Characteristics and Cutoff of Porosity and Permeability of the Effective Volcanic Gas Reservoirs of the Lower Cretaceous Yingcheng Formation in Songliao Basin, Northeast China*

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Abstract

Effective volcanic gas reservoirs of the Lower Cretaceous Yingcheng Formation in the Xujiaweizi Depression of northern Songliao Basin are primarily found in rhyolite, rhyolitic welded tuff, trachyte and basalt. There are six types of reserve spaces together with their assemblages which indicate effective reservoirs, including unfilled vesicles, dissolved pores, inter-spherulite pores, columnar jointing fractures and tectonic fissures. Porosity of 1262 pieces of volcanic rock samples mainly ranges between 1.5% and 10%, and those of intermediate and low porosity below 10% amount to a percentage of 88.4%. Permeability of 1197 pieces of samples ranges between 0.01×10^{-3} μm^2 and 1.0×10^{-3} μm^2, and those of low permeability less than 0.1×10^{-3} μm^2 amounts to 66.7%. Consequently, these indicate volcanic reservoirs with characteristics of intermediate to low porosity and low permeability.

By means of porosity, permeability and productivity testing data from eighty wells, three methods including distribution function curves, cross-plots and statistical method are used to determine the porosity and permeability cutoff values of the four types of volcanic rocks respectively. The results of porosity and permeability cutoff of basalts are 6.2%, 0.005×10^{-3} μm^2 and trachyte 4.2%, 0.011×10^{-3} μm^2, rhyolite 5.4%, 0.046×10^{-3} μm^2, rhyolitic welded tuff 5.7%, 0.036×10^{-3} μm^2. Moreover, the results are proved by data of other twenty wells from neighboring areas with an order of accuracy of 90%. The lower limits of

reservoir porosity and permeability of different types of volcanic rocks are primarily related to their reservoir heterogeneities, which were mainly controlled by reservoir space constitution and lengthwise continuity. The lower limits of porosity of trachytic and rhyolitic reservoirs which show larger thickness of continuous lengthwise layers, compared to that of less continuous basalt and ignimbrite. Synchronized mineralogical studies indicate a higher content of dark-colored minerals in basalt which is easier to form secondary fractures that resulted by a higher stress sensitivity. Moreover, dark minerals and mafic feldspars are more easily altered into clay minerals which expand with water and thus forming micro-fractures. As a result, permeability of basalt is the best among all the volcanic rocks, and the lower limit of reservoir permeability is significantly lower than the other three types.

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Smith, R.L., and R.A. Bailey, 1966, The Bandelier Tuff; a study of ash-flow eruption cycles from zoned magma chambers: Bulletin of Volconology, v. 29, p. 83-103.

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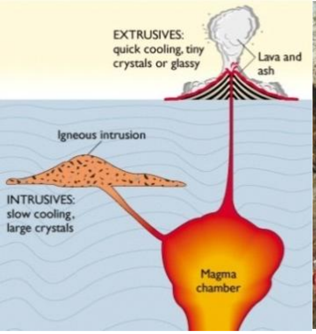
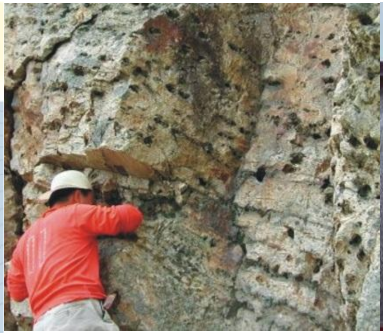
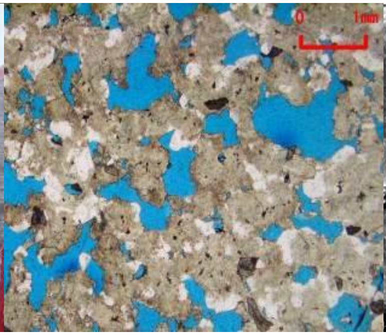
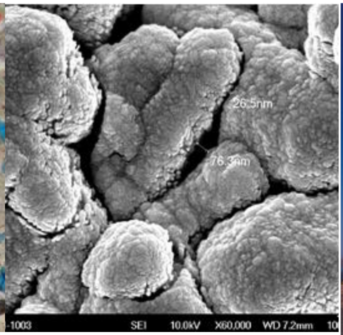








Outline

- Volcanic reservoirs in Songliao Basin
- General characteristics
- Effective reservoirs: Definition, methods and results
- Characteristics of effective volcanic reservoirs and their controlling factors
- Conclusions

Volcanic reservoirs in the world

Clastic reservoirs

(approx. 60%)

Carbonate reservoirs

(approx. 40%)

水

water

Volcanic reservoirs

(less than 1%)

火

fire

Long history, 'low yielding'

Volcanic reservoirs in China

Junggar Basin
C-P

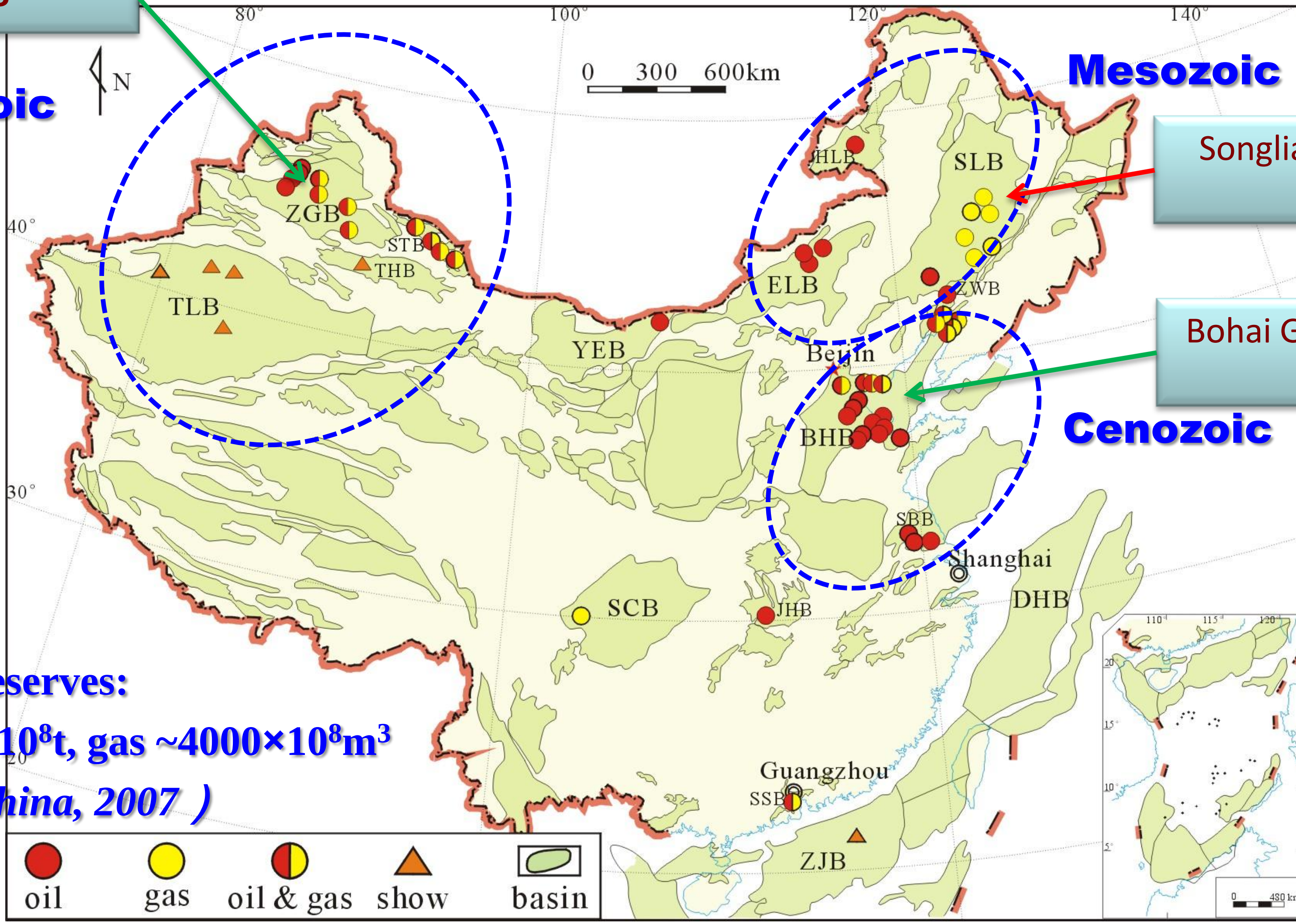
Paleozoic

Mesozoic

Songliao Basin
K

Bohai Gulf Basin
E

Cenozoic

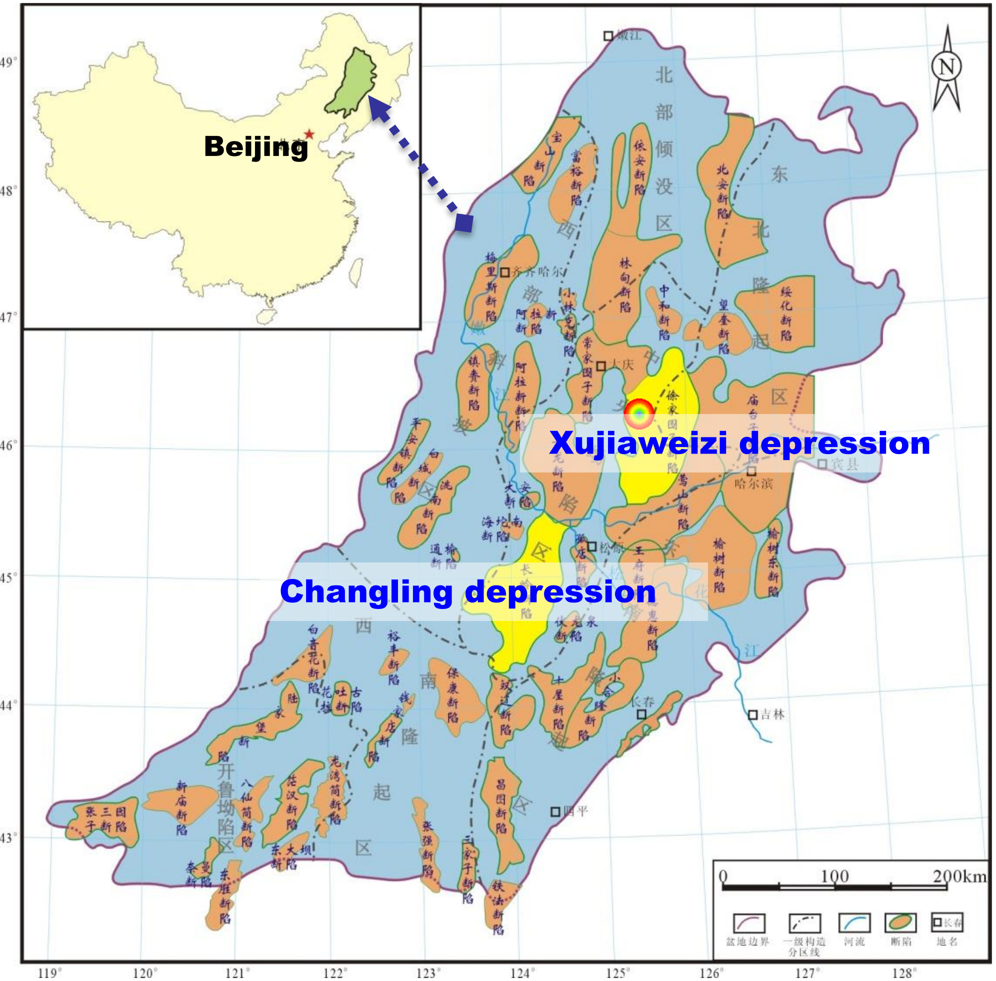


Proved reserves:
Oil ~0.5×10^{8}t, gas ~4000×10^{8}m^3
(PetroChina, 2007)

