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Compaction and Migration of Hydrocarbons in East Baghdad Oil Field

Ayad A.Al-Haleem
Department of Geology, College of Science, University of Baghdad
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Abstract

An attempt is done to present a simple concept to combine the geochemical results with the concept of compaction- abnormality, reflecting a high variation in the porosity and internal pore pressure.

The different compaction levels and the variation of the bulk volume may lead to the expulsion of fluids both hydrocarbon and interstitial H_2O from high potential zones towards low potential zones, or in other words from low porosity towards high porosity areas. Furthermore, the both formations (Ratawi and Zubair) of lower Cretaceous age showing compaction trend as well as fluid expulsion current with a NW-SE trend of the primary hydrocarbon migration, while the sedimentary basin revealing a deepening towards the southern eastern part of the anticline structure.

A change in thickness and the facieses of the rock packages is manifested. The horizontal porosity distribution of shales in Ratawi formation particularly in the upper part (15m thick) reveal differential compaction and such a mechanism is responsible for the kinetic of fluid and gas.

الخلاصة :

في هذه الدراسة تم تقديم محاولة لعرض فكرة بسيطة لدمج النتائج الجيوكيميائية مع مفهوم الانحرافات التضاغطية والتي عكست اختلافات كبيرة في المسامية والضغط المسامي الداخلي.

إن مستويات الانضغاط المختلفة والاختلافات الحاصلة في الحجم الكلي قد تؤدي إلى طرد الموائع سواء كانت هايدروكاربونات أو مياه محصورة من أنطقة الجهد العالي باتجاه أنطقة الجهد الواطئ أو بكلمات أخرى من مناطق المسامية الواطئة باتجاه مناطق المسامية العالية. إضافة إلى ذلك فإن كلا التكوينين (الرطاوي والزبير) في زمن الكرياتسي الأسفل يظهران اتجاه تضاغطي وكذلك اتجاه طرد للمائع مع مسار من الشمال الغربي إلى الجنوب الشرقي للهجرة الأولية للهايدروكاربونات بينما الحوض الرسوبي يصبح أكثر عمقاً باتجاه الجنوب الشرقي من الطيّة.

إن الاختلاف في السمك وسحنة الحزمة الصخرية قد تم تشخيصها. إن توزيع المسامية الأفقية للطفل في تركيب الرطاوي وخاصة في الجزء العلوي (١٥متر سمك) يظهر انضغاط تفاضلي وهذه الآلية تكون مسؤولة عن حركة المائع والغاز.

Introduction :

East – Baghdad oil field is a conspicuous structure covering an area of approximately 1000Km^2, (Fig. 1)[1]. Aziziah and Rashdyah area forming it's southern and northern borders respectively. It is axial plunging with a north vergency.

The lower Cretaceous formations namely Ratawi and Zubair are considered as the main source rocks for the hydrocarbons generation and accumulation forming one petroleum system, Fig.2, [1].

The formations hydrocarbon quality is well known due to the geochemical and lithological characteristics [2].

If the process of hydrocarbon generation within these formations could be evaluated to acceptable degree of precision, the way of how and when the primary, secondary, and ternary hydrocarbons took place remains problematic.

In general, any theory of hydrocarbon generation must explain two sets of observations: geological and chemical to precise the details of hydrocarbon generation and migration. The method of compaction – expulsion is applied and gave best reliable results when it was coupled with geochemical data of the generation – migration process. Compaction – Expulsion method value was proved by a number of authors [3,4,5,6,7,8,9].

In this study the data of fifteen oil wells were selected to rebuild the generation – migration process in addition to geochemical data which are presented to corroborate the results.

Sediment logical Setting :

Ratawi formation represents a secondary sedimentary cycle with Zubair and Shuaiba formations that was terminated in the lower Cretaceous, Fig. 2. The sediments were deposited in anoxic environment represented by mudstones and shales of light to dark color. This mechanism has been proposed to explain the extensive Upper Jurassic – Lower Cretaceous black shales that occur in so many parts of the world [10,11].It was shown that about 85 percent of the world's oil was sourced from such formations [12].

Zubair formation is represented by alternations of shales and sandstones with some thin beds of limestone at upper part of the formation. As shown from Fig.2, its age is considered to be Valanginian – Barresian. The total thickness of Zubair formation is approximately 400 meters in studied field where the sequence are subdivided to three distinct members [2].

1. Lower member (110-120m.) consisting of alternating sandstones and shales.
2. Middle member (134-140m.) predominately thick bedded sandstone with subsidiary shales and siltstones.

3. Upper member (145-150m.) consisting of alternating limestones and shales, while the thickness of the massive sandstone are 5-10 m.

Structural View :

Two tectonic events can be indicated from analyzing the complex structural and tectonic features that cause the present form of the field :

1. The upper Cretaceous showed tensile – tectonics which is resulted in a running garben zones through a system of growth faults oriented NW-SE. It seems that the extensional movements ceased in the Maestrichtian stage.
2. The Zagros Miocene – Pliocene diashophism formed the anticlinal folds which are trending NW-SE.

Geochemist Analysis:

A detailed study of Ratawi and Zubair formations was established to be the main source rocks for the hydrocarbon accumulation in the field [2]. The main geochemical properties of the incorporated organic matter in both formations have been identified, Table (1). The type of organic matter was found to be type II Kerogen. The type II Kerogen signifies the nature of the organic – materials in the source rocks which is composed from amorphous organic matter (OM), algae and foraminifers.

Expulsion and Migration of Hydrocarbons :

The primary migration i.e., the emigration of hydrocarbons from source bed to carrier, have been investigated by many authors [13,14,15,16]. The essential energy necessary to expel fluids (water or/and hydrocarbons) is being provided through the compaction process of source rocks under the lithostatic pressure of the sediments. At the first stage of oil generation, capillary pressure might be greater enough to stop the expulsion process. Through the stage of advanced maturation of organic matter, any further compaction of the sediment would load to the expulsion of the generated hydrocarbons to regions of less fluid potential [8,9,17,18].

