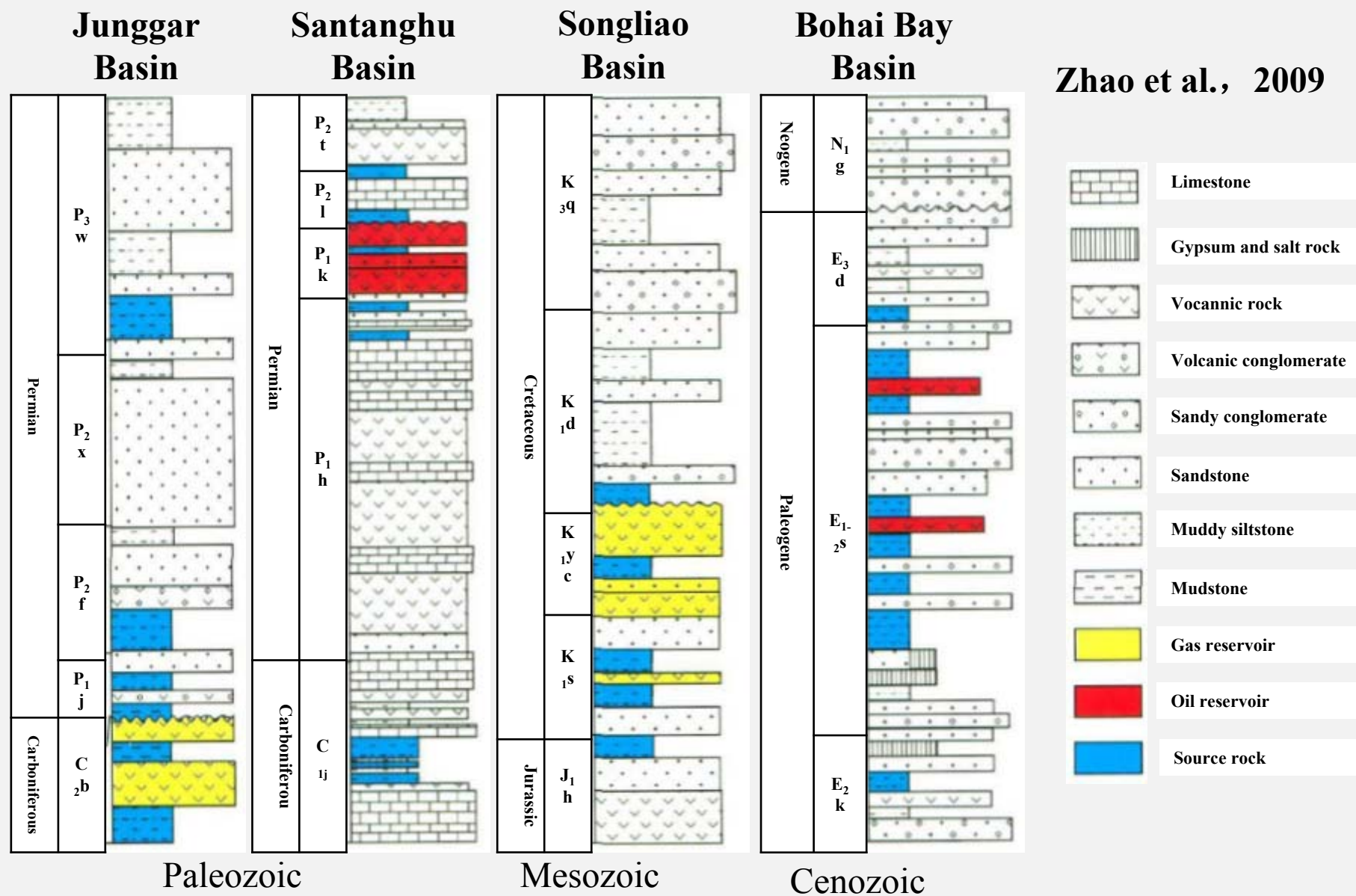


## Distribution of volcanic rocks in hydrocarbon bearing basins of China (according to Shang Xiangru, 2002)

**Near source type (in source, below source):** Source rock is located at the top, bottom, and lateral part of the volcanic reservoirs, have much more favorable conditions, most favorable for hydrocarbon enrichment.

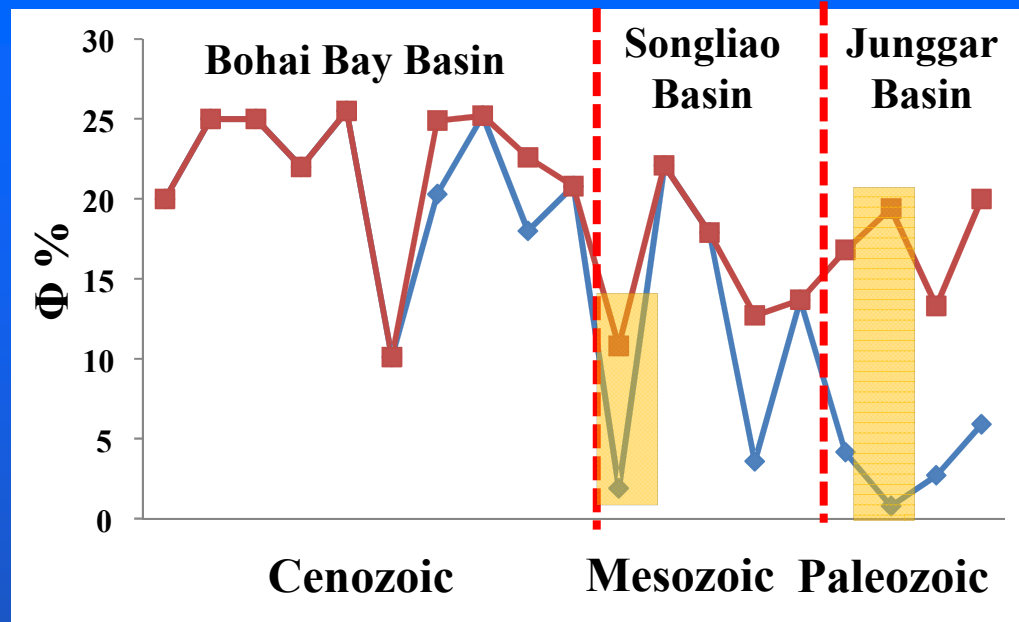
**Distal play (source top):** Can ' t meet industrial requirements.





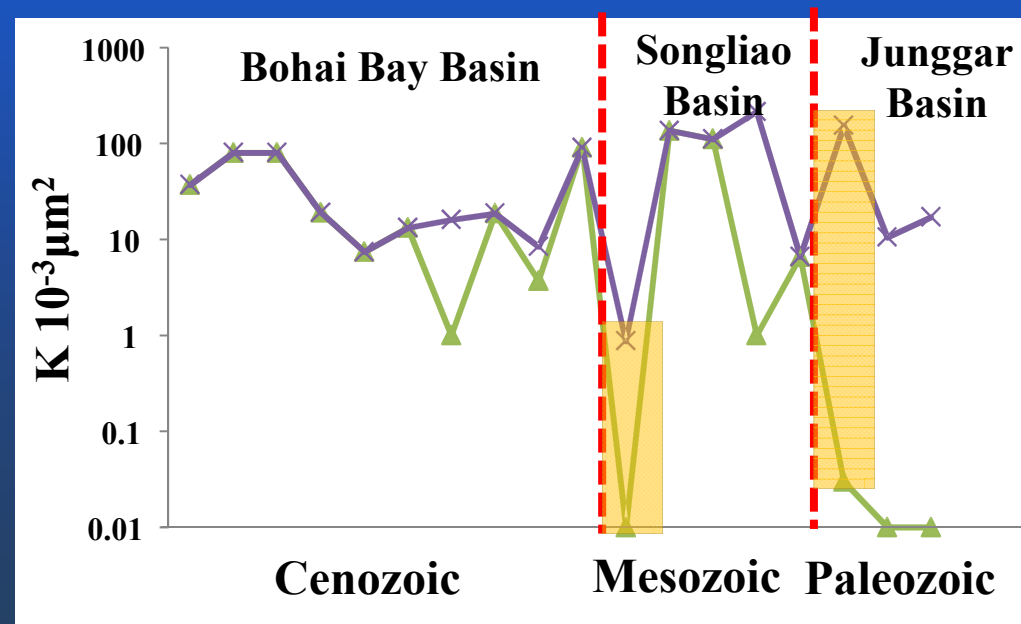
**Sketch of volcanic hydrocarbon reservoir plays in the main hydrocarbon bearing basins of China**





Physical characteristics of volcanic reservoirs in the basins of China.

