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TEMPERATURE ENVIRONMENT OF OIL AND GAS

Notes on a Workshop

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Temperature Environment of Oil and Gas

AAPG Research Workshop, Santa Fe, New Mexico, 13-17 September, 1981

Notes on Proceedings

Monday 13 September

Introductory remarks by Paul Jones included the following statements or questions.

-why is there no petroleum above 300°F. (150°C) in the Gulf Coast Basin

-water is the principle agent of mass migration and heat transfer in a basin.

-occurrence of petroleum is associated with pressure and temperature anomalies.

-There were 27 presentations at the Workshop.

Paper 1 - Exploration applications of temperatures recorded on log headings: Theory, data analysis and examples, by Stan Ball of Amoco Houston.

-Started off with a review of temperature measuring devices and processes and came to the conclusion that the results were not very good. This conclusion and discussion occurred several times during the conference.

-Pointed out the association of temperature anomalies with oil and gas fields and suggested that this was due to the increased thermal resistance of oil in the pores of the rocks rather than water.

My comment - this is unlikely to be anywhere near sufficient to cause significant temperature anomalies.

-Developed some rather complex ways of drawing vectors on the temperature data to outline fields of the reservoirs, and these seemed to be in fair agreement with the reservoir boundaries but it took rather a lot of manoeuvering to get there. A copy of this paper was available.

Paper 2 - Subsurface Temperature Calculated by chemical geothermometers applied to formation waters from the northern Gulf of Mexico and California basins by Joseph Kharaka, U.S. Geological Survey.

This paper was concerned with geopressure zones, which were stated to be at a temperature of about 160°C and to contain energy in 3 forms. 1-thermal energy, 2-mechanical energy, due to the high pressure and 3-dissolved gas.

-Both temperature and pressure gradients increase as one enters the geopressure gradient, the pressure gradient increasing from a hydrostatic value of .465 psi/ foot (10.5 kPa/m) to a value approaching a lithostatic value of 1 psi/ foot.

-Different temperature gradients are attributed to one or more of 1) different heat flow 2) different rock type 3) degree of compaction of sediment and cementation of rocks 4) effects of water and other fluids 5) erroneous temperatures.

-Metamorphic facies geothermometers depend on water content during formation, for example zeolites can be formed at all temperatures depending on the chemical environment.

-chemical thermometers are of various types including mineral compositions, fluid inclusions, isotopes and vitrinite reflectance.

-carbon dioxide-methane ratio will give good temperatures if the gases have not moved, silica is good at temperatures of 70°C and higher. The silica system began as a tool in geothermal energy exploration but it is also good in sedimentary aquifers.

-the sodium potassium geothermometer does not work well.

-the sodium potassium calcium geothermometer is reasonable above 100°C.

-a computer program for geochemical analysis is available on request.

-scatter from geochemical thermometers results from the chemical environment of the reaction, different crystalinity of the same mineral, using concentration instead of activities, precipitation, and poor temperature date.

Paper 3 - Effect of temperature and pore pressure on velocity and attenuation of seismic waves in rocks: Applications to crustal exploration by Terry Jones, Stanford University.

-there is temperature information in a seismic signal but it is masked by an assortment of other things. This speaker went on at length about attenuation factors, Q-factors and the velocities of P and S waves related to temperature, pressure and pore saturation, but he made no attempt to explain how to use field data to determine temperature in real formations. One comment from the audience pointed that it is necessary to go through about 10,000 ft. of rock to see a measurable Q-effect and that any temperature derived from this would be integrated over that range. The speaker advocated borehole to borehole measurements giving average temperatures between holes as opposed to spot measurements implying that the average is preferrable to direct measurement of temperature.

Paper 4 - Estimation of heat flow in oil wells based on a relation between heat conductivity and sound velocity, by Joseph Houbolt, Shell Oil, The Netherlands.

This paper was based entirely on the assumption that thermal conductivity is exactly proportional to sonic velocity. From this he used Simmons' equation of relation of conductivity to temperature to develop an expression that gives heat flow in terms of temperature and travel time. He commented that this does not work in granites or salt domes but he implied that it worked in all other sorts of rocks, particularly sediments. A copy of a paper by Houboult and Wells was available.

Paper 5 - Calculation of Thermal Conductivity from lithology and measurements on oil well cores and cuttings by V. Vacquier of Scripps Institute of Oceanography.

This paper was really a repeat of the work in Sumatra on heat flow derived from oil well data using assumed conductivities for various rock types. Conductivity for shale, sandstone, limestone, silt and claystones that were collected from the literature and the values used were shale 4.31, sandstone 7.17, limestone 6.30 and silt and claystone 6.03, all in CGS units. He calculated the average conductivity for each basin and used these conductivities to calculate heat from temperature data, he also added sediment compaction as a modification of conductivity and derived a slight improvement in the scatter of heat flow.

