Diagenetic Sequences Analysis of Fuyu Reservoir in Qijia – Gulong Depression, Northern Songliao Basin

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Abstract Five paragenetic associations are recognized in Fuyu reservoir of Qijia – gulong depression of Daqing oil field: 1) detrital illite permeation, glauconite and pyrite precipitation; 2) feldspar dissolution, kaolinite precipitation and the incipient quartz overgrowths; 3) early calcite cements; 4) postdate quartz overgrowths and pore – filling quartz, authigenetic illite and chlorite formation, feldspar overgrowths, petroleum injections, K – feldspar and calcite cement dissolution; 5) pore – filling calcite and calcite replacement.

Key words *Diagenetic sequence, Fuyu reservoir, Diagenesis*

Introduction

The ordering of diagenetic events is one of the most important keys to the ultimate interpretation of the ways in which the geological and geochemical history of a sandstone affected its composition and texture. This article give a detail description and origin explanation to the all kinds of diagenetic minerals and events.

1 Geological Setting

Qijia – gulong sag lies in western Songliao Basin, with an area of 5 270km^2. With the development of the basin, it underwent syn – rift stage, post – rift stage, as well as uplift.

Fuyu reservoir belongs to Quantou Formation which was formed during Early Cretaceous with burial depths from 1 585.5 ~2 535m to 1 675 ~2 645.5m. It deposited in dry climate when the basin was subsiding quickly and filling with distributary plain, deltaic front and shore – shallow lake faces (Gao, 1997).

2 Material and Methods

A total of 80 representative samples covering a wide range of burial depths from 1 633.50m to 2 517.42m were selected for thin section analysis. Seventeen of the samples were overpressured and vacuum – impregnated with red epoxy resin prior to thin – section preparation. The purpose is to examine easily the classification, structure, and web of pores and to observed the porosity. The model compositions of the sandstones were estimated counting 300 points in each thin section performed by a single operator. Thirteen of the sample were coated with a thin layer of carbon and examined with Scanning Electron Microscope (SEM) at an accelerating voltage of 20kv for 50 hours. Eighteen polished thin sections were coated with a thin layer of carbon for Electron Microprobe (EMP) analysis. X – ray diffraction analysis were done to identify clay minerals species in the $< 2\mu m$ fraction of 10 representative sandstone samples. Two intra – red spectrum analysis were performed in order to improve whether some dark brown matters remained in the thin sections were organism.

3 Diagenetic Sequences

Be based on the above material and methods, according to the first or late of authigenetic mineral or diagenetic effects were found, the generalized diagenetic paragenesis for the Fuyu reservoir is given in Tab. 1.

3.1 Paragenetic association 1

The paragenetic association 1 includes the detrital illite permeation, glauconite and pyrite precipitation.

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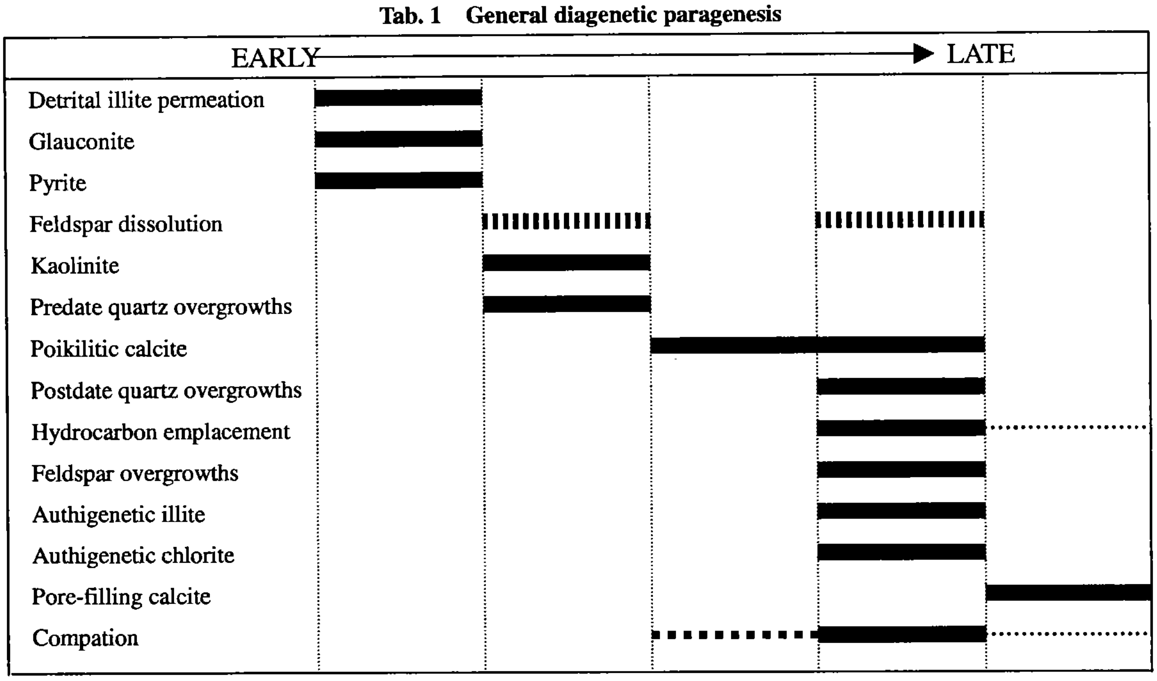
Tab. 1 General diagenetic paragenesis



