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CONCEPTUALIZING A DUAL POROSITY OCCURRENCE IN SANDSTONES BY UTILIZING VARIOUS LABORATORY METHODS

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Abstract

Dual porosity in sandstones is considered as a key parameter that controls hydrocarbon production. Understanding of distribution of secondary pores, might give some insights about the heterogeneity of the reservoir for a particular area and as a result can help to produce more oil applying more efficient well-planning and design techniques. The studied oilfield is located about 40 km offshore Brunei Darussalam. In order to find out mechanisms that could lead to the development of secondary pores number of studies was conducted including helium porosity measurements, Mercury Injection Capillary Pressure, Micro-CT images (μ-CT images), X-Ray Diffraction, Petrography analysis, Scanning Electron Microscopy with Energy Dispersive Spectroscopy and Focus Ion Beam Scanning Electron Microscopes. The results showed that effective porosity that was formed by secondary pores was caused by the erosion, fracturing, and dissolution of sedimentary grains, authigenic minerals that are a part of pore-filling cement, and authigenic replacive minerals.

Keywords:
Secondary porosity;
Pressure solution;
Reservoir compartmentalization;
Diagenetic processes;
Core analysis.

1. Introduction

Champion field is located about 40 km offshore Brunei Darussalam [1-3]. The production of oil on this field was started in 1972 from offshore platforms at a water depth between 10 to 45 meters. This field is divided into several productive zones such as West, Peragam, Main, Southest and East, that bring to Brunei Shell Petroleum about 80% of the total production of oil [4,5].

Each of these producing zones is highly compartmentalized due to presence of sub-parallel faults [6]. The given faults divide the field into many isolated compartments [7], that are characterized by its poor connectivity between blocks and as a result make the production of oil very challenging [8-10]. The field consists of sands of different lithofacies such as shallow marine to delta plain sands which makes it even more heterogeneous [11,12]. Reservoir has good petrophysical properties, where the average porosity varies from 25% to 30% and permeability about 5D for shallow zones and as for deeper zones the average porosity is distributed between 10% and 14% while permeability is about 100 mD [1]. Champion field contains approximately 142 475 269 888 m^3 of gas and 476 961 885 m^3 of oil in place [2]. According to production history, the field is characterized by its low natural drive mechanisms due to presence of diverse fault barriers, low initial gas-oil ratio and the absence of large gas caps. Because reservoir rock has high values of porosity and permeability, solution gas plays the main role as driving mechanism [13-15].

Despite long-decade efforts, no one tried to explain mechanisms that led to the formation of secondary pores that form effective porosity in Champion field [16]. The starting point was to check petrophysical properties of the outcrop sample by helium porosimeter in order to make sure that it has similar properties to core that is taken from Champion Field. Then it was a quantitative estimation of secondary porosity that is a part of dual porosity, applying Mercury Injection Capillary Pressure (MICP). Several conventional methods of investigation were conducted such as Micro-CT, X-Ray Diffraction (XRD), Petrography analysis, Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS), Focus Ion Beam Scanning Electron Microscopes (FIB-SEM) in order to find out strong indicators of the processes that were involved in the formation of secondary pores. All of these methods were analyzed separately as

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well as there were comparisons and correlations of some of them for a better understanding of geological aspects in the depositional model. The main limitation of this research is to work only with one outcrop sample that was taken from a particular place since it doesn't reflect changes of rock properties in lateral and vertical ways for the whole reservoir. However, to eliminate this misinterpretation, the given results of the outcrop sample considered information from published papers as well as from available production history data about core analysis for Champion field.

This way, the main objective of this paper is to present a systematic explanation of mechanisms that could lead to the development of secondary pores in the sandstone of Champion Field.

2. Methods

After the initial evaluation of several outcrops of Belait Formation in the Berakas Syncline, a sandstone outcrop (4°, 53′, 7.92″ N and 114°, 57′, 15.12″ E) was selected for sampling as the representation of shallow zone and tidal-channel facies of Champion field. By this occasion, the outcrop samples of deeper zones were not collected and studied since these zones are located relatively close to sub-parallel faults that might lead to poor reservoir rock properties.

2.1. Helium porosimeter

Determination of porosity by using helium porosimeter was conducted at the School of Minerals and Energy Resources Engineering, UNSW. The estimation of sandstone's porosity included several steps such as calculation of reference volume, cup volume, grain volume and bulk volume. Calculation of reference volume was presented by two steps. In the first step calculation was based on reference volume using cup with all billets while in second step one of billets was removed [17-19].

$$V_R = \frac{V_{billet}}{\frac{P_3 - P_0}{P_4 - P_0} - \frac{P_1 - P_0}{P_2 - 0}} \quad (1)$$

In the formula (1) that is above, V_R – reference volume, where P_0 – zero pressure, P_1 - reference pressure, P_2- pressure and all of them are applied for cup with all billets. As for the other variables that are applied for cup without one of the billets, they are presented by P_3 - Reference pressure, P_4 - pressure, V_{billet} - billet volume.

$$V_{cup} = V_R \times \left(\frac{P_5 - P_0}{P_6 - P_0} - 1 \right) \quad (2)$$

$$V_G = V_{cup} - V_R \times \left(\frac{P_5 - P_0}{P_6 - P_0} - 1 \right) \quad (3)$$

In the formulas (2), (3) that are above, variables are volume of cup without core (VCUP), P_5 - Reference pressure, P_6 - pressure and V_G - grain volume.

