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Quartz Cement in Middle Jurassic Reservoir Sandstones i n North Sea.A Review. Part Ⅰ: Occurrence and Character

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Abstract Quartz cementation is a very important diagenetic event and main porosity-occluding factor in the reservoir sandstones in middle Jurassic i n North Sea. Petrological studies indicate the quartz cementation is limited in shallower burial depth and increases significantly at depth around 3.5 - 4 km. T he amount of quartz cement increases with burial depth from an average of approx imately 4%-5 vol% at 2.5 km to 17%-20 vol% at 4 km. Highest abundances of quartz cement exceeds 28% which has been found in the Ness Formation. Variations in qu artz cementation between different sandstone facies is minimal for any one forma tion, with exception of the generally lower quantities present in the heterolith ic sandstone. Homogenisation temperatures of fluid inclusion in quartz overgrowt h from the North Sea reservoirs indicate that few quartz cement occur below the temperature 70 ℃～80 ℃, the onset of large volume quartz cement starts at the temperatures higher than 90 ℃ which suggests the quartz cementation is temperat ure - dependent during progressing diagenesis of sandstones.

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INTRODUCTION

Quartz cement has been extensively studied in recent years (e.g. McBride, 1989, Land and others, 1990, B · rlykke and Egeberg, 1993). It is one of the most abundant cements in quartzose sandstones and the main cause of porosit y reduction in deeply buried clay-poor and quartz-rich reservoir sandstones in m iddle Jurassic in the North Sea (Bj · rlykke et al. 1986; Ehernberg, 1990) and al so in other sedimentary basins around the world (Blatt, 1979; Land and Fisher, 1 987; Bloch et al, 1990). Based on the petrographic studies using thin section, q uartz cement seems tobe one of the first minerals to precipitate, and the quartz cementation is, therefore, frequently interpreted as early diagenesis which too k place before significant burial (Gluyas, 1985). The quantitative data by Dixon et al. (1989) indicate that most quartz cementation occurred after sandstones h ave been buried 1 to 2 km and are subjected to temperatures greater than 50℃. I n continually subsiding sedimentary basins

little quartz cement (Bj · r lykke and Egeberg, 1993). The percentage of quartz cement vary greatly in the Br ent Group sandstones at depth exceeding 4 km and range from less than 10 to 20% (Bj · rlykke et al., 1992; Giles et al., 1992). Despite the common occurrence and economic significance of quartz cement in reservoir sandstones, it does still n ot appear to be a general agreement regarding the temperatures and depths at whi ch quartz cementation takes place and identifying the sources of silica that con tribute to quartz cementation during diagenesis is still a matter of dispute. Th is paper will present the regional characteristics of petrology and the distribu tion of quartz cements with depth in middle Jurassic reservoir sandstones in the North Sea.

GEOLOGICAL SETTING

The middle Jurassic is economically the most important succession in th e North Sea (Fig.1), the thickness is approximately 300 m, which is divided into five formation status (Fig.2) called Brent Group, i.e. Broom formation; Rannoch formation, Etive formation, Ness formation, and Tarbert formation. Brent Group strata are absent over some fault crests in the East Shetland Basin, the Magnus Ridge to the north, most of the Shetland Platform, and probably also over the Tr ansitional Shelf in the southwest of the basin (Richards, 1992). The Broom forma tion has consisted of variously medium to coarse grained, poorly sorted, frequen tly carbonate cemented sandstones, mudstones with floating coarse sand grains, p ebbly sandstones and conglomerates. The facies varies from place to place as tra nsgressive tidal flat, offshore sheet and fan delta system. The Broom formation ranges in thickness about 48 m from western margin of the basin and thins to the east and northeast. The Rannoch and Etive formations overlying the Broom format ion can be considered together in terms of a single genetic package. These two f ormations generally represent the marine to coastal, progradational phase of the Brent delta. The thickness of the two formations attain a combined maximum abou t 154 m or more in the NE part of the basin. The Ness formation is the most lith ologically variable unit of the Brent Group, and occurs in successions up to abo ut 180 m thick, as a complex of deltaic and coast-plain sediments. The Tarbert f ormation is often defined by a sharp-based coarse- to very coarse-grained sandst one interpreted as a transgressive lag deposit. Overlying sandstones are occasio nally fine grained and highly bioturbated, with rare, planar, dipping laminae.