Illite permeation

The equal thickness clay film which enclosed detrital grains and dominanted by illites existed in the boundary of tangential, straight and concave – convex contacts, reveal a condition of relatively stable without mechanical compaction. After sandy sediments deposit until away low water, the clay matrix adhere slowly on the surface of grains through permeation and form the clay lamina dominated by illite. Similar phenomena also were found in Quantou Formation, the southern of Songliao Basin (Long et al, 1999), and the quartzose sandstones of Cambrian Period in Ras Dib – Zeit area of Suez Gulf (Wahab,1998).

Glauconite and pyrite

It has been illustrated that the transgression took place during the deposition of Fuyu reservoir (Gao et al, 1989), consequently it is not surprised to find glauconite in thin section. Pyrite (Fig. 1) is formed in medium – alkaline conditions at syndiagenesis stage (Pettijohn, 1987).

3.2 Paragenetic association 2

The paragenitic association 2 includes feldspar dissolution, kaolinite precipitation and the incipient quartz overgrowths.

Feldspar dissolution and kaolinite precipitation

SEM observation revealed that the pores were filled by kaolinite whose rims were coated by illite, indicating that the kaolinite formed relatively later than illite. Authigenetic kaolinite can be formed in acid condition, in general, it is formed by the dissolution of feldspar in meteoric water or acid strata water which is formed from the pyrolysis of kerogen or the reaction of light hydrocarbon and water at the interface of petroleum – water. Abundance photomicrographs illustrated that there were a lot of dissolution of feldspars in oil – bearing sandstones (Fig. 2) but no kaolinite coexisting with them. In contrast, feldspar dissolution coexisted with kaolinite in common sandstones (Well Jin55, 1 922.77 ~ 1 939.70m). Well Jin55 just is located in a fracture zone, which allow the meteoric water to the strata and dissolve feldspar to form kaolinite, it suggested that the formation of kaolinite was not related to the petroleum emplacement. Because the kaolinite filled in the primary pores which