2.2. MICP

MICP measurements were hosted at the School of Minerals and Energy Resources Engineering, UNSW. These measurements involved 33000 psi PoreMaster porosimeter. In order to get petrophysical properties, there was analysis of cumulative saturation of mercury (Hg) under conditions of high pressure that was obtained by injection of Hg into rock samples.

$$P_c = \frac{2 \times \sigma \times \cos\theta}{r_c} \quad (4)$$

Where P_c – capillary pressure between air phase and mercury, σ – interfacial tension between air and mercury, θ – contact angle of mercury in air and r_c – radius of pore throat.

2.3. μ-CT images

μ-CT analysis was hosted at the School of Minerals and Energy Resources Engineering, UNSW. The analysis was conducted by using Itrax Corescanner that provided high resolution digital RGB images down to 50 microns and also digital radiographic images down to 20 microns. Also, this scanner is non-destructive and performs measurement without contact to the sample surface.

2.4. XRD

The XRD analysis was hosted at School of Chemical Engineering, UNSW. The laboratory equipment system was presented by PANalytical Empyrean with Co tube, electrical parameters of X-Ray Generator were 45 kV and 40 mA. A Rietveld fit was performed with HighScore Plus software for quantitative estimation of individual phases. Samples were prepared as random powder by back-loading method and the quantitative limit was between 10 and 20 parts per million.

2.5. Petrographic analysis

Production of thin sections of 26 × 46 mm was conducted by experts from Adelaide Petrographic Laboratories Pty Ltd in perpendicular way to bedding of the rock sample in order to see changes in rock properties. The thin sections are not covered by glass slide since it was also used for scanning electron microscopy analysis. The polished thin sections were examined microscopically in transmitted and reflected light, with representative microphotographs.

2.6. SEM-EDS

SEM-EDS was conducted at a laboratory of Chemical Engineering School, UNSW. NanoSEM 450 was used in order to get ultra-high imaging resolution. This instrument was fitted with retractable annular backscattered electron detector as well as a Bruker SDD-EDS detector for the convenient visualisation of compositional differences across the specimen surface. The settings of the microscope had field- Free lens mode.

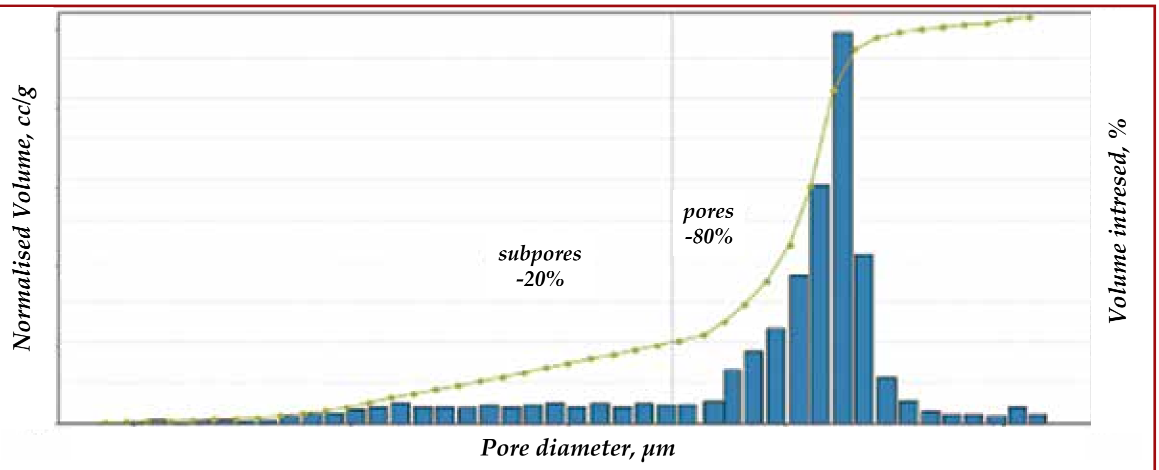

Fig.1. MICP results

2.7. FIB-SEM

FIB-SEM was hosted at a laboratory of Chemical Engineering School, UNSW. FIB-SEM analysis was conducted using Carl Zeiss AURIGA CrossBeam that is combined with a powerful focused ion beam (FIB) system. The specimen studied under InLens Tilt angle that was about 70° with value of EHT that is equal to 5.00 KV.

3. Results and discussion

3.1. Helium porosimeter measurements and MICP

The average value of effective porosity was estimated at 25% by the helium porosimeter. This value was mentioned as the average one by petroleum engineers from Brunei Shell Petroleum as well, so this way the given outcrop sample can be considered as a reliable representation of sandstone's Champion field.

