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ORIGINAL ARTICLE

Basin modeling analysis and organic maturation for selected wells from different oil fields, Southern Iraq

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Abstract One dimension petroleum system modeling was performed on selected wells located within four oil fields in Southern Iraq, these are: Rumila, Subba, Tuba and Ratawi. The geo history analysis was applied for the studied fields; and it shows that the stratigraphic section contains many periods which are different in the tectonic and sedimentary subsidence, burial history, sedimentary, and erosion rates. It was seen that the burial depth was greater in the Ratawi oil field than the other fields. There is a different period of subsidence, which ranges from high to moderate subsidence, occurred at upper Jurassic to Mid-Cretaceous. Also, special uplift occurred in the Miocene and moderate subsidence occurred during the Paleogene. Four unconformities took place during the geological history of the Mesopotamian basin. In general, there is similarity to the burial histories that indicates all formations were deposited in the same basin of the studied oil fields, which was effected by the tectonic and sedimentary subsidence. Heat flow is in range (27–70 mW/m^2) which influence in the thermal maturity.

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Introduction

The term of basin modelling is widely used for a range of geological disciplines such as formation analyses, thermal evolution of sedimentary basins, and evaluation of potential hydrocarbon reserves. The aim of basin and petroleum system modelling is to predict the distribution and movement of petroleum within the basin and determining the generation, migration and accumulation of the hydrocarbons in addition to temperature history and pressures. PetroMod petroleum systems modeling software combines the seismic methods and geological information to build the evolution model of sedimentary basin (Hantschel and Kauerauf 2009). In order to assess the basin modelling, the following properties need to be calculated: (1) the burial and thermal history of the basin, (2) the maturity history of the source rocks, and (3) the expulsion, migration and trapping of hydrocarbons (Lerche 1990; Duppenbecker and Eliffe 1998).

The early Cretaceous–Miocene petroleum system is the most important hydrocarbon system in the Mesopotamian Basin. This petroleum system consist of effective petroleum source rocks (Sulaiy and Yamama Formations) as well as seal rocks (Tanuma, Shransih and Rus Formations),and reservoir rocks (Yamama,Zubair,NahrUmr, and Mishrif formations) (Aqrawi, et al., 2010). In this study the thermal maturity of various source rocks were calculated to evaluate the level of thermal maturity of the Cretaceous and Cenozoic formations in the southern Iraq. Hydrocarbon generation began in the late Paleocene and reached its peak at the Miocene period. The past geological history of the basin, the heat flow value and overburden pressure have been calculated to reconstruct the 1D basin modelling for the study area.

Geological setting

The study area consists of four oil fields, these are: Ratawi, Tuba, Subba and Rumila. One oil well from each field was used in this study, which are Rt-3, Tu-2, Su-9 and Ru-72 (Fig. 1). The study area is located within the Mesopotamian Zone according to Jassim and Goff (2006).This zone is subdivided into three subzone; these are: the Zubair, Euphrates and Tigris subzone. According to Numan (1997), the Mesopotamian Zone is located within the Sagged Basin of the Mesopotamian Zone according. There are no structural features can be seen on surface because of the high thickness of the Quaternary sediments that range from few meters up to 180 m (Fouad and Sissakian 2011). The Jurassic, Cretaceous and Tertiary rocks consider the most important petroleum systems in Iraq.

The Rumaila oil field is a giant oil field located in the southern Iraq, roughly 32 km from the Kuwaiti border. This field was discovered in 1953 by the Basrah Petroleum Company, combined with company of Iraq Petroleum Company (IPC). The predictable value of the field is 17 billion barrels, which stand for 12% of Iraq's oil reserves expected at 143.1 billion barrels. Therefore, Rumaila oil field represents the third largest oil field in the world (Alsharan and Narin 1997; Marius 2009).

The Ratawi oil field is located in the southern Iraq, about 70 km west of Basra city and about 12 km to the west of the North Rumaila, within Zubair subzone in the Mesopotamian zone according to the tectonic subdivision of Jassim and Goff (2006). Ratawi oil field was discovered for the first time by the gravitational surveys in 1940, then wiped with establishment of the Basrah Oil Company during the years 1947–1948 by applying the seismic method. Ratawi structure is assumed to be a low relief anticline thought faintly N–S elongated.

Subba oil field is located in Dhi-Qar governorate, in southern Iraq, about 70 km south–east of Nasiriyah city, and about 30 km north of Luhais field, in addition to 40 km

Fig. 1 Map of the study area (Almutury and Al-Asadi 2008)
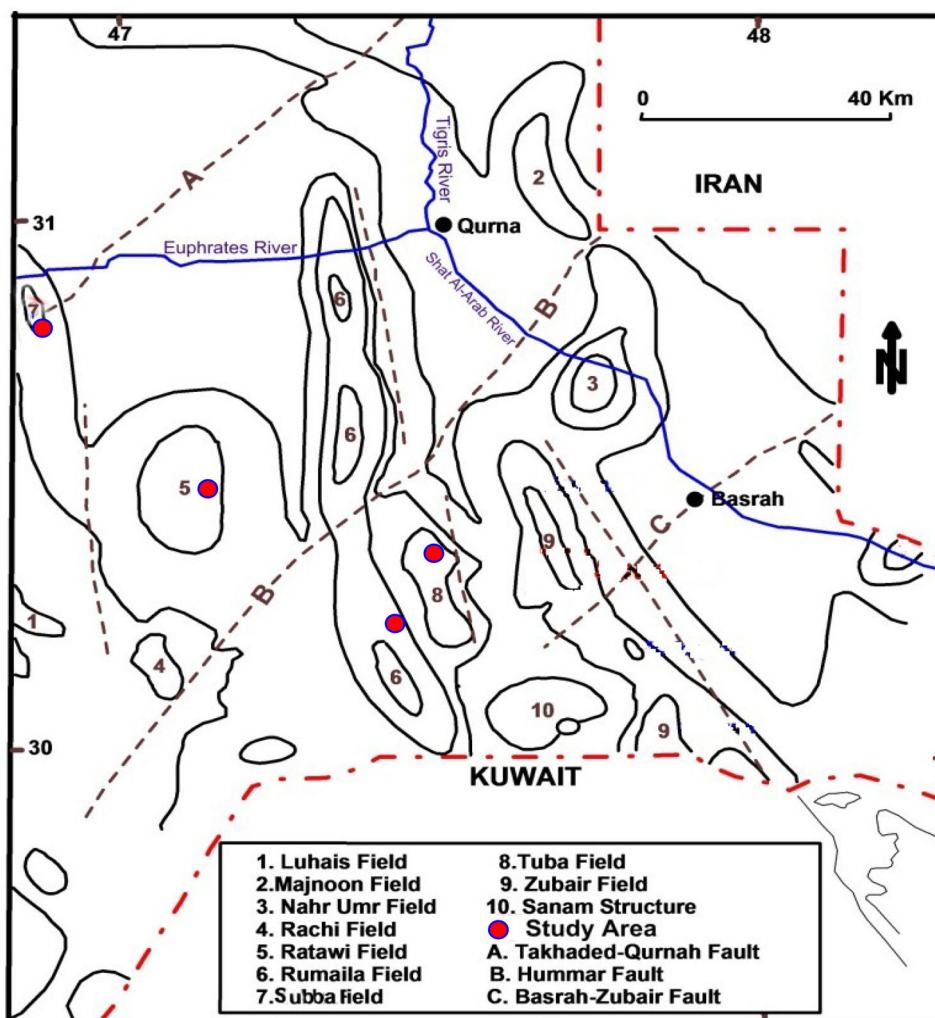
north–west of Ratawi field. The latest structural image shows that the field is a convex fold as regards 30 km long and 8.7 km wide. The axis trending fold is North–South (Al-Agaili 2012).