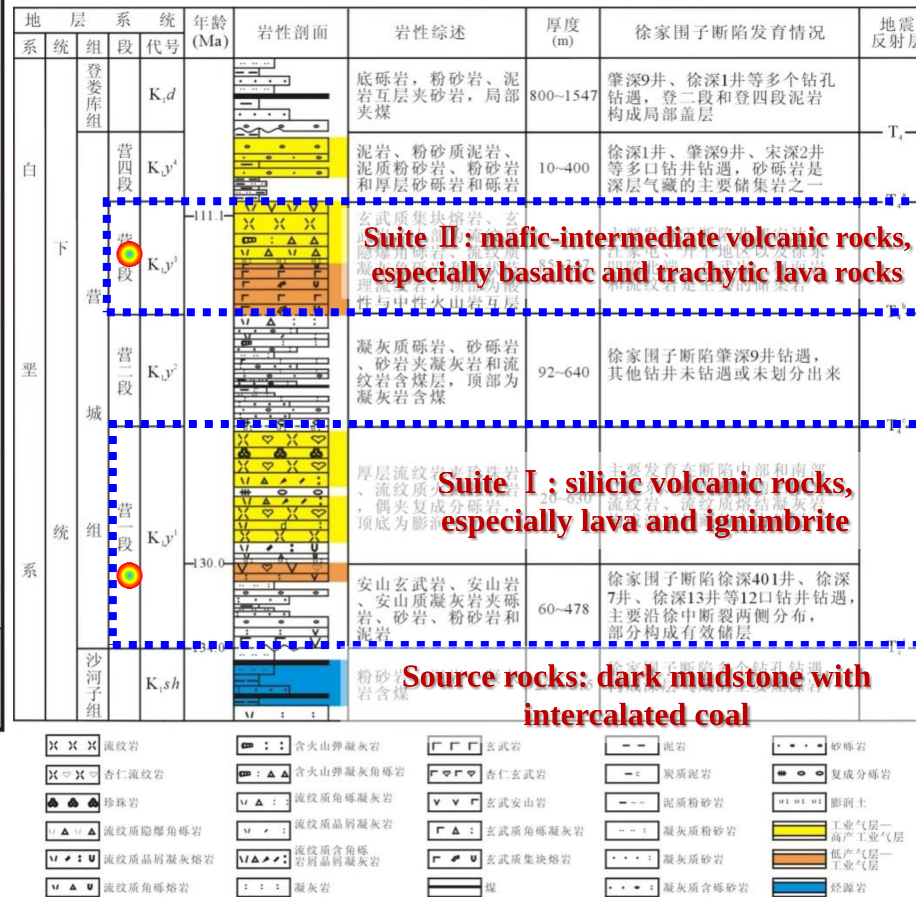
Distribution of volcanic reservoirs in sedimentary basins of China

Volcanic reservoirs in Songliao Basin

- 80 boreholes
- 4 with continuous core samples
- Tens to hundreds meters long core sections for each

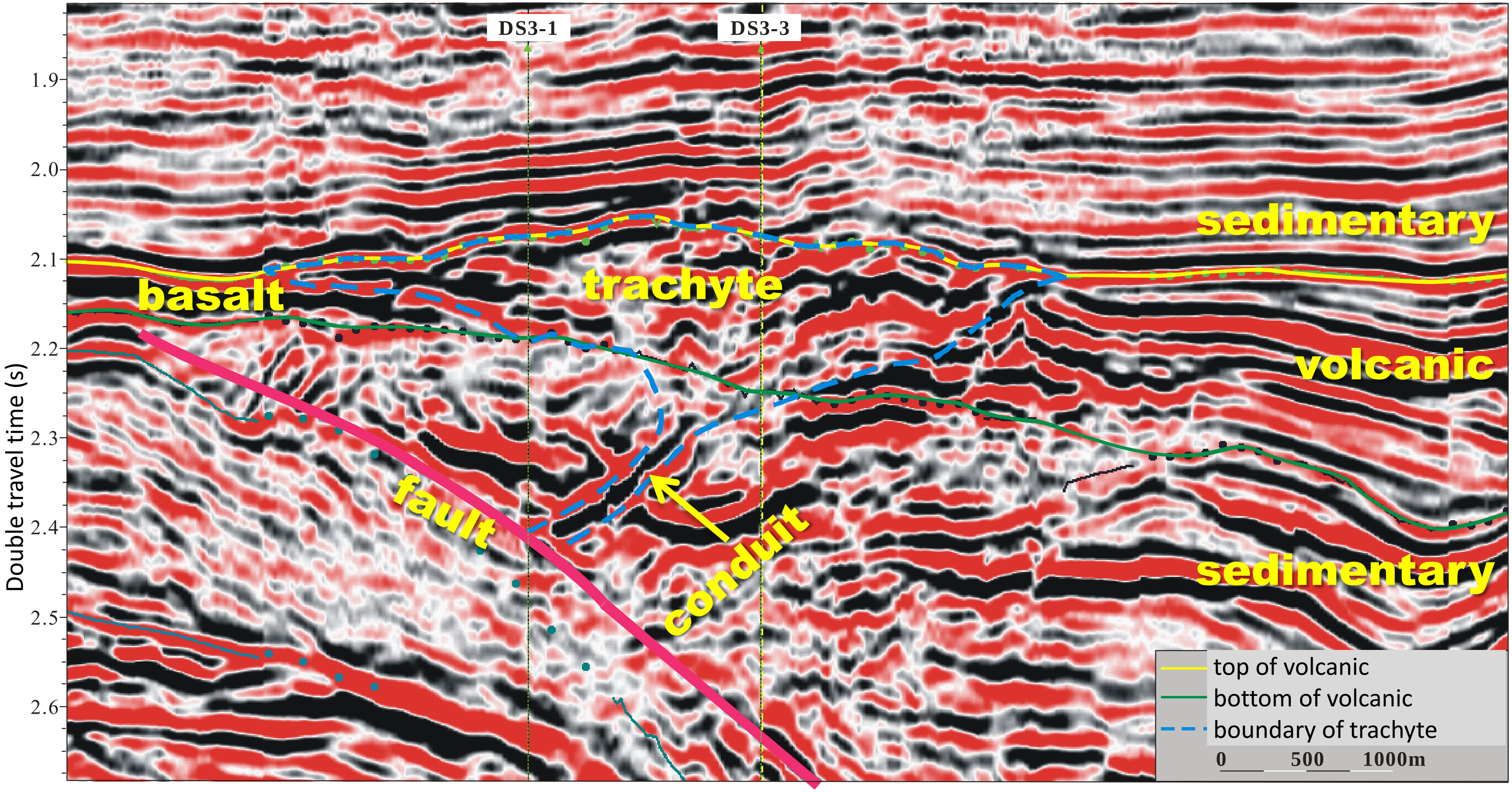


Distribution of the depressions in Songliao Basin



the Cretaceous stratigraphic column

sandwich-like source-reservoir-seal assemblages



Typical seismic profile of a volcanic-sedimentary strata in Songliao Basin

Data come from

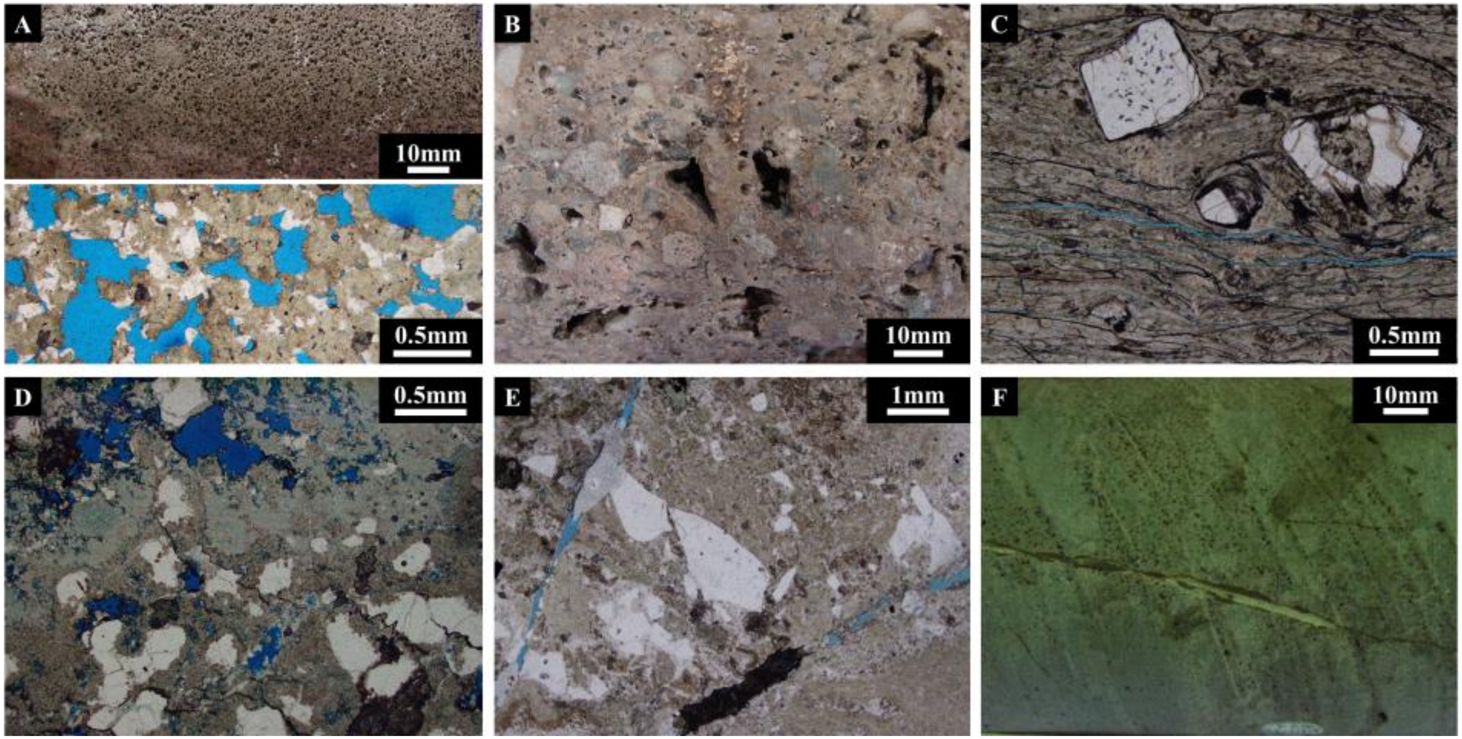
- ~80 boreholes (with natural gas yielding test data to prove whether the reservoir is effective or not)
- 4 with continuous core samples (to do series of tests)
- Tens to hundreds meters long core sections for each well

Series of tests and analyses

- Core analysis
- Casting thin sections
- Porosity and permeability
- Mercury injection
- SEM (scanning electron microscope)

Boreholes	Y3D1	DS3-1	XS9-1	XS1-2
lithology	basalt	trachyte	rhyolite	ignimbrite
lithofacies	effusive	extrusive	extrusive and effusive	explosive
length of core sections In meters	254	85	228	304

Pores and fractures in volcanic rocks



A- vesicles in rhyolite

B- intergranular porosity in volcanic breccias

C- contraction joints in rhyolitic ignimbrite

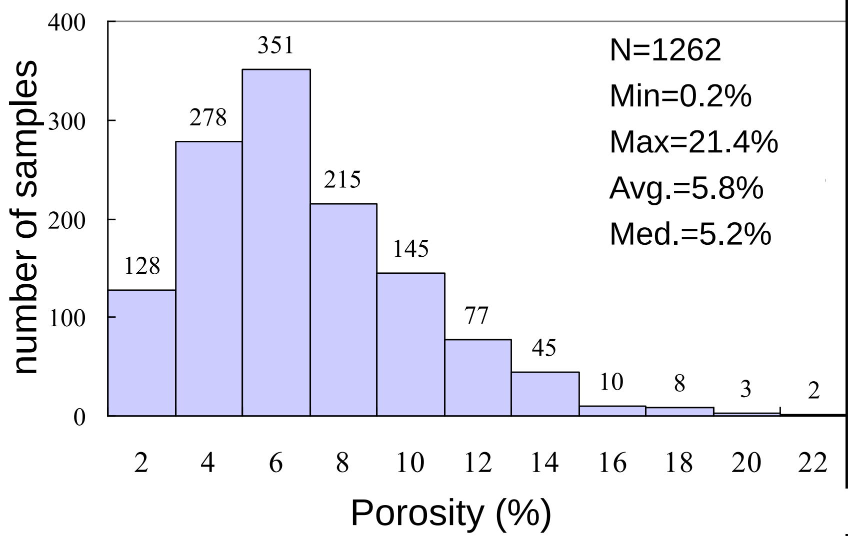
D- dissolution porosity in rhyolite

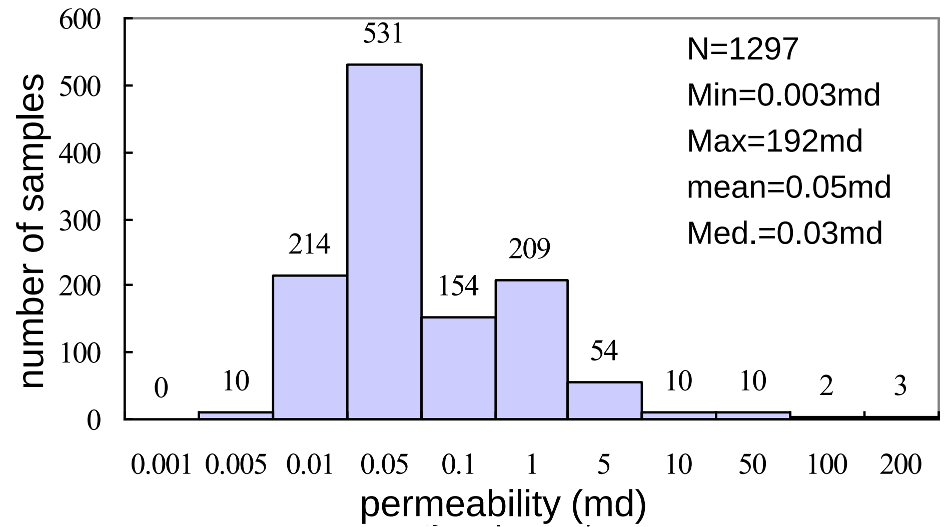
E- dissolution fractures in rhyolitic breccia lava

