PS Hydrocarbon Accumulations in and Around Basalts in the Cenozoic of Northeast Bohai Bay Basin, China*

Y. Huang[1], Q. Leng[1], J. Zhao[1], and S. Wang[1]

Search and Discovery Article #11256 (2019)**
Posted September 16, 2019

*Adapted from poster presentation given at 2019 AAPG Annual Convention and Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/11256Huang2019

[1]College of Earth Sciences, Jilin University, Changchun, China (long@jlu.edu.cn)

Abstract

As the most wide-spread extrusive volcanic rocks, reservoir properties of basalts are considerable due to vesicles and contraction cracks and fractures, which is significant to reserving of hydrocarbons, ground water and heat resources, and also to permanent carbon dioxide storage. Commercial oil and gas reserves had been found in the deep part of major basins in China, including Bohai Bay, Songliao and Junggar. In the Liaohe Depression of Bohai Bay Basin, Cenozoic basalts with a total thickness over 1000 meters revealed by hundreds of boreholes were primarily formed in subaerial surroundings. Based on observations and descriptions of drilled cores with a total length of 673 meters from 60 boreholes, resin-impregnated thin section and scanning electron microscope analysis, mercury injection and porosity and permeability tests are used to characterize pore networks and evaluate reservoir properties. The multiple pore network of basalts is composed of diverse pores and fractures with different scales, ranging from nanometers to tens of millimeters. Porosities and permeabilities of basaltic rocks are highly heterogeneous due to the zonation of vesicles, fractures and brecciations. Overall, porosities range from 0.9% to 30.2%, and permeabilities are between $0.01\times10^{-3}\mu m^2$ to $36.6\times10^{-3}\mu m^2$. Four subcategories of basalts were divided by their textural diversities, respectively vesicular, brecciated, fractured and massive basalts. Variances of porosities and permeabilities among these four subcategories shows the highest porosity in vesicular basalt (avg. 13.4%), medium porosity in brecciated basalt (avg. 11.7%) and the lowest porosity in massive basalt (avg. 8.3%), and highest permeabilities are revealed by fractured basalts. Moreover, dissolution-related boundaries of lava flow units and fracturing by multi-stage of faulting activities are significant to the enhancement of secondary porosity and connectivity of pore networks. Hydrocarbon shows indicate that oil and gas are preferentially accumulated underneath the boundaries of basaltic lava flow units. The highest oil production from a single borehole is 33.4 m^3 (210 BO) per day. Three genetic types of lava flow units are dominant in the hydrocarbon bearing basalts, including the compound-braided flow, tabular flow and hyaloclastite. Reservoir properties and hydrocarbon shows are favorable in compound lava flows and hyaloclastites, which should be taken as the primary hydrocarbon exploration targets.

www.jlu.edu.cn

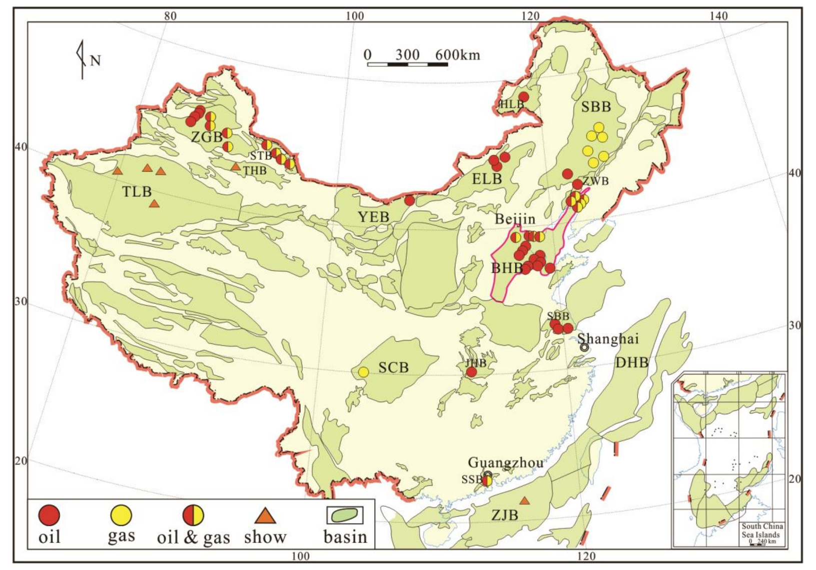
geo.jlu.edu.cn

Hydrocarbon Accumulations In and Around Basalts in the Cenozoic of Northeast Bohai Bay Basin, China

