

Jurassic Geology of Kuwait

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ABSTRACT

Until the late 1970s only one well penetrated the entire Jurassic section of Kuwait. A few other scattered wells partially penetrated it. During the 1980s an appreciable number of deep wells revealed that the Jurassic sequence is inverted with respect to the Cretaceous sequence and that the main Cretaceous arches were sites of Jurassic sedimentary troughs. This new interpretation marks a revolution in the existing concepts for Jurassic oil exploration in Kuwait. One of the most effective methods for defining of Jurassic structures is the isopach of the Upper Jurassic Gotnia Formation. The main Jurassic reservoirs include the Najmah, Sargelu and Marrat formations which were detected as a result of the exploration activities during the 1980s. Selective stratigraphic and structural cross-sections reveal the stratigraphic relationships of the Jurassic sediments.

INTRODUCTION

Between 1938, when oil was first discovered in Kuwait, and 1975, when the Kuwaiti oil industry was nationalized, all oil discoveries were limited to the Cretaceous and Tertiary reservoirs. Only three exploration wells were drilled to the Jurassic sequence: at Minagish, Sabiriyah and Burgan; however, these Jurassic tests were negative (Figure 1).

After 1975, a number of deep exploration wells discovered oil in three reservoirs within the Jurassic section: Unit "C" of the Marrat Formation and the Najmah and Sargelu formations. A development plan was subsequently established to produce these new reservoirs in Minagish, Magwa, Burgan, Umm-Gudair, Abduliyah and Dharif fields (Figure 1).

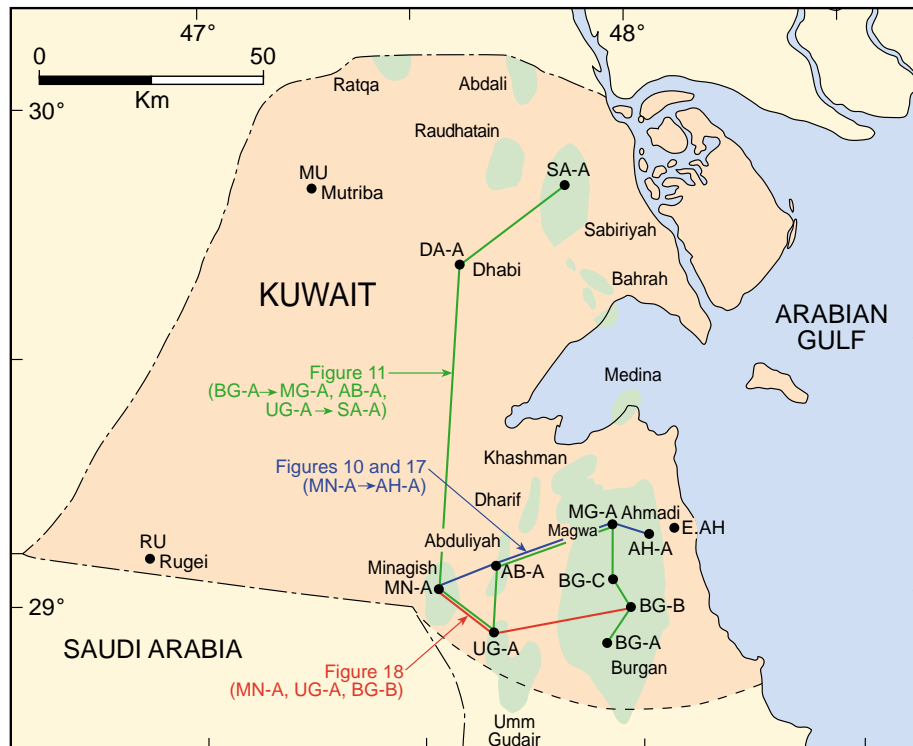


Figure 1: Location map of Kuwait showing oil fields, Jurassic wells and location of cross-sections.

This study combines results from published studies of the Jurassic in the Arabian Gulf, with data from geographically representative wells in Kuwait, to develop a regional model of the Jurassic System of Kuwait. Our study complements several other recent papers on the geology of Kuwait (e.g. Ali, 1995; Yousif and Nouman, 1995; Bou-Rabee, 1996; Carman, 1996).

We present a series of isopach maps and cross-sections to show the evolution of the depositional basins within Kuwait. Boundaries of the different Jurassic formations and sub-formations, determined in this study, are informal and are meant to suit the local requirements in Kuwait.

DEPOSITIONAL HISTORY

During the Early Jurassic (Liassic Epoch) the Arabian Gulf region was a vast carbonate-evaporite platform (Figure 2; Murriss, 1980). Further westwards the platform continued to receive substantial clastic influx from the west and southwest. Evaporitic conditions were limited to the northwestern half of this platform. Near the end of the Early Jurassic the climate became more humid and the deposition of anhydrites rare.

During the Middle Jurassic (Bathonian Age), a broad carbonate platform extended over the Arabian Gulf (Figure 2; Murriss, 1980). In the north mixed clastics and carbonates were deposited in a deeper marine shelf which extended over Kuwait. To the west and south the deposition was dominated by clastics and probably influenced by the Rimtham Arch to the south of Kuwait (Langdon and Malacek, 1987).

By the late Callovian (Middle Jurassic) major flooding of the platform caused the deposition of deeper-water, organic-rich source facies under euxinic conditions, within an intra-shelf basin which extends over Kuwait (Murriss, 1980). These deposits are a likely source for much of the Middle Jurassic oil found in the central part of the Arabian province (Murriss, 1980; Ayres et al., 1982; Wilson, 1984). The Najmah Formation in Kuwait is the time-equivalent strata of these source rocks.

By the Late Jurassic (late Oxfordian-early Kimmeridgian) siliciclastics were absent, and an intra-shelf basin extended over most of the platform (Figure 2; Murriss, 1980). The northern intra-shelf basin (Figure 2) is referred to as the Lurestan Basin by Murriss (1980) or the Gotnia Basin in more recent papers (e.g. Ali, 1995). During the latest Jurassic time (Tithonian) the climate became arid and extensive evaporites were deposited on a very shallow southern platform in a sabkha environment. At this time deposition in the northern Gulf consisted of basinal salt and laminated anhydrite and shale (Figure 2; Murriss, 1980).

In Figure 3, the regional isopach of the Jurassic illustrates the thickness variations of the section in the Arabian Gulf area (Kamen-Kaye, 1970). It shows that the thickest part of the basin develops northward towards Kuwait.

STRATIGRAPHY

Rock Stratigraphy

A reference section of the Jurassic sequence in Kuwait from the Minagish area is shown in Figure 4. The main Jurassic facies in Kuwait consist of evaporites, limestones and dolomites. Shales are subordinate. The Upper Jurassic Gotnia salt is developed in all of Kuwait. Ali (1995) describes the Upper Jurassic Gotnia Formation in Kuwait and also identifies Minagish-27 as the reference section in Kuwait.

Regionally, the Jurassic section in Kuwait thins towards the north (Figures 3 and 5). The thinnest section seen to date is at Dhabhi (DA-A), and the thickest section is in the Burgan area. In the southwestern corner of Kuwait, the partially penetrated Jurassic section in the Rugei area (RU) defines the thickest Upper Jurassic sequence. It is evident that the southern area of Kuwait forms the northern edge of the Jurassic basin in the Arabian Gulf region (Figures 3 and 5). This basin trends in a north-south direction and extends from Kuwait into Central Saudi Arabia.

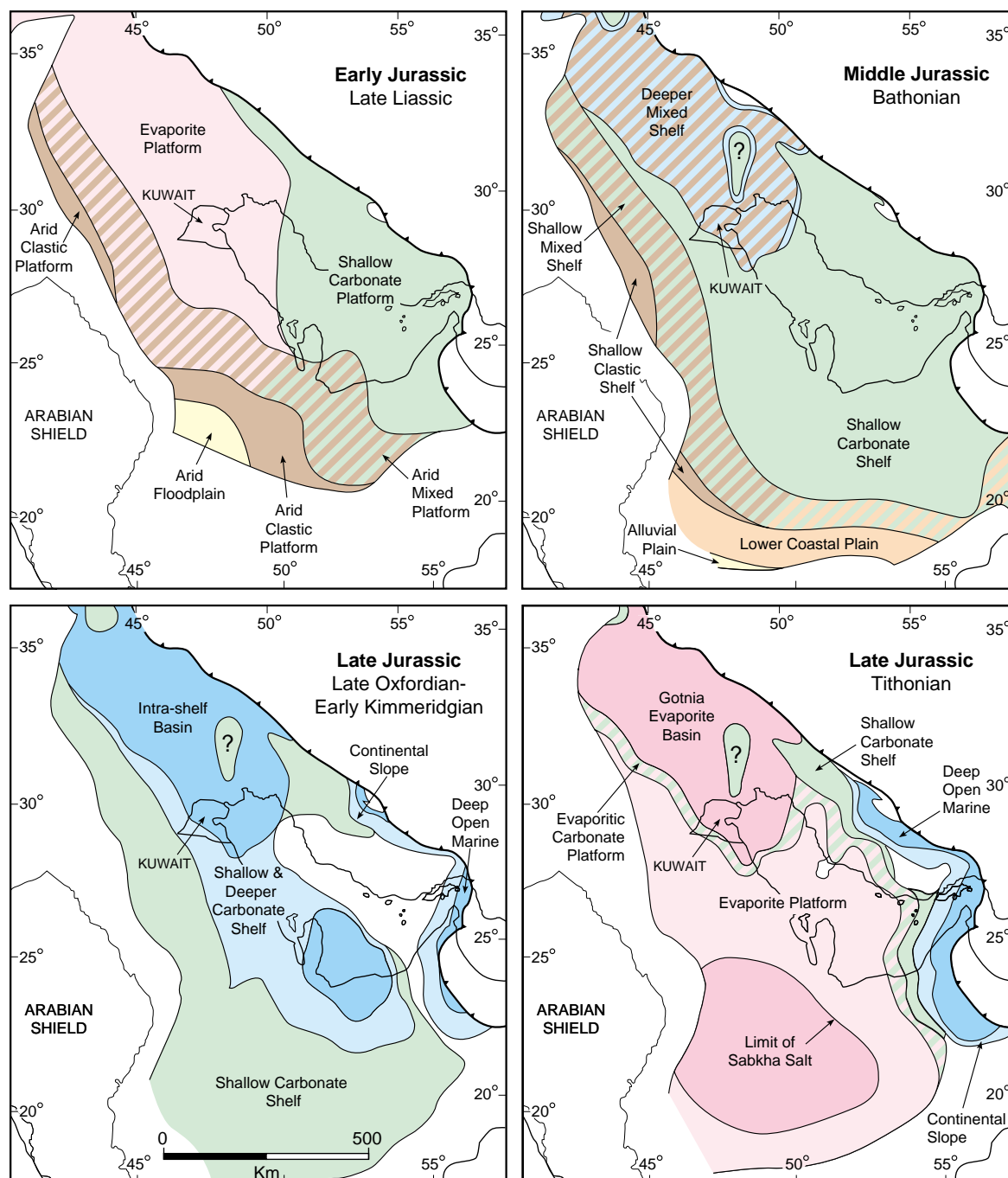


Figure 2: Jurassic environments of deposition in the Middle East (Murriss, 1980). During the Early Jurassic (Late Liassic, approximately 190 Ma) evaporitic deposition extended over Kuwait. During the Middle Jurassic (Bathonian, approximately 169-175 Ma) Kuwait was at the edge of a deeper-water mixed shelf. In Late Jurassic time (late Oxfordian to early Kimmeridgian, approximately 156 Ma) Kuwait was part of a deep, intra-shelf basin referred to as the “Lurestan Basin” by Murriss (1980) or the corresponding “Gotnia Basin” (Ayles et al., 1982; Ali, 1982). In the Late Jurassic (Tithonian, approximately 144 to 150 Ma) the Gotnia Formation, consisting of salt with laminated anhydrite and shale was deposited in the Gotnia Basin.

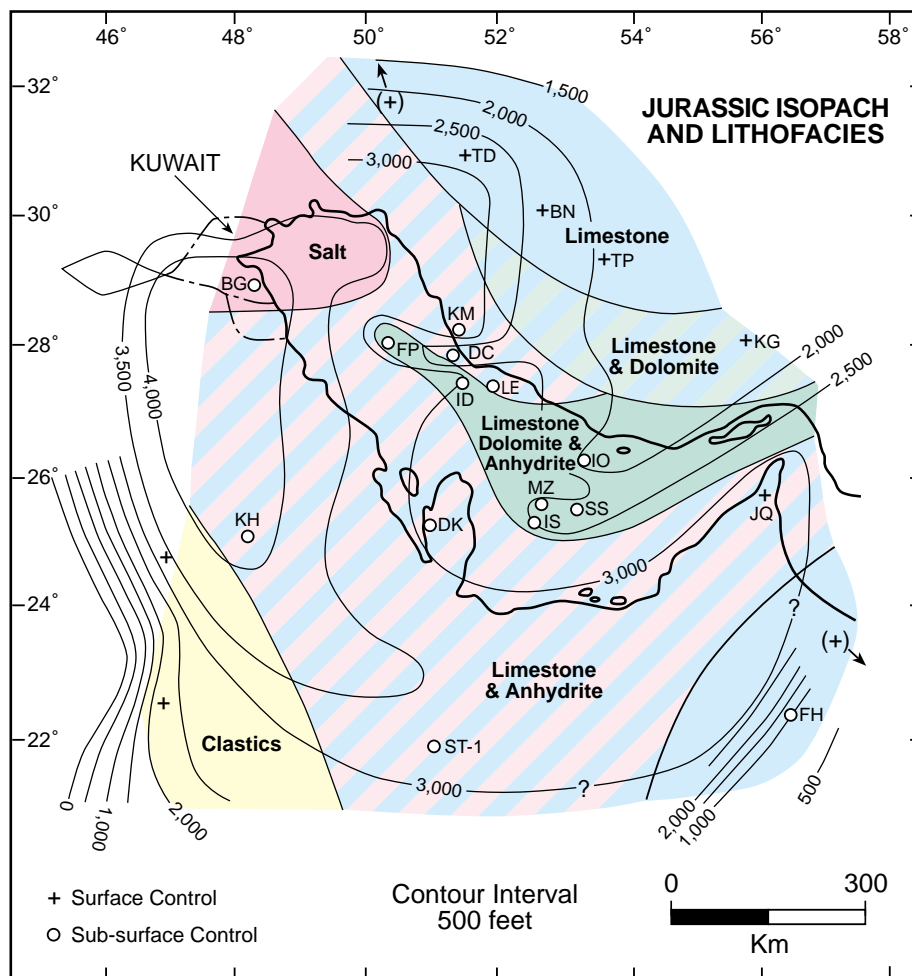


Figure 3: Jurassic isopach and lithofacies (Kamen-Kaye, 1970). Locations are Banish (BN), Burgan (BG), Dopco C-1 (DC), Dukhan (DK), Fahud (FH), F.P.C. A-1 (FP), Idd-el-Shargi (IS), Iminoco D-1 (ID), Iminoco O-1 (IO), Jabal Qamar (JQ), Khurais (KH), Kuh Gakun (KG), Kuh-i-Mund (KM), Lapco LE-1 (LE), Mahzam (MZ), Sassan (SS), Stratigraphic Well-1 (ST-1), Ting-i-Dina (TD) and Tang-i-Pohreh (TP).

Type Section

In Minagish well 27 a complete Jurassic section is penetrated and is considered as typical for Kuwait (Figure 4). A total of 6 formations are locally divided into members and/or units and define the rock stratigraphic scheme of the Jurassic System in Kuwait. Although most of these units are informal, they nevertheless generally satisfy most of the exploration requirements of Kuwait. The following is a brief description of the lithological characteristics of the Jurassic section from bottom to top.

Marrat Formation

During the Early Jurassic the Marrat Formation was deposited on a widespread carbonate platform. It consists of a sequence of dense micritic limestones with subordinate wackestones, packstones and oolitic grainstones, frequently with anhydrite, dolomite and rare shale. The Marrat Formation has been informally subdivided into five units: from top to bottom A, B, C, D and E (Figure 4). Each of these units can be traced from well to well throughout Kuwait. As shown in Figure 6, the Marrat isopach thins markedly towards the north and east of the main Burgan field area. The maximum thickness is encountered at Burgan well A in the south, while the thinnest at Sabiriyah well A.

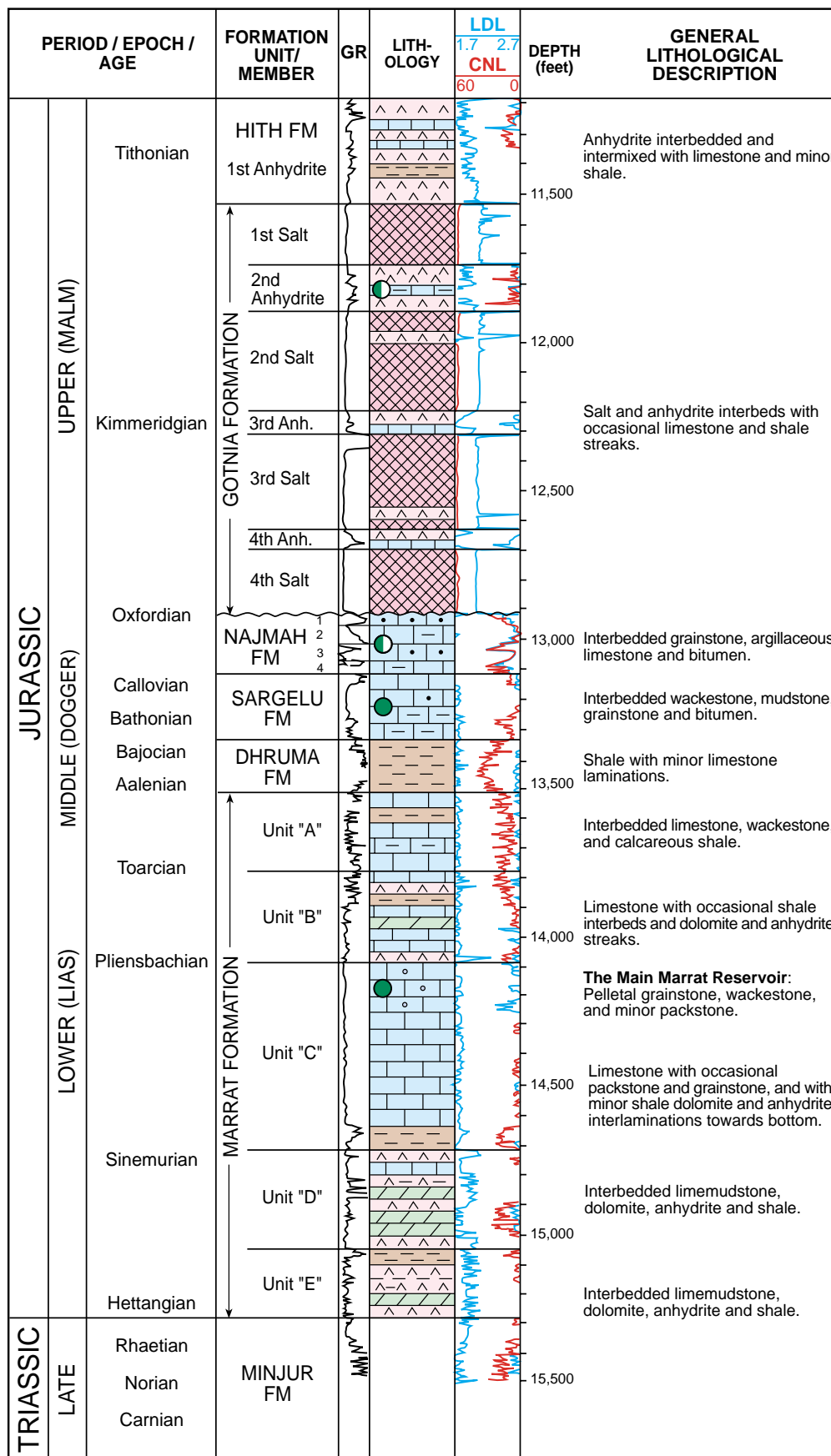
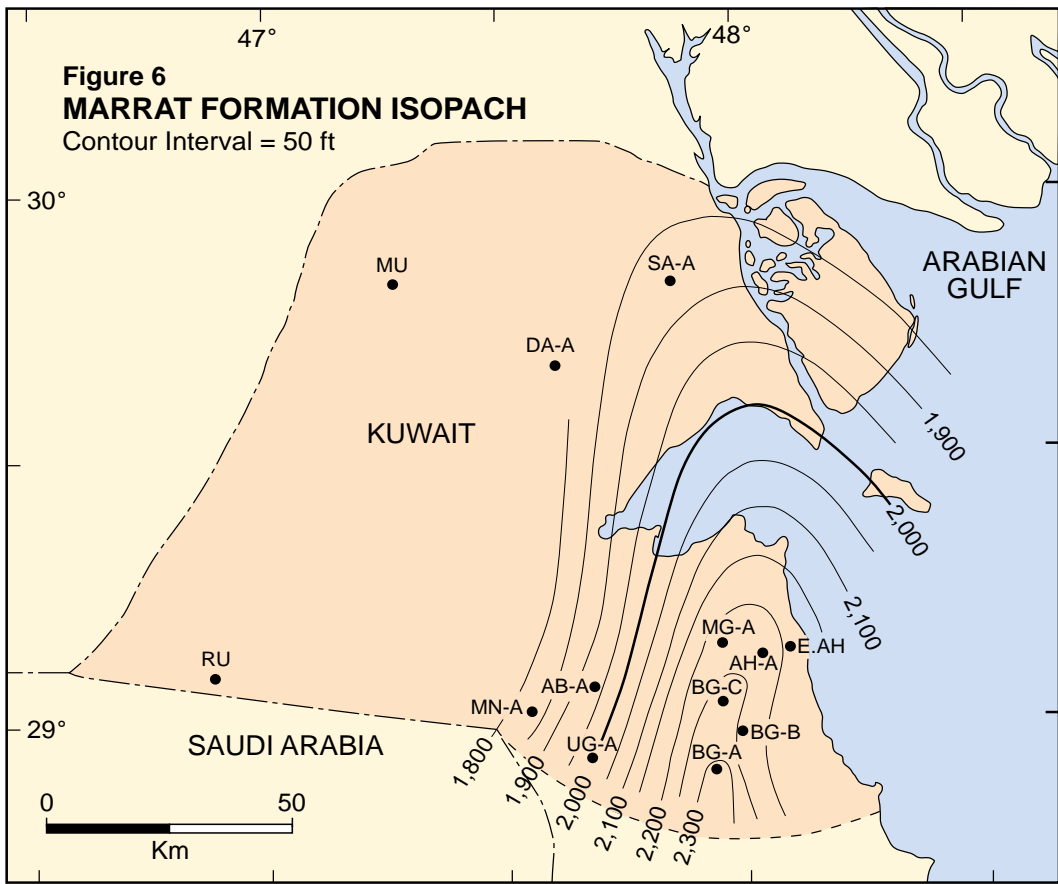
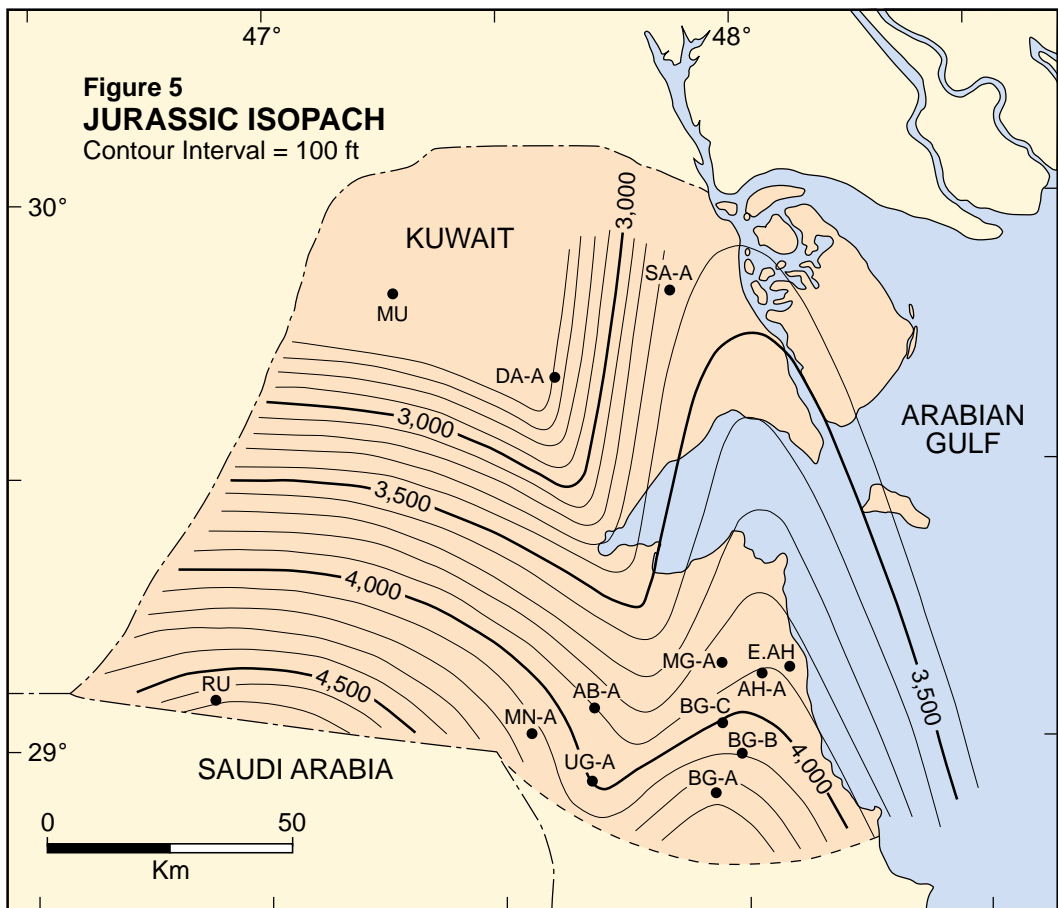


Figure 4: Jurassic type section based on Minagish well 27. The main Jurassic reservoir is Unit "C" of the Marrat Formation. Abbreviations are Gamma Ray (GR), Litho-Density Log (LDL in gm/cc) and Compensated Neutron Log (CNL).



In west Kuwait the Marrat Formation has not been penetrated. The isopach contours covering east Kuwait show a basin trending north-south across Burgan, Medina, Bahra and Sabiriyah fields. This observation indicates that the Greater Kuwait (Burgan) Arch was a major depocenter during the deposition of the Marrat Formation. In this basin, subsidence kept pace with the deposition of carbonates.

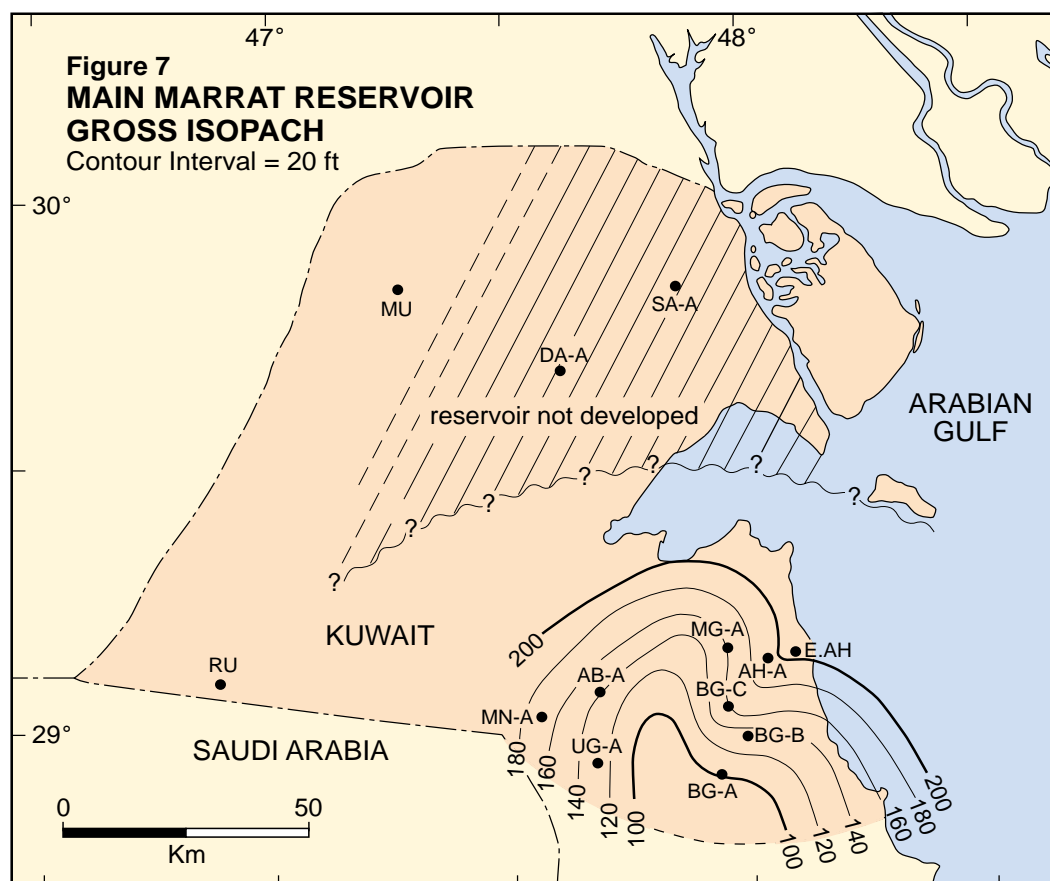
Marrat Reservoir

The Marrat "C" is one of the most important units in the entire Jurassic section (Figure 4). Its uppermost part has good reservoir quality and it is the deepest known oil reservoir in Kuwait. This unit is the thickest in the Marrat Formation and is the dominant carbonate section within the Jurassic sequence. In the Minagish type section it is greater than 600 ft thick. The Marrat reservoir is characterized by a clean gamma ray response (except for the lowermost part).

The Marrat reservoir consists mainly of oolitic grainstone and packstone, and is primarily in the uppermost portion of the Marrat "C" unit (in the south). The rest of the limestone is mainly micritic with scattered packstone, wackestone and some grainstone. The depositional environment of the Marrat "C" unit is a restricted inner shelf and the reservoir is not developed in north Kuwait (Figure 7).

The basal part of the Marrat "C" was probably deposited in the supratidal zone, as the main constituents of this lower interval are dolomite, anhydrite, claystone and some limestone. This was followed by an abrupt increase in water depth that changed the depositional environment into a subtidal zone leading to the deposition of a massive section of limestone.

During the deposition of the limestone, some streaks of grainstone and packstone were deposited when the environment oscillated into the intertidal zone. The uppermost 100 to 200 ft of the Marrat "C" constitute the main Marrat reservoir in the southern half of Kuwait. Here the environment of



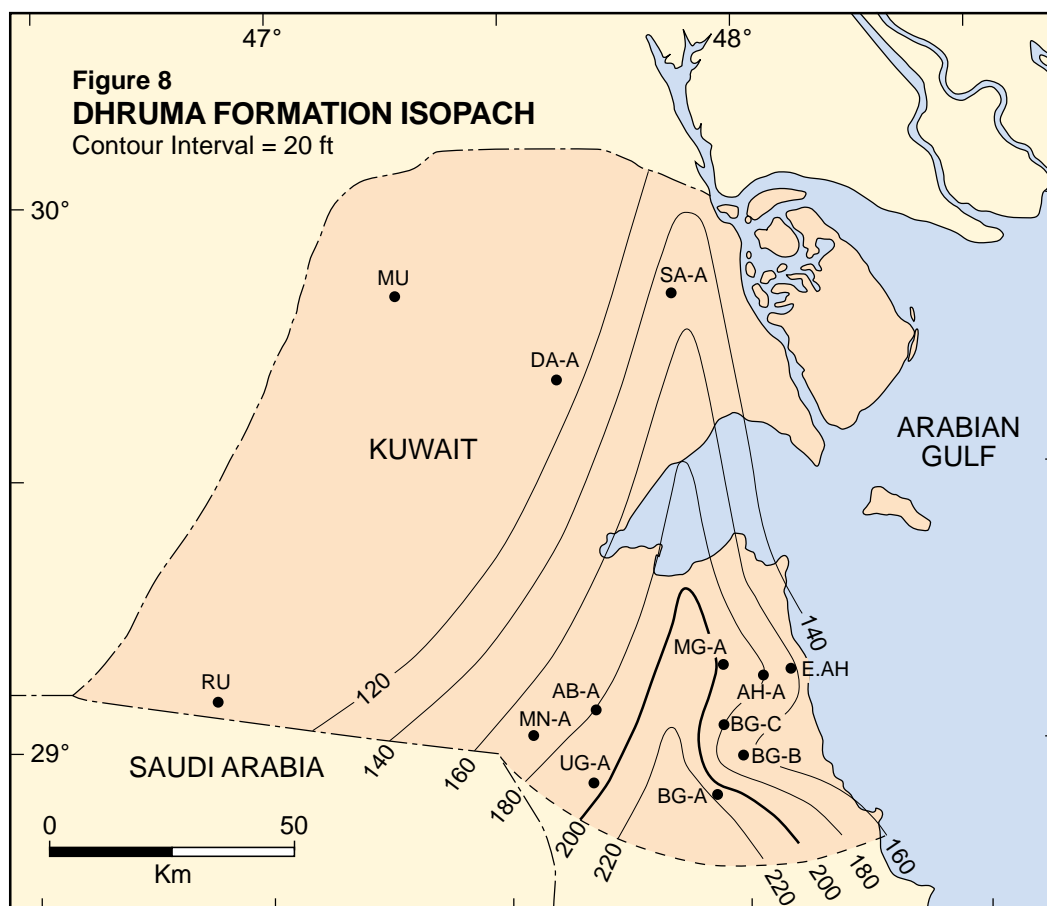
deposition was probably a barrier or shoal, as the main deposits are grainstones, packstones and wackestones. In the north and northwest, the depositional environment continued to be subtidal, where the deposits were mainly lime mudstones.

Dhruma Formation

The Dhruma Formation is Middle Jurassic in age. It consists of calcareous shale with occasional limestone interbeds. Its thickness varies from around 200 ft in Burgan well A (BG-A in Figure 8), to 100 ft at Dhabi well A (DA-A). The Dhruma isopach also shows a continuation of the trough over Burgan field seen in Figure 6. The Dhruma Formation is conformable with the underlying Marrat and overlying Sargelu formations.

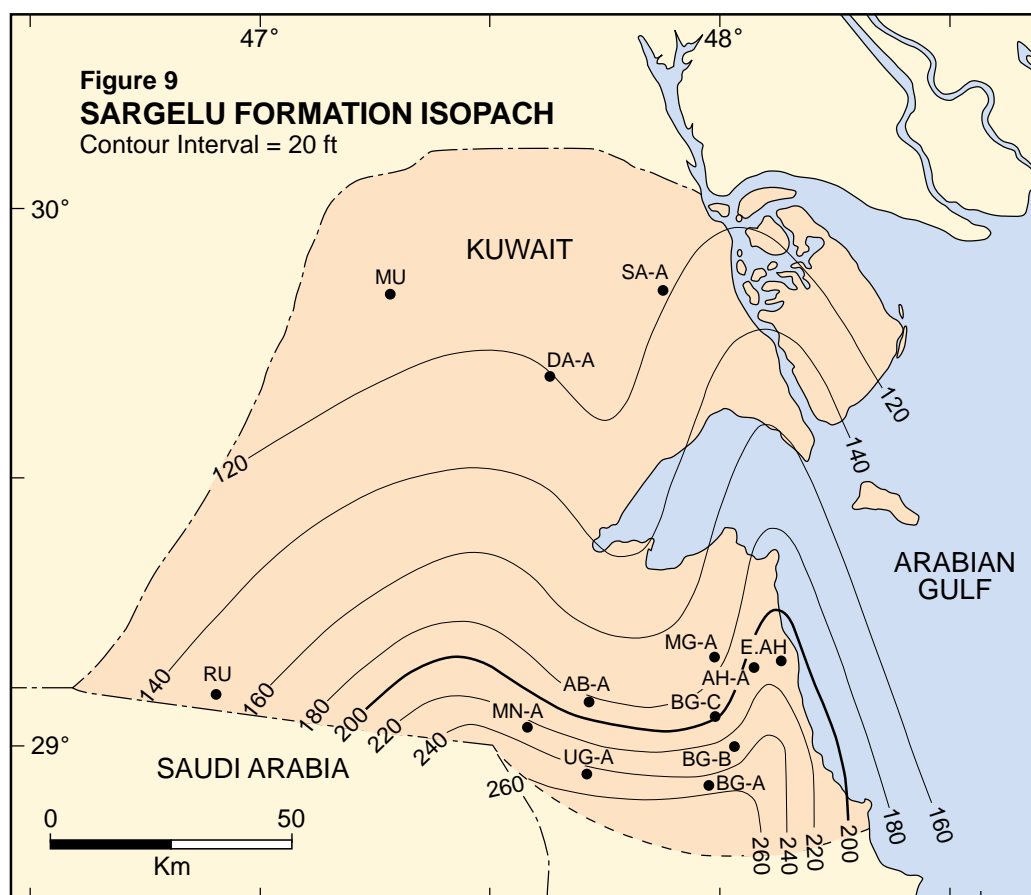
The Dhruma Formation is the most recognizable rock unit in the entire Jurassic section. Its facies are regionally homogeneous as seen in the similar log response over the entire study area. The Dhruma Formation is considered an excellent caprock for the Marrat reservoir.

The depositional environment for the Dhruma Formation is mainly restricted to the subtidal zone of the inner shelf, and therefore it represents an extension of the transgressive cycle which started with the deposition of the Marrat "A" unit.



Sargelu Formation

The Sargelu Formation is Middle Jurassic in age. It is the second potential Jurassic reservoir. This formation is mainly composed of interbedded wackestone, packstone and mudstone with some bitumen-bearing horizons. The thickness of the Sargelu decreases from around 250 ft at Burgan well A (BG-A in Figure 9), to around 110 ft at Sabiriyah well A (SA-A).



The Sargelu Formation is conformable with the overlying Dhurma and underlying Najmah formations. The distribution of the lithological components indicates that the energy level increased gradually upward as the argillaceous mudstone, at the base, is followed with wackestone and peloidal packstone, at the top. The entire Sargelu section represents, therefore, an evolution of a new regressive cycle, where the intertidal, high energy, peloidal packstone overlie subtidal argillaceous mudstone.

Najmah Formation

The Najmah Formation is Middle Jurassic (Callovian to Oxfordian) age. It represents the uppermost carbonates of the whole Jurassic section. It is mainly composed of interbeds of cemented peloidal packstone, argillaceous and bitumenous limestone. The formation is divided into four units, as shown in Figure 4, and the stratigraphic profiles in Figures 10 and 11. The lower two units (4 and 3) persist over the entire study area, while the upper two units are restricted to the Minagish and Umm-Gudair areas (Figures 10 and 11). The absence of the upper two units in the rest of the study area, could be either due to non-deposition or erosion. In this paper the top of the Najmah has been interpreted as an unconformity which is easy to recognize just below the Gotnia evaporites.

The isopach of the Najmah Formation thins along a north-south trend in central Kuwait (Figure 12). The abrupt thickening of the lower Najmah units together with the slight thickening of Sargelu Formation at the Ahmadi area, relative to the Magwa area, is possibly due to the deposition of the fourth and third units of the Najmah Formation as well as the Sargelu Formation over a subsiding area. This subsidence could be related to faulting.

The Najmah Formation is quite uniform and can be correlated across Kuwait. It corresponds to the widespread, late Callovian flooding event which affected the entire Middle East platform. The Najmah Formation was deposited in restricted marine outer ramp and anoxic conditions. The lower stratigraphic section is characterized by a high gamma and low density response (Figure 4) suggesting

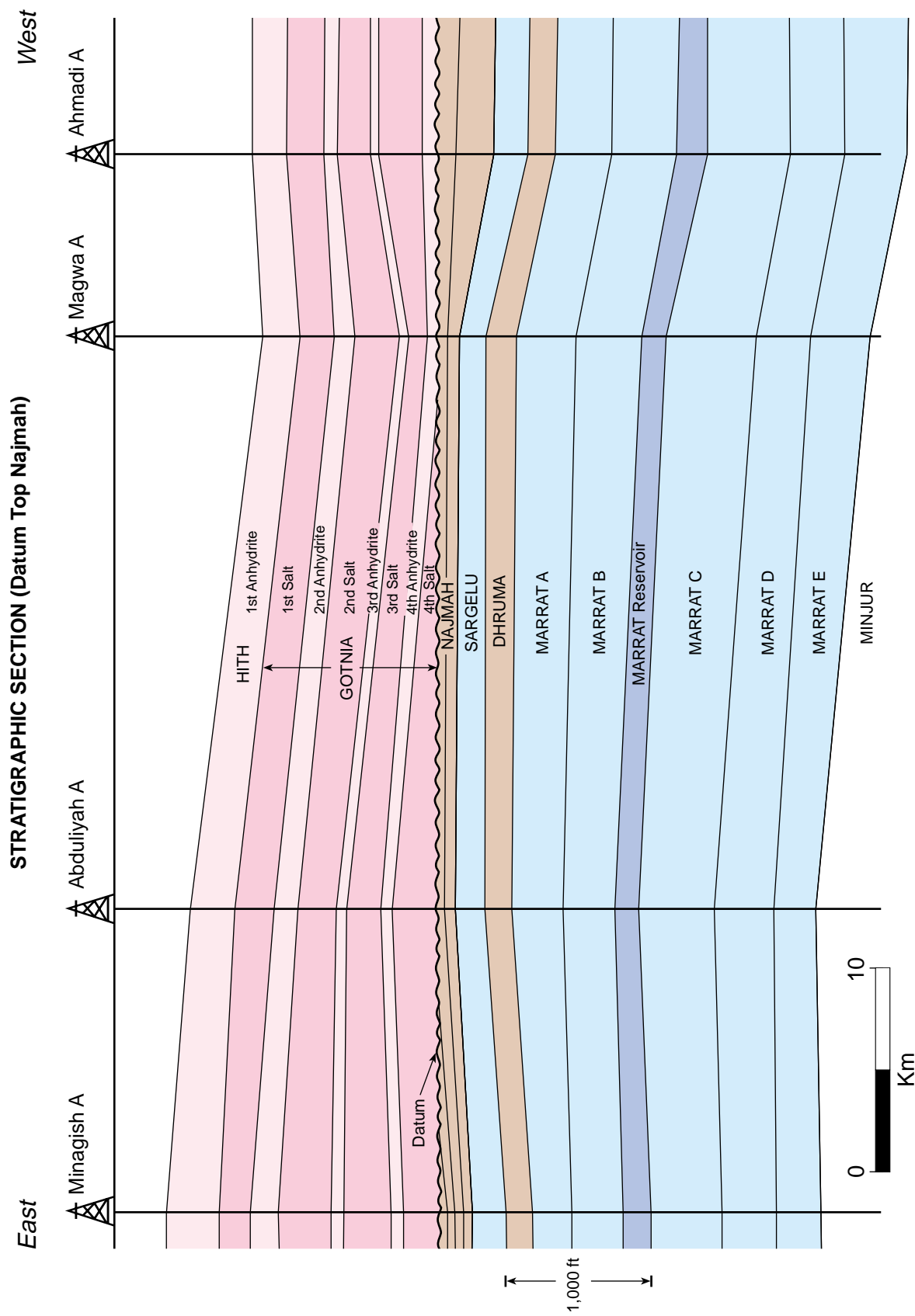


Figure 10: East-west stratigraphic cross-section (see Figure 1 for location).

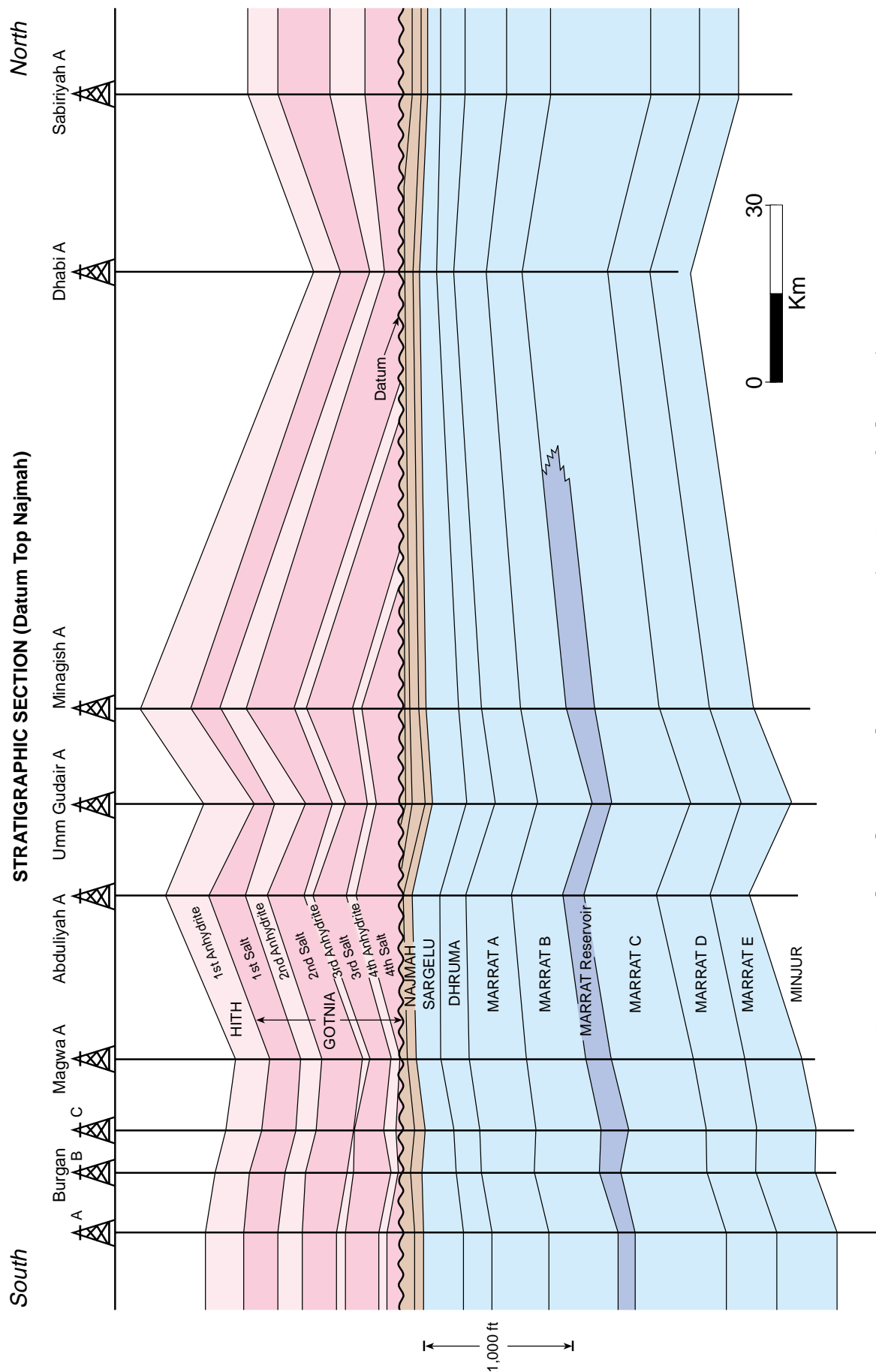
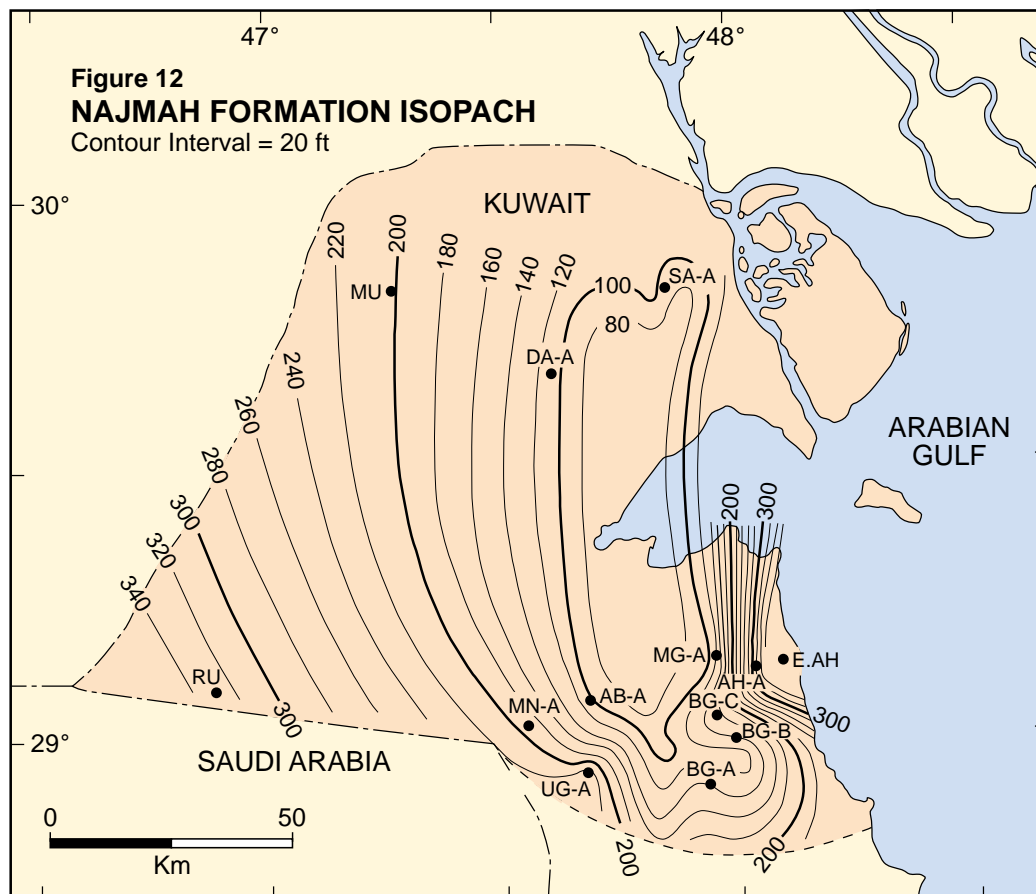


Figure 11: North-south stratigraphic cross-section (see Figure 1 for location).



good source rock potential. The Oxfordian to Callovian sequences, such as the Najmah Formation, are generally considered the main source rocks for both the Jurassic and Cretaceous reservoirs in most of the Arabian Gulf (Ayres et al., 1982; Wilson, 1984; Abdullah and Kinghorn, 1986). In some fields in Kuwait, the Najmah limestone is fractured and produces oil.

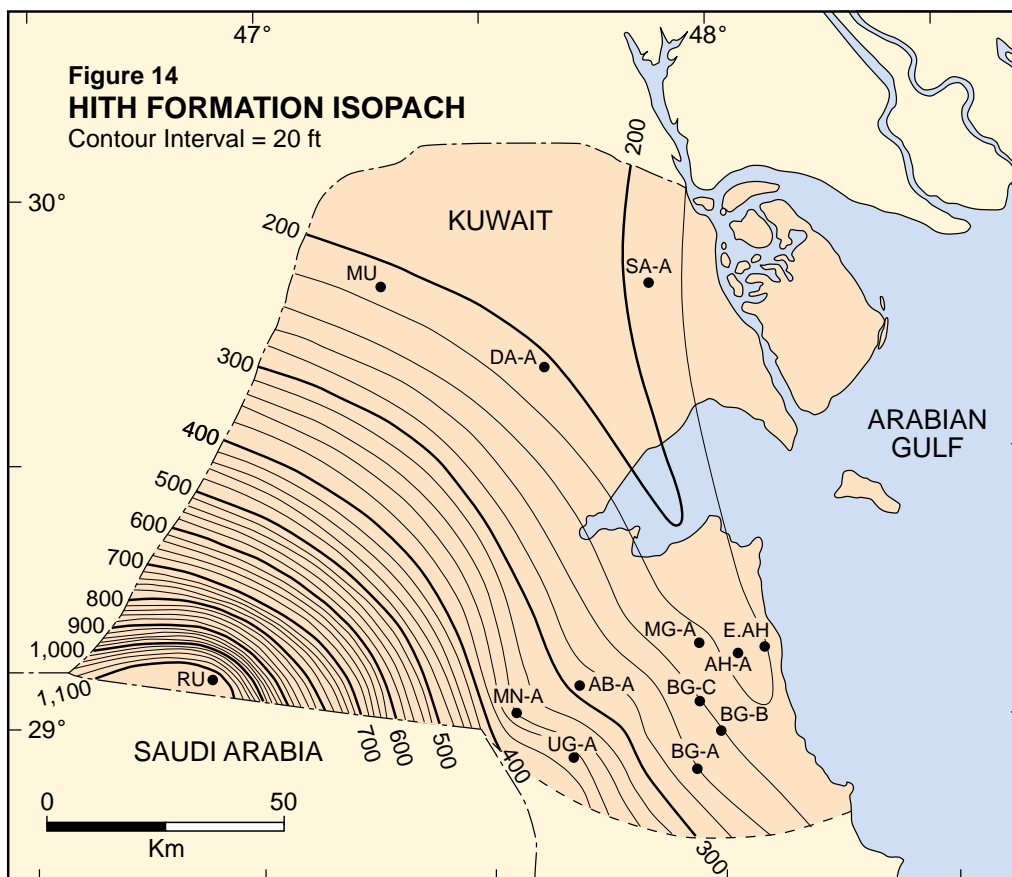
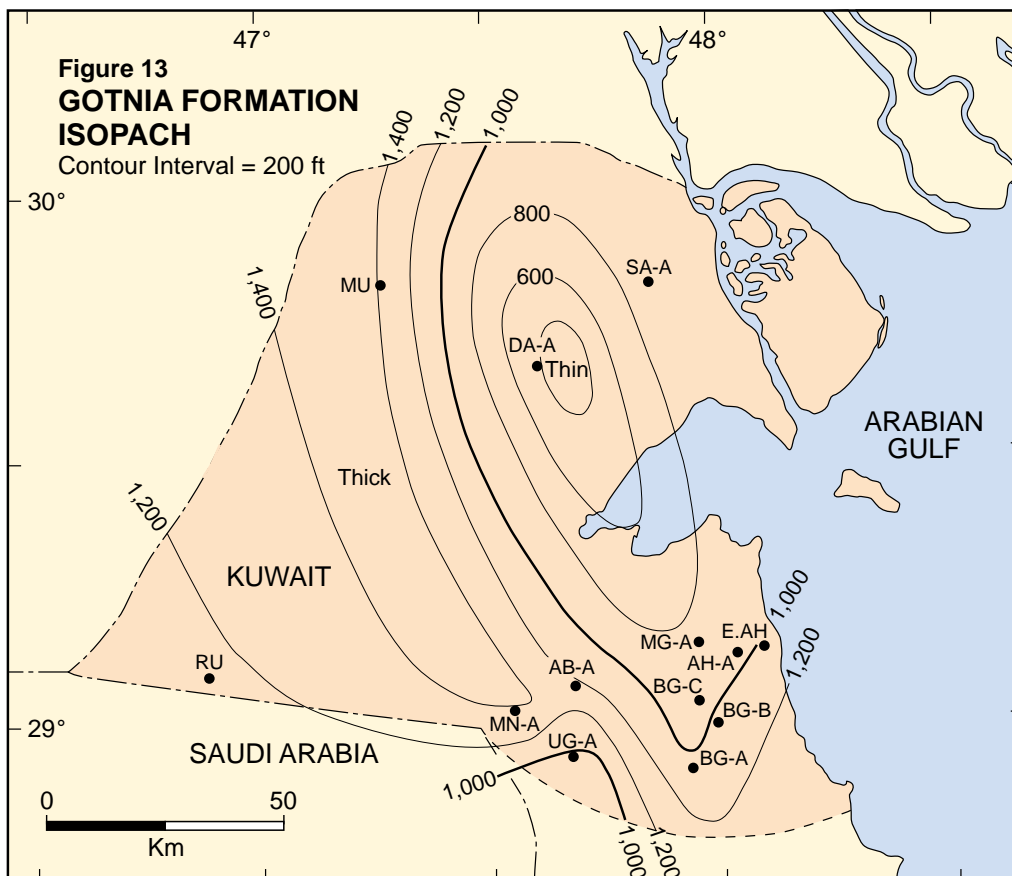
Gotnia Formation

Very shallow depositional conditions followed the late Callovian flooding event that deposited the Najmah Formation. In Kuwait, a hypersaline setting during the Late Jurassic was responsible for deposition of the thick anhydrite, salt, with some shales and limestones of the Gotnia Formation.

The typical Gotnia section is located within the Burgan, Umm-Gudair, Minagish, Rugei and Mutriba fields, where the Gotnia Formation consists of four salt units, separated by three anhydrite units (Figure 4). These anhydrite interbeds are mostly interlaminated with limestones, shales and some bitumenous limestones. The Gotnia Formation was deposited in a sabkha-lagoonal (supratidal) environment.

All the Gotnia units persist in the southern and western areas of Kuwait. Noticeable thinning is evident towards the northeast of Kuwait due to a gradual pinchout of the basal Gotnia units (4th salt, 4th anhydrite, 3rd salt and 3rd anhydrite), as shown in Figure 11.

The Gotnia isopach (Figure 13) shows that the thickest section is encountered in the Mutriba area. The thinnest is found at Dhabi well A, probably due to the non-deposition of the basal Gotnia units and/or faulting. Future deep drilling in Dhabi area will shed more light on the nature of that thinning.



Hith Formation

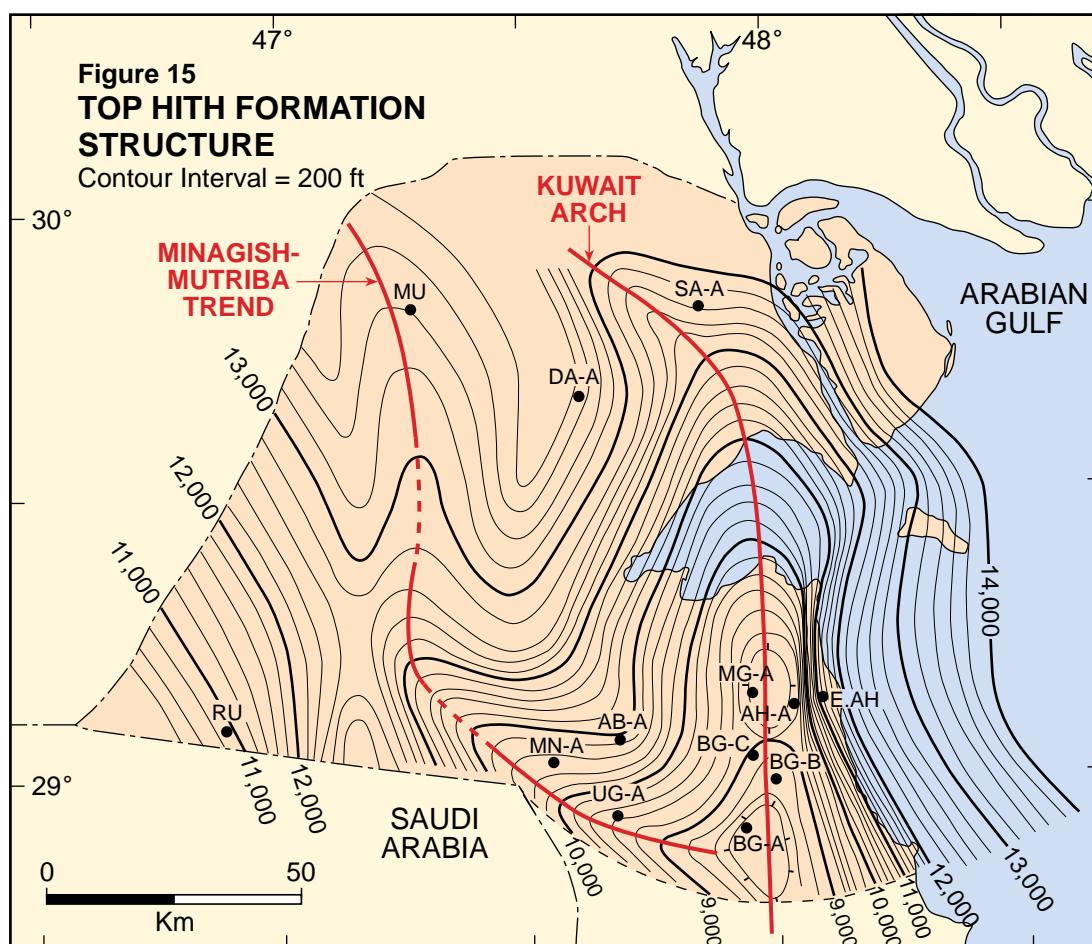
The Late Jurassic (Tithonian) Hith Formation is the uppermost formation in the Jurassic section. It is conformable with the overlying Lower Cretaceous Makhul (Sulaiy) Formation and underlying Gotnia Formation. This Hith Formation is mainly composed of a sequence of massive anhydrite interbedded and intermixed with argillaceous limestone and minor shales. In the Rugei area, the formation mainly consists of a much thicker section of lime mudstone, anhydrite and shale interbeds and interlamination.

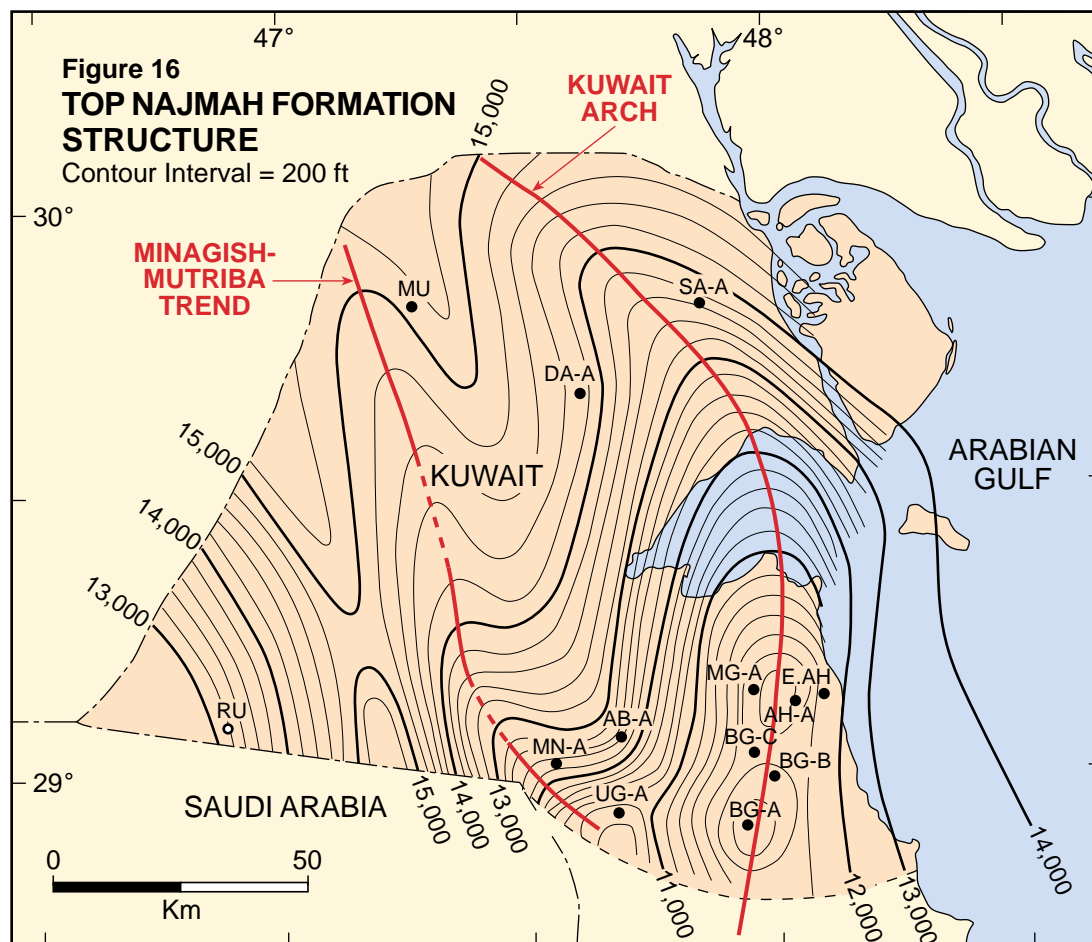
The thickness of the Hith Formation varies from more than 1,100 ft in the Rugei area to around 200 ft at Dhabi well A (Figure 14). The area of Rugei, in the southwestern corner of Kuwait, was a thick depocenter at the end of the Jurassic period during the deposition of the Hith Formation.

Both the Gotnia and Hith formations are excellent caprocks for the underlying reservoirs. As in the case of the Gotnia Formation, the Hith anhydrite was also deposited in the supratidal environment.

STRUCTURE

The total Jurassic isopach (Figure 5) shows the structural developments of the south and southwest areas of Kuwait during the Jurassic time, where sedimentation was greater than in the northern area. The regional primary dip of the Jurassic sediments in Kuwait was to the south and southwest. At the end of Jurassic period and Early Cretaceous this regional dip was disrupted by regional tectonic events, and by the Tertiary, it reversed to the present northeast (Carman, 1996).





Carman (1996) provided a review of the structural elements of Kuwait. The main arches are predominantly north-south trending. The main Kuwait (Burgan) Arch extends from Burgan field in south Kuwait, to Sabiriyah field in the north. A subsidiary Minagish-Mutriba arch has a well-defined north-northwest trend. The structural contour maps on the level of Hith and Najmah formations (Figures 15 and 16) show these mentioned trends.

Two structural cross-sections which also use seismic control (Figures 17 and 18) illustrate the different closures in south Kuwait. The first cross-section (Figure 17) is from west-southwest to east-northeast and it illustrates the closures in Minagish, Abduliyah, Dharif, Magwa and Ahmadi fields. In the Abduliyah area, a slight positive structure is shown at the level of Hith Formation while a significant closure appears on the Najmah and deeper levels.

The second structural cross-section (Figure 18) illustrates the structural configuration of the Jurassic section in the east-west direction through Minagish, Umm Gudair and Burgan structures. The Gotnia isopach and isochrons help identify local structures and favorable drilling locations.

Figure 19 illustrates the relation between some structures within Umm Gudair, Abduliyah and Dharif areas and their equivalent Gotnia Formation isopach. This correspondence is probably due to the plastic deformation (thinning) in the Gotnia salts as a result of the vertical tectonic pulses which took place after the deposition of the Late Jurassic Hith Formation.

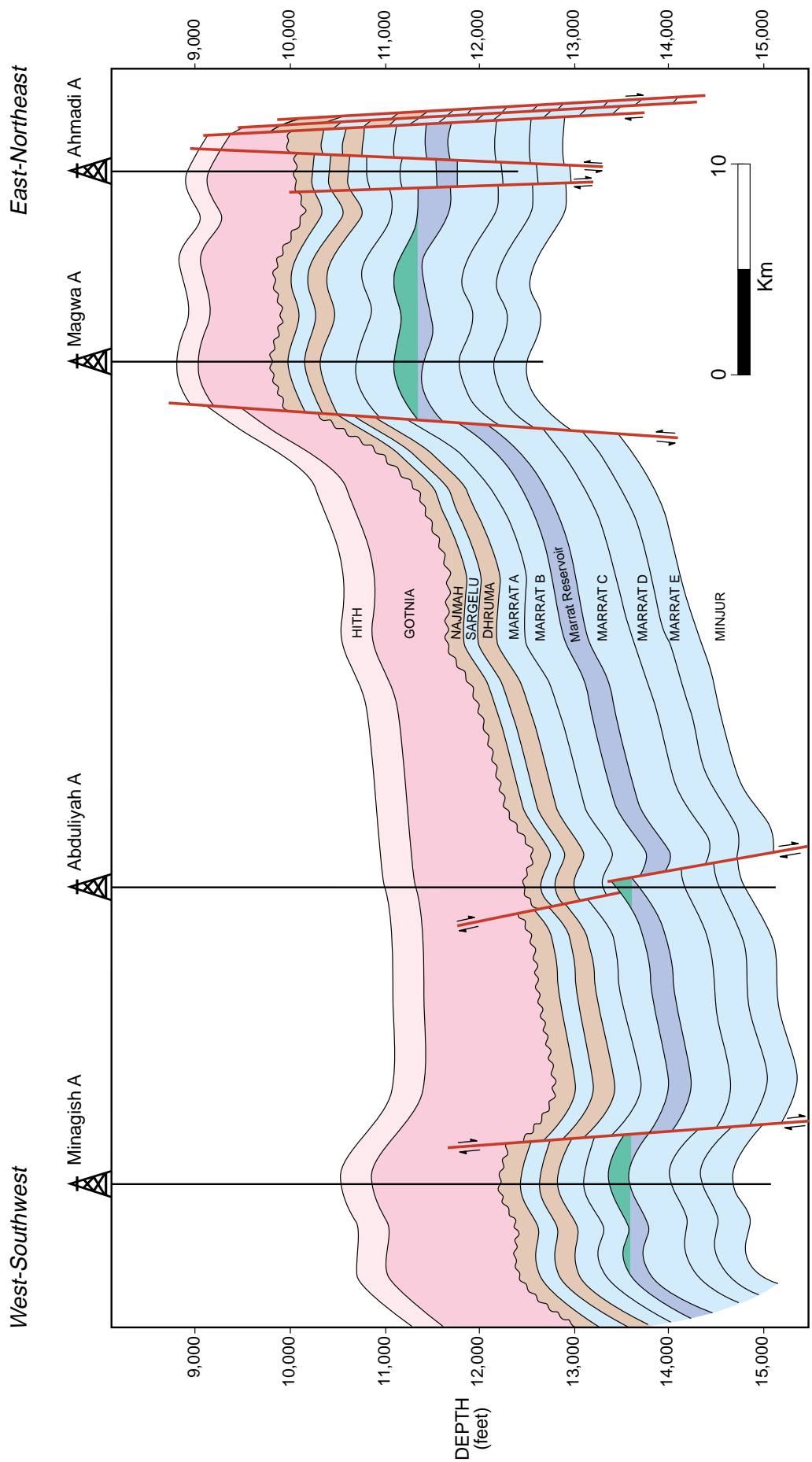


Figure 17: East-west structural cross-section (see Figure 1 for location).

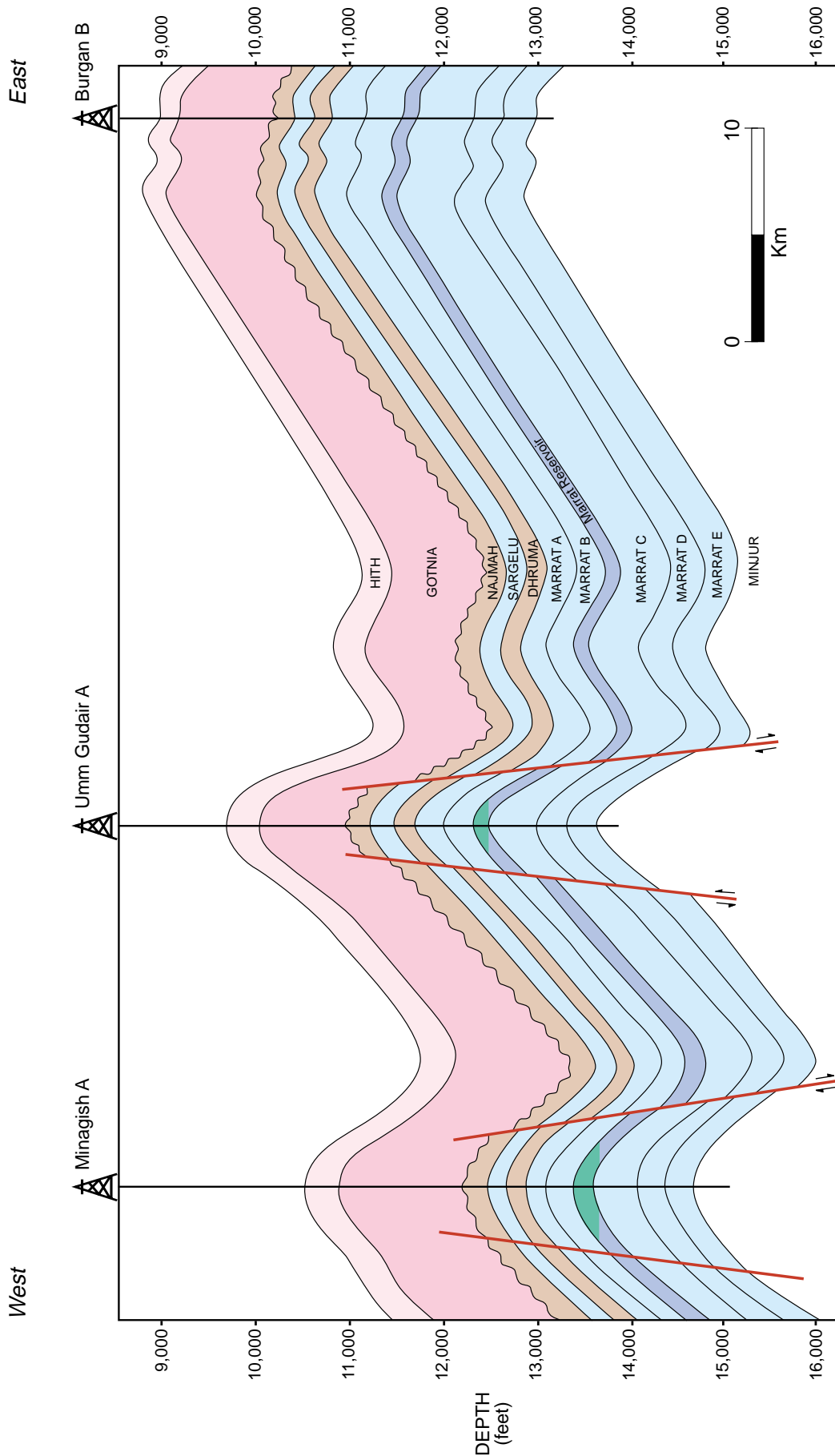


Figure 18: East-west structural cross-section (see Figure 1 for location).

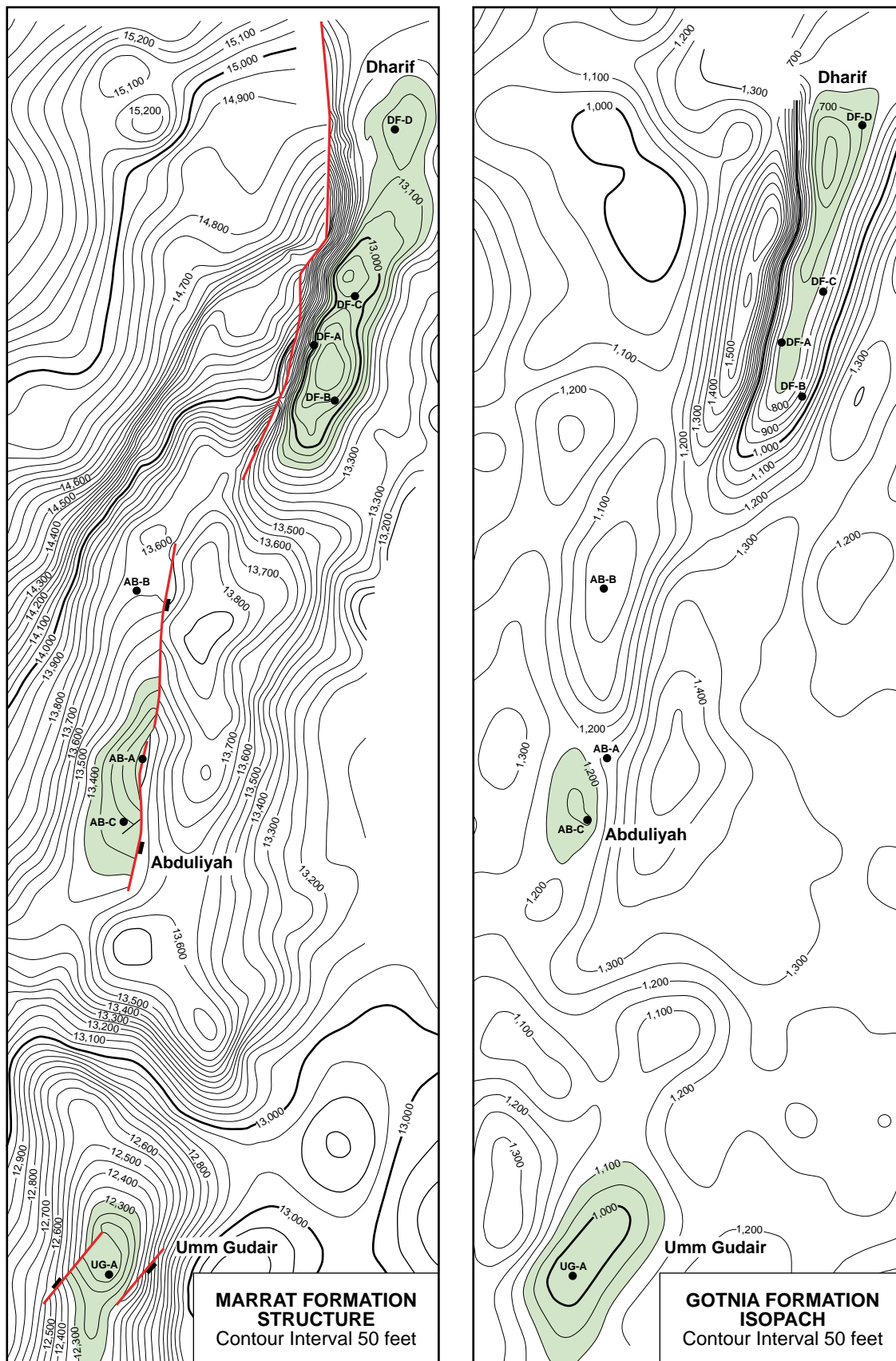


Figure 19: Structurally high areas in the Lower Jurassic Marrat (left) correlate with isopach thin areas of the Upper Jurassic Gotnia Formation (right). The Gotnia Formation consists mostly of salt and anhydrite.

CONCLUSIONS

The Jurassic formations and sub-formations of Kuwait can be correlated from well to well with a high degree of confidence due to their similar log responses. Except for an unconformity at the top of Najmah Formation the Jurassic layers are conformable. Isopachs of either individual or cumulative Jurassic formations reflect a consistent northward thinning and a basinal development to the south. The present northward regional dip took place after the Jurassic and Early Cretaceous period.

The majority of the Jurassic sediments in Kuwait were restricted to the inner shelf environment. The oolitic grainstone and packstone which correspond to the main Marrat reservoir in the southern half of Kuwait change into a tight lime mudstone in the north. The exact boundary between the two facies is not well-defined. The Marrat traps may be controlled by both structural and stratigraphic elements. Fracturing may provide the main porosity within both of Najmah and Sargelu reservoirs, as neither ditch samples nor core data show any significant primary porosity within them.

The Dhurma shale is good caprock for the underlying Marrat reservoir, while the Hith and Gotnia evaporite seal the underlying Najmah and Sargelu. The Gotnia isopach can be used to identify local structural developments within the southern half of the Kuwait.

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