Tuba oil field is located about 40 km SW Basrah city. It is surrounded from east by Zubair oil field, about 5 km distance, and from west by Rumaila oil field, about 2 km distance. The field is separated by two depressions (Alrrawi et al. 2015).

Methods

One-dimensional modelling of burial history and thermal maturity was performed on four oil fields using PetroMod 1D (version 2011). PetroMode 1D is a software package that fully integrates seismic and geological interpretation with multi-dimensional simulation of thermal 3-phase fluid and petroleum migration histories in sedimentary basins. This software is combines among deposition, pore pressure calculation, compaction, heat flow analysis, temperature determination, the kinetics of calibration parameters, modeling of hydrocarbon generation, adsorption and expulsion processes, fluid analysis, and finally migration(Schlumberger 2011).The software basically needs huge information asan input data, these are:

Deposition

The upper surface of the layer is created during the sedimentation or removed by erosion process. It is supposed that the geological event of deposition and hiatus are identified, as a result, you can determine the paleo times of deposition to the layers,and then any new bed is calculated via porosity controlled backstripping form current thickness or impetrated form structural restoration programs (Hantuschel and Kaueranf 2009).

Porosity determination

Compaction and porosity are losing during the burial, and the question is how porosity can be expected in the subsurface. There are many methods to calculate the porosity, the best one is open hole well logs such assonic, neutron and density logs, then could be plotted versus depth to determine the compaction. The relationship between porosity and depth is exponential formula (Allen and Allen 2005).

$$\phi_P = \phi_\circ e^{-cZ}$$

where ϕ_P: porosity at depth (z) $\phi_\circ$: initial porosity {0.49 for Sandstone, 0.55 for Shale, 0.52 for Limestone, 0.42 for Dolomite}c: coefficient (the slope of porosity − depth) curve {0.0003 for Sandstone, 0.0005 for Shale, 0.0006 for Limestone, 0.0004 for Dolomite}

Eroded thickness

The following equation to determine the eroded thickness as input data in PetroMod software:

$$Eroded\ thickness = T_\circ \times \frac{age\ of\ erosion}{age\ of\ deposition}$$

$$Eroded\ thickness = R_F \times 10 \times age\ of\ erosion$$

where $T_\circ$ is the original sediment thickness.

Sediment decompaction

The first step in backstripping is to reconstruct the original sediment thickness $T_\circ$ of growing sedimentary fill from the basin floor up to date stratigraphic boundaries in particular exposure or well logs (Al-Matary and Ahmed 2011). The present porosity (ϕ_P) and present—thickness (T_P) were used in the following equation to determine the $T_\circ$:

$$T_\circ = \frac{(1 - \phi_P)}{(1 - \phi_\circ)} \times T_P$$

Heat flow

Heat can be transferred by conduction and radiation in sediments (Beardsmore and Call 2001). The main boundary conditions for heat flow analysis in sediments are the sediment–water–interface temperature and the basal heat flow. Mechanical and thermal processes of the crust and mantel are lead to magnitude, orientation and distribution of the heat flow at the baseof the sediments (Allen and Allen 2005).The following equation used to calculate the heat flow: (Mccullogh and Nasser 1989).

$$Q_z = k\frac{dt}{dz}$$

where Q_z: vertical component of heat flow (MW m^{-1})k: thermal conductivity (Wm^{-1} °C^{-1}) dt/dz: geothermal gradient (°C/km).

The following equation used to calculate the thermal conductivity: (Selley 1998)

$$k = k_m^{(1-\phi)} * k_w^\phi$$

where k: bulk thermal conductivity, kw: water conductivity (0.59 Wm^{-1} °C^{-1}), φ: porosity (%), which calculates from well logs, k_m: rock matrix conductivity (1.45 for shale, 3.75 for dolomite, 2.64 for sandstone, 2.56 for limestone, 5.4 for anhydrite).

Date of heat flow calculations is gathered and estimated as follows: (1) values of porosity were derived from well logs, such as density and sonic. (2) K$_m$ values were obtained from lithological sections of the wells and assign constant value for each lithology unit. (3) Geothermal gradient was estimated