Yulong Huang, Qinglei Leng, Jiaqi Zhao, Siqi Wang

College of Earth Sciences, Jilin University, Changchun, China

1. Introduction

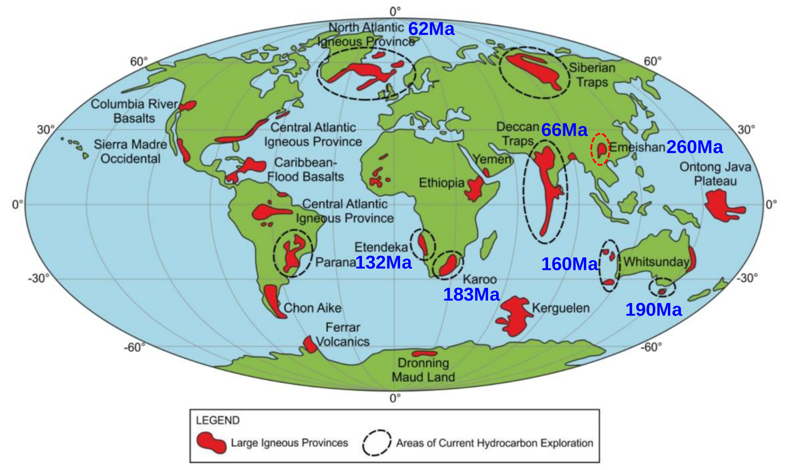


Distribution of volcanic reservoirs in sedimentary basins of China (Huang et al., 2009)

As the most wide-spread extrusive volcanic rocks, reservoir properties of basalts are considerable due to vesicles and contraction cracks and fractures, which is significant to reserving of hydrocarbons (Nelson et al., 2009), ground water and heat resources (Lindsey et al., 2009; Gunerhan and Hepbasli, 2004), and also to permanent carbon dioxide storage (Matter et al., 2016; Gislason et al., 2014). Commercial oil and gas reserves had been found in the deep part of major basins in China including Bohai Bay, Songliao and Junggar (Huang et al., 2009; Zou et al., 2008). In Liaohe Depression of Bohai Bay Basin, Cenozoic basalts with a total thickness over 1000 meters revealed by hundreds of boreholes were primarily formed in subaerial surroundings. Based on observations and descriptions of drilled cores with a total length of 673 meters from 60 boreholes, resin-impregnated thin section and scanning electron microscope analysis, mercury injection and porosity & permeability tests are used to characterization of pore networks and evaluation of reservoir properties. Multiple pore network of basalts is composed of diverse pores and fractures with different scales ranging from nanometers to tens of millimeters. Porosities and permeabilities of basaltic rocks are highly heterogeneous due to the zonation of vesicles, fractures and brecciations.

Typical hydrocarbon accumulations discovered in basalts (Schutter, 2003)

Country/ Region	Field or show	Basin	Type	Reservoir rock
United States	Rozel Point	North Basin	oil	fractured vesicular basalt
	North Basin	North Basin	oil	fractured vesicular basalt, agglomerate
United States	Rattlesnake Hills	Columbia	gas	vesicular basalt
Cuba	Cristales; Jatibonico	South Cuba	oil	basaltic tuff
Greenland	Marrait	Nussauq	oil	vesicular basalt
Argentina	YPF Palmar Largo es-1	Noroeste	oil & gas	vuggy basalt
Indonesia	Jatibarang	NW Java	oil & gas	fractured basalt
China	Minqiao	Subei	oil	vesicular, fratured basalt
China	Zhougongshan	Sichuan	gas	vesicular, fratured basalt
China	Xujiaweizi	Songliao	gas	vesicular, brecciated basalt
China	Luxi、Ludong-Wucaiwan	Junggar	oil & gas	vesicular, fratured basalt



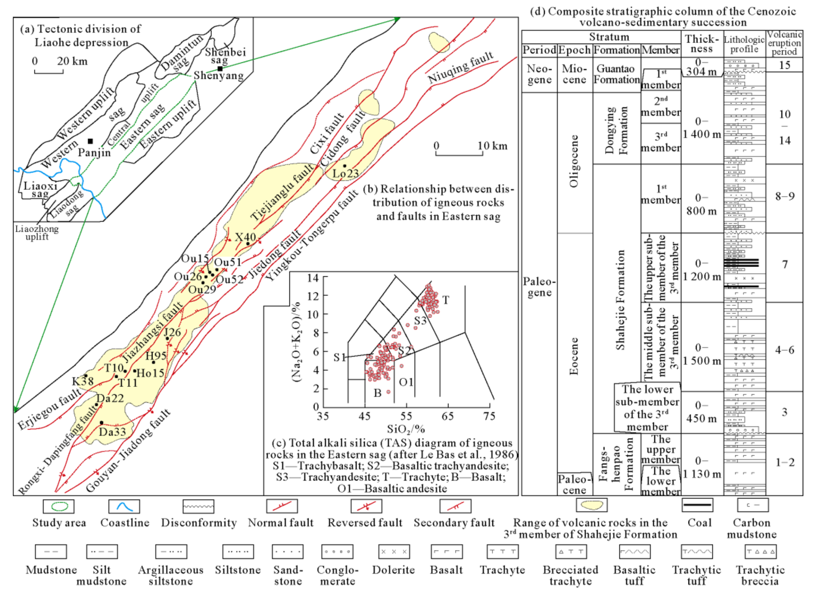
Global distribution of large igneous province and prospective hydrocarbon exploration basins (Modified from Wright et al., 2013)