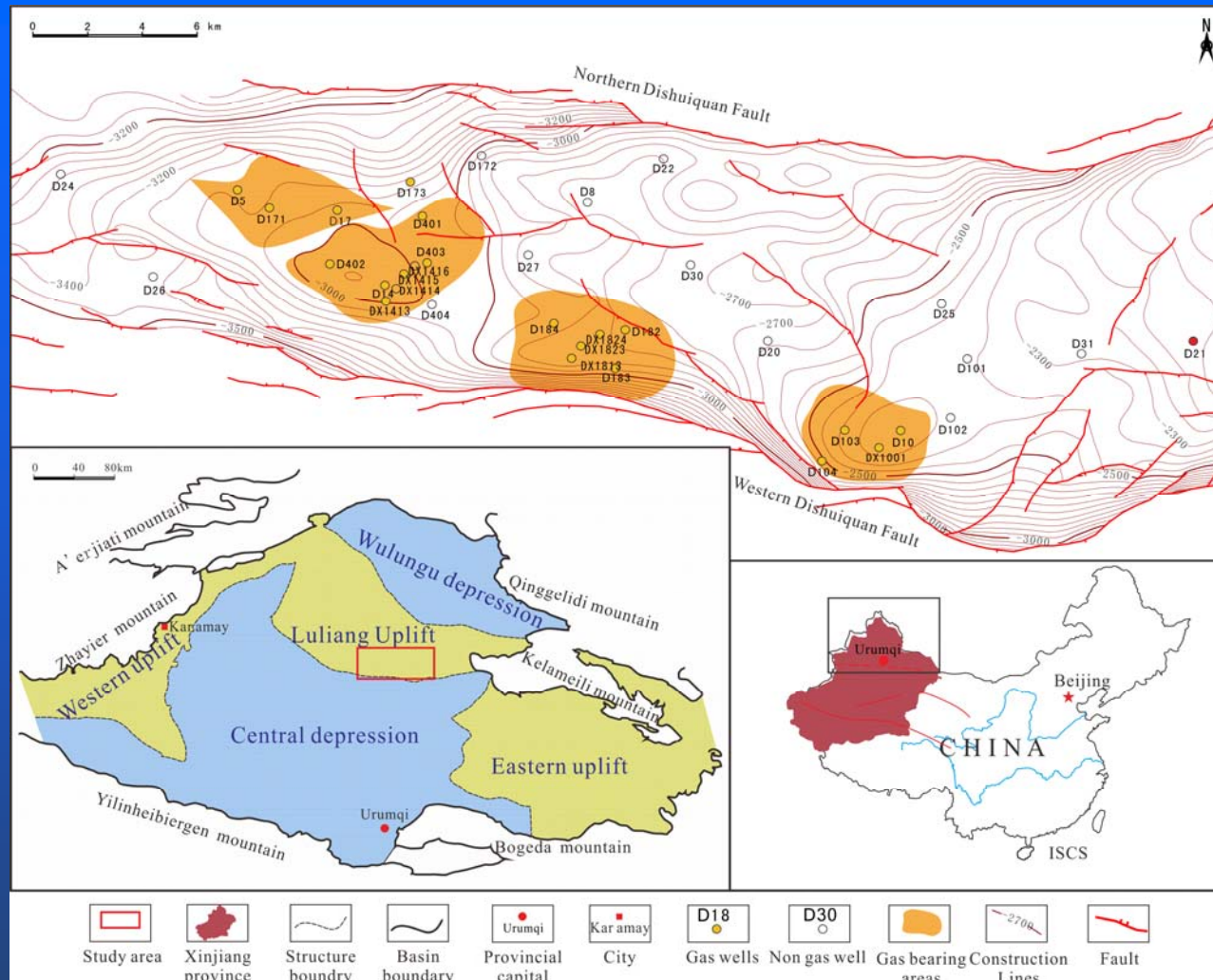
Songliao basin and Junggar basin represent the two different typical volcanic reservoir of China.



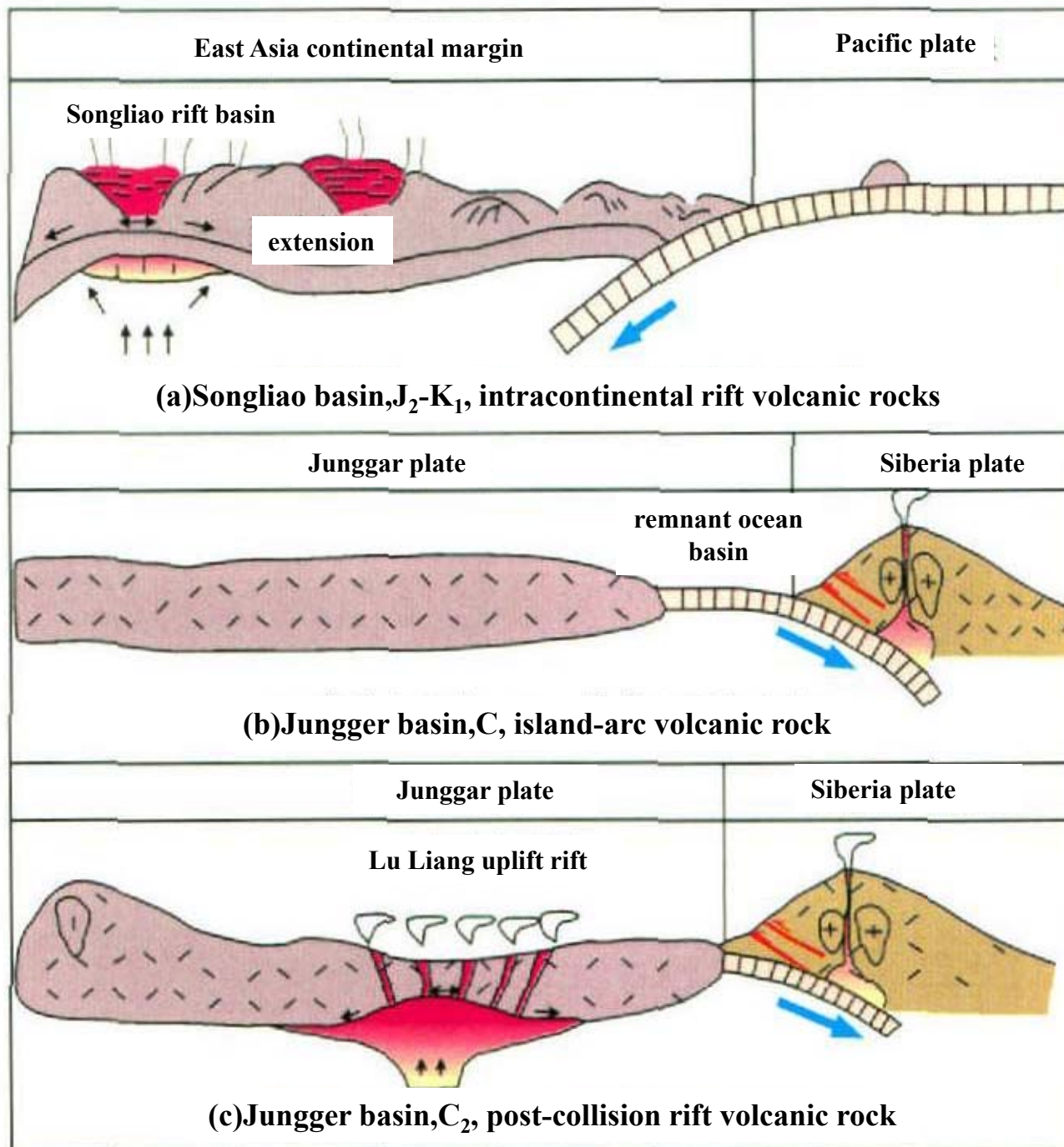
## The comparison of volcanic reservoir between the east and the west of china

Accumulation characteristics	Eastern China	Western China
Times	Mesozoic/Cenozoic	Paleozoic
Distribution	NEE/NE	NWW
Rock series	Calc alkaline, alkaline rock emerged in later	Calc alkaline
Tectonic setting	Tension at first, then compression	Island arc or active edge orogenic belt
Lithology	Intermediate- acidic rocks, alkaline rocks	intermediate-basic rocks
Volcanic lithofacies	Dominated by explosive facies, followed by effusive facies	Dominated by effusive facies , followed by explosive facies
Environment	Continental facies	Marine facies/marine and continental facies
Volcanic mechanism	Stratovolcano	Stratovolcano, lava dome
Late reformation	Weak	Strong
Reservoir	Primary reservoir	Reconstructive reservoir

The key factors of volcanic reconstructive reservoir include *lithology, lithology facies, fracture, erosion zone and Leaching & corrosion mechanism.*



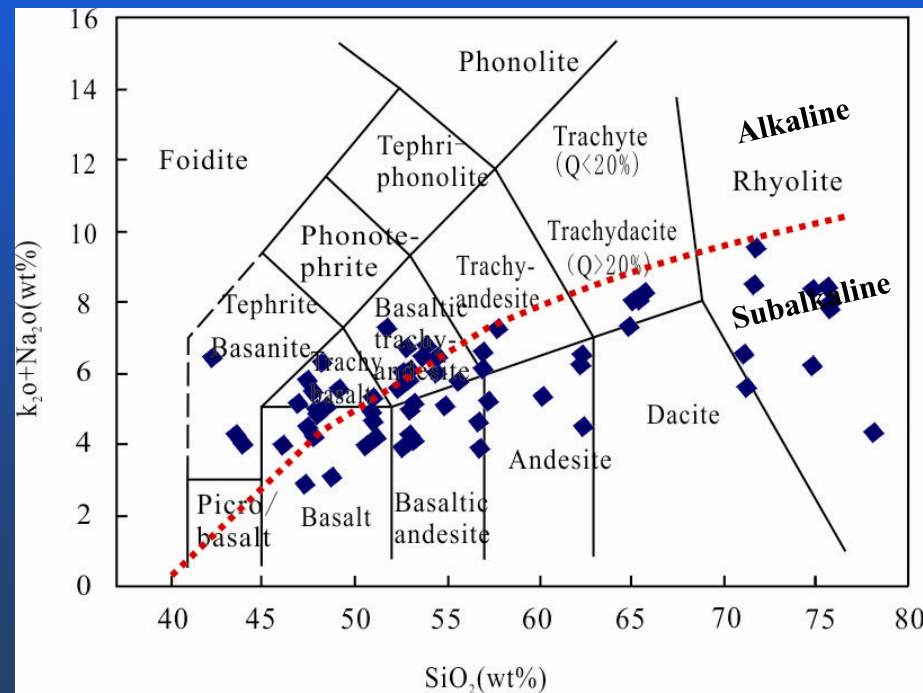
**The Dixi area lies in the central part of the Dinan sub-uplift of Luliang Uplift, the Junggar Basin, Xinjiang province, China.**






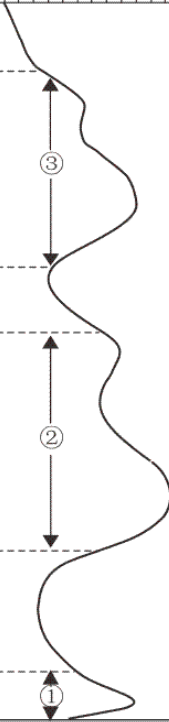









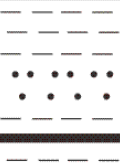
Comparison  
of tectonic  
background  
patterns of  
volcanic  
rocks in the  
eastern and  
western  
regions of  
China (Zhao  
et al, 2009)





- The Carboniferous system is divided into the Lower Carboniferous Tamugang, the Dishuiquan and the Upper Carboniferous Batamayineishan Formation.
- Three eruptive- sedimentary cycles separate the Bashan Formation. The volcanic energy in each cycle weakened gradually, forming several sets assemblages of lower volcanic rocks and upper sedimentary rocks .