The migration and the movement of the hydrocarbons and water is the result of compaction current which will be useful to define and calculate the directions and volume of the currents in the ancient geological time. The horizontal and vertical porosity distributions were determined by using acoustic log technique.

The timing of source rock maturation and generation of hydrocarbons from formations under study have been estimated to be within late Tertiary period by applying Waples method [19], Fig.3.

The measurement of thermal maturity index (TTI) for both Ratawi and Zubair formations with a constant geothermal gradient of 2.1^{o}C/100 meters, gave values of 20 and 10 respectively. An overlying sediment column of rocks as well as tectonism during and after the Miocene might have led to fluid migration from source rocks to carrier beds or reservoirs.

To realize the purpose of determining the direction and volume of compaction current which occurred during and after the Miocene age, fifteen wells cover entirely the field area, were studied in detail (Fig.4), while the wells no.9 and 57 don't provide any measurable data.

The shale horizons were identified by Spontaneous Potential (SP) and gamma ray logs, whereas shale porosity values were calculated from sonic logs due to the minimum influence by caving.

The interval transit time (Δt) can be used to calculate porosity (ϕ) according to the following equation [20] :

$$\phi = \frac{\Delta t_{\log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where :

(Δt_{log}) = the interval transit time recorded on the log ($\mu \sec/ft$).

(Δt_{ma}) & (Δt_f) = the transit time for the acoustic waves in matrix and of pore fluid respectively ($\mu \sec/ft$).

Accordingly, a linear relationship between actual shale porosity (ϕ) and the measured depth (Z) on the normal compaction trend can be given as [21] :

$$\phi = \phi_o e^{-cz} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

and $C = \frac{1}{Z}\log\left(\frac{\Delta t}{\Delta t_o}\right)$ ………………(3)

Where :

ϕ_o = initial porosity of shale and is equal to 68%. [22].

C = constant represents the slope of compaction trend.

Δt_o = transit – time at the surface of deposition ($\mu \sec/ft$).

Results and Discussion:

Estimation of shale porosity as a function of depth will reflect the degree of compaction. The calculated shale porosity values of both formations are identical particularly at large depths exceeding 2000m. The high values of porosity have been recorded even at depths exceeding 3000m, (Fig.5). Such values could indicate rapid subsidence and probably well sorted sediments.

Figs. 6,7 and 8 are plots of $\log \Delta t$ vs depth of all the studied wells. Δt_{sh} seems to decrease more or less uniformly with depth. As known, a section which is under compacted with regard to its burial depth will reflect a section of abnormally high fluid pressure. The depth - $\log \Delta t$ relationship is a measure of this abnormality. It is clear from these figures that the compaction of shales within Zubair and Ratawi formations in some wells show abnormal trend at the contact of formations, while wells no.58, 4, 16and 11 show a slight abnormality.

Representation of horizontal porosity distribution of the most upper layer (15 m.) of shales from Ratawi formation is shown, (Fig.9). The differential compaction trend in this field is shown also within this figure.

The compaction currents are representing here the proposed fluid migration in Ratawi formation and at the same time indicate potential accumulation zones of hydrocarbons. This accumulation would lie to the northern and median parts of the oil field.

Fig. 10 shows the same pattern of (Fig.9), in the case of Zubair formation, which might be the results of differential compaction. The sedimentary basin at the studied area show a deeping towards southern part and a change in thickness and facies is manifested. It is important to observe that the well known concept that the compaction currents travel in source rocks from zones of low porosity and high potential to zones of high porosity and low potential is shown clearly through Figs. 9 and 10.

Conclusions:

1. The geochemical evaluation of organic materials reveals that both of Zubair and Ratawi formations are potential source rocks.
2. Abnormal trend of some wells at the formation contact reflects the compaction of shales within these formations. The plots of depth vs. $\log \Delta t$ confirmed this abnormality.
3. The studied formations show compaction trend as well as fluid expulsion currents which is characterized generally by NW-SE direction of primary hydrocarbon migration.
4. Retarded compaction (or porosity) in source rocks at the phase of generation are attributed to oil mobilization where organic solid phase converts to liquid and gas phase. The aeration

of different compaction levels and porosity values lead to the expulsion of fluid from high potential zones (low porosity zones) towards low potential zones (high porosity zones) Figs. 9 and 10.

Table (1). Geochemical analysis of organic matter from Zubair and Ratawi formations, East – Baghdad oil field[2].

Parameter \ Formation	Zubair	Ratawi
TOC (Wt%)	0.16 – 6.41	0.19 – 1.51
EOM (Wt%)	0.1 – 1.13	0.01 – 0.57
H/C (atomic)	0.49 – 1.18	0.91 – 0.98
O/C (atomic)	0.14 – 0.26	0.12 – 0.18
HI (mg/g)	57 – 501	94 – 260
OI (mg/g)	10 – 270	63 – 222
PP (kg/ton)	0.34 – 13.2	0.36 – 5.59
PI	0.03 – 0.6	0.04 – 0.36
T_{max} (^oC)	418 – 439	429 – 439

Abbreviations

Abbreviation	Definition
OM	Organic Matter
TTI	Thermal Maturity Index
Z	Measured depth, m
TOC	Total Organic Carbon (%)
EOM	Extracted Organic Matter (%)
H/C	Hydrogen/Carbon
O/C	Oxygen/Carbon
HI	Hydrogen Index
OI	Oxygen Index
PP	Petroleum Potential, kg/ton
PI	Petroleum Index
SP	Spontaneous Potential
G.G	Geothermal Gradient, C^o/100m