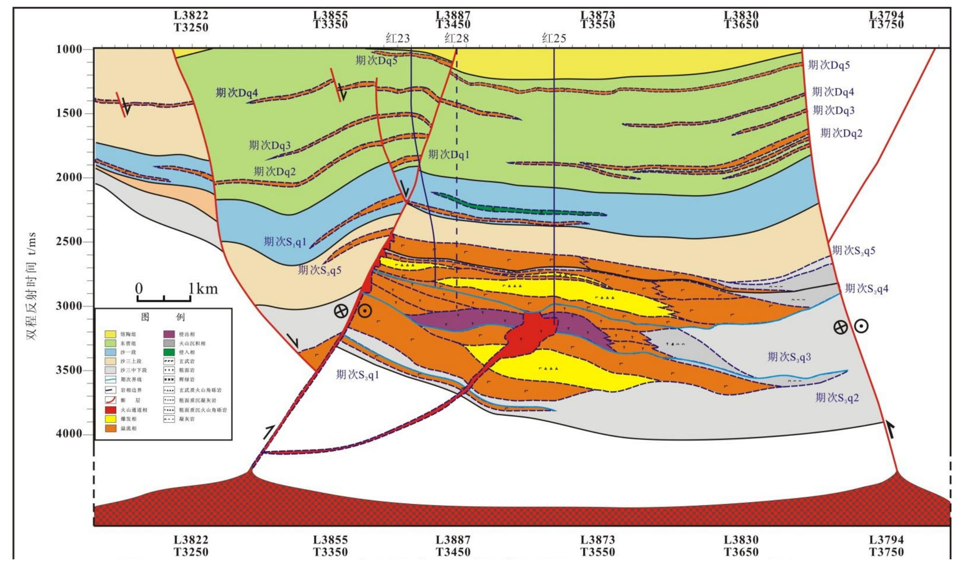
2. Geological setting

Liaohe Depression, a continental rift basin developed in Mesozoic to Cenozoic, stretches in northeast to southwest direction with a total area of 12 400 km². Its onshore part consists of seven secondary structural units including four sags and three uplifts, which are all narrow belts in NE direc-tion. Due to the effect of long term activities of Tanlu fault, there de¬veloped a series of NE and NNE fault systems in the study area.

Due to the multi-phase movements of Tanlu fault and di-agonal subduction of Indian and Pacific plates, Liaohe De-pression experienced several phases of magmatic activities, volcanic activities were especially frequent in the Cenozoic. From the Paleogene Fanshenpao Formation to Neogene Guan¬taozu Formation, there developed fifteen phases of ig-neous rocks in all, which were formed either by eruption or by intrusion and emplaced in both subaerial and subaqueous environments (Huang et al., 2014). The Cenozoic igneous rocks, most widespread in the Eastern Sag of Liaohe Depression, occur vertically in Fanshenpao, Shahejie, Dong¬ying and Guantao formations from bottom to top.

Liaohe Depression has gone through four evolution stages, initial depression, intense depression, continuous depression and atrophy stages. During the initial depression stage in the depositional period of Fangshenpao Formation, volcanic activities were mainly subaerial fissure eruptions of mafic magma. The intense depression stage during the depositional period of the 3rd member of Shahejie Formation featured fast subsidence in the background of extensive rifting and multiple deposition centers, when volcanic activities were dominated by subaqueous eruptions, giving rise to massive basalt and trachyte, which are interlayered with source rocks into favorable hydrocarbon reservoir combinations. During the expansion stage of the depression (depositional period from the 1st member of Shahejie Formation to Dongying Formation), the volcanic center transferred towards north and south end of the Eastern Sag, volcanic activities were dominated by subaerial intermittent eruption of mafic magma. At the end of Dongying Formation deposition, residual mafic magma intruded into Shahejie Formation, forming diverse dolerite sills and dykes. Atrophy of the basin began from the deposition of Guantao Formation, when volcanic eruptions weakened and were dominated by subaerial basaltic effusions.