F- vesicles and tectonic fracture in rhyolite

Reservoir quality

- Medium - low porosity
- low permeability





high Φ（>10%）--------------11.4%

medium Φ（5%~10%）----41.3%

low Φ（<5%）----------------47.3%

high K（≥5md）----------------2.1%

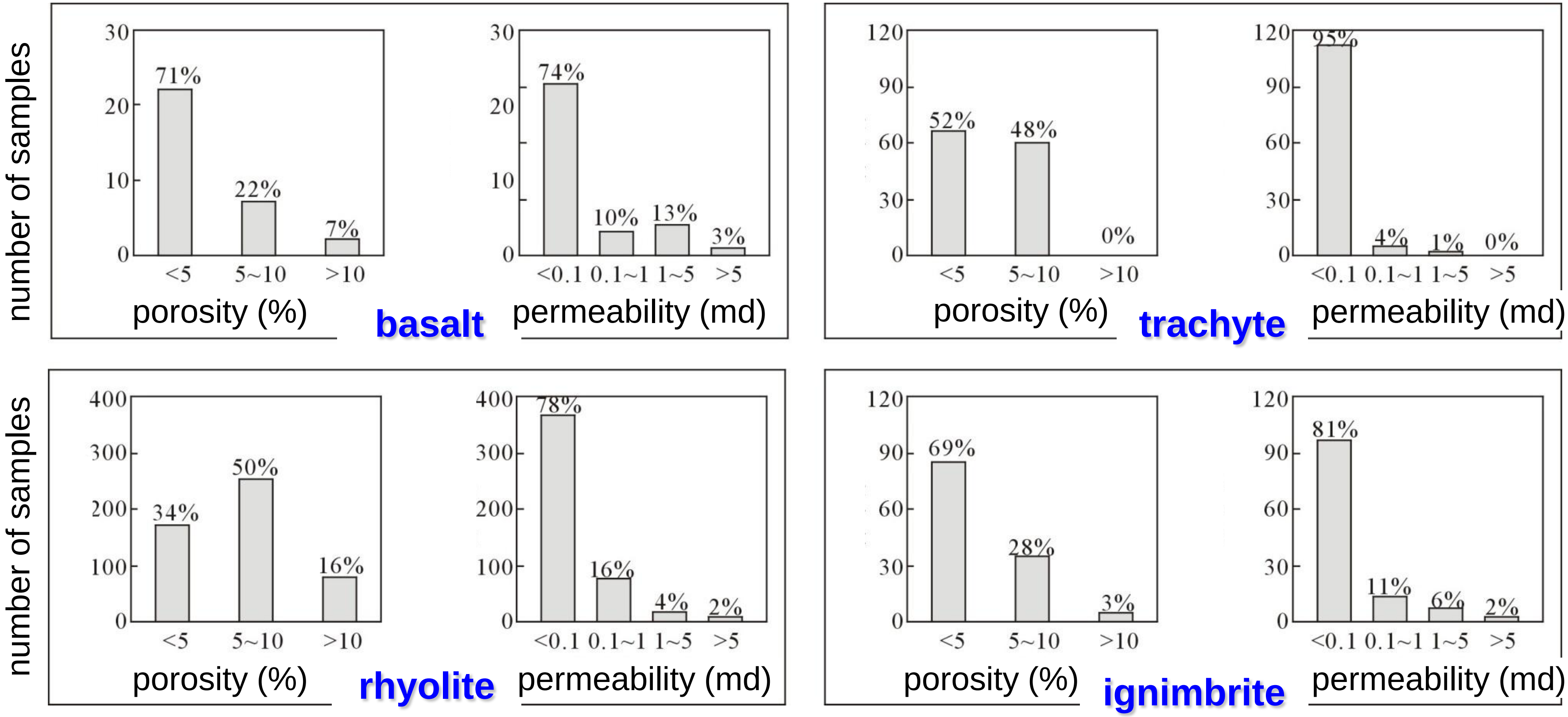
mid-high（ 1~5md ）-----------4.5%

medium（ 0.1~1md）-----------17.5%

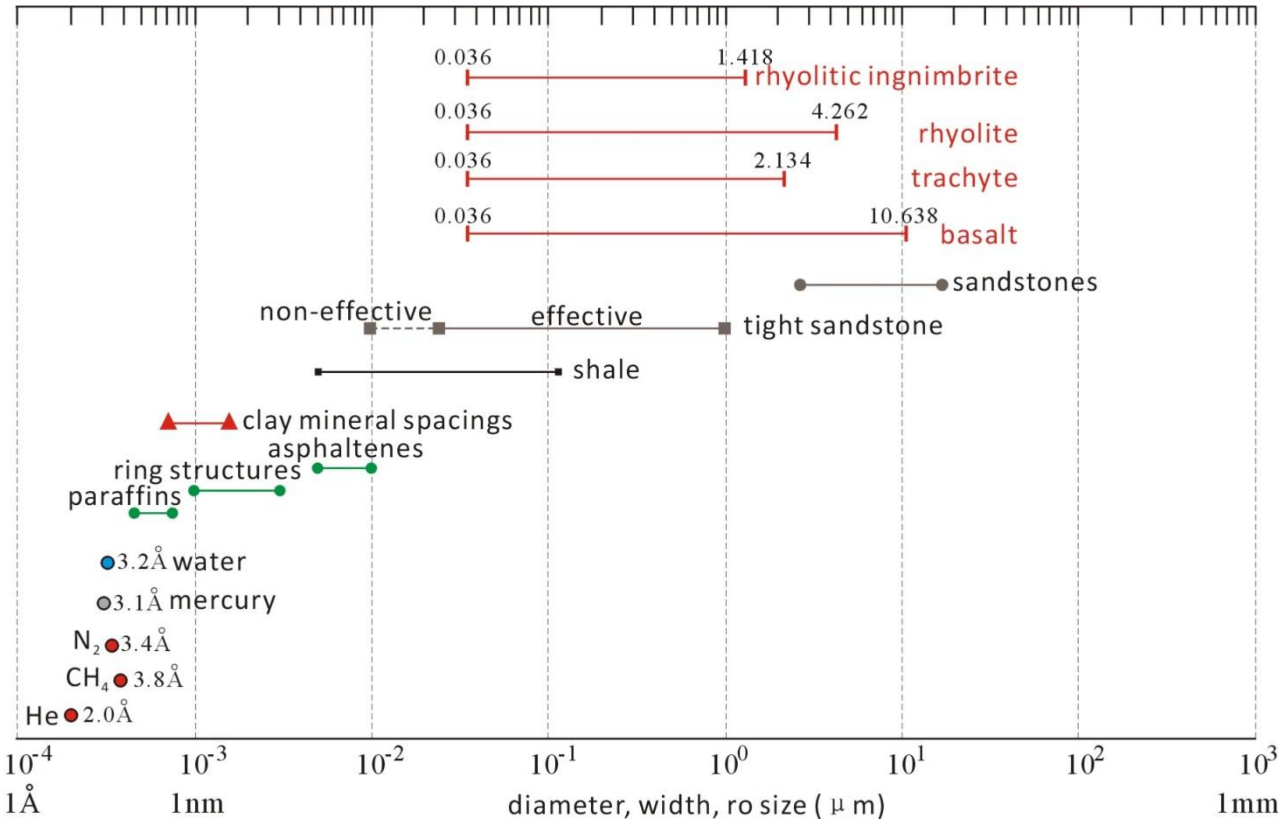
low（ <0.1md）-----------------75.9%

Correlation and sequencing of the porosity and permeability of the four types of volcanic reservoirs

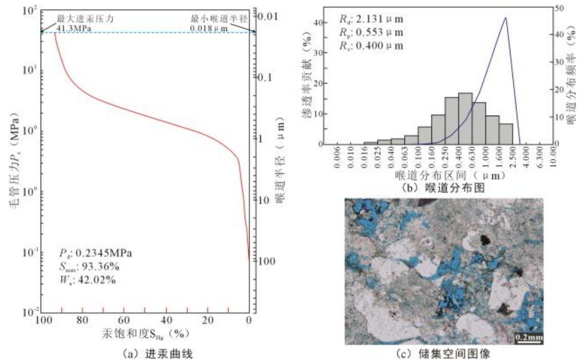
lithology	basalt	trachyte	rhyolite	ignimbrite
porosity	IV	II	I	III
permeability	I	IV	III	II



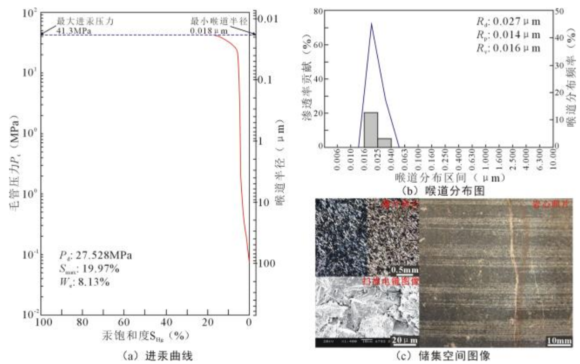
Pore-throats of volcanic rocks compared to clastic rocks



Modified from Nelson, 2009



Porosity: 16.3%
Permeability: 1.88×10^{-3}μm^2



Porosity: 5.8%
Permeability: 0.05×10^{-3}μm^2

Definitions

Effective reservoir

-Reservoirs with relatively higher porosity and permeability, which are able to yield enough fluid (oil, gas or water) with an commercial value of productivity.