As for MICP measurements, the given results are presented on figure 1 and as you can see there that about 20% of pores are secondary ones. Their size varies from three microns to values that are even less. These results follow common guidelines about the influence of depth, time, and temperature of burial during diagenesis. Since the rock is composed of well-sorted sediments, it did not find out any primary pores of the same pore diameter as secondary ones.

Roughly speaking, the percentage of primary pores reduces as these parameters increase while the percentage of secondary pores has a reverse trend [20, 21].

The influence of all these factors is mostly related to processes such as chemical, physical and physicochemical ones that happen during different maturity stages of the reservoir, for instance, chemical compaction had a place to be during the semi-mature stage, and it led to the dissolution of quartz grains [22] and contributes to the effective porosity.

3.2. μ-CT images

According to *μ*-CT images, the pore system presents dual porosity features including micro-pores and nanoscale porous media. This feature is matched with that of MICP data. These nano-pores are considered to be formed by erosion process that occurred in some minerals such as quartz (fig.2), that possibly happened during changes of temperature and pH environment and as a result led to the occurrence of secondary pores [23]. These pores in some cases formed interconnected pore volumes.

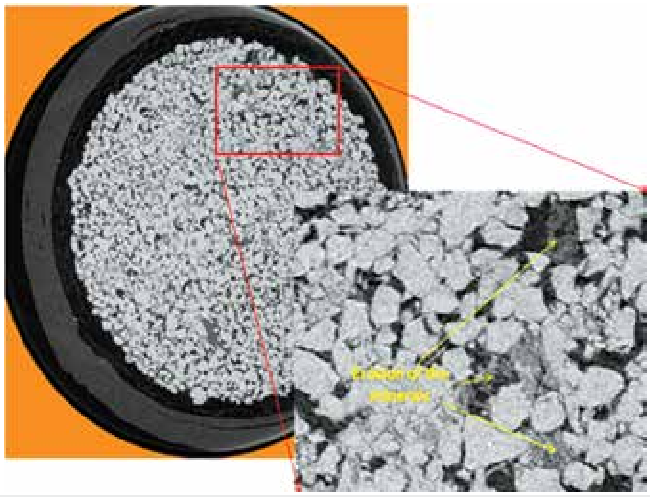

Fig.2. Erosion of minerals that was found out in μ-CT

3.3. XRD and Petrographic analysis

The results of petrographic analysis and XRD measurements are presented in table 1. The initial theory expected to have calcite as part of carbonate cement in sandstone that afterward was replaced by siderite and as a result of this authigenesis, there was the occurrence of secondary pores.

Unfortunately, XRD analysis didn`t prove it, since the percentage of this mineral was found as relatively small and moreover the percentage of hematite was very close to the percentage of siderite. Interpretation of these close values might be related to the fact that both of these minerals weren't authigenic minerals and they went together through several changes from the depositional stage [24, 25]. However, it found out some presence of muscovite and kaolinite that can be an indicator of the other type of authigenesis and can be considered as one of the mechanisms that led to the occurrence of

Table 1

Combined results of petrographic analysis of thin sections and XRD data

Thin sections		XRD	
Mineral	**Abundance, %**	**Mineral**	**Abundance, %**
Quartz	85	Quartz	97.2 (±5.2)
Quartz rich litchics	14	Muscovite	0.5(±0.0)
Rutile,clay, K-fedspar, pyrite	1	Kaolinite	2.0(±0.3)
		Hematite	0.1(±0.0)
		Siderite	0.2(±0.0)

secondary pores [26-28].

Petrography analysis of the outcrop sample showed that the rock is a massive, fine to medium-grained, quartz-rich sandstone, and although having a grain-supported texture, there is considerable inter-grain void space or porosity that was estimated at nearly 30%. There is very little matrix interstitial to the larger detrital grains. The rock also has several small irregulars to elongate interstitial aggregates of carbonaceous material (up to 0.8 mm long) that could be represented by phytoliths or mature coaly material (fig.3). In some places, there are small interstitial patches composed of fine-grained quartz and possible clay minerals such as kaolinite (fig.4).

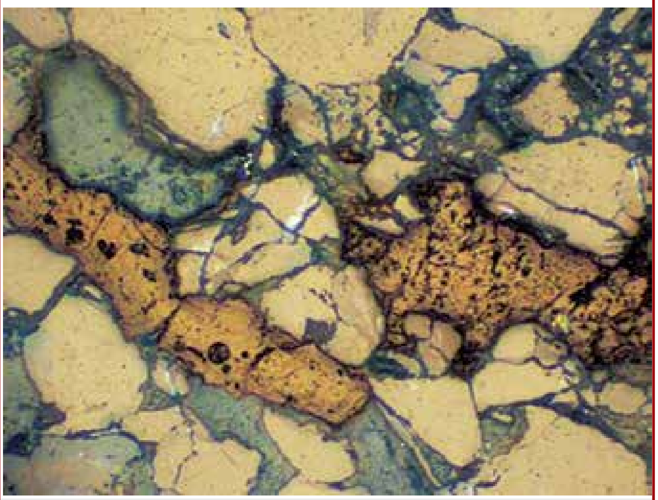

Fig.3. Couple of elongated, pale brownish-grey carbonaceous (phytolith) aggregates occurring interstitially to detrital quartz grains. Bluish-grey zones represent void space. Plane polarised reflected light, field of view 0.8 mm across

Petrography analysis did not show any presence of cement. Close inspection of detrital grains did not reveal overgrowths (e.g. of diagenetic quartz) or clay infill.