Geological map of the study area


Stratigraphic profiles and volcanic layers interpreted by boreholes and seismic reflections

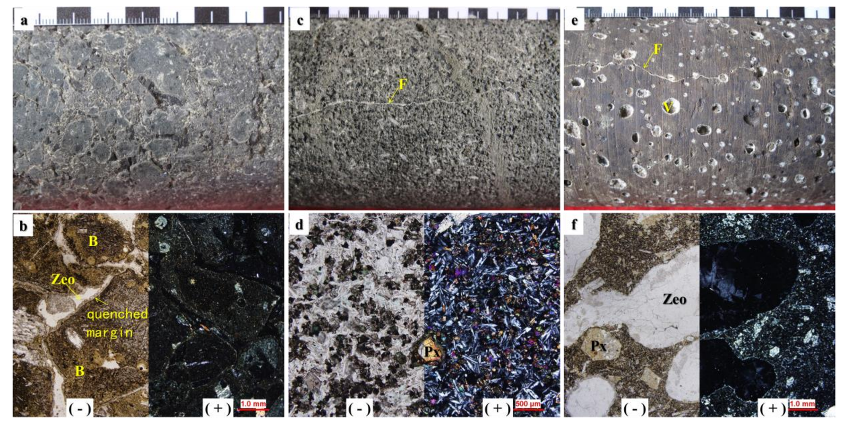
3. Lithofacies

Effusive facies

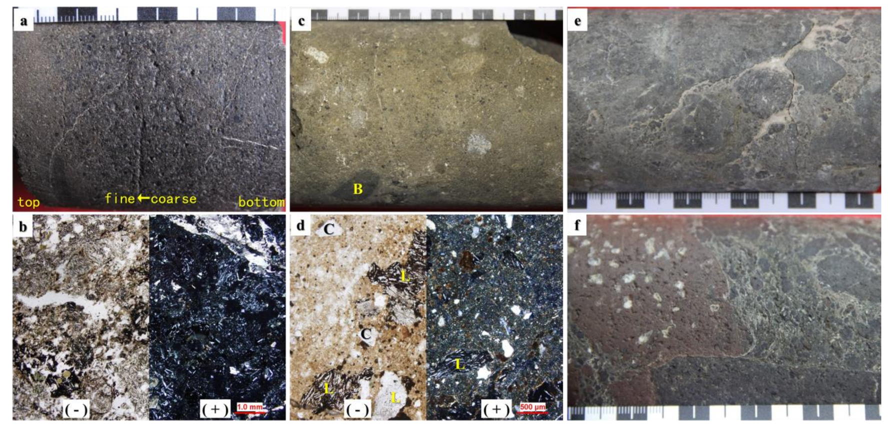
Effusive facies refers to the assemblages of lava flows after the processes of flowage, condensation, deposition and superposition. Most widespread in the study area (accounting for about 62.6% in total), it is found in all of the Cenozoic successions, and occurred at the peak of each eruption period. Three subfacies are identified according to eruption style and emplacement environment, hyaloclastite, tabular flow and compound flow subfacies, which can be distinguished by the different composition and proportion of tightness, gas pores and brecciated lava rock.

Explosive facies

Explosive facies refers to the volcanic accumulation formed by explosive eruption. Mostly occurring in the beginning of cyclic volcanic activities, it comprises nearly 9.8% of the Cenozoic igneous rocks revealed by drilling. According to genesis and transport process of pyroclasts, the explosive facies is subdivided into three subfacies, namely pyroclastic fall, surge and flow deposits, which can be differentiated by grain-size, sorting and beddings.