Fig. 2 Heat flow results of the studied wells
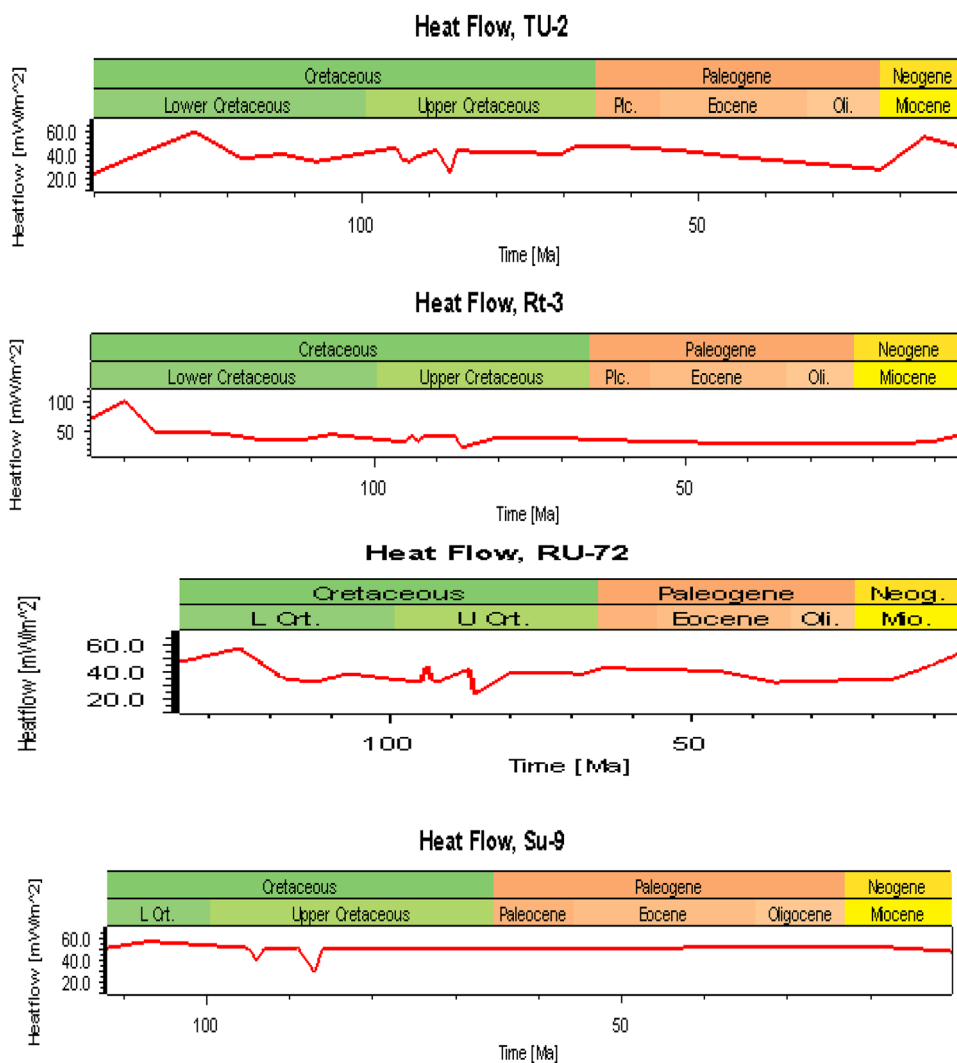
after knowing the values of Ts, TD and BHT from well logs records. By applying equation-reasonable good values of heat value were obtained for the study area that ranges from (24–70 MW/m^2) (Fig. 2), which may reflects the maturity of the organic matter, as well as there is notable decreasing in the heat flow value during the upper cetaceous especially at 88 M. Y in Khasib Formation. Generally, there are slightly differences between the studied wells in the heat flow values.

After running PetroMod software, many results for the evaluation of petroleum system were obtained such as thermal conductivity, porosity, heat flow, all types of pressure, burial history, thermal history and vitrinite reflectance. The important outputs are:

Porosity

Porosity is defined as the ratio of the pore volume to bulk volume of the rock. In oil and gas reservoirs, the pore volume is the space available for the storage of the hydrocarbons and water. The porosity of typical hydrocarbon productive sandstones ranges between 3 and 38% in gas reservoir and 10–38% in oil reservoir (Bowen 2005). Porosity in carbonate rocks can be much more variable in magnitude than sandstone; it is very high, in few cases exceeding 47%. The development of vuggs and fractures as found in carbonate reservoir rocks is termed as a secondary porosity and is a function of the depositional history and diagenesis for the rocks (Fig. 3). The porosity in the studied oil fields is almost same, it present less value in the evaporatic formations such as Gotnia formation, while it represent high value in the carbonate formations which effected by secondary porosity such as Ghar and Dammam formations.

Thermal history

Simulation of burial and thermal histories is significant to build up the conceptual models which define the relationship between the geology and data used (Welte andYükler
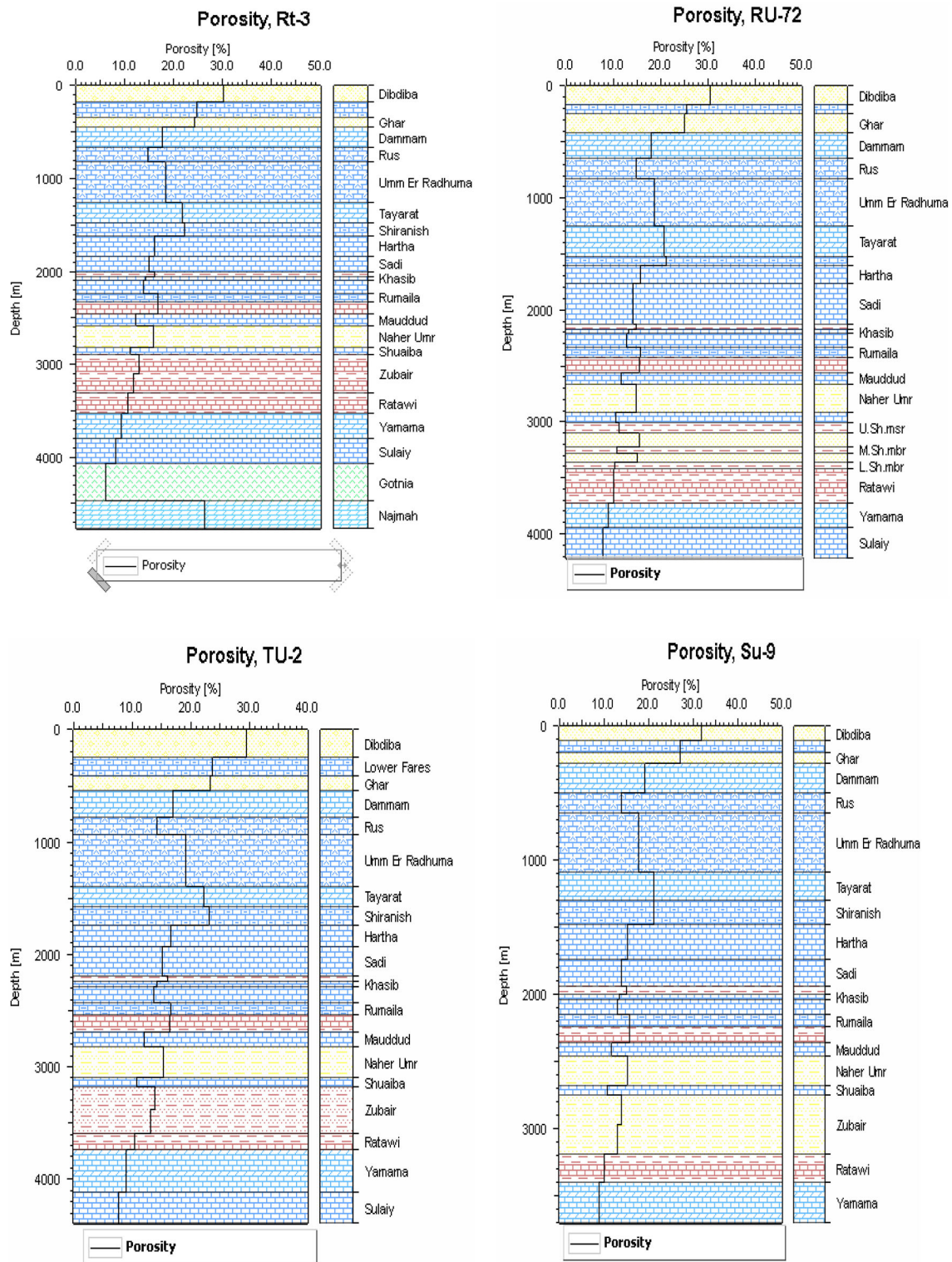
Fig. 3 Porosity of the studied wells