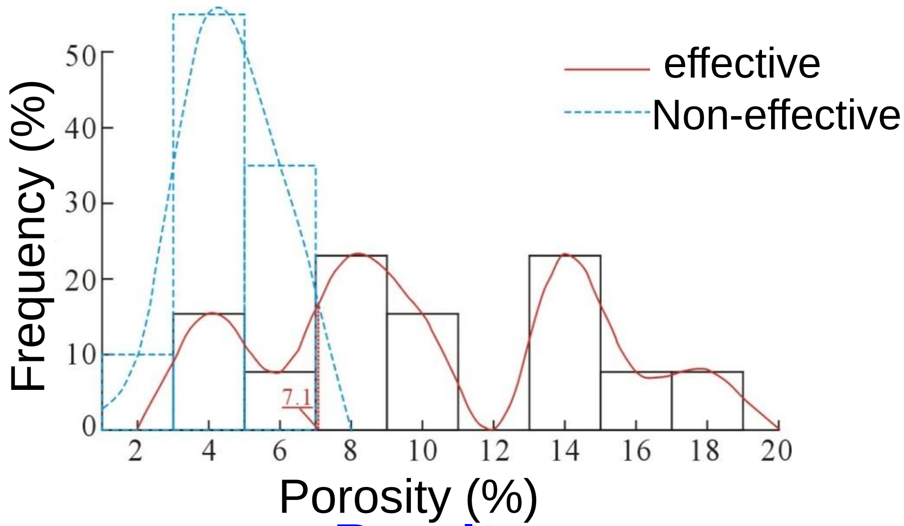
- Total gas equivalent higher than **40, 000 m^3/d** *(in the study area)*

Cutoff of porosity and permeability

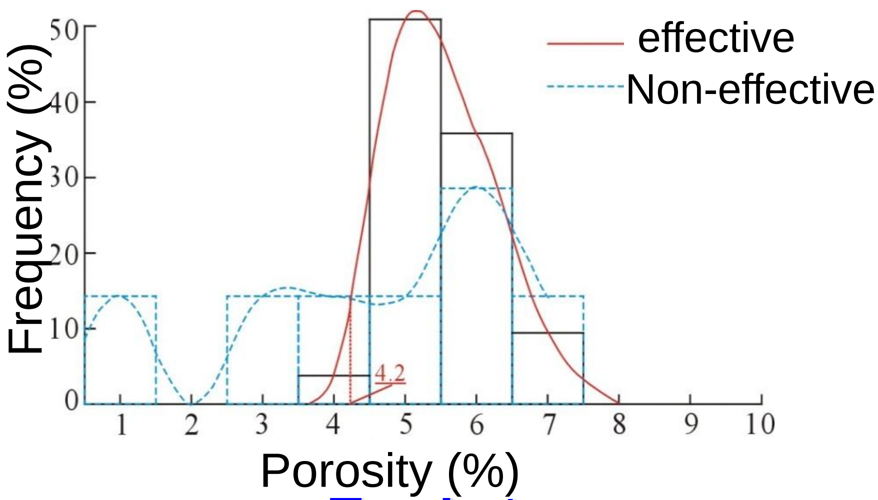
-Reservoirs with porosity and permeability less than cutoff value will not be able to yield commercial value of fluids.