The structural studies show that the major crustal extension occurred in the ear ly Triassic and again in the late Jurassic. The early extension caused tilting o f basement fault blocks. the late Jurassic faulting caused further block-tilti ng and created the main structural traps for the Brent Province oil and gas (Yie lding, et al., 1992).

PETROLOGY OF MIDDLEJURASSIC RESERVOIR SANDSTONES IN THE NORTH SEA

The middle Jurassic reservoir sandstones in North Sea, based on point-count analyses of

and subarkoses with rare occurrences of sublitharenites. Th e sandstones are of variable grain size (fine to coarse grained). Average quartz content ranges from 40 to 96%, which is dominantly monocrystaline . Detrital feldspar (dominantly K-feldspar) typically comprises from 10 to 20% o f reservoir sandstone, the total feldspar content decreases systematically with increasing burial depth from an average of 21.8% of detrital constituents to 5.0 % with exception of sandstones developed by albitization. Significant local vari ation in feldspar abundance often linked up the facies and grain-size and grain dissolution is also an important mechanisms affecting feldspar abundance. The ro ckfragments are mostly quartzi te and partly altered volcanic rock fragments. Th e content of lithic clasts dose not show any variation with increasing depth and facies. Muscovite and biotite range from 11% to less than 1% varying with the g rain-size and show strikingly alteration to kaolinite. Pyrite, glauconite, and heavy minerals occur as accessory components. The dominant clay minerals are ill ite, kaolinite and small amounts of chlorite. These minerals occur both as detri tal clasts and authigenic minerals. Authigenic kaolinite is virtually the only c lay present at shallow depth and below 3.5-4 km there is evidence of replacement of kaolinite by illite where K-feldspar is abundant. Smectite is rare and illit e occurs only in minor amounts at burial depths shallower than 3.5 km. The rapid increase in the concentration of illite below 3.5 to 4 km is related to illitiz ation of kaolinite, which seems to require temperatures of 130 to 140 ℃(Bj · rly kke et al., 1986; Ehrenberg and Nadeau, 1989). Chlorite is commonly present, but in relatively low concentration. Chlorite may replace kaolinite starting at 90 to 100°C, but the amount is limited by the supply of iron and magnesium from di ssolving mafic minerals and rock fragments (Bj · rlykke and Aagaard, 1992). Progr essive changes in the composition of chlorite observed with increasing burial de pth (Jahren and Aagaad, 1989). The pervasive distribution of authigenic kaolinit e in shallow burial depth suggests that exposure to meteoric water is a prerequi site for kaolinite to form at the expense of dissolving feldspar and mica (Bj · r lykke, 1984). The authigenic kaolinite in the Fulmar reservoir sandstone , which was deposited as turbidites on a marine shelf (Johnson et al., 1986), is partic ularly absent and no evidence shows feldspar leaching by meteoric water during e arly diagenesis at shallow burial depth (Saigal et al., 1992). Quartz cement is increasing with burial depth and may be temperature-dependent during the diagene sis of reservoir sandstones according to the data of fluid inclusion.