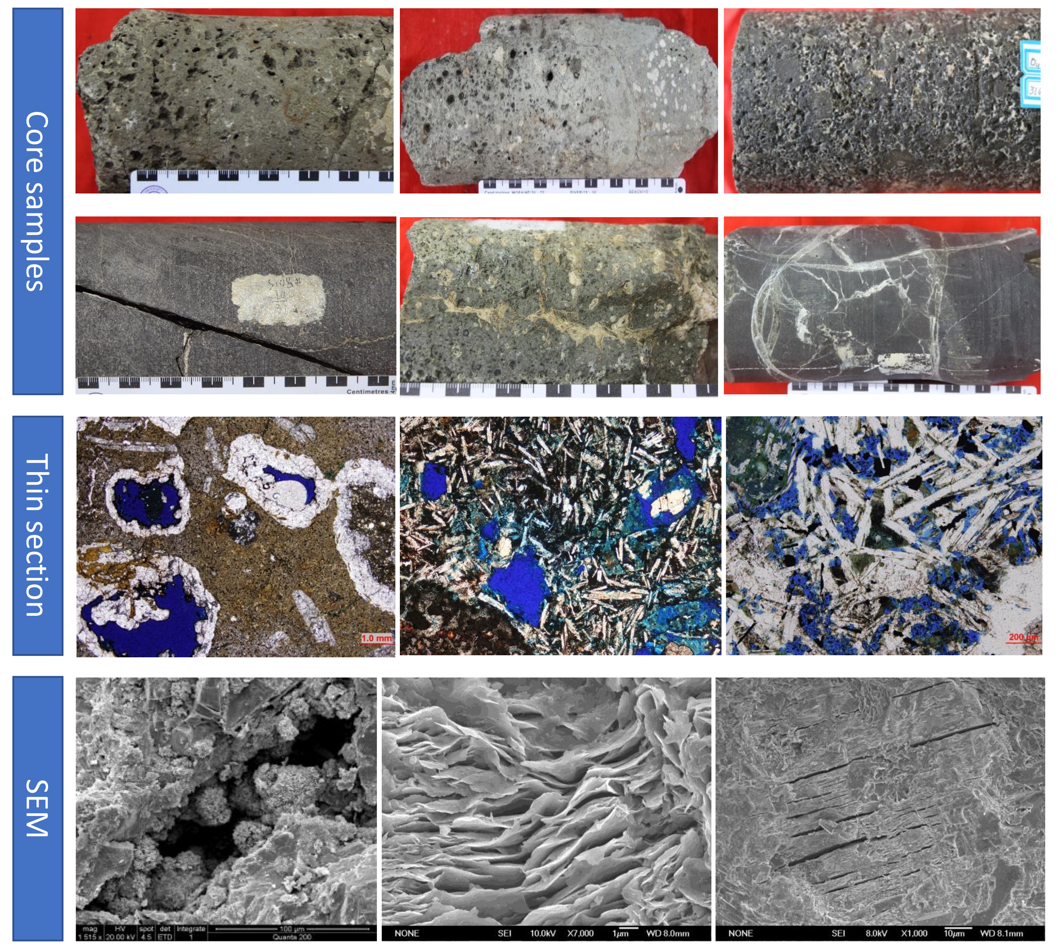
Typical core samples and thin section photomicrographs of the three subfacies of effusive facies
(a) Well Ou52, 2 773.4 m, hyaloclastite subfacies, brecciated basalt, vitriclastic texture; (b) The corresponding thin section photomicrograph of (a), the breccia (B) is vitreous porphyritic basalt with quenched edges, the intergranular pores are filled with zeolite (Zeo); (c) Well K38, 2 361.93 m, tabular flow subfacies, coarse-grained basalt, massive, vertical fractures (F); (d) The corresponding thin section photomicrograph of (c), intergranular texture, porphyritic texture, the phenocrysts are pyroxene (Px); (e) Well T11, 1 985.61 m, compound flow subfacies, vesicular and amygdaloidal basalt, vesicles (V) are common; (f) The corresponding thin section photomicrograph of (e), the vesicles are filled with zeolite (Zeo)



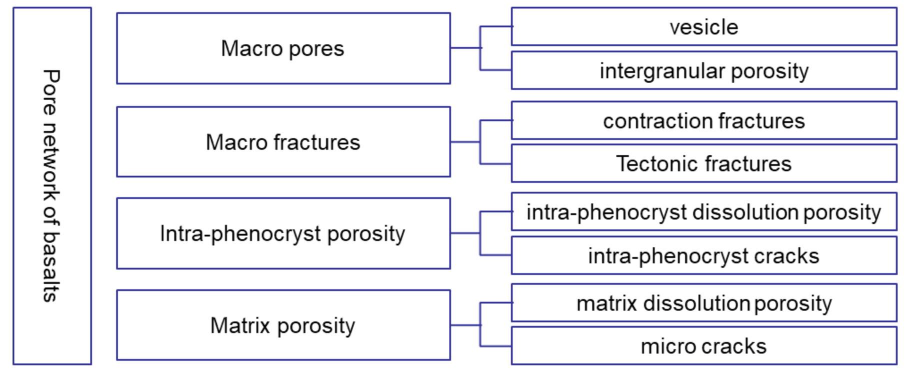
Typical core samples and thin section photomicrographs of the three subfacies of explosive facies
(a) Well Ou29, 2 490.61 m, pyroclastic fall subfacies, basaltic tuff, fine grained tuffaceous texture, normal graded bedding, mainly consist of tephra less than 2mm in diameter; (b) The corresponding thin section photomicrograph of (a); (c) Well Da22, 2 469.56 m, pyroclastic surge subfacies, basaltic crystal and lithic tuff, breccia (B) can be seen; (d) The corresponding thin section photomicrograph of (c), consist of feldspar crystals (C), basaltic lithic clasts (L) and fine-grained volcanic ash, matrix-supported; (e) Well Lei110, 3 091.2 m, pyroclastic flow subfacies, basaltic breccia, the breccias are subangular to subrounded, cemented by volcanic ashes; (f) Well Lei15, 2 841.3m, pyroclastic flow subfacies, basaltic agglomerate bearing breccia, cemented by coarse ashes.