1981). To conclude the oil and gas potential of the basin and to estimate the reservoir porosities, the burial and thermal histories must be used and come together with information on thermal maturity, then the result become powerful tool in evaluating the timing of oil migration (Allen and Allen 2005).The time of maximum temperature and burial have great importance for the petroleum system in the study area. For the most of studied wells, the
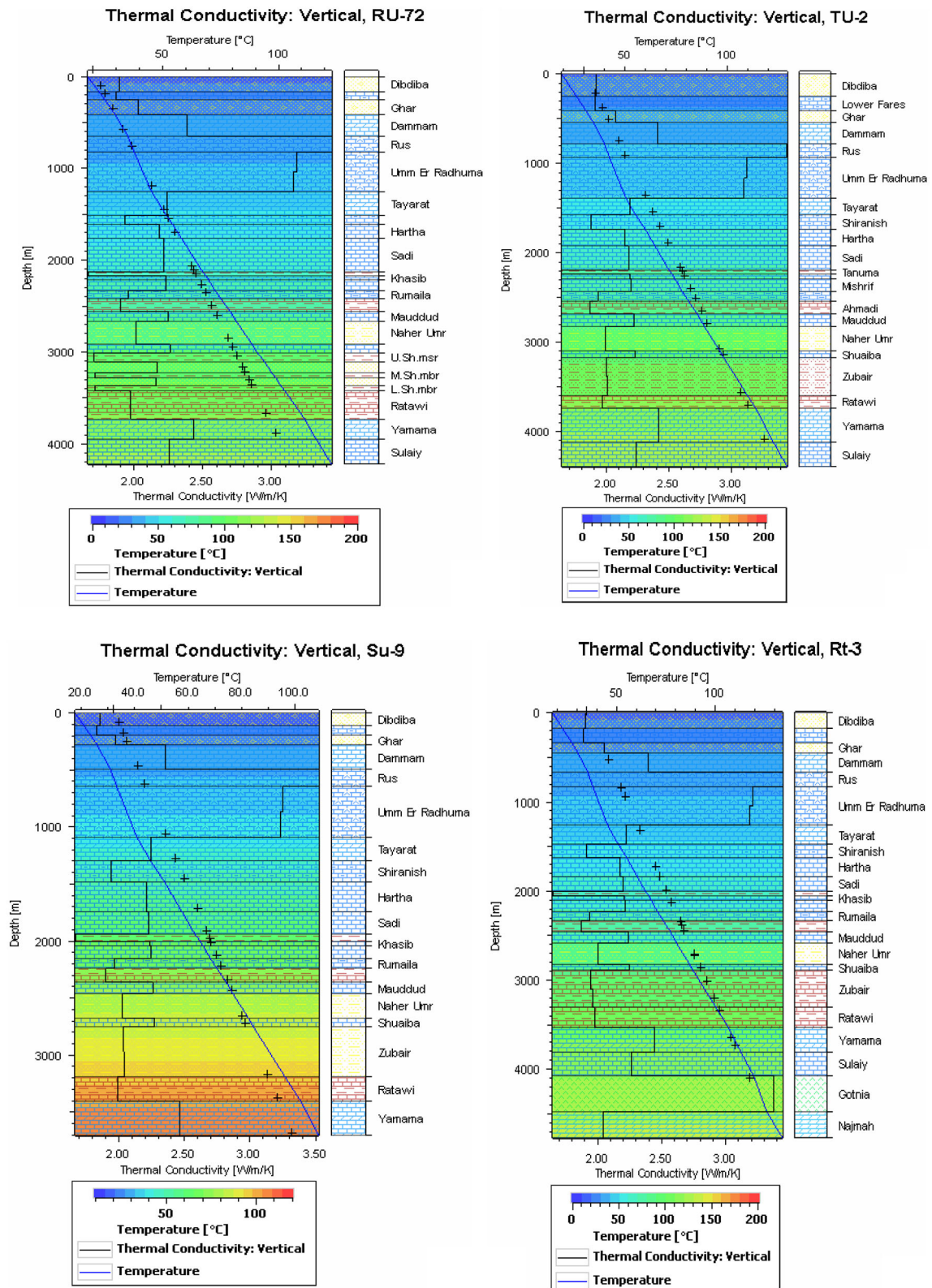
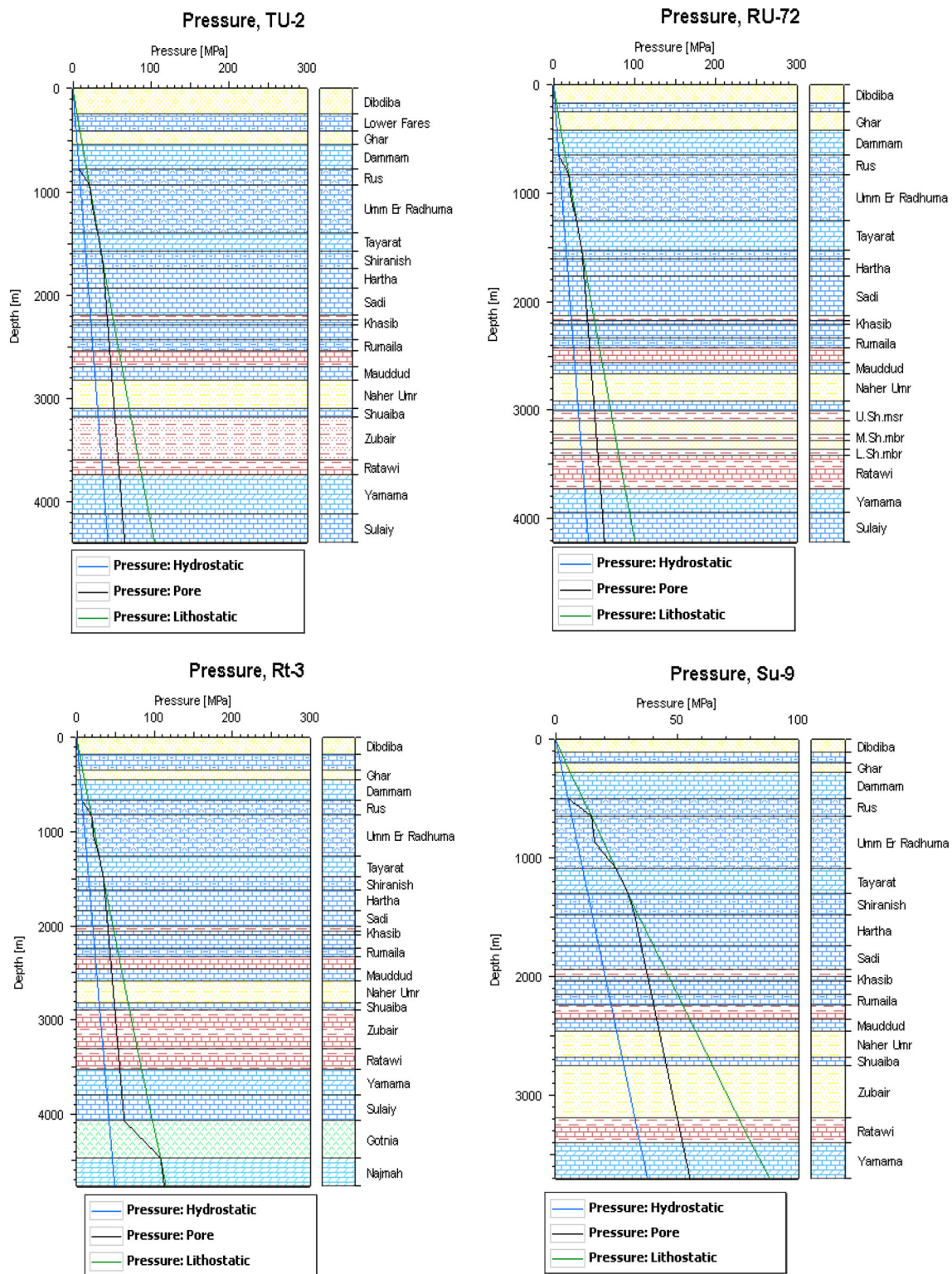Fig. 4 Thermal conductivity for the studied wells