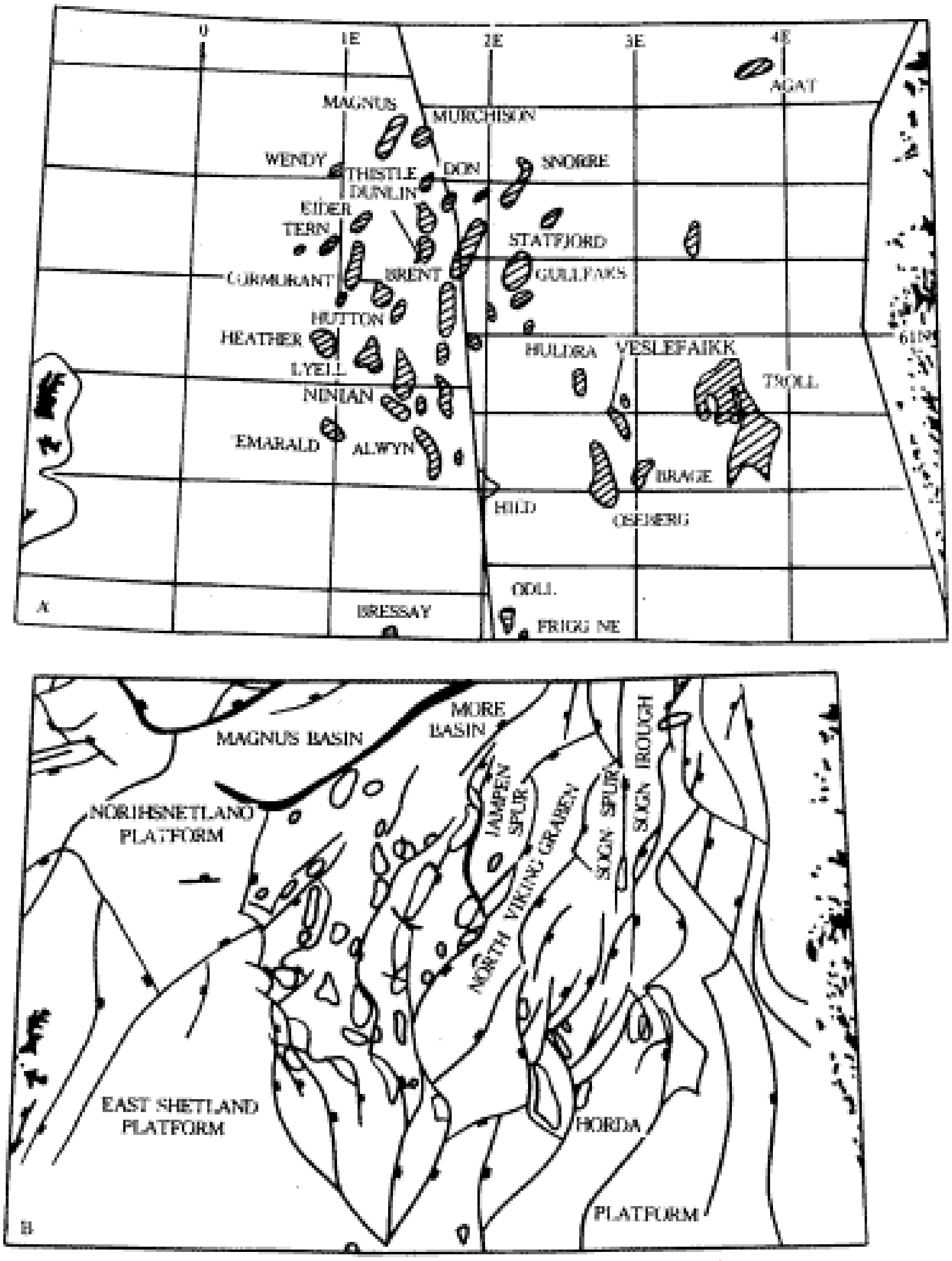

Fig.1 Location map for the major oil and gas fields(A) and the main structural elements (B) in northern North Sea (after K. Bj · lykke et al.1992)