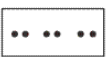



TAS chemical classification of volcanic rocks

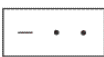
Formation	Member	Lithology /Lithofacies		Volcanic energy <i>Weak</i> $\longrightarrow$ <i>Strong</i>
Wutonggou		P <sub>3w</sub>	 Sedimentary facies	
Batamayineishan	Third member	C <sub>2</sub> b <sub>3</sub> <sup>1</sup>	 Volcanic-sedimentary facies	
			 Subvolcanic facies	
		C <sub>2</sub> b <sub>3</sub> <sup>2</sup>	 Effusive facies	
			 Eruption facies	
	second member	C <sub>2</sub> b <sub>2</sub> <sup>1</sup>	 Volcanic-sedimentary facies	②
		 Subvolcanic facies		
	First member	C <sub>2</sub> b <sub>2</sub> <sup>2</sup>	 Eruption facies	①
			 Volcanic-sedimentary facies	
		C <sub>2</sub> b <sub>1</sub> <sup>2</sup>	 Effusive facies	
 Effusive facies				
Dishuiquan		C <sub>1d</sub>	 Sedimentary facies	<b>Source rock</b>


  
Conglomerate

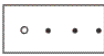
  
Sandstone


  
Siltstone


  
Mudstone


  
Shaly Sandstone


  
Silty mudstone


  
Pebbly andstone

  
Shed coal

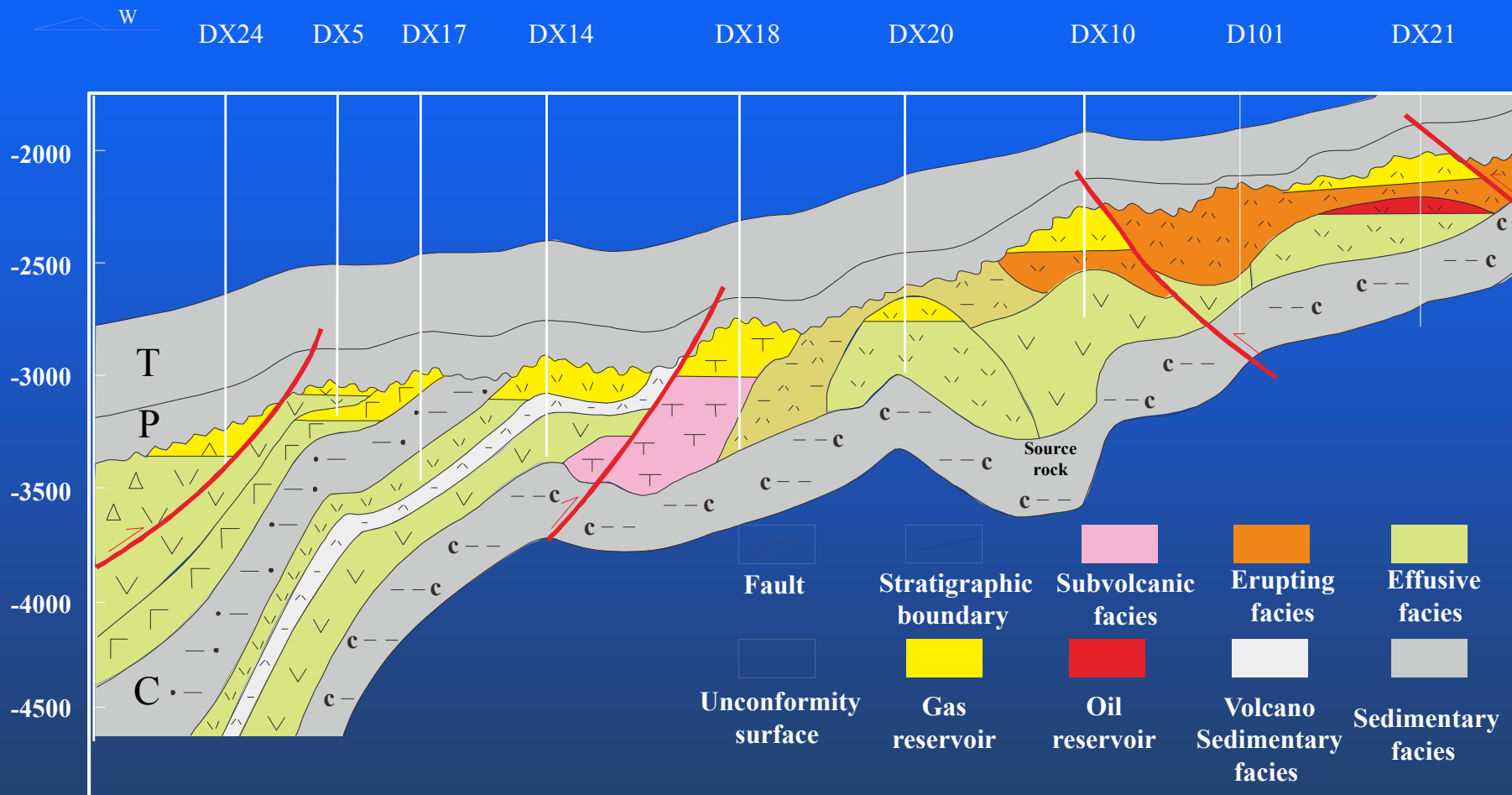
  
Syenite Porphyry

  
Volcano breccia

  
Basalt

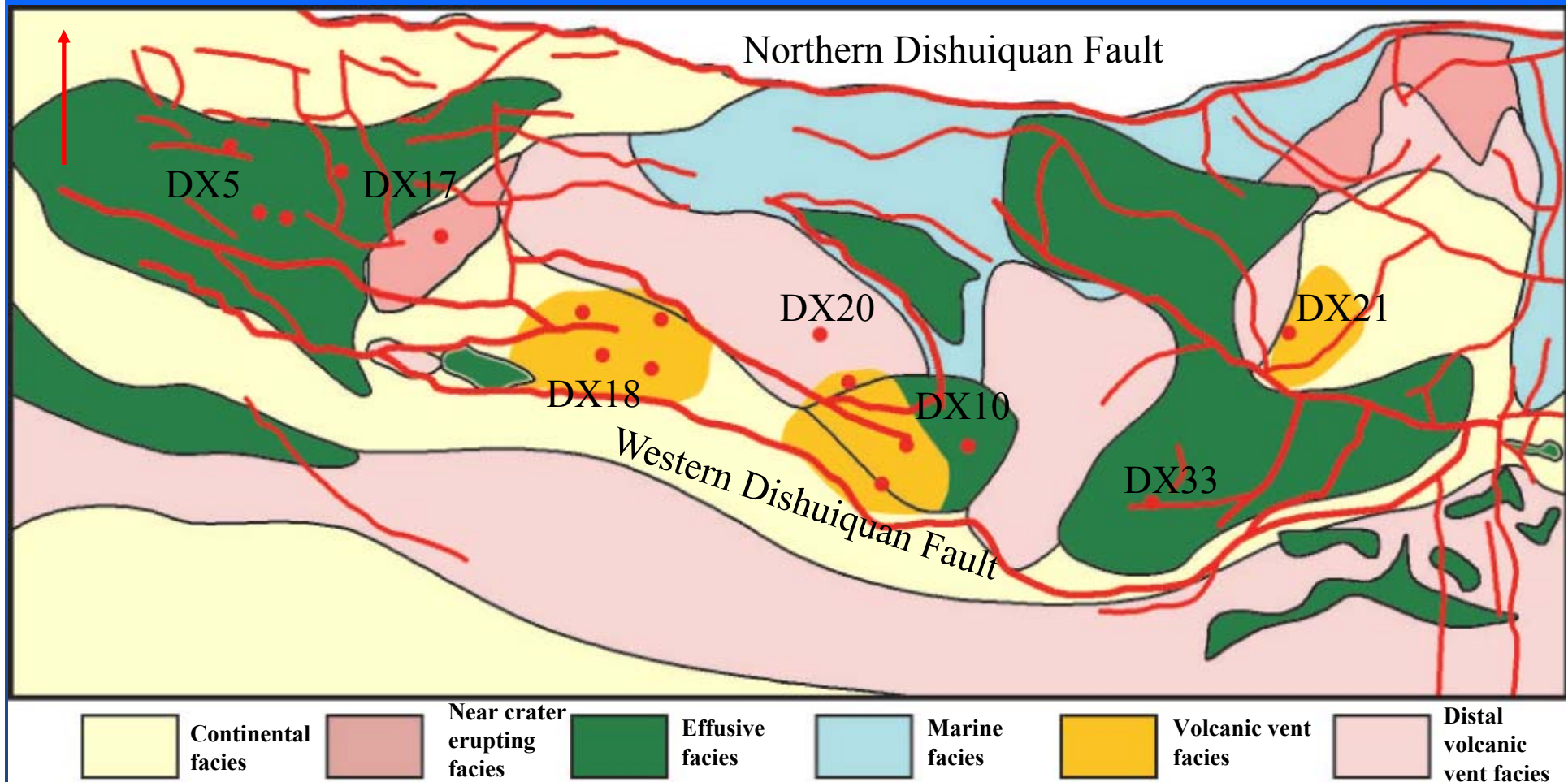
  
Dacite

# Relationship between volcanic lithology, facies and gas reservoirs of Dinan uplift, Kelameili Gas Field



The reservoirs are mainly located near the Carboniferous top unconformity because of the overall uplift at the end of the Carboniferous.