The figures above show that some quartz grains are significantly fractured. This is related to lithification that is a part of diagenesis during this stage there are many solid-to-solid interactions [23, 29]. These interactions resulted in the deformation of quartz grains that in some cases can be seen as fractions into grain [30]. Since lithification has a continuous process, the number of fractures increased with a time that led to erosion of minerals and occurrence on their place secondary pores [31, 32] that contributes to permeability in the reservoir.

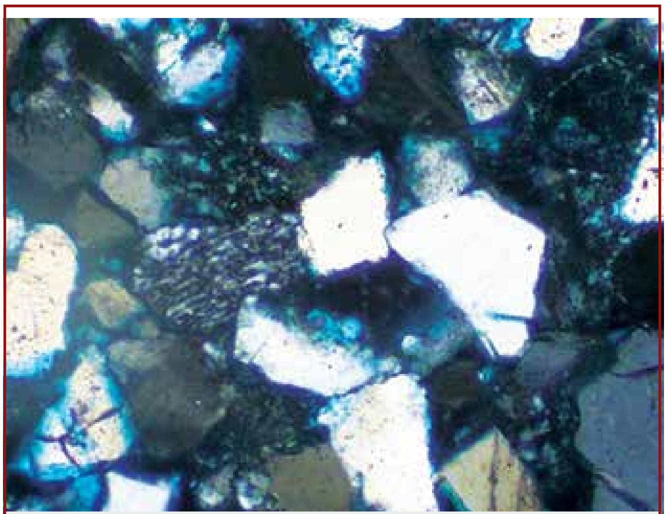

Fig.4. Detail of detrital grains, with generally angular quartz (grey to creamy white) and fine grained, darker quartz-rich lithics (e.g. cherty material). Interstitial void space is dark blue to black. Transmitted light, crossed polarisers, field of view 1 mm across

3.4. SEM-EDS

Representation of minerals according to SEM-EDS method is introduced on figure 5a, where the red boundary circle represents the deformation of grains due to tectonic stresses or compression at the initial stages [33]. As one can see from figure 5b most of these minerals have «Si» content and represent by themselves quartz grains. As an example, the presence of secondary pores between quartz grains is shown on figure 6. The occurrence of these pores might be caused by the dissolution of some amount of carbonate cement [34] or a mineral that was included in this cement [35] and contributed to the formation of void space in the reservoir rock.

Also, SEM-EDS showed that between quartz grains there is carbonaceous material (phytolith) of unknown character. This material is represented only by «C» content according to EDS analyses (fig.7) and it means that it can be one of the major types of coal. The third type of kerogen might be considered as a source from which this coal was

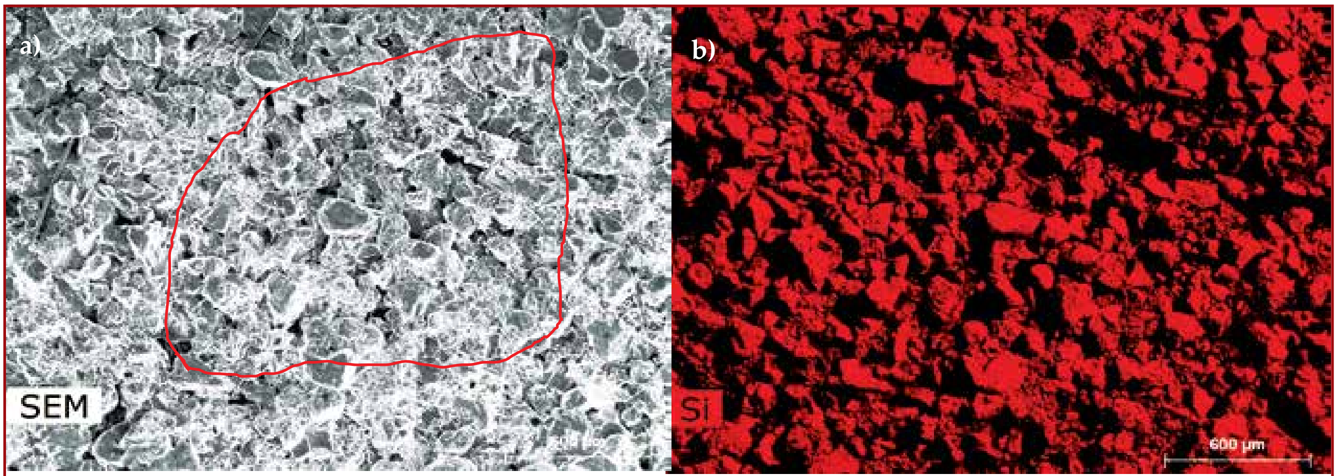

Fig.5. a) Overall representation of minerals. The red boundary represents deformation of grains due to tectonic stresses; b) Representation of minerals that have Si content

