Detection of salt beds using thermal properties in selected deep wells in Southern Iraq basin

By

Rafid Kadhem Abbas
MSc. Petroleum Engineering
College of Science
Al-Qadisiya University

E-mail: Rafid_usmc@yahoo.com

Abstract:

This research deals with the intrusion of salt layers in selected deep wells in southern Iraq . Salt has its behaviours which should studied in order to know its effect on drilling operations. Two methods are used to illustrate the behaviour of salt namely thermal conductivity and linear thermal expansion of salt. Results of both methods showed that two zones, in most of deep oil wells in Southern Iraq basin, have high content of salt and consequently represent a signal of hazard in drilling operations . Two main salt series have an affect on wells in Southern Iraq basin , Injana salt series which affects on Misan fields and secondly Gotnia salt layer which affects on Basrah fields and the region between those fields yields to both effect of salt series.
A stratigraphic correlation between selected wells in South Iraq basin has been sketched for further illustration of salt extension on these wells and therefore special drilling operations must be taken into consideration to prevent the effects of probable high formation pressure which consequently might complicate drilling operation and increase it's costs.

الخلاصة:

هذا البحثِ يَتعاملُ مع تداخلِ طبقاتِ الملحِ على آبارِ عميقةِ مختارةِ في جنوب العراق. الملح لهُ سلوكُهُ الذي يجب أنْ يُدْرَسَ لمعرفة تأثيرهُ على عملياتِ الحفر . تم استعمال طريقتان لتوضيح سلوكِ الملحِ: ، طريقة التوصيل الحراري و طريقة التوسّع الحراري الخطيّ للملحِ. نَتائِجَ كلتا الطريقتين أوضحت بأنّ منطقتين في أغلب آبارِ النفط العميقةِ في حوض جنوبِ العراق لَها محتوى عاليُ مِنْ الملحِ في تشكيلِ الصخرةِ و بالتالي تُمثّلُ إشارة خطرِ.

سلسلتان طبقيتان رئيسيتان من الملحِ تُؤثّرُ على الآبارِ في حوض جنوبِ العراق، سلسلة ملحِ Injana التي تُؤثّرُ على حقولِ ميسان وثانياً طبقات ملح Gotnia التي تُؤثّرُ على حقولِ البصرة والمنطقة بين تلك الحقولِ تخضع إلى تأثير كلتا سلسلتي الملحِ .

تم رسم ارتباط التتابع الطبقي بين الآبارِ المختارةِ في حوض جنوبِ العراق لتوضيح المزيد عن امتداد الملحِ على هذه الآبارِ و لذلك عملياتِ حفر خاصّةِ يجب أنْ تُؤْخَذَ بنظر الاعتبار لمَنْع تأثيراتِ الضغط المسامي العاليِ المحتملِ و الذي قَدْ يعقّدُ عملية الحفر ويزيدُ من تكاليف الحفر .

Introduction:

Salt domes and ridges, that form the boundaries of salt withdrawal mini basins, cause an increase in pore pressure in the surrounding sediments. This fact results in anomalously high pore pressures in wells drilled on the flanks of a salt dome relative to wells drilled through equivalent strata towards the center of the basin. Overpressure may also occurred adjacent to salt masses and some deep wells had to be abandoned during attempts to drill through overpressured fractured shale associated with a salt diaper before the reservoir interval was reached. Below tabular salt sheets, formations can be overpressured because of an effective seal, and in some subsalt wells, a pressure kick may encounter in the rubble zone below salt. In general, however the top of sub-salt geopressure occurs at greater depths and deeper in the stratigraphic section than in wells without salt **(Michael and Smith 1976)**.

Lianbo and Shuriong (2003) studied the effect of salt which occurring in high pressure zones. They concluded that the distribution of overpressure is nearly related with gypsum-salt bed and gypsum-mudstone bed in the Paleogene system.

They added that generally, if the thickness of gypsum-salt bed or gypsum-mudstone bed is over 400-500 m , it is a possibly an overpressure zone. The good sealing property of gypsum-salt bed or gypsum-mudstone bed in Paleogene system is a necessary condition for the formation of overpressure.