## The distribution of volcanic lithofacies in the study area



Fracture- pore reservoir is the main reservoir type of the Carboniferous volcanic rocks. The filling process of fractures is an important indicator used to evaluate whether reservoirs have developed.



# Samples and analytical methods

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- Casting thin section and dying
- Scanning Electron Microscope and Energy Spectrum analysis
- EPMA combined with XRD.
- Cathode Luminescence analysis
- Fluorescence analysis
- Fluid Inclusion Temperature and Component analysis
- Calcite Carbon and Oxygen Isotopes analysis
- Pyrites sulfur isotopic composition.

**Based on their morphological and filling characteristics, the fractures could be classified as:**

Fracture Type		Characteristics and Identifying Features	Filling	Development Position	Formation mechanism
Primary fractures	Explosion fracture	Multiple fracture directions, uneven fracture widths, possibly irregular radial patterns from centers, and matching adjacent boundaries.	Quartz (non-luminous), no alteration halo	Near to the shattered zone	Explosion of water and volatiles below a crystalline rind
	Contraction fracture	Extremely irregular shapes, possibly reticular, concentric, horsetail-shaped, broom-shaped or cracked.	Calcite, orange light, without Fe, no alteration halo	Widely developed in its top, bottom and edge position.	Contraction of the crystallized magma on cooling
	Vertical tension (open) fracture	A series of steeply dipping and near-vertical fractures of varying widths and matchable serrated walls, bypassing phenocryst.	Quartz, purplish red, contain Ti, Mn, alteration halo	Great thickness, near to magma channel	Upwelling forces of magma from the depth
Weathered fracture		Non-directional; horsetail-shaped, echelon, leaf vein type.	Calcite, reddish orange light, associated with hematite	Upper part of rock masses.	Weathering.
Structural fracture	Oblique crossing fracture	Nearly vertical, dip angle exceeding 75°, uneven fracture surface, and cutting through rocks.	Calcite, reddish orange light, without Fe, alteration halo	Lower part of rock masses.	Regional stress
	Shear fracture	Two groups of conjugated fractures, one having a large dip angle and the other having a small one, superimpose on other fractures.	Calcite, dark red light, contain Fe, hydrocarbons	Near to faults.	
Dissolution fracture		Non-directional, irregular fracture walls, connected with dissolution pores and cavities.	Quartz, calcite, hydrocarbons	Along fractures and high parts of structures.	Weathering, leaching, hydrothermal fluids and organic acids

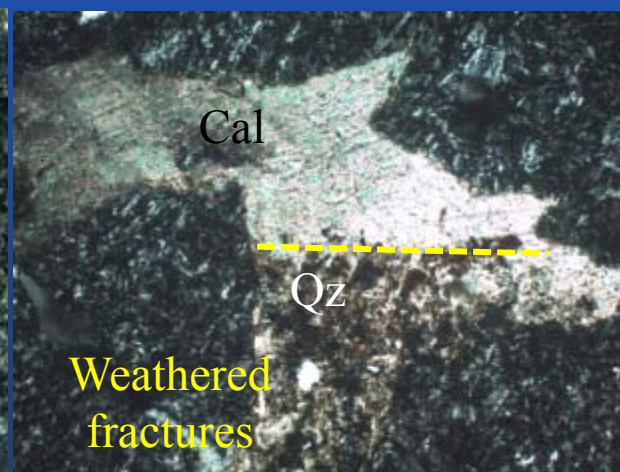
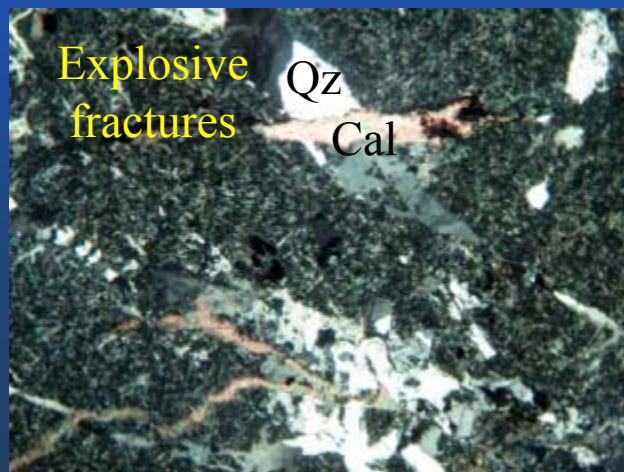


## • Explosion fracture

- ✓ Multiple directions, uneven widths, irregular radial patterns from centers, and matching adjacent boundaries.
- ✓ Near to the shattered zone

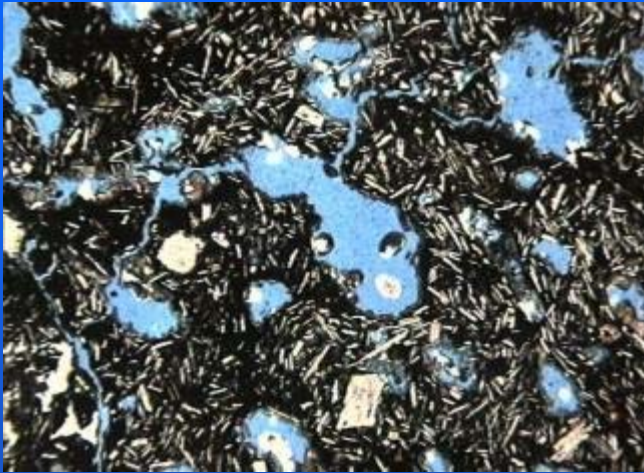
## • Weathered fracture

- ✓ Non-directional, horsetail-shaped, echelon, leaf vein type, geopetal structure.
- ✓ Upper part of rock masses.

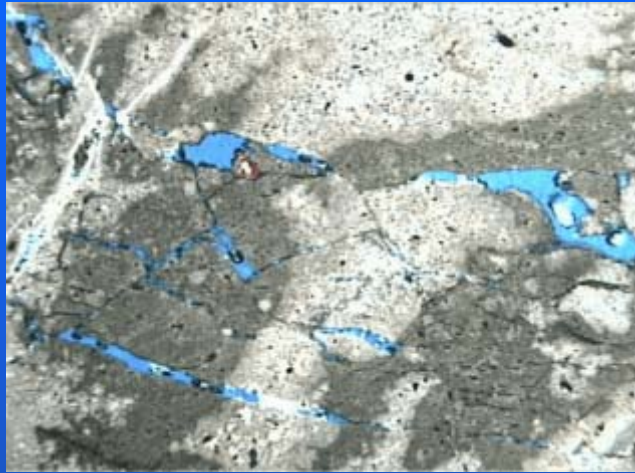




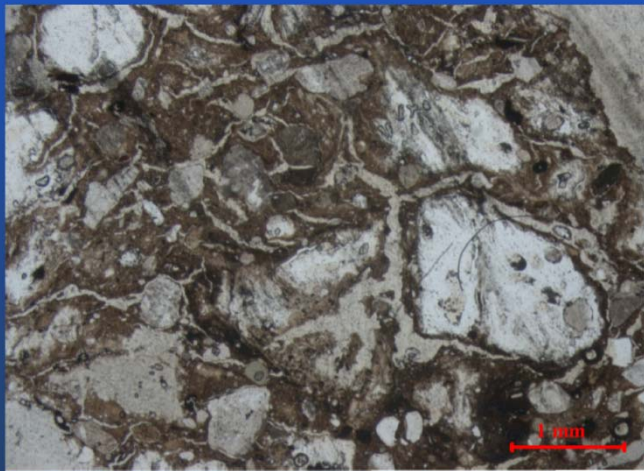
- Contraction fractures



Basalt



Tuff



Volcanic breccia



Trachyte porphyry

- Extremely irregular shapes, possibly reticular, concentric, horsetail-shaped, broom-shaped or cracked.
- Widely developed in the top, bottom and edge position of the volcanic rock.