4. Pore spaces and reservoir properties

Core observation, thin section and SEM analysis reveal the development degree of pores and fractures directly, the results show reservoir spaces are mainly developed in compound lava flows and hyaloclastites. On one hand, primary pores and fractures are developed in these subfacies, which also provide preconditions for later dissolution, for example, vesicles and contraction fractures are developed in basaltic lava flow subfacies; on the other hand, dissolution which may significantly enhance porosity and permeability is most intense near boundaries inside the volcano-sedimentary successions, such as the boundaries between lava flow units in compound lava flows. Overall, porosities range from 0.9% to 30.2%, and permeabilities are between $0.01 \times 10^{-3} \mu m^2$ to $36.6 \times 10^{-3} \mu m^2$. Four subcategories of basalts were divided by their textural diversities, respectively vesicular, brecciated, fractured and massive basalts. Variances of porosities and permeabilities among these four subcategories shows the highest porosity in vesicular basalt (avg. 13.4%), medium porosity in brecciated basalt (avg. 11.7%) and the lowest porosity in massive basalt (avg. 8.3%), and highest permeabilities are revealed by fractured basalts. Moreover, dissolutions related boundaries of lava flow units and fracturing by multi-stage of faulting activities are significant to the enhancement of secondary porosities and connectivity of pore networks. Hydrocarbon shows indicate that oil and gas are preferentially accumulated underneath the boundaries of basaltic lava flow units. The highest oil production by single borehole is amount to 33.4 m³ per day.