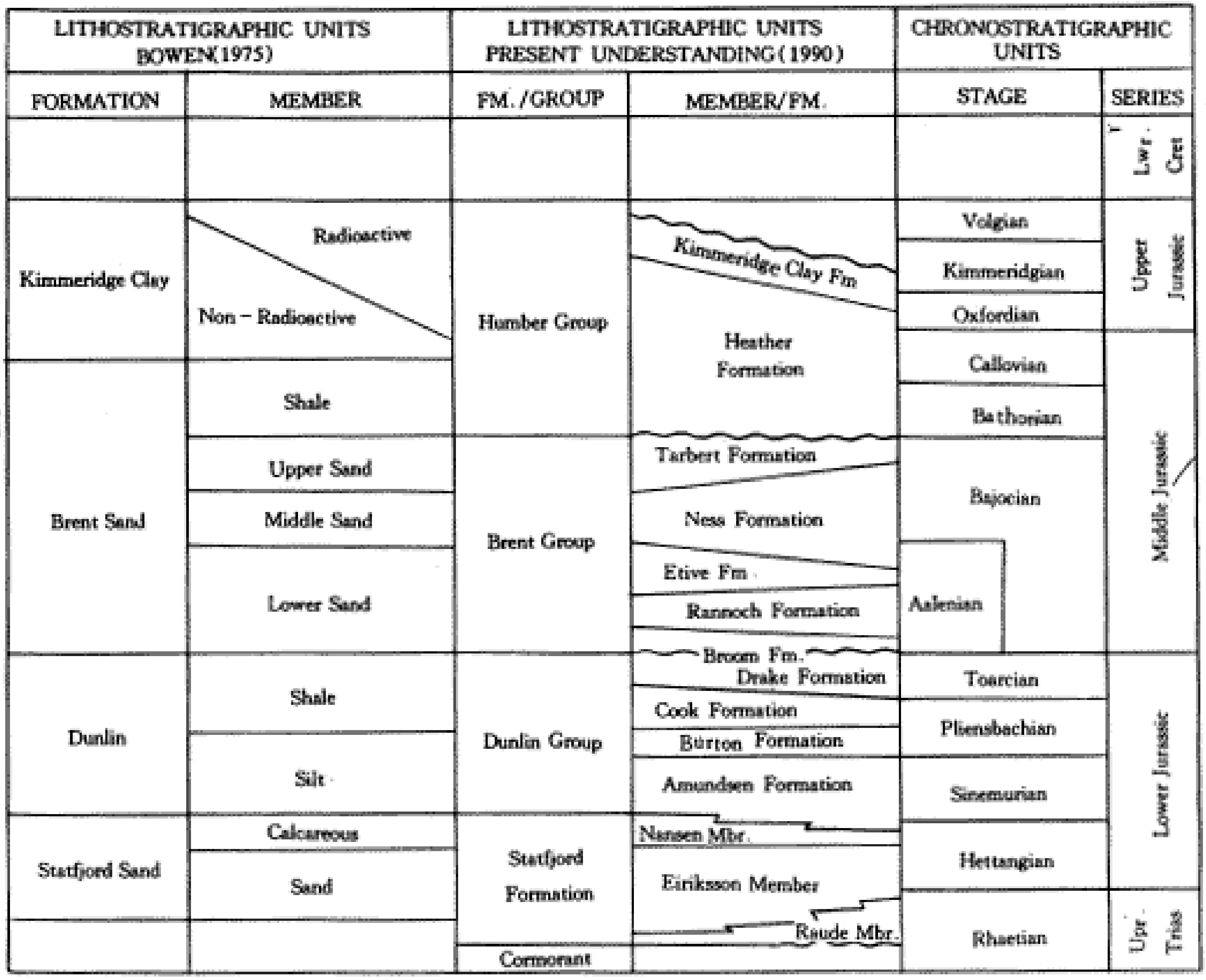

Fig.2 Jurassic stratigraphy of the Brent area as orignall y proposed compared with preesent usage.(after J. M. Bwen,1992)

OCCURRENCE AND CHARACTER OF QUARTZ CEMENT

Authigenic quartz is commonly precipitated as overgrowth on detrital qu artz grains, developed by the precipitation of silica directly from pore solutio n as well ordered quartz, which is a syntaxial rim with the same crystallographi c orientation and optical continuity as that of the detrital grain. Overgrowths start as numerous tiny crystals that coalesce into a single faces if conditions of silica supply, time and space permit. The petrographic data of Jurassic sands tones in North Sea show the absence of quartz cement and loose sands in shallow burial depth, for instance, the amount of quartz cement is only about 1-3% of th e total rock volume in Statfjord Field at 2.5 km burial depth. Kittilsen (1987) found that some intervals in the Brent Group of the Statfjord Field are almost d evoid of cement and are so poorly cemented. The abundant of quartz cement genera lly increases with a burial depth of between 3.0-4.5 km (Bjorlykke et al., 1992; Giles et al.; 1992). The Middle Jurassic Brent