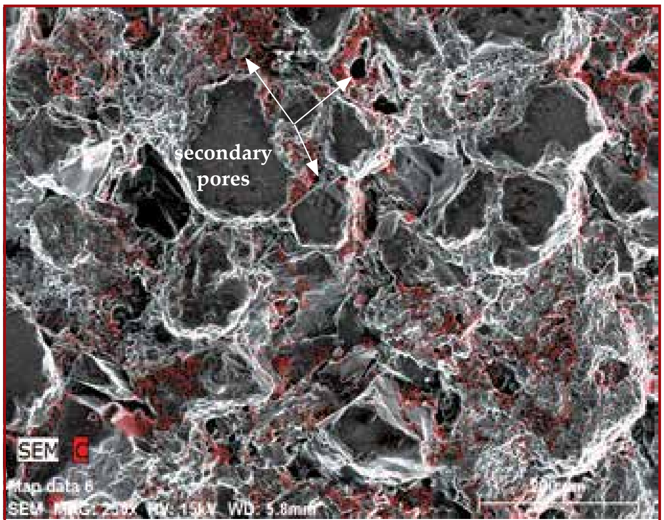

Fig.6. Secondary pores in the carbonate cement between quartz grains

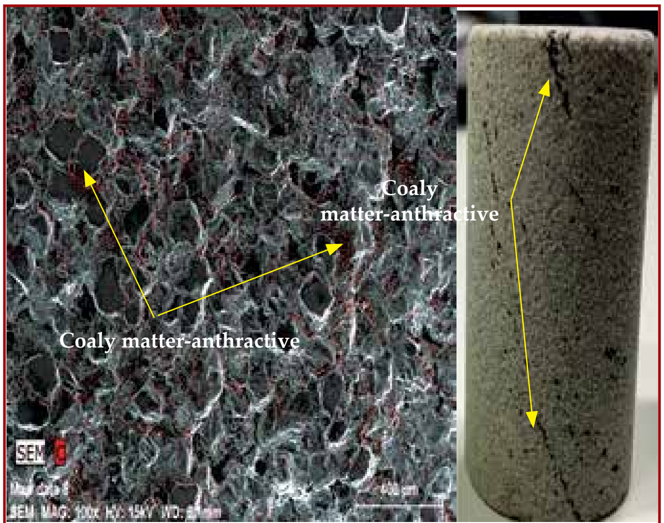

Fig.7. Example of possible anthracite between quartz grains

composed since this coal distribution in the core sample doesn't spread widely it is most likely that this type of kerogen was derived from plant matter [36-38]. Since the Champion field was subject to high pressure and temperatures [38, 39] it could lead to partial dissolution of this plant matter and the rest of it was transformed into a third type of kerogen and afterward to anthracite [40].

The analyses of the outcrop sample proved that the outcrop sample is characterized as shiny black, hard, and brittle that answers the common features of anthracite [41, 42].

Also, several fields around Champion field such as Brunei Muara district found out presence of coal in geological formation [3] that might make the theory about coal inclusions in the sandstone of Champion field even more valid for our assumptions. An example of this coaly matter is introduced on figure 7, where there is the presence of possible anthracite between quartz grains that can be noticed by the naked eye as well as on nanoscale level according to SEM measurements.

3.5. Focus Ion Beam Scanning Electron Microscopes

Applying the high resolution of Focal Ion Beam (FIB)-SEM helped to find a spot that possibly went through several transformations (fig.8). Since quartz is the most stable mineral [35] it means that this dissolution was possible only when there was a combination of chemical and physical weathering under conditions of high pressures [30, 32, 43]. Champion delta is of Miocene age this way in the middle of this epoch temperature took sharp drop [44] that as a result caused physical weathering [45]. Nonetheless, the rock sample can be considered as weakly cemented sandstones, it could be possibly affected by chemical influence. It means that there could be the partial dissolution of cement that was caused by presence of acid water [46, 47].

Also, this region is characterized as an active tectonic zone [4, 11] thus, Champion field was subject to high pressures that also played a key role in the dissolution of minerals [48] and in the formation of effective porosity of the reservoir.