Pore spaces of basaltic rocks under different scales



Pore network and porosities of basaltic rocks

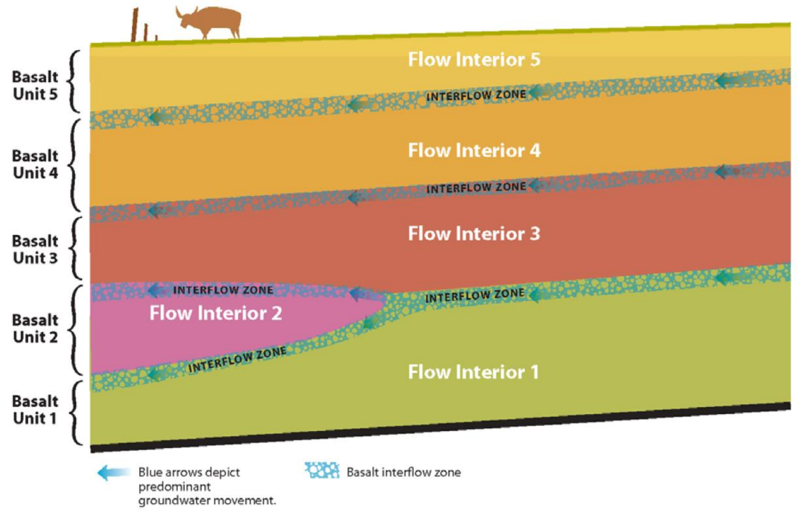
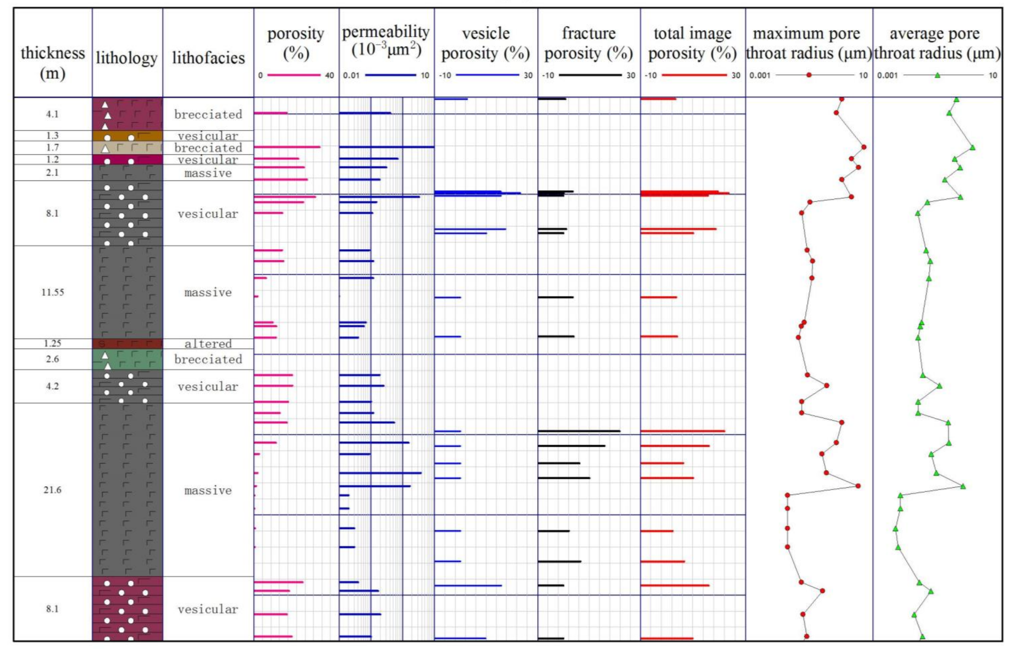
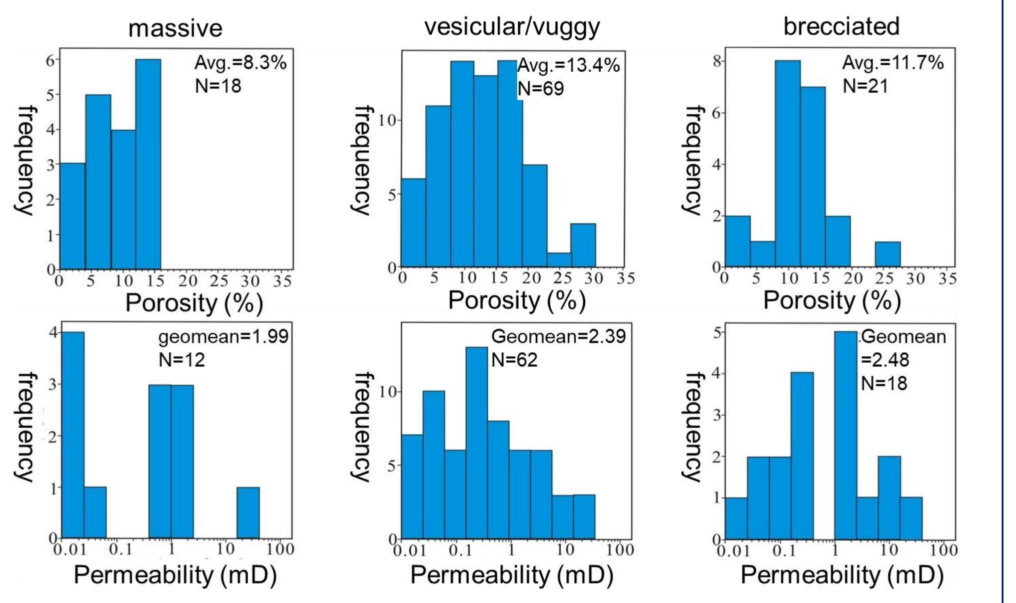


Diagram illustrating the probable hydrogeologic conditions likely occurring as CRBG units pinch out up-dip (Tolan et al., 2009).