The unique salt petrophysical properties contribute to substantial changes in the pore pressure gradients in the host sediments above and below. Salt's low density is responsible for retarding the overburden gradient and its negligible permeability creates a perfect seal. Moreover, salt's ductile nature generates a variety of structure styles that affect the stresses orientation. A distinctive shift of the pore pressure and normal compaction trends takes place across the salt body. Density difference between the salt and host sediments are considered the main driving mechanism for pore pressure development and the salt body acts as floating seal **(Shaker 2002)**.

Although drilling through salt formations in not new , the various depths of the salt formations and high pressures encountered above and below the salts , preclude the use of standard casing string design. These issues, as well as the extreme collapse pressures imparted by the point type loading of the salt formations have presented some real drilling challenges **(Bruce and Urband 1997)**.

Pressure build-up in the internal cavern fluid following closure primarily for two reasons:

1- The inward creep of the salt will compress the internal fluid; and

2- The temperature of the internal fluid will rise until it reaches the temperature of the surrounding salt.

This temperature rise will result in an expansion of the internal fluid and an associated increase in the internal fluid pressure**(Spiers and Brzesowsky 1993)**.

Pressure of salt structures in prospects for oil and gas exploration is ,in itself , a factor that increases the probability of success due to favourable conditions for hydrocarbon generation and trapping ,However many operational problems such as stuck pipes and casing collapse have been reported by the industry when drilling through those salt layers. The lack of a reliable way to predict salt behaviour at high temperatures and high differential stresses led to very high drilling costs and even the loss of wells.

A methodology for mud weight, casing design and also to define the drilling strategies are employed for drilling through thick salt layers. Numerical simulations to evaluate the creep behaviour of salt submitted to high differential stresses and high temperatures were done through the applications of computer.

As a result, stuck rods and casing collapse were avoided and drilling costs reduced **(Mai , Poiate and Falcao 2005)**.

Theoretical background:

It is well known that the strength and deformation properties of salt are site dependent. There is some evidence to suggest that such variability is caused by differences in salt chemistry, mineralogy, or other physical characteristics such as sub grain size , grain size distribution , or grain aspect ratio**(Fossum and Fredrich 2002)**.

Salt deformation behaviour:-

Fossum and Fredrich added that the thermo-mechanical behaviour of salt is divided into the following four categories: thermal behaviour, elastic deformation, inelastic deformation, and failure **.** A comparison of data from different sites shows that thermal and elastic behaviour do not vary significantly from site to another, but that inelastic behaviour and failure vary significantly among different sites. The extent to which the above four categories contribute to observed behaviour depends on temperature, stress and the history of deformation. Mechanical behaviour is also influenced by moisture.

Only thermal conductivity varies significantly with temperature for the range of temperatures that will be experienced by salt in a deep well drilled in Qurna field Southern Iraq, i.e. West Qurna well #15.

The thermal conductivity can be represented as a function of temperature as:

$$\lambda = 5.40\left(\frac{300}{T}\right)^{1.14} \qquad \text{..............(1)}$$

Where T is temperature in degrees Kelvin (K^o) and λ represents thermal conductivity in K^{o-1} units **(Krieg 1984)**.

When salt at constant load , i.e. at constant stress is heated , it expands .This thermal expansion is described by the coefficient of linear thermal expansion. Mathematically this expansion is expressed by:

$$\alpha = \frac{1}{L}\left(\frac{\partial L}{\partial T}\right)_{\sigma} \qquad \text{..............(2)}$$

Where α is the coefficient of linear thermal expansion, L is the length over which the expansion is measured and $(\partial L/\partial T)$is the partial derivative of length with respect to temperature at constant stress (σ) **(Krieg 1984)**.

Yang (1981) has summarized the evaluation of the coefficient of linear thermal expansion of salt over a wide range of temperatures. The temperature dependence of the coefficient of linear thermal expansion is given by:

$$\alpha = 3.025 \ * \ 10^{-5} + 2.942 \ * 10^{-8} T + 2.5677 \ * 10^{-12} T^{2} \quad .... \quad (3)$$

where T is in degrees Kelvin and α has units K^{o-1} .

Yang also added that the elasticity of salt might be regarded as linear with temperature dependent elastic constants.
Temperature, stress and loading rate strongly influence the inelastic deformation of salt .An increase in temperature causes an increase in inelastic deformation .
Salt failure depends on stress and loading rate. (Shear stress at failure increases with increasing pressure).