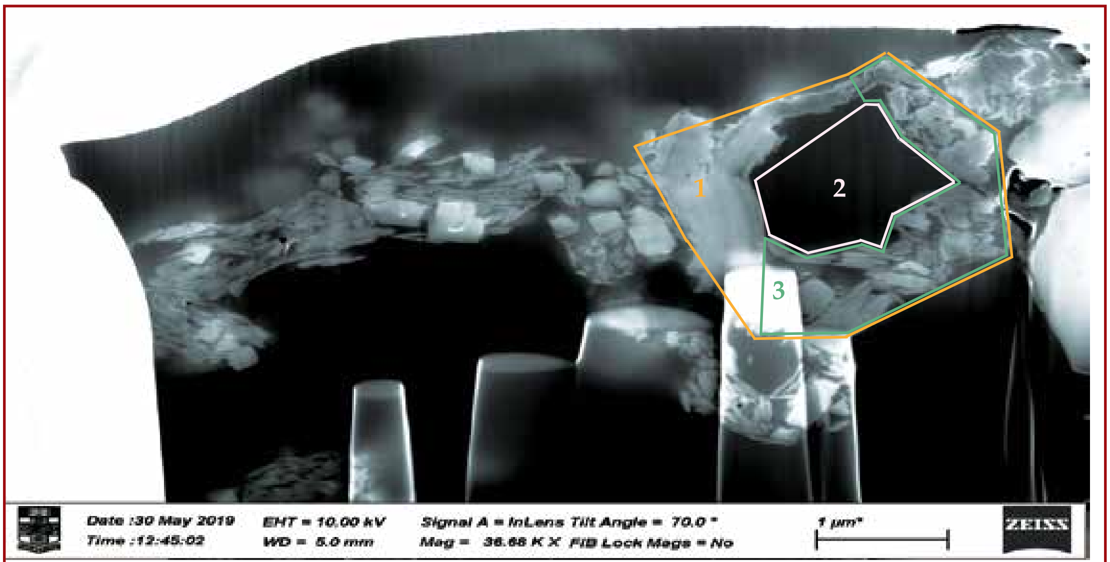

Fig.8. Possible spot of quartz overgrowth observed in FIB-SEM
1 - Possible initial position of quartz grain; 2 - Possible quartz overgrowth; 3 –Recrystallization and transformation that led dissolution of this quartz grain and as a result created secondary pore

Conclusion

The reservoir rock of Champion field is characterized as dual porosity system. The origin of secondary pores is related to a combination of mechanisms such as the influence of tectonics and post-depositional processes. Regional tectonics led to conditions of high pressure and temperature that caused the partial dissolution of plant matter(phytolith) and an indicator of this activity is anthracite. As for the influence of post-depositional processes, diagenetic stages played a key role, and it can be seen in the positive friendly correlation of XRD and petrography analysis. This correlation found out that at the initial stages it had more K-feldspar that afterward was replaced by muscovite and kaolinite during lithification. Also, compaction of sediments led to erosion, the fracturing of grains, and in some cases to their dissolution that overall resulted in the formation of secondary pores.

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References

1. Hadley, D. F., Arochukwu, E. C., Nishi, K., et al. (2006, January). Depositional modelling of Champion field, Brunei: assessing the impact of reservoir architecture on secondary recovery. SPE-101033-MS. In: *SPE Asia Pacific Oil & Gas Conference and Exhibition. Society of Petroleum Engineers.*

2. Hodgetts, D., Imber, J., Childs, C., et al. (2001). Sequence stratigraphic responses to shoreline-perpendicular growth faulting in shallow marine reservoirs of the Champion field, offshore Brunei Darussalam, South China Sea. *AAPG Bulletin*, 85(3), 433-457.

3. Fah, Y. K., Carter, R. R., Walton, W., Hupje, R. (1997, January). Technology-driven infill oil development planning of a mature offshore area, Brunei Darussalam. SPE-38051-MS. In: *SPE Asia Pacific Oil and Gas Conference and Exhibition. Society of Petroleum Engineers.*

4. Tingay, M. R., Hillis, R. R., Swarbrick, R. E., et al.. (2009). Origin of overpressure and pore-pressure prediction in the Baram province, Brunei. *AAPG Bulletin*, 93(1), 51-74.

5. Sommerauer, G., Zerbst, C. (2006, January). Rapid pressure support for Champion SE reservoirs by multi-layer fractured water injection. SPE-101017-MS. In: *SPE Asia Pacific Oil & Gas Conference and Exhibition. Society of Petroleum Engineers.*

6. Childs, C. J. J. P., Walsh, J. J., Watterson, J. (1997). Complexity in fault zone structure and implications for fault seal prediction. *Norwegian Petroleum Society Special Publications*, 7, 61-72.

7. Harding, T. P. (1976). Tectonic significance and hydrocarbon trapping consequences of sequential folding synchronous with San Andreas faulting, San Joaquin Valley, California. *AAPG Bulletin*, 60(3), 356-378.

8. Smalley, P. C., England, W. A., El Rabaa, A. W. M. (1994). Reservoir compartmentalization assessed with fluid compositional data. *SPE Reservoir Engineering*, 9(03), 175-180.

9. Jolley, S. J., Fisher, Q. J., Ainsworth, R. B. (2010). Reservoir compartmentalization: an introduction. *Geological Society, London, Special Publications*, 347(1), 1-8.

10. Zoback, M. D. (2010). Reservoir geomechanics. *London: Cambridge University Press.*

11. Van Rensbergen, P., Morley, C. K. (2003). Re-evaluation of mobile shale occurrences on seismic sections of the Champion and Baram deltas, offshore Brunei. *Geological Society, London, Special Publications*, 216(1), 395-409.