Fig. 5 The pressure of the studied wells

Paleocene to Miocene age present the perfect time for the maximum prevailed temperature that associated with deep burial. In all of the studied area, deep burial was followed by erosion in Pliocene and Miocene, and could be that the age is the late petroleum generation and an additional filling of traps.
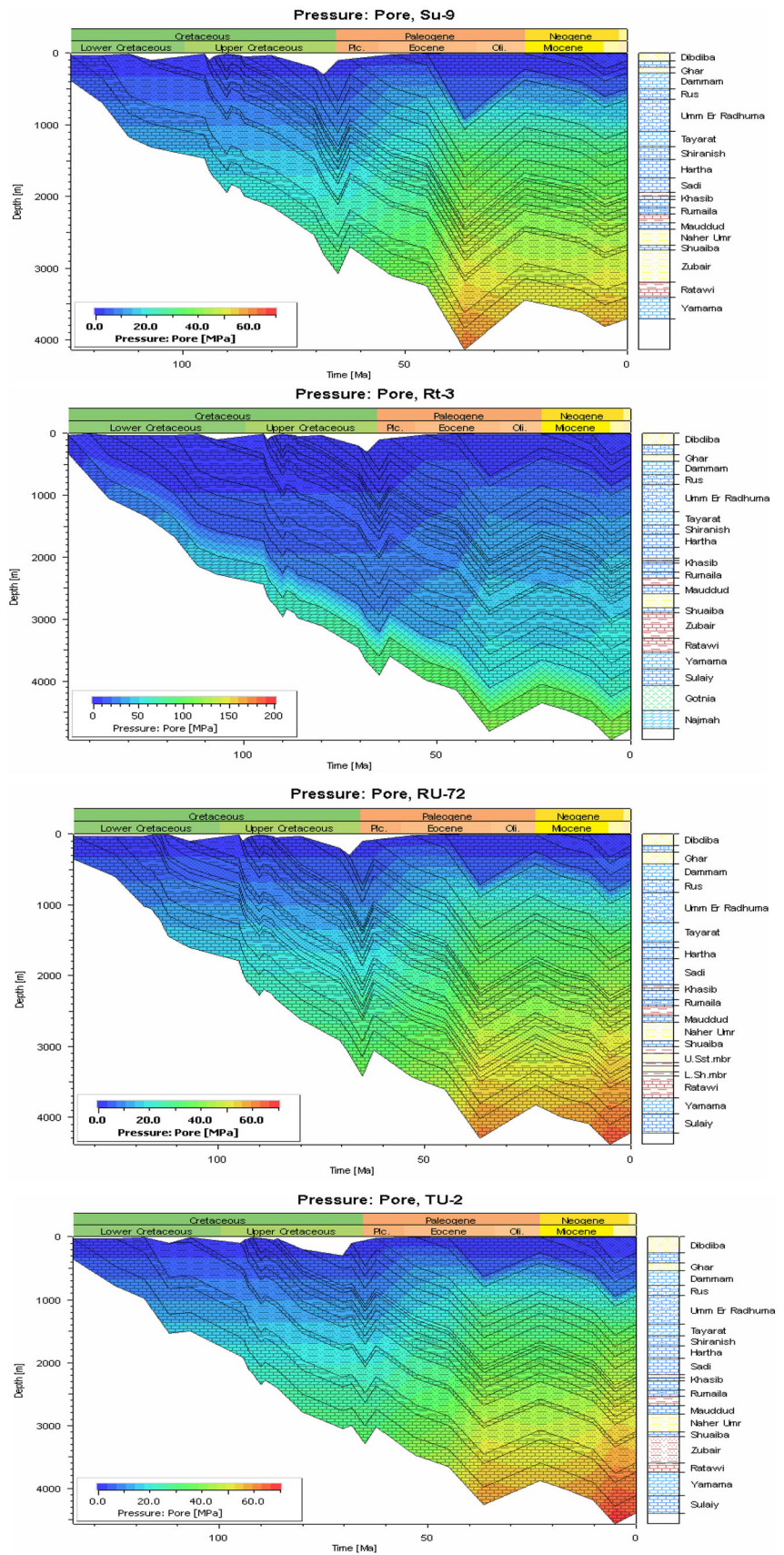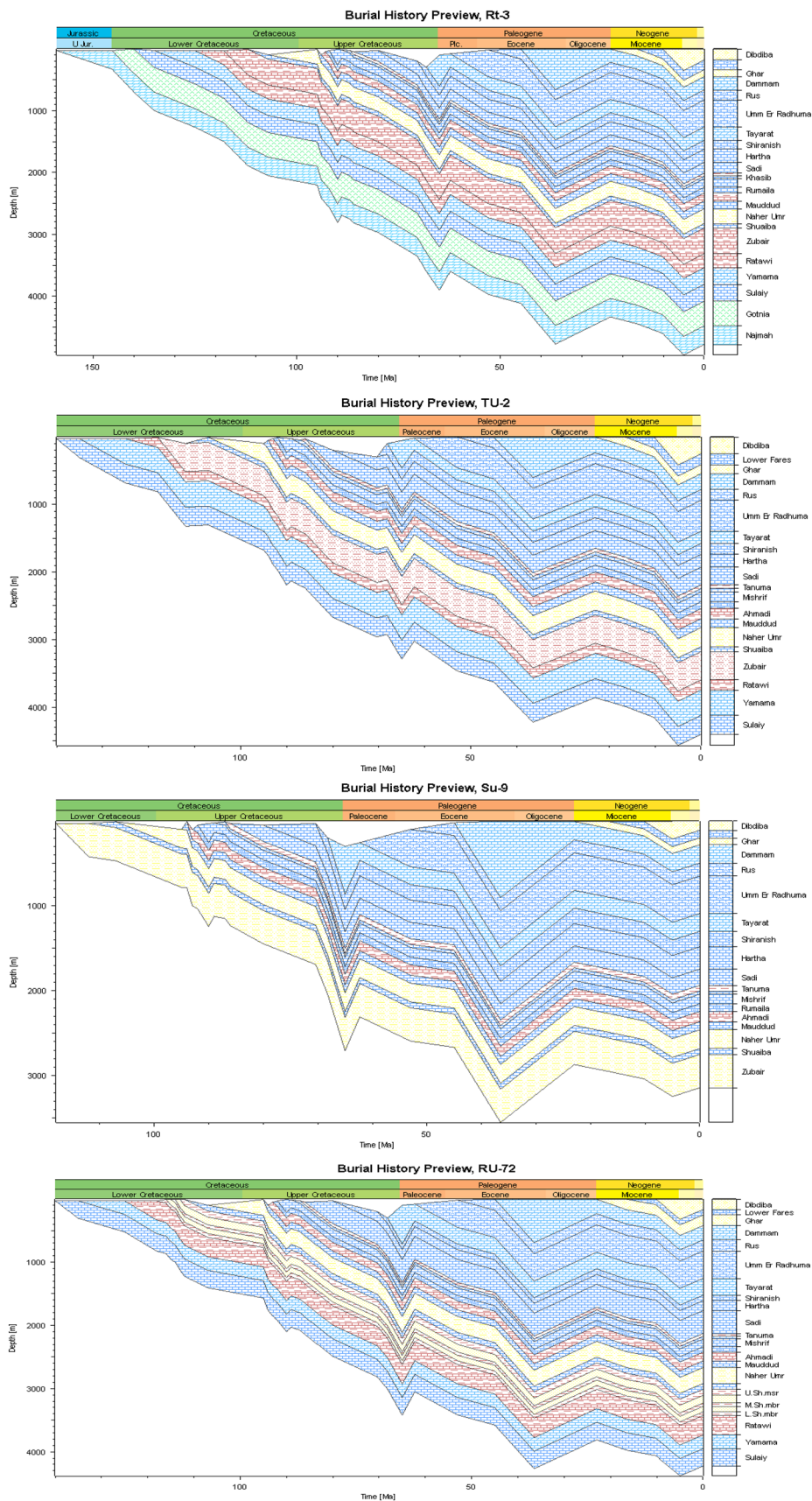
Fig. 6 Pore pressure of the studied wells