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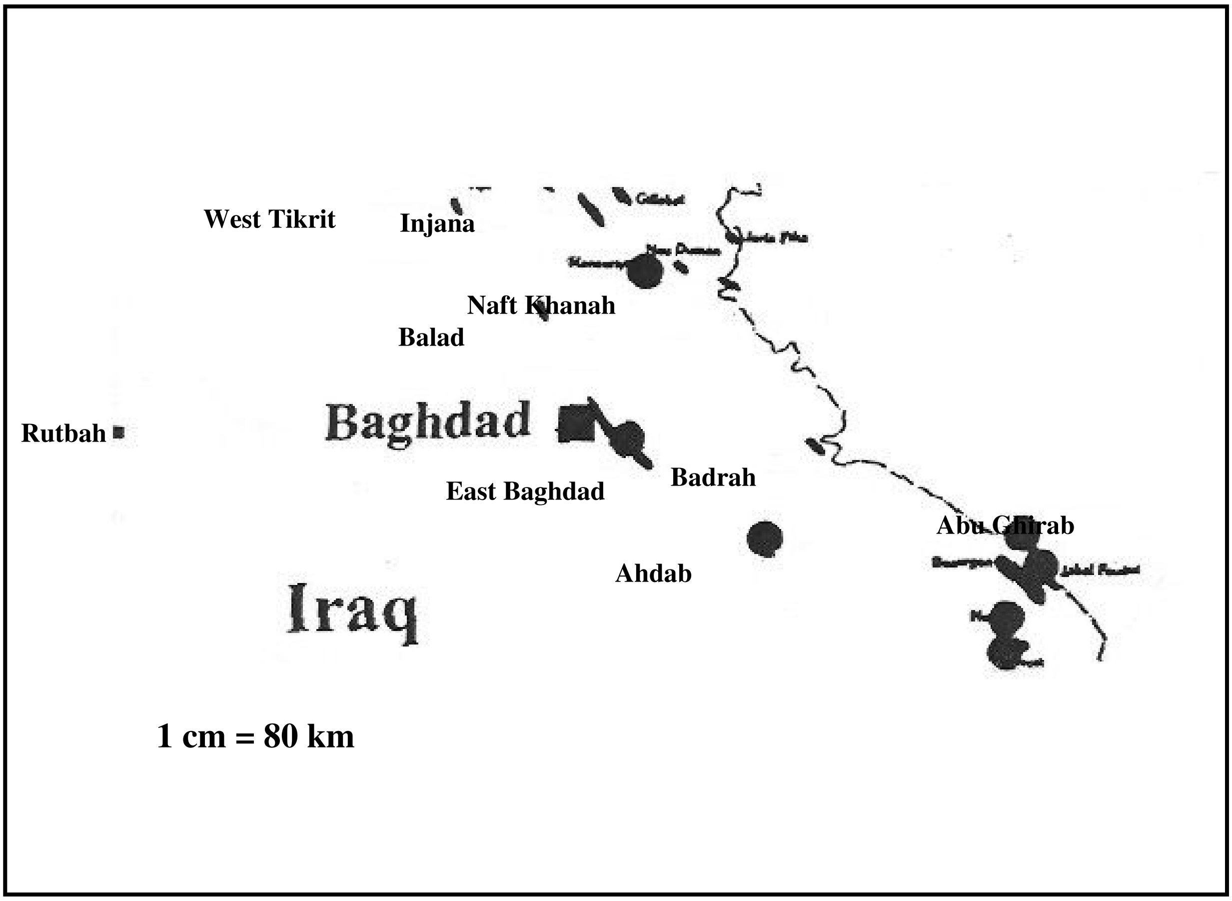

Fig.1 : Geographical location map of the studied area[1].