Paper 6 - Geothermal heat flux determined from COST wells on the Atlantic Continental Margin by Dick Von Herzen.

COST wells are drilled as a cooperative venture between industry and U.S. government at places on the continental shelf that are of particular scientific interest; so far two wells have been drilled off Nantucket, one off New York and one off Georgia. Well B2 is about 14,000 ft. deep and penetrates almost to the top of the Jurassic. There could be as much as 24 km of sediments at that point on the shelf. From temperature logs the temperature gradient averages 24 mK/m. A few cores are available giving conductivities of 8 to 10 cgs units and a heat flow of 2.7 hfu (108 mW/m^2). These cores were predominantly sandstone, giving too high an average conductivity. The conductivity of drill cuttings was measured by means of a divided bar, and when conductivity values typical of the net rock distribution were used heat flow was reduced to 54 mW/m^2.

Paper 7 - Present thermal conditions in the Baltimore Canyon Basin in relation to extensional models, by D.S. Sawyer of the Massachusetts Institute of Technology.

-This speaker described his model in great detail. The model shows initial rifting subsidence of 2 to 3 km followed by thermal subsidence of up to 10 km where no lithosphere is left. There was a reasonable relation of the model to the real earth but the speaker gave too much detail to absorb in a short time. The models predicted temperature gradients of 17 to 20 compared with the 22 to 27 observed on the shelf in the area considered.

Tuesday 14 September

Paper 8 -Limits of the subsurface temperature fluid pressure field of commercial oil and gas reservoirs, by T. McCulloh of the U.S. Geological Survey.

-This author showed plots of temperature against pressure for oil field condensates and dry gas. He then broke down the oil plots into geographical areas showing effectively geothermal gradients with depth replaced by pressure. He claimed a limit of oil is at about 140°C rather than the conventional value of 175°C. He also stated that methane has a tendency to migrate down the pressure gradient into the hydrate zone if that exists locally. He also said that having sediment under 3000 ft. of water creates a situation where hydrates can form easily and he also said that this refers even to Cerro Prieto, but I find that rather puzzling since Cerro Prieto is a hot geothermal field on land.

Paper 9 -Stability of natural gas at high temperatures in the deep subsurface by C. Barker, University of Tulsa.

-This speaker plotted depth against temperature gradient of oil reservoirs and found boundaries of 65° to 150°C for oil and 150°C as the lower limit for gas. He showed a plot of the maximum depth drilled to date against time and showed that the maximum depth had increased at an average rate of 450 ft. per year, remarkable linearly since 1930. The main part of this paper was about a program written to calculate the equilibrium gas mixtures in any system resulting from rearrangement of methane and water in various pressure, temperature and chemical rock systems. It was based on the mimimum free energy of the mixture under the conditions, in order to derive an equilibrium chemically stable mixture.

-crude oil is not stable at any depth but it exists because the reaction rate is very low.

-pressure has little effect on gas equilibrium but high temperature encourages carbon dioxide at the expense of methane. Carbonate in the rocks cuts down the free hydrogen.

-methane is not stable in the presence of sulphur, only hydrogen sulphide and carbon dioxide.

-in the presence of iron methane is stable to 20,000 ft. but not deeper because iron seems to tie up the sulphur to that depth.

Paper 10 - Temperatures in Gulf coast sediments as a consequence of overpressuring, by M. Hodson, Marathon Oil.

-This speaker described a model of a vertical section of gulf coast reservoir including water migration, sediment compaction, mineral reaction, temperature etc., but it was difficult to follow since he gave far too much detail for an oral presentation.

Paper 11 - Geotemperature of the North Sea Basin by, Brian Jepsen of Saga Petroleum, Norway.

-This paper dealt with temperature gradients in the North Sea, mainly the northern part including the Norwegian sector and the northern part of the British sector.

-gradients range betwen 20 to 45 mK/m, highest in the centre and high towards the northeast coast of England.

-Oxburgh considers that gradients are largely water controlled.

-they have tried to use multiple temperatures in wells to give two or three intervals over which gradients and heat flow may be estimated.

-they have used conductivity values for each geological period to interpolate temperatures to chosen depths. Temperatures at a depth of 3 km are in the range of 90 to 120°C, the high temperature occurring in the central graben areas and on the Horda platform area.

-the Horda platform is interpreted as being a slab of anonomously high heat generation.

