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Impact of thermal regime on quartz cementation in Cambrian sandstones of Lithuania

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Cambrian deposits in Lithuania are of economic interest, because they contain numerous oilfields and are still more prospective as they have a high geothermal potential and are very attractive for establishing underground gas storages. The reservoir properties range considerably. A distinct basin-scale trend of a decreasing reservoir quality to the west with increasing the depth and temperature is recognised. The porosity of the sandstones is as high as 20–25% in the east, whereas Cambrian sandstones are strongly quartz-cemented and have a very low porosity (3–8%) in West Lithuania. The reservoir quality shows a clear correlation with the thermal regime. Due to considerable variations in burial depth (from a few hundred meters in the southeast to 2.3 km in the west) the temperature changes accordingly from 7–10 °C to more than 90 °C. The occurrence of quartz cement is related to ~40 °C isotherm, whereas the most significant change in quartz cement content is observed at a 60 °C isotherm. The latter isotherm is considered as a basic threshold for quartz dissolution and precipitation. Against this background trend, drastic variations in the porosity and permeability are documented in West Lithuania, which cannot be explained by thermal variations. The depositional architecture is evidently highly important for quartz cementation.

Key words: quartz cementation, Cambrian, Baltic, thermal regime

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INTRODUCTION

Quartz cement is the major agent controlling reservoir quality of the Cambrian sandstones in Central and West Lithuania (Lashkova, 1979; 1993; Vosylius, 2000). Therefore it is essential to construct a predictive model of quartz cementation seeking to diminish risks for future oil exploration. Temperature is supposedly one of the main factors controlling quartz cementation of sandstones (Vosylius, 1997). Cambrian hydrocarbon reservoir sandstones in Lithuania show a considerable variation in petrophysical properties, which indeed seems to be partly correlated with burial depth. Present day temperatures of the Cambrian reservoir range from 10 °C in the shallow parts of the Baltic basin to 90 °C in West Lithuania. The wide range in thermal conditions in this basin provides a unique possibility to investigate the thermal control on quartz cementation. Moreover, an extensive database derived from thermal investigations of deep wells (mainly oil exploration wells) enables a detailed study. Temperature is, however, not the only parameter that influenced quartz cementation (Giles et al., 2000; Kilda, Friis, 2002). Other factors such as grain size and lithofacies (*e.g.*, Waldehaug et al., 2001) should be taken into consideration, as indicated by the distinct variations of porosity and permeability of the Middle Cambrian sandstones in West Lithuania even on a local scale.

The thermohysical properties of Cambrian rocks are also strongly influenced by burial conditions via porosity variations, changes in mineral framework and fluid composition (Jõeleht et al., 2002).

GEOLOGICAL SETTING

Lithuania is situated on the eastern flank of the Baltic sedimentary basin overlying the Early Pre-

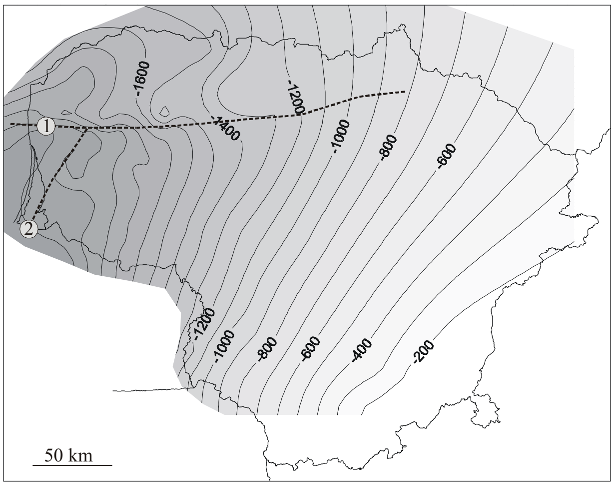

Fig. 1. Depth of Cambrian top of Lithuania. The Telšiai (*1*) and Gargždai (*2*) faults which control the major oil fields of Lithuania are indicated

1 pav. Lietuvos kambro kraigo gylių žemėlapis. *1* – Telšių ir *2* – Gargždų lūžiai, kontroliuojantys pagrindinius naftos telkinius Lietuvoje

cambrian crystalline basement. The thickness of the sedimentary fill ranges from 0.2 km in the east to 2.3 km in the west (Fig. 1). Cambrian deposits represent the basal part of the sedimentary cover. They are overlain by a carbonaceous-shaly succession of Ordovician age. The thickness of the Cambrian ranges from a few tens of meters in the east to 170 m in the west. It consists of Lower and lower-Middle Cambrian marine clastic sediments (Jankauskas, 2002) composed by an alternation of sandstones, siltstones and shales showing different proportions across the basin.

The Lower Cambrian attains 80 m in thickness. It consists of fine-grained sandstones that grade into an alternation of siltstones and shale in the west. The lowermost Cambrian "Blue Clay" formation occurs in the eastern part of Lithuania. Middle Cambrian deposits are documented in the western part of Lithuania and are up to 70–80 m thick. The offlap pattern with respect to the Lower Cambrian is attributed to the regression of the shallow marine basin that led to a shift of the sandy peripheral lithologies to the west, so that Middle Cambrian sandstones overlie the Lower Cambrian and lowermost Middle Cambrian shales. The fine-grained sandstones with sparse argillite and siltstone layers are referred to as the Deimena Group that overlies the about 10 m thick shales of the Kybartai Group. Both are attributed to the *Paradoxides oelandicus* trilobitic zone of the Middle Cambrian. Furtherwest in the Polish offshore area, these deposits grade into deeper-water siltstones and shales. The younger Paneriai Formation of the *Paradoxides paradoxissimus* zone was encountered in few wells in West Lithuania, constituting small isolated residues several meters thick, whereas it is widely distributed in the east on the western flank of the Moscow palaeobasin (up to 20–30 m thick) and the western periphery of the Polish Basin. Sandstones and siltstones are the dominant lithologies.

