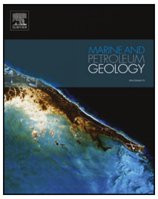
Marine and Petroleum Geology 96 (2018) 371–390

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo



Research paper

Water saturation-driven evolution of helium permeability in Carboniferous shale from Qaidam Basin, China: An experimental study

Jun Gao[a], Zongxing Li[b,*]

[a] Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences, Shijiazhuang 050061, PR China
[b] Key Laboratory of Shale Oil and Gas Geological Survey, Institute of Geomechanics, Chinese, Academy of Geological Sciences, Beijing 100081, China

ARTICLE INFO

Keywords:
Helium permeability
Water saturation
Gas slippage
Gas–water flow
Carboniferous shale
Qaidam Basin

ABSTRACT

Permeability is an important parameter for describing the transport properties of gas shales. This study investigates the effects of water saturation on stress-dependent permeability and the slip factor of Carboniferous shales in the Qaidam Basin, China.

To analyze correlations between water saturation, effective stress, helium permeability, and slip factor, helium permeability of 12 shale samples with different water saturation at pore pressures up to 6.89 MPa and effective stresses up to 27.58 MPa at 25 °C is measured. Subsequently, shale characteristics, including mineral composition, total organic carbon (TOC) content, thermal maturity, vitrinite reflectance, and pore structure distribution (PSD; pore volume and type), are determined.

The analyses reveal a consistent (exponential) relation between apparent effective gas permeability (at 6.89 MPa) and effective stress. The apparent effective helium permeability (at 4.13 MPa) decreases exponentially with increasing water saturation, particularly in shale samples with a high intrinsic permeability. The critical water saturation value of shale is 30%–40%. Two different modes of gas–water two-phase flow are observed. When water saturation is ~30%, helium permeability decreases sharply and gas–water flow in the shale samples appear as channel flow. However, when water saturation is > 40%, helium permeability slowly decreases, gas–water flow in the shale samples appear as funicular flow, gas and water simultaneously flow in all capillaries, and thin films of structured water on mineral surfaces reduce the pore-throat diameter. Thus, increased water films in narrow flow paths increase the gas slippage effect. Furthermore, the slip factor initially decreased with increasing water saturation before increasing. Helium permeability exhibits a negative correlation with TOC and clay contents and a positive correlation with quartz content. The micropores and mesopores in samples with high clay content and TOC are favorable to gas adsorption but not to gas transport. Permeability measurements of humidity oven–dried samples reveal a power–law relation between the gas slip factor and Klinkenberg-corrected permeability; the slope of the resulting curve (−0.29) is lower than that obtained for low-permeability gas sands. This study provides practical information for further studies of shale gas migration and the gas slippage effect in certain gas–water flows.