-high temperatures in gradients in the central graben are interpreted as being due to ascending fluid along the faults.

Paper 12- organic geochemistry and petroleum exploration - problems, by L.C. Price, U.S. Geological Survey, Denver.

-this paper bore very little resemblance to the abstract. This speaker set out to give the impression of disagreeing with almost everything, specifically with the concept of the disappearance of oil at vitrinite reflectance levels of about 1 and with the occurrence of greenschist metamorphism at about 200°C.

-high paleotemperatures have not been properly taken into account, particularly in basins such as the Amazon, Camaroon, Sulu and the Taranaki.

-present temperatures have been associated with maturation levels rather than higher paleotemperatures, which were commonly attributed to volcanism.

-geochemists have consistently ignored geological history evidence.

-Karweil disregarded the proper paleogradients.

-there is a strong relation of reflectance with temperature regardless of time over a range of 3 to 250 million years.

-burial time is not important in the maturation of hydrocarbon.

-100,000 years is all the time needed for full organic maturation.

-the Connan and Karweil data bases are erroneous.

-the chemical reactions involved are not first order, i.e. time cannot be substituted for temperature.

-reflectance is a powerful tool for direct inference of paleotemperature.

-there are in the industry many 'house concepts' due to the fact that major companies have closed data and do not encourage or even allow comparison with the work of any other companies.

Paper 13 - the present thermal state of the western Canada sedimentary basin by Jacek Majorowicz and A. Jessop.

There is no need to report on the content of this paper, it is published in Tectonophysics, 74, 209-238, 1981.

Paper 14 - relations between hydraulics, temperatures and crude oil and natural gas composition in some upper Devonian reefs of Alberta, Canada, by Brian Hitchon, Research Council of Alberta.

-Hitchon proceeded to discuss the same data set that Jacek and I had used and he showed how details in the temperature gradients corresponded very closely to the topography of the prairies. In addition to the large scale water migration from the high to the low topographic areas discussed in our paper Hitchon showed that detailed low gradient areas are to be found in hilly parts of the prairies and high gradient anomalies are often found in low areas or water discharge areas. He showed diagrams of the Peace River area and the Red Earth area in northern Alberta where he could expound this concept in detail.

-From coal maturation data he had calculated an oligocene surface with its major valleys. He compared this with the known bedrock valleys that are now obscured by glacial drift and showed that there was general agreement with these patterns.

Paper 15 -Subsurface temperatures, Sacramento Valley, California: Guide to

F-Zone gas accumulations, by F.A. Berry of Abiquiu, New Mexico.

-this paper was concerned with a small area of California and was not of general application. However the author showed that small gas pockets are, in this area, associated with high temperature and can produce a virtually isothermal profile over a large depth range. He postulates that with accurate and closely spaced temperature data, a zig-zag temperature profile would be seen, but has no direct evidence of this.

Wednesday-16 September

Paper 16 - Geothermal trends in petroliferous regions of Louisiana by M.B. Kumar, Louisiana State University.

-this speaker showed data sets that suggested a gradient of about 20 mK/m above 13,000 ft. (4000 m) and 33 mK/m below 13,000 ft., this being the top of the geopressure zones. In addition to the changing gradient there also seems to be a temperature offset at that point. This speaker showed isotherms at the 14,000 ft. and 16,000 ft. levels, showing temperature highs associated with structures and with areas of production. At this point he mentioned an AAPG temperature correction chart. I enquired about this afterwards and discovered that it was derived from the AAPG Geothermal Survey of North America and I was given a copy of a paper by Paul Jones which included this chart. Unfortunately it was never adequately published because the original members of the Geothermal Survey Team dispersed rather rapidly before a lot of this material could be written up. The speaker showed several examples of temperature highs surrounding structures such as domes where oil and gas is produced and finished with the conclusion that fluid flow is needed to explain most geothermal highs.

Paper 17 - Diagenesis and Low Grade Metamorphism in Shales, by C.E. Weaver.

This paper was incomprehensible to anyone not thoroughly familiar with the technical language of shale metamorphism, and consequently I derived very little from it.

Paper 18 - Temperature Anomalies and Gulf Coast Structures by G.M. Gatenby of Union Oil.

-fluid migrating upwards from geopressure zones can cause temperature highs around faults.

-his temperatures were corrected by means of a curve developed by Cayley (this is the same correction curve mentioned by Kumar). He commented that he does not recognize temperature highs as being anonamolous if they coincide with structure contours, which presumably means that he expects formations to be isothermal.

Paper 19 - Shallow Geothermal Survey of Durkee Oil Field and Woodgate Fault, Harris County, Texas by L.D. Ambs, of Atlantic Richfied.