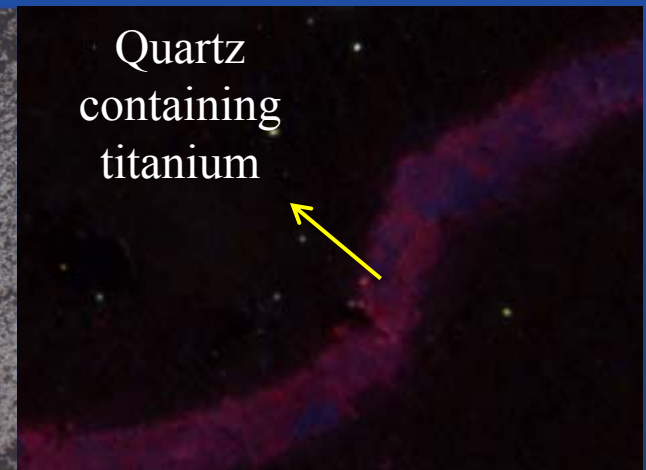
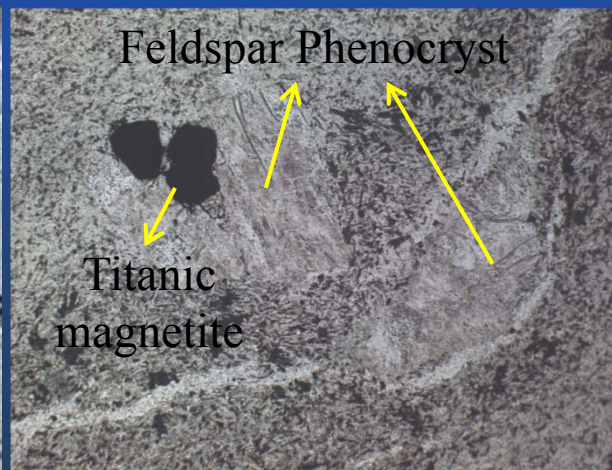
- Vertical Tension Fracture



- ✓ A series of steeply dipping and near-vertical fractures of varying widths and matchable serrated walls, bypassing phenocryst.
- ✓ Near to magma channel

- Shear fracture

- ✓ Two groups of conjugated fractures, one having a large dip angle and the other having a small one, superimpose on other fractures.
- ✓ Near to faults

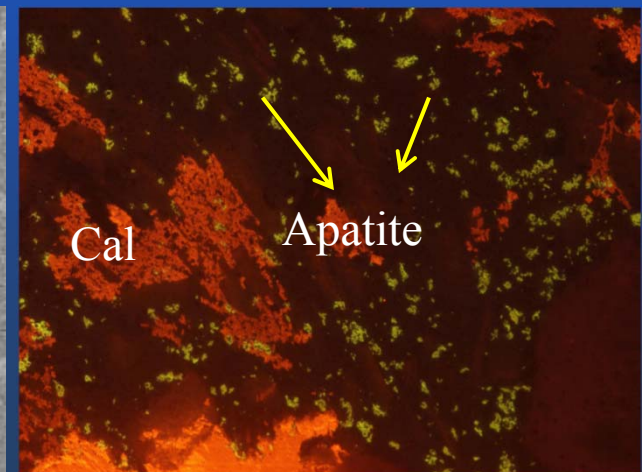
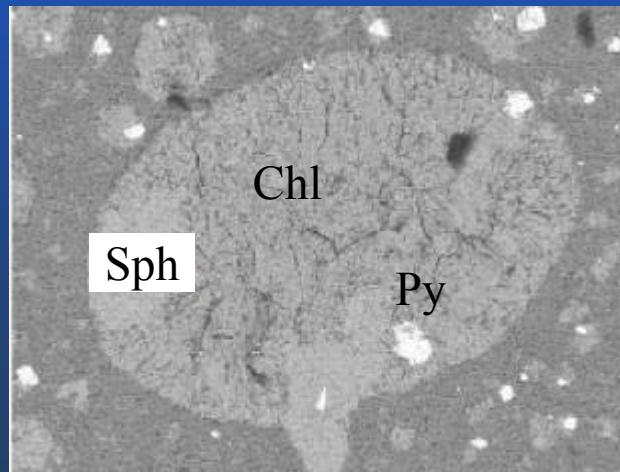






- Oblique crossing fracture

- ✓ Nearly vertical, dip angle exceeding  $75^\circ$ , uneven fracture surface, and cutting through rocks.
- ✓ Lower part of rock masses.
- ✓ The channel of the upwelling deep hydrothermal fluids.



# How to determined the fluid properties and sources ?

## Trace elements and Stable Isotopic Compositions

### Electron probe - spectroscopy data of secondary minerals of Carboniferous volcanic rocks

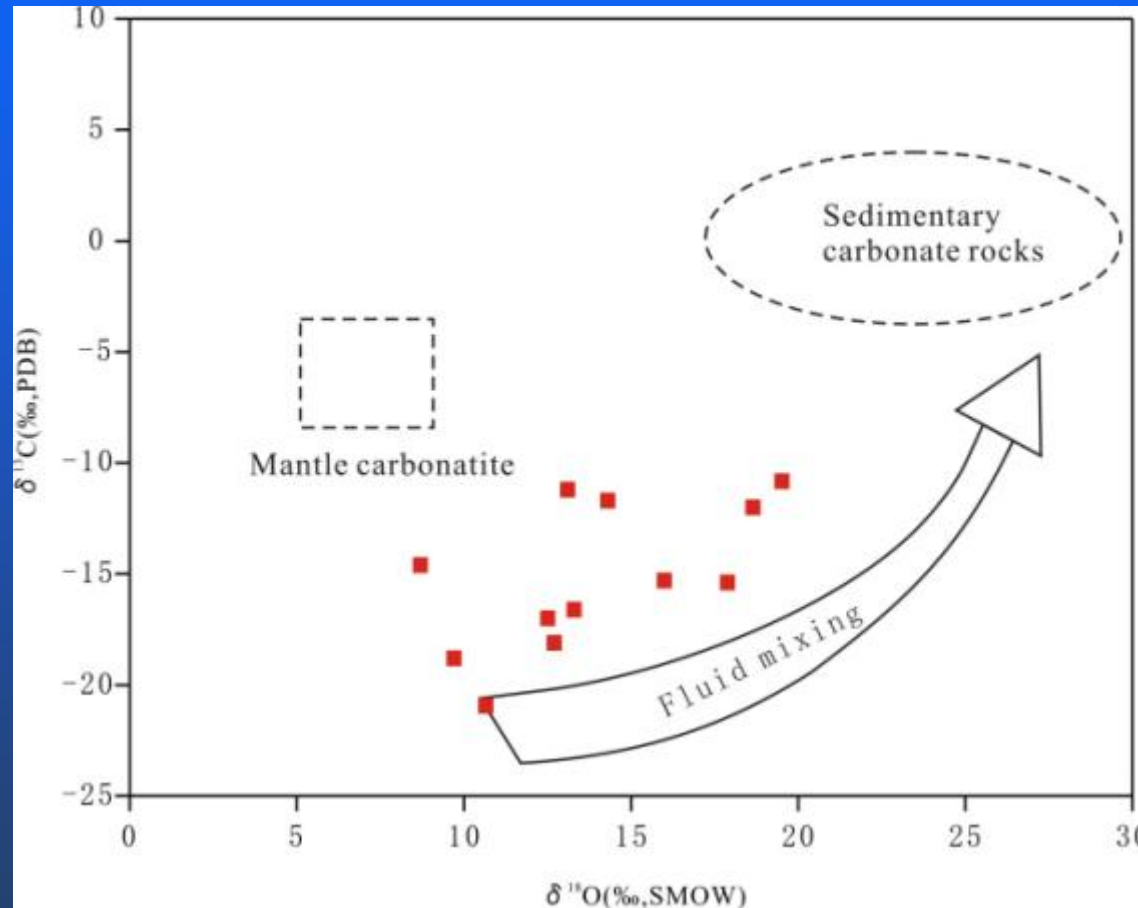
Well No.	Depth (m)	SiO <sub>2</sub>	CaO	TiO <sub>2</sub>	FeO	Fe <sub>2</sub> O <sub>3</sub>	MnO	Fe	F	S	P <sub>2</sub> O <sub>5</sub>	CO <sub>2</sub>	C	Total	Mineral name
DX1824	3548.3	99.97		0.022	0.004		0.004							100	quartz
DX1824	3548.3	99.97			0.006		0.021							100	quartz
DX1824	3548.3		38.53						4.92		39.16		8.2	90.8	apatite
DX1824	3637		37.17		2.41							53.64		93.2	calcite
DX1824	3637			39.30	14.24	15.82	21.19								ilmenite
DX1824	3548.3			0.48	26.35	64.40									magnetite
DX1824	3548.3			2.64	24.25	59.27									magnetite
D18	4058.55							44.61		55.39				100	pyrite
D18	4058.55							55.87		44.13				100	pyrite
D18	4058.55		32.57									56.17		88.7	calcite
D18	4058.55		32.74						5.47		35.36		11.17	84.7	apatite

- ✓ About 0.02% TiO<sub>2</sub> and 0.02% MnO was detected in the quartz fillings in the vertical tension fracture.
- ✓ Fracture- filling calcite has almost pure end-member CaCO<sub>3</sub> composition with small amounts of Fe.
- ✓ The opaque minerals in the alteration halo on both sides of the quartz veins are magnetite, while the opaque minerals in calcite vein are pure pyrite.
- ✓ The apatite associated with calcite and pyrite is mainly carbonate fluorapatite.