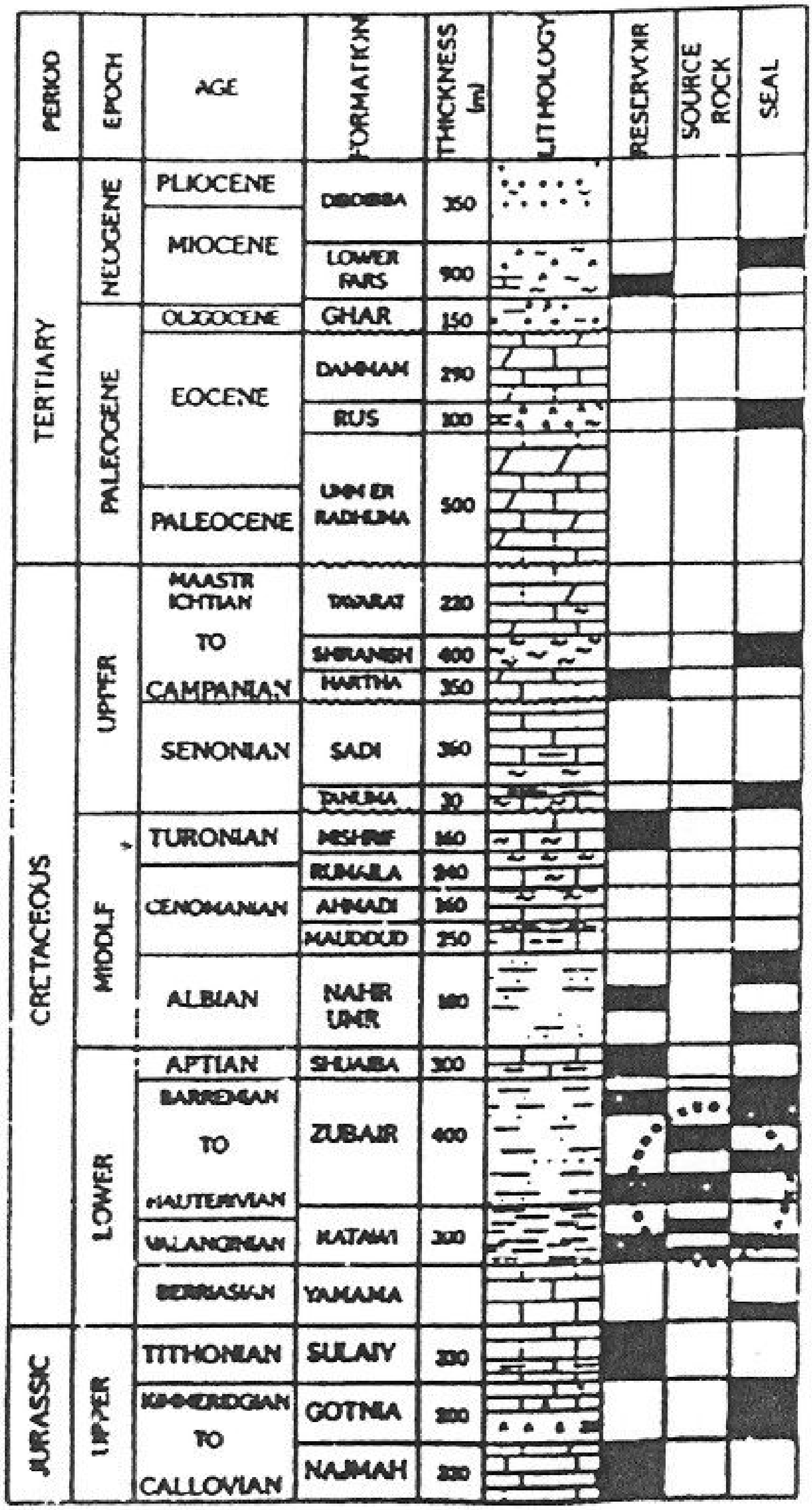

Fig. 2 : Stratigraphy and lithofacies of Jurassic, Cretaceous and Tertiary formations(1).

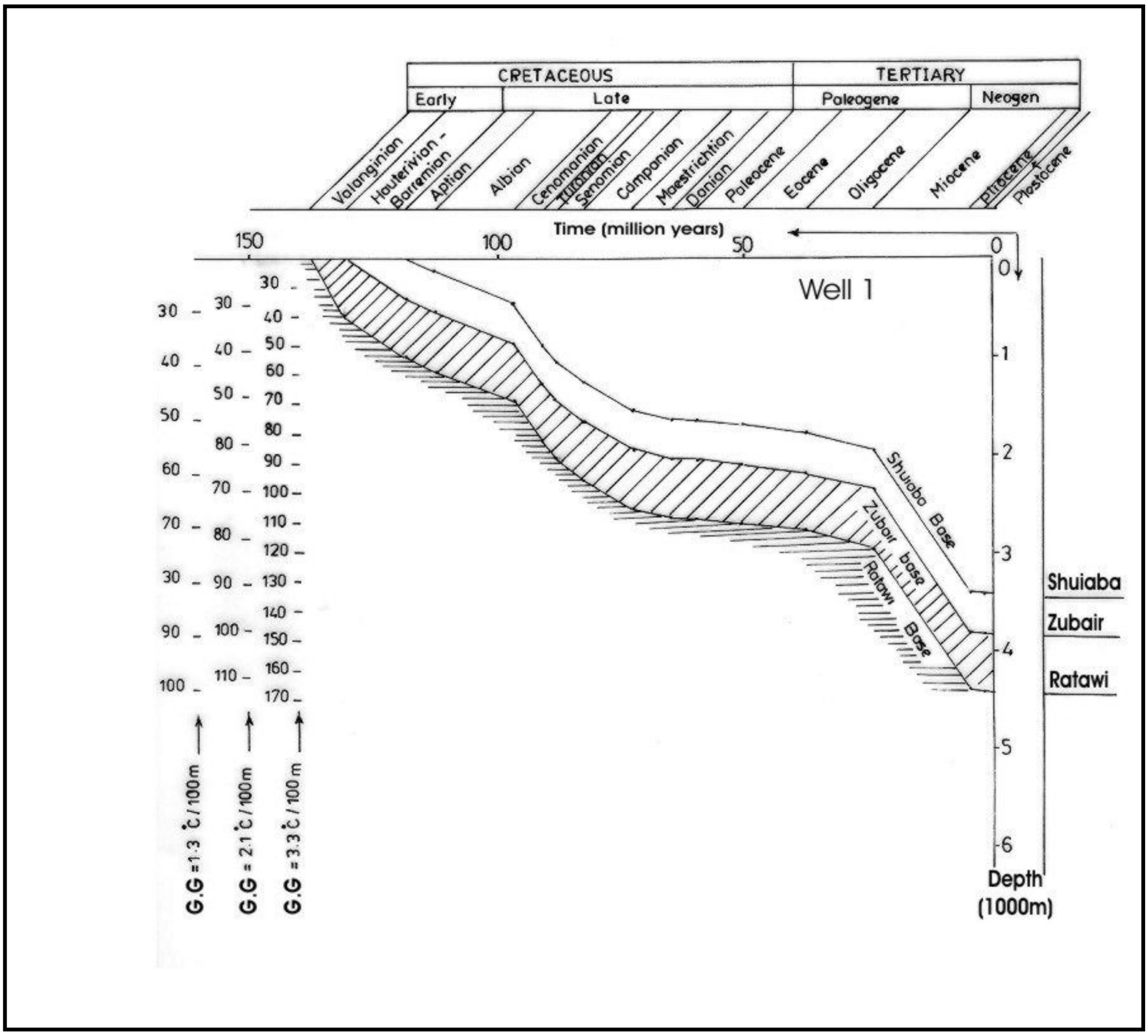

Fig. 3 : Burial history of Ratawi and Zubair formations in well (1).