Two statistical methods

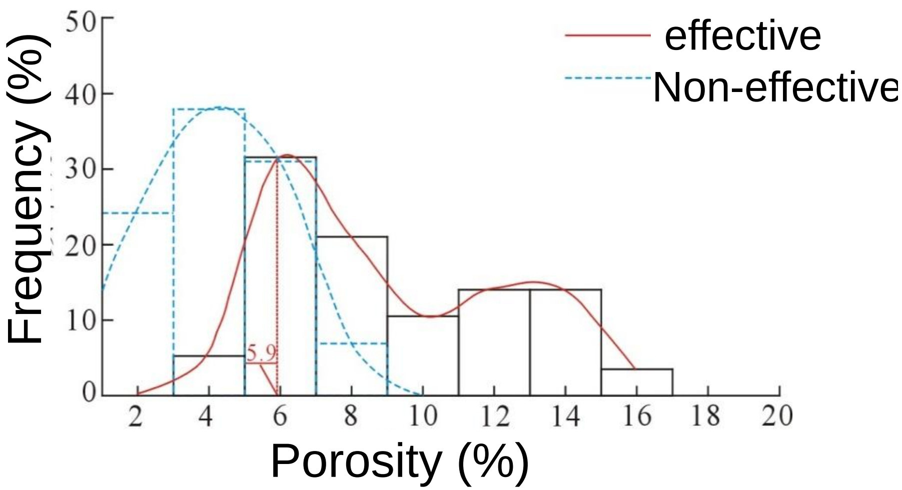
Distribution function curves



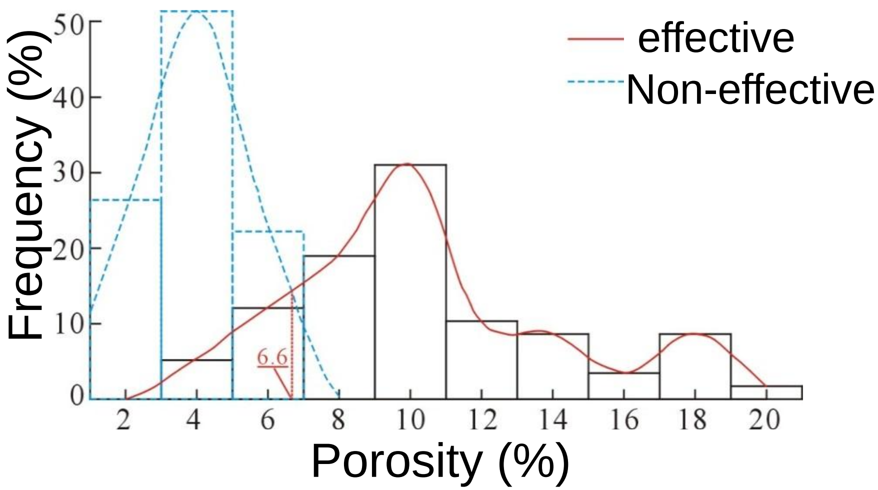
Basalt



Trachyte

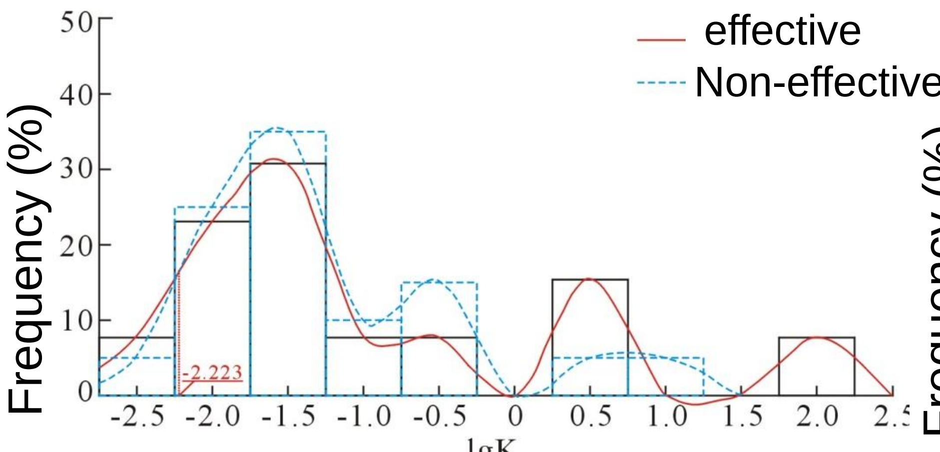


Rhyolite

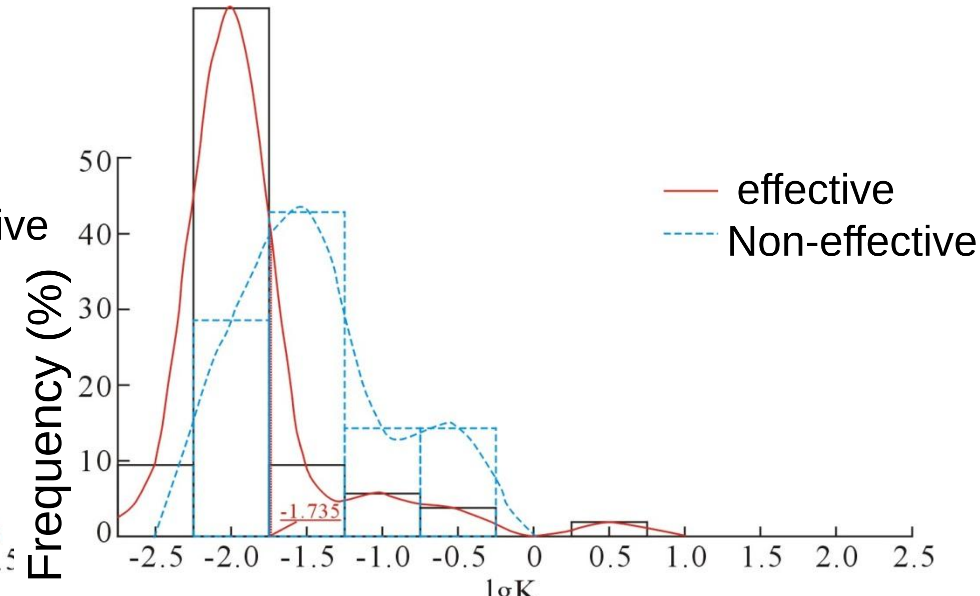


Rhyolitic ignimbrite

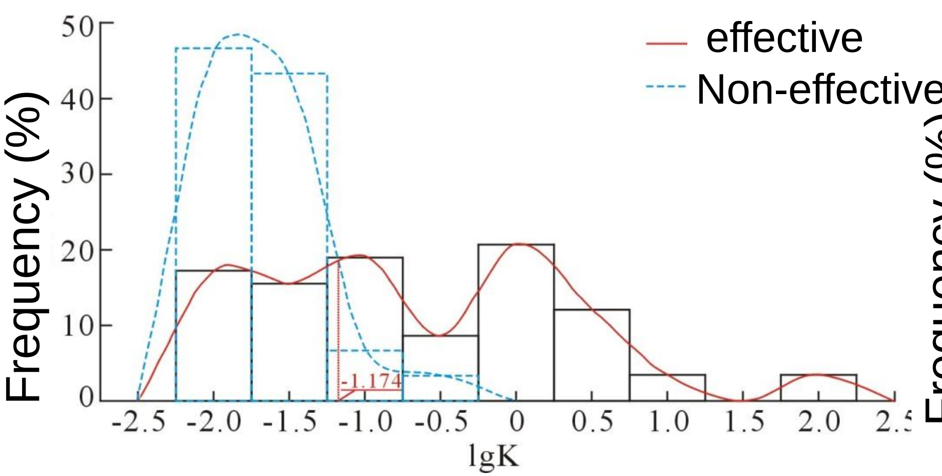
Distribution function curves



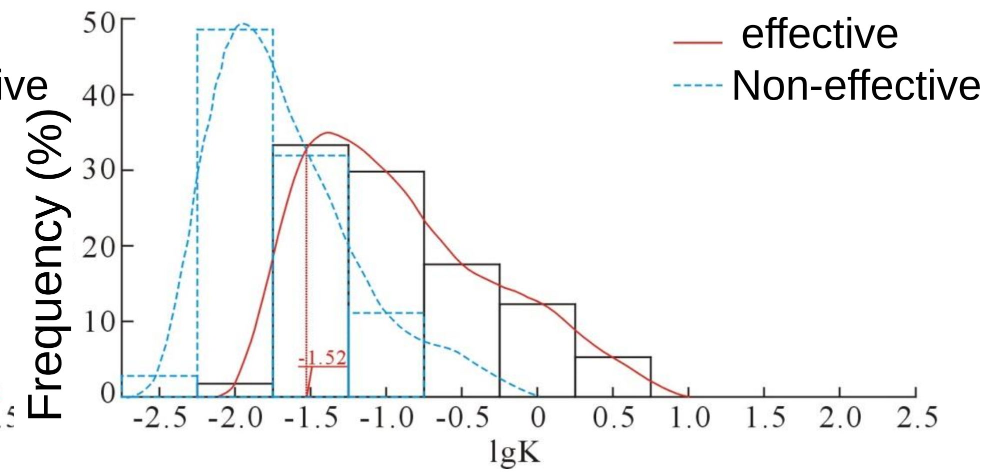
Basalt



Trachyte



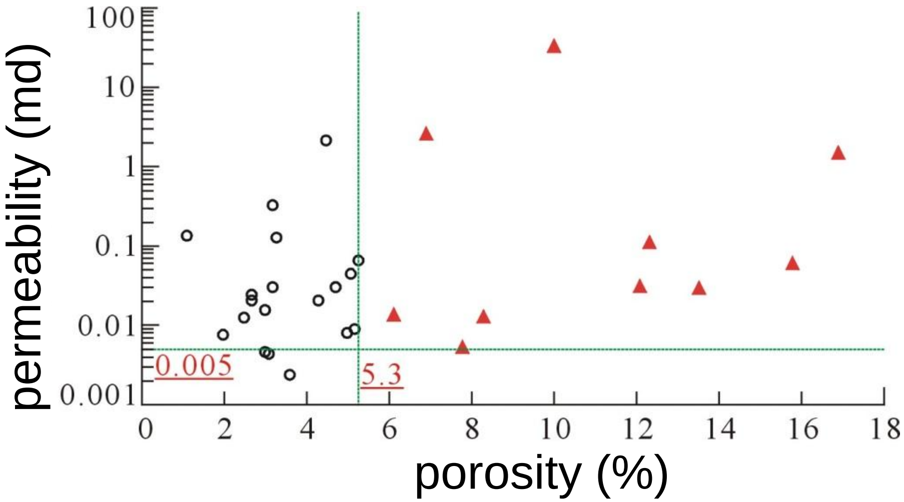
Rhyolite



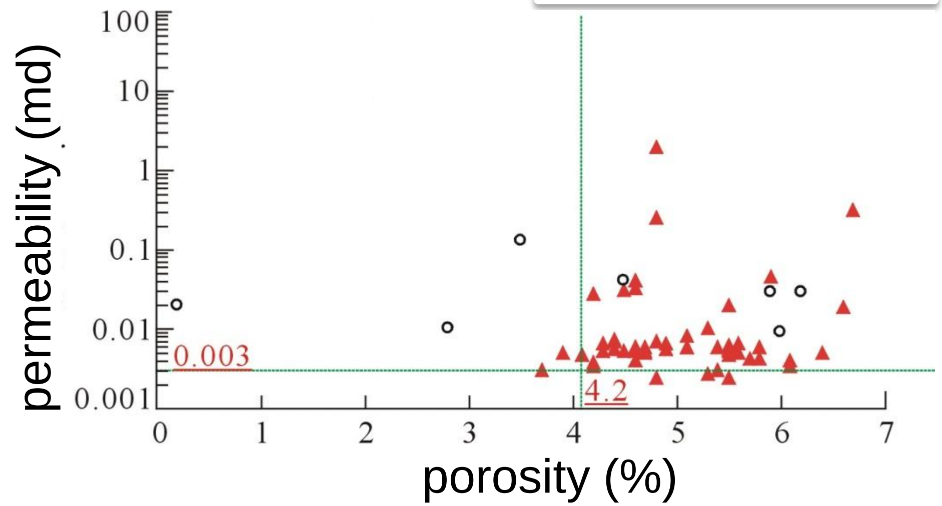
Rhyolitic ignimbrite

Cross-plots

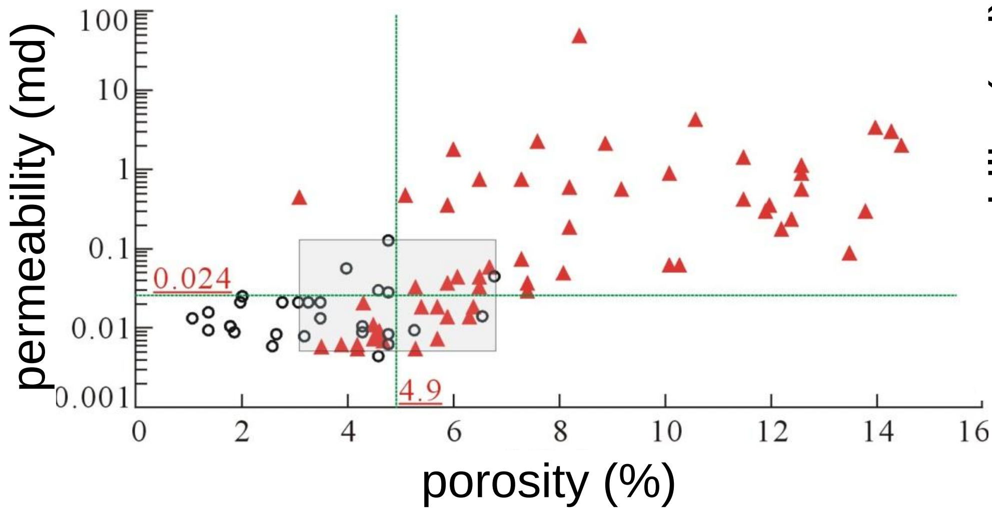
▲ effective
○ non-effective



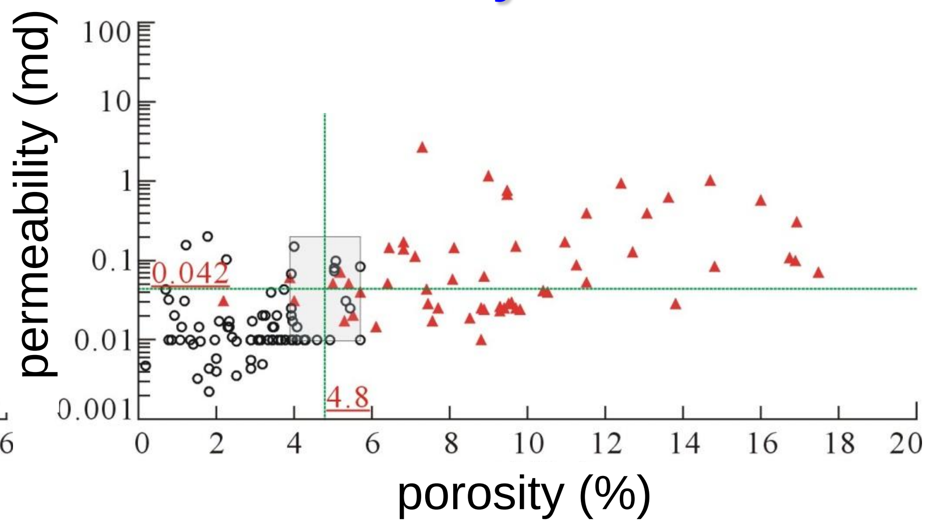
Basalt



Trachyte



Rhyolite



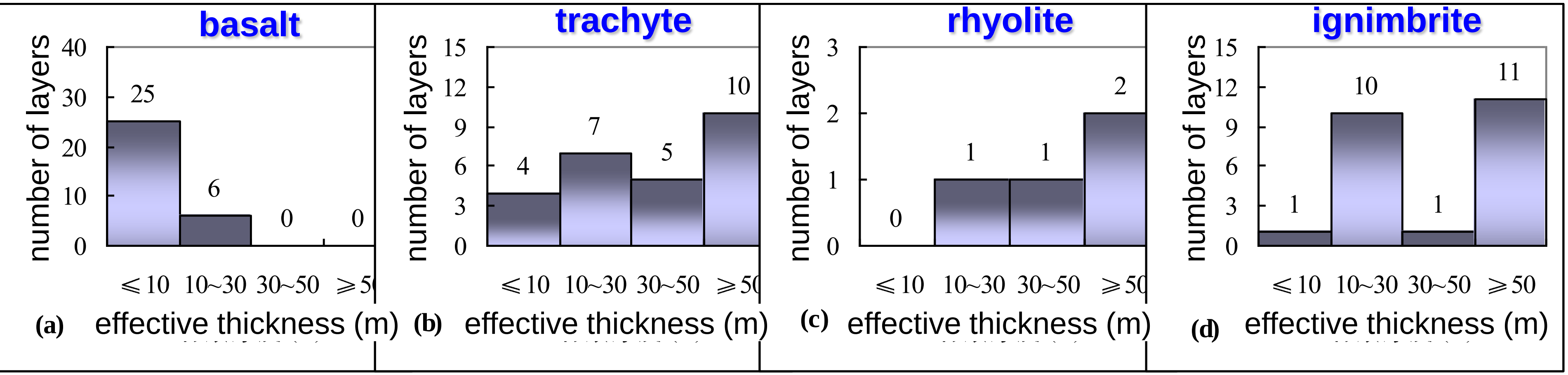
Rhyolitic ignimbrite

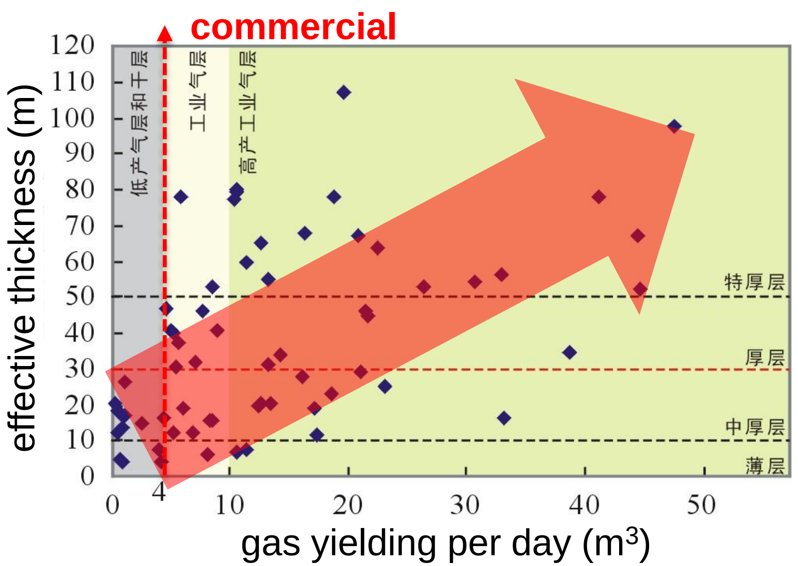
Results

Cutoff of porosity and permeability of the four types of volcanic rocks

lithology	cutoff value	
	porosity (%)	permeability (md)
basalt	6.2	0.005
trachyte	4.2	0.011
rhyolite	5.4	0.046
ignimbrite	5.7	0.036

Application to determine the effective thickness



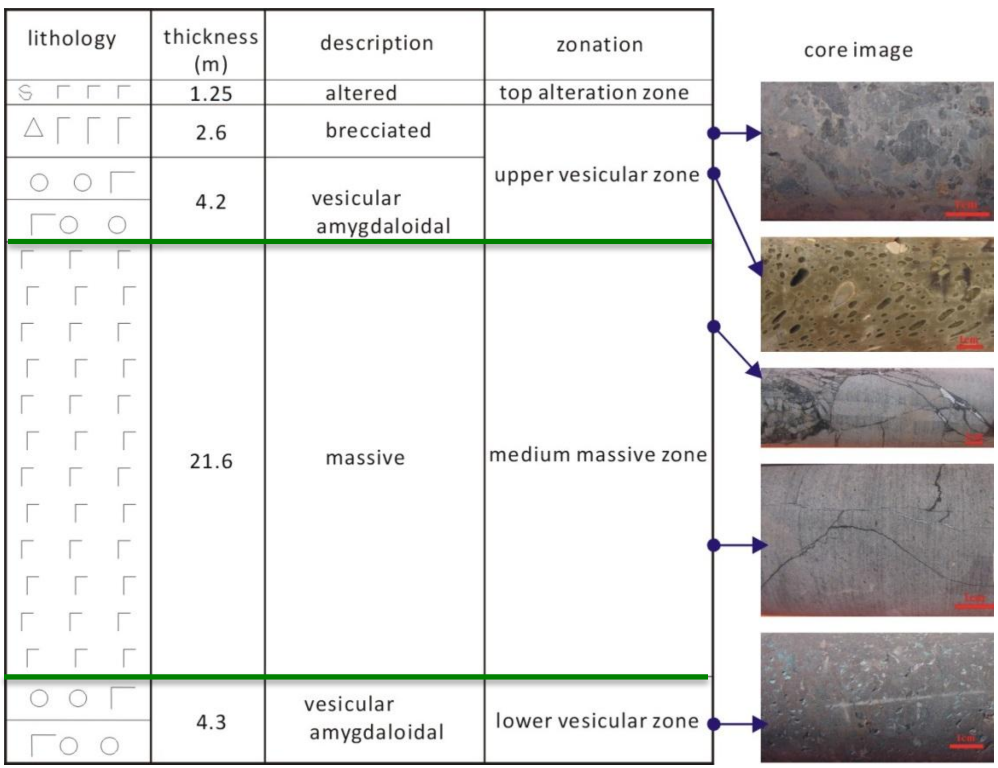


The thicker of the effective reservoir,

the higher yielding of natural gas

Basaltic

Graphic log of a single basaltic lava flow unit



Upper vesicular zone

Thickness: 8.05 meters
Vesicle porosity by image analysis: 10%~25%
Porosity: 4.5%~16.9%