# How to determined the fluid properties and sources ?

## Trace elements and Stable Isotopic Compositions



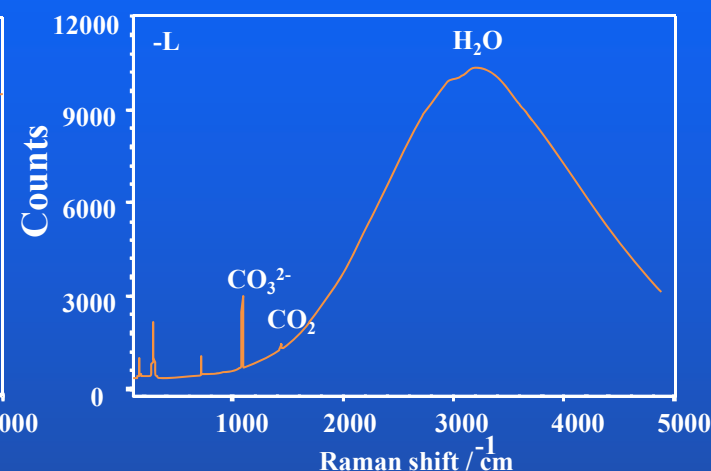
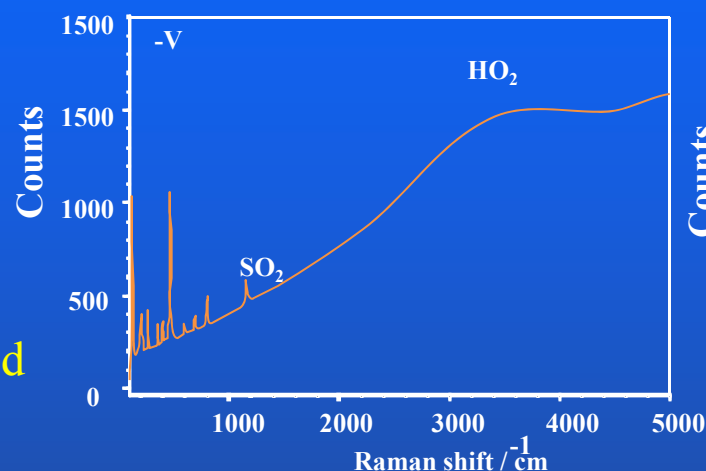
- ✓ Isotope datas are far lower than sedimentary carbonate, and different from magmatic minerals and the minerals effected by organic matter.
- ✓ These isotopes originally came from carbonate related to organic matter.
- ✓ The calcite was formed during a relatively late diagenetic stage and subject to relatively high temperatures.

**Carbon and oxygen isotope distribution of calcite veins**

# How to determined the formation time of veins and hydrocarbon fluid flow?

## Laser Raman Spectrum Characteristics of Fluid Inclusions

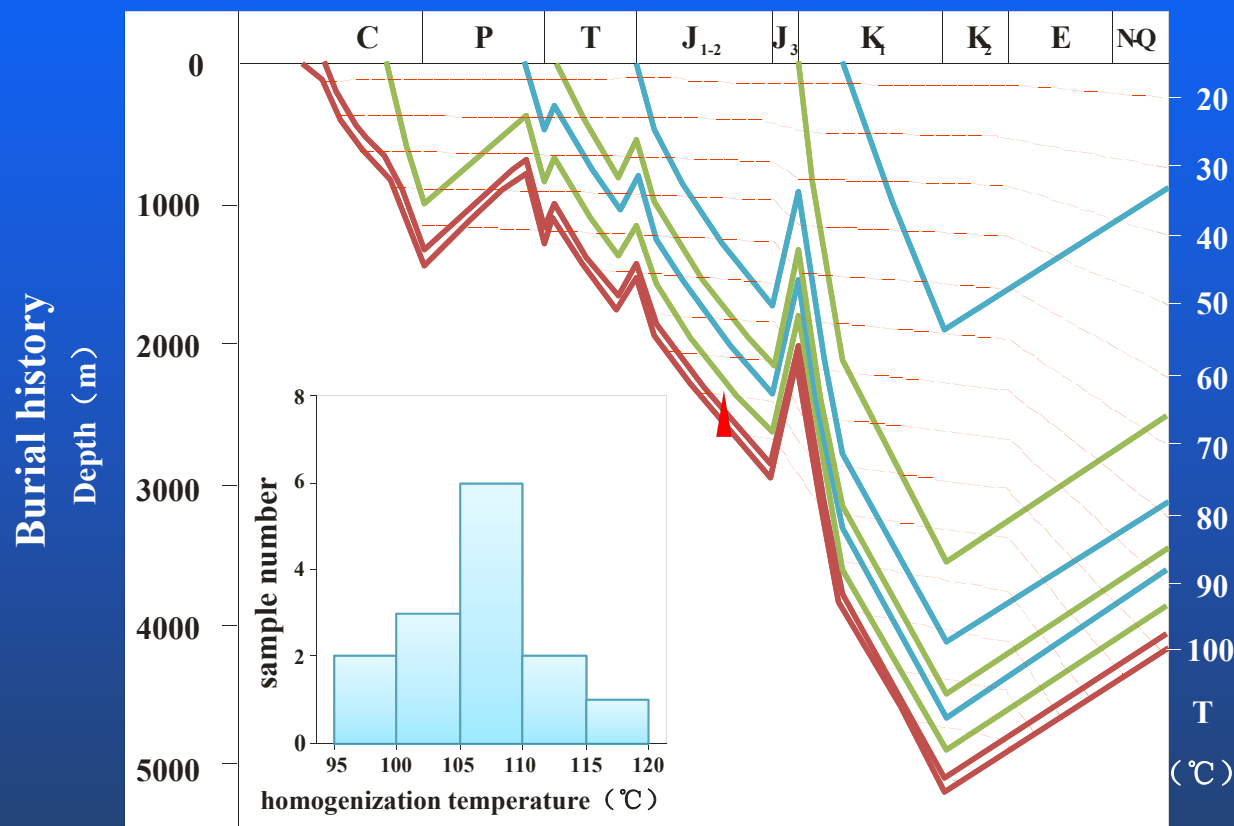
The range of homogenization temperature measured from the salt water inclusions of calcite veins is 99 to 115°C (av. 105.7 °C)



We could not get the homogenization temperature from the fluid inclusions of quartz veins, which have the main components of SO<sub>2</sub> and H<sub>2</sub>O with smaller individual size

# How to determined the formation time of veins and hydrocarbon fluid flow?

## Burial History and Hydrocarbon Generation History



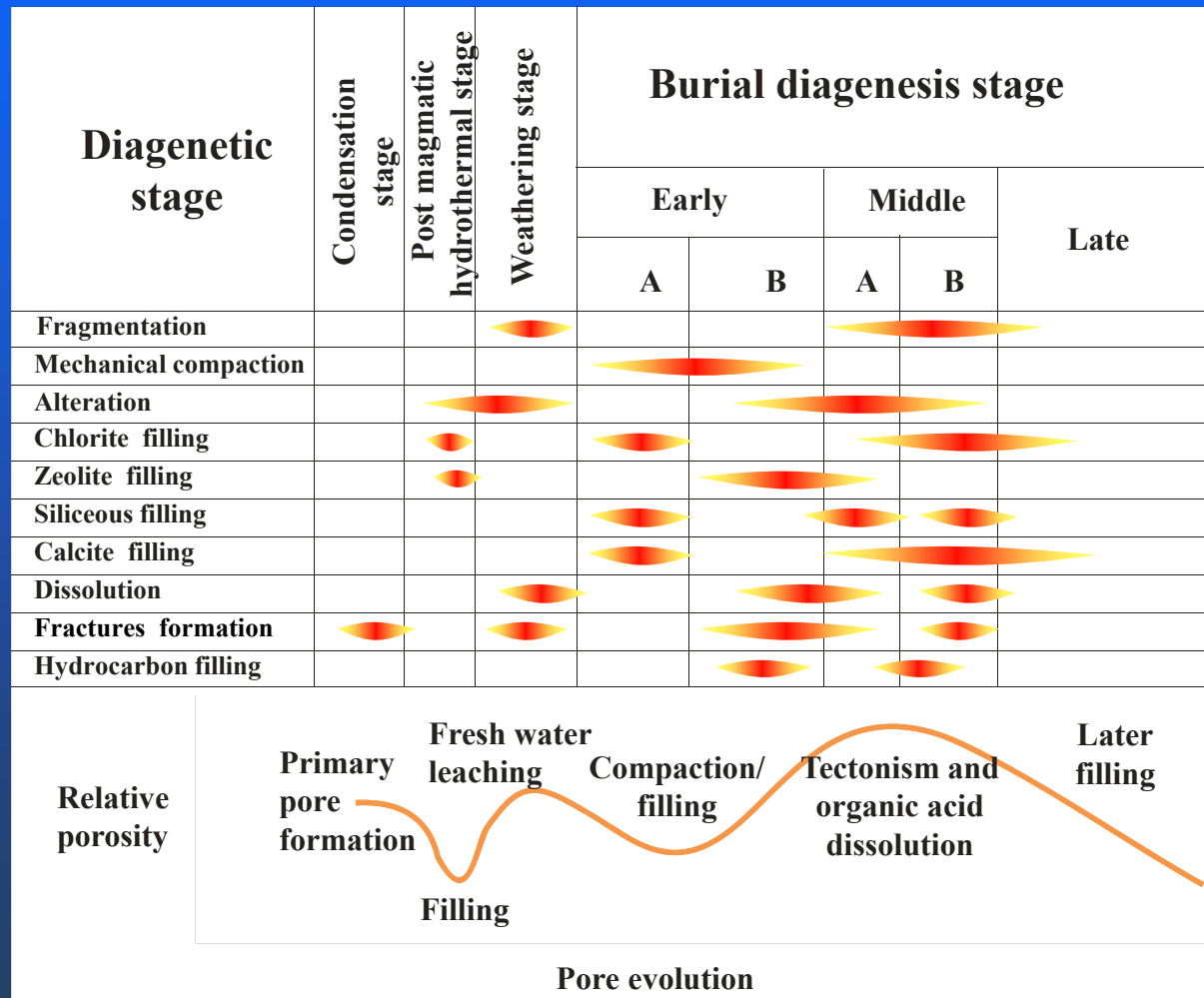
Detection Result			Calculation Temperature °C
$\delta^{13}\text{C}_{\text{V-PDB}}$ (‰)	$\delta^{18}\text{O}_{\text{V-PDB}}$ (‰)	$\delta^{18}\text{O}_{\text{V-SMOW}}$ (‰)	
-11.7	-16.1	14.3	79.5
-14.6	-21.5	8.7	120.3
-15.57	-12.64	17.87	56.8
-18.1	-17.6	12.7	90.5
-18.8	-20.5	9.7	112.6
-15.3	-14.4	16	68.4
-11.01	-11.06	19.50	47.3
-11.2	-17.3	13.1	95.5
-16.6	-17.1	13.3	86.3
-21.06	-19.65	10.64	105.4
-17	-17.8	12.5	91.9

*Good match  
between measured  
and calculated  
temperature*

The formation time of inclusions is in the end of the Middle Jurassic (Late Indosinian) by the homogeneous temperature peak of calcite vein (100 to 115°C).