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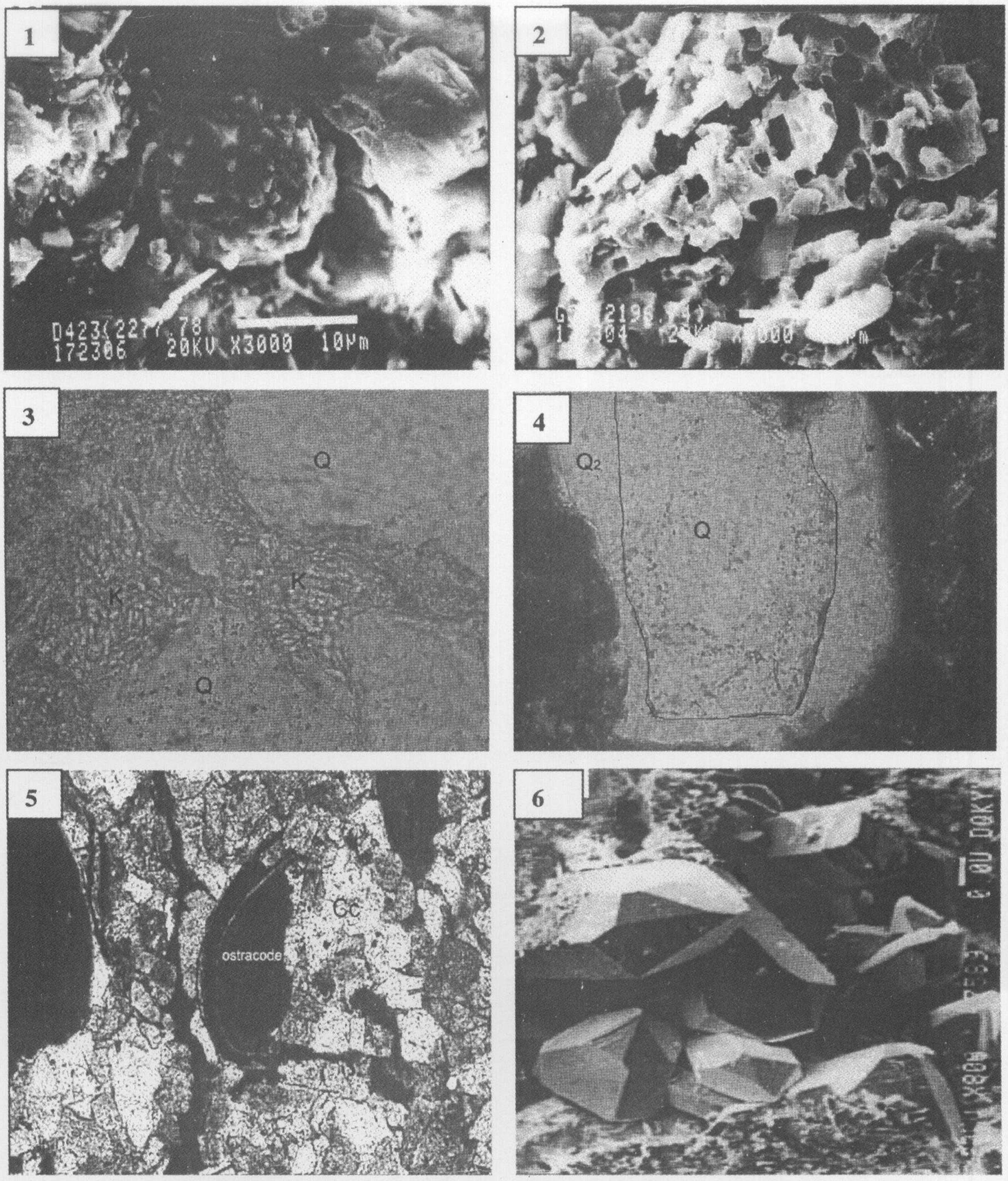

Fig. 1 **Strawberry – shape pyrite, well Da423, 2 277.78m, Q4, sandstone, SEM 3000**
Fig. 2 **Albite dissolution, well Gu59, 2 196.74m, Q4, sandstone, SEM 1000**
Fig. 3 **Authigenetic kaolinite, well Jin55, 1 922.77 – 1 939.70m, Q4, sandstone, XN 10**
Fig. 4 **Predate quartz overgrowths, well Jin55, 1 922.77 – 1 939.70m, Q4, sandstone, XN 10**
Fig. 5 **Poikilitic calcite cements, ostracode is dissolved, well Jin55, 1 900.38 – 1 918.00, The Number 1 of Qingshangkou Formation – Q4, sandstone, XN 10**
Fig. 6 **Authigenetic quartz in pores, well Gu431, 1 958.5m, Q4, grey – brown oil siltstone, SEM 800**

Note: Q4 – The Number 4 of Quantou Formation; Q3 – The Number 3 of Quantou Formation; SEM – Scanning Electron Microscope; XN – Crossing Nicol

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were lightly compaction (Fig. 3), consequently it's undoubted that it formed in the early diagenesis.

Sedimentary facies research indicated that the well Jin55 lies in alluvial plain during the deposition of the Number 3 and Number4 of Quantou Formation (Ren et al, 1999). Bjφrlykke (1994) proved that kaolinite usually distributes in the fluvial sandstones, coastal sandstones and sandstones near the unconformity, indicating that the kaolinite form as the result of the leaching of meteoric water. Authigenetic kaolinite isotope study also supports the above ideas (Longstaffe, 1984). In North Sea and Haltenbanken reservoirs, isotope research of the carbonate cement which formed as the same as or later than the kaolinite formation showed that kaolinite form in the course of meteoric water leaching below the 60℃ (Saigal et al, 1992), therefore the kaolinite formation probably is related to the leaching of meteoric water.