at depth between 1. 8-4.5 km. The amount of quartz cement increases from 3-5% at 2.5 km to 17-20vol% up to 28vol% at depth 4.5 km giving rise to a quartz/depth gradient of around 1 0 vol % per kilometer. Thus, the primary control on the distribution of quartz c ement appears to be burial depth which suggests that the quartz cementation is t emperature-dependent during progressing diagenisis of sandstones. Cathodolumines cence(CL) also shows clearly the differences between detrital and authigenic qua rtz, detrital quartz grains generally luminesces red, blue or brown under extinc tion by electronics, whereas quartz cement do not luminescence or luminescence f aintly (Sipple, 1968). The luminescence of quartz overgrowth in North Sea has be en studied using SEM. Cemented grains had euhedral to subhedral grain boundarie s whereas, under CL, the detrital grains are angular to subangular or subrounded . A detrital quartz grains show the bright luminescence, whereas authigenic quar tz cements show the weak or dull luminescence. Hogg et al.(1992) indicates that the negative CL image shows dark to bright multiphase quartz overgrowths on dark subangular detrital quartz. This suggests that quartz overgrowths had a comple x internal structure. The CL image, however, shows generally one major generatio n of quartz overgrowth in Huldra field and Fulmar reservoir, which are uniformly dulland may range from 5 to 50 μm. These phenomena suggest that the major phas es or stages of quartz overgrowths vary from place to place and continual precip itation of silica or interrupted by short silica supply or the changes of pore g eochemistry.The temperatures of fluid inclusions of quartzovergrowth show the co ntinuous precipitation of silica, the unimodal distribution of the ice final mel ting temperature (Fig.3) indicates that there is no major variation in fluid che mistry and suggest that a single inclusion generation is present in each instanc e (Robinson and Gluyas, 1992).

Fig. 4 shows the distribution of quartz cement with depth. It clearly indicates that the quartz cement amount significantly increase at the depth deeper than 3. 0 km. If we extrapolate back to the zero on the authigenic quartz, axis would g ive a depth of about 2.4 km (see Fig.4),it confirms the result given by the petr ologic studies. In Hutton Field a progressive increase in the degree of quartz o vergrowth is observed from an average of about 10% quartz overgrowth at 3430 m t o about 18% at 3886 m (Scotch-man et al.,1989). The homogenization temperatures of quartz overgrowth in North Sea (Table 1) range from 68 ℃～170 ℃. B ecause of the rare temperaturelower than 80 ℃, this implies that precipitation of significant amounts of quartz overgrowth in sandstones did not start before temperatures reached 75 ℃～80 ℃. Published fluid inclusion data from the North Sea Basin suggest that quartz overgrowth does not generally take place below 75 ℃(Walderhaug, 1994). The homogenization temperatures lower than 75 ℃ may have pressure corrections of variable magnitude. The plot of temperature versus dept h shows the significant quartz overgrowt h of sandstones typically starts at temperatures above 70 ℃～80 ℃ despite vari ations in age and geographical location (Fig.4). The distribution and trend of q uartz cement may also indicate that quartz cementation is temperature or depth d ependence. The higher temperatures required for quartz cementation in the younge r sediments suggest a kinetic control on porosity loss and quartz cementation (B loch et al., 1986, 1990; Harrison, 1989).