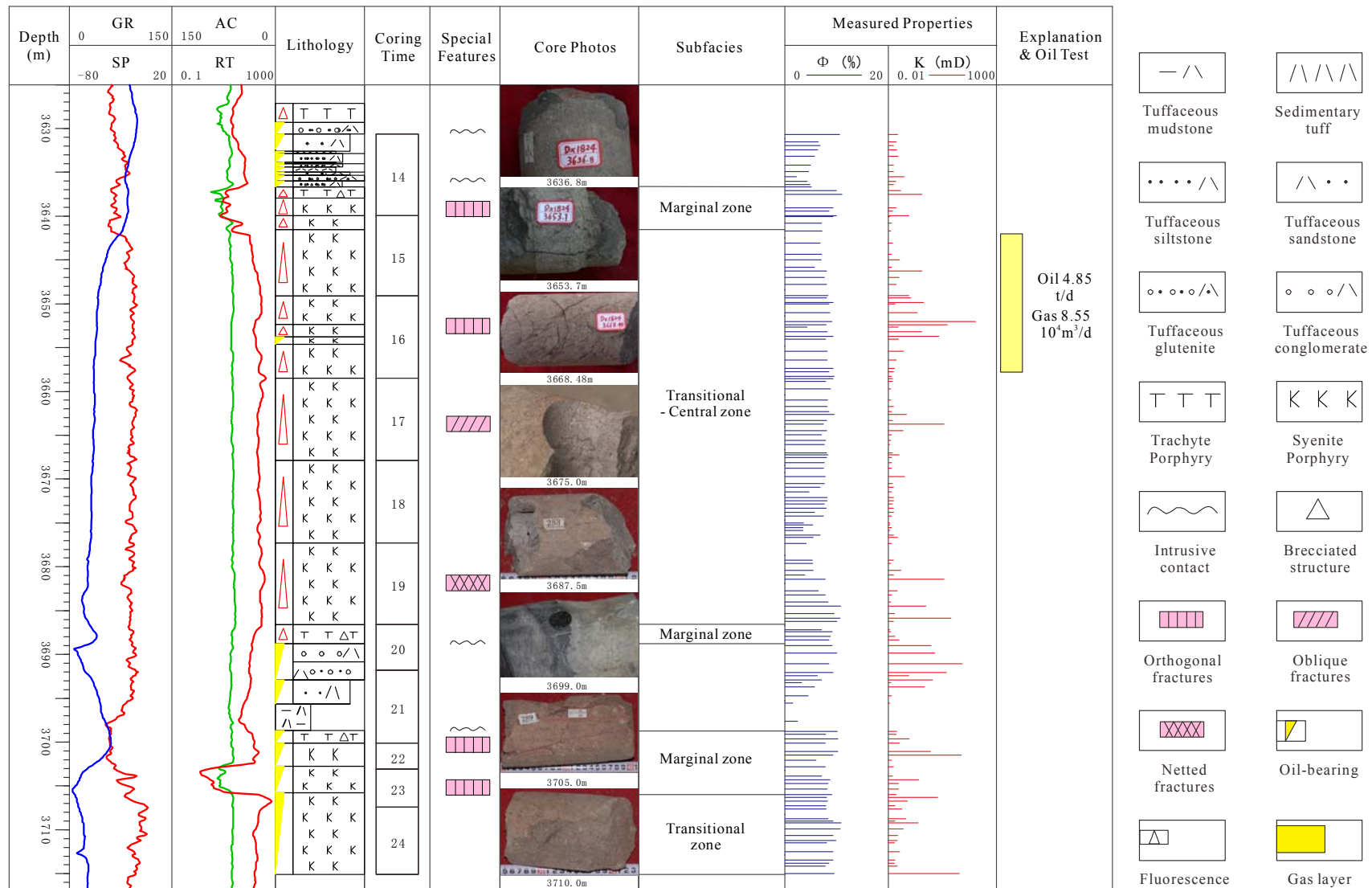
# How to determined the formation time of veins and hydrocarbon fluid flow?

## Symbiotic Combination Sequence



- Based on the fact that the asphalt is mainly distributed at the edges of fractures, that calcite mainly fills the fractures and that the contact area of calcite particles and cleavage cracks emit blue fluorescence while being non-luminous inside.
- It is believed that this kind of calcite was formed later than the early-stage oil and gas filling and earlier than the later-stage oil and gas filling.

# Fractures filling processes and its significance to reservoir



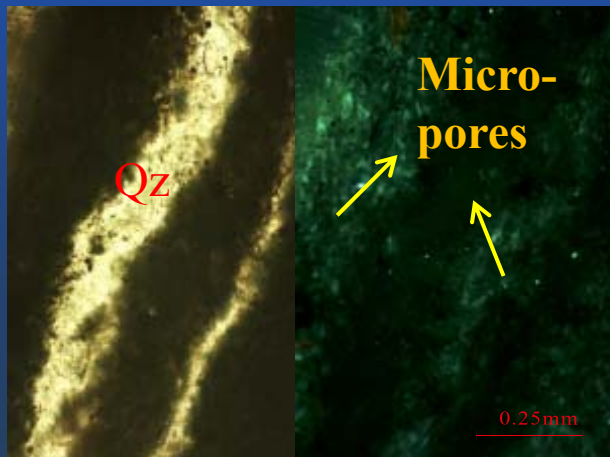
Compact volcanic rock formed a available reservoir with effective porosity and permeability because of fractures.



# Fractures filling processes and its significance to reservoir



- Fillings of quartz and calcite closed previously open fractures, mainly destructive to the physical properties of the reservoirs.
- Secondary pore developed anomalies along the weathered fractures at the top of the rock.
- A large number of intergranular **micro-pores** are formed by the recrystallization of the clay mineral matrix and calcite in the alteration zone, which are conducive to the later minerals dissolution.