Data collection:

The data collected from West-Qurna field , well no.15 . The data are: - Bit record data and flow line temperature vs. depth taken from temperature log. Also formations and lithology for selected deep wells in Southern Iraq basin had been documented from Iraqi National Oil Company(INOC) during 1990.These wells are: Khader El-Mai , North Rumali #172 , Abu-Amoud , while Misan field include wells A, B , C , D and E as mentioned by **(Al-Rubaiee 1987)**.

Results and discussion:

Thermal conductivity:

Using field data, the temperature in C° vs. depth, which obtained from temperature log which taken from INOC (Iraqi National Oil Company) report and then converted to Kelvin units by: K° = 273.16+ C° , then applying equation (1) , thermal conductivity have been computed. Table (1) shows flow line temperature and computed thermal conductivity vs. depth. It is noticed that the values of thermal conductivity of salt varies from 3.5478 K^{o-1} to 4.759096 K^{o-1} . Values of thermal conductivity of salt which determined by using equation (1) had been drawn versus depth as shown in figure (1). This figure showed that thermal conductivity of salt decreases normally versus depth and when it reaches depth 3720m , thermal conductivity of salt starts to increase and that means the percentage of salt increases in rock formation. By referring to geological report of (INOC) and figure (4) , nearly at depth (3720m) , we faced anhydrite and gypsum salty layers which affect on drilling operations and arising pore pressure gradient and due to that increasing drilling difficulties.
When crossing depth 4020m thermal conductivity of salt increase again , which at that depth a second layer of salt present and behave as cap rock and makes thermal conductivity increases vs. depth . It is observed that Gotnia salt series present nearly at that depth as illustrated in (INOC) geological report .

Tabel (1)

Data of temperature , calculated thermal conductivity of salt and linear thermal expansion of salt vs. depth in west-Qurna well #16 in Basrah.

Depth (M)	Temp. (C°)	Temp. (K°)	Thermal conductivity of salt ($K^{\circ -1}$)	Linear thermal expansion of salt ($K^{\circ -1}$)
2935	62	335.16	4.759096	4.03988E-05
2960	65	338.16	4.710995	4.04923E-05
2965	69	342.16	4.648263	4.0617E-05
2975	63	336.16	4.742961	4.043E-05
2985	67	340.16	4.679431	4.05546E-05
2990	67	340.16	4.679431	4.05546E-05
2995	69	342.16	4.648263	4.0617E-05
3005	67	340.16	4.679431	4.05546E-05
3045	69	342.16	4.648263	4.0617E-05
3060	69	342.16	4.648263	4.0617E-05
3065	73	346.16	4.58708	4.07417E-05
3090	73	346.16	4.58708	4.07417E-05
3095	71	344.16	4.617481	4.06793E-05
3110	71	344.16	4.617481	4.06793E-05
3135	76.5	349.66	4.534774	4.08509E-05
3140	76	349.16	4.542177	4.08353E-05
3160	74	347.16	4.57202	4.07729E-05
3170	74	347.16	4.57202	4.07729E-05
3180	74	347.16	4.57202	4.07729E-05
3195	77	350.16	4.527392	4.08665E-05
3210	74	347.16	4.57202	4.07729E-05
3215	78	351.16	4.512698	4.08978E-05
3240	77.5	350.66	4.520034	4.08821E-05
3245	79.5	352.66	4.490823	4.09446E-05
3280	77.5	350.66	4.520034	4.08821E-05
3320	84	357.16	4.426377	4.10852E-05
3360	85	358.16	4.412291	4.11164E-05
3400	90	363.16	4.343104	4.12728E-05
3440	92.7	365.86	4.306584	4.13573E-05
3480	95	368.16	4.275927	4.14293E-05
3520	109.7	382.86	4.089276	4.18901E-05
3560	110	383.16	4.085626	4.18995E-05
3600	122.3	395.46	3.941078	4.2286E-05
3640	125	398.16	3.910626	4.23709E-05
3680	140.2	413.36	3.74712	4.28498E-05
3720	129.9	403.06	3.856475	4.25252E-05
3760	129.3	402.46	3.86303	4.25063E-05
3800	126	399.16	3.899459	4.24024E-05
3840	140.5	413.66	3.744022	4.28592E-05
3880	152.8	425.96	3.621025	4.32476E-05
3920	152	425.16	3.628794	4.32223E-05
3960	156	429.16	3.590261	4.33488E-05
4000	155.8	428.96	3.59217	4.33425E-05
4040	151.4	424.56	3.63464	4.32034E-05
4080	155	428.16	3.599822	4.33172E-05
4120	156.2	429.36	3.588355	4.33551E-05
4160	156.4	429.56	3.58645	4.33615E-05
4200	157.8	430.96	3.573171	4.34057E-05
4240	159	432.16	3.561863	4.34437E-05
4280	160.5	433.66	3.547821	4.34912E-05