Predate quartz overgrowths

The thickness of predate quartz overgrowths is nearly equal, suggesting that there were enough pore spaces when the overgrowths were growing, and the sediments almost didn't undergo mechanical compaction (Fig. 4). In addition, quartz overgrowths were enclosed by early calcite cements in the predate calcite cement sandstones, indicating that calcite postdated quartz overgrowth. The precipitation of quartz cement needs acid environment, so the kaolinite and incipient quartz overgrowths probably were synchronous.

3.3 Paragenetic association 3

The paragenetic association 3 consists of early calcite cements which was precipitated in the alkaline pore fluids with the increasing of burial depths.

Poikilitic calcite cement

Detrital grains were cemented by poikilitic calcite with tangential and straight. Some sandstone contact boundary contains calcareous organism detritals and ooids such as ostracode, which were dissolved partially, suggesting that some calcite cements probably derived from the dissolution of calcareous organism detrital (Fig. 5). The EMP analyses for the early calcite in studied area show the contents of FeO and MgO are 0.7 ~ 1.93% and 0.23 ~ 0.43%, respectively (Tab. 2).

3.4 Paragenetic association 4

Paragenetic association 4 is the dominant diagenesis and consists of postdate quartz overgrowths and pore – filling quartz (Fig. 6), authigenetic illite and chlorite formation, feldspar overgrowths, petroleum injections, K – feldspar and calcite cement dissolu -

Tab. 2 Electron Microprobe analyses dates of authigenetic minerals

No	Ingredient	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	<FeO>	MnO	MgO	CaO	Na_2O	K_2O	Total
46	Late calcite	0.54	0.05	2.45	0	1.23	0.72	0.52	44.5	0.06	0.24	50.31
	Late calcite	0.3	0.24	0.12	0.16	1.66	1.93	0.62	53.85	0	0.02	58.92
47	Early calcite	0.08	0.05	0	0.12	1.32	2.94	0.42	55.41	0	0	60.34
	Late calcite	0.43	0	0.15	0	1.32	2.04	0.38	55.29	0.05	0.08	59.74
11	Clastic quartz	99.87	0	0	0.08	0	0	0.03	0	0.03	0	100
	Overgrowth	99.72	0	0.12	0	0.09	0	0	0.05	0.03	0	100.01
18	Clastic quartz	99.79	0	0.07	0	0	0	0.04	0.03	0.05	0	100
	Overgrowth	99.37	0.17	0.16	0.09	0	0.04	0.03	0.03	0.03	0.07	99.99
28	Early calcite	0.03	0	0	0.22	1.93	0.86	0.43	56.53	0.05	0.05	60.1
31	Late calcite	0	0	0	0.12	0.51	0.42	0.24	54.79	0.03	0.03	56.13
	Early calcite	0.17	0.17	0	0	0.88	0.41	0.3	55.56	0	0	57.5
21	Clastic quartz	100.12	0.15	0.09	0.14	0	0.02	0	0	0.02	0	100.56
	Overgrowth	98.5	0.08	0.53	0	0	0	0	0	0.03	0	99.15

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tion, the change of smectite to illite and petroleum injecting are the main diagenetic events.

Postdate quartz overgrowths and pore – filling quartz

The presence of the late calcite cements is precipitated near the postdate quartz overgrowths rims illustrated that the quartz overgrowth predate calcite. Quartz overgrowths contains hydrocarbon inclusions, suggesting that the overgrowths and petroleum injection are synchronous.

EMP analyses of quartz revealed that the content (Al_2O_3, FeO, MgO, Cr_2O_3, TiO_2) of the overgrowths are different from detrital quartz grains (Tab. 2), suggesting that the sources of silica wasn't related to the compaction dissolution. Silica which is needed for late quartz overgrowth probably released from the conversion of smectite to illite in the mudstone which intercalated with sandstone, the evidences include: (1) There are no smectite in the sandstones, indicating that smectite has altered illite or missed – layer I/S. (2) Hair – like authigenetic illite and pore – filling quartz are paragenetic. (3) Authigenetic chlorite was found. The following equations are the alteration of smectite to illite:

$$4.5K^{+} + 8Al^{3+} + \text{smectite} \rightarrow \text{illite} + Na^{+} + 2Ca^{2+} + 2.5Fe^{3+} + 2Mg^{2+} + 3Si^{4+} + 10H_2O;$$

$$3.93K^{+} + 1.57\text{smectite} \rightarrow \text{illite} + 1.57Na^{+} + 3.14Ca^{2+} + 4.78Fe^{3+} + 24.66Si^{4+} + 57O^{2-} + 11.4(OH)^{-} + 15.7H_2O$$