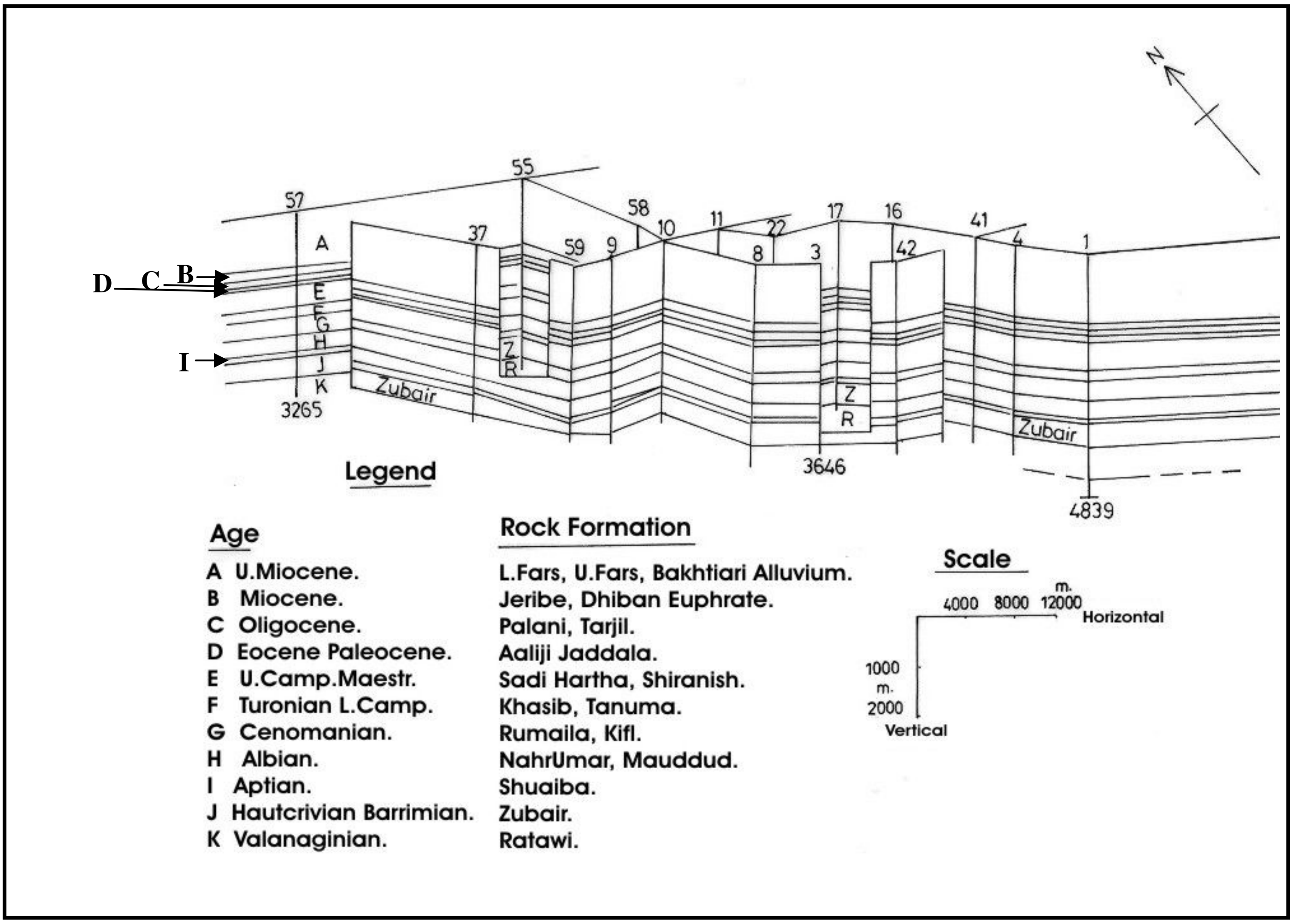

Fig. 4 : Panel diagram of East-Baghdad oilfield.

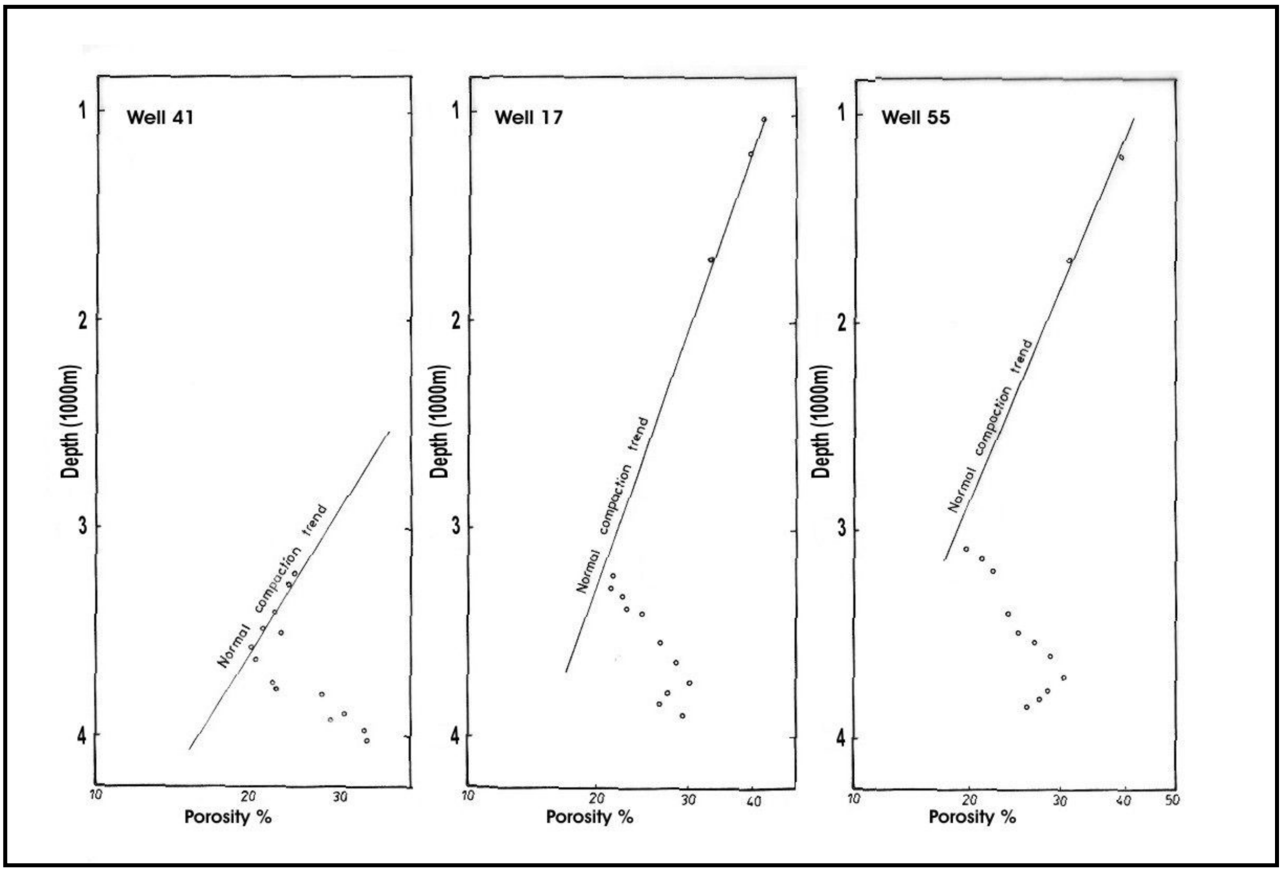

Fig. 5 : Compaction trend in selected wells.