Cambrian sandstones in 95–99% are composed of quartz, they are mainly fine-grained, locally grading into medium- and coarse-grained, cemented by authigenic quartz with minor dolomite and clay cement.

METHODS AND DATA

The petrographic characterisation, including the textural and mineralogical composition of Cambrian sandstones, is based on polished thin sections of 149 samples from 50 wells, analyzed by means of polarized light microscopy. The components in 49 samples collected from 24 wells of West and Central Lithuania were quantified by image analysis using microphotographs from back-scattered electron (BSE) microscopy, cathode luminescence scanning electron (SEM-CL) and cold cathode (CL) luminescence microscopy, using the ImagePro Plus point counting and image analysis software. The study was focussed mostly on West and Central Lithuania where most of the producing oilfields occur and consequently most of core material and geophysical well logs are available for detailed study.

The open porosity and permeability data, mainly of sandstones, were collected from existing industrial reports listing nearly 10,000 measurements that provide consistent information on the lateral changes of the reservoir properties of Cambrian sandstones. The average porosities of sandstones separately for each of three formations (Pajūris, Ablinga, Giruliai) of the Deimena Regional Stage were calculated from these laboratory data. The total porosity was also estimated from thin sections of sanstones. Five wells were processed using logging data to estimate the open porosity correlated with the shale content, calculated from gamma-ray logs, and geothermal gradient was derived from thermal logs.

Temperature logging and point measurements of the Cambrian reservoir were carried out in 160 deep wells drilled through the Cambrian reservoir. The measurements were mainly related to oil exploration and geological mapping carried out in Lithuania throughout the past 40 years (Šliaupa, 2002). Different methods were used to measure the well temperatures (Rasteniene, Šliaupa, 2000): (*a*) thermal logging; (*b*) mercury "maximum" thermometer during the drill stem test; (*c*) temperature measurement of the water pumped up from the deep aquifer to the surface. Thermal logging was performed under equilibrium state of a well, which had been reached by keeping the well in undisturbed state for about a dozen of days before temperature logging. This minimises the error in the temperature estimation. For example, in the wells Vydmantai-1 and Vydmantai-2 in West Lithuania the temperatures of the Cambrian aquifer were measured 18 days and 3 years after drilling had been stopped. The differences between the measurements are less than 2 °C (Rasteniene, Šliaupa, 2000).

Thermal conductivity data on 274 samples through the basin with different lithology were collected within the frames of the CAMBALTICA project (Jõeleht et al., 2002).

THERMAL CHARACTERISTICS OF THE CAMBRIAN RESERVOIR

The thermal conditions of the Cambrian reservoir show significant differences across the basin as a result of considerable changes in burial depth and heat flow intensity. The geothermal gradient of the sedimentary cover increases from 1.3–1.7 °C/100 m in the east to 4.5 °C/100 m in the west (Kepezinskas et al., 1996; Šliaupa, 2002). This can be attributed to several factors such as hydrodynamic cooling, deep heat flow, lithological variations, and locally to advective heat transfer along the major faults (Šliaupa, 1994). In hydrogeological terms, the eastern and southern parts of Lithuania represent a recharge area with a higher elevation and tilting of the sedimentary strata to the west and southwest and with a highly permeable sedimentary succession as a result of persistent shallow-water sedimentary environments in the peripheral position in the Baltic Basin during the Phanerozoic. This leads to cooling of the Cambrian reservoir in the shallow margins of the basin.

The thermal conductivity of the Cambrian sandstones of Lithuania varies from 1.76 to 6.7 W/mK (Kepezinskas et al., 1996). The highest values are recorded in the most intensely quartz-cemented sandstones in West Lithuania (Jõeleht et al., 2002), which are pure quartzarenites with only a 4–5% porosity (Brigaud, Vasseur, 1989). Accordingly, the geothermal gradient changes significantly in the Cambrian succession. The highest gradient is confined to the shales that dominate the Lower Cambrian and Kybartai Group in West Lithuania. The average values of shales range in the order of 3–5 °C/100 m (Fig. 2). The overlying Deimena RSt sandstones are characterised by a drastically reduced gradient which points to a very high thermal conductivity. The thermal conductivity of Deimena Group sandstones in West Lithuania is 5.1–6.7 W/mK. Consequently, the gradient should be in the range 0.7–1.5 °C/100 m for a heat flow of 55–90 mW/m^2, which is in agreement with the calculated gradients in wells of West Lithuania. The gradient is very sensitive to the porosity variations of sandstones (Fig. 3), as it strongly influences the thermal conductivity of rocks (Fig. 2). For all lithologies and in particular for the sandstones, the thermal conductivity shows a statistically significant linear correlation with porosity, which can be described by a first-order equation:

$$k = -0.14 * \omega + 6.1 \quad (1)$$

where k is the thermal conductivity (W/mK) and ω is the porosity (%).

The correlation coefficient is very high for sandstones (+0.76) but lower for siltstones and shales

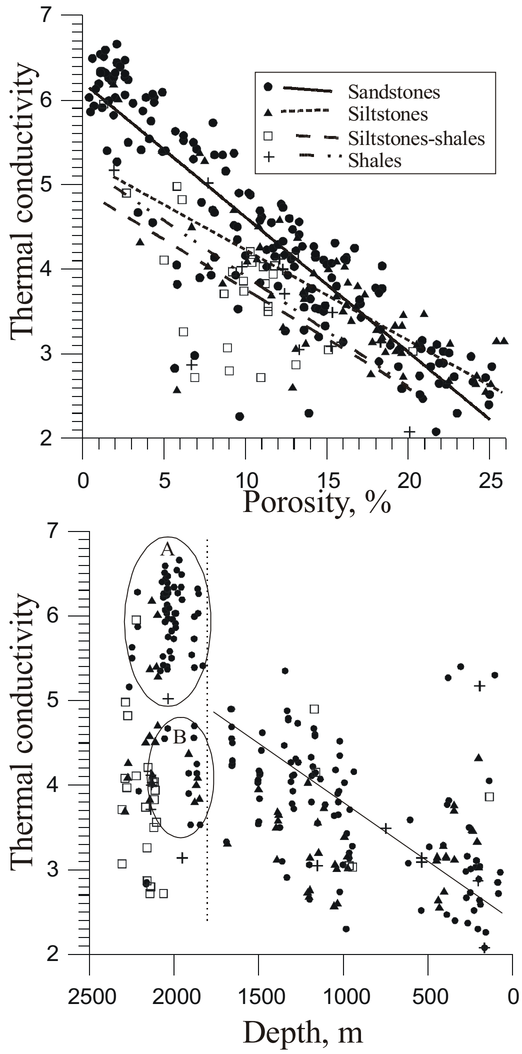

Fig. 2. Correlation of thermal conductivity of Cambrian sediments of the Baltic basin with porosity and depth. Two populations (*A* and *B*) of sandstones are distinct in the high-temperature range

2 pav. Baltijos baseino kambro uolienų terminio laidumo koreliacija su poringumu ir gyliu. Aukštų temperatūrų intervale aiškios dvi grupės (*A* ir *B*)

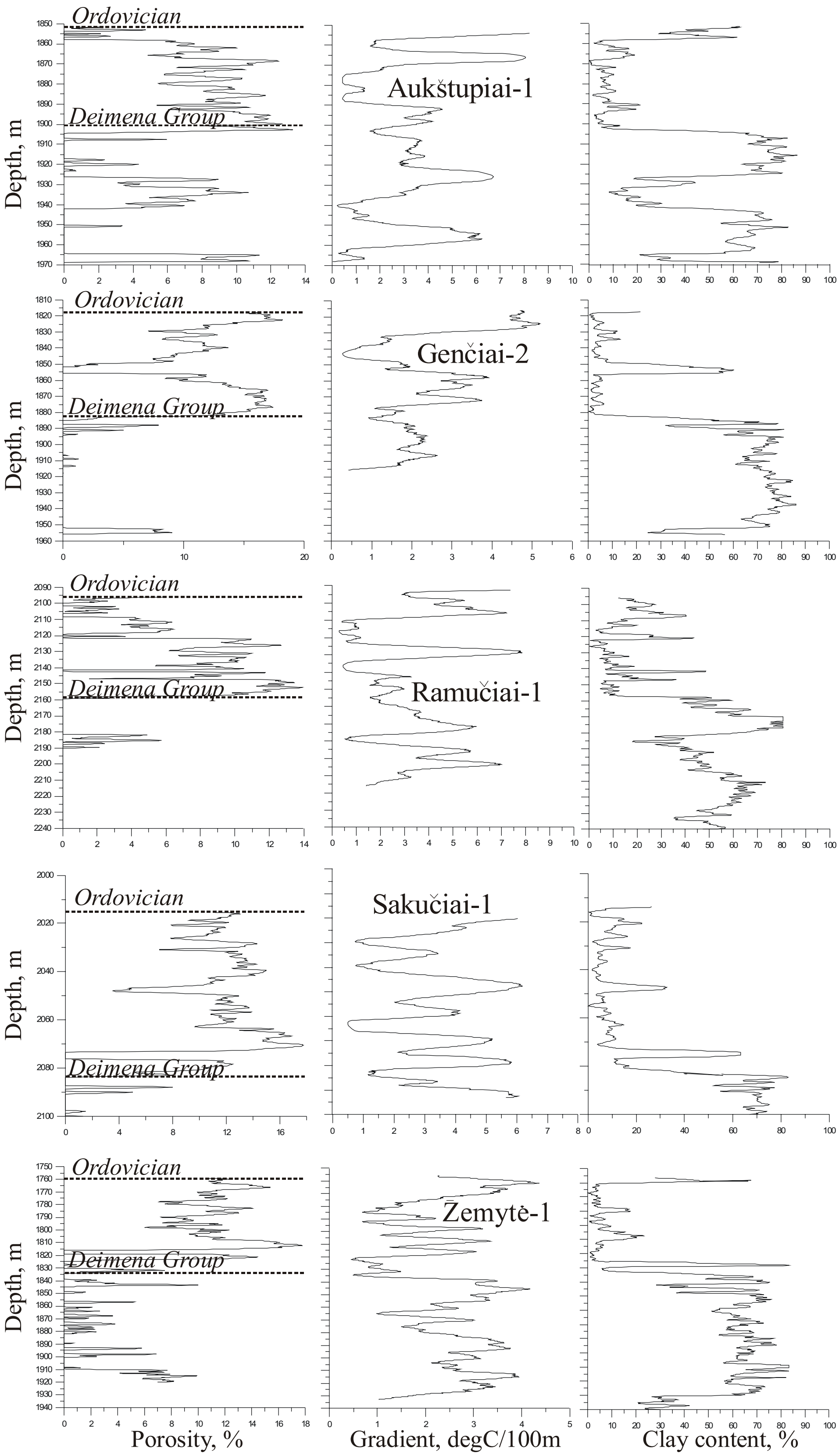

Fig. 3. Porosity (left), geothermal gradient (centre) and clay contents (right) calculated from logging data of representative wells of West Lithuania (Aukštupiai-1, Genčiai-2, Ramučiai-1, Sakučiai-1, Žemytė-1)

3 pav. Kambro uolienų poringumas (kairėje), geoterminis gradientas (viduryje) ir molio kiekis (dešinėje) diagrafijos duomenimis (Aukštupiai-1, Genčiai-2, Ramučiai-1, Sakučiai-1, Žemytė1)

(+0.59 and +0.56, respectively) and for intercalated siltstones and shales (+0.34). The thermal conductivity is only 2.2 W/mK in sandstones with a porosity of about 25%, while it averages to 6.3 W/mK in sandstones with a 1–3% effective porosity. The trend in siltstones is very close to that of sandstones. The difference in thermal conductivity between siltstones/shales and sandstones increases with decreasing porosity from around 0.4 W/mK for porosities of 20–25% to 1.2 W/mK in the low porosity range (Fig. 2).

In the eastern half of the Baltic basin, at a depth less than 1.8 km, the thermal conductivity of Cambrian rocks correlates well (Fig. 2), increasing to the west. This can be explained by the depth–porosity correlation. The linear correlation is disturbed at a depth greater than ~1.8 km. The thermal conductivity of sandstones drastically increases from around 4.8 W/mK to an average of 6 W/mK. It is evidently a result of a sharp decrease in porosity. The second group of sandstones is recognised within the deep part of the basin showing a much lower thermal conductivity (about 4 W/mK). A petrographic study indicates that the former group is related to strongly quartz-cemented clean sandstones, whereas the latter relates to sandstones with increased porosity (*e.g.*, Grobina well, West Latvia) outside the West Lithuanian geothermal anomaly. Also, it includes some sandstones from within this geothermal anomaly: following the petrographic studies, the high reservoir quality of the latter sandstones is related mainly to the second porosity (*e.g.*, Aukštupiai well).

Heat flow (HF) is the main factor controlling variations of the geothermal gradient of Lithuania. It systematically increases from east to west. In East Lithuania, HF is 32–43 mW/m^2 and in Central Lithuania 47–59 mW/m^2. A geothermal anomaly occurs in West Lithuania, with HF ranging from 65 to 95 mW/m^2. The differences in HF are attributed to a different heat generation of the crustal lithologies and to an increased mantle activity in West Lithuania (Šliaupa, Rasteniene, 2000).

The temperature of the Cambrian aquifer increases westward with depth. In East Lithuania, the temperature of the Cambrian is only 7–10 °C (Fig. 4). It sharply increases from 20 °C to 40 °C in Central Lithuania within a zone 50–80 km wide, which is roughly confined to the first-order suture zone of the crystalline basement separating the West Lithuanian Granulites and the East Lithuanian Belt. In West Lithuania, the temperature of the Cambrian aquifer reaches 65–96 °C. The eastern limit of the anomaly is rather sharp; the temperature increases from 50 °C to 70 °C within a zone 10–20 km wide. The highest temperatures of the Cambrian are reported from the southern part of West Lithuania, it is related also to the maximum intensity of the heat flow. The main oil fields of West Lithuania are located within the area where the temperature of the Cambrian is >65 °C. The low quality of the Cambrian reservoir is due to an intense quartz cementation.

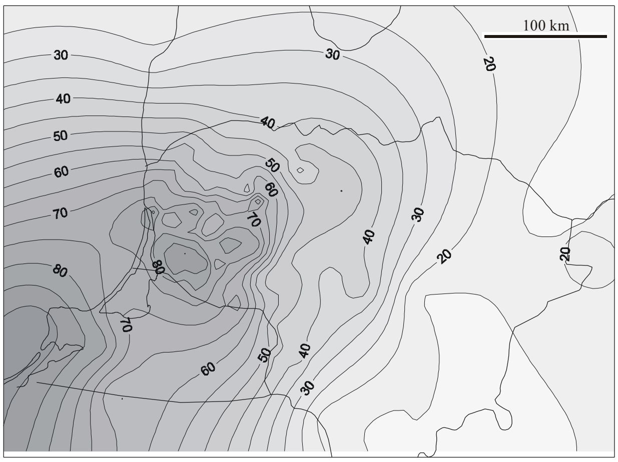

Fig. 4. Temperatures (°C) of top of the Cambrian of Lithuania and adjacent territories.
4 pav. Kambro kolektoriaus temperatūra Lietuvoje ir gretimose teritorijose

The chemistry of the Cambrian formation water closely correlates with temperature changes (Šliaupa et al., 2001, 2003). Its salinity systematically increases to the west. In the eastern part of Lithuania, the salinity ranges from 0.3 g/l to 10 g/l and sharply increases from 10 g/l to 100 g/l within a zone 40–50 km wide in Central Lithuania, marking the collision zone of the meteoric water flow from the east and the thermobaric-compactional water flow from the west (Puronas, Šliaupa, 2001). The most drastic change in the Cambrian water composition occurs at a depth of 600–700 m. The second sharp increase in salinity marks the limits of the West Lithuanian geothermal anomaly; the salinity increases from 120–130 g/l to 180–200 g/l. This points to a close relationship of the water composition with the temperature-controlled fluid–rock interaction. The pH decreases from the east to the west. It is as high as 6–7.5 in East Lithuania and 6–4 in West Lithuania.

RESERVOIR PROPERTIES

The thickness of the Cambrian sandstone reservoir is 50–70 m. In the east it comprises 15–30 m in the Lower Cambrian, while in West Lithuania the reservoir takes 30–40 m in the Middle Cambrian Deimena Group. The effective thickness shows a considerable variation in the west, which is largely accounted for by drastic changes in the content of quartz cement, increasingly important in the west. The minimum thickness (10–20 m) in the Cambrian reservoir occurs in the central and southern parts of West Lithuania; this coincides with the maximum heat flow intensity.

The porosity of Cambrian sandstones varies within 20–25% in the shallow eastern part of the basin. The permeability of sandstones ranges in the order of 100–2300 mD. A reduction from 20 to 15% is documented in Central Lithuania, while it is only 3–18% (permeability ranges from <0.01 to 20 mD, in some places 300–500 mD) in West Lithuania.

Distinct porosity variations (from 3% to 15%) are common in the Deimena Group in West Lithuania, even within the same well or oilfield, indicating that other parameters than temperature are also important in quartz cementation, the major one being variations in depositional lithology. It is well recognized that intervals containing thin shale laminas in sandstones are more intensely quartz-cemented than thick sandstone bodies without shale intercalations. All three parts of the Deimena Group show similar trends in a plan view, *e.g.*, minimum

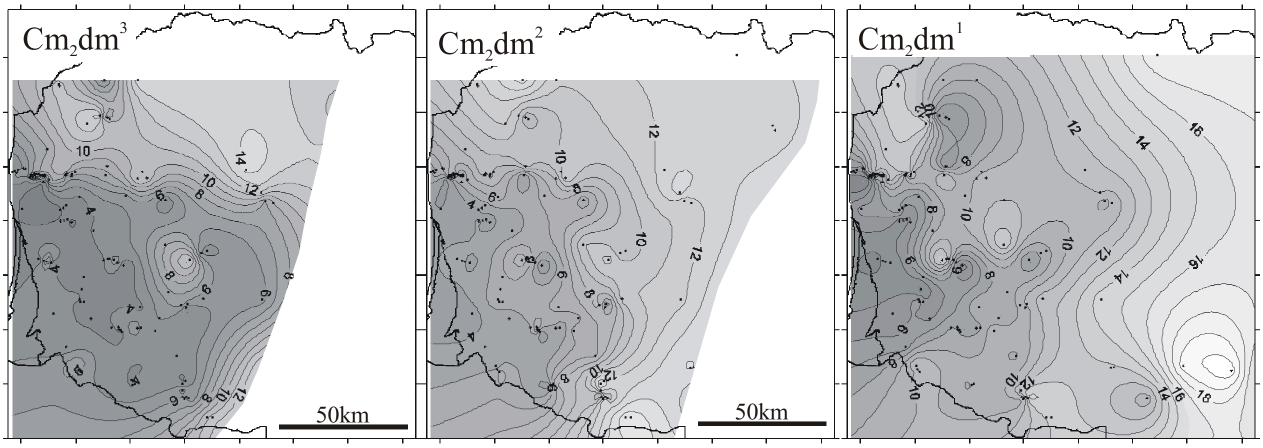

Fig. 5. Average porosities of the upper, middle and lower parts of the Deimena Group of West Lithuania (left, centre and right respetively)

5 pav. Deimenos regioninio aukšto viršutinės, vidurinės ir apatinės dalies poringumo žemėlapiai (atitinkamai kairėje, centre ir dešinėje)

porosities in the southwest of West Lithuania, whereas increasing to the east and north (Fig. 5). This correlates well with the temperature distribution. The main difference is the absolute values of the porosity, such as predominant maximum values in the lower part of the Deimena Group, with the commonly minimum values in the upper part of the reservoir.

QUARTZ CEMENTATION AND TEMPERATURE

The porosity of the Cambrian sandstones shows a clear basin-scale trend of attenuation from the east to the west, which correlates with the temperature increase to the west. Following the petrographic studies, quartz cement is documented at temperatures higher than 40 °C. Small amounts of quartz overgrowths are reported also from the shallow eastern periphery of the basin, but they have no major impact on reservoir properties. The most distinct reduction of the porosity and permeability, however, is recorded at temperatures higher than 60–70 °C (Fig. 6).

The porosity variations are mainly related to the uneven quartz cementation of sandstones of the Dei-

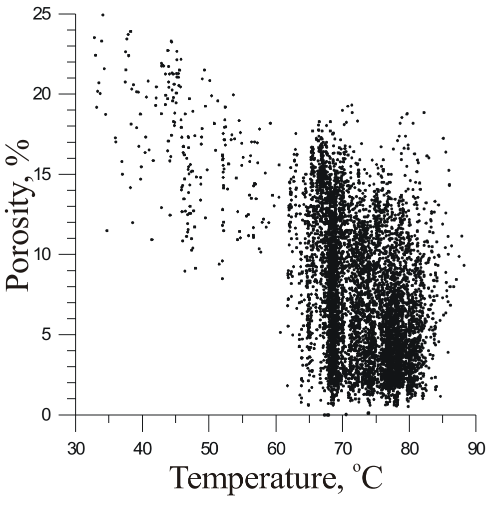

Fig. 6. Temperature *vs*. porosity of Cambrian sandstones of Lithuania

6 pav. Lietuvos kambro smiltainių poringumo priklausomybės nuo temperatūros grafikas

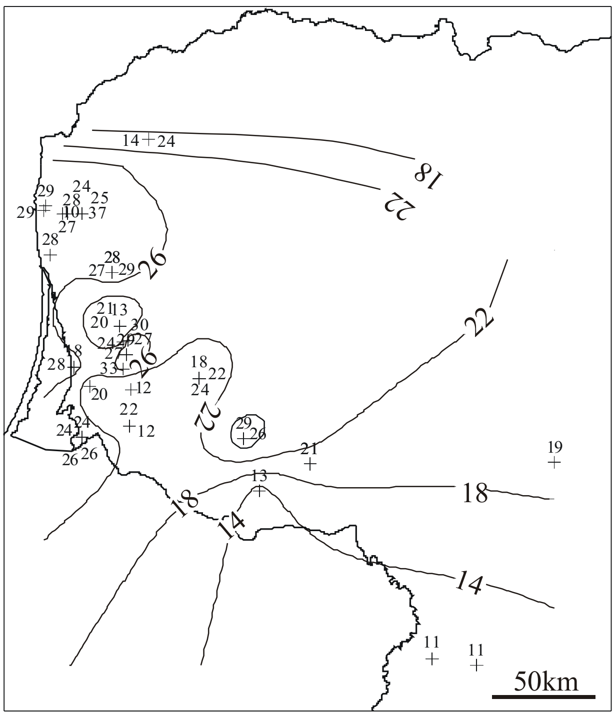

Fig. 7. Content of quartz cement in Middle Cambrian sandstones of Central and West Lithuania

7 pav. Kvarco kiekis kambro smiltainiuose Centrinėje ir Vakarų Lietuvoje

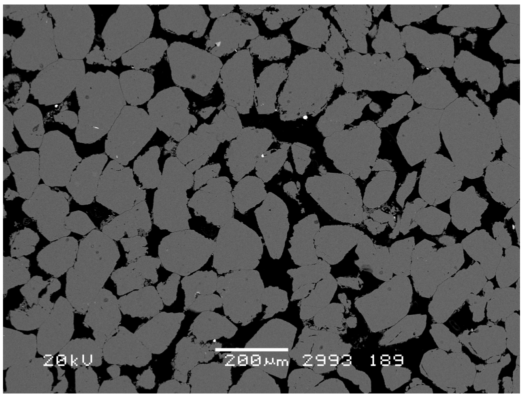

Fig. 8. BSE image of Middle Cambrian sandstone of Vilkaviškis-127 well (Central Lithuania), depth 1240.5, temperature 42 °C. Porosity 23%, content of authigenic quartz 11%

8 pav. BSE šlifo nuotraukos. Vidurinio kambro smiltainis, Vilkaviškio-127 gręžinys (Centrinė Lietuva); gylis 1240,5 m, temperatūra 42°C, poringumas 23%, antrinio kvarco kiekis 11%

mena Group. In Central Lithuania, the content of quartz cement in the Deimena sandstones is about 10% (Figs. 7, 8). The higher amount of cement in the Geluva-99 well is probably related to a palaeothermal event that was recognized from anomalous thermal maturity of organic matter of the Lower Palaeozoic shales (Lazauskiene, Marshall, 2002). In the west of Lithuania, the content of authigenic quartz increases to 24–28% (Fig. 9), in some places reaching even 30–33% (Kretina, Pociai areas) (Fig. 10). In the south of West Lithuania its content decreases to 12–22%, though opposite is expected in view of maximum temperatures recorded in this area. The hampering by the clay is not a satisfactory explanation, for the minimum quartz cementation is confined to the lower half of the Deimena Group showing the lowest clay content. The petrographic studies indicate that it is largely related to

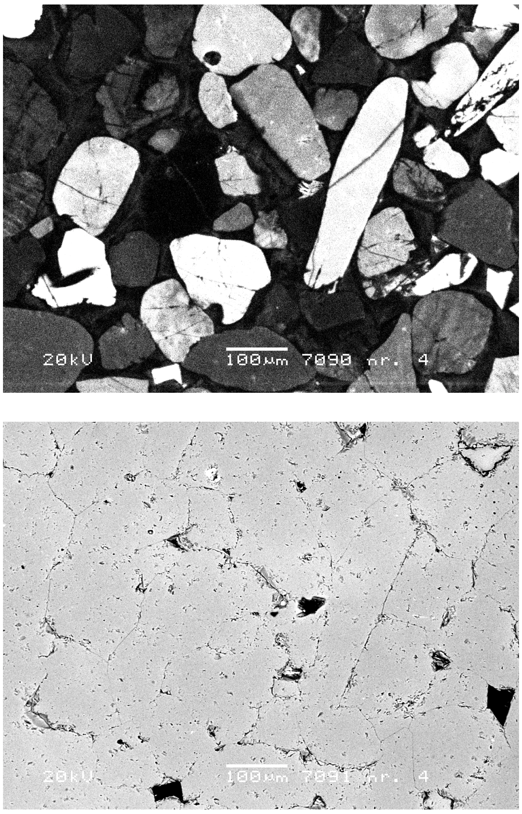

Fig. 9. SEM+CL and BSE images of Middle Cambrian sandstones of P. Šiupariai-5 well (central West Lithuania), depth 1990.5 m, temperature 84 °C. Moderately and well rounded quartz grains are cemented with authigenic quartz amounting to 28%, porosity 3%

9 pav. SEM+CL ir BSE šlifo nuotraukos. Vidurinio kambro smiltainis, P. Šiūparių-5 gręžinys (Vakarų Lietuva); gylis 1990,5 m, temperatūra 84°C, kvarco grūdus cementuojančio antrinio kvarco 28%, smiltainio poringumas 3%

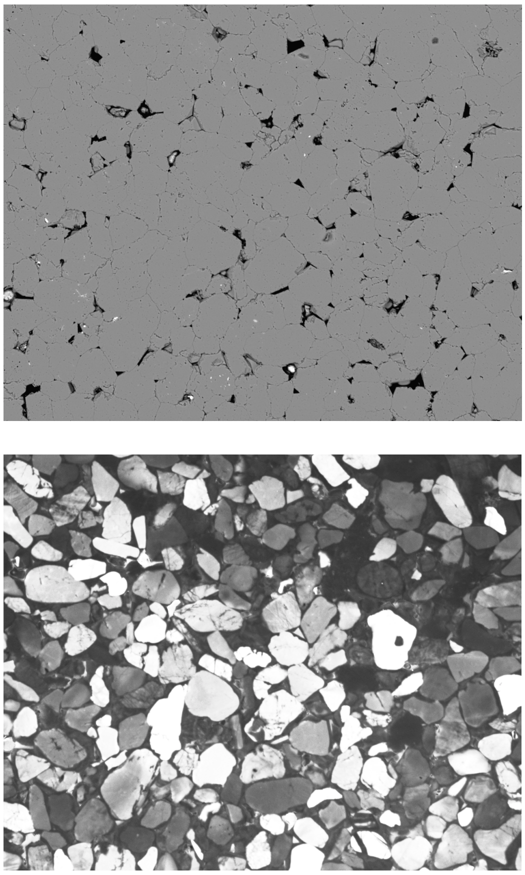

Fig. 10. BSE image of Middle Cambrian sandstone of Kretinga-2 well, depth 1883 m, temperature 70 °C. Authigenic quartz amounts to 33.6%, porosity is as low as 3.6%

10 pav. BSE ir CL šlifo nuotraukos. Vidurinio kambro smiltainis, P. Kretingos-8 gręžinys (Vakarų Lietuva); gylis 1883 m, temperatūra 70°C, kvarco grūdus cementuojančio antrinio kvarco 33,6%, smiltainio poringumas 3,6%

secondary porosity, *i.e*. dissolution of both the clastic grains and authigenic quartz cement. The secondary porosity and an associated low content of quartz cement are also reported from a few samples collected in the northern half of Lithuania (Genciai area, where quartz cement in some samples amounts only to 11%) (Fig. 11).

The correlation between the present temperature and quartz cement, ignoring anomalous values, can be roughly estimated (Fig. 12):

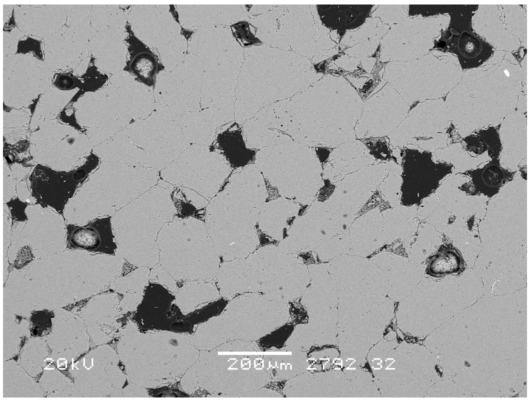

Fig. 11. BSE image of Middle Cambrian sandstone of Genčiai-2 well, depth 1857.6 m, temperatūre 71 °C. The reservoir quality is increased by secondary porosity, some detrital grains are completely dissolved
11 pav. BSE šlifo nuotrauka. Vidurinio kambro smiltainis, Genčių-2 gręžinys (Vakarų Lietuva); gylis 1857,6 m, temperatūra 71°C. Ištirpus detritiniams grūdams, kolektorines smiltainio savybes gerina antrinis poringumas

$$\text{Quartz cement } (\%) = 0.47^* \text{ T °C} - 8.8 \qquad (2)$$

The linear correlation between those two factors is complicated by other processes, as is seen from a distinct scatter of some values (Fig. 12). The decreased content of quartz cement in the high temperature range (70–90 °C) is mainly related to samples indicating secondary porosity higher than 2%. Furthermore, the lowest quartz cement values are typical of sandstones that have a 2–10% clay admixture, implying hampering of quartz cementation in sandstones containing clay. The former is advocated by petrographic studies. The clay partially influenced the packing of Cambrian sandstones, while the packing density (PD) does not show any any significant relationship with temperature (Fig. 13). The packing density, as defined by (Kahn, 1956), is the ratio of the sum of the grain length encountered along a traverse across a thin section to the total length of the traverse, and PD can be expressed as $PD = \Sigma g_i/t \times 100\%$, where g_i is the detrital grain intercept length of the ith grain in the traverse; t is

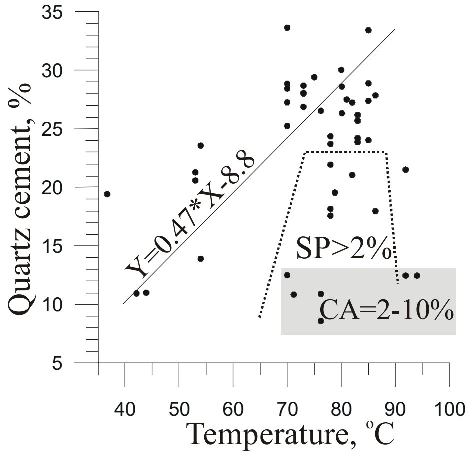

Fig. 12. Temperature *vs*. quartz cement of Middle Cambrian sandstones of Central and West Lithuania. Two fields show sandstone samples that have secondary porosity (SP) higher than 2% and clay content 2–10%
12 pav. Centrinės ir Vakarų Lietuvos vidurinio kambro smiltainių kvarco cemento kiekio priklausomybės nuo temperatūros grafikas. Du laukai apibrėžia smiltainių pavyzdžius, turinčius didesnį nei 2% antrinį poringumą ir molio priemaišą 2–10%

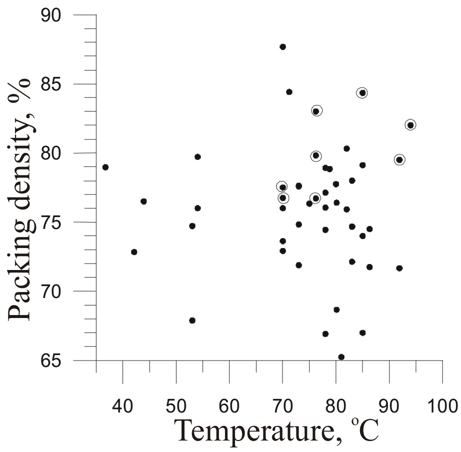

Fig. 13. Temperature *vs*. packing density of Middle Cambrian sandstones of Central and West Lithuania. Samples that contain more than 1% of clay are marked (coated)
13 pav. Centrinės ir Vakarų Lietuvos vidurinio kambro smiltainių sutankinimo indekso priklausomybės nuo temperatūros grafikas

the total length of the traverse; in other words, PD indicates how closely detrital grains are spaced in a sandstone. Both in Central and West Lithuania of PD of sandstones is in the range of 70–80%, sometimes lower. Samples containing more than 1% of clay show a typical PD > 76.

The porosity measured in thin sections of the sandstones showed a similar temperature-dependent trend estimated by petrophysical measurements. The porosity showed a reverse correlation with temperature (Fig. 14).

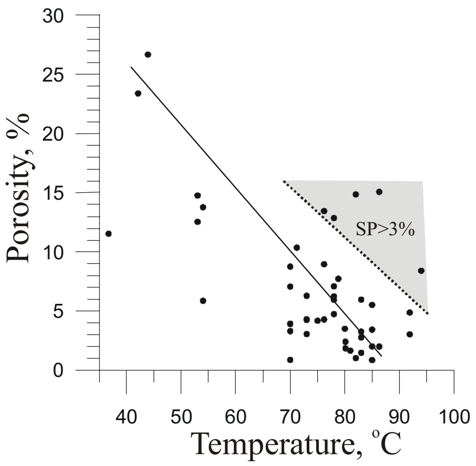

Fig. 14. Temperatūre *vs*. porosity of Middle Cambrian sandstones of Central and West Lithuania measured from petrographic studies of sanstone samples. A field of sandstones with secondary porosity higher than 3% is distinguished

14 pav. Centrinės ir Vakarų Lietuvos vidurinio kambro smiltainių poringumo, matuoto šlifuose, priklausomybės nuo temperatūros grafikas. Išskirta smiltainių grupė, kuriuose antrinis poringumas viršija 2%

DISCUSSION AND CONCLUSIONS

A clear correlation between quartz cementation and temperature has been found in the Baltic basin. On average, a temperature increase of 10 °C leads to a 1.5% reduction in porosity through an increase in the amount of quartz cement in Cambrian sandstones. Authigtenic quartz occurs at temperatures higher than 40 °C, but the main increase in the quartz cementation rate is recorded at temperatures higher than 60–70 °C. The content of quartz cement is around 10% in Central Lithuania, reaching 23–33% in West Lithuania.

Nevertheless, considerable variations are observed in quartz cementation within the same temperature range, indicating other factors involved. The sinsedimentary features, such as clay content and its distribution in the formation, largely account for that. It is notable that the most drastic differences in porosity are recognised in the temperature range 80–90 °C, *i.e*. in the central part of the West Lithuanian geothermal anomaly. As shown by petrographic studies, this is a result of the secondary porosity on the one hand and of the most severe quartz cementation of sandstones on the other. The amount of authigenic quartz is 22–26% in West Lithuania. Sandy bodies showing an anomalous increase in reservoir properties contain only 12–18% of authigenic quartz due to quartz dissolution and removal from sandy bodies. Secondary porosity is most common in the south of West Lithuania, indicating the maximum temperatures and thus showing a clear temperature-depended trend, though of a reverse kind than the basin-scale tendencies.

The lithology of the Cambrian deposits somewhat influences the geothermal field by controlling the geothermal gradient. The gradient is sensitive to the porosity variations of sandstones as porosity strongly influences thermal conductivity. In particular for sandstones, thermal conductivity is negatively correlated to porosity, a relation that can be described by a first-order correlation equation $k = -0.14*\omega + 6.1$ (k is the thermal conductivity, ω is the porosity). The correlation coefficient is the highest for sandstones (+0.76), whereas lower for siltstones and shales (+0.59 and +0.56, respectively) and essentially lower for intercalating siltstones and shales (+0.34). The thermal conductivity is only 2.2 W/mK in sandstones having a ~25% porosity, while averaging to 6.3 W/mK in sandstones having a 1–3% effective porosity. The trend of siltstones is very close to that of sandstones though having a less steep correlation angle as compared to shales. The difference between siltstones/shales and sandstones increases with the porosity decreasing from around 0.4 W/mK for 20–25% porosities to 1.2 W/mK in the low porosity range.

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TERMINIO REŽIMO POVEIKIS KAMBRO SMILTAINIŲ KVARCO CEMENTACIJAI LIETUVOJE

S a n t r a u k a

Kvarco cementas yra vienas pagrindinių veiksnių, lemiančių kambro smiltainių kolektorines savybes Centrinėje ir Vakarų Lietuvoje. Kylant temperatūrai, didėja kvarco cemento kiekis. Ši priklausomybė yra tiesinės formos: vidutiniškai 10°C temperatūros padidėjimas koreliuojamas su 1,5% poringumo sumažėjimu. Tačiau ši koreliacija skirtingoms Deimenos grupės svitoms yra vidutiniškai pasislinkusi 2–4%. Apatinė, Pajūrio, svita pasižymi didesniu poringumu, lyginant su Ablingos ir ypač Girulių svitomis. Tai rodo, kad ne tik temperatūra yra lemiamas kvarco cementacijos veiksnys. Formuojant prognozinį kolektorinių savybių modelį reikia patyrinėti ir kitas priežastis. Skirtumą tarp svitų daugiausia lemia skirtingas molingumas ir smiltainių grūdėtumas.

Petrografiniai tyrimai rodo, kad antrinio kvarco Centrinėje Lietuvoje yra apie 10%, vietomis šis kiekis padidėja iki 19%, ir tai siejama su paleogeoterminėmis anomalijomis. Vakarų Lietuvoje antrinio kvarco kiekis išauga iki 22–26%, kartais viršija 30%. Tačiau vietomis autigeninio kvarco cemento sumažėja iki 12–22%. Tai ypač būdinga Pietvakarių Lietuvai. Šis antrinio kvarco sumažėjimas ir atitinkamai poringumo padidėjimas susijęs su detritinio ir autigeninio kvarco antriniu tirpinimu, kuris buvo maksimalus didžiausių temperatūrų srityje.

Kambro uolienų termofizinės savybės veikia geoterminį lauką, daugiausia sukeldamos geoterminio gradiento variacijas pjūvyje. Šios variacijos susijusios su šilumos laidumo koeficiento kaita, o pastarasis ypač glaudžiai susijęs su poringumo pokyčiais.

Саулюс Шляупа, Йоланта Чижене, Николаас Моленаар

ВЛИЯНИЕ ТЕРМАЛЬНОГО РЕЖИМА НА КВАРЦЕВУЮ ЦЕМЕНТАЦИЮ КЕМБРИЙСКИХ ПЕСЧАНИКОВ ЛИТВЫ

Р е з ю м е

Кварцевый цемент является основным фактором, определяющим коллекторские свойства кембрийских песчаников Центральной и Западной Литвы. Его количество коррелирует с температурой коллектора. Автигенный кварц появляется в песчаниках при температуре >40°C. Основное же окварцевание связано с температурой >60–70°C. Так, в зоне средних температур количество кварцевого цемента является около 10%, тогда как в Западной Литве его количество в песчаниках резко увеличивается до 25–33%. В зоне максимальных температур однако отмечается резкое уменьшение количества кварцевого цемента до 12–22% в некоторых частях коллектора. Это связано со вторичной пористостью. Кроме того, корреляцию температура–кварцевый цемент усложняют влияние гранулометрического состава песчаников и присутствие глинистого материала.