According to the second equation, 423.1g smectite entirely expanded can form 382.9g I/S minerals which contains 35% smectite and 40.2g SiO_2. In the reaction, K – feldspar supply K^{+} the for smectite to illite, remnant silica form quartz overgrowth or pore – filling quartz, and Mg^{2+} form chlorite. During the clay minerals alteration, intrastratal water released from smectite flow into sandstone with Mg^{2+}, Fe^{3+}, Ca^{2+} and Si^{4+} under the overlying pressure from mudstones, and supply materials for the diagenesis of sandstones. Another source of quartz overgrowth is probably the dissolution of volcanic fragments.

Authigenetic illite and chlorite

Authigenetic quartz coexists with illite, in some samples chlorite (Fig. 7) and authigenetic illite (Fig. 8) occur together, obviously they are synchronous.

Petroleum injection

The identifications of petroleum injection are residual oil traces and hydrocarbon inclusions in the authigenetic minerals. The infra – red spectrum analyses showed that those dark brown matter in thin sections contain functional group of H – O, C – C – C, CH_2, CH_3, and CO_2, indicating those are organic. When late calcites and organic materials occur together, organic matter are often replaced by calcite without exception. This indicates oil – gas injected before calcite filling but after poikilitic calcite formation.

Hydrocarbon inclusions had been found in the quartz overgrows, clay – lines, filled fissure of quartz grains and late calcite cements, this phenomenon proved that oil – gas migration was multi – period. Considering all the above, the conclusion is that oil primary injection synchronized with the postdate quartz overgrowths and its abundance injection happened before late calcite cementation with a small – scale migration of oil.

Dissolution and alteration

Casting thin section observation found early calcite cement is partly dissolved (Fig. 9) and feldspar is altered. Feldspar alteration has something to do with acid water leaching which includes meteoric water and strata water. It is notable that the feldspar corrosion in studied area often happens in oil – bearing siltstones. That shows there is relation between feldspar dissolution and hydrocarbon, it is that oil emplacement happened before feldspar alteration.

In the process of alteration feldspar often turns into kaolinite. However, in studied area there isn't this association because of property difference of sandstones. Recent years research showed that permeable fluid is needed in kaolinite formation. According to

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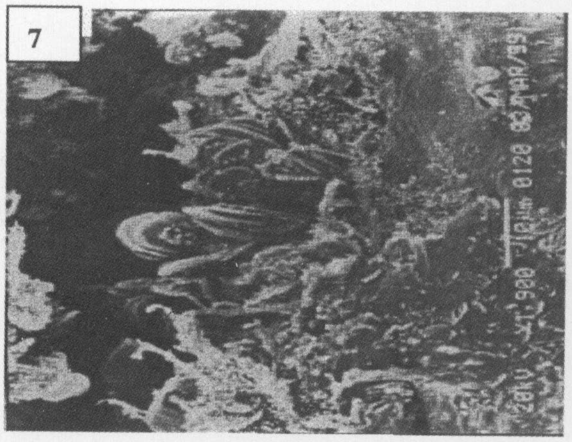
research (Fu et al, 1994) on sandstone reservoir in Tarim Basin, when porosity and permeability are higher in sandstones, water in pores flows well, alkalic ions separated out during feldspar dissolution can be taken away on time and the production is kaolinite, inversely illite and smectite. Although large amount of smectite wasn't detected in studied sandstones, there is quite a little mixed – layer I/S minerals, some may be the production of smectite which is the result of feldspar alterataion has happened further diagenesis.