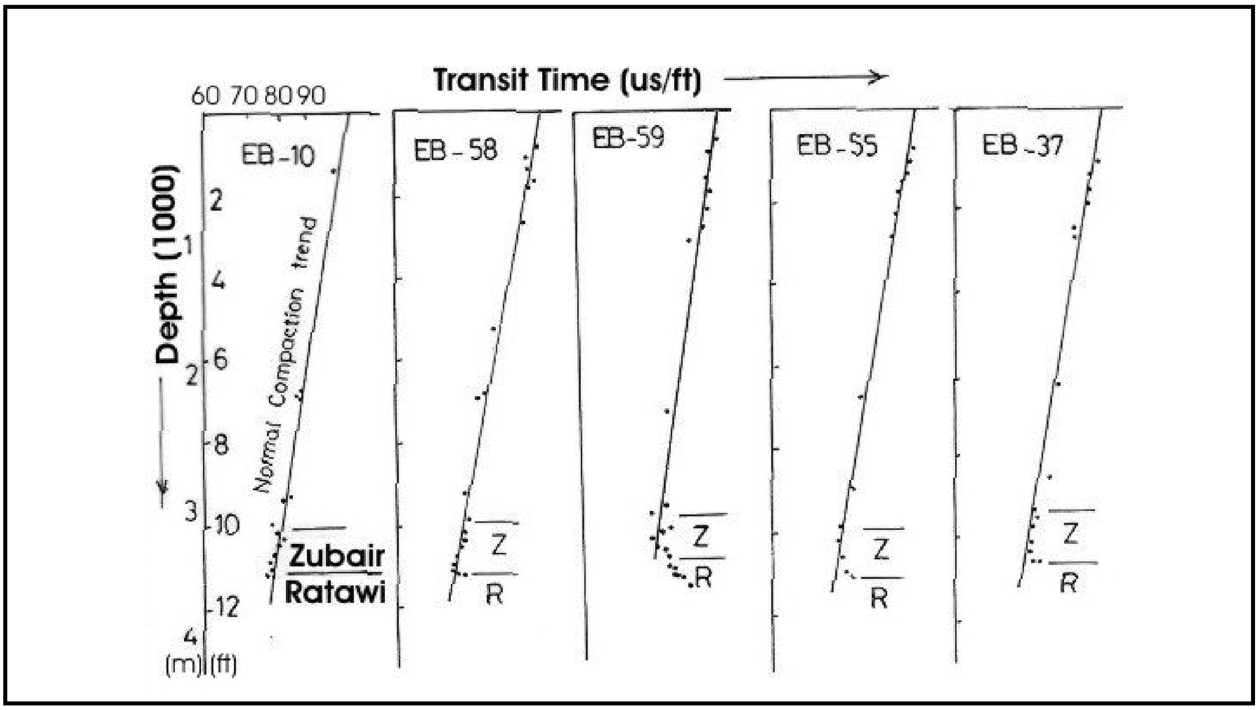

Fig. 6 : Shale transit time Δt with increasing depth in Zubair and Ratawi formations (wells 10, 58, 59, 55 and 37).

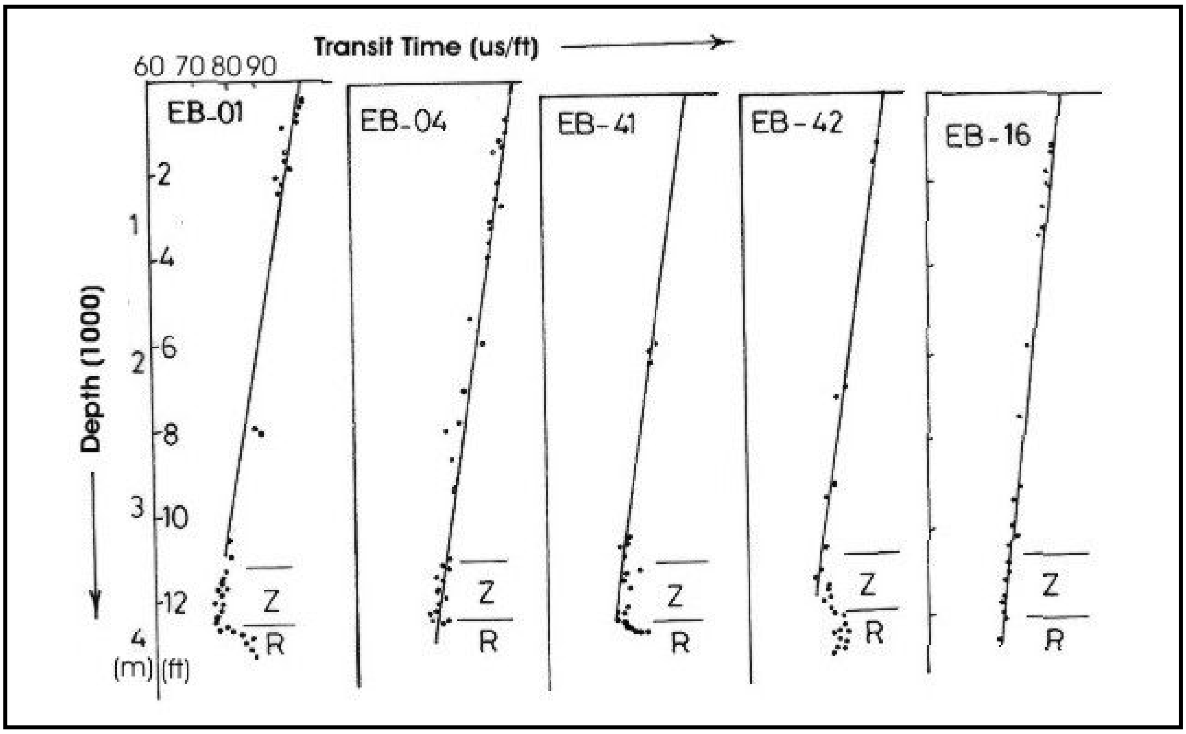

Fig. 7 : Shale transit time Δt with increasing depth in Zubair and Ratawi formations (wells 1, 4, 41, 42 and 16).