Fig. 7 Burial history of the studied wells

Thermal conductivity

Conductive heat transport is the primary method to identify the distribution of temperature with depth (geotherm) in the continents (Allen and Allen 2005). Thermal conductivities of sediments vary as a function of depth because of their porosity loss with burial. Thermal conductivity is largely depending on the lithology of formations, therefore if the high thermal conductivity minerals (Quartz, Halite and Anhydrite) increased in the formations then the thermal conductivity will increase too. In the our studied fields, the Rt-3 well noted that the Rus Formations has high value of thermal conductivity in spite of having low geothermal gradient, while Khasib formation has low thermal conductivity in spite of having high geothermal gradient (Fig. 4). Most of the results are similar in the studied fields except the Ru-72 well is different in the other wells.

Pressure

Pressure is the force per unit area. Unit of pressure is (kg/cm^2) or (psi) or KPa. The products show particular curves for unique rock type that deposited with constant sedimentation rates for shale and silt stones. The pressure gradient in sandstone is equal to the hydrostatic gradient, while the pressure in the shale returns quickly back to almost the level of the pure shale curve. Hence, increase of pressure in seal could be much higher than in the lithostatic gradients (Hantuschel and Kaueranf 2009). All overburden loads above the seal are added to the pore pressure of all layers below the seal that caused increasing in lithostatic pressure. There are different factors effect on the pore pressure distribution; these are: the seal capacity, migration of fluids and gases, hydrocarbon column heights, hydrocarbon source rock maturation, the kinetics of vitrinite, and the evolution of basin structure and lithostratigraphy, in addition to compaction and hydrocarbon generation and cementation.

The occurrence and distribution of overpressure in the basin of study area, which is an active subduction wedge, by linking the stratigraphic and structural history of the basin (Fig. 5). The basin has a complex pore pressure distribution, with high overpressures in the Cretaceous through Paleogene section and variable overpressure in the Neogene sections (Fig. 6). Pore pressure is poorly predicted by depth. The model allows hypothesis testing to examine the role of mudstones as seals, faults in basin compartmentalization, the structural history of uplift and erosion, horizontal tectonic forces in the development and distribution of overpressure.

Burial history

The main data to build up the model of the studied burial history studies are: the thickness layer, lithology of each layer, age of deposition and erosion with eroded thickness, in addition paleo water depth, heat flow and surface temperature. Eroded thickness of the individual stratigraphic succession is necessary to construct burial history. A burial history usually has breaks or gaps in the stratigraphic column, because of stopping in the deposition or erosion process (Wangen 2010).The results of burial history of the study area are (Fig. 7):

1. Generally, there is resemblance in the output figures to the burial histories, that reflect the same geological events which happened to the studied oil fields, perhaps the well Su-9 is show a little different from the others, could be effected to the Takhaded-Qurnah fault.
2. Four distinctive unconformities occur during the geological history to the Mesopotamian basin.
3. Moderate to rapid subsidence periods during the geological history.It corresponds to the tectonic movement that effected in the Arabian plate motion and typical example to Peripheralforeland basin within overfilled phase.