-this speaker had carried out a detailed study of a small area of about 500 ft. lateral extent of grass land near Houston and had measured temperatures at a depth of 2 metres over this area. Temperatures were measured by thermistors and were corrected for seasonal effects by means of a single hole that was continuously monitored over the course of the experiment. He applied various corrections, including a correction for the height of the grass in the area of the measurement. He claimed that anomalies can be associated with structure of the subsurface oil field and with a fault, but in my opinion this association needed some imagination. He claimed that an extra 100 ft. thickness of sand at a depth of 7000 ft. can account for temperature anomalies of .5 K at 2 metres, his basic assumption being that all isotherms are exactly horizontal beneath that particular sand formation, and that there was no lateral smoothing of isotherms above the sand. He also showed that some of the anomalies could be attributed to water movement in a fault that passes through the area, giving an anomaly of about 2.5°C. This looked a little more believable, but was still not convincing.

Paper 20 - Clay Mineral Evidence for Movement of High Temperature sub-surface Fluid, by R.E. Ferrell of Louisiana State University.

-Showed a map of temperature at 11,500 ft., which showed various anomalies near faults and their structures. He showed that temperature highs and structures are often associated with offsets that can be up to half the lateral extent of the anomalies.

-The afternoon session from 5 to 7:30 was highlight of the conference. It consisted of three papers, all by experienced people who were able to put over their material very well, with a high level of enthusiasm.

Paper 21 - Geothermal and Hydrocarbon Regime in the Northern Gulf of Mexico Basin by P.H. Jones of Batton Rouge, Louisiana.

Paul Jones has been interested in geopressure zones for a very long time, and has been one of the prime exponents of research into geopressure zones as sources of gas and of geothermal energy. He started off by outlining some of the characteristics and scales of the gulf coast basin.

-there is as much as 15,000 ft. of Pleistocene sediment in southern Louisiana.

-there are a million cubic miles of sediments of Tertiary and Quaternary age.

-temperatures as high as 273°C have been encountered in Texas and many wells have temperatures in excess of 200°C.

-the average porosity in the basin ranges from 10 to 12%.

-a maximum depth of the basin is about 50,000 ft. (15 km).

-it is difficult to account for the energy required to heat this material to its present temperatures in 40 million years. (By my calculation this amounts to about 4 mW/m^2 for 15 km of sediments heated over 40 million years, which is the heat required to satisfy the heat capacity only and does not include any contribution removed by water flow, absorbed by metamorphism of clays, or for heating of basement).

-there are salt domes every 8 or 9 miles in southern Louisiana, having diameters of about 3 miles, and there is also a large salt 'roller zone' near the edge of the shelf. Salt diapirs collect a shale envelope that prevents them from being dissolved away.

-a 20,000 ft. salt column is sufficient to cause failure in the crust below, resulting in possible intrusion and strong heating, which can cause melting of salt and strong expansion.

-most oil deposits are associated with growth faults.

-in the geopressure zone pressure gradients are typically .7 to .85 psi per foot, changing from the hydrostatic gradient over as little as 500 ft.

-oil is often found in this transition zone.

-the top of the geopressure zone ranges from 5000 to 15,000 ft. over an area of over 150,000 sq. miles.

The speaker then showed slides of wells that have produced both large quantities of gas and steam, and he stated that it was necessary to develop this resource for gas, for heat, and for the mechanical energy of the high pressure.

Paper 22 - Temperature Anomalies Associated with Rocky Mountain Oil and Gas Fields, by H. Meyer of Amoco.

This speaker showed several examples of oil fields in the mid-western and Rocky Mountain states that have associated temperature anomalies. In some case the temperature anomalies coincide exactly with the oil and gas fields, while in other cases the geographical fit is not entirely perfect. 15 out of a total of 20 fields were found to have a temperature high. The fields specifically mentioned, with gradients both on the anomaly and in the background were: Madden, Wyoming, 35 and 24, Salt Creek, Wyoming 51 and 33, Elk Basin, Wyoming 36 and 22, Peoria, Colorado 38 and 31, Wattenberg, Colorado 49 and 31, Red Wing Creek, North Dakota 38 and 27, Bell Creek, Wyoming 35 and 22, all gradients given in mK/m. This speaker favoured drill stem test temperatures over bottom hole temperatures and showed a plot that illustrated drill stem test data as being generally higher than the bottom hole data. He showed some data taken over long time periods compared with bottom hole temperatures at the same point, and these yielded differences of up to 55K with an average of about 28K. This speaker gave as possible causes for the temperature anomalies 1-surface effect, 2-meteoric water movement, 3- juvenile water moving up, 4-sources of heat in rock, chemical or radioactive, 5-lateral variations of conductivity and permeability, 6-recent volcanism, 7-non-uniform deep heat flow. He also commented that North Americans usually cite no. 5 as the reasons for the temperature anomalies whereas Europeans, the Russians in particular, favour no. 3. During the discussion on the paper the question arose of the ability of oil and gas in the rocks to lower significantly the conductivity. In my opinion this cannot be an adequate factor.