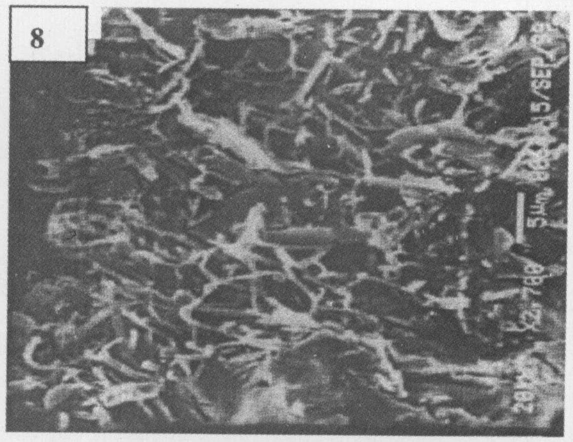
Feldspar overgrowths

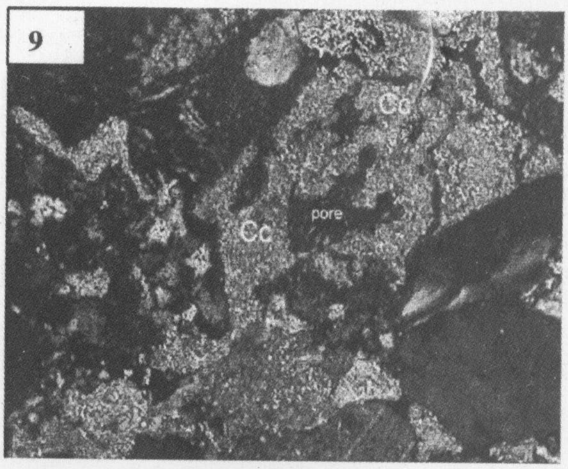
SEM observation found the postdate quartz overgrowth rims develop authigenetic albite, showing the albite postdates the overgrowth. Generally it is considered that feldspar overgrowth (Fig. 10) at 100 ~ 150℃ which is higher than the homogeneous temperature of fluid inclusions in quartz overgrowths in Fuyang Reservoir. This also shows that feldspar overgrowth postdates quartz's. There is illite on the surface of authigenetic quartz, implying that authigenetic illite formed after quartz or simultaneously but early than albite.

3.5 Paragenetic association 5

Paragenetic association 5 contains pore – filling







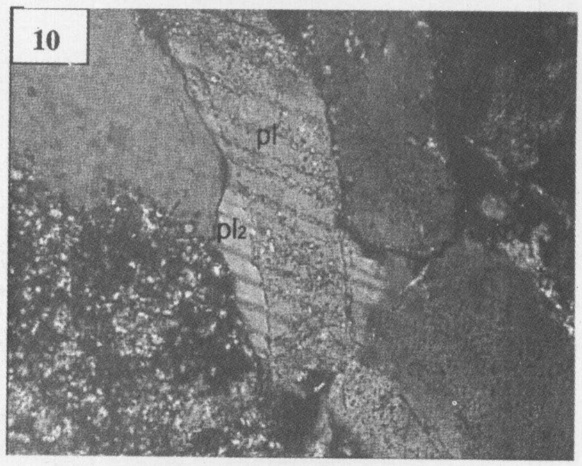


Fig. 7 Authigenetic chlorite, well Ying331, 2 472.81m, Q4, brown – black oil siltstone, SEM 5000
Fig. 8 Hair – like authigenetic illite, well Gu56, 1 980.4 – 1 997.62m, Q4, siltstone, SEM 1600
Fig. 9 Calcite dissolution, well Ta15, 1705.41m, Q3, sandstone, casting thin section, XN 10
Fig. 10 Plagioclase overgrowths, well Jin55, 1 922.77 – 1 939.79m, Q4, sandstone, XN 10

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calcite and calcite replacement.

Pore - filling calcite

Late calcite cements distribute in the residual pores, and it is notable that in the oil sandstones quartz overgrows, illite, hydrocarbon and calcite arranged one by one from the grains rims to center of pores. This shows that calcite formed after oil emplacement and expelled the oil.

In the late calcite cements the content of FeO is 0.51 - 1.66%, Mg is 0.24 - 0.62%, Fe^{2+} and Mg^{2+} are more (Tab. 2). Perhaps its formation is related to the reprecipitation of Ca^{2+}, Fe^{3+}, and Mg^{2+} which were separated in the transform process of smectite to illite.

Calcite replacement

The replacement to calcite was the last burial diagenesis. Detritals and authigenetic minerals replaced by calcite are clastic feldspar, quartz, debris and secondary overgrowth of quartz, etc.

4 Conclusions

(1) The diagenetic sequences of Fuyu reservoir contains five paragenetic. Paragenetic associations 2 and paragenetic associations 4 are principle diagenesis.

(2) There were a lot of dissolution of feldspars in oil - bearing sandstones but no kaolinite coexisting with them. whereas feldspar dissolution coexisted with kaolinite in common sandstones, this showed that kaolinite formation isnt related to the petroleum injection.

(3) Silica for late quartz overgrowth probably released from the conversion of smectite to illite, another source is possibly the dissolution of volcanic fragments.

Acknowledgement

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