12. Crevello, P., Morley, C., Lambiase, J., Simmons, M. (1997, May). The interaction of tectonics and depositional systems on the stratigraphy of the active tertiary Deltaic Shelf Margin of Brunei Darussalam. In: *Proceedings of an International Conference on Petroleum Systems of SE Asia and Australasia.*

13. Buckley, S. E., Leverett, M. (1942). Mechanism of fluid displacement in sands. *Transactions of the AIME*, 146(01), 107-116.

14. Ahmed, T. (2018). Reservoir engineering handbook. *Gulf Professional Publishing.*

15. Zhuravljov, A., Lanetc, Z. (2019). Relevance of analytical Buckley–Leverett solution for immiscible oil displacement by various gases. *Journal of Petroleum Exploration and Production Technology*, 9(1), 617-626.

16. Vishnyakov, V., Suleimanov, B., Salmanov, A., Zeynalov, E. (2019). Primer on enhanced oil recovery. *Gulf Professional Publishing.*

17. Hook, J. R. (2003). An introduction to porosity. *Petrophysics,* 44 (03), 205-212.

18. Salimov, F. S., Kotenev, Y. A., Mukhametshin, V. S., et al. (2020, August). Development of oil deposits in tectonic conditions. In: *IOP Conference Series: Materials Science and Engineering*, 905(1), 012086.

19. Stenkin, A. V., Kotenev, Y. A., Sultanov, S. K., et al. (2020, August). Increased production of oil reserves in low production deposits of West Siberian oil and gas province. In: *IOP Conference Series: Materials Science and Engineering*, 905(1), 012088.

20. Wilkinson, M., Darby, D., Haszeldine, R. S., Couples, G. D. (1997). Secondary porosity generation during deep burial associated with overpressure leak-off: Fulmar Formation, United Kingdom Central Graben. *AAPG Bulletin,* 81(5), 803-813.

21. Lindquist, S. J. (1977). Secondary porosity development and subsequent reduction, overpressured Frio Formation sandstone (Oligocene), South Texas. *AAPG Bulletin,* 71(2), 191-206.

22. Schmidt, V., McDonald, D. A. (1979). The role of secondary porosity in the course of sandstone diagenesis. *SEPM Special Publication,* 26, 175-207.

23. Thomson, A. (1959). Pressure solution and porosity. *SEPM Silica in Sediments* (SP7).

24. Mozley, P. S. (1989). Relation between depositional environment and the elemental composition of early diagenetic siderite. *Geology,* 17(8), 704-706.

25. Gautier, D. L. (1982). Siderite concretions; indicators of early diagenesis in the Gammon Shale (Cretaceous). *Journal of Sedimentary Research,* 52(3), 859-871.

26. Wang, W. H. (1992). Origin of reddening and secondary porosity in Carboniferous sandstones, Northern Ireland. *Geological Society, London, Special Publications*, 62(1), 243-254.

27. Blatt, H. (1979). Diagenetic processes in sandstones. *SEPM Special Publication*, 26, 141-157.

28. Blatt, H. (1982). Sedimentary petrology. *San-Francisco: W.M. Freeman and Co.*

29. Dewers, T., Ortoleva, P. (1990). A coupled reaction/transport/mechanical model for intergranular pressure solution, stylolites, and differential compaction and cementation in clean sandstones. *Geochimica et Cosmochimica Acta,* 54(6), 1609-1625.

30. Renard, F., Ortoleva, P., Gratier, J. P. (1997). Pressure solution in sandstones: influence of clays and dependence on temperature and stress. *Tectonophysics*, 280(3-4), 257-266.

31. Houseknecht, D. W. (1988). Intergranular pressure solution in four quartzose sandstones. *Journal of Sedimentary Research,* 58(2), 228-246.

32. Bjorkum, P. A. (1996). How important is pressure in causing dissolution of quartz in sandstones?. *Journal of Sedimentary Research,* 66(1), 147-154.

33. Hayes, J. B. (1979). Sandstone diagenesis—the hole truth. *SEPM Special Publication,* 26, 127-139.

34. Bjorlykke, K. (1984). Formation of secondary porosity: How important is it?: Part 2. Aspects of porosity modification. In: *Clastic Diagenesis.*

35. Dapples, E. C. (1972). Some concepts of cementation and lithification of sandstones. *AAPG Bulletin*, 56(1), 3-25.

36. Larter, S. R., Senftle, J. T. (1985). Improved kerogen typing for petroleum source rock analysis. *Nature*, 318(6043), 277-280.

37. Dow, W. G., O'Connor, D. I. (1982). Kerogen maturity and type by reflected light microscopy applied to petroleum exploration.

38. Edwards, M. B. (2002). Sequence stratigraphic responses to shoreline-perpendicular growth faulting in shallow marine reservoirs of the Champion field, offshore Brunei Darussalam, South China Sea: discussion. *AAPG Bulletin*, 86(5), 919–921.