Vitrinite reflectance (R_0)

Vitrinite reflectance is a percentage measure of the incident light that reflected from the surface of vitrinite particles in a sedimentary rock (Beaumont and Foster 1999). It is termed as $\%R_0$. It is optical parameters and is symbolized by VR or R_0 (reflectance in oil) (Tissot and Welte 1984). Vitrinite is a coalification product of humic substance which is originated from the lignin and cellulose of plant cell wells (Tayloret al. 1998).

The relationship between $\%R_0$ and hydrocarbon generation is dependent on the chemistry of the vitrinite as well as the chemistry of the kerogen (Beaumont and Foster 1999). Sweeny and Burnham (1990) evaluated simple

Table 1 Easy vitrinite reflectance after Sweeny and Burnham (1990)

0.25–0.55	Immature
0.55–0.70	Early oil
0.7–1.00	Main oil
1.00–1.30	Late oil
1.30–2.00	Wet gas
2.00–4.00	Dry gas
>4.0	Over mature

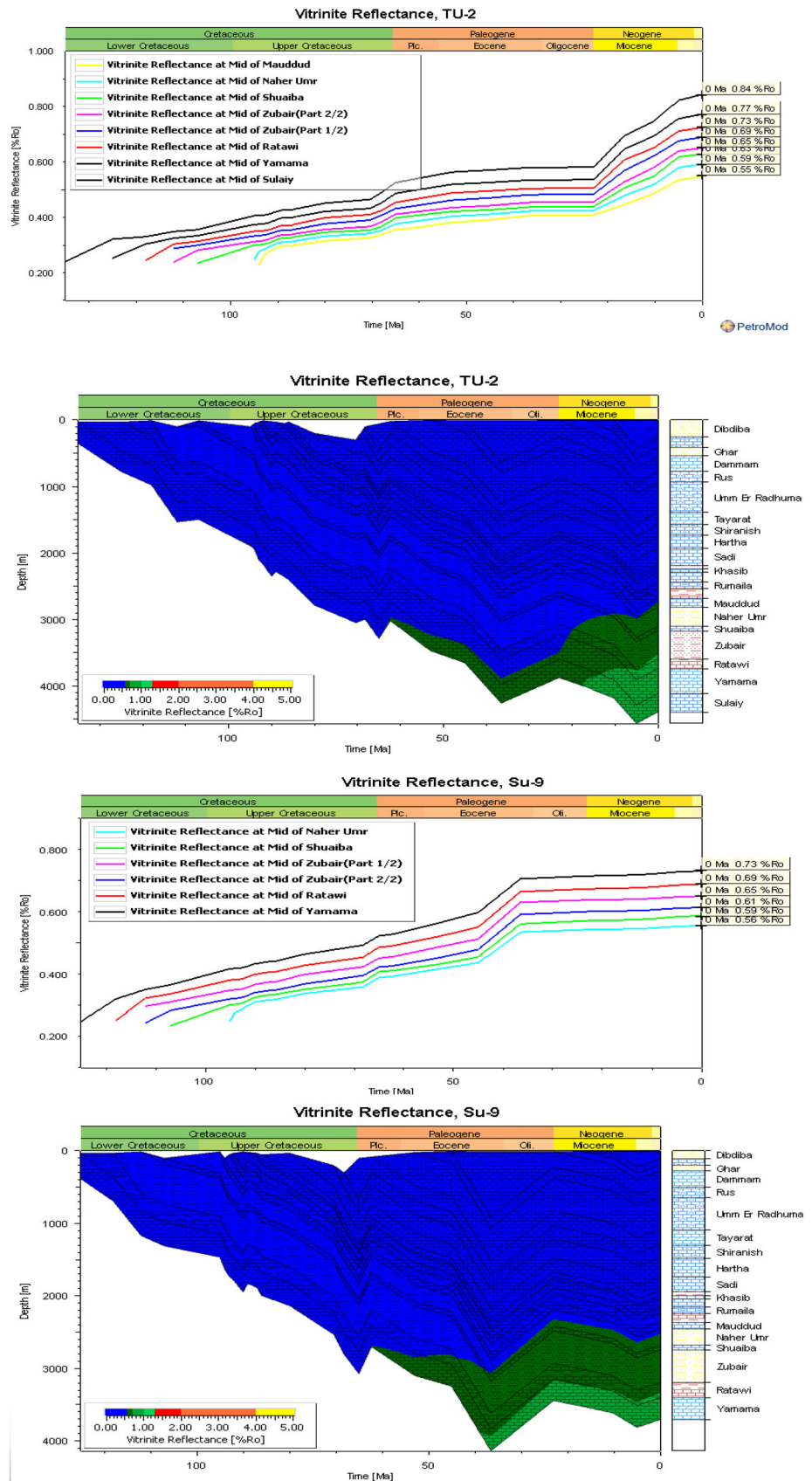**Fig. 8** Vitrinite reflectance for
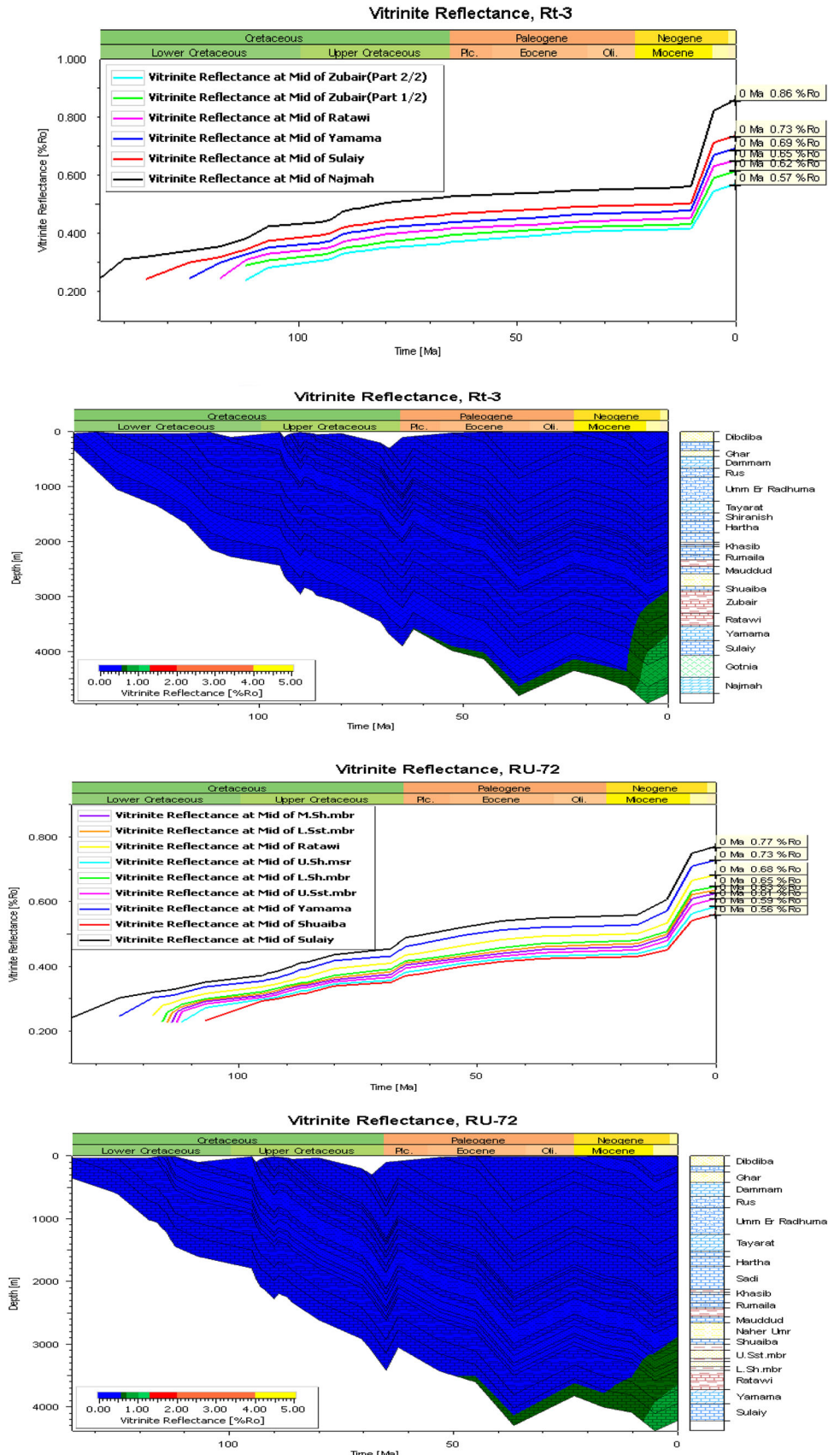the study area