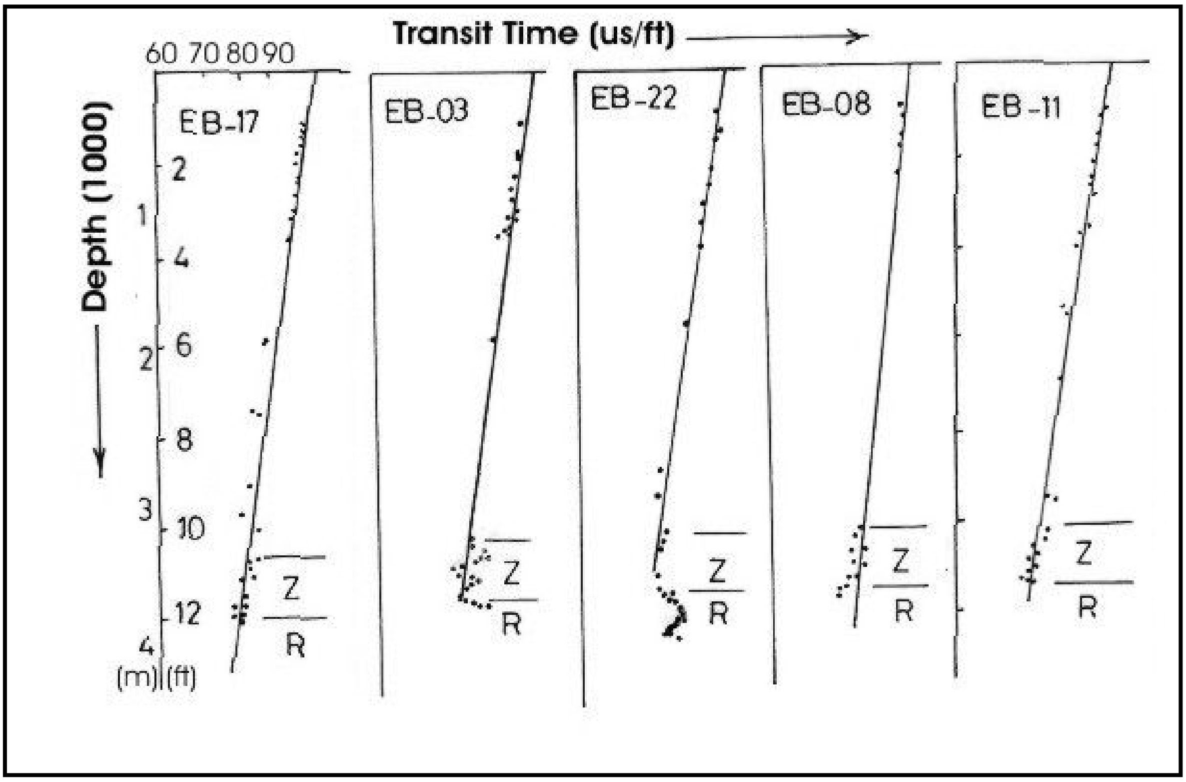

Fig. 8 : Shale transit time Δt with increasing depth in Zubair and Ratawi formations (wells 17, 3, 22, 8 and 11).