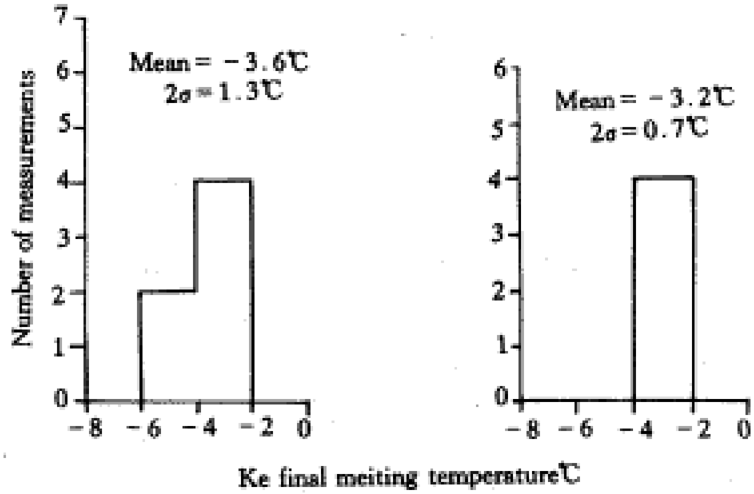

Fig.3 Ice final melting temperatures for fluid inclusions in quartaz overgrowth (after A. Robinson and J.Gluyas,1992). Left panel:Tarbe rt formation.northern North Sea.Right panel:Garn Formation,Haltenbanken,offsho re Norway.

Table 1 Homogenezation temperatures of fluid inclusions in qu artz overgrowth in North Sea

Location	Age	℃	Re ferences
Huldra Field	Middle Jurassic	115～155	Glasmann et al., 1989
Alwyn Field	Middle Jurassic	120-140	Jourdan et al., 1987
Alwyn Field	Middle Jurassic	93-132	Hogg, 1989
Bergen High	Middle Jurassic	135 -115	Glassman et al., 1989
Tartan Field	Middle Jurassic	60-122	Burley et al., 1989
Heidrun Field	Middle Jurassic	138 -131	Grant and Oxtoby, 1992
Sm · rbukk Field	Middle Jurassic	120-140	Robinson et al., 1992
Gyda Field	Middle Jurassic	125-155	Robinson et al., 1992

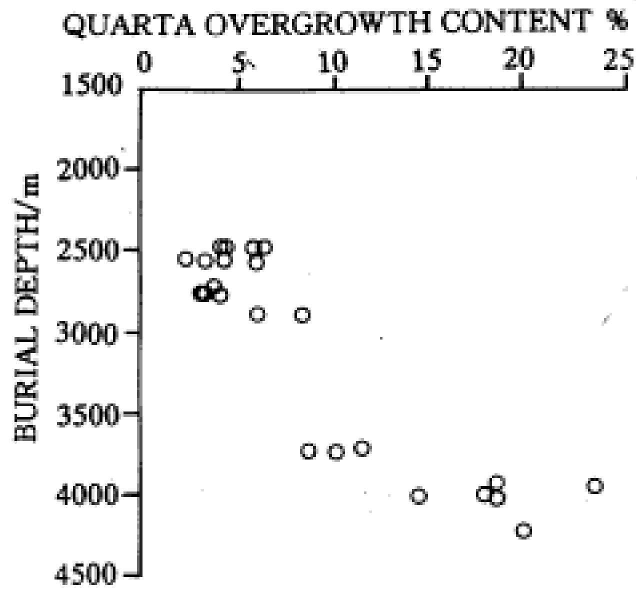

Fig.4 Relationship between quartz overgrowth and burial dep th for the reservoir sandstones of middle Jurassic of northerm North Sea

CONCLUSIONS

Quartz cement in reservoir sandstones increasing with burial depth stro ngly indicates that silica precipitation as quartz overgrowth is time and temper ature-dependent, there are only small amount of quartz cement down to a burial d epth of about 2.5 to 3 km. The destruction of reservoir properties is due to the quartz cement and pressure solution at the burial depth of about 4 km. The tren d of quartz cement with depth, based on the quantitative data of petrologic stud ies, contrasts the explanation of quartz cementation as an early diagenetic even t at shallow burial depth, and shows that quartz cement is continuously developi ng process other than separate stages or pulse. Homogenezation temperatures of f luid inclusion show that significant quartz cementation starts at the temperatur es higher than 85℃ and continues up to the maximum burial depth.

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