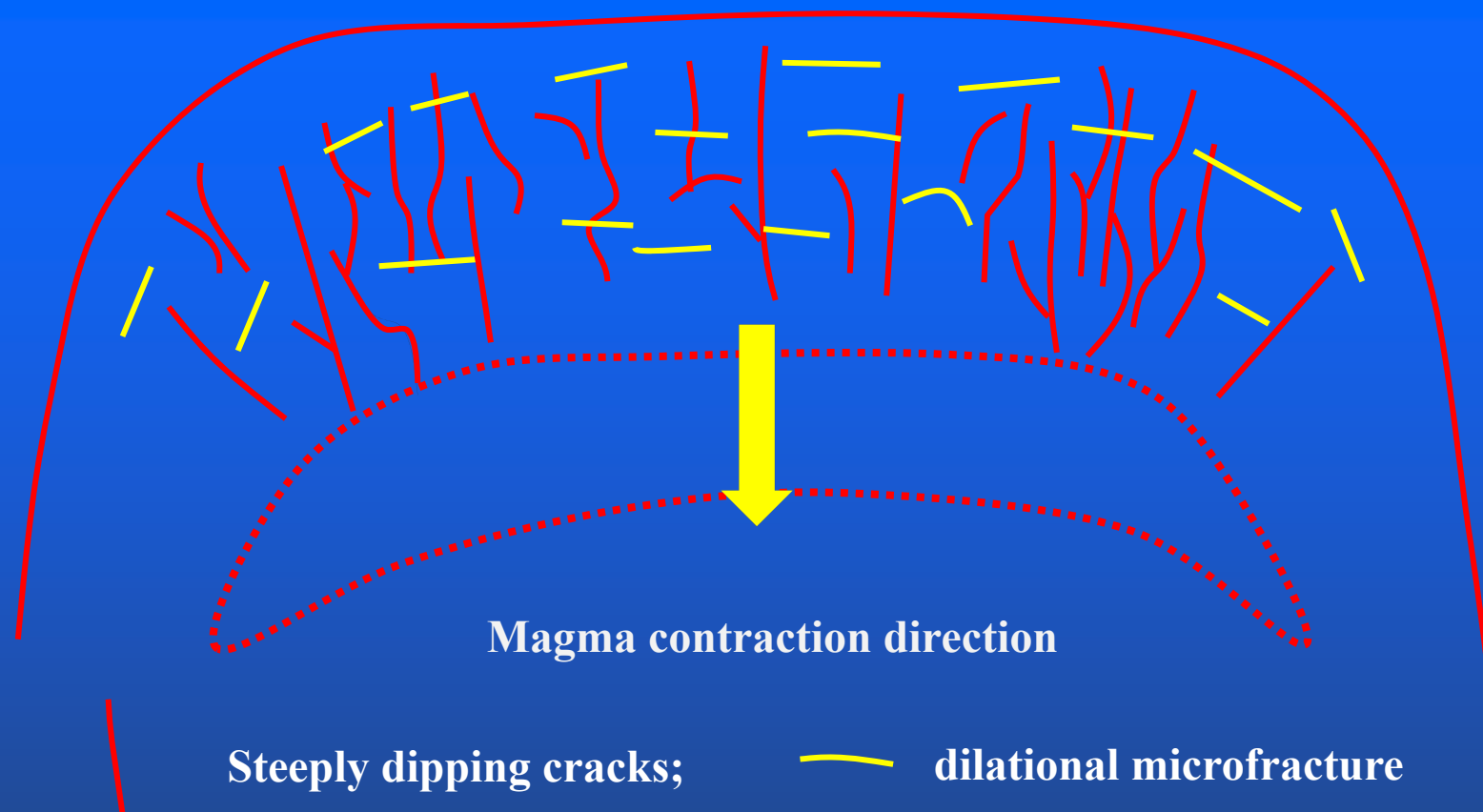
# CONCLUSIONS

- Many kinds of fluids coexist in the volcanic rocks, such as



- The  $\text{SiO}_2$ , a component of the quartz veins, mainly originated from deep hydrothermal fluids; The  $\text{CO}_2$ , a component of the calcite veins, derived from sources characterized by mixing and alteration of deep hydrothermal and hydrocarbon fluids.
- Under the dual driving force of **pressure gradient** and **buoyancy**, siliceous hydrothermal fluids rich in  $\text{SO}_2$  and other volatile components flowed upwards and sideways along the fractures, forming quartz veins that retain both archaic -high temperature characteristics and concealed explosive - low temperature characteristics.
- As deep fluids turned from acidic to slightly alkaline and their pressure,  $\text{CO}_2$  content, temperature changes and salinity decreased, early calcite precipitated in contraction fractures.

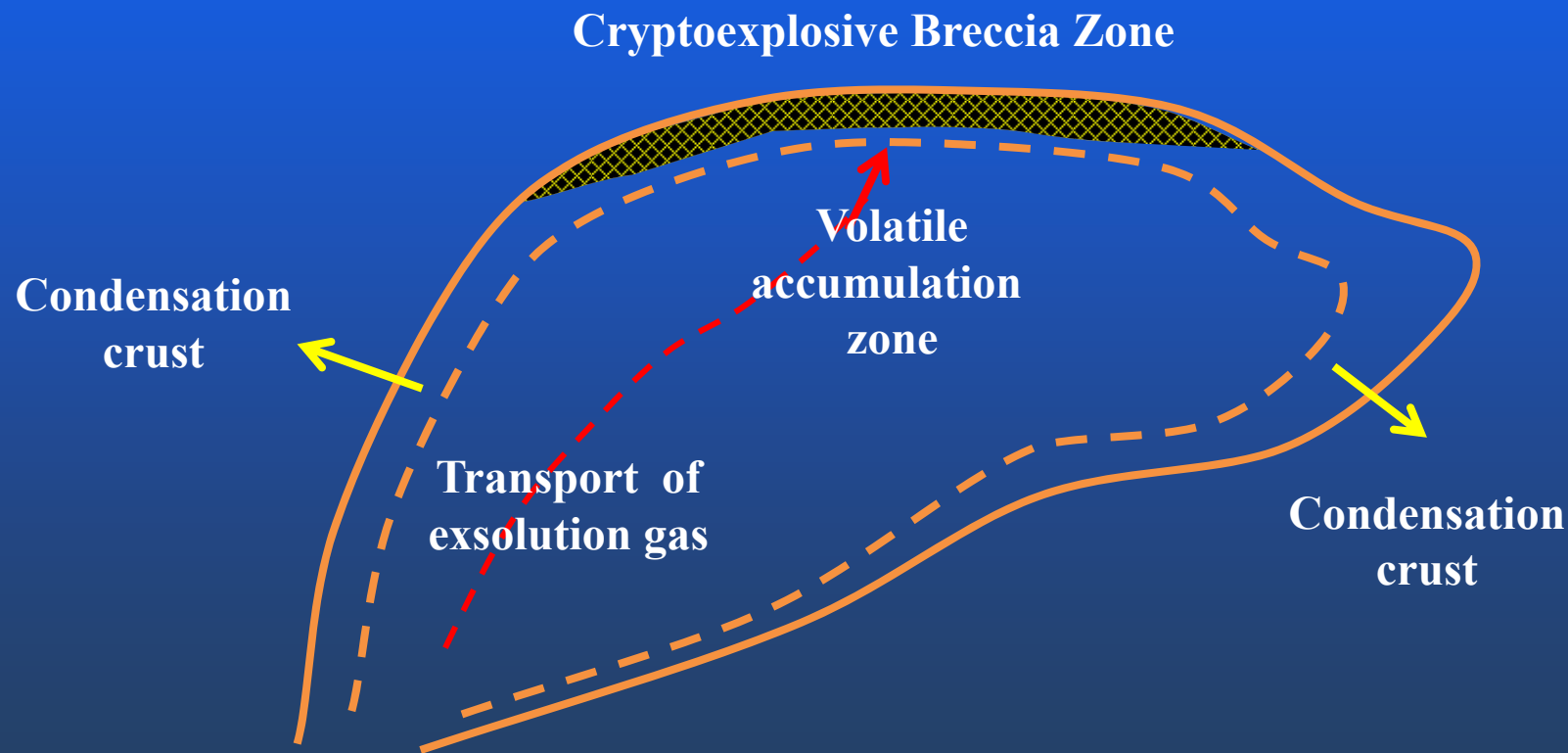




**Formation mechanism of shrinkage fractures at the top of a sub-volcanic intrusion in Dixi area**

# CONCLUSIONS

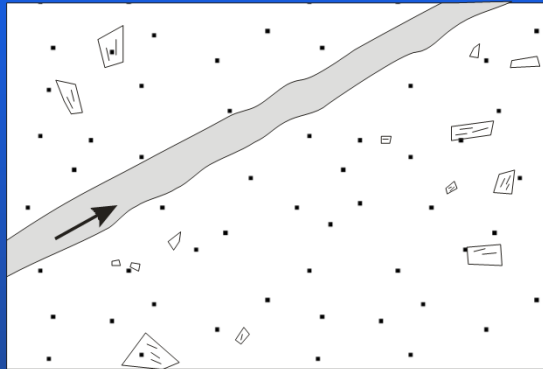
- The rock surface long term exposed, when the fresh water mix the partial alkaline fluid leaking out of the deep basin, formed calcite cements retain characteristics of seepage environment in the weathered fractures.



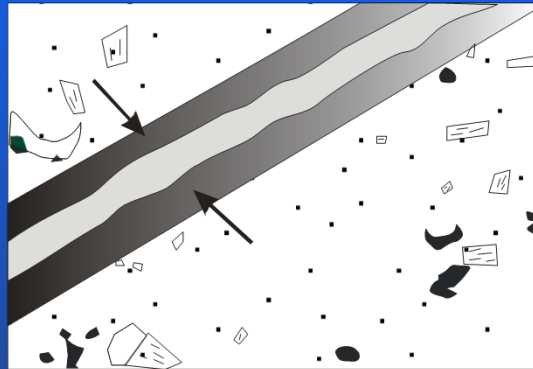
Formation mechanism of cryptoexplosive breccias

# CONCLUSIONS

- Tectonic fractures occurred due to tectonization in a burial period.
- Filling and leakage of hydrocarbons caused pore acidic fluids becomes alkaline, precipitating late sparry calcite in dissolution fractures.



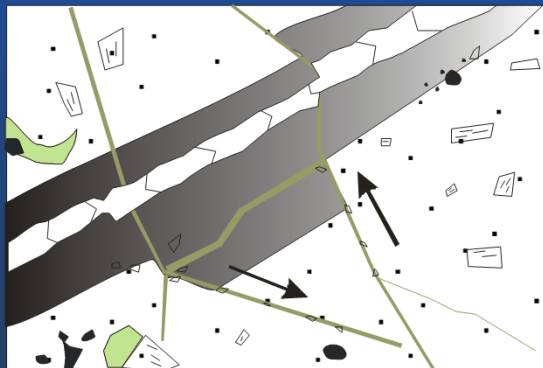
**Hydrothermal fluids infilling**



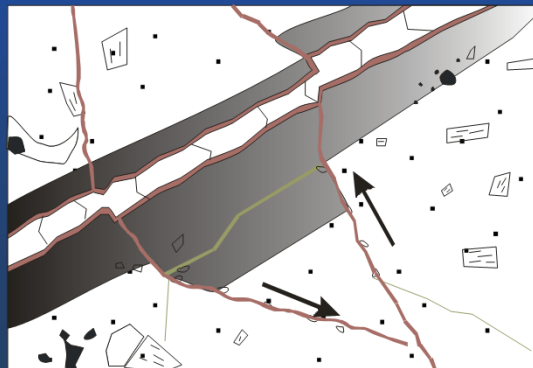
**Migration of element**



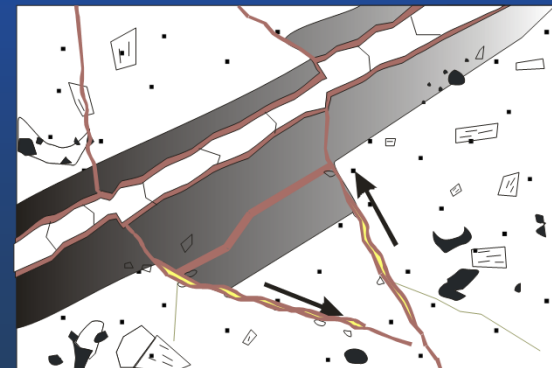
**Quartz veins formation**



**Tectonic fractures formation**



**Hydrocarbon emplacement**



**Calcite precipitation**

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