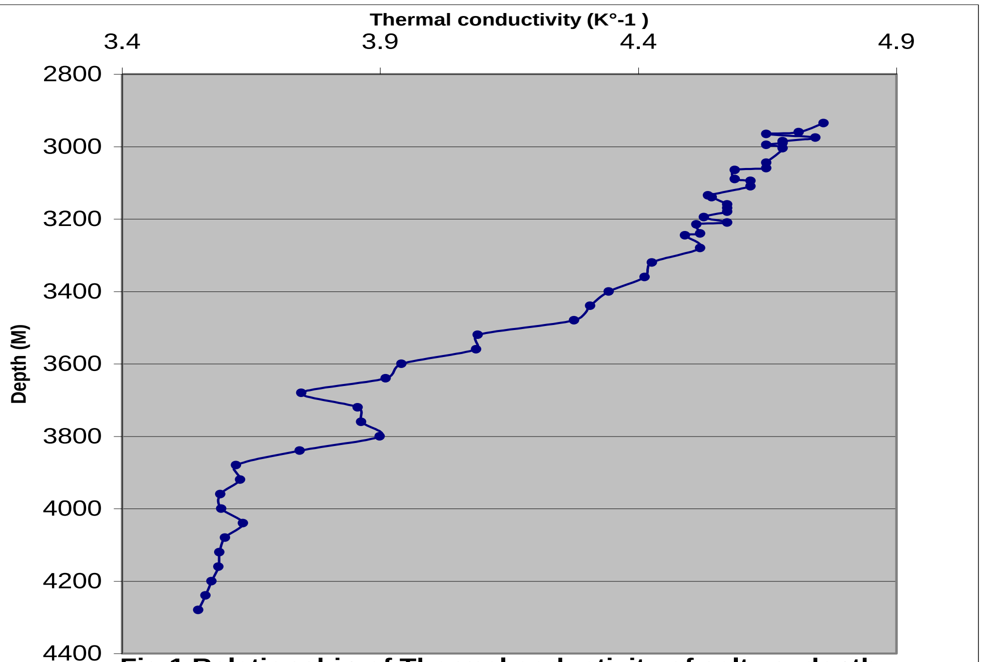

Fig.1 Relationship of Thermal coductivity of salt vs. depth

Thermal conductivity method is a useful approach to detect salt layers in order to avoid drilling problems which might happen and due to that drilling costs will be reduced.

Thermal expansion and temperature effect:

Coefficient of linear thermal expansion of salt can be determined by using equation (3) , after converting raw temperatures in C° to K°, the results arranged in table(1). Plotting linear thermal expansion of salt versus depth (fig.2) showed that linear thermal expansion values increases normally vs. depth and varies from $4.03988*10^{-5}$ K^{o-1} to $4.34912*10^{-5}$ K^{o-1} , which means that the rock penetrated had low content of salt or low thermal expansion of salt , but between depths (3680m)and (3720m) linear thermal expansion of salt decreases vs. depth , which means crossing rock of high content of salt. Moreover, when crossing depths from (3960m) to (4040m) linear thermal expansion of salt returns to decreases vs. depth. Hence the lithology of fig.(4) and (INOC) geological report emphasize the occurrence of Gotnia salt series at nearly that depth .

From equation (1) and (3) ,the results gave us signs of salt occurrence which might complicates drilling operations by causing high overpressure zones and consequently special treatment should applied with this case.