Reservoir properties revealed by continuous borehole cores and tests

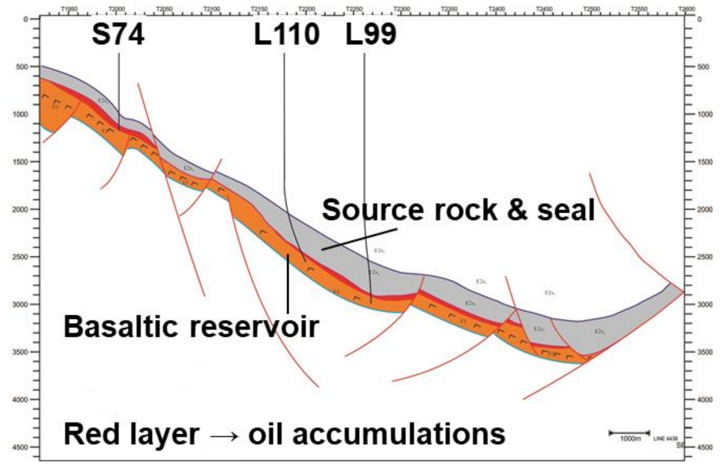


Correlation of porosity and permeability of different basaltic lava rocks

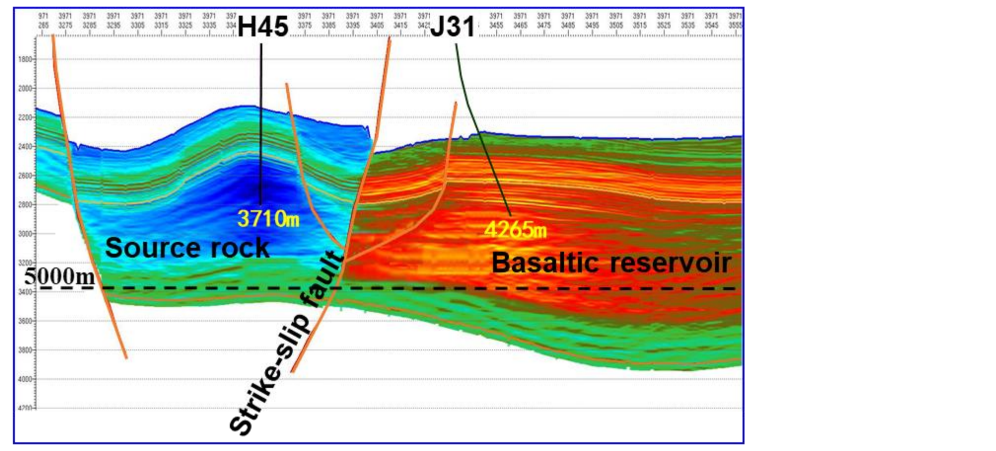
5. Hydrocarbon shows and accumulations

Three genetic types of lava flow units are dominant in the hydrocarbon bearing basalts, including the compound-braided flow, tabular flow and hyaloclastite. Reservoir properties and hydrocarbon shows are favorable in compound lava flows and hyaloclastites, which should be taken as the primary hydrocarbon exploration targets. Two types of hydrocarbon accumulations were discovered: ① basaltic reservoir lying under beneath the upper source rocks, and the oil shows and accumulations were close to the boundary with a thickness usually no more than 30 meters; ② basaltic reservoir being surrounded by source rocks due to strike-slip faulting before hydrocarbon migration, and the oil shows and accumulations were determined by the vertical distribution of high porosity layers and their lateral continuities with a total thickness of tens of meters to over 100 meters.

Occurrences of bitumen in vuggy pores, vesicles and fractures of basalts



Basaltic reservoir under beneath source rock



Basaltic reservoir surrounded by source rock due to strike-slip faulting

References

Gislason S R and Oelkers E H. Carbon storage in basalt. Scinece, 2014, 344(6182):373-374.
Gunerhan H and Hepbasli A. Utilization of basalt stone as a sensible heat storage material. Energy Sources, 2005, 27(14): 1357-1366.
Huang Y L, Wang P J and Chen S M. Distribution and characteristics of volcanic reservoirs in China. Global Geology, 2009, 12(2): 64-79.
Huang Y L, Shan J F, Bian W H, et al. Facies classification and reservoir significance of the Cenozoic intermediate and mafic igneous rocks in Liaohe Depression, East China, Petroleum Exploration and Development, 2014, 41(6): 671-680.
Lindsey K, Morgan D, Vlassopoulos D, et al. Hydrogeology of the Columbia River Basalt Group in the Columbia Plateau: Road log and field trip stop descriptions. GSA field guides 15, 2009: 673-696.
Matter J M, Stute M, Snæbjörnsdottir S Ó, et al. Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emissions. Science, 2016, 352(6291): 1312-1314.
Nelson C E, Jerram D A, Hobbs R W. Flood basalt facies from borehole data: Implications for prospectivity and volcanology in volcanic rifted margins. Petroleum Geoscience, 2009, 15(4): 313-324.
Schutter S R. 2003. Occurrences of hydrocarbons in and around igneous rocks. Geological Society, London, Special Pubjlications, 214: 35-68.
Tolan T, Lindsey K and Porcello J. A Summary of Columbia River Basalt Group Physical Geology and its Influence on the Hydrogeology of the Columbia River Basalt Aquifer System: Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties. 2009.
Wright, Kirstie,Anne-Marie, 2013. Seismic Stratigraphy and Geomorphology of Palaeocene Volcanic Rocks, Faroe-Shetland Basin , Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/8487/
Zou C N, Zhao W Z, Jia C Z, et al. Formation and distribution of volcanic hydrocarbon reservoirs in sedimentary basins of China. Petroleum Exploration and Development, 2008, 35(3): 257–271.

Acknowledgements

This study was funded by the National Natural Science Foundation of China (Grant No. 41702128) and the Research Institute of Liaohe Oilfield, China National Petroleum Company.

N S F C
National Natural Science Foundation of China

中国石油

Dr. **Yulong Huang**
Associate Professor
College of Earth Sciences, Jilin University
Research field & interest: Reservoir Geology, Volcanology
Room 306-1, No.2199 Jianshe Str. (Pigeon Building)
Changchun City, Jilin Province, China (P.C. 130061)
Mobile： +86 13604330378
Office： +86 431 88502620
E-mail： long@jlu.edu.cn
www.petrorevol.com