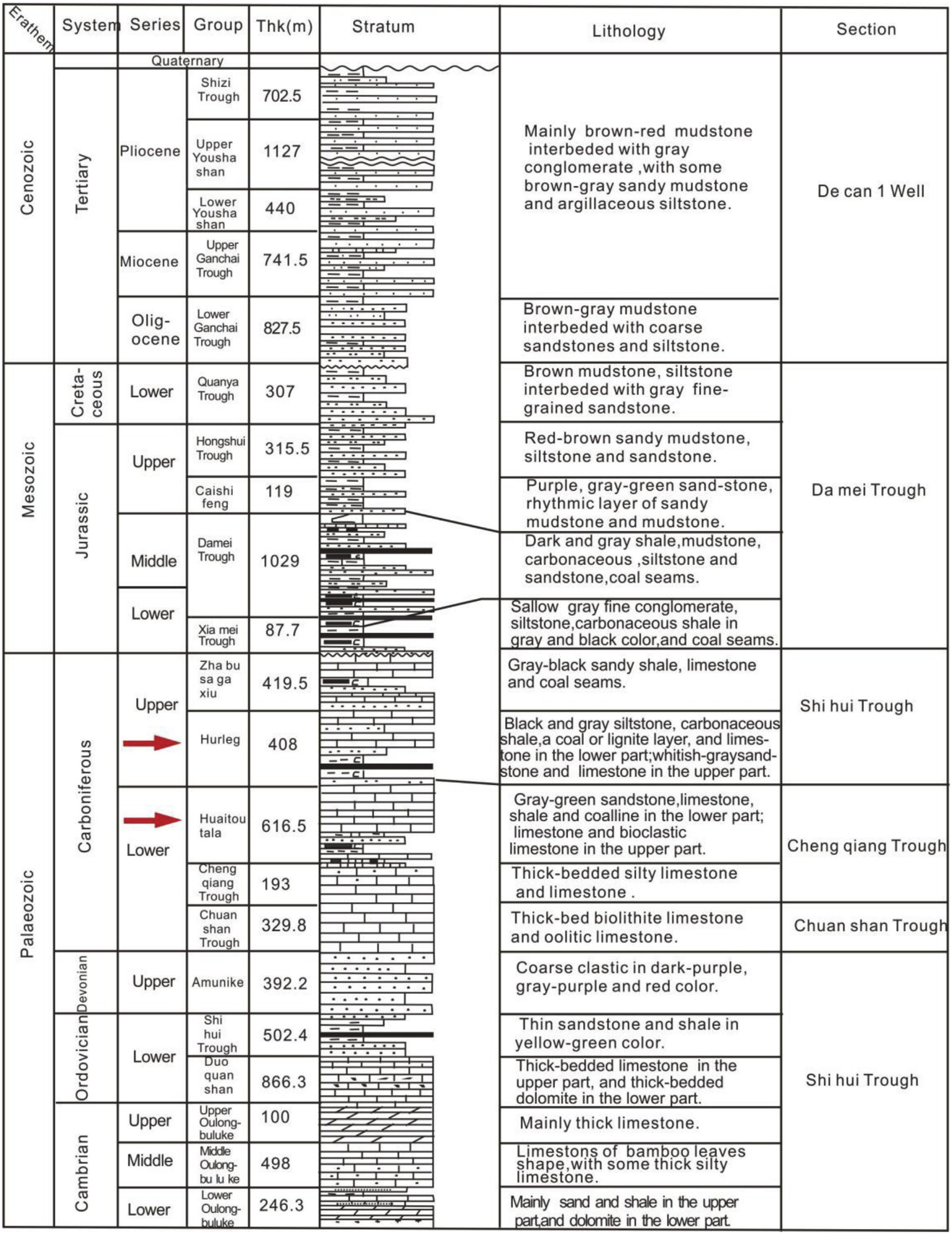
1. Introduction

The permeability of shale controls the flow characteristics of fluid, including its directional movement and flow rate. The permeability of shales ranges from sub-nanodarcies (nd) to tens of microdarcies (μd) and is much lower than that of sandstones. Pore-throat sizes (diameters) in shales generally range from 0.1 to 0.005 μm (Nelson, 2009). Due to gas flow complexities in shale nanoscale pore throats, the gas permeability of shales remains understudied (Sakhaee-Pour and Bryant, 2012). Gas transport through the matrix of shales occurs as a combination of desorption and diffusion within its micropores and Darcy flow within its macropores, microfractures, and fracture network system (Ghanizadeh et al., 2014). Gas transport through sandstones is governed by Darcy's law due to their high permeability (Neuman, 1977; Whitaker, 1986). Gas flow within shales, however, deviates from the conventional Fick's and Darcy's laws (Javadpour et al., 2007; Civan, 2010). Continuous gas flow occurs in macropores, whereas the gas velocity at the walls of micropores and mesopores is non-zero; thus, gas transport is enhanced due to the phenomenon of “gas slippage”, which increases the apparent permeability (Fathi et al., 2012; Firouzi et al., 2014a). Klinkenberg (1941) observed the phenomenon of gas slippage in the pore capillary system, and determined the following equation (1):

---

[*] Corresponding author.
E-mail address: lizongxing@cags.ac.cn (Z. Li).

https://doi.org/10.1016/j.marpetgeo.2018.05.028
Received 8 January 2018; Received in revised form 24 May 2018; Accepted 29 May 2018
Available online 01 June 2018
0264-8172/ © 2018 Elsevier Ltd. All rights reserved.



Erathem	System	Series	Group	Thk(m)	Stratum	Lithology	Section
Cenozoic		Quaternary				Mainly brown-red mudstone interbeded with gray conglomerate ,with some brown-gray sandy mudstone and argillaceous siltstone.	De can 1 Well
	Tertiary	Pliocene	Shizi Trough	702.5			
			Upper Yousha shan	1127			
			Lower Yousha shan	440			
		Miocene	Upper Ganchai Trough	741.5			
		Olig- ocene	Lower Ganchai Trough	827.5		Brown-gray mudstone interbeded with coarse sandstones and siltstone.	
Mesozoic	Creta- ceous	Lower	Quanya Trough	307		Brown mudstone, siltstone interbeded with gray fine-grained sandstone.	Da mei Trough
	Jurassic	Upper	Hongshui Trough	315.5		Red-brown sandy mudstone, siltstone and sandstone.	
			Caishi feng	119		Purple, gray-green sand-stone, rhythmic layer of sandy mudstone and mudstone.	
		Middle	Damei Trough	1029		Dark and gray shale,mudstone, carbonaceous ,siltstone and sandstone,coal seams.	
		Lower	Xia mei Trough	87.7		Sallow gray fine conglomerate, siltstone,carbonaceous shale in gray and black color,and coal seams.	
Palaeozoic	Carboniferous	Upper	Zha bu sa ga xiu	419.5		Gray-black sandy shale, limestone and coal seams.	Shi hui Trough
			Hurleg	408		Black and gray siltstone, carbonaceous shale,a coal or lignite layer, and limestone in the lower part;whitish-graysandstone and limestone in the upper part.	
		Lower	Huaitou tala	616.5		Gray-green sandstone,limestone, shale and coalline in the lower part; limestone and bioclastic limestone in the upper part.	Cheng qiang Trough
			Cheng qiang Trough	193		Thick-bedded silty limestone and limestone .	
			Chuan shan Trough	329.8		Thick-bed biolithite limestone and oolitic limestone.	Chuan shan Trough
	Devonian	Upper	Amunike	392.2		Coarse clastic in dark-purple, gray-purple and red color.	Shi hui Trough
	Ordovician	Lower	Shi hui Trough	502.4		Thin sandstone and shale in yellow-green color.	
			Duo quan shan	866.3		Thick-bedded limestone in the upper part, and thick-bedded dolomite in the lower part.	
	Cambrian	Upper	Upper Oulongbuluke	100		Mainly thick limestone.	
		Middle	Middle Oulongbu lu ke	498		Limestons of bamboo leaves shape,with some thick silty limestone.	
		Lower	Lower Oulongbuluke	246.3		Mainly sand and shale in the upper part,and dolomite in the lower part.	

Fig. 1. Generalized stratigraphic column of the Qaidam Basin (modified from Liu et al., 2012). The Hurleg and Huaitoutala formations, which were analyzed in this study, are marked by red arrows. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Download English Version:

https://daneshyari.com/en/article/8909004

Download Persian Version:

https://daneshyari.com/article/8909004

Daneshyari.com