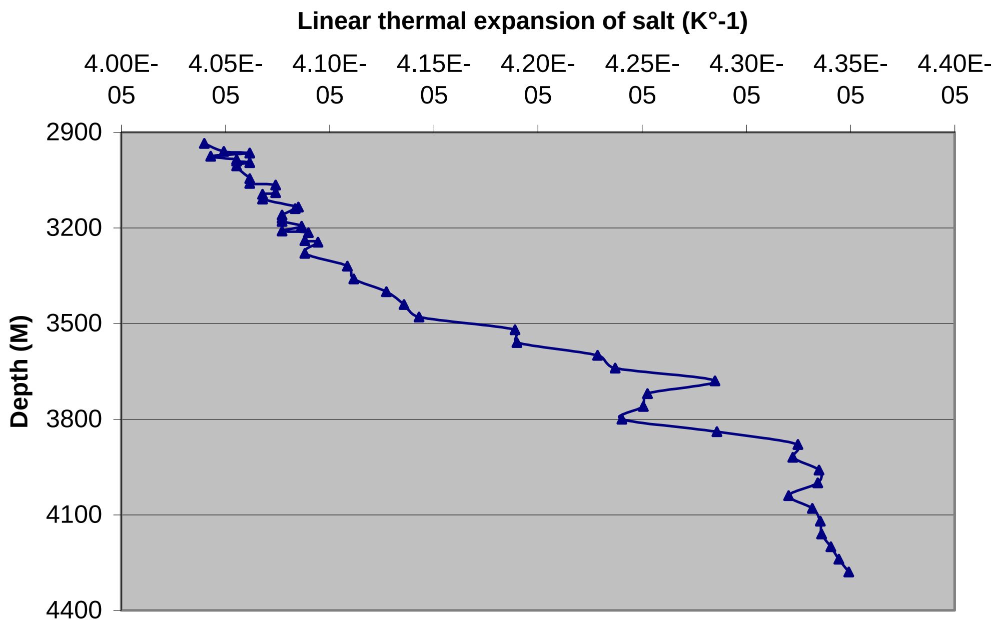

Fig.2 Relationship of Linear thermal expansion of salt vs. depth

Stratigraphic correlation for selected wells in Southern Iraq:
From geological interpretation* of Misan field #1 , which includes wells: A , B , C , D and E **(Al-Rubaiee 1987)**, and four other deep wells selected randomly in Southern Iraq: (Khader El-Mai , Abo Amoud , West Qurna #15 and North Rumaila #172). Figure (3)** shows the location of the selected wells in South Iraq basin and the extension of two main salt series :

1- Injana salt series or formally known as lower faris salt series , which affects mainly on Misan fields as shown in fig.(3).
2- Gotnia salt series which mainly affects on the four deep wells , while they are not affected by Injana salt series.

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*Geological lithology and formation beds as well as the ages that the selected wells lies in vs. depth were illustrated so well in figure (4).