39. van Kessel, O. (2000, November). Champion East, low cost redevelopment of shallow, stacked and faulted heavy oil reservoirs. SPE-64719-MS. In: *International Oil and Gas Conference and Exhibition in China. Society of Petroleum Engineers.*

40. Daniels, E. J., Altaner, S. P., Marshak, S., Eggleston, J. R. (1990). Hydrothermal alteration in anthracite from eastern Pennsylvania: Implications for mechanisms of anthracite formation. *Geology,* 18(3), 247-250.

41. Hryckowian, E., Dutcher, R. R., Dachille, F. (1967). Experimental studies of anthracite coals at high pressures and temperatures. *Economic Geology,* 62(4), 517-539.

42. Xia, W., Xie, G. (2014). Changes in the hydrophobicity of anthracite coals before and after high temperature heating process. *Powder Technology*, 264, 31-35.

43. Maxwell, J. C. (1964). Influence of depth, temperature, and geologic age on porosity of quartzose sandstone. *AAPG Bulletin*, 48(5), 697-709.

44. Saller, A., Blake, G. (2003). Sequence stratigraphy and syndepositional tectonics of upper Miocene and Pliocene deltaic sediments, offshore Brunei Darussalam. *SEPM Special Publication*, 76, 219–234.

45. Smith, B. J. (2009). Weathering processes and forms /in «Geomorphology of Desert Environments». *Dordrecht: Springer.*

46. Meshri, I. D. (1986). On the reactivity of carbonic and organic acids and generation of secondary porosity. *SEPM Roles of Organic Matter in Sediment Diagenesis.*

47. Surdam, R. C., Boese, S. W., Crossey, L. J. (1984). The chemistry of secondary porosity: Part 2. Aspects of porosity modification. *AAPG Memoir,* 37(2), 127-149.

48. Nesbitt, H. W., Young, G. M. (1989). Formation and diagenesis of weathering profiles. *The Journal of Geology*, 97(2), 129-147.

Формирование концепта возникновения вторичной пористости с использованием различных лабораторных методов

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Реферат

Вторичная пористость в песчаниках считается ключевым параметром, контролирующим добычу углеводородов. Понимание распределения вторичных пор может дать определенное представление о неоднородности коллектора для конкретной области месторождения и, как результат, может помочь в применении более эффективных технологий проектирования скважин для повышения показателей нефтеотдачи. Изучаемое месторождение расположено примерно в 40 км от Брунея-Даруссалама. Для того, чтобы выяснить механизмы, которые привели к образованию вторичной пористости был проведен ряд исследований таких как: применение гелиевого порозиметра, измерение капиллярного давления за счет нагнетания ртути в образец, применение микрокомпьютерной томографии, рентгеновской дифракции, петрографического анализа, растрового электронного микроскопа с энергодисперсионной спектроскопией, а также использование фокусируемого ионного луча. Результаты показали, что эффективная пористость состоящая из вторичных пор была образована за счет эрозионных процессов, появления трещин в зернах песчаника, а также растворения минералов, в том числе и аутигенных, которые являются частью цемента заполняющего поры.

Ключевые слова: вторичная пористость; растворимость минералов; диагенетические процессы; геологическая неоднородность; анализ керна.

Müxtəlif laboratoriya metodlarının istifadəsi ilə törəmə məsaməliliyin əmələgəlmə konsepsiyasının formalaşması

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Xülasə

Qumdaşlarında törəmə məsaməlilik karbohidrogen hasilatına nəzarət edən əsas parametr hesab olunur. Törəmə məsamələrin paylanmasının başa düşülməsi yatağın konkret sahəsi üçün kollektorun qeyri-bircinsliyi haqqında müəyyən təsəvvür yaradır və nəticə olaraq neftverimi göstəricilərinin yüksəldilməsi üçün daha səmərəli quyu layihələndirmə texnologiyalarının tətbiqinə kömək edir. Tədqiq olunan yataq Bruney Darusallamdan təxminən 40 km məsafədə yerləşir. Törəmə məsaməliyin əmələ gəlməsinə səbəb olan mexanizmləri araşdırmaq üçün helyum porozimetrinin (məsamə ölçən) istifadəsi, nümunəyə civə vuraraq kapilyar təzyiqin ölçülməsi, mikrokompüter tomoqrafiyasının istifadəsi , rentqen difraksiyası, petroqrafik analiz, enerji dispersion spektroskopiya ilə skanedici elektron mikroskop, həmçinin fokuslanmış ion şüasının istifadəsi ilə bir sıra tədqiqatlar aparılmışdı. Nəticələr göstərmişdir ki, törəmə məsamələrdən ibarət effektiv məsaməlilik eroziya prosesləri, qumdaşı dənəciklərində çatlaqların meydana gəlməsi, həmçinin məsamələri dolduran sementin bir hissəsi olan mineralların, o cümlədən autigenlərin həllolması hesabına əmələ gəlmişdir.

Açar sözlər: törəmə məsaməlilik; mineralların həllolma qabiliyyəti; diagenetik proseslər; geoloji qeyri-bircinslik; kernin analizi.