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Quartz cements in the Cambrian sandstones, Żarnowiec region, N Poland: a fluid inclusion study

Katarzyna JARMOŁOWICZ-SZULC

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Fluid inclusion studies were conducted in quartz cements of the Cambrian sandstones from two boreholes in the Żarnowiec region (northern Poland). The research based on the microscope observations of inclusions aiming at their petrography and fluorescence characteristics as well as it comprised the routine microthermometric runs. The cathodoluminescence studies resulted in determination of generations of quartz cementing the sandstones. Two types of fluid inclusions have been found — aqueous and hydrocarbon ones. They are connected with two generations of the quartz cements in the sandstones under discussion. The aqueous inclusions yield homogenisation temperatures of about 100°C and salinities of about 8% eq. NaCl. The hydrocarbon inclusions studied display three temperature groups ranging from 71 to 110°C. An attempt of interpretation of the entrapment conditions of coeval oil and aqueous inclusions was made resulting in p-T values. Due to the limited number of fluid inclusions in the cements the representativeness of the data is, however, rather poor.

Katarzyna Jarmołowicz-Szulc, Polish Geological Institute, Rakowiecka 4, 00-975 Warszawa, Poland *(received: 30.03.1998; accepted: 9.06.1998).*

Key words: Żarnowiec region, Cambrian sandstones, fluid inclusions, homogenisation, depression point, salinity, hydrocarbons.

INTRODUCTION

Fluid inclusions may be entrapped during formation of diagenetic cements in microspaces of the minerals. The term fluid is referred to the state of the filling at the moment of its entrapment, not to the present physical state (E. Roedder, 1984).

Fluid inclusions in the diagenetic minerals may be used to determine palaeotemperatures (E. Roedder, *op. cit*; R. H. Goldstein, T. J. Reynolds, 1994).

Temperature is a very important factor in a discussion on diagenetic sequence of the filling of the pore space in the sedimentary rocks as well as for maturity of the organic matter and hydrocarbon migration in the geological environment.

Determination of the palaeotemperatures aims at reconstruction of the palaeofluids and their migration in thesedimentary complexes (M. Pagel *et al.*, 1993; R. K. Mc Limans, 1987).

The following procedures are important for the proper interpretation of the fluid inclusion data, provided that the method may be generally applied to the rocks:

— detailed petrological description of the rocks — for the succession of the inclusions;

— detailed analysis of the burial history and tectonics of the area — to combine diagenesis with the history of the basin (P. Lattanzi, 1991);

— analysis of the phase equilibrium curves and chemical composition of the inclusions — to define PVT conditions of the entrapped fluids (O. Leeder *et al.*, 1987).

The aim of the present paper is to show results of the fluid inclusion studies conducted on the cements of the Cambrian rocks from the Żarnowiec region (N Poland).

The Middle Cambrian sandstones represent the most important reservoir rocks for oil and oil-condensate in the northern part of Poland (P. Karnkowski, 1993), being a fragment of a greater basin which extends further to the southern Baltic Sea.

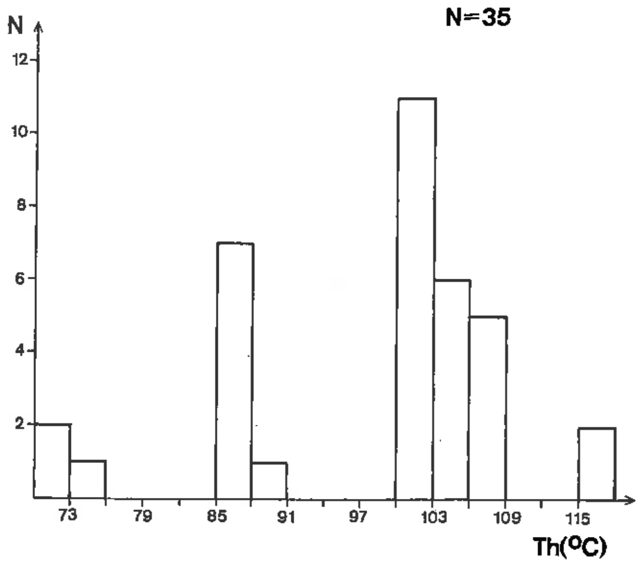

Fig. 1. Results of microthermometrical determinations. Żarnowiec IG 4 borehole, depth of 2739.8 m
N — frequency; Th — homogenization temperature

Wyniki oznaczeń mikrotermometrycznych. Otwór wiertniczy Żarnowiec IG 4, głęb. 2739,8 m
N — częstość; Th — temperatura homogenizacji

The origin of the accumulated hydrocarbons has been all the time under discussion. The source rocks are believed to be the Middle and Late Cambrian shales (*op cit.*) which in the Silurian reached the conditions of the oil window (M. Schleicher, 1994; M. Sikorska, J. Pacześna, 1997; M. Schleicher *et al.*, 1998).

The present studies comprised analyses of fluid inclusions in the reservoir material, measurements of the homogenisation temperatures of the fluid inclusions and evaluation of the possibilities of application of the method in the reservoir area which should further lead to a solution of the reciprocal problem of utilization of fluid inclusions in search for hydrocarbons.

PETROLOGICAL CHARACTERISTICS OF THE ROCKS

A detailed geological description of the Żarnowiec region has been already presented by different authors (e.g. L. Bojarski, 1973; P. Karnkowski, 1993).

The Cambrian sandstones in the Polish part of the East European Craton were in detail petrologically studied by M. Sikorska (1992, 1996). The Middle Cambrian sediments from the Żarnowiec boreholes, which are a part of the widespread area, display the same characteristic features.

In general they are nearly monomineral rocks, which mostly consist of quartz, both as detrital material and the cement. Other minerals are subordinate. The dominant quartz cement occurs as syntaxial overgrowths around the rounded detrital grains.

According to M. Sikorska (1996) two phases of the quartz cement may be distinguished due to the cathodoluminescence studies — the older cement with a brown luminescence and the younger nonluminescent one. The first phase is considered by the quoted author as the result of the early cementation, while the second is referred to the main silification processes during deep diagenesis.

The cements present in the Middle Cambrian quartz arenites in the Żarnowiec IG 1 and IG 4 boreholes were studied from the fluid inclusion point of view by K. Jarmołowicz-Szulc (1995, 1997).

EXPERIMENTAL PART

Fluid inclusions were studied by the present author in the drilling core samples from the reservoir depths in the Żarnowiec region (drillings of the Polish Geological Institute). The material was analysed at the point of view of presence of hydrocarbons (K. Jarmołowicz-Szulc, 1995, 1997).

The present research concerns the quartz cements in the rocks under discussion. The performed fluid inclusion studies may be divided into the following stages:

— a preliminary stage — sampling and preparation;

— an introductory stage — microscope evaluation of the geological material in terms of fluid inclusions;

— main studies: analysis of fluorescence of inclusions and cathodoluminescence of the cements; petrological characteristics of inclusions; homogenisation and freezing temperature measurements;

— data computing and interpretation of the results.

The fluid inclusion studies were conducted microscopically on special double-polished wafers (C. E. Barker, T. J. Reynolds, 1984) by means of a modified USGS gas-flow stage (freezing-heating equipment — *Fluid Inc. System*) as well as *Nikon* fluorescence device. Microthermometric runs were performed in the temperature interval from –196 to 150°C with an accuracy of ±0.1°C.

RESULTS OF THE FLUID INCLUSION STUDIES

Fluid inclusions are not abundant in the diagenetic cements in the rocks under research. They are also rather small, rarely exceeding 5 µm in size.

In the light of a mercury lamp some inclusions display a distinct white-blue fluorescence. Such studies allow a recognition of colourless hydrocarbon inclusions from the similar aqueous (brine) ones trapped in the filling of the pore space (R. C. Burruss, 1992; K. Jarmołowicz-Szulc, 1997). In the Cambrian rocks from the drilling cores of the boreholes Żarnowiec IG 1 and IG 4, the studies on fluorescence were conducted dually — in ultraviolet (Pl. I, Fig. 3) and blue (Pl. I, Fig. 4) lights. The luminescence was mostly observed in the fissure filling. The luminescence colours revealed in the ultraviolet and blue radiation were white-blue and yellow, respectively.

On the basis of the studies conducted, the following associations of the inclusions may be distinguished (Pl. II): Q1 — at the boundary of detrital quartz and neogenic quartz rim; Q2 — within the regeneration quartz cement; Q3 — in the fissures healed with quartz. The inclusions are generally very small. They have a size of 1–3 μm in Q1, less than 1 μm in Q2 and 2–5 μm, or rarely more, in Q3. They are in general two phase ones. Different groups of aqueous inclusions show an entirely close liquid to vapour ratio.

Inclusions which have a distinct white-blue fluorescence in the ultraviolet light and yellowish colours in the blue light occur mainly in Q3 association and are there distinct both due to their fluorescence and size (Pl. III). They are not so evident in other positions. The fluorescing inclusions are hydrocarbon (oil) ones. They are colourless in the plain light and display irregular shapes. They are two phase ones with an entirely consistent liquid to vapour ratio.

It can be stated from the fluorescence studies conducted in the present paper that oil inclusions occur in some samples of the borehole Żarnowiec IG 4 (depth interval of 2739.8–2783.4 m) and only sporadically in the samples of the borehole Żarnowiec IG 1. They will be, therefore, discussed in such an order.

Hydrocarbon inclusions are most abundant in the samples taken uppermost in the profile. Their occurrence comprises generally both the interval of sandstones saturated with oil and the rocks underlying and covering this horizon. Deeper in the geological column oil inclusions were not observed.

Significantly primary hydrocarbon inclusions are present within the quartz rims around the detrital grains. They are, however, rare and difficult to find. Homogenisation of these inclusions has occurred in the temperature interval of 90–105°C with a distinct maximum slightly over 100°C (Żarnowiec IG 4). Data are presented in Figure 1, their statistics being, however, rather poor due to a low number of the suitable inclusions found.

Homogenisation temperatures of oil inclusions at the boundary of the regeneration rim and the detrital quartz in the borehole Żarnowiec IG 1 are close to these above and are equal to about 105°C. The inclusions homogenised in liquid phase (K. Jarmołowicz-Szulc, 1995).

The generation Q2 comprises so small inclusions that the temperature measurements were impossible. Still in the generation Q3 — within the quartz that healed the microfissures — both temperatures of oil and brine inclusions were measured. The two-phase inclusions homogenised in liquid at temperatures of 87–90 and 107°C, respectively. The measurement of the depression point for brine inclusions was difficult due to their small size, still some results obtained fall into the interval from –14 to –10°C, which corresponds to the salinity of about 8% eq. NaCl.

The calculation of the temperature data was done using the FLINCOR programme (P. E. Brown, 1989). On the basis of the computed data and phase diagramme for light oils (R. C. Burrus, 1992; R. H. Goldstein, T. J. Reynolds, 1994) an attempt the determination of the isochores of both the inclusion types was undertaken (Fig. 2). An assumption has been made that the joint occurrence of oil and brine (aqueous) inclusions means their coeval trapping as the immiscible fluids in the quartz cement.

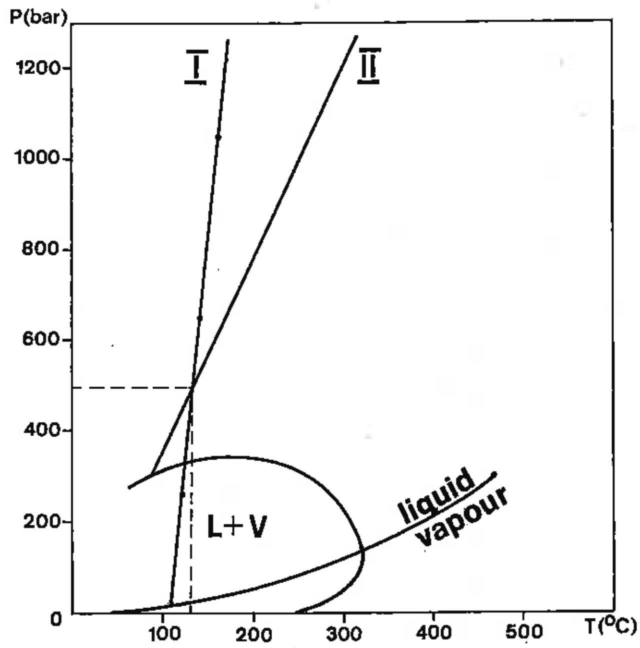

Fig. 2. Isochore interpretation of oil (II) and brine (I) inclusions; borehole Żarnowiec IG 1

I — isochore based on the present paper data; II — isochore adapted from R. H. Goldstein and T. J. Reynolds (1994)

Izochorowa interpretacja inkluzji ropy (II) i solanki (I); otwór wiertniczy Żarnowiec IG 1

I — izochora obliczona na podstawie danych z niniejszej pracy; II — izochora zaczerpnięta z pracy R. H. Goldsteina i T. J. Reynoldsa (1994)

The isochores under discussion cross at the point that indicates temperature and pressure, which may be interpreted as the estimation of the entrapment conditions of these fluids in the quartz cement. This is the first attempt of such an estimation in the Żarnowiec region. The recent paper of M. Schleicher *et al.* (1998), presenting a reservoir characteristics, has totally omitted the fluid inclusion problem.

Within the quartz cements of the Żarnowiec boreholes there exist inclusion groups which have distinctly late position in terms of the cementation. These are the "real clouds" of oil inclusions in the quartz that seems to heal microfissures. Their homogenisation occurs approximately at 100°C, although there exist also some inclusions in which one phase disappears at a distinctly higher temperature (e.g. 116 or 118°C).

In the material studied there exist also linear associations which display lower homogenisation temperatures (Żarnowiec IG 4). These fall into the intervals of 74–79 and 84–86°C.

The temperature results obtained in the quartz cements from the Middle Cambrian quartz arenites are very consistent both for the inclusions of distinct regeneration rims over the detrital grains and the inclusions in the quartz zones.

DISCUSSION OF THE RESULTS AND CONCLUSIONS

Fluid inclusions were studied in the reservoir area of the Middle Cambrian rocks in the Żarnowiec region. Two types of the inclusions were found: the aqueous and hydrocarbon ones. Hydrocarbon inclusions are present in the top parts of the Middle Cambrian stratigraphical column. The deeper in the profile, the lower number of the fluorescing inclusions. This fact suggests hydrocarbon migration from the top towards the bottom.

It can be stated from the fluorescence studies that the maturity of oil in the inclusions may be concerned as about 40–45° API.

Homogenisation temperatures of inclusions differentiate in the cements of the Żarnowiec region due to the filling phase and boreholes. The general tendency of temperature intervals of 71–76, 85–91 and 100–110°C may be observed, the data corresponding mainly to the latest cementation stage, i. e. the healing of the microfractures by quartz.

The aqueous inclusions yield the homogenisation temperatures of about 100°C and salinities of about 8% eq. NaCl. The earlier data on the homogenisation temperatures of the aqueous fluid inclusions in the second phase of the quartz cement in Cambrian sandstones from different boreholes in the East European Craton (K. Jarmołowicz-Szulc *fide* M. Sikorska, 1996) fall into the interval of 90–130°C. The present paper values lie within this interval, too.

M. Sikorska and J. Pacześna (1997) constructed the subsidence curves for the borehole Żarnowiec IG 1 and assumed that the maximum palaeogradient in the Polish part of the East European Craton was about 40°/km. All together — the subsidence data and fluid inclusion temperatures point to the timing of the second phase of cementation during Silurian at the depth of about 2 km.

Hydrocarbon inclusions are present in the quartz cements in the Żarnowiec region, occasionally together with the brine ones. Such an occurrence gives wide interpretation possibilities of the homogenisation temperatures assuming that the present occurrence means original coeval trapping of the immiscible fluids. To draw final conclusions for the widespread area, however, the temperature data should be more numerous than these obtained till present.

Still, partly on the basis of the present paper data and the literature ones, an attempt was done to find out trapping conditions.

Isochores for the aqueous inclusion from the second phase cement (Żarnowiec IG 1 — this paper) and light oil (adapted from R. C. Burruss, 1992; R. H. Goldstein, T. J. Reynolds, 1994) cross in one point in the p-T diagram which may be interpreted as the entrapment conditions. The coordinates are 135°C and 500 bars. These p-T values are high and must be confirmed by other pairs of inclusions. They suggest, however, deep crystallisation. M. Schleicher *et al.* (1998) point to much lower values for quartz cementation (58–78°C) on the basis of the other methods applied.

Fluid inclusions were rather small and rare in the described cements so the greater number of data than 35 shown in the present paper will be more significant. Also the thermodynamic equilibrium curve when constructed for the oil inclusions from the area under research may have different slope which may result in another effective value. The point in p-T diagram is a preliminary attempt of the possible future complex interpretation of fluid inclusion measurements from the Żarnowiec region together with the present Baltic offshore area. Such an interpretation seems to require, however, more reproducible and numerous data as well as, possibly, an introduction of an independent pressure correction to the temperature values when treating them individually.

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CEMENTY KWARCOWE W PIASKOWCACH KAMBRYJSKICH, REJON ŻARNOWCA, POLSKA PÓŁNOCNA: STUDIUM INKLUZJI FLUIDALNYCH

Streszczenie

W czasie tworzenia się cementów diagenetycznych w mikroprzestrzeniach minerałów powstają mikrowrostki — inkluzje fluidalne. Mogą one być użyte do określania paleotemperatur przy wprowadzeniu szeregu założeń.

Inkluzje fluidalne badano w cementach kwarcowych skał kambru środkowego w rejonie Żarnowca. Badania przeprowadzano mikroskopowo w specjalnych obustronnie polerowanych preparatach z użyciem aparatury wymrażająco-grzewczej *Fluid Inc.* i zestawu fluorescencyjnego *Nikon*.

Inkluzje fluidalne zaobserwowano w cemencie kwarcowym typu obwódek wokół ziarn detrytycznych oraz wtórnych zabliźnień kwarcem spękań i mikroszczelinek. Generalnie w piaskowcach z otworów Żarnowiec IG 1 i IG 4 istnieją dwa typy inkluzji (wodne i węglowodorowe). Genetycznie wiążą się one z dwoma rodzajami spoiwa kwarcowego piaskowców. Wrostki te są bardzo małe i nieliczne. Charakterystyczny dla nich jest brak zabarwienia w świetle przechodzącym. Inkluzje o wyraźnej biało-niebieskiej fluorescencji (uV) występują przede wszystkim w asocjacji Q3 i przeważają w otworze wiertniczym Żarnowiec IG 4, zwłaszcza w górnej partii opróbowanej.

Wykonano badania eksperymentalne homogenizacji inkluzji wodnych i węglowodorowych. Oba typy inkluzji dwufazowych homogenizowały w fazę ciekłą, a temperatury wyniosły odpowiednio 87–90 i 107°C. Pomiar zasolenia był utrudniony z racji małej wielkości inkluzji wodnych, ale uzyskane wyniki odpowiadają wartościom około 8% wag. NaCl. Temperatury homogenizacji dla inkluzji węglowodorów grupują się w trzech przedziałach wartości, ogólnie w obrębie 74–110°C.

Przeprowadzona została próba wspólnej interpretacji izochorycznej obu typów inkluzji fluidalnych. Izochory uzyskane na podstawie przeprowadzonych prac badawczych i założeń metodycznych przecinają się w punkcie o współrzędnych temperatury i ciśnienia, które interpretować można jako przybliżenie warunków uwięzienia tych fluidów w spoiwie kwarcowym. Jest to pierwsza próba przeprowadzenia tego typu interpretacji na obszarze Żarnowca i w obrębie basenu kambryjskiego, przy czym z racji niewielkiej liczebności współwystępujących inkluzji pożądane są dalsze badania w celu sprawdzenia wyników i polepszenia ich wiarygodności.

EXPLANATIONS OF PLATES

PLATE I

Fig. 3. Hydrocarbon inclusions displaying white-bluish fluorescence in ultraviolet light. Microphotograph of quartz arenite. Żarnowiec IG 4, depth of 2739.8 m. Scale bar 40 µm

Inkluzje węglowodorowe wykazujące biało-niebieskawą fluorescencję w ultrafiolecie. Mikrofotografia arenitu kwarcowego. Żarnowiec IG 4, głębokość 2739,8 m. Skala 40 µm

Fig. 4. Same hydrocarbon (oil) inclusions in blue light of the mercury lamp. Yellow fluorescence. Scale bar 40 µm

Te same inkluzje węglowodorowe (ropa) w świetle niebieskim lampy kwarcowej. Żółta fluorescencja. Skala 40 µm

PLATE II

Fig. 5. Fluid inclusions within the quartz cements. The generation Q1 at the boundary of the detrital quartz and regeneration rim. Żarnowiec IG 1, depth of 3045 m. Scale bar 40 µm

Inkluzje fluidalne w obrębie spoiwa kwarcowego. Generacja Q1 na granicy kwarcu detrytycznego i obwódki neogenicznej. Żarnowiec IG 1, głębokość 3045 m. Skala 40 µm

Fig. 6. Fluid inclusions within the quartz rim. The generation Q2 in the rim. Żarnowiec IG 4. Scale bar 40 µm

Inkluzje fluidalne w obrębie obwódki kwarcowej. Generacja Q2 w obrębie obwódki. Żarnowiec IG 4. Skala 40 µm

PLATE III

Fig. 7. Oil inclusions of the generation Q3 visible distinctly due to their white-bluish fluorescence (uV). Żarnowiec IG 4. Scale bar 20 µm

Inkluzje ropy generacji Q3 wyraźne dzięki biało-niebieskawej fluorescencji (uV). Żarnowiec IG 4. Skala 20 µm

Fig. 8. Colourless, two-phase oil inclusions of the generation Q3, observed in the plain light. Żarnowiec IG 4. Scale bar 20 µm

Inkluzje ropy generacji Q3 bezbarwne i dwufazowe w świetle przechodzącym. Żarnowiec IG 4. Skala 20 µm

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Fig. 3

Fig. 4

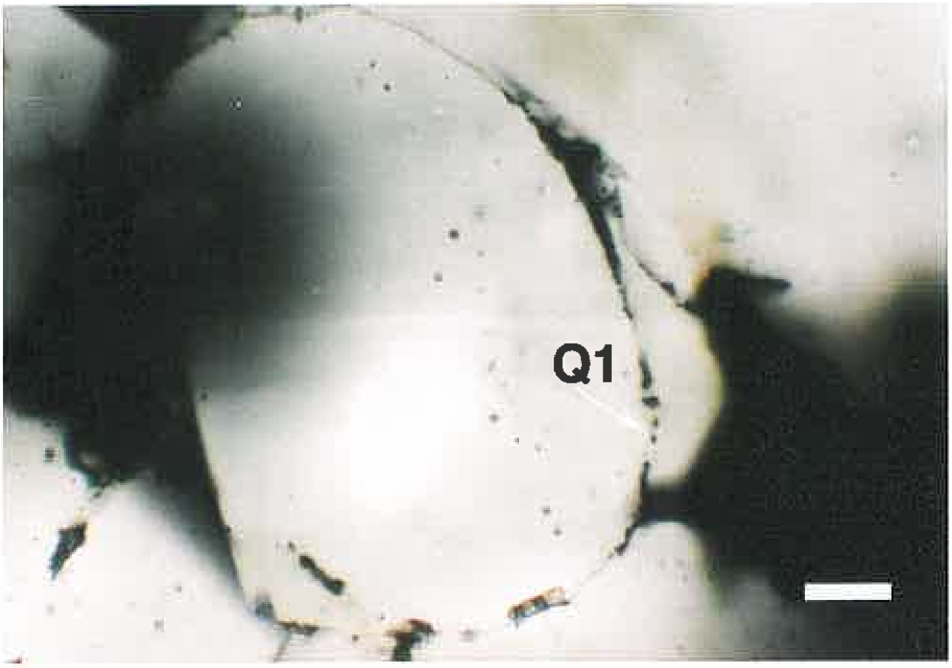

Fig. 5

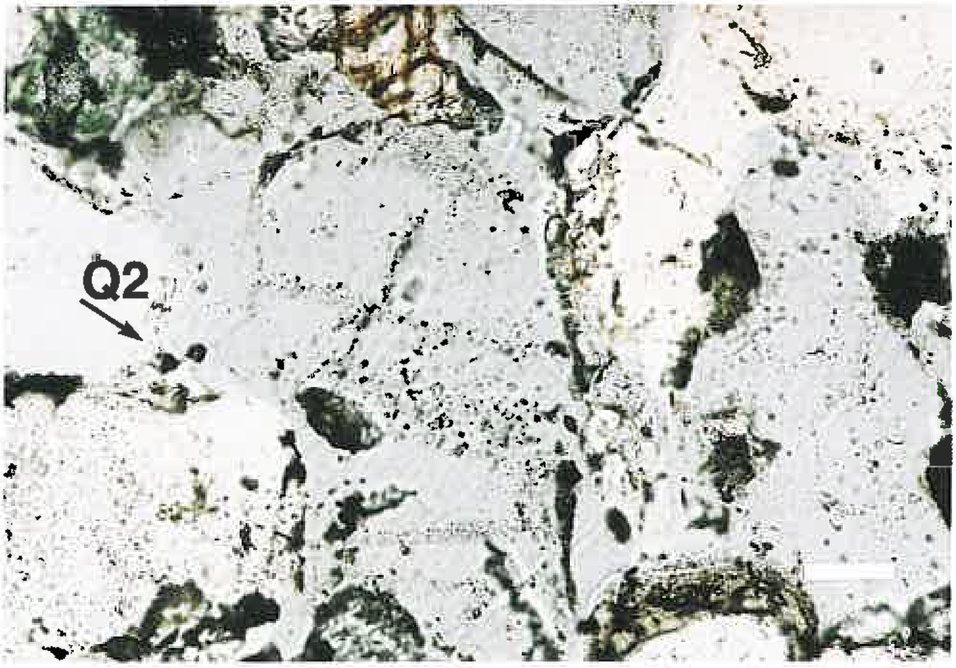

Fig. 6

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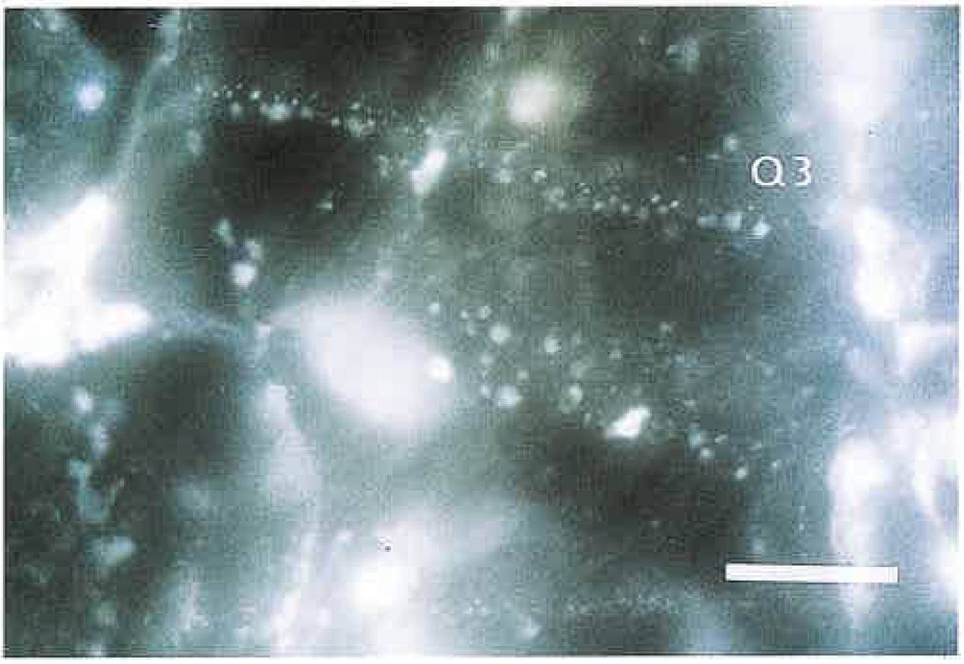

Fig. 7

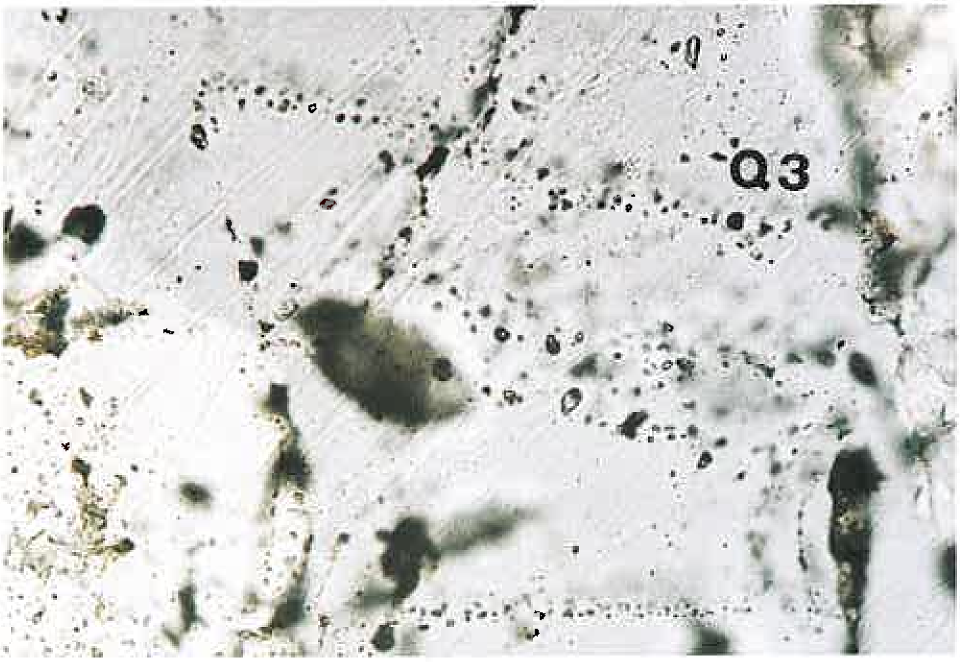

Fig. 8