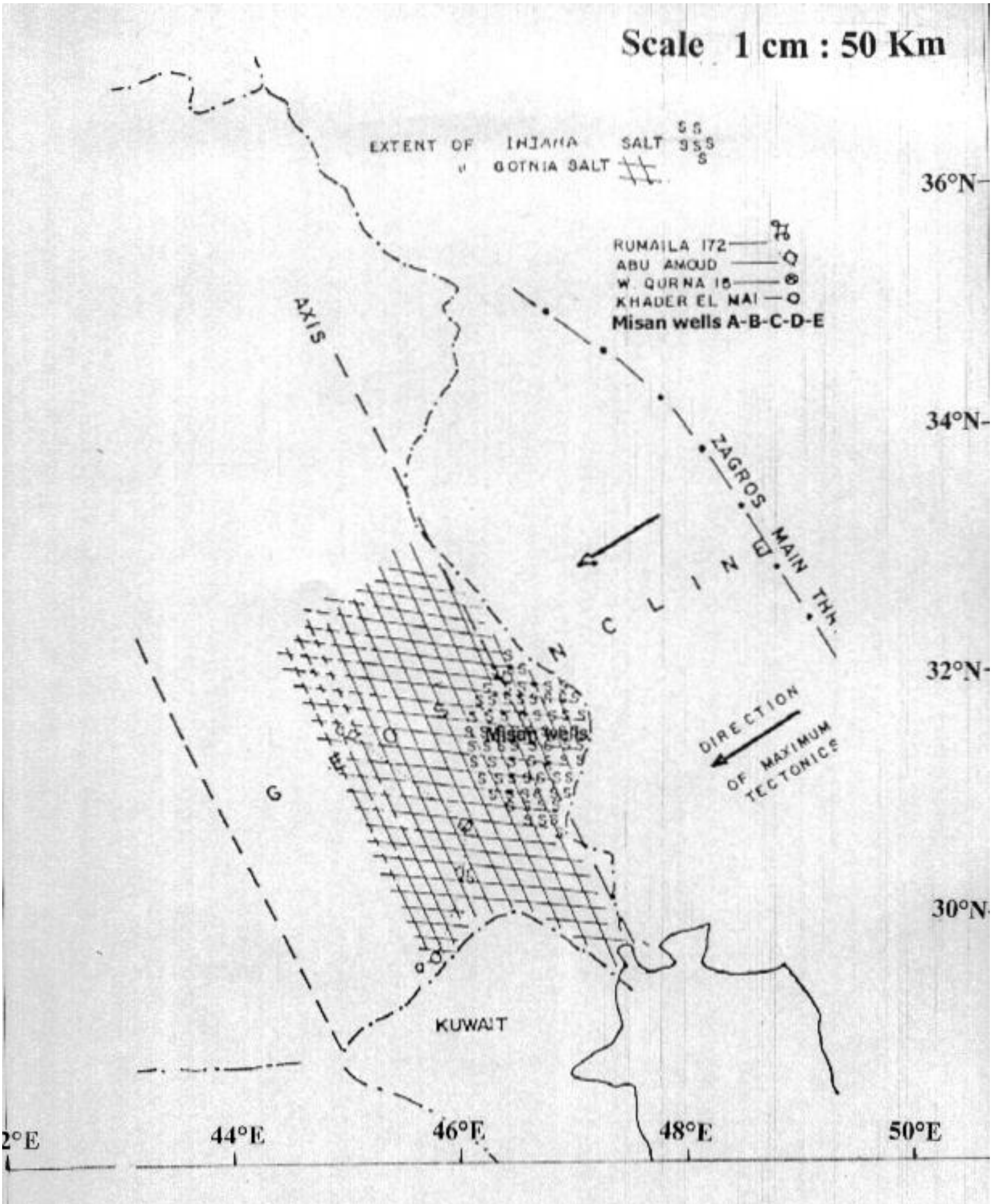

Fig.(3) Extension of salt series in Southern Iraq basin

** Figure (3) took from (INOC.S) report (Iraqi national oil company) and had been modified by the author to determine the North direction as well as including Misan fields in the map .

The four deep tested wells in Southern Iraq have been correlated with Misan field #1, which includes as mentioned five wells. This correlation is shown in figure(4) .
falls in It is observed from the correlation that Misan field #1 falls in Tertiary age (and it which falls in the geosyncline) , while other deep wells in the correlation reaches upper Triassic as illustrated in fig.(4).Also fig.(4) shows that the extension of multiple cap rocks (Anhydrite) and salt in Misan field is the main cause of overpressure in this area , while other deep wells subject to the effect of Gotnia salt series ,which considered the major cause of high pressure in most Southern Iraq region and consequently increased drilling problems.
In addition fig.(4) indicates that Khader El-Mai deep well is structurally higher than North Rumaila #172 deep well and the latter well is structurally higher than West Qurna #15 and so on **(Al-Hilali 1996)**.

Conclusions:

1- Both thermal conductivity of salt and linear thermal expansion of salt are so useful methods to detect rock formations with high salt content and consequently drilling operations should be cautious when dealing with such formations to prevent undesirable drilling problems, which may complicate and increases drilling costs.

2- Both used methods give an earlier indication of salt occurrence than other geological methods as compared to INOC report and consequently both used methods could applied in different wells in different fields and even in different regions of the world and especially in drilling wells that may concur salt accumulation.