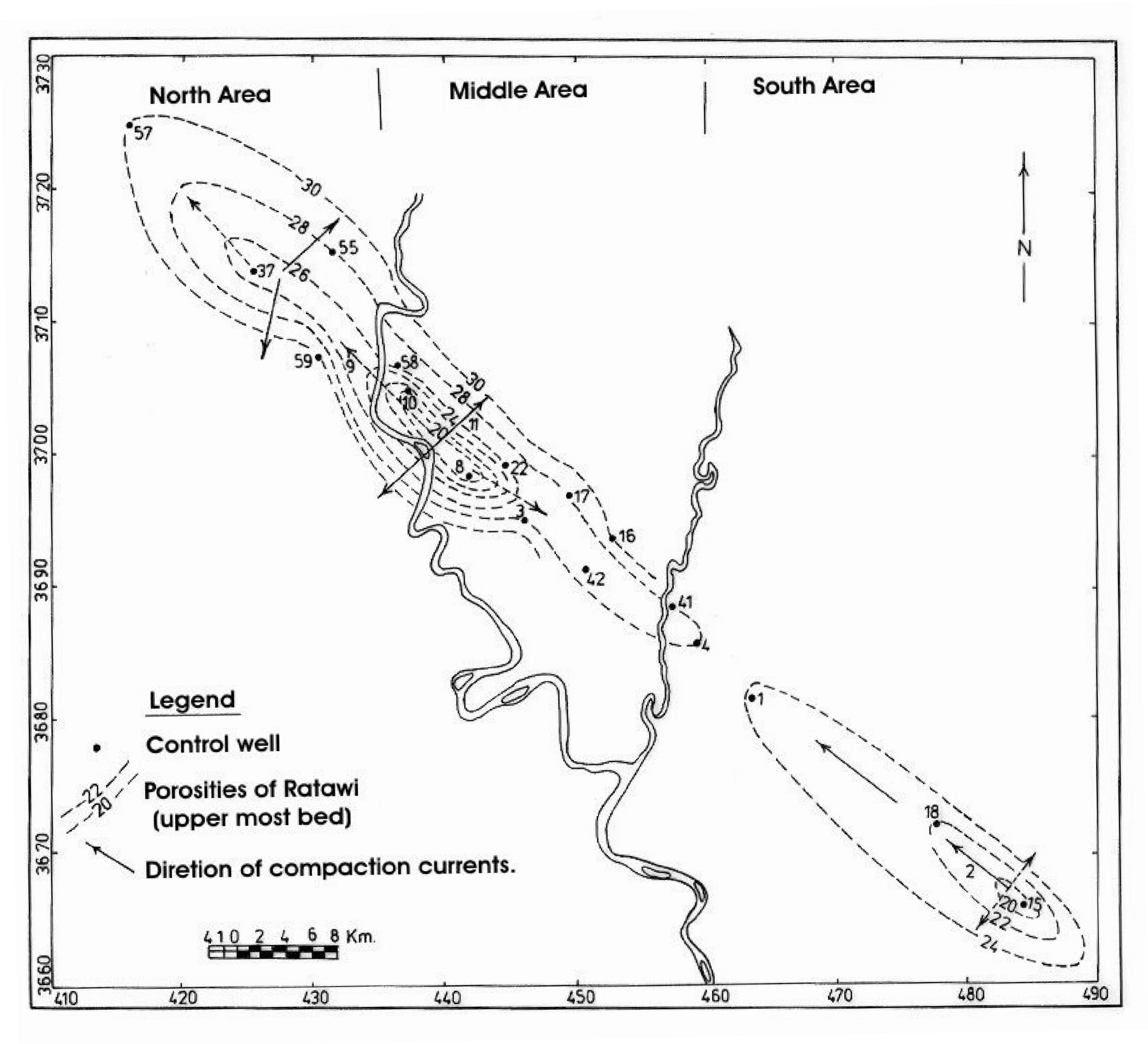

Fig. 9 : The varied direction of compaction current in the mudstone of Upper Ratawi

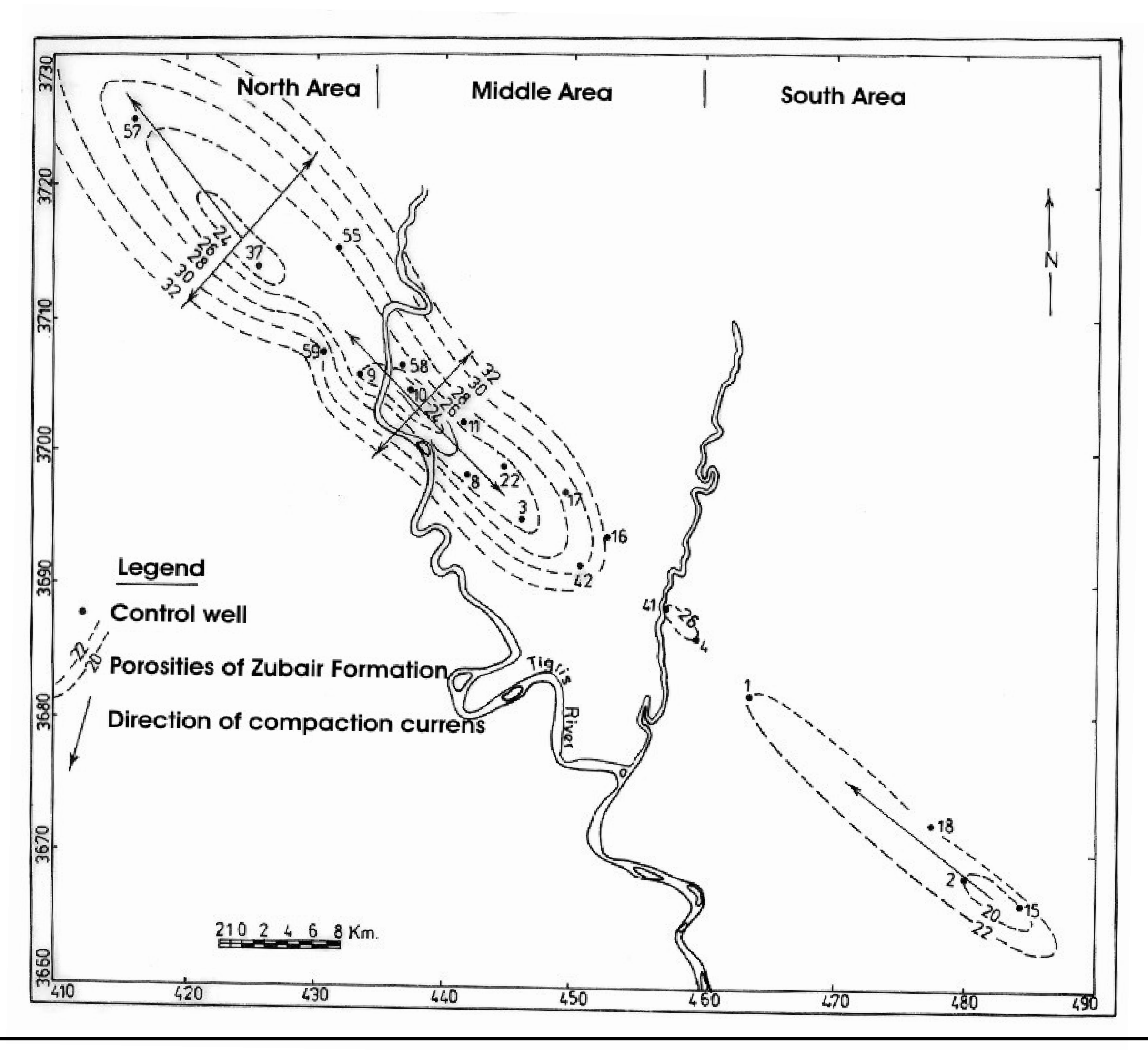

Fig. 10 : The varied direction of compaction current in the mudstone of Zubair formation.