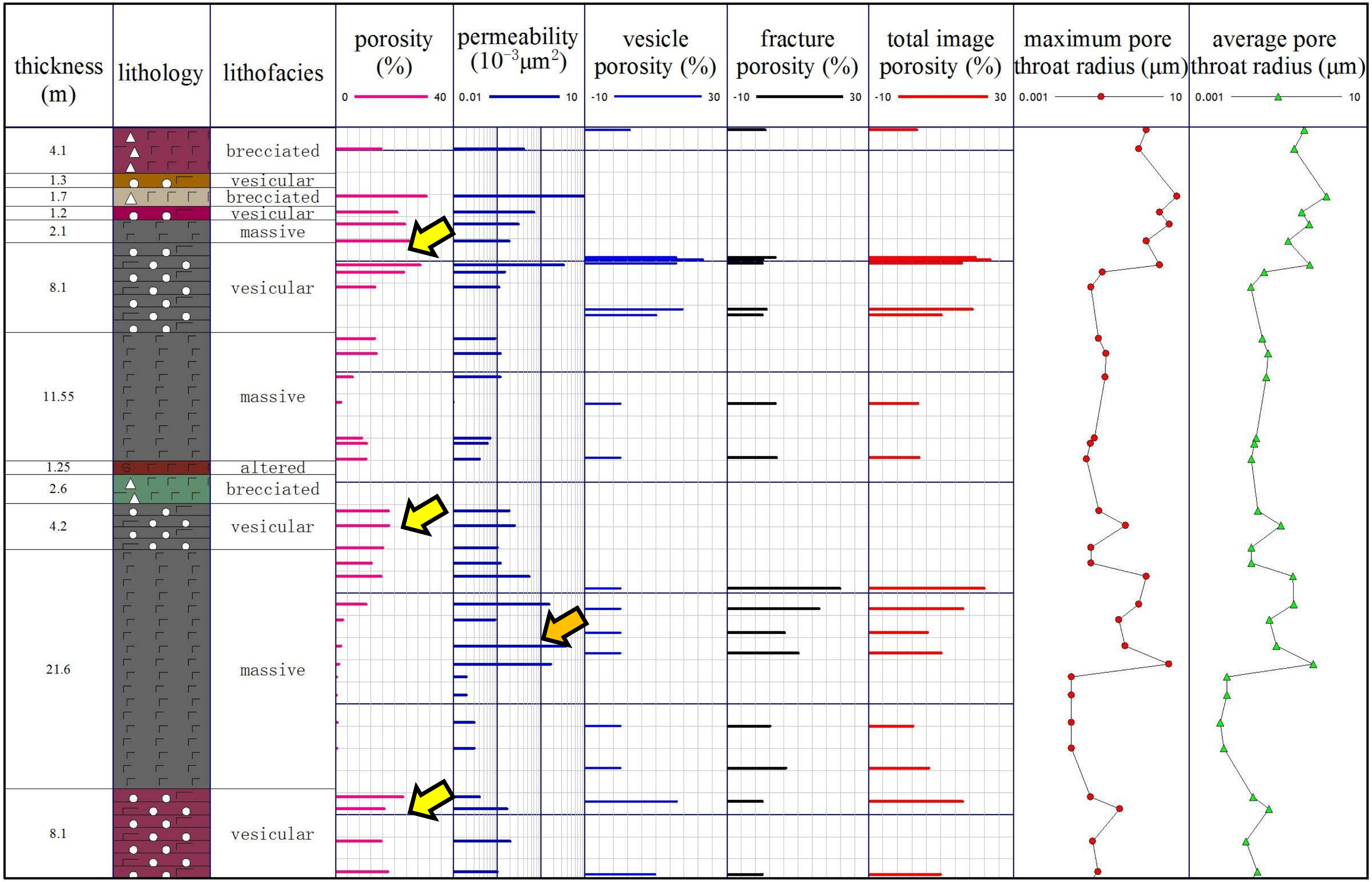
Medium massive zone

Thickness: 21.6 meters
Vesicle porosity by image analysis: <4%
Porosity: 1.1%~5.2%

Lower vesicular zone

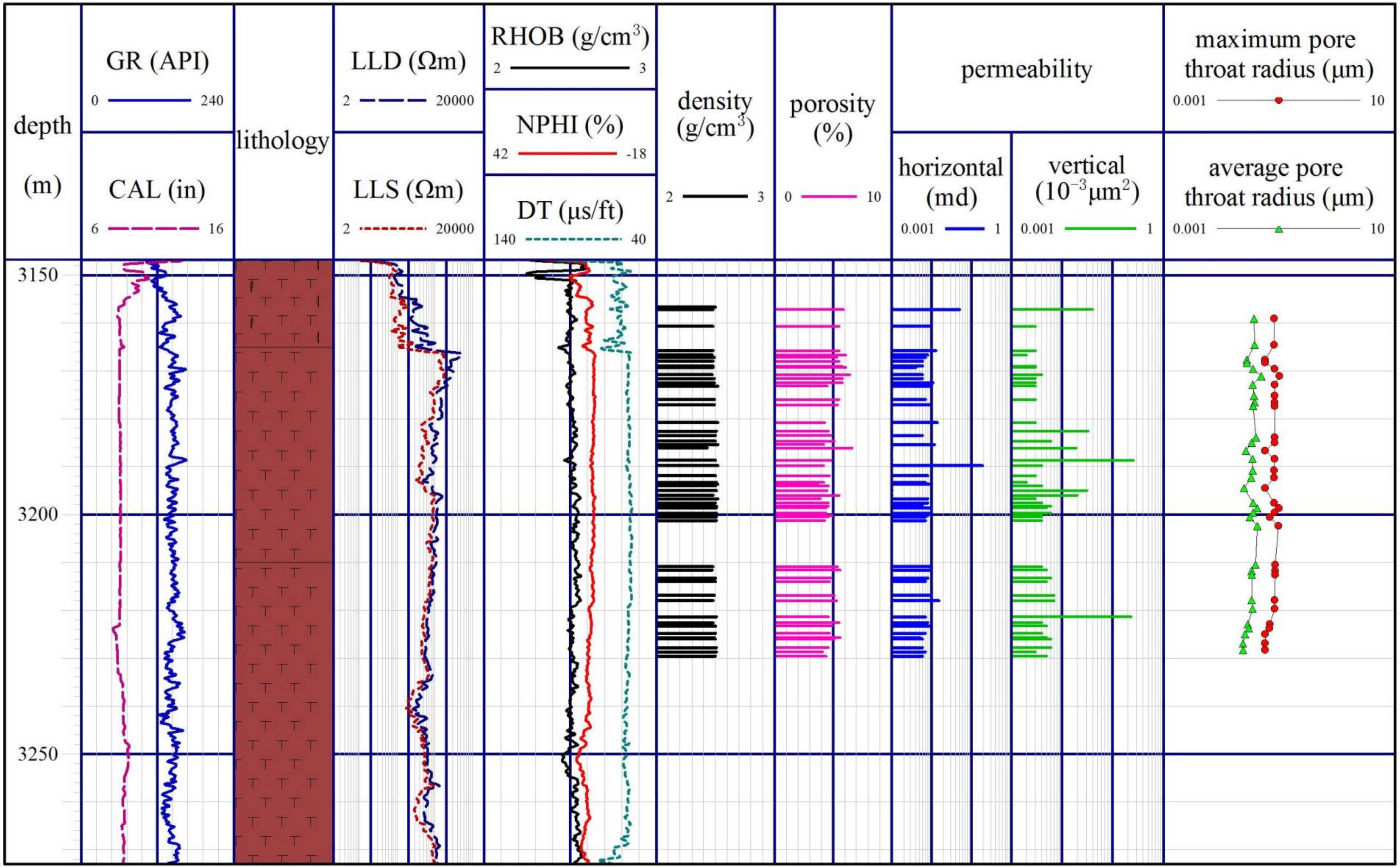
Thickness: 4.3 meters
Vesicle porosity by image analysis: 6%~15%
Porosity: ~5.0%

Basaltic



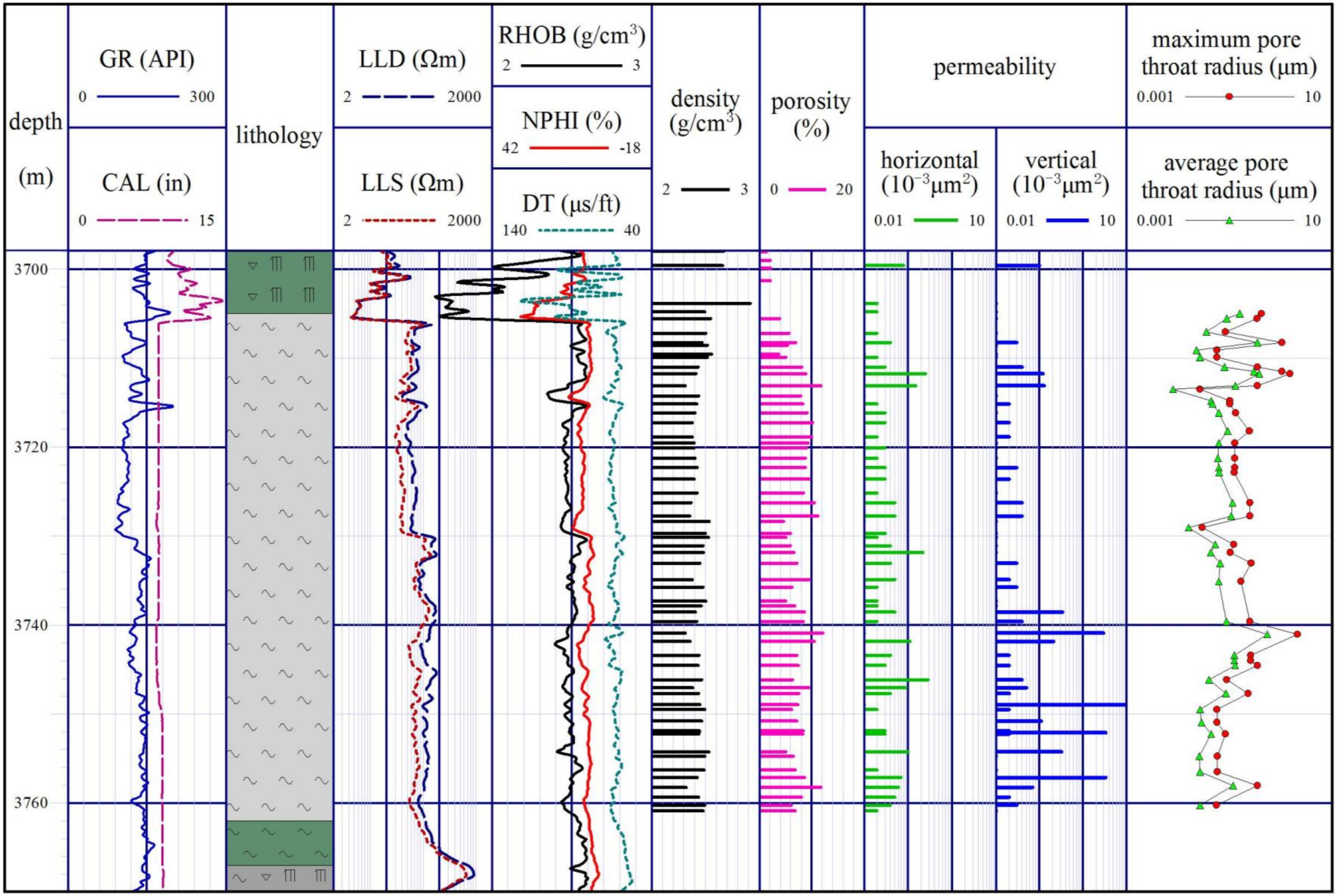
Controlling factors: primary vesicles and fractures, infilling