Fig. 8 continued

Table 2 Vitirinite reflectance values, Transformation ratio (T_R) Generation mass for the studied wells

Well no.	Formation	R_0 %	Time (Ma)	Stage	Formation	Ro %	Time (Ma)	Stage
Tu-2	Sulaiy	0.84	0	Main oil	Zubair (2/2)	0.65	0	Early oil
	Yamama	0.77	0	Main oil	Shuaiba	0.63	0	Early oil
	Ratawi	0.73	0	Main oil	Nahr Umr	0.59	0	Early oil
	Zubair(1/2)	0.69	0	Early oil	Mauddud	0.55	0	Early oil
Su-9	Yamama	0.73	0	Main oil	Zubair (2/2)	0.61	0	Early oil
	Ratawi	0.69	0	Early oil	Shuaiba	0.59	0	Early oil
	Zubair(1/2)	0.65	0	Early oil	Nahr Umr	0.56	0	Early oil
Rt-3	Najmah	0.86	0	Main oil	Ratawi	0.65	0	Early oil
	Sulaiy	0.73	0	Main oil	Zubair (1/2)	0.62	0	Early oil
	Yamama	0.69	0	Early oil	Zubair (2/2)	0.57	0	Early oil
Ru-72	Sulaiy	0.77	0	Main oil	Zubair (m. sh. member)	0.63	0	Early oil
	Yamama	0.73		Main oil	Zubair (U. ss. member)	0.61	0	Early oil
	Ratawi	0.68	0	Early oil	Zubair (u. sh. member)	0.59	0	Early oil
	Zubair (L.sh.member)	0.65	0	Early oil	Shuaiba	0.56	0	Early oil
	Zubair (l.ss.member)	0.64	0	Early oil				

model of R_0 based on chemical kinetics due to changes in vitrinite composition with time and temperature (Table 1).

It is clear from these figures that the vitrinite reflectance for all studied formation belongs to our study area, have differ values according to its data, the results are shown in Fig. 8 and Table 2. Comparison between Tu-2 and Su-9 wells shows that the Vitirinite reflectance values in Tu-2 were higher than Su-9; and the comparison between Tu-2 and Ru-72 wells shows the Vitirinite reflectance values in Tu-2 were higher than Ru-72. The comparison between Tu-2 and Rt-3 wells, the Vitirinite reflectance values in Tu-2 have higher than that for Rt-3. The comparison between Su-9 and Ru-72 wells, the Vitirinite reflectance values in Su-9 have higher than that for Ru-72. The order of Vitirinite reflectance values for interested area was follows: Tu-2 > Su-9 > Ru-72 > Rt-3 (Fig. 8).

Conclusions

1. Geohistory analysis applied on four oil fields. The results showed that the stratigraphic section of the study area contains periods that are different in tectonic and sedimentary subsidence, burial history, sedimentary and erosion rates. It was seen that the burial depth was greater in the Tuba Field in compared with other fields in the study area. There are different periods of subsidence during the geological age in the study area. The subsidence is high to moderate at Upper Jurassic to Mid Cretaceous, which was tectonic subsidence. Slow subsidence with distinctive uplift represented at Miocene.

2. There is similarity in the burial histories of the study area. It indicated that the formations are deposit in the same basin to the studied oil fields, which was effected by tectonic and sedimentary subsidence.

3. The thermal conductivity of Rt-3 wellin Rus formation has the high values of thermal conductivities in spite of the low geothermal gradient, while the Khasib formation has low thermal conductivities in spite of the high geothermal gradient.

4. Heat flow rangesfrom 27–70 mW/m^2, and it affects the thermal maturity in the study area. There is notable decreasing in the heat flow value during the upper Cretaceous, especially in the Khasib formation. Generally, there is similarity in the results among the studied oil field.

5. The porosity in the studied oil fields is almost the same. The less value of porosity was measured in the evaporatic formations, while it was higher in the carbonate formations due to the secondary porosity.

6. The basin of studied area has a complex pore pressure distribution with high overpressures in the Cretaceous through Paleogene section and variable overpressure in the Neogene Sects.

7. The organic maturation increasing towards the Tuba Oil Fields (Tu-2) which have greater maturation than others Oil Fields (Su-9, Ru-72, Rt-3). The processes of organic maturity have been started at early Tertiary. Due to the increasing of sedimentary burial through Miocene, the rocks become more mature in the study area.

8. The organic maturation in the region has entered in the main oil stage, especially Suliay and Yamama formations. Therefore, they are good generated and mature source rocks in the studied wells.

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