3- stratigraphic correlation showed that the extension of multiple cap rocks and salt in Misan field i.e; Injana salt series is the major cause of overpressure in this field, while extension of Gotnia salt series in other deep wells in Southern Iraq basin, is the main cause of high pressure in this area.

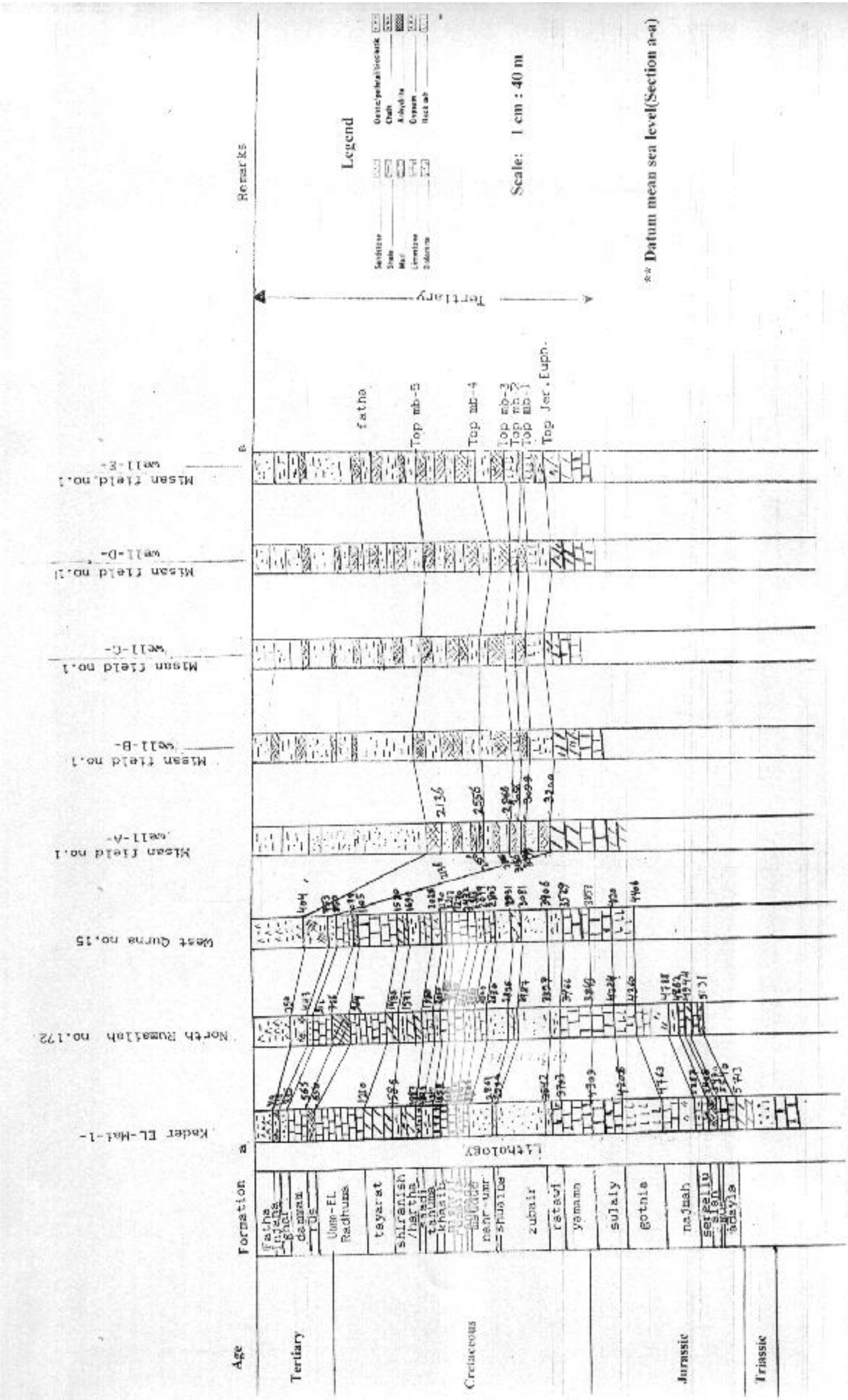

Fig.(4) Stratigraphic correlation for selected wells
in South Iraq basin (after Al-Hilai,R.K)

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