Trachytic



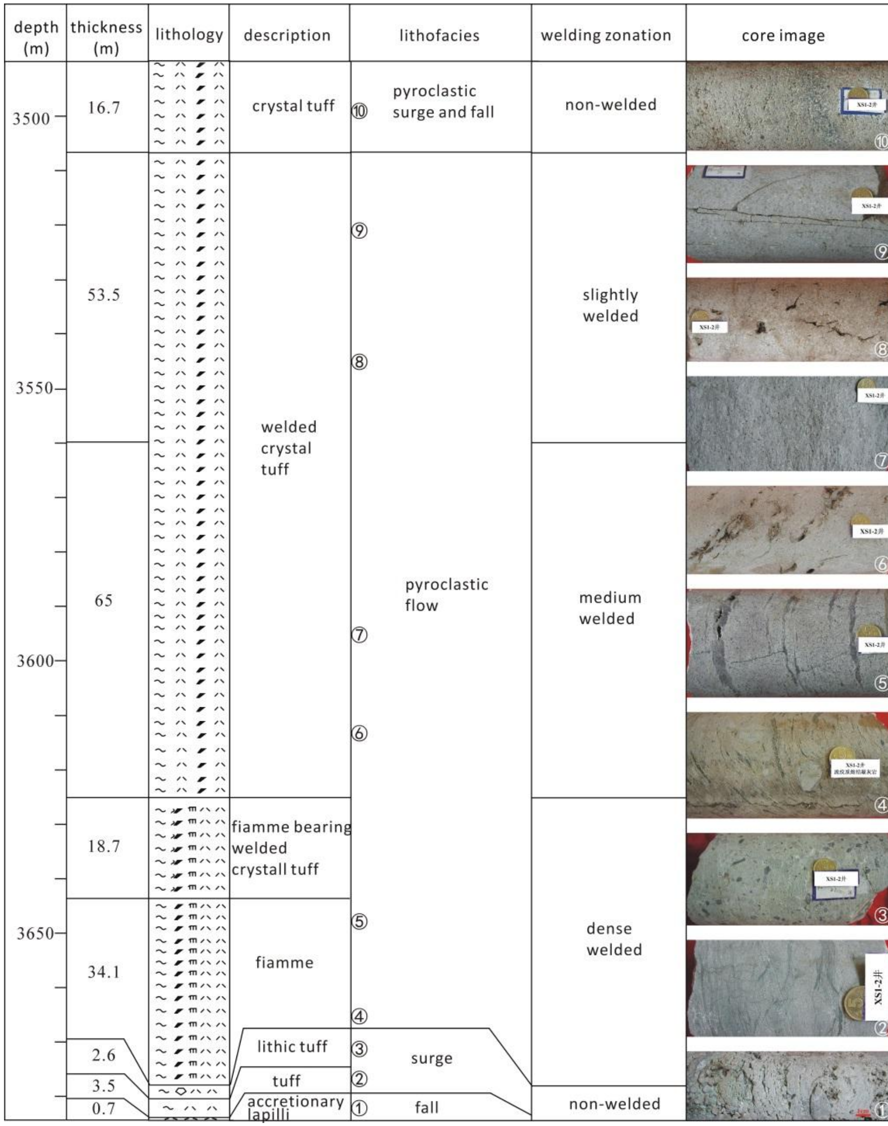
Controlling factors: primary vesicles and fractures

Rhyolitic

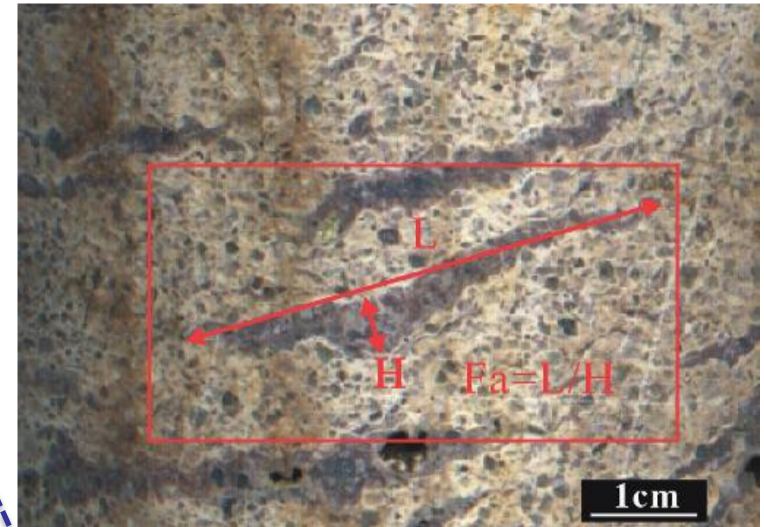


Controlling factors: primary vesicles and fractures

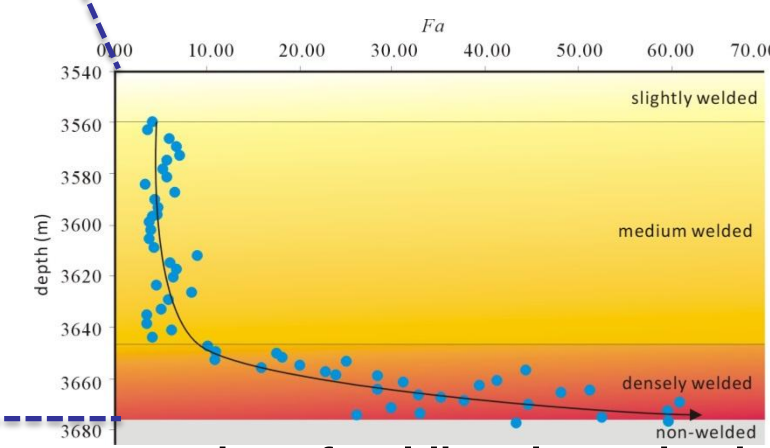
Rhyolitic ignimbrite



Graphic log by continuous core sections

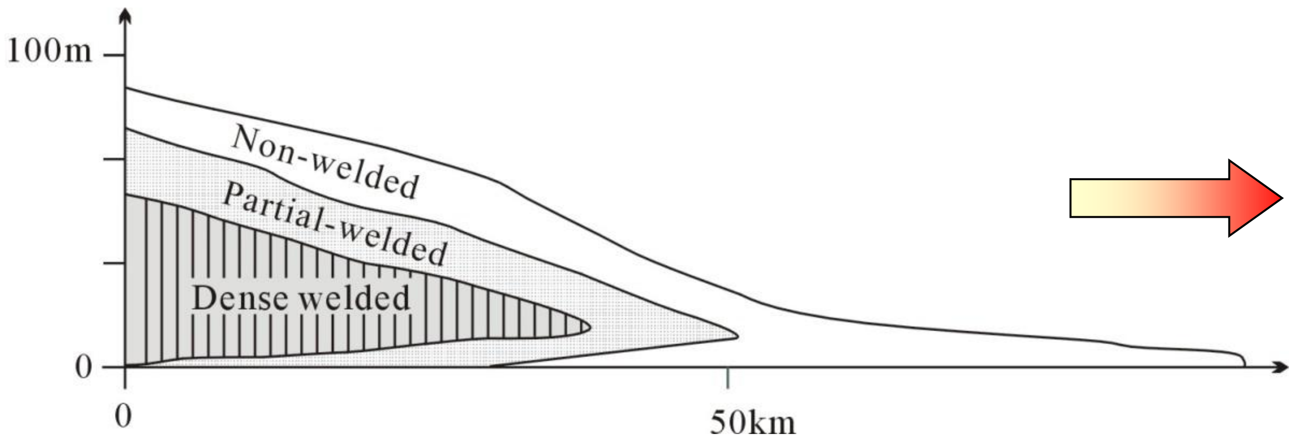


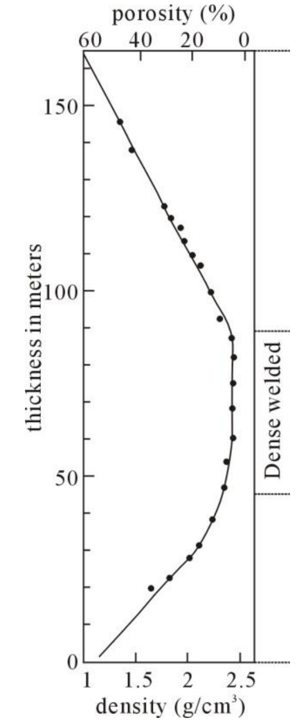
Fa value calculation for welding degree determination



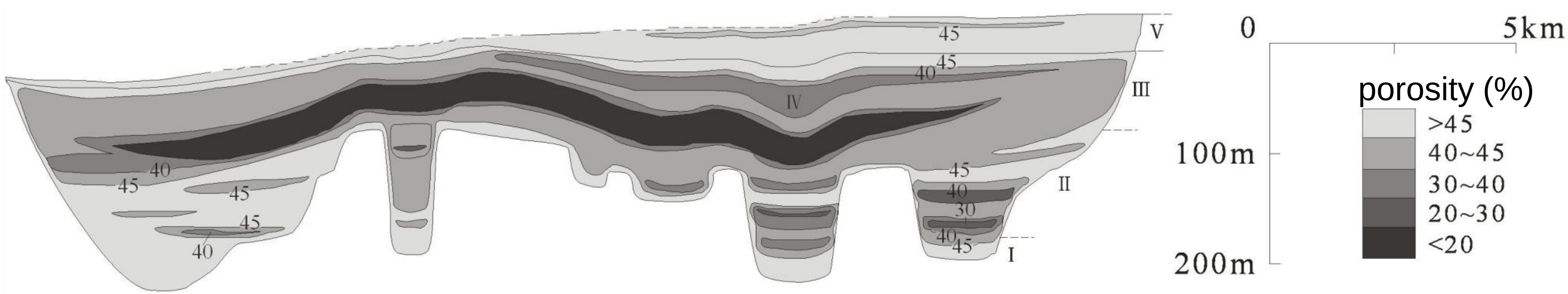
Zonation of welding determined by *Fa* value

Welding zonation and porosity changes of ignimbrite: Indication from outcrops



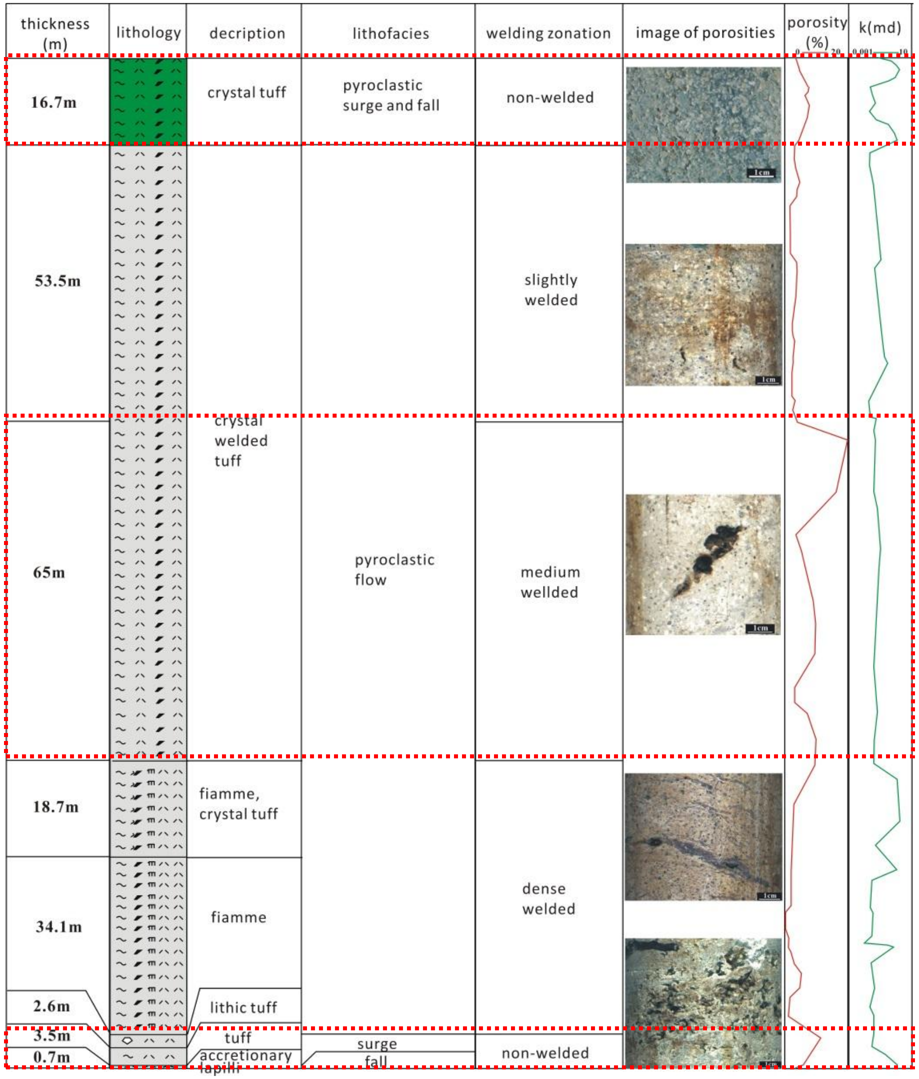


Porosity decreases with welding
(Cas and Wright, 1987)



Porosity zonation of ignimbrite (Smith and Bailey, 1966)

Three layers of relatively high porosity and permeability

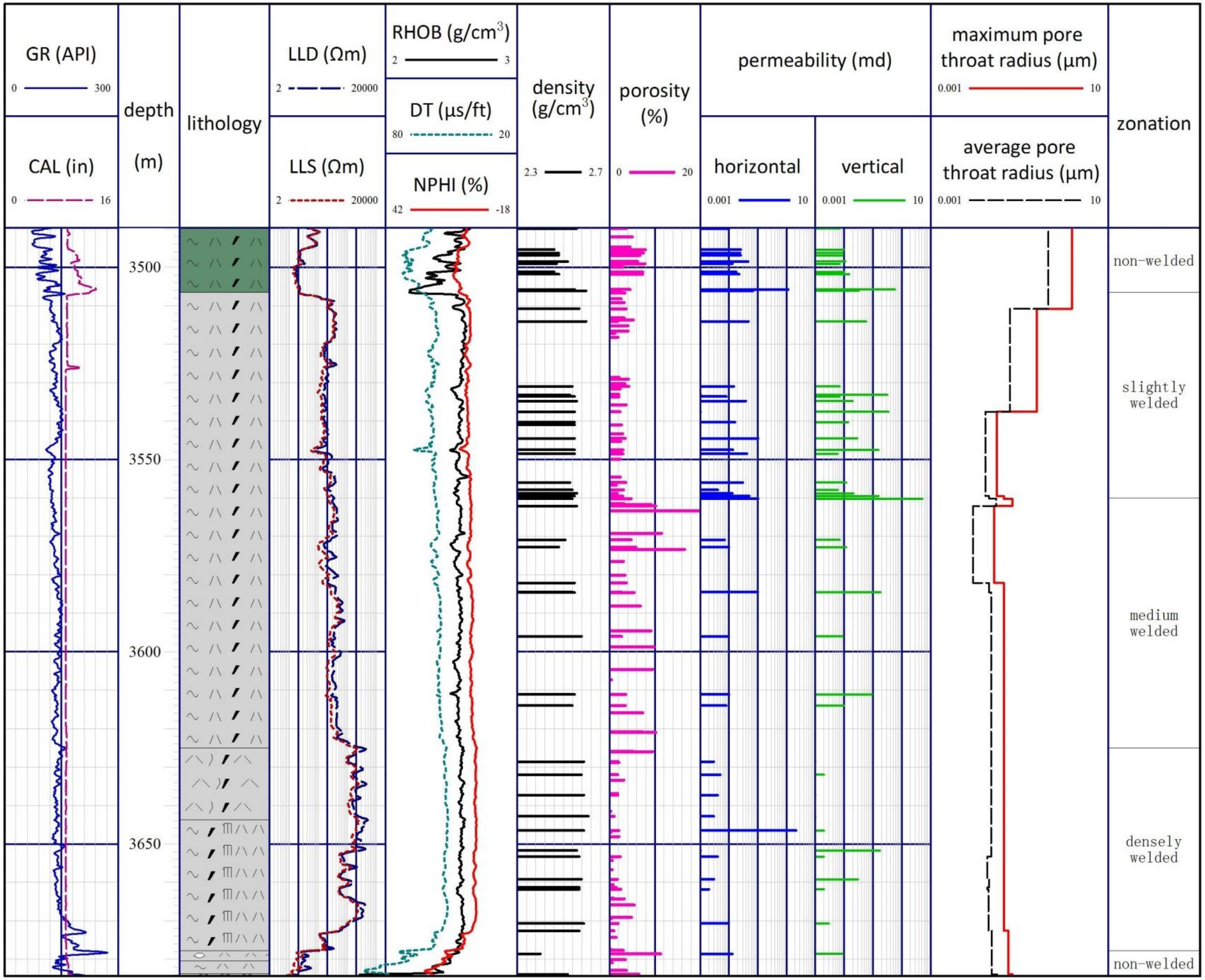


dissolution porosity

Intra-granular residual porosity

Inter-granular residual porosity

Rhyolitic ignimbrite

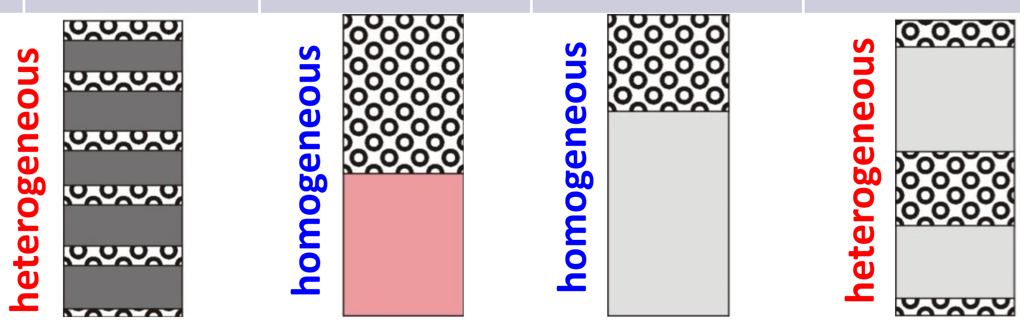


Controlling factors: welding, compaction and dissolution

Conclusions

reservoir characteristics		basalt	trachyte	rhyolite	ignimbrite
porosity (%)	range	1.1~16.9	0.2~7.2	0.6~16.3	0.2~21.4
	cutoff	6.2	4.2	5.4	5.7
permeability (md)	range	0.006~51.1	0.004~1.686	0.005~192	0.003~34.7
	cutoff	0.005	0.011	0.046	0.036
pore spaces	primary	vesicle	vesicle	vesicle	lithophysae intergranular pores
	secondary		dissolution pores	inter-spherulitic	dissolution devitrification
effective thickness	average (m)	6	88	40	44
reservoir body	shape	sheet, wedge	wedge, lens, dome	wedge, lens, dome	sheet, wedge
	internal structure	laminated	laminated circle-layered	laminated circle-layered	laminated
	thickness (m)	100~250	250~460	100~700	300~500
	extended length (km)	10~22	3~7	2~9	4~10

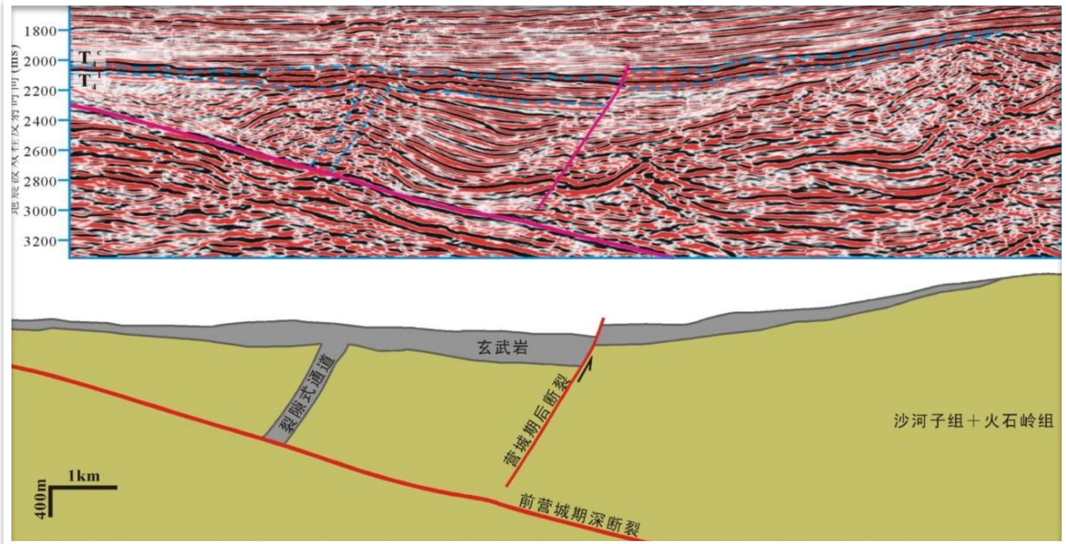
Sketch section map showing the distribution and proportion of effective reservoirs in each of the four types of volcanic rocks *(not to scale)*



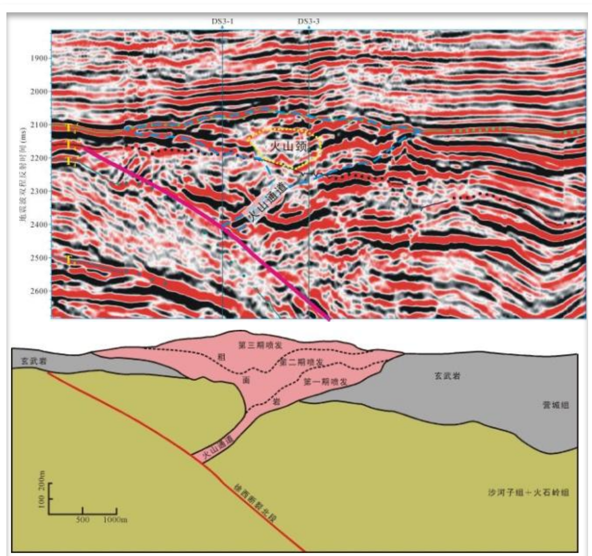
Conclusions

Seismic profiles and interpretations of the four types of volcanic rocks

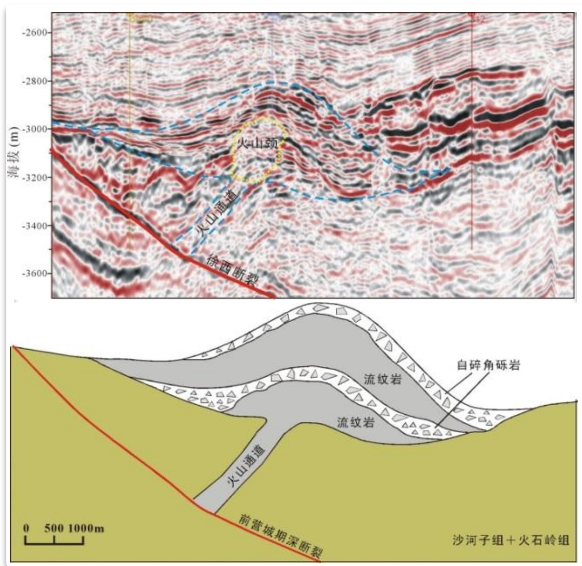
- -basaltic: effusive, sheet, wedge, sub-parallel, continuous
- -trachytic: extrusive, lenticular, discontinuous
- -rhyolitic: extrusive and effusive, dome, circle-layered
- -ignimbrite: explosive, sheet, sub-parallel, continuous



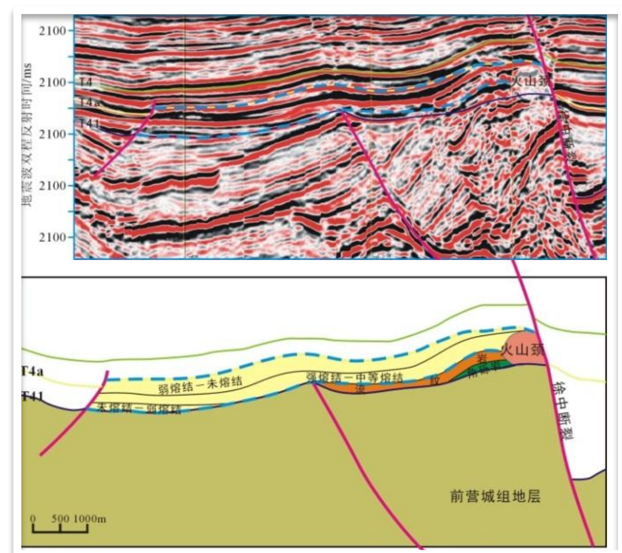
basaltic



trachytic



rhyolitic



ignimbrite

Conclusions

Cutoff and reservoir heterogeneity

- Cutoff is strongly determined by reservoir heterogeneities, which were essentially determined by primary porosities (vesicles and contractions joints), and then by secondary changes (infilling, compaction, dissolution and tectonic fracturing)
- The more heterogeneous, the higher of the cutoff value (especially porosity)
- Heterogeneous -- basalt, ignimbrite
- Homogeneous -- trachyte, rhyolite

More applications

- Drilling trajectory
  -vertical
  -inclined
  -horizontal
- Fracturing--need or not?

Future works

- For homogenous volcanic reservoirs, quantifying the micro-porosities
- For heterogeneous volcanic reservoirs, quantifying macro-porosities and fractures
- Pore throats and pore networks of different magnitudes in different scales