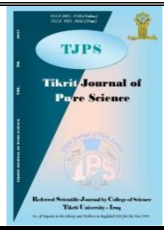
Tikrit Journal of Pure Science (2024) 29 (1):136-148
Doi: https://doi.org/10.25130/tjps.v29i1.1484

TJPS

IASJ
المجلات الاكاديمية العراقية

Tikrit Journal of Pure Science
ISSN: 1813 – 1662 (Print) --- E-ISSN: 2415 – 1726 (Online)

Journal Homepage: http://tjps.tu.edu.iq/index.php



Dolomitization of the Lower Part of the Sargelu Formation, Northeastern Iraq

Shwan A. Muhammad [1], Azad T. Saeed[2]
[1]Earth Sciences and Petroleum Department, College of Science, Salahaddin University, Erbil, Kurdistan Region, Iraq
[2]Department of Petroleum Geosciences, Faculty of Science, Soran University, Soran, Kurdistan Region, Iraq

Keywords: Dolomitization, Sargelu Formation, Northeastern Iraq.

ARTICLE INFO.

Article history:

-Received:	21 June 2023
-Received in revised form:	22 Aug. 2023
-Accepted:	23 Aug. 2023
-Final Proofreading:	24 Feb. 2024
-Available online:	25 Feb. 2024

Corresponding Author*:
Shwan.Muhammad@su.edu.krd

ABSTRACT

The prominent characteristic of the lower part of the Sargelu Formation of the Middle Jurassic is the occurrence of destructive dolomitization. This dolomitized unit, cropped out in the high folded and Imbricated zones in Northern Iraq, is situated in the Gotnia Basin and has been distinctly identified and are documented in previous studies. Dolomite crystals are euhedral in shape; hence, they are classified as saccharoidal dolomite, resulting in the elimination of all biocontent and the destruction of the original rock fabrics. Despite the abundance of intercrystalline pores in this unit and their role in the quality of reservoirs in the oil fields, the origin or mechanism of dolomitization is not well understood yet. The aim of this investigation is to find out a suitable model for the dolomitization and to propose possible mechanisms that led to the dolomitization. At the top of the Lower Jurassic Sehkaniyan Formation, an extensive mass of destructive dolomitization has also occurred. The dolomitic unit of the Sargelu Formation, which extends for hundred kilometers constantly. Stratigraphic correlation reveals that the Sargelu Formation is juxtaposed with different successions, such as the Alan and Sehkaniyan formations, that show evidence about peritidal and sabkha environments, where the dolomitization units were associated with solution collapse breccia and microbial stromatolite. This study proposes that the reflux and burial dolomitization models for the lower part of the Sargelu Formation by comparing the paleoenvironmental conditions of the late Lower Jurassic and early Middle Jurassic in the Gotnia basin with a modern analogue model.

Tikrit Journal of Pure Science (2024) 29 (1):136-148
Doi: https://doi.org/10.25130/tjps.v29i1.1484

TJPS

عملية دلمتية في الجزء السفلي لتكوين (سارجلو) لشمال شرق العراق

[1] شوان عزيز محمد، [2] آزاد طاهر سعيد

[1] قسم علوم الأرض والبترول، كلية العلوم، جامعة صلاح الدين، أربيل، إقليم كوردستان، العراق

[2] قسم عموم الأرض البترولية، كلية العلوم، جامعة سوران، سوران، اقليم كوردستان، العراق

الملخص

السمة البـــــارزة للجزء السفلي لــتكوين سارگلو فـــــي الــعصر الـــــجوراسي الأوسط هو حـدوث عملية تحويل الدلمة (Dolomitization). تقع هذه الوحدة الدولوميتية، التي تم اقتصاصها في المناطق عالية الطي والمتداخلة في شمال العراق ، في حوض قطنية وقد تم تحديدها وتوثيقها بشكل واضح في الدراسات السابقة. بلورات الدولوميت ذات شكل احادي السطوح؛ و بالتالي، يتم تصنيفها على أنها دولوميت سكركويدية غير حصري، مما يؤدي إلى القضاء على جميع المحتويات الحيوية وتدمير الأنسجة الصخرية الأصلية. على الرغم من وفرة المسام بين البلورات في هذه الوحدة ودورها في كمية الخزانات في حقول النفط، فإن أصل و آلية الدولوميت ليست مفهومة جيدًا حتى الآن.الهدف من هذا العمل هو العثور على نموذج مناسب للدولوميت واقتراح الآليات الممكنة التي أدت إلى هذه العملية. في الجزء العلوي من تكوين سيكانيان في عصر جوراسي السفلي حدثت ايضا كتلة واسعة من عملية الدلمة (Dolomitization) بحيث يمكن اعتبارها الوحدة الدولوميتية لتكوين سارگلو والتي تمتد لمئات الكيلومترات باستمرار واعتبارها تكوين اقليمي. يظهر الارتباط الطبقي بأن تكوين سارگلو متداخلة مع تتابعات مختلفة، مثل تكويني علان وسيكانيان، التي تظهر أدلة على البيئات المحيطة بالمد والجزر والسبخة، حيث ارتبطت وحدات الدولوميت بهدم المحلول بريشيا و ستروماتولايت الميكروبي. تقترح هذه الدراسة نموذجًا لاستعادة دولوميت المدفن للجزء السفلي من تكوين سارگلو من خلال مقارنة الظروف البيئية القديمة للعصر الجوراسي السفلي المتأخر وأوائل العصر الجوراسي الأوسط في حوض قطنية مع نموذج تناظري حديث.

Introduction

Previous researches have pointed the consistent distribution of destructive “saccharoidal” dolomitization in the lower part of the Sargelu Formation [1-3]. The dolomitized unit extends constantly for hundreds of kilometers (from Halabja to Zakho) and ranges in thickness from 10 to 30 meters. In this study, regional influences on diagenetic processes will be analyzed based on the available evidence. According to current research, the dolomitization process has had an extensive impact on the lower part of the Sargelu Formations in both sections (Barzewa and Warte).

Carbonate diagenesis is controlled by a number of factors, including mineralogy and crystal chemistry, pore water chemistry, water flow, dissolution and precipitation rates, particle sizes, and interactions with organic substances [4]. The dolomites account for over half of the world's carbonate rock supply [5]. Dolomites can occur in variety of environments, including hydrothermal, alkaline lacustrine, marine carbonate platforms and deep burial [6]. However, dolomitization on a big scale is generally observed in marine environments [6-9].

Carbonate sediments are rock formations that have either been biogenetically precipitated or have formed from solution precipitation at or near the surface of the Earth. Carbonate rocks are sedimentary rocks composed mostly of calcite minerals. The two most prevalent types are limestone, which is composed of calcite or aragonite (different crystal forms of $CaCO_3$), and dolostone, which is composed of the mineral dolomite ($Ca Mg (CO_3)_2$). Carbonate rocks are the simplest to deposit but the most complicated to understand diagenesis. Dolomite may replace $CaCO_3$ minerals and precipitate dolomite cement either shortly after sediment deposition, i.e., penecontemporaneously and during early diagenesis, or for a very long period, often after cementation, during burial [10].

Two sections were chosen to explore the dolomitization in the Imbricated zones of northern Iraq [11]. Barzewa section is located along the main street next to the Balak River and roughly 2.5 kilometers north of Barzewa Village and 12 kilometers east of Soran District in Erbil Governorate, Northeastern Iraq, the coordinates are (lat. 36° 63' 80'' N) and (long. 44° 63' 96'' E). The Warte section; is located 3.5 km northwest of Warte District, at the northern limb of the Karukh Anticline, and 35 km southeast of Soran Town in Erbil Governorate, Northeastern Iraq, the coordinates are (lat. 36° 51 83'' N) and (long. 44° 72' 54'' N).

Geological and structural setting

The studied sections (Warty and Barzewa) are located in the Imbricated (Balambo-Tanjero Subzone) [11]. The Imbricated Zone is distinguished by thrusting the Lower Jurassic strata of the Sehkaniyan Formation over the Upper Cretaceous Tanjero Formation [11]. The Barzewa area is located in the Imbricated Zone of the Zozik Anticline. The Sargelu Formation in the Barzewa area overlies the Sehkaniyan Formation, and it occupies the core of the Zozik Anticline. The Zozik Anticline is characterized by axial valleys and a plunge toward Southeast -to- Northwest, and the anticline is characterized by thrust faults dipping to the northeast.

However, the Sargelu Formation, situated in the Warte section, is positioned within the High Folded Zone along the Hendren Anticline. Imbricated Zone often appears as asymmetrical anticlines with a fold axis that trends in a northwest to southeast direction. This anticline dips to the northwest, is approximately 30 kilometers long, and dips steeply to the northeast, while the dip to the southwest is relatively gentle. Triassic and Jurassic rocks form the core of the anticline, while Cretaceous rocks comprise the limps (fig. 1).

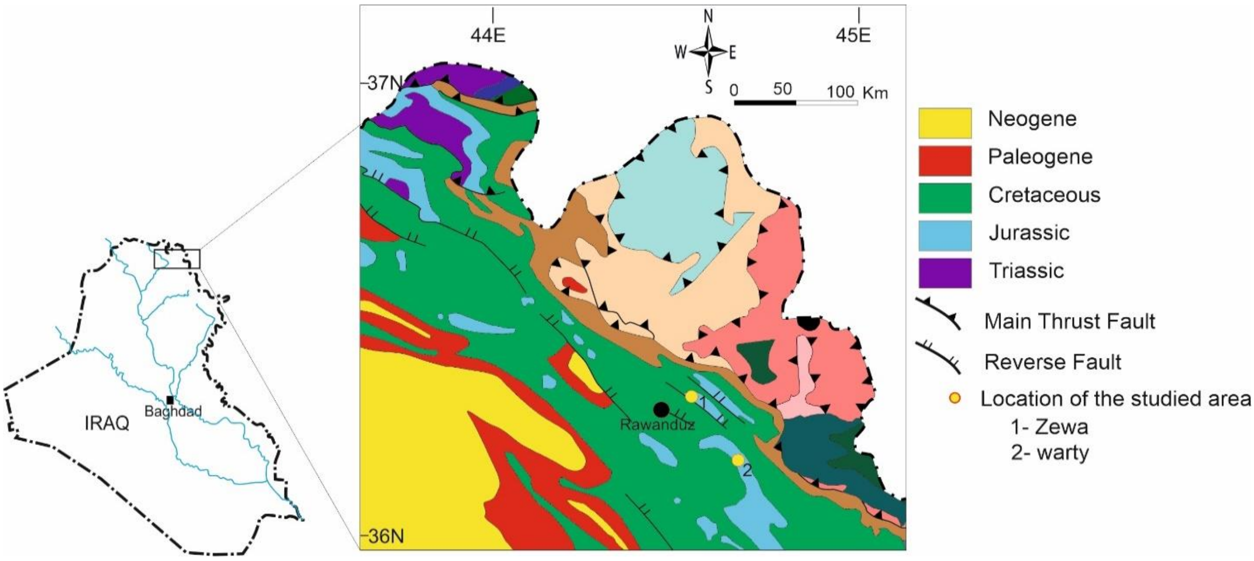


Fig. 1: Geological map of studied area [12]

Depositional succession of the latest Early Jurassic and early Middle Jurassic

The Neo-Tethys initiated the opening at the end of the Permian and lasted into the end of the Jurassic Period, resulting in basins as broad as hundred kilometers and several thousand km on the eastern margin of the Arabian Plate [13]. Gotnia Basin is the regional name for the developed basin, which has been fragmented into several smaller basins due to the influence of tilted faults. The Lorestan Basin from the Zagros Sutures of western Iran represents the equivalent of the Gotnia Basin [14]. Gotnia Basin is the name for the area of the basin that is in Kuwait, along the southern border of Iraq, and at the northeastern border of Saudi Arabia as well.

The Arabian Plate was an inner platform near the equator during the Lower to Middle Jurassic Period. In the Lower Jurassic (Hettangian), rifting started in the Central Mediterranean, it is thought to have spread eastwards towards the Arabian Plate, where it ended in the Early Jurassic (Late Toarcian) with the collapse of the large "pre-rift Adaiyah, Mus, and Alan shallow-water carbonate platforms"[15]. At the beginning of the Toarcian Age in Iraq, some formations began to deposit e.g., the Adaiyah, Mus, and Alan, formations and their equivalent Sehkaniyan Formations (fig. 2); the Adaiyah, Mus, and Alan formations were deposited in the carbonate-evaporate inner shelf, but the Sehkaniyan Formation was deposited in the restricted lagoon. Sediments from the late Norian to late Toarcian were deposited in a shallow-water basin and platform that subsided relatively slowly [16]. During the end of the Toarcian, a considerable transgression covered the Arabian platform. The environmental setting ranged from the detrital deposit platform in the west to the erosional conditions in southern Arabia. To the north and east, a shallow marine platform was formed primarily of carbonate [17].The greatest width of the Neo-Tethys occurred between the Bajocian and Bathonian Ages. This Neo-Tethys opening coincided with the collapse of the unstable Arabian barrier, transforming the Iraqi Unstable Shelf into a deep-sea habitat [18]. Near the completion of the Late Toarcian time, a wet climate caused evaporites cyclicity to stop. At the same time, a transgression filled in isolated basins and made them more similar [1, 11] The Arabian Intrashelf Basin, as well as the Gotnia-Mesopotamian

Doi: https://doi.org/10.25130/tjps.v29i1.1484

Basin, were episodically cut off from the Tethys Ocean by uplift and a tilt toward the west, with further variations brought on by eustatic sea-level rise and fall [19].

The juxtaposition of the Sargelu Formation strata with the evaporitic rock units is very common and well documented [1, 2, 11, 20, 21]. At all cropped-out sections in the core of the High Folded and Imbricated zones, the Middle Jurassic Formation overlies the Sehkaniyan Formation, which shows evidence of evaporitic mineral and solution collapse textures. Furthermore, the Lower Jurassic Period successions have been studied by [22-24] within the Kurdistan Region's hydrocarbon fields (the Miran, Barda Rash, and Zab oil fields), where they discovered that the evaporitic Alan Formation is just beneath the Sargelu strata.

A brief description of the stratigraphy

Lower Jurassic

The strata of the Lower Jurassic are distinguished by their predominant arid and evaporitic conditions. The Sehkaniyan Formation comprises dark saccharoidal dolomites, dolomitic limestones, and solution breccias. The Sehkaniyan Formation, which was formed in a restricted lagoon is known for having an assemblage like that of "Lithiotis limestone" [11]. The formation's top unit correlates to the evaporitic Alan Formation in one of the depositional basins (fig. 2). The Alan Anhydrate Formation mostly comprises evaporitic deposition and is mostly located beneath the Sargelu Formation [11, 22].

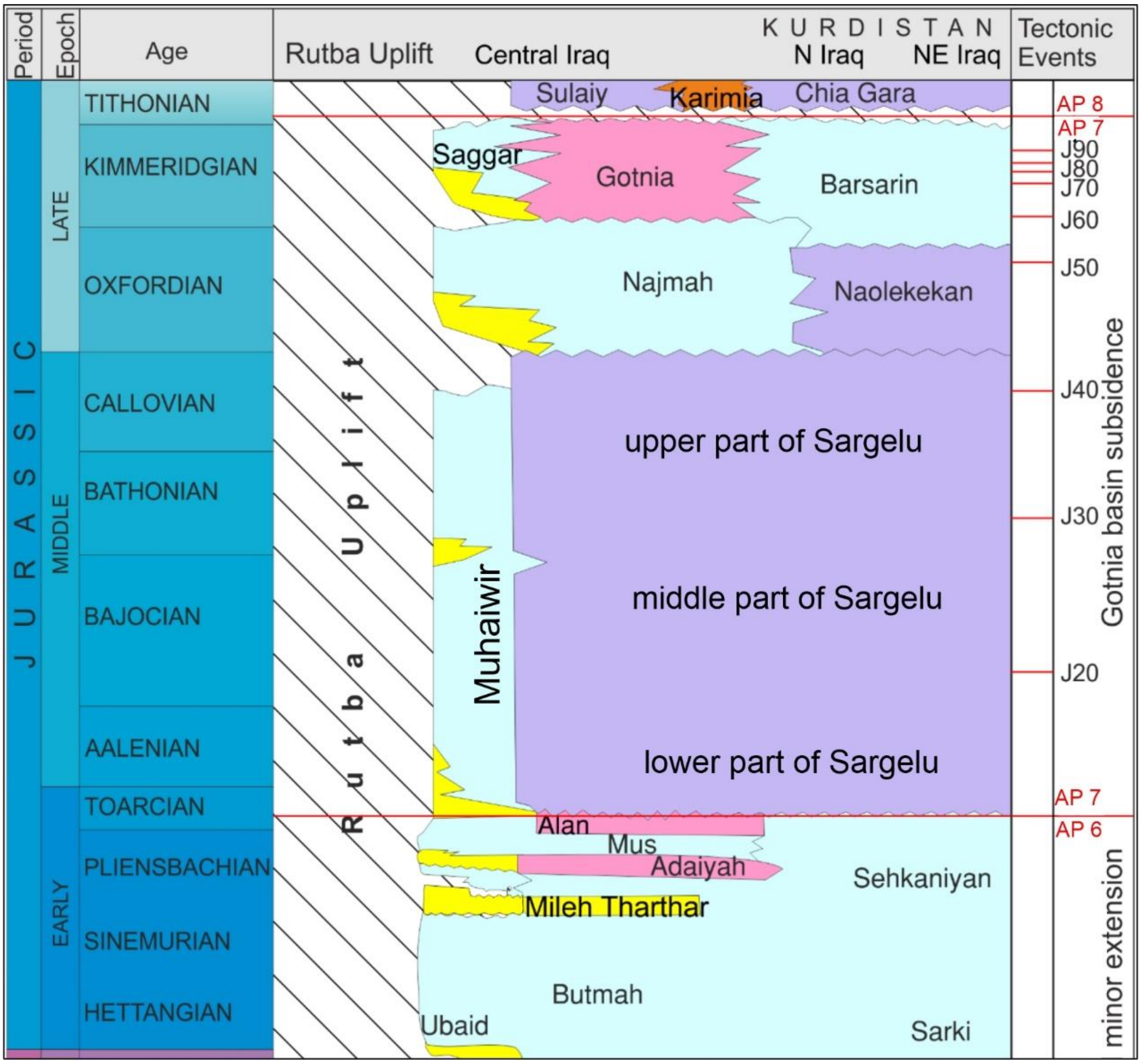


Fig. 2: Correlation diagram of the Jurassic formations of Iraq, modified after Jassim and Buday [11].

Middle Jurassic

The Middle Jurassic succession of the Gotnia basin, which mostly includes two formations (Sargelu and Muhaiwir Formation), was deposited between the Aalenian and Callovian ages, and during this time the basin was drowned as a result of transgression. The Muhaiwir Formation is a common representation of the Mid Jurassic's broadly transgressive phase in Stable Shelf Zone of Iraq [11, 16]. The formation is heterogeneous and contains marly and coralline limestone as well as oolitic limestone, argillaceous sandstone, and siltstone. Wide variations in facies such as shallow reef, depositional systems conditions and normal saline water, were recorded in the Muhaiwir Formation due to the peritidal environment [1, 3, 25].

The Sargelu Formation was first introduced by Wetzel [20] in the Surdash Anticline near the Sargelu Village. The formation is around 115 meters thick in the type section. Their thicknesses are roughly 57 m and 56 m for both exposure sections, the Warte and Barzewa areas, respectively. According to Balaky [2], Banik Village, which is located north of Dohuk, has the thinnest section, and it is about 30 meters. On average, the outcrops are thinner than the subsurface sections [11]. The Sargelu Formation is well known as the most important organic-rich formation of the Mid Jurassic [1, 11, 16, 26-36].

In the field search for this methodological investigation, 29 samples were gathered for the Barzewa section, 18 of which were dolomite in the lower Sargalu Formation, and 33 samples for the Warte section, 14 of which were dolomite. Alizarin Red S Solution (ARS) was applied to thin sections cut parallel to the bedding plane to identify calcite from Dolomite. Detail petrographic and microfacies investigation was done using a polarised microscope. The Sargelu Formation is divided into three main lithological units from bottom to top: first, destructive dolomitization unit, which leaves no visible fossils or sedimentary structures, distinguishes the dolomite unit; second, *Bositra*-bearing limestone, which can be determined by the first appearance of *Bositra* (Fig. 3A,B and C). third, the top unit comprises dark-colored limestone interbedded with thin-bedded banded cherts and highly fissile black shale. The lower boundary with the Sehkaniyan Formation in the outcrops is apparently gradational and conformable. The presence of evaporite at the top of the Alan Formation, however, determines that the boundary between the Lower and Middle Jurassic to the west and south of Iraq is a transitional facies form restricted to normal marine facies [11]. The current research will focus only on the lower dolomitized unit of the formation, where destructive dolomitization prevails.

Saccharoidal Dolomite Unit of the Sargelu Formation

The lower unit (saccharoidal dolomite) of the formation is about 23–31 m thick. The bedding thickness ranges from 10 to 20 metres, which shows grey to dark brown on the fresh surface and grey to bluish on the weathered. The dark color may be related to bitumen filling saccharoidal dolomite intercrystalline pores. As a result of dolomitization, sedimentary rocks have lost their initial texture, making it impossible to identify original structures. Only a few double-ended clear quartz crystals measuring between 2 and 5 cm (Fig.4A and B) in diameter have been observed, which usually occur in small cavities.

Petrographic investigations revealed that this unit consists mainly of saccharoidal dolomite. Dolomite crystals range in size from 0.3 to 0.6 mm, have a clear rim but cloudy centers, and are predominantly euhedral. Dolomite rocks are usually gray to dark gray in color due to their intercrystalline pores being filled with bituminous material (Fig. 3C and D). Furthermore, the original texture has also been obscured by dolomitization.

Tikrit Journal of Pure Science (2024) 29 (1):136-148
Doi: https://doi.org/10.25130/tjps.v29i1.1484

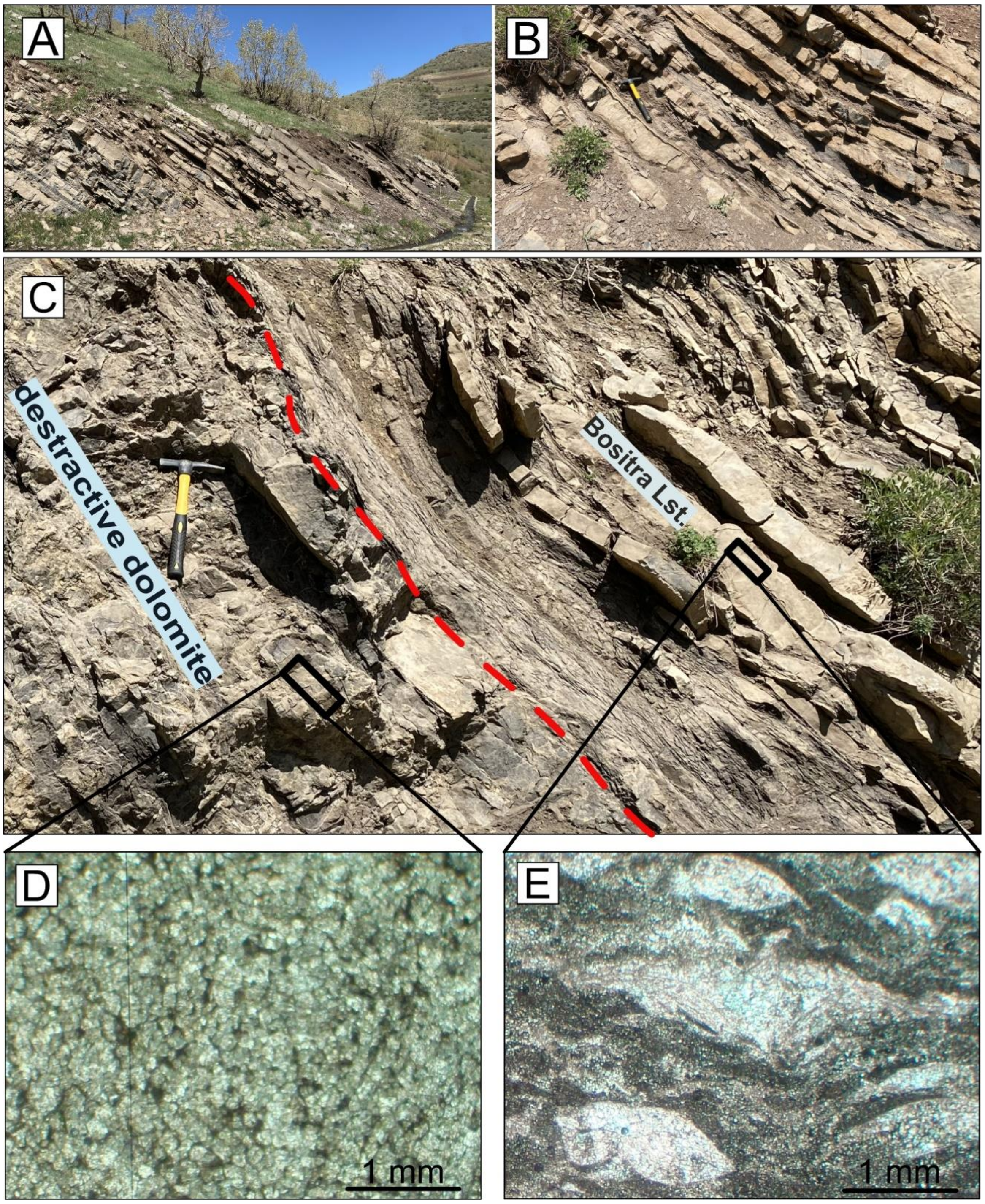


Fig. 3: (A) Upper part of Sargelu Formation, (B); Middle part (Bositra bearing limeston), (C); sudden change in facies between the lower and middle parts of the Sargelu Formation (red dashes), the boundary between them in Warte section (D); saccharoidal dolomite in the lower part in Warte section (E); Limestone contains *Bositra* (bivalve) in Warte section

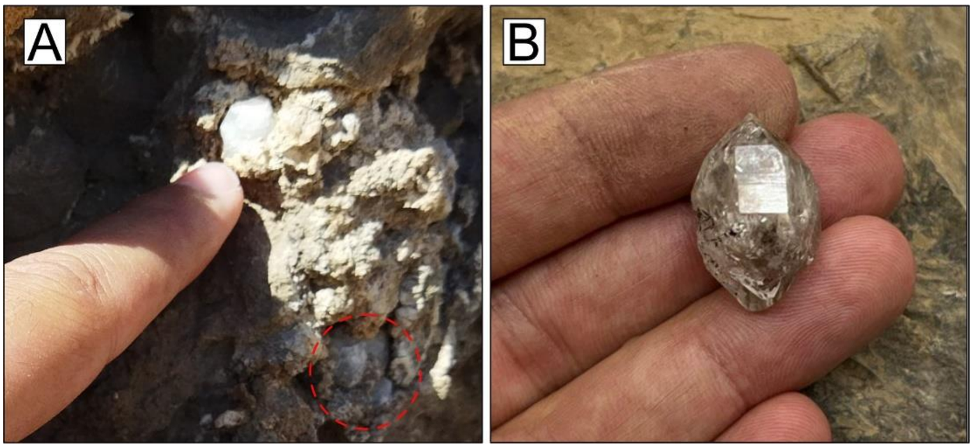


Fig. 4: (A); Euhedral crystal of quartz within a pocket host rock in the lower part of Sargelu Formation, (B); Double-ended clear quartz crystal

Sehkaniyan – Sargelu Formations Boundary

The observed contact between the Sargelu Formation and the underlying Sehkaniyan Formation apparently conformable. The first appearance of brecciated clasts "up to several centimeters in diameters" in the massive beds at the top of the Sehkaniyan Formation marks the contact between the Sehkaniyan and Sargelu formations. Both formations exhibit significant dolomitization, but the Sehkaniyan Formation appears more massive and brownish in the field, whereas the Sargelu Formation appears darker and thinner. At the type locality, the top section of Sehkaniyan consists of 51 m of dark, foetid saccharoidal dolomite and dolomitic limestone, sometimes with chert. It might be a collapse breccia formed by the dissolving of evaporites, as observed in the Alan Formation [16, 20]. However, in Kurdistan exposures, where the Middle Jurassic Age sits conformably on the Lower Jurassic Age, this unconformity is not proven there [3, 21].

Tectonic Development and Drowning of the Middle Jurassic rock units

It was found that the Gotnia Basin was exposed to drowning during the deposition of the Sargelu Formation, where quick facies that change from shallow environments to deep or basinal deposits distinguish the lower to middle Jurassic boundary in the studied area [3, 29, 38]. On the northern shelf, certain intra-shelf depressions began to form due to the Tethys' regional seafloor spreading, partly due to the Middle Jurassic tectonic reactivates [25]. The pre-Toarcian depositional basin drowned as a result of the thinning platform, collapse, faulting, and lithospheric extension [16]. Sargelu carbonates filled these basins; the Zagros collision later destroyed parts of these basins.

The Gotnia Basin, a large-scale intrashelf basin in Iraq, originated after the Early Jurassic Period. The basin included much of southern, central, northern, and northeastern Iraq and was mostly separated from Tethys' open-marine waters. The beginning of rifting in the Toarcian Age resulted in the normal fault's collapse and, subsequently, the drowning of the platforms. in the central and eastern Mediterranean [16, 39]. The drowning event may be observed through the clear transitions from shallow sedimented environments to deep marine environments in a slight vertical thickness in the Middle Jurassic Sargelu Formation [3]. Furthermore, the sudden appearance of *Bositra* and the deposition of shale (Fig.3) indicate subsidence and deepening of the depositional basin from the evaporite environment to the deep marine environment of more than 300 meters.

Dolomitization models

It has been indicated that field observation, thin sections, and geochemical methods can all be employed to learn more about diagenetic habitats, which are defined as surface or subsurface places affected by certain diagenetic events [4, 40]. The following paragraphs will be an attempt to gather the available evidence to present a potential model for the dolomitization mystery in the lower part of the Sargelu Formation. Based on Flugel and Munnecke and Bogs and Bogs [4, 41], the most common models for the dolomitization process are as follows (fig. 5):

i. Seepage-reflux dolomitization.
ii. Evaporative (Sabkha) dolomitization.
iii. Mixing-Zone dolomitization.

iv. Seawater dolomitization.
v. Burial dolomitization.

The evaporative (sabkha) dolomitization model often occurs when storm-driven saltwater replaces the evaporation-lost water from the sabkha sediments (water table) (Fig. 4i). This saltwater, regularly directed into the proximal zone, the supratidal sediments, and along the remaining creeks, provides the magnesium needed for the dolomitization process [4, 41-43]. This model can be excluded due to the absence of any evidence indicating that the Sargelu Formation was deposited in the Sabkha Plane. The ability of the mixing model (dorag model) to produce huge dolostones has been vastly overstated. No place has ever been found to have significant dolomitization in a freshwater-seawater mixing zone in either new or ancient carbonates (fig. 4iii). Several lines of evidence suggest that such huge dolomitization is so improbable as to be practically impossible [9, 44].

According to the burial dolomitization model, sediment loading is compressed during burial, which raises pore pressures and stimulates the flow of fluids both laterally and vertically. Before compaction cementation takes place and diminishes porosity and permeability, burial compaction-induced flow occurs at very shallow depths, sometimes less than 1000 meters. Burial compaction takes place at low depths; hence, dolomitization by fluids caused by burial compaction has to begin shortly after the basin sinks [41, 46]. Oliver [46] compares this compactional reaction to a huge "squeegee," which has been reported to be able to push fluids hundreds of kilometers. Burial dolomites are subsurface cements and replacements that occur in permeable intervals flushed by warm to hot magnesium-enriched basinal and hydrothermal fluids under the active phreatic zone (reflux and mixing zones). Locally produced zonally structured saddle-shaped differential crystals with wavy extinction, non-uniform under cathode rays, and some having a "foggy core with clear rim" appearance [49-51]

The seepage-reflux dolomitization model usually happens behind an obstruction bodies like a reef with lagoonal and shallow-marine settings (Fig. 4ii). Brine condenses fluid from evaporating seawater, sinks downward in carbonate sediments, and replaces less dense seawater in their pores [41, 52, 53].

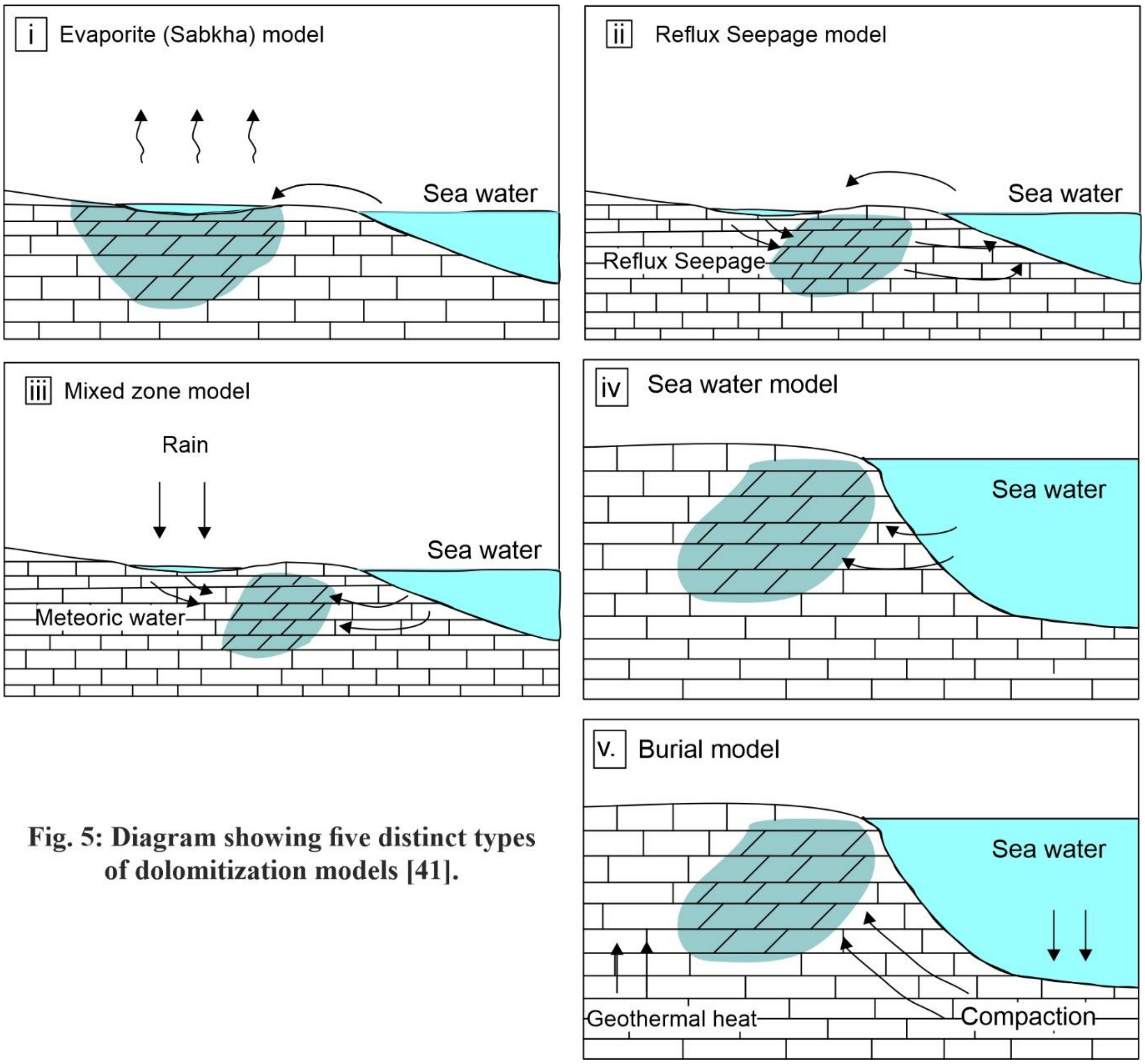
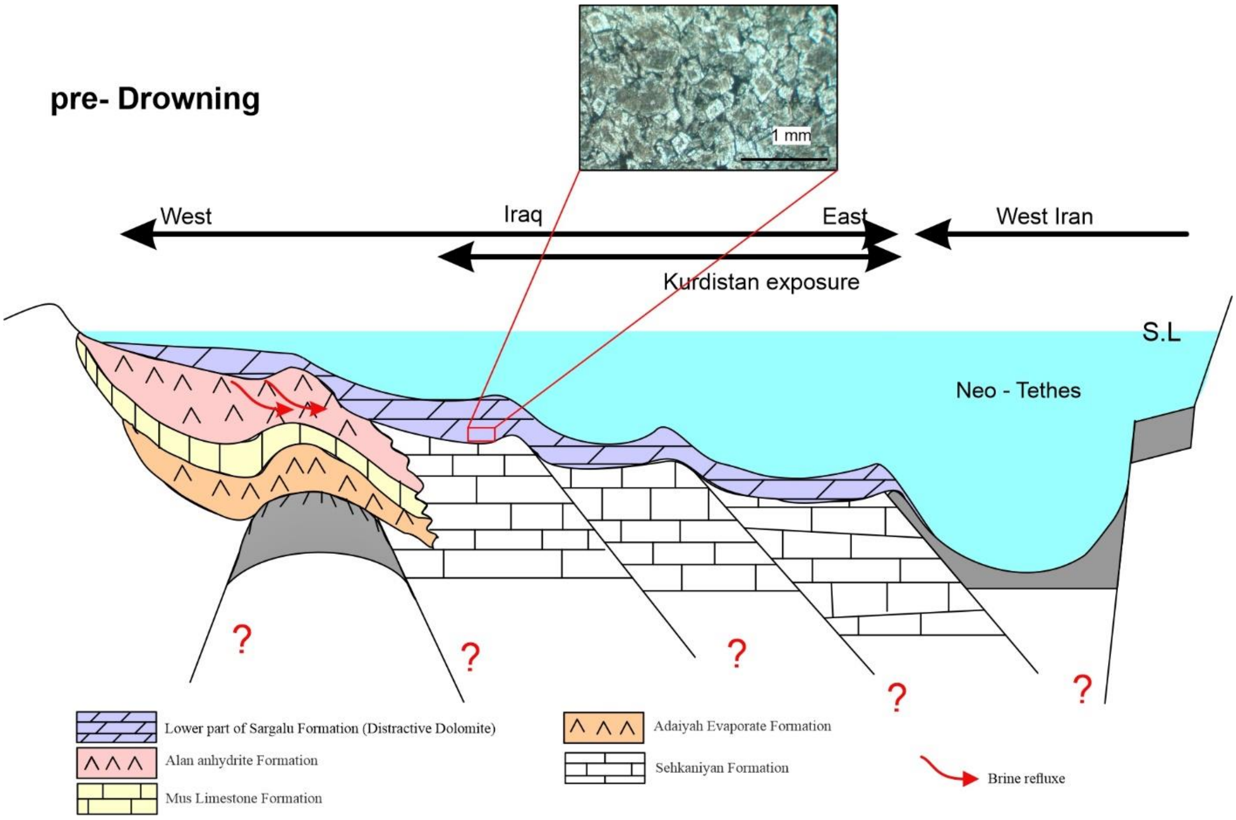


Fig. 5: Diagram showing five distinct types of dolomitization models [41].

Reflux dolomitization occurs when hypersaline brines push the connate seawaters out of the lagoon and slowly seep down through the porous carbonates at the bottom [8, 52]. Jones and Rostron [53] demonstrated that active reflux could occur at depths of several hundred metres. High-frequency sea level drops that repeatedly occur when the following sea level rise causes reflux dolomitization. The alternating reflux's recurring infiltration horizons, which were dependent on sea-level changes, caused the peritidal limestone succession to repeatedly dolomitize [54, 55].

The potential mechanism of the dolomitization

At the begins of the Torcian Age and the completion of the sedimentation of the Sehkaniyan Formation, which was deposited in an evaporite basin, a series of rifts led to the additional expansion of the Gotnia Basin [3, 15, 56]. The Mid Jurassic was initially cumulated in shallow marine carbonate environments in this basin. The entire lower part of the Sargelu Formation, made up of limestone, was subjected to destructive dolomitization [1-3, 11, 22, 27]. It is not easy to identify the original textures and components of the limestone. The lower part of the Sargelu Formation is mostly juxtaposed and/or partially equivalent to the evaporitic Alan Formation (fig. 6). According to Buday, Buday and Jassim, and Al-Husseini [1, 11, 17], depositional setting of the Alan Formation, which is situated to the southwest of the Sargelu Formation, extends more than a thousand kilometers, and both formations are in the Gotnia Basin. The depletion of calcium during the evaporite deposition in the Alan Formation resulted in a high Mg/Ca ratio. The occurrence of the production of high Mg/Ca ratio solutions and their subsequent eastward migration may be the primary factor in the dolomitization of the Sargelu strata. So, refluxed brine from the evaporitic Alan Formation could be the main factor of dolomitization (fig. 6).



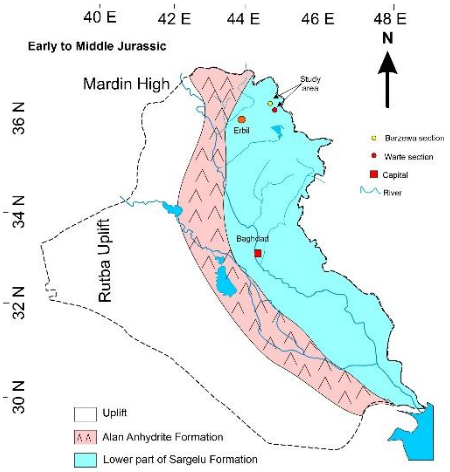


Fig. 6: Hypothetical paleogeography of the evaporite (Alan Formation) and intrashelf (Sargelu Formation) at the end of the Early Jurassic of Iraq, showing reflux brine solution from the Alana sub-basin towards the Sargelu Formation.

Furthermore, the lower part of the Sargelu Formation is underlain by the Sehkaniyan Formation, which contains of saccharoidal dolomite, dolomitic limestone, and solution-collapsed breccia [15, 19]. The burial dolomitization model could be another scenario, as the Sehkaniyan Formation is well known as an evaporitic-bearing sequence (fig 6). The Sehkaniyan Formation's interstitial water is full of a solution with a high Mg/Ca ratio due to the Ca being exhausted when gypsum formed. This could be another source of dolomitization, which can be interpreted as a burial dolomitization model when the interstitial solution moves upward and laterally to the lower part of the Sargelu Formation and results in dolomitization. The faults and rifts of the Gotnia Basin enhance the hypersaline and lagoonal environments.

Facies changes between the Early and Middle Jurassic units suggest continuous drowning that led to the deepening of the Gotnia Basin and increasing eustatic sea level, where *Bositra* fauna dominated during that time. The abrupt change of depositional environment of Alan and Sehkaniyan Formation to depositional environment of Sargelu Formation that shows clear transitions from shallow settings to deep settings. An additional factor in the dolomitization of the lower part of the Sargelu Formation is drowning, which deepened the sediment basin, raised sea levels, and increased sediment load on the Sehkaniyan Formation, all of which led to the pumping high Mg/Ca solution upward, converted limestone to dolomite in the lower part of the Sargelu Formation.

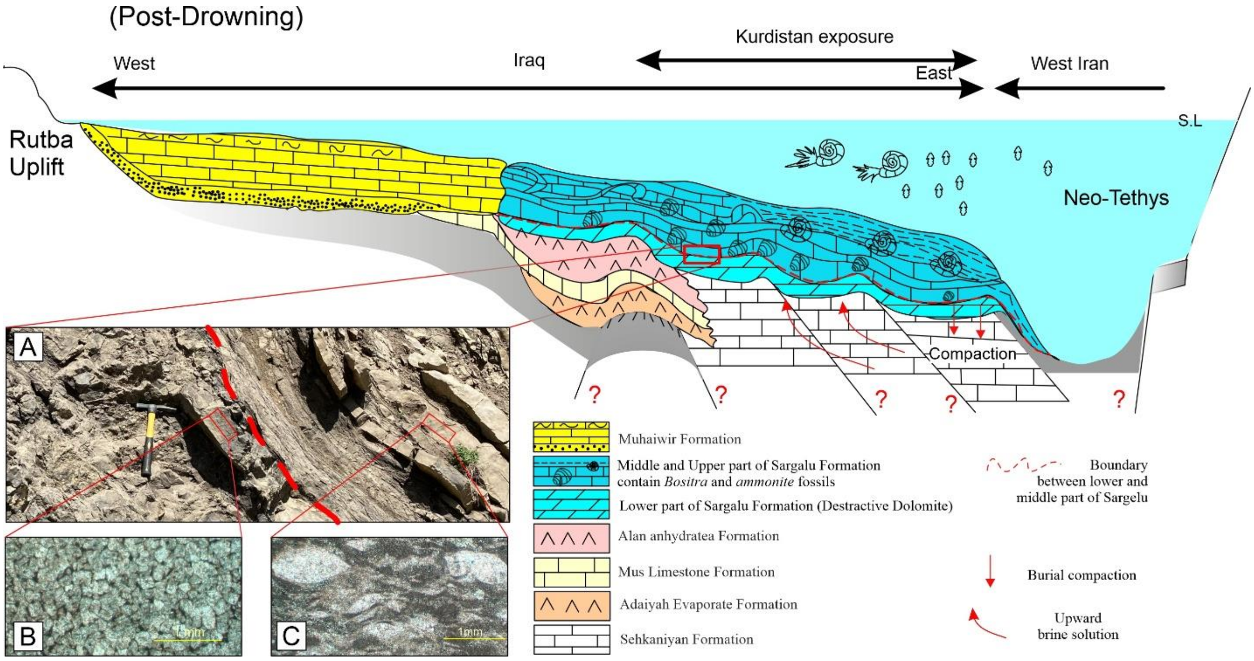


Fig. 7: A hypothetical model of the depositional setting of the Sargelu with burial dolomitization models. The brine solution of the Sehkaniyan Formation (red arrows) moves up towards the lower part of the Sargelu Formation. A: sudden change facies between the lower and middle parts of the Sargelu formation (red dashes), the boundary between them in Warte section B; saccharoidal dolomite in the lower part in Warte section C; Limestone contains *Bositra* (bivalve) in Warte section.

Conclusion

It is interpreted that reflux-seeps of brine water from the evaporitic Alan Formation and burial dolomitization models are belived to be the main causes of dolomitization in the lower part of the Sargelu Formation. Destractive (saccharoidal dolomitization) has increased its porosity so that the intercrystalls are filled with kerogen, turning the Sargelu Formation into a reservoir in the Kurdistan oil fields. Faults and rifts in the Gotnia Basin created fragmented sub-basins with juxtaposed shallow and deep basins, resulting in the formation of hypersaline environments adjacent to normal saline deep seas. Thus, the tilted basin created a drowned basin on the eastern side of the Gotnia Basin, where the Sargelu accumulated. This drowned basin was later invaded by refluxed brine water from the magnesium/calcium rich fluid of the Alan Formation.

References

[1] Buday, T. (1980). The regional geology of Iraq: stratigraphy and paleogeography (Vol. 1). State Organization for Minerals, Directorate General for Geological Survey and Mineral Investigations.
[2] Balaky, S.M.H. (2004). Stratigraphy and sedimentology of Sargelu Formation (Middle Jurassic) in selected sections in Erbil and Duhok governorates, Iraqi Kurdistan. M. Sc. Thesis, Univ. of Salahaddin, 109p.
[3] Saeed, A. (2017). Sedimentology and stratigraphy of the Middle to Upper Jurassic succession of northern Iraq. Unpublished (Doctoral dissertation, Royal Holloway, University of London).
[4] Flügel, E., & Munnecke, A. (2010). Microfacies of carbonate rocks: analysis, interpretation and application (Vol. 976, p. 2004). Berlin: springer.
[5] Zenger, D.H., Dunham, J.B., & Ethington, R.L. (1980). Concepts and models of dolomitization. SEPM Society for Sedimentary Geology.

[6] Zhu, D., Zhang, D., Liu, Q., Xing, F., He, Z., Zhang, R., & Liu, Z. (2018). Formation mechanism of dolomite reservoir controlled by fourth-order sequence in an evaporated marine environment–an example from the lower Ordovician Tongzi Formation in the Sichuan Basin. Energy Exploration & Exploitation, 36(4), 620-644.
[7] Land, L.S. (1980). The isotopic and trace element geochemistry of dolomite: The State of the Art.
[8] Warren, J. (2000). Dolomite: occurrence, evolution and economically important associations. Earth-Science Reviews, 52(1-3), 1-81.
[9] Machel, H.G. (2004). Concepts and models of dolomitization: A critical reappraisal. Geological Society, London, Special Publications, 235(1), 7-63.
[10] Tucker, M.E., Sedimentary petrology: An introduction to the origin of sedimentary rocks. 2001: John Wiley & Sons.
[11] Jassim, S. Z., & Goff, J. C. (Eds.). (2006). Geology of Iraq. DOLIN, sro, distributed by Geological Society of London.
[12] Fouad, S. F., & Sissakian, V. K. (2011). Tectonic and structural evolution of the Mesopotamia Plain. Iraqi Bulletin of Geology and Mining, special issue, 4, 33-46.
[13] Dercourt, J.E.A., Zonenshain, L.P., Ricou, L.E., Kazmin, V.G., Le Pichon, X., Knipper, A.L., ... & Biju-Duval, B. (1986). Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the Lias. Tectonophysics, 123(1-4), 241-315.
[14] Faqi, A., Abdullah, B., Bowden, S., & Ali, A. (2018). Source rock evaluation and lateral changes in thermal maturity of the Sargelu Formation (Middle Jurassic) in Kurdistan Region-Northern Iraq. UKH Journal of Science and Engineering (UKHJSE), 2(1), 7-17.
[15] Sharland, P.R., Casey, D.M., Davies, R.B., Simmons, M.D., & Sutcliffe, O.E. (2004). Arabian Plate sequence stratigraphy–revisions to SP2. GeoArabia, 9(1), 199-214.

[16] Aqrawi, A.A., Goff, J.C., Horbury, A.D., & Sadooni, F.N. (2010). The petroleum geology of Iraq. Scientific press.
[17] Al-Husseini, M.I. (1997). Jurassic sequence stratigraphy of the western and southern Arabian Gulf. GeoArabia, 2(4), 361-382.
[18] Numan, N.M. (1997). A plate tectonic scenario for the Phanerozoic succession in Iraq. Iraqi Geological Journal, 30(2), 85-110.
[19] Wilson, A.O. (2020). Chapter 1 Introduction to the Jurassic Arabian Intrashelf Basin. Geological Society, London, Memoirs, 53(1), 1-19.
[20] Bellen, R.V., Dunnington, H.V., Wetzel, R., & Morton, D. (1959). Lexique stratigraphique international. Asie, Iraq, 3(10a), 324.
[21] Surdashy, A.M. (1999). Sequence stratigraphic analysis of the Early-Jurassic central and northern Iraq. Unpublished (Doctoral dissertation, Science College, University of Baghdad).
[22] Mohialdeen, I.M. (2018). Hydrocarbon generation potential and palynological study of the early Jurassic succession (Alan, Mus, and Adaiyah Formations) in well Miran-2, Sulaimaniyah, Kurdistan region, Iraq. Iraqi Bulletin of Geology and Mining, 14(1), 13-30.
[23] Rashid, F. (204820). Reservoir productivity analysis of intercalated limestone and anhydrite beds in Zagros Folded Belt, Kurdistan Region of Iraq. Kurdistan Journal of Applied Research, 5(1), 1-15.
[24] Abdula, R.A. (2016). Organic geochemical assessment of Jurassic potential source rock from Zab-1 well, Iraqi Kurdistan. Iraqi Bulletin of Geology and Mining, 16(3), 53-64.
[25] Sissakian, V.K., & Mohammed, B.S. (2007). Stratigraphy. Iraqi Bulletin of Geology and Mining, (1), 51-124.
[26] Csató, I., Kiss, K., Toth, S., & Varga, M. (2014). Upper Triassic-Jurassic depositional systems in the Akri-Bijeel exploration block, Iraqi Kurdistan. MOL Group Scientific Magazine, 1, 54-71.
[27] Abdula, R.A., Balaky, S.M., Nurmohamadi, M.S., & Piroui, M. (2015). Microfacies analysis and depositional environment of the Sargelu Formation (Middle Jurassic) from Kurdistan Region, northern Iraq. Donnish Journal of Geology and Mining Research, 1(1), 001-026.
[28] Al-Ameri, T.K., & Al-Nagshbandi, S.F. (2015). Age assessments and palynofacies of the Jurassic oil source rocks succession of North Iraq. Arabian Journal of Geosciences, 8, 759-771.
[29] Aqrawi, A.A., & Badics, B. (2015). Geochemical characterisation, volumetric assessment and shale-oil/gas potential of the Middle Jurassic–Lower Cretaceous source rocks of NE Arabian Plate. GeoArabia, 20(3), 99-140.
[30] Hussein, H.S., & Abdula, R.A. (2018). Multiple linear regression approach for the vitrinite reflectance estimation from well logs: A case study in Sargelu and Naokelekan Formations–Shaikhan-2 Well, Shaikhan oil field, Iraq. Egyptian journal of petroleum, 27(4), 1095-1102.

[31] J. Al-Atroshi, S.,H. Sherwani, G., & Al-Naqshbandi, S.F. (2019). Assessment of the hydrocarbon potentiality of the Late Jurassic formations of NW Iraq: A case study based on TOC and Rock-Eval pyrolysis in selected oil-wells. Open Geosciences, 11(1), 918-928.
[32] Abdula, R.A., Asaad, H.R., Qasim, O.K., Hashmi, H.S. K., & Abdi, B.S. (2020). Volumetric Calculation of Generated Hydrocarbon from Sargelu Formation in Kurdistan Region, Iraq. UKH Journal of Science and Engineering, 4(2), 166-177.
[33] Hakimi, M.H., Najaf, A.A., Abdula, R.A., and Mohialdeen, I.M.J., 2018, Generation and expulsion history of oil-source rock (Middle Jurassic Sargelu Formation) in the Kurdistan of north Iraq, Zagros folded belt: Implications from 1D basin modeling study, Journal of Petroleum Science and Engineering, v. 162, pp. 852-872.
[34] Abdula, R.A., 2015, Hydrocarbon potential of Sargelu Formation and oil-source correlation, Iraqi Kurdistan, Arabian Journal of Geosciences, v. 8, issue 8, pp. 5845-5868
[35] Abdula, R.A., "Petroleum source rock analysis of the Jurassic Sargelu Formation, northern Iraq," Master's thesis (unpublished), Colorado School of Mines, Golden, Colorado, June 2010, 106p.
[36] Akram, R., Edilbi, A. N., Mamaseni, W. J., Sherwani, G. H., & Al-Ansari, N. (2021). Source Rock Evaluation and 1-D Basin Modelling Approach for the Sargelu Formation, Atrush-2 Well, Kurdistan Region-Iraq. Open Journal of Geology, 11(3), 49-60.
[37] Coe, A.L. (Ed.). (2003). The sedimentary record of sea-level change. Cambridge University Press
[38] Emery, D., & Myers, K. (Eds.). (2009). Sequence stratigraphy. John Wiley & Sons.
[39] Bernoulli, D., & Jenkyns, H. C. (1974). Alpine Mediterranean and central Atlantic Mesozoic facies in relation to the early evolution of the Tethys.
[40] Purdy, E.G. (1964). Sediments as substrates. Approaches to paleoecology, 238.
[41] Boggs, S. (2009). Petrology of sedimentary rocks. Cambridge university press.
[42] Sibley, D.F., & Gregg, J.M. (1987). Classification of dolomite rock textures. Journal of Sedimentary Research, 57(6), 967-975.
[43] Meister, P., Mckenzie, J.A., Bernasconi, S.M., & Brack, P. (2013). Dolomite formation in the shallow seas of the Alpine Triassic. Sedimentology, 60(1), 270-291.
[44] Melim, L.A., & Scholle, P.A. (2002). Dolomitization of the Capitan Formation forereef facies (Permian, west Texas and New Mexico): Seepage reflux revisited. Sedimentology, 49(6), 1207-1227.
[45] Qing, H., Bosence, D.W., & Rose, E.P. (2001). Dolomitization by penesaline sea water in Early Jurassic peritidal platform carbonates, Gibraltar, western Mediterranean. Sedimentology, 48(1), 153-163.
[46] Oliver, J. (1986). Fluids expelled tectonically from orogenic belts: their role in hydrocarbon migration and other geologic phenomena. Geology, 14(2), 99-102.
[47] Moore, C.H., Carbonate diagenesis and porosity. 1989: Elsevier.
[48] Sadooni, F., & Al Awadi, M. (2009). Dolomite: perspectives on a perplexing mineral. Oilfield review, 21(3).
[49] Reinhardt, E.G., Cavazza, W., Patterson, R.T., & Blenkinsop, J. (2000). Differential diagenesis of sedimentary components and the implication for strontium isotope analysis of carbonate rocks. Chemical Geology, 164(3-4), 331-343.
[50] Xiulian, Z., Yinghua, W., & Xiaolong, C. (2000). Diagenesis and Porosity of the Cambrian-Ordovician Carbonate Shoal Facies at Yangjiaping, Shimen, Hunan. Acta Geologica Sinica-English Edition, 74(1), 29-45.
[51] Xiulian, Z., & Lingzhi, J. (2001). Research on diageneses of Cambrian shoal facies carbonate rocks in the Xiadong area, Hubei province. Acta Geologica Sinica-English Edition, 75(2), 161-174.
[52] Adams, J.E., & Rhodes, M.L. (1960). Dolomitization by seepage refluxion: American Association of Petroleum Geologists Bulletin, v. 44.
[53] Jones, G.D., & Rostron, B.J. (2000). Analysis of fluid flow constraints in regional-scale reflux dolomitization: constant versus variable-flux hydrogeological models. Bulletin of Canadian Petroleum Geology, 48(3), 230-245.
[54] Rameil, N. (2008). Early diagenetic dolomitization and dedolomitization of Late Jurassic and earliest Cretaceous platform carbonates: a case study from the Jura Mountains (NW Switzerland, E France). Sedimentary Geology, 212(1-4), 70-85.
[55] Makhloufi, Y., Rusillon, E., Brentini, M., Moscariello, A., Meyer, M., & Samankassou, E. (2018). Dolomitization of the Upper Jurassic carbonate rocks in the Geneva Basin, Switzerland and France. Swiss Journal of Geosciences, 111, 475-500.
[56] Sharland, P.R., Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., ... & Simmons, M.D. (2001). Sequence stratigraphy of the Arabian Plate. GeoArabia, 2(37), 1.