Paper 23 - The Hydrothermal Approach to Petroleum Exploration, by W.H. Roberts, Gulf Research and Development, Houston.

Hydrothermal systems deposit minerals, and this paper raised the suggestion that they also deposit hydrocarbons. The speaker proposed a strong similarity between mineral and hydrocarbon deposition. Waters in sedimentary basins never really stop moving. Water is both a solvent and a vehicle for material at moving rates of 1 mm to 1 km per year. The association of oil and gas deposits with temperature anomalies has been observed for over one hundred years. It is common to find hydrocarbons accumulated in areas of ascending water. Water movement can be thought of in three orders of magnitude, the shallow, the medium and the deep movements, which have already been dealt with at this workshop for the Canadian Prairies by a combination of Hitchon and Majorowicz. Deep water discharge phenomena include salt solution and collapse, mud volcanoes, hydrochemical plumes, hydrocarbon seepage, and cap rock formation. The upward flow through an aquitard such as a shale can be higher than a horizontal flow through an aquifer because of the contrast in the area available for flow. This speaker went on to show examples of fields, some of which had been explored by temperature techniques, particularly in the Caspian sea margin area. A copy of his paper was available.

Thursday 17 September

Paper 24 - Current Geothermal Environment of Oil and Gas in the Indus River Basin of Pakistan, by R.J. Schoeppel, Mississipi State University.

This paper started off with a few jingoistic comments about the way they do things in Pakistan, particularly as a result of their previous Russian advisors. The main part of this paper was concerned with the collection of temperature data from wells in Pakistan, to form the Geothermal Survey of Pakistan, of the same character as the Geothermal Survey of North America of 10 or 12 years previously. In the course of a normal two week logging period there were often good bottom hole temperatures, but the speaker had several strange conceptions of underground temperature and heat flow.

-if he found a hole with a high gradient zone below a low gradient zone he would ignore the high gradient zone and record only the shallow low gradient.

-in general if he could not get a near surface gradient he threw out the data.

-gradients ranged from a low of 15 mK/m in the Indus Valley to a high of over 40 mK/m in the central part of the country with smaller highs in the south and offshore.

-crystalline rocks have no porosity,

-heat flow depends on the density of the rocks.

Paper 25 - Mass Transfer and Fluid Convection in Sandstone Relevant to Temperature Gradients, by J.R. Wood.

This speaker supports the concept of similarities between hydrothermal systems and fluid circulation in basins and suggests that convective drive is responsible for much diagenesis. In convection, instability can be caused by differences of temperature, salinity, dissolved gas or dissolved hydrocarbons. There is a characteristic lateral size of convection cells, for example 64 km for volcanoes in the Aleutians, 9 miles for diapirs on the Gulf Coast. The speaker reviewed the Rayleigh number criterion for convection and went on to describe a second criterion that takes precedence over the Rayleigh condition. It was not entirely clear how this worked but he gave a reference to Borie and Combarous, J. Fluid Mech.

Paper 26 - A Thermal Anomaly Detected by Shallow Measurement Across the San Sebastian Oil and Gas Field, Eastern Tierra del Fuego, by G.W. Zielinski, Gulf Research and Development, Pittsburg.

This author had made a large number of temperature measurements to depths of up to 2 in a wide uniform peat deposit on the eastern shore of Tierra del Fuego. The low conductivity and diffusivity of the peat, the reasonably uniform climate because of the almost continuous cloud cover, and the presence of a weather station in Rio Grande, quite close to the area, all helped to provide surface data for the correction of these temperatures. He found that surface temperatures ranged from 7 to 10°C and most profiles showed a maximum at about 1 m. He interpreted this as being the remnant summer maximum, since measurements were made in the local autumn. From this short record he extracted by a statistical process a heat flow pattern showing an anomaly of about 350 mW/m^2. He interpreted this as being a high heat flow over the oil and gas field, which must be due to water discharge.

That was the last paper of the workshop. There was an open discussion afterwards and the usual questions of data quality and quantity, including the willingness of the Companies to acquire better data came up again. Judging from many of the remarks the participants went away with good intentions to do better in the future, but it remains to